PROBLEMS
IN
ALTERNATING CURRENT MACHINERY

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PROBLEMS IN ALTERNATING CURRENT MACHINERY

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PREFACE

These problems chiefly concern the theory of the operation of alternating current machinery, and are such as we give to the fourth year students in electrical engineering in this subject.

In each chapter the problems of a similar nature are grouped together, and those of each group are then arranged in the approximate order of their difficulty. The groups in each chapter follow each other in as logical an order as possible, both from point of difficulty and the presentation of the subject.

In order that this collection of problems may be useful among different classes of students a large variety has been included, ranging from the very simple to those of considerable difficulty. Wherever it is essential the data have been taken from actual apparatus. This was possible through the courtesy of two of the large manufacturing companies. In some of the problems so few data are given that approximate methods of solution must be used, but care has been taken to so state them that the errors thus introduced need not be large. This lack of data is frequently met in practice.

It has been thought best not to give introductory paragraphs for each chapter as was done in the preceding volume of problems inasmuch as they would have to be of considerable length to be of much value.

The answers to the problems will probably be ready for publication in the fall of 1914. They will be available to all but undergraduate students at a nominal price. Undergraduate students can obtain them only on the recommendation of their instructors.

WALDO V. LYON.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
December, 1913.

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INTRODUCTION

The great importance of problem work in the training of students of engineering is now generally recognized. No other work so efficiently develops analytical power and clear, logical thinking, so necessary to success in the engineering profession. Yet notwithstanding the importance of problem work in general, the first consistently developed book of electrical engineering problems was that prepared by Mr. Lyon in 1908, its wide use being conclusive evidence of the needs that were felt among both teachers and students for such a work, and of the appreciation of the importance of the training which it exemplifies.

It requires a special gift to originate and develop problems which shall give sound training in the fundamentals of engineering and whose solution shall not only interest the student, but develop his intellectual power as well. In general the problems must be closely related to engineering practice, graded as to difficulty, and must carefully avoid being mere mathematical puzzles. Mr. Lyon, as his earlier book also shows, has a most unusual ability in the preparation of problems for the electrical engineering field.

The present collection of problems relating to electrical machinery, more particularly in the field of alternating current engineering, has been prepared with the same point of view as was Mr. Lyon's earlier work, and should likewise prove most useful to both instructor and student.

H. E. CLIFFORD.

HARVARD UNIVERSITY,
December, 1913.

PROBLEMS IN ALTERNATING CURRENT MACHINERY

CHAPTER I

TRANSFORMERS

1. The iron loss in a reactor is 240 watts of which 48 watts is due to eddy currents. If the amount of iron in the magnetic circuit were doubled by doubling the cross-section of the core, what would be the iron loss for the same impressed voltage and frequency? Neglect the resistance drop.

2. The iron loss in a reactor is 312 watts of which 86 watts is due to eddy currents. If a similar reactor were constructed in which laminations of twice the thickness were used, what would be the iron loss for the same impressed voltage and frequency? Neglect the resistance drop.

3. When 110 volts at 30 cycles is impressed on a reactor the iron loss is 276 watts of which 204 watts is due to hysteresis. If the impressed voltage and frequency are both doubled what will be the iron loss? Neglect the resistance drop.

4. When 110 volts at 60 cycles is impressed on a reactor, the iron loss is 248 watts of which 25 per cent. is due to eddy currents. (a) What will be the iron loss when 220 volts at 60 cycles is impressed on the reactor? (b) What will be the iron loss when 110 volts at 30 cycles is impressed on the reactor? Neglect the resistance drop.

5. A reactor has two electric circuits having the same number of turns which may be connected in series or in parallel. When they are connected in series across 220-volt, 60-cycle mains the iron loss is 326 watts, of which 89 watts is due to eddy currents. What will be the iron loss if the coils are connected in parallel across the same mains? Neglect the resistance drop.

6. With 425 volts at 25 cycles impressed on the low-tension winding of a transformer 2500 watts is supplied at no load. If the frequency of this impressed voltage is increased to 40 cycles without changing its root-mean-square value or form factor, 2020 watts is supplied at no load. What is the division between the eddy current and hysteresis losses at 25 cycles?

7. With 440 volts at 50 cycles impressed on the low-tension winding of a transformer 641 watts is supplied at no load. If the frequency and voltage are each reduced 50 per cent. without changing the form factor 278 watts is supplied at no load. What is the division between the-eddy current and hysteresis losses at 50 cycles?

8. With 440 volts at 60 cycles impressed on the low-tension winding of a transformer 371 watts is supplied at no load. If the voltage is reduced 50 per cent. without changing the frequency or the form factor 114 watts is supplied at no load. What is the division between the eddy current and hysteresis losses at 440 volts?

9. If a simple harmonic electromotive force of 2200 volts at 60 cycles is impressed on the low-tension winding of a transformer the core loss is 940 watts, 23 per cent. of which is due to eddy currents. (a) What will be the core loss if an electromotive force of the same effective value and frequency but with a form factor of 1.05[1] is impressed on the low-tension winding? (b) What will be the core loss if an electromotive force of the same effective value and frequency but with a form factor of 1.2[2] is impressed on the low-tension winding?

10. The magnetic circuit of a transformer has a mean length of 77.3 in. and an average cross-section of 34.4 sq. in. The low-tension winding has 399 turns. Find the core loss, the no-load current, and the power factor at no load when 2300 volts at 60 cycles is impressed on the low-tension winding. The curve of core loss at 60 cycles and flux density, and the *B–H* curve are given by the data on the following page:

11. A magnetic circuit has a mean length of 69.5 in. and an average cross-section of 30.0 sq. in. It is wound with a coil of 94 turns. A constant voltage of 440 volts at 50 cycles is impressed on this coil. How long an air-gap would it be necessary to cut in the magnetic circuit in order that the coil would take a current 20 times as great? What is the power factor before and after cutting the air-gap? Neglect the resistance of the coil and use the magnetic data given in problem 10. Assume that the core loss at 50 cycles is 80 per cent. of the loss at 60 cycles.

[1] Flat topped.

[2] Peaked.

Ordinates	Abscissæ	
Flux density Kilolines per sq. in.	Magnetizing force $H=\frac{4\pi}{10}\frac{NI}{l_{cm.}}$	Core loss at 60 cycles Watts per cu. in.
40.0	2.0	0.132
53.0	3.0	0.206
61.5	4.0	0.262
67.0	5.0	0.300
73.6	7.0	0.352
80.0	10.0	0.406
86.0	15.0	0.457
89.6	20.0	0.490

This data is for a good grade of sheet steel.

For all of the problems to which this data applies assume that at the working flux density the joints in the magnetic circuit require 75 additional ampere turns.

12. The magnetic circuit of a 5000-kv.-a. transformer has a mean length of 140 in. and an average cross-section of 613 sq. in. The number of turns in the high-tension winding is such that with the rated voltage of 52,000 volts at 50 cycles impressed on this winding, 17,500 watts is supplied at no load. How many turns has the high-tension winding? What are the no-load current and power factor? Use the magnetic data given in problem 10. Assume that the core loss at 50 cycles is 80 per cent. of the loss at 60 cycles.

13. If the transformer described in problem 12 is connected to a 66,000-volt, 50-cycle circuit, what will be the no-load current and power?

14. The magnetic circuit of a 1000-kv.-a. transformer has a mean length of 95 in. and an average cross-section of 278 sq. in. This transformer is designed to operate from a 66,000-volt, 60-cycle circuit. If the maximum flux density is to be 70,000 lines per square inch how many turns should the high-tension winding have? What are the no-load current and power? Use the magnetic data given in problem 10.

15.[1] At no load a 500-kv.-a. transformer takes a current of

[1] Assume that the original flux density is 70 kilolines per sq. in., and that the relation between the flux density and the permeability for this quality of iron is expressed by:

$$B=102-0.017\mu$$

between B equals 45 kilolines and B equals 95 kilolines per sq. in. In problems where this applies the effect of the joints in the magnetic circuit will be neglected.

3.35 amperes and a power of 2960 watts, when the voltage impressed on the high-tension side is 11,000 volts at 60 cycles. What current and power will this transformer take at no load if 12,700 volts at 60 cycles is impressed on the high-tension winding? Assume that the core loss varies as the 1.7 power of the flux density.

16.[1] A 50-kv.-a. transformer takes a current of 0.1 ampere and a power of 641 watts at no load when 30,000 volts at 50 cycles is impressed on the high-tension winding. What current and power will this transformer take at no load if 30,000 volts at 60 cycles is impressed on the high-tension winding? Assume that the core loss varies as the 1.3 power of the frequency and the 1.7 power of the flux density.

17. The resistance to direct current of a reactor which has a laminated magnetic circuit is 0.2 ohm. When 110 volts at 60 cycles is impressed on this reactor the current is 10 amperes and the power is 550 watts. What are the apparent resistance and reactance of the reactor? What is the actual inductance of the reactor at this voltage and frequency?

18.[1] When 110 volts at 60 cycles is impressed on a reactor which has a laminated magnetic circuit it absorbs 500 watts. At this time the inductance of the reactor is 25 mil-henrys and the resistance is negligibly small. (a) What are the current and power factor? What are the apparent resistance and reactance of the reactor? (b) If 146 volts at 60 cycles is impressed on this reactor what will be the current and power factor? What will be the apparent resistance and reactance of the reactor? Assume that the iron loss varies as the 1.7 power of the flux density.

19. A reactor with a laminated magnetic circuit has a negligibly small resistance to direct current. When 110 volts at 25 cycles is impressed on this reactor the current is 20 amperes and the power is 1000 watts. If a very small air-gap is cut in the mag-

[1] Assume that the orignal flux density is 70 kilolines per sq. in., and that the relation between the flux density and the permeability for this quality of iron is expressed by:

$$B = 102 - 0.017\mu$$

between B equals 45 kilolines and B equals 95 kilolines per sq. in. In problems where this applies the effect of the joints in the magnetic circuit will be neglected.

netic circuit the current becomes 100 amperes. By what amount are the apparent resistance and reactance of the reactor changed by the introduction of the air-gap?

20. A reactor with a laminated magnetic circuit has a resistance to direct current of 0.5 ohm. When 110 volts at 60 cycles is impressed on this reactor the apparent resistance and reactance are 2.0 ohms and 4.0 ohms respectively. What is the actual inductance of the reactor at this voltage?

21. At no load with 220 volts at 60 cycles impressed on a transformer the ratio of eddy current loss to hysteresis loss is 1:3. What is this ratio if 220 volts at 50 cycles is impressed on the transformer?

22. At no load with 220 volts at 60 cycles impressed on a transformer the ratio of eddy current loss to hysteresis loss is 1:3. What is this ratio if 110 volts at 60 cycles is impressed on the transformer?

23. At no load with 110 volts at 60 cycles impressed on a transformer the current is 1.3 amperes and the power is 52 watts. What will be the no-load current and power taken by a transformer similar to this in every particular, except that the cross-section of the magnetic circuit is double, when 220 volts at 60 cycles is impressed on it?

24. At no load with 110 volts at 30 cycles impressed on a transformer the current is 1.2 amperes and the power is 53 watts, of which 14 watts is dissipated in eddy currents. What will be the current and power at no load if 220 volts at 60 cycles is impressed on this transformer?

25. The high-tension winding of a transformer consists of two coils which may be connected in series or in parallel. When these coils are connected in series across 2200 volts at 60 cycles the current is 0.30 amperes and the power is 140 watts on open circuit. What is the no-load current and power if the coils are connected in parallel across 1100 volts at 60 cycles?

26.[1] In problem 25 what is the no-load current and power when the coils are connected in parallel across 1550 volts at 60 cycles?

[1] Assume that the original flux density is 70 kilolines per sq. in., and that the relation between the flux density and the permeability for this quality of iron is expressed by:

$$B = 102 - 0.017\mu$$

between B equals 45 kilolines and B equals 95 kilolines per sq. in. In problems where this applies the effect of the joints in the magnetic circuit will be neglected.

Assume that the core losses vary as the 1.7 power of the flux density.

27. The high-tension winding of a transformer consists of two coils which may be connected in series or in parallel. When these coils are connected in parallel across 22,000 volts at 60 cycles the no-load current is 0.077 amperes and the power is 371 watts, 28 per cent. of which is eddy current loss. What are the no-load current and power when the coils are connected in series across 22,000 volts at 30 cycles?

28. At no load, with 460 volts impressed on the primary of a transformer, the current is 0.94 ampere and the power is 122 watts. Another transformer is similar to this one except that the primary winding has twice as many turns and the cross-section of the magnetic circuit is one-half as great. What no-load current and power will this transformer take with 460 volts impressed on its primary winding?

29. In a transformer having a ratio of transformation of $N_1 : N_2$ the windings are so designed that the current densities in the primary and secondary are the same. What is the ratio of primary to secondary resistance if both windings have the same mean length per turn? What is this ratio if the mean length per turn of the primary is 15 per cent. greater than that of the secondary? (b) If the current density in the primary had been 15 per cent. greater than in the secondary what would have been this ratio of the resistances if the windings had the same mean length per turn?

30. In a transformer having a ratio of transformation of $N_1 : N_2$ the windings are so designed that the heating losses in the primary and secondary are the same. What is the ratio of primary to secondary resistance if both windings have the same mean length per turn? What is this ratio if the mean length per turn of the primary winding is 15 per cent. greater than that of the secondary? (b) If the heating loss in the primary had been 15 per cent. greater than in the secondary what would have been this ratio if both windings had the same mean length per turn?

31. What effect will be produced on the iron losses of a transformer and on the kilowatt rating, on the basis of the same total losses, by doubling the number of turns in the primary and secondary windings and halving the cross-section of the wires: first, when the impressed voltage is doubled; and second, when the impressed voltage is unchanged and the cross-section of the magnetic circuit is halved? Assume that originally the iron and copper losses are equal.

32. In a given transformer the ratio of the iron losses to the copper losses at full load is 0.7. Another transformer with the same rating has a magnetic circuit of the same length but of 25 per cent. greater cross-section, due to which the mean length of one turn of the winding is 10 per cent. greater. Both transformers are wound with the same size wire. The second transformer is designed so as to have the same maximum flux density as the first. What is the ratio of the total losses at full load, and what is the ratio of the iron losses to the copper losses in the second transformer at full load? Compare the amounts of copper in the two transformers. Both transformers are designed for the same voltage.

33. Two transformers have identical magnetic cores and the same rated output. Both are wound for the same voltage but in the first the iron losses are 25 per cent. greater than in the second due to a higher flux density. In the first transformer the ratio of the iron losses to the copper losses at full load is 0.7. Both transformers have the same size of wire in their windings, but the mean length of one turn is 5 per cent. greater in the second than in the first. What is the ratio of the iron losses to the copper losses at full load in the second transformer? What is the ratio of the total losses at full load in the two transformers? Compare the amounts of copper in the two transformers. Assume that the iron losses vary as the 1.7 power of the flux density.

34. Two transformers have identical magnetic cores and the same rated output. Both are wound for the same voltage but the first has 15 per cent. more turns in all of its coils than the second, due to which the mean length of one turn is 5 per cent. greater in the first. The windings of each are of the same size wire. Assume that the iron losses vary as the 1.7 power of the flux density. The ratio of the iron losses to the copper losses at full load is 0.7 in the first transformer. What is the ratio of the iron losses to the copper losses at full load in the second transformer? What is the ratio of the total losses at full load in the two transformers?

35. In a given transformer the ratio of the iron losses to the copper losses at full load is 0.75. Another transformer with the same radiating capacity has a magnetic core of the same length but with a cross-section 15 per cent. larger. The winding of the second transformer is designed so that the iron losses are one-third greater than the iron losses of the first. The same size of wire is used in winding both transformers but the mean length of one turn is 5 per cent. greater in the second on account of the larger magnetic core. Assume that the iron losses vary as the 1.7 power of the flux density. Both transformers have the same voltage rating. The first transformer has a full-load capacity of 100 kw. and a full-load efficiency of 97.9 per cent. at unit power factor. On the basis of the same total losses what should be the full-load rating of the second transformer? What is the ratio of the iron losses to the copper losses at full load in the second transformer?

36. Three equal 10 to 1 transformers, each of 100 kv.-a. capacity, are arranged with both the primaries and secondaries in Y to receive power from a 3-phase, 2200-volt circuit. The losses in each transformer at full load are 1960 watts of which 940 are core losses. If these transformers are connected in delta to this circuit, what power will they deliver without exceeding their full-load heating losses? Assume that the iron losses vary as 1.7 power of the flux density.

37. The name plate of a transformer gives the following data: 100 kv.-a., 6600 : 220 volts, 25 cycles. The percentage distribution of the losses at full load is: copper loss, 1.0 per cent.; eddy current loss, 0.3 per cent.; hysteresis loss 0.8 per cent. If the insulation of the transformer will safely stand double voltage what should be its rating on the basis of the same total heating losses when taking power from an 11,000-volt, 50-cycle circuit?

38. The name plate of a transformer gives the following data: 500 kv.-a., 13,200 : 400 volts, 50 cycles. At full load the copper loss is 4600 watts and the iron loss is 2800 watts. Of the latter 22 per cent. is due to eddy currents. If this transformer is to receive power from an 11,000-volt, 60-cycle circuit what should be its full-load rating on the basis of the same total heating losses?

39. A 10-kw. lighting transformer takes 122 watts on open circuit and 178 watts on short circuit with full-load current in the windings. This transformer is connected to the supply circuit continuously. It delivers its rated load, however, during but 6 hours each day and is idle the remaining 18 hours. What is the all-day efficiency?

40. A 100-kv.-a. transformer supplies a lighting and power load. The iron loss is 1010 watts and the copper loss is 1004 watts with full-load current. This transformer is connected to the supply circuit continuously. During 7 hours the load is 60 kw. at 0.75 power factor, and for the remaining 3 hours of the working day the load is 80 kw. at 0.83 power factor. The rest of the time no load is supplied. What is the all-day efficiency?

41. A 500-kv.-a. power transformer is connected to the supply circuit for 12 hours each day. The iron loss is 3330 watts and the copper loss is 4680 watts with full-load current. During 5 hours it delivers 400 kw. at 0.80 power factor and during 4 hours, 250 kw. at 0.75 power factor. The remaining hours it is idle. What is the all-day efficiency?

42.[1] The magnetic core of a transformer has a mean length of 77.3 in. and a cross-section of 34.4 sq. in. How many turns should there be in the high-tension winding if the applied voltage is 22,500 volts at 60 cycles? The maximum flux density to be used is 63,000 lines per square inch, at which the permeability of the iron is 1600. The core loss per cubic inch of iron at this flux density and frequency is 0.364 watts. What are the no-load high-tension current and power factor?

43.[1] The magnetic core of a 25-kv.-a. transformer has a cross-section of 17.5 sq. in. and an average length of 57.5 in. The high-tension winding is designed for an impressed voltage of 22,000 volts at 60 cycles and for a maximum flux density in the magnetic circuit of 70,000 lines per square inch. At this flux density the permeability is 1860 and the iron loss is 0.37 watts per cubic inch. How many turns should there be in the high-tension winding? What are the no-load current and power factor?

44.[1] A small experimental transformer has a magnetic circuit with a net cross-section of 3.4 sq. in. and a mean length of 22.5 in. Assume that the permeability of the iron is 1800. There are four coils, each of which has 232 turns, and a resistance of 0.23 ohm. (a) If all of the coils are connected for a 2 :1 ratio of transformation what is the magnetizing component of the no-load current when 220 volts at 60 cycles is impressed on the primary? (b) If the eddy current and hysteresis losses are 50 watts what is the no-load current? (c) What is the efficiency of this transformer when the secondary delivers 20 amperes at 110 volts and 100 per cent. power factor?

[1] Assume that at this flux density 75 additional ampere turns are required because of the joints in the magnetic circuit.

TRANSFORMER DATA.

No.	Kv.-a.	Type	Cycles	Voltage H.T.	Voltage L.T.	Turns H.T.	Turns L.T.	Magnetic circuit Area sq. in.	Magnetic circuit Av. length in.
A	50	Core	60	22,500	2,300	......	......	34.4	77.31
B	100	Shell	60	11,000	2,200	900	180	66	47
C	500	Core	60	11,000	2,300	......	......	88.25	131
D	500	Shell	25	13,200	425	558	18	276	68
E	1,000	Shell	60	32,400	11,500	......	......	372	86.8
F	3,333	Shell	60	55,000	6,600	733	88	348	92.8

45.[1] (a) How many turns should there be in the high- and low-tension windings in order that the maximum flux density shall be 69,000 lines per square inch in transformer No. A? What is the core loss? What is the ratio of the no-load current to the full-load current? Use the magnetic data given in problem 10. (b) How many turns should there be in the high- and low-tension windings in order that the maximum flux density shall be 69,000 lines per square inch in transformer No. C? What is the core loss? What is the ratio of the no-load current to the full-load current? Use the magnetic data given in problem 10. (c) How many turns should there be in the high- and low-tension windings in order that the maximum flux density shall be 69,000 lines per square inch in transformer No. E? What is the core loss? What is the ratio of the no-load current to the full-load current? Use the magnetic data given in problem 10.

46.[1] (a) What are the no-load current and core loss in transformer No. B? Use the magnetic data given in problem 10. (b) What are the no-load current and core loss in transformer No. D? Use the magnetic data given in problem 10. (c) What are the no-load current and core loss in transformer No. F.? Use the magnetic data given in problem 10.

TRANSFORMER DATA

No.	Kv.-a.	Type	Cycles	Voltage H.T.	Voltage L.T.	Turns H.T.	Turns L.T.	Magnetic circuit Area sq. in.	Magnetic circuit Av. length in.	Open circuit Watts	Open circuit Volt-amps.
G	500	Shell	60	12,700	2,300	376	68	170	66.4	3,330	25,800
H	1,000	Shell	60	66,000	6,600	1,240	124	278	95	9,300	60,000
I	5,000	Shell	50	52,000	33,000	529	336	613	140	17,500	146,000

47.[1] (a) What are the maximum flux density, the permeability, and the iron loss in watts per cubic inch for transformer No. G? (b) What are the maximum flux density, the permeability, and

[1] Assume that at this flux density 75 additional ampere turns are required because of the joints in the magnetic circuit.

the iron loss in watts per cubic inch for transformer No. H? (c) What are the maximum flux density, the permeability, and the iron loss in watts per cubic inch for transformer No. I?

48. A 100-kv.-a., 11,000 : 2200-volt, 60-cycle transformer has primary and secondary resistances of 6.0 ohms and 0.24 ohm respectively, and primary and secondary leakage reactances of 16 ohms and 0.64 ohm respectively. What is the maximum percentage change that can occur in the mutual flux from no-load to full-load current? At what power factor would this occur? Neglect the no-load current.

49. A 500-kv.-a., 11,000 : 2300-volt, 60-cycle transformer has primary and secondary resistances of 0.81 ohm and 0.0358 ohm respectively, and primary and secondary leakage reactances of 3.7 ohm and 0.162 ohm respectively. With the low-tension winding short circuited what voltage should be impressed on the high-tension winding so that the current will have its full-load value? Neglect the no-load current.

50. A 7.5-kv.-a., 2080 : 208-volt, 60-cycle transformer has the following constants:

$r_1 = 7.53$ ohms $\qquad x_1 = 14.2$ ohms
$r_2 = 0.0662$ ohm $\qquad x_2 = 0.128$ ohm

The core loss with 208 volts impressed on the secondary is 200 watts. Neglect the exciting current. (a) What is the regulation of this transformer for full-load current at 0.8 power factor? (b) What is the efficiency of the transformer for this load?

51. A 50-kv.-a., 30,000 : 440-volt, 50-cycle transformer has the following constants:

$r_1 = 120$ ohms $\qquad x_1 = 428$ ohms
$r_2 = 0.0258$ ohm $\qquad x_2 = 0.092$ ohm

The iron loss at the rated voltage is 641 watts. Neglect the exciting current. (a) What is the regulation of this transformer for a load of 40 kw., at 0.75 power factor? (b) What is the efficiency of the transformer for this load?

52. A 500-kv.-a., 13,200 : 425-volt, 25-cycle transformer has primary and secondary resistances of 1.6 ohms and 0.00166 ohm respectively, and primary and secondary leakage reactances of 14.5 ohms and 0.0151 ohm respectively. At no load with 425 volts impressed on the low-tension winding the power is 2.5 kw. and the kilovolt-amperes are 16.0. Neglect any change in the exciting current with change in the load. Calculate (a) the regulation and (b) the efficiency of this transformer when 400 kw. is supplied to the high-tension winding at 13,200 volts and 0.75 power factor. Use the complete transformer diagram in the solution of this problem. (c) Calculate the regulation and efficiency of this transformer for the same load on the assumption that the no-load current is negligible and that the core losses are constant.

53. The following data are given concerning a 1000-kv.-a., 66,000 : 6600-volt, 60-cycle transformer:

	No-load	Short-circuit
Current..........	9.1	15.15[1]
Voltage..........	6600	3240
Power............	9300	7490

Assume that the primary and sceondary resistances are equal when reduced to the same side and that the primary and secondary leakage reactances are similarly equal. Assume that the magnetizing current varies as the generated voltage and that the core loss varies as the square of this voltage.

Calculate (a) the regulation and (b) the efficiency when the secondary delivers full-load current at 0.80 power factor and a terminal voltage of 6680 volts. (c) Calculate the regulation and efficiency of this transformer for the same load on the assumption that the no-load current is negligible and that the core losses are constant.

TRANSFORMER DATA

No.	Kv.-a.	Type	Cycles	Voltage		Open circuit		Short circuit		
				H.T.	L.T.	Watts	Volt-amperes	Volts	Amperes[1]	Watts
J	25	Core	60	22,000	440	371	1,700	1,020	1.136	351
K	50	Core	50	30,000	440	641	3,000	1,360	1.665	665
B	100	Shell	60	11,000	2,200	940	3,750	310	9.1	1,000
C	500	Core	60	11,000	2,300	2,960	7,710	345	45.5	3,375
D	500	Shell	25	13,200	425	2,500	16,000	1,100	37.9	4,600
H	1,000	Shell	60	66,000	6,600	9,300	60,000	3,240	15.15	7,490
F	3,333	Shell	60	55,000	6,600	13,940	161,000	2,350	60.6	18,850
I	5,000	Shell	50	52,000	33,000	17,500	146,000	1,800	151.5	27,000

54. Calculate (a) the regulation[2] and (b) the efficiency of the transformer No. J for a load of 22 kw. at 0.85 power factor and rated voltage.

[1] Full-load current.

[2] Neglect the exciting current.

55. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. K for a load of 40 kw at 0.78 power factor and rated voltage.

56. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. B for a load of 100 kw. at 0.90 power factor and rated voltage.

57. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. C for a load of 460 kw. at 0.91 power factor and rated voltage.

58. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. D for a load of 500 kw. at 0.93 power factor and rated voltage.

59. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. H for a load of 1100 kw. at unit power factor and rated voltage.

60. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. F for a load of 3500 kw. at unit power factor and rated voltage.

61. Calculate (a) the regulation[1] and (b) the efficiency of the transformer No. I for a load of 5100 kw. at 0.92 power factor and rated voltage.

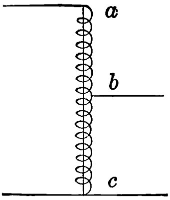

FIG. 1.

62. The resistance of the high-tension winding (a–c) of a 2:1 autotransformer is 0.072 ohms and that of the low-tension winding (b–c) is 0.035 ohms. The leakage reactance of the low-tension winding is 0.106 ohm and that of the remaining portion of the winding (a–b) is 0.108 ohm. If an electromotive force of 12 volts at the rated frequency is impressed on the high-tension winding and the low-tension winding is short-circuited what will be the current and power taken from the line?

63. The resistance of the high-tension winding (a–c)—see Fig. 1—of a 25-kv.-a., 550 : 110-volt, auto-transformer is 0.0682 ohm and that of the low-tension winding (b–c) is 0.0042 ohm. The leakage reactance of the winding (a–b) is 0.214 ohm and that of the low-tension winding is 0.0132 ohm. If the winding (a–b) is short-circuited what percentage of the rated voltage should be applied to the low-tension winding (b–c) in order that full-load current should exist in the windings? What power would be supplied?

[1] Neglect the exciting current.

64. The resistance of the high-tension winding (a–c)—see Fig. 1—of a 50-kv.-a., 440 : 110-volt auto-transformer is 0.02156 ohm and that of low-tension winding (b–c) is 0.00216 ohm. The leakage reactance of the winding (a–b) is 0.068 and that of the low-tension winding is 0.00756 ohm. If the high-tension winding is short-circuited, what voltage should be impressed on the low-tension winding in order that there will be full-load current in the windings? What power would be supplied?

65. Calculate the regulation of the auto-transformer described in problem 63 for a load of 22 kw. at 0.80 power factor on the low-tension side. If the core loss at the rated voltage is 288 watts what is the efficiency of the transformer at this load?

66. Calculate the regulation of the auto-transformer described in problem 64 for a load of 46 kw. at 0.87 power factor on the low-tension side. If the core loss is 512 watts at the rated voltage what is the efficiency of the transformer at this load?

AUTO-TRANSFORMER DATA

	Kv.-a.	Voltage	Short circuit			Core loss at rated veltage
			Watts	Current[1]	Volts[1]	
A	10	155:110	168	64.5	7.2	122
B	20	440-220	320	45.5	20.2	264
C	25	660:220	340	37.9	29.0	371
D	50	550:110	620	91.0	25.0	664
E	100	6,600:440	940	15.15	275.0	980
F	500	11,000:330	3,850	45.5	460.0	2,980

67. Calculate the regulation of the auto-transformer No. A for a load of 10 kw. at unit power factor on the low-tension side. What is the efficiency of the transformer at this load?

68. Calculate the regulation of the auto-transformer No. B for a load of 16 kw. at 0.78 power factor on the high-tension side. What is the efficiency of the transformer at this load?

69. Calculate the regulation of the auto-transformer No. C for a load of 22 kw. at 0.80 power factor on the high-tension side. What is the efficiency of the transformer at this load?

70. Calculate the regulation of the auto-transformer No. D. for a load of 55 kw. at unit power factor on the low-tension side. What is the efficiency of the transformer at this load?

71. Calculate the regulation of the auto-transformer No. E for a load of 93 kw. at 0.87 power factor on the low-tension side. What is the efficiency of the transformer at this load?

[1] The low-tension winding is short-circuited and voltage is applied to the high-tension winding so that there is full-load current in the windings.

72. Calculate the regulation of the auto-transformer No. F for a load of 510 kw. at 0.90 power factor on the low-tension side. What is the efficiency of the transformer at this load?

73. If the high-tension winding of the auto-transformer No. E is short-circuited what voltage should be applied to the low-tension winding so that there will be full-load current in the windings?

74. If the high-tension winding of the auto-transformer No. F is short-circuited what voltage should be applied to the low-tension winding so that there will be full-load current in the windings?

75. An induction regulator is connected in a 2300-volt circuit as shown in Fig. 2. With no load on the line and with 2300 volts impressed on the circuit as shown in the figure the voltage measured from *a* to *c* is 2550 volts. If the winding *b–c* is short-circuited and a reduced voltage of 460 volts is impressed on the winding *a–b*, the line current in (*o–a*) is 15 amperes and the power supplied is 2.2 kw. (a) When the station supplies 250 kw. at 0.78 power factor and a voltage of 2300 volts at *a–b* what is the line voltage at *a–c?* (b) This regulator is adjusted to reduce the voltage so that with no load on the line and with 2300 volts impressed on the circuit (at *a–b*) the voltage at *a–c* is 2050. The short-circuit data are unchanged. What is the voltage at *a–c* when the station supplies 300 kw. at a leading power factor of 0.92 and a line voltage of 2300 volts at *a–b?*

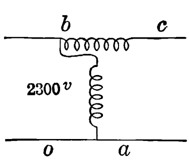

FIG. 2.

76. An induction regulator is connected in a 6600-volt circuit as shown in Fig. 2. With no load on the line and with 6600 volts impressed on the circuit (at *a–b*) the voltage measured from *a* to *c* is 7370 volts. If the winding, *b–c*, is short-circuited, and a reduced voltage of 1060 volts is impressed on the winding, *a–b*, the line current (in *o–a*) is 8.6 amperes and power supplied is 4.2 kw. (a) When the station supplies 430 kw. at 0.80 power factor and a voltage of 6600 volts at *a–b* what is the line voltage at *a–c?* (b) This regulator is adjusted to reduce the voltage so that with no load on the line and with 6600 volts impressed on the circuit (at *a–b*) the voltage at *a–c* is 5850 volts. The short-circuit data are unchanged. What is the voltage at *a–c* when the station supplies a line current (in *o–a*) of 81 amperes at a leading power factor of 0.83 and a line voltage of 6600 volts at *a–b?*

77. A small experimental transformer has four equal coils which may be inter-connected in different ways. In the first case all of the coils are connected to form a regular transformer with a ratio of transformation of 2:1, and in the second case they are connected to form an auto-transformer with the same ratio of transformation. When connected as a regular transformer with the low-tension winding short circuited the current, voltage and power, measured on the high-tension side are 8 amperes, 52 volts, and 59 watts respectively. On open circuit with 220 volts impressed on the high-tension side the core loss is 26 watts. Assume that the paths of the leakage flux are the same for each connection. Compare (a) the regulations and (b) the efficiencies of this transformer for the two cases given above for a load of 1.5 kw. at 0.9 power factor and 110 volts on the low-tension side.

78. Two transformers, one connected as a regular and the other as an auto-transformer, have identical magnetic cores and the same amount of copper in their windings. Each of the transformers gives a ratio of transformation of 330:220 volts, and the windings are so designed that the core losses in each are 122 watts when 330 volts is impressed on their primaries. The primary and secondary resistances of the regular transformer are 0.097 ohm and 0.0431 ohm respectively. The resistance of the auto-transformer measured on the low-tension side is also 0.0431 ohm. The leakage reactance of the primary winding of the regular transformer is 0.37 ohm. Assume that all of the windings have the same mean length per turn, and that the leakage reactance of the coils vary as the square of the number of turns. (a) On the basis of the same total heating losses, what is the ratio of the outputs of these two transformers? (b) What is the regulation and efficiency of each transformer for a load of 10 kw. at 0.87 power factor and 220 volts?

79. Two transformers, one connected as a regular and the other as an auto-transformer, have identical magnetic cores and the same amount of copper in their windings. Each of these transformers gives a ratio of transformation of 330:110 volts and the windings are so designed that the core losses of each are 371 watts when 330 volts is impressed on their primaries. The primary and secondary resistances of the regular transformer are 0.0306 ohm and 0.0034 ohm respectively. The resistances of the auto-transformer measured on the high- and low-tension sides are 0.017 and 0.0034 ohm respectively. The equivalent leakage reactance of the regular transformer referred to the high-tension side is 0.202 ohm. Assume that the leakage reactances of the windings vary as the square of the number of turns in them.

(a) If the high-tension winding of the regular transformer has 186 turns how many turns are there in each of the other windings of the regular and auto-transformer?

(b) The regular transformer is rated to deliver 25 kw. at 110 volts. If the losses at full load are the same for both transformers what is the kilovolt-ampere rating of the auto-transformer?

(c) What is the regulation and efficiency of each transformer when it is delivering its rated full-load current at 0.83 power factor and its rated voltage?

80. Two transformers, one connected as a regular, and the other as an auto-transformer, have identical magnetic cores and the same amount of copper in their windings. Each of these transformers gives a ratio of transformation of 550:220 volts and the windings are so designed that the volts per turn are the same for each. With 25 volts impressed on the high-tension winding of the regular transformer and with the low-tension winding short circuited the current and power are 91 amperes and 665 watts. At the rated voltage the core loss in the regular transformer is 641 watts. Assume that the resistances and leakage reactances of all of the windings vary as the square of the number of turns in them.

(a) The regular transformer is rated to deliver 50 kv.-a. at 220 volts. If the losses at full load are the same for both transformers, what is the kilovolt-ampere rating of the auto-transformer?

(b) What are the regulation and efficiency of each transformer when it is delivering its rated full-load power at 0.9 power factor?

81. Two transformers, one connected as a regular and the other as an auto-transformer, have identical magnetic cores and the same amount of copper in their windings. Each of these transformers gives a ratio of transformation of 440:110 volts, and the windings are so designed that the volts per turn are the same for each. With 14 volts impressed on the high-tension winding of the regular transformer and with the low-tension winding short circuited the current is 227 amperes and the power is 1004 watts. The core loss of this transformer at rated impressed voltage is 1010 watts. Assume that the resistances and leakage reactances of all of the windings vary as the square of the number of turns in them.

(a) The regular transformer is rated to deliver 100 kw.-a. at 110 volts. If the losses at full load are the same for both transformers, what is the kilovolt-ampere rating of the auto-transformer?

(b) What voltage should be impressed on the high-tension winding of the auto-transformer so that there will be full-load current in the short-circuited low-tension winding?

(c) What are the regulation and efficiency of each transformer for full-load current at 0.8 power factor?

82. A 10-kv.-a. and a 25-kv.-a. transformer, each of which has a ratio of transformation of 5:1, have their primaries connected in parallel across an 1100-volt circuit. Their secondaries are also connected in parallel and supply 152 amperes at 0.84 power factor to an induction motor. Referred to the secondary sides the equivalent resistances are 0.0865 ohm and 0.0272 ohm respectively and the equivalent reactances are 0.143 ohm and 0.0856 ohm respectively.

What current does each transformer take from the circuit? Compare these currents with their rated full-load values.

83. The following short-circuit data are given on two 100-kv.-a., 11,000:460-volt transformers:

Type	Amperes[1]	Voltage	Watts
Core	9.1	265	1004
Shell	9.1	310	1000

These transformers are connected in parallel on both the high- and low-tension sides and supply a load of 186 kw. at 0.93 power factor. What percentage of its full-load current does each transformer supply?

84. The following short-circuit data are given on two transformers which have a ratio of transformation of 11,000:2300 volts:

Kv.-a.	Type	Amperes[1]	Volts	Watts
100	Core	9.1	265	1004
500	Core	45.5	345	3375

These transformers are connected in parallel on both the high- and low-tension sides and supply a total current of 293 amperes at 0.92 power factor on the low-tension side. What is the current

[1] Full-load current.

in each transformer? Compare the copper losses with their full-load values.

85. The following short-circuit data are given on two 500-kv.-a., 11,000:2300-volt transformers:

Type	Amperes [1]	Voltage	Watts
Core	45.5	345	3375
Shell	45.5	345	4680

These transformers are connected in parallel on both the high- and low-tension sides and supply a total current of 452 amperes at 0.95 power factor on the low-tension side. What current does each transformer supply?

86. The following short-circuit data are given on three 66,000:6600-volt transformers:

No.	Kv.-a.	Type	Amperes[1]	Volts	Watts
A	1000	Shell	15.15	3240	7,490
B	3333	Shell	50.5	2820	18,850
C	5000	Shell	75.8	3600	27,000

These transformers are connected in parallel on both their high- and low-tension sides, and supply a load of 9200 kw. at a power factor of 0.93 and their rated voltage. Compare the division of the total current between the transformers with their ratings.

87. The following short-circuit data are given on three 11,000:460-volt transformers:

Kv.-a.	Type	Amperes [1]	Volts	Watts
100	Core	9.1	265	1004
500	Shell	45.5	917	4600
500	Core	45.5	345	3375

These transformers are connected in parallel on both the high- and low-tension sides, and supply a load of 754 kw. at 0.88 power factor and their rated voltages. What current does each transformer supply? Compare the copper loss in each transformer with the copper loss at full load.

88. Consider the transformers, Nos. B and C, described in problem 86. The high-tension windings receive power from the same 66,000-volt circuit, while the low-tension windings deliver power to independent circuits. Each transformer delivers its

[1] Full-load current.

rated full-load current, the first at unit power factor and the second at 0.88 power factor. If the low-tension circuits are now connected in parallel what is the current in each transformer? Compare these currents with their full-load values.

Assume that the currents taken by the low-tension circuits and the power factors at which they operate remain unchanged.

89. Two 50-kw. transformers are connected in parallel on both the high- and low-tension sides. Their constants are given in the following table:

Open-circuit voltage		High tension		Low tension	
High tension	Low tension	r_1	x_1	r_2	x_2
22,500	2310	61.6	110.	0.661	1.16
22,400	2320	61.6	110.	0.661	1.16

They are alike except for the difference in their ratios of transformation. These transformers supply a combined load of 93 kw. at 0.89 power factor on the low-tension side at a terminal voltage of 2300 volts. What is the current in each transformer?

90. The following data are given on two transformers which are operating with both their high- and low-tension windings in parallel:

Kv.-a.	Type	Rated open-circuit voltage		Short circuit		
		High tension	Low tension	Amperes[1]	Volts	Watts
100	Core	11,000	440	9.1	265	1,004
500	Shell	13,200	520	37.9	1,100	4,600

The ratios of transformation are slightly different. These transformers take a combined power of 460 kw. at 0.90 power factor from an 11,000-volt circuit.

(a) What is the current in each transformer?

(b) If the ratios of transformation are made equal by the removal of a few turns from the high-tension winding of the 500-kw. transformer, what is the current taken by each transformer for this load? Assume that the short circuit data would be unchanged.

91. The following data are given on two transformers which are operating in parallel on both the high- and low-tension sides:

Kv.-a.	Type	Rated open-circuit voltage		Short circuit		
		High tension	Low tension	Amperes[1]	Volts	Watts
500	Core	13,200	2,340	37.9	413	3,375
500	Shell	12,700	2,170	39.4	332	4,680

[1] Full-load current at rated voltages.

The ratios of transformation are slightly different. These transformers take a combined power of 960 kw. at 0.92 power factor from a 12,800-volt circuit.

(a) What is the current in each transformer?

(b) If the ratios of transformation are made equal by removing a few turns from the high-tension winding of the shell-type transformer what is the current taken by each transformer for this load? Assume that the short-circuit data would be unchanged.

92. Consider the transformers described in problem 82. They are operating in parallel on both the high- and low-tension sides. What are the least values of resistance and reactance that should be added to each transformer on the low-tension side in order that the currents supplied by the transformers shall be in phase and in proportion to their capacities?

(b) For a given load on the transformers compare the total heating in the transformers and reactors with that in the transformers alone before the addition of the reactors.

93. Consider the transformers described in problem 83. They are operating in parallel on both the high- and low-tension sides.

(a) Compare the sum of their rated outputs with the kilovolt-ampere load they can deliver without overloading either of them.

(b) A reactor of negligible resistance is added on the low-tension side of one transformer of such a value that the resultant impedance volts of the transformer and reactor on short circuit with full-load current is the same as that of the other transformer alone when it also carries full-load current. What is the impedance of this reactor? By what amount can the combined output of the transformers be increased by the addition of this reactor without overloading either transformer?

94. Consider the transformers described in problem 84. They are operating in parallel on both the high- and low-tension sides.

(a) Compare the sum of their rated outputs with the greatest kilovolt-ampere load they can deliver without overloading either of them.

(b) A reactor of negligible resistance is added on the low-tension side of one transformer of such a value that the resultant impedance volts of the transformer and reactor on short circuit with full-load current is the same as that of the other transformer alone when it also carries full-load current. What is the impedance of this reactor? By what amount can the combined output of the transformers be increased by the addition of this reactor without overloading either transformer?

95. The following data are given on two transformers which are operating in parallel on both their high- and low-tension sides:

Kv.-a.	Type	Voltage		Short circuit		
		High tension	Low tension	Volts	Amperes[1]	Watts
1,000	Shell	66,000	6,600	3,360	15.15	7,490
3,333	Shell	66,000	6,600	2,780	50.5	18,850

These transformers are delivering a combined load of 4333 kv.-a. at 6600 volts. A reactor of negligible resistance is added in series with one of these transformers on the low-tension side so that they divide this load in proportion to their ratings. Assume that this does not effect the low-tension voltage.

(a) What per cent. of its rated capacity is the load on each transformer before the reactor is added?

(b) What is the ractance of this reactor? By what amount is the total copper loss in the transformers reduced?

96. Two similar 5-kw. lighting transformers which give a ratio of transformation of 1100:110 volts are connected in series on both the high- and low-tension sides. With both low-tension windings short circuited and with 326 volts impressed on the high-tension windings connected in series the current is 4.55 amperes and the power supplied is 101 watts. On the low-tension side these transformers supply power to a three-wire system. The resistances of the lamp loads on the two sides of the neutral are 2.8 ohms and 2.1 ohms. The high-tension line voltage is 2200 volts. What is the current in the neutral conductor? What is the voltage across each lamp load? If each lamp takes approximately 50 watts how many should be turned off on one side in order that all of the lamps shall burn with the same brilliancy?

97. The transformers described in problem 96 are connected in series on both the high- and low-tension sides, and are delivering power to a three-wire circuit on each side of which there are two equal lamp loads taking 32 amperes at 110 volts.

What is the high-tension line voltage? If one of these loads is short circuited what will be the voltage across the other on the assumption that its resistance and the high-tension line voltage are both unchanged?

[1] Full-load current.

98. The transformers described in problem 96 are connected in parallel on the high-tension and in series on the low-tension sides and are delivering power to a three-wire lighting circuit. The resistances of the lamp loads on the two sides of the system are 2.8 and 2.1 ohms. What is the current in the neutral conductor? If the neutral conductor is disconnected from the transformers what is the voltage across each lamp load?

CHAPTER II

SYNCHRONOUS GENERATORS

1. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and is zero between the poles.

If the ratio of pole arc to pole pitch is 0.75 and the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

2. In problem 1 if the ratio of pole arc to pole pitch is 0.75 and the coil pitch 0.67, what is the generated armature voltage per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

3. In problem 1 if the ratio of pole arc to pole pitch is 0.5 and the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

4. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and decreases uniformly to zero at points midway between the poles.

If the ratio of pole arc to pole pitch is 0.75 and the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

5. In problem 4 if the ratio of pole arc to pole pitch is 0.75 and the coil pitch is 0.67, what is the generated armature voltage per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

6. In problem 4 if the ratio of pole arc to pole pitch is 0.5 and the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

7. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. This flux is sinusoidally distributed along the air-gap.

If the coil pitch is 1.0, whatis the generated armature voltage per turn? What is the form factor of this e.m.f.?

8. In problem 7 if the coil pitch is 0.8, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

9. In problem 7 if the coil pitch is 0.67, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

10. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the curve which represents the flux density in the air-gap is:

$$B = B_1 \sin x + B_3 \sin 3x.$$

x is the electrical angle measured from the point midway between the poles. Take $B_3 = 0.3B_1$.

If the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

11. In problem 10 if the coil pitch is 0.8, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

12. In problem 10 if the coil pitch is 0.67 what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

13. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the curve which represents the flux density in the air gap is:

$$B = B_1 \sin x + B_3 \sin \left(3x + \frac{\pi}{2}\right).$$

x is the electrical angle measured from the point midway between the poles. Take $B_3 = 0.3B_1$.

If the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

14. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the curve which represents the flux density in the air-gap is:

$$B = B_1 \sin x + B_3 \sin (3x + \pi)$$

x is the electrical angle measured from the point midway between the poles. Take $B_3 = 0.3B_1$.

If the coil pitch is 1.0 what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

15. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the curve which represents the flux density in the air-gap is:

$$B = B_1 \sin x + B_5 \sin 5x$$

x is the electrical angle measured from the point midway between the poles. Take $B_5 = 0.2B_1$.

If the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

16. In problem 15 if the coil pitch is 0.8, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

17. In problem 15 if the coil pitch is 0.67 what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

18. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the curve which represents the flux density in the air-gap is:

$$B = B_1 \sin x - B_5 \sin 5x$$

x is the electrical angle measured from the point midway between the poles.

If the coil pitch is 1.0, what is the generated armature voltage per turn? What is the form factor of this e.m.f.?

19. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and is zero between the poles. The armature has 8 equally spaced slots per pole. The ratio of pole arc to pole pitch is 0.67 and the coil pitch is 1.0.

(a) If the armature winding consists of 2 inductors in series per pole placed in adjacent slots, what is the generated armature voltage per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

(b) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated—*i.e.*, with 2 inductors in series per pole, placed in the same slot.

20. In problem 19 if the armature winding consists of 4 inductors in series per pole placed in adjacent slots, what is the generated armature voltage per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

(b) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated—*i.e.*, with 4 inductors in series per pole placed in the same slot.

21. In problem 19 if the armature winding consists of 4 inductors in series per pole placed in alternate slots, what is the generated armature voltage per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

(b) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated—*i.e.*, with 4 inductors in series per pole placed in the same slot.

22. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The flux density is constant under the pole face and decreases uniformly to zero at points midway between the poles. The armature has 8 equally spaced slots per pole. The ratio of pole arc to pole pitch is 0.67 and the coil pitch is 1.0.

If the armature winding consists of 2 inductors in series per pole placed in adjacent slots, what is the generated armature voltage per pole? What is the form factor of this e.m.f.? Sketch the graphs of the flux density and the e.m.f.

23. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole and is sinusoidally distributed along the air-gap. The armature has 12 equally spaced slots per pole. The coil pitch is 1.0.

(a) If the armature winding consists of 6 inductors in series per pole placed in alternate slots, what is the generated armature voltage per pole? What is the form factor of this e.m.f.?

(b) Compare this e.m.f. with what it would have been had the 6 inductors per pole been concentrated in one slot.

24. In problem 23 if the armature winding consists of 12 inductors in series per pole, one in each slot, what is the generated armature voltage per pole? What is the form factor of this e.m.f.?

(b) Compare this e.m.f. with what it would have been had the 12 inductors per pole been concentrated in one slot.

25. In problem 23 if the armature winding consists of 8 inductors in series per pole placed in adjacent slots, what is the generated armature voltage per pole? What is the form factor of this e.m.f.?

(b) Compare this e.m.f. with what it would have been had the 8 inductors per pole been concentrated in one slot.

26. With normal excitation the resultant air-gap flux in a 60-cycle alternator is 10^6 lines per pole. The equation of the curve which represents the flux density in the air-gap is

$$B = B_1 \sin x + B_3 \sin 3x$$

x is the electrical angle measured from a point midway between the poles. Take $B_3 = 0.3B_1$.

(a) If the armature winding consists of 3 equally spaced inductors per pole connected so as to give a winding which has a spread of one-third the pole pitch and a coil pitch of 1.0, what is the generated armature voltage per pole? What is the form factor of this e.m.f.? (b) Compare this e.m.f. and form factor with what they would have been had the winding been concentrated in one slot per pole.

27. A single-phase turbo-alternator is rated to deliver 1000 kv.-a. at 5200 volts when driven at 1500 rev. per min. The armature has 48 slots, 8 of which, or 2 per pole, carry no inductors, so that the spread of the winding is 0.83. In each of the other 40 slots there are 4 inductors in series. What is the no-load terminal voltage when the air-gap flux is 40 megalines per pole and the speed is 1510 rev. per min.?

28. A single-phase alternator is rated to deliver 250 kv.-a. at 2200 volts when driven at 375 rev. per min. The field structure has 24 poles and the armature, 240 slots. The spread of the armature winding is 0.6 and all of the inductors are connected in series. The coil pitch is one. In any belt each of the four central slots contains 3 inductors while each of the outer slots contains 2 inductors. What is the no-load terminal voltage when the air-gap flux is 3.9 megalines per pole and the speed is 370 rev. per min.?

29. A two-phase water turbine driven generator is rated to deliver 900 kv.-a. at 5000 volts. The field structure has 46 poles and the armature has 2 slots per pole per phase. There are 11 inductors in series per slot. The coil pitch is one. What is the no-load terminal voltage when the air-gap flux is 5.4 megalines per pole and the generator is driven at its normal speed of 120 rev. per min.?

30. A 2-phase, 60-cycle, engine driven alternator is rated to deliver 3500 kv.-a. at 11,500 volts. The armature has 576 slots with 5 inductors in series per slot. The coil pitch is one. The field structure has 96 poles. What is the generated armature voltage when the resultant air-gap flux is 6.3 megalines per pole and the speed is 74 rev. per min.?

31. The armature of a 3-phase, 50-cycle, 12-pole alternating current generator has 54 slots with 2 inductors per slot. The inductors are arranged symmetrically in the following order, which repeats itself for every pair of poles, *i.e.*, for every 9 slots. In the first, third, fourth, sixth, seventh and ninth slots both inductors are in phases 1, 3, 2, 1, 3 and 2 respectively. In the second, fifth and eighth slots the top inductors are in phases 3, 1, and 2 respectively, and the bottom inductors are in phases 1, 2 and 3 respectively. The inductors in each phase are connected in series and the phases are connected in Y.

(a) If the resultant no-load air-gap flux is sinusoidally distributed and has a value of 8×10^5 lines per pole what is the terminal voltage?

(b) What are the reduction factors for the fifth and seventh harmonics in the phase voltage?

(c) For what harmonics are the reduction factors zero?

32. The armature core of a 3-phase alternating-current generator has 12 slots per pole. Each slot contains 2 coil sides, so that while there are 8 inductors per slot each coil has 4 turns. The coil pitch is 10 slots.

What are the total reduction factors for the fundamental and the third, fifth and seventh harmonics in the phase voltage?

33. A 3-phase, Y-connected, 25-cycle, alternating-current generator is rated to deliver 7500 kv.-a at a terminal potential difference of 12,000 volts. The field structure has 12 poles and the armature has 180 slots. There are 4 inductors in series per slot. What is the no-load terminal voltage when the air-gap flux is 52 megalines per pole and the generator is driven at its rated speed? The coil pitch is 12 slots.

34.[1] (*a*) In problem 27, what is the armature reaction in ampere turns per pole when the alternator is delivering its rated load at unit power factor?

(*b*) What is the leakage reactance voltage at this load? The armature inductors are 41 in. long. Assume that the leakage flux is 7 lines per ampere per inch of inductor.

(*c*) If the armature winding had been equally distributed in 5 adjacent slots instead of in 10 what would have been the leakage

[1] See note I, page 51.

reactance voltage at this load? Assume 7 leakage lines as in (b).

35.[1] (a) In problem 28 what is the armature reaction in ampere turns per pair of poles when the alternator is delivering 200 kw. at 0.8 power factor, and its rated voltage?

(b) What is the leakage reactance voltage at this load? The armature inductors are 23 in. long. Assume that the leakage flux is 8 lines per ampere per inch of inductor.

(c) If the armature winding had been equally distributed in the four central slots, *i.e.*, with 4 inductors per slot, what would have been the leakage reactance voltage at this load? Assume 8 leakage lines as in (b).

36.[1] (a) In problem 29 what is the armature reaction in ampere turns per pair of poles when the alternator is delivering full-load kilovolt-amperes?

(b) What is the leakage reactance voltage per phase at this load? Assume that the leakage flux is 96 lines per ampere per inductor.

(c) If the armature winding had been concentrated, *i.e.*, with one slot per pole per phase, holding 22 inductors, what would have been the leakage reactance voltage? Assume the same leakage flux per inductor as in (b).

37.[1] (a) In problem 33 what is the armature reaction in ampere turns per pole when the alternator is delivering 7650 kw. at 0.9 power factor and its rated voltage?

(b) What is the leakage reactance voltage per phase at this load? The armature inductors are 48 in. long. Assume that the leakage flux is 6.5 lines per ampere per inch of inductor.

38.[2] A three-phase, Y-connected alternating-current generator which is rated to deliver 760 kv.-a. at 2200 volts has an armature with 6 slots per pole. There are 3 inductors in series per slot.

What are the cross-magnetizing and demagnetizing ampere turns per pole due to armature reaction when the alternator delivers its full-load current (a) if the power factor is such that the current in any phase reaches its maximum value 60 degrees after the inductors of that phase pass the center of the pole? (b) if the power factor is such that the current in any phase reaches its maximum value of 30 degrees before the inductors of that phase pass the center of the pole?

39.[2] A three-phase, 1500-kv.-a., 5500-volt alternating-current generator has a field structure with 72 poles and an armature

[1] See note I, page 51.

[2] Assume ratio pole arc to pole pitch equals 0.75. See note II, page 51.

with 216 slots. There are 12 inductors in series per slot. The phase windings are connected in star.

(a) What are the cross-magnetizing and demagnetizing ampere turns per pole due to armature reaction when the alternator delivers its full-load current at 0.85 power factor (inductive load)? Assume that for this power factor the current in any phase is 0.7 of its maximum value at the time the inductors of that phase are under the center of the pole.

(b) What are the cross-magnetizing and demagnetizing ampere turns per pole due to armature reaction when the alternator delivers its full-load current at 0.85 power factor (condensive load)? Assume that for this power factor the current in any phase is 0.2 of its maximum value at the time the inductors of that phase are midway between the poles.

DATA ON ALTERNATING-CURRENT GENERATORS

	A	B
Rated output (kv.-a.)	100	5000
Phases	2	3, Y
Frequency	60	60
Line voltage	480	6600
Armature iron:		
Effective length of core	5.75 in.	17.5 in.
Diameter of core at air-gap	26.4 in.	148 in.
Slots (open)	96	360
Depth of slot	1.488 in.	2.2 in.
Width of slot	0.37 in.	0.58 in.
Field magnets:		
Poles	8	30
Pole arc: Pole pitch	0.70	0.768
Armature copper:		
Inductors per slot	8 (2 in parallel)	4 (2 in parallel)
Size of inductor	No. 8 wire	$\frac{9}{64} \times \frac{7}{8}$-in. strap
Thickness of insulation between inductor and sides of slot.	0.042 in.	0.114 in.
Mean length per turn	44.4 in.	107.26 in.

40.[1] Calculate the cross-magnetizing and demagnetizing ampere turns in alternator A for full-load current and such a power factor that the current is lagging and has a value of 0.70 of its maximum value in any phase when that phase is opposite the center of the poles.

41.[1] Calculate the cross-magnetizing and demagnetizing ampere turns in alternator B for full-load current and such a power factor

[1] See note II, page 51.

that the current is lagging and has a value of 0.80 of its maximum value in any phase when that phase is opposite the center of the poles.

42. A 25-cycle alternating-current generator has an armature core with slots that are 1.35 in. wide and 2.625 in. deep. There are four inductors in series per slot. (a) Calculate the slot reactance per inch of slot on the assumptions that the path of the leakage flux across the inductors is parallel to the bottom of the slot, that the permeability of the iron is great and that the inductors completely fill the slot.

(b) If the slot reactance is calculated on the assumption that all of the leakage flux per slot is linked with all of the inductors in that slot, what value of leakage flux per ampere per inch of inductor will give the same slot reactance as calculated by the preceding method?

43. A 125-cycle alternating-current generator has an armature core with slots that are 1.0 in. wide and 3.5 in. deep. Each slot holds 12 inductors in series which completely fill it. (a) Calculate the leakage reactance per inch of slot on the assumption that the path of the leakage flux across the inductors is parallel to the bottom of the slot, and that the permeability of the iron is great.

(b) If the 12 inductors fill the slot to a depth of but 2.5 in. calculate the leakage reactance per inch of slot on the same assumptions.

44. A 60-cycle alternating-current generator has an armature core with slots that are 1.1 in. wide and 2.75 in. deep and 15 in. long. There are 6 inductors in series per slot which fill it to a depth of 2.0 in. (a) Calculate the slot reactance on the assumption that the path of the leakage flux between the sides of the slot is parallel to the bottom of the slot, and that the permeability of the iron is great.

(b) If the slot reactance is calculated on the assumption that all of the leakage flux per slot is linked with all of the inductors in that slot, what value of leakage flux per ampere per inch of inductor will give the same slot reactance as calculated by the preceding method?

45. A 3-phase, 25-cycle altenator is rated to deliver 850 kv.-a. at 5000 volts. The slots in the armature core are 1.31 in. wide and 3.625 in. deep. The gross length of the armature core is 14.5 in. and the effective length, deducting for the ventilating ducts and the insulation on the laminations, is 10.75

in. There are 14 inductors in series per slot which occupy a space 0.75 in. by 2.75 in. The thickness of the insulation between the inductors and the armature core is the same at the sides and at the bottom of the slot. The mean length of one turn is 93 in. Each coil consists of 14 turns.

(a) Calculate the leakage reactance per coil on the following assumptions. Where the inductors are embedded in iron the path of the leakage flux between the sides of the slot is parallel to the bottom of the slot. For the portions of the coil that are not embedded in the armature core the leakage flux links with all of the turns in that coil and has a value of 0.8 line per ampere per inch of turn.

(b) If the leakage reactance is calculated on the assumption that all of the leakage flux per coil links with all of the turns in the coil, and that the length of the coil is but *twice* the length of the inductor, *i.e.*, twice the gross length of the armature core, what value of leakage flux per ampere per inch of inductor will give the same value of leakage reactance as calculated by the preceding method?

46. (a) Calculate the slot and coil end leakage reactance for alternator A (see problem 40). Use the most exact method at your command for the data given.

(b) Calculate the slot and coil end leakage reactance for alternator B (see problem 41). Use the most exact method at your command for the data given.

47. A special 60-cycle generator has a field structure with 6 poles and an armature with 72 slots. There are 9 inductors in series per slot. The coils in adjacent slots are connected in series by pairs so that each of the 6 independent armature windings thus formed has a spread of one-sixth and a pitch of 1.0. When the 6 windings are arranged to form a 3-phase, Y-connected armature winding, the synchronous reactance voltage is 46 volts for an armature current of 30 amperes. Assume that the armature leakage flux is 72 lines per inductor per ampere, and that the approximate formula for armature reaction, $0.75 \frac{NI}{P}$, holds exactly in every case.

(a) What is the synchronous reactance voltage with an armature current of 30 amperes when the 6 armature windings are connected in series to form a single-phase, open-circuit armature winding?

(b) The synchronous reactance voltage is 24 per cent. of the open-circuit phase voltage when the armature winding is connected in Y. With the same field current what per cent. of the open-circuit armature voltage will the synchronous reactance voltage be when the windings are connected to form a single-phase, open-circuit armature winding?

48. In problem 47 what is the synchronous reactance voltage with an armature current of 60 amperes—*i.e.*, 30 amperes per inductor—when the 6 windings are connected to form a single-phase, 2-circuit armature winding?

(b) With the same field current as in 47 (b) what per cent. of the open-circuit armature voltage will the synchronous reactance voltage be when the windings are connected to form a single-phase, 2-circuit armature winding?

49. In problem 47 what is the synchronous reactance voltage with an armature current of 30 amperes when the 6 windings are connected to form a 2-phase armature winding?

(b) With the same field current as in 47(b) what per cent. of the open-circuit armature voltage will the synchronous reactance voltage be when the windings are connected to form a 2-phase armature winding?

50. Two three-phase, 60-cycle alternating-current generators have the same current and voltage rating. The first has 12 slots per pole and the second has 9 slots per pole.[1] Each alternator has the same number of turns per phase. The first has 4 poles and the second 6 but the dimensions of the magnetic circuit are such that the same number of ampere turns on the field produces the same flux per pole in each. The shape of the armature slots is such that the leakage flux per ampere per inductor is also the same for each.

The armature leakage reactance and the synchronous reactance of the first alternator are respectively 0.54 ohms and 2.13 ohms. What are the corresponding constants of the second alternator?

51. A 3-phase, delta-connected alternating-current generator is rated to deliver 15 kv.-a. at 230 volts when running at a speed of 1200 rev. per min. There are 6 field poles each of which is wound with 398 turns. The armature has 72 slots with 8-inductors in series per slot. Each inductor is 5 in. long. The hot resistance of the armature measured between any two terminals is 0.126 ohm. The effective resistance is 1.6 times the ohmic

[1] The coil pitches are respectively 10 slots and 8 slots.

resistance. In calculating the leakage reactance assume 8 leakage lines per ampere per inch of inductor. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
2.0	104	22
4.0	199	44
5.0	240	55
6.0	275	
7.5	315	

(a) Calculate the regulation of this generator by the general method for an inductive load of 15 kw. at 0.8 power factor. What is the field current calculated by this method?

(b) Calculate the regulation of this generator for the specified load by the synchronous impedance method. What is the field current calculated by this method?

(c) Calculate the regulation of this generator for the specified load by the magnetomotive force method. What is the field current calculated by this method?

52. A 760-kv.-a, 2200-volt alternating-current generator delivers energy directly to a 3-phase, 50-cycle system. The neutral of the generator is grounded. The field structure consists of 64 poles each of which is wound with 50 turns. The armature core has 384 slots with 3 inductors in series per slot. The length of the armature core parallel to the shaft is 10 in. The effective resistance of the armature winding is 0.172 ohm per phase. In calculating the leakage reactance assume 6.5 leakage lines per ampere per inch of slot per inductor. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
50	1060	280
80	1650	450
100	1950	....
120	2160	....
150	2420	....
200	2650	....

(a) Calculate the regulation of this generator for 25 per cent. overload current at unit power factor by the general method. What is the field current calculated by this method?

(b) Calculate the regulation of this generator for the specified load by the synchronous impedance method. What is the field current calculated by this method?

(c) Calculate the regulation of this generator for the specified load by the magnetomotive force method. What is the field current calculated by this method?

53. A 3-phase, Y-connected, 1500-kv.-a., 5500-volt alternating-current generator is driven by a 2000-h.p. reciprocating engine that runs at 83 rev. per min. at full load. The field structure has 72 poles each of which is wound with 35 turns. The armature core has 1 slot per pole per phase with 12 inductors in series per slot. Each inductor is 9 in. long. The armature winding has an effective resistance of 0.36 ohm per phase. In calculating the leakage reactance assume 7.5 equivalent leakage lines per ampere per inch of inductor. The data for the open- and short-circuit characteristics are:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
150	5100	300
200	5900	400
250	6500	....
300	6800	....
350	7100	....

(a) Calculate the regulation of this generator by the general method for 20 per cent. overload current at 0.85 power factor (induction load). What is the field current calculated by this method?

(b) Calculate the regulation of this generator for the specified load by the synchronous impedance method. What is the field current calculated by this method?

(c) Calculate the regulation of this generator for the specified load by the magnetomotive force method. What is the field current calculated by this method?

54. A 3750-kv.-a. alternating-current generator delivers energy at 2200 volts to a 2-phase, 30-cycle system. The field structure has 20 poles, each of which is wound with 60 turns. The armature has 360 slots with one inductor per slot. Each inductor is 20.5 in. long. The armature resistance by direct-current measurement is 0.0196 ohm per phase at 25° C. Assume that the ratio of effective resistance to ohmic resistance is 1.3 at 25° C. In calculating the leakage reactance assume that the leakage flux is 6.5 lines per ampere per inch of inductor. The data for the open- and short-circuit characteristics are:

Field ampere turns	Open circuit	Short circuit
per pole	Terminal voltage	Armature current
4,000	680	606
8,000	1360	1210
12,000	2000	....
16,000	2480	....
18,000	2660	....

(a) Calculate the regulation of this generator for a condensive load of 3500 kw. at 0.92 power factor by the general method. What is the field current calculated by this method? Assume that the temperature of the armature windings is 70° C.

(b) Calculate the regulation of this generator for the specified load by the synchronous impedance method. What is the field current calculated by this method?

(c) Calculate the regulation of this generator for the specified load by the magneto-motive force method. What is the field current calculated by this method?

55. A 3-phase water-wheel generator whose armature winding is Y-connected is rated to deliver 5000 kv.-a. at 6600 volts. Normal speed is 240 rev. per min. The field structure has 30 poles with 67.5 turns per pole. The armature core has 360 slots with 2 inductors in series per slot. The length of the armature core is 21.5 in. The measured resistance of the armature between any two terminals is 0.0836 ohm at 25° C. The ratio of effective resistance to ohmic resistance is 1.65 at 25° C. In calculating the leakage reactance assume that the leakage flux is 6.5 lines per ampere per inch of slot per inductor.

The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
100	4800	680
150	6500	1020
200	7400	....
250	7900	....

(a) Calculate the regulation of this generator by the general method for full-load kilovolt-amperes at 0.8 power factor (inductive load). What is the field current calculated by this method? Assume that the temperature of the armature windings is 70° C.

(b) Calculate the regulation of this generator for the specified load by the synchronous impedance method. What is the field current calculated by this method?

(c) Calculate the regulation of this generator for the specified load by the magnetomotive-force method. What is the field current calculated by this method?

56. A 2-phase, 60-cycle alternating-current generator is rated to deliver 100 kv.-a. at 480 volts. The armature has an effective resistance of 0.138 ohm and a leakage reactance of 0.159 ohm per phase. When the power factor of the load is 0.8 the armature demagnetizing ampere turns are 11.8 and the cross-magnetizing ampere turns are 15.2 per pole per ampere. The field poles are each wound with 265 turns. The data for the open circuit characteristic are:

Field current	Open-circuit voltage
10	400
15	500
20	560
25	598

What is the regulation of this generator when delivering full-load current at 0.8 power factor (inductive load)?

(a) Assume that the cross-magnetizing and demagnetizing ampere turns act on magnetic circuits of the same reluctance as that of the resultant field. This is a modification of the general method.

(b) Assume that the cross-magnetizing ampere turns act on a magnetic circuit whose reluctance is determined by the lower part of the saturation curve, and that the demagnetizing ampere turns act on the same magnetic circuit as do the impressed field ampere turns. This is the Blondel method.

57. A 3-phase, 25-cycle alternating-current generator is rated to deliver 850 kv.-a. at 5000 volts. The armature windings are connected in Y, and have an effective resistance of 0.398 ohm and a leakage reactance of 1.46 ohms per phase. When the power factor of the load is unity the armature demagnetizing ampere turns are 5.8 and the cross-magnetizing ampere turns are 31 per pole per ampere. The field poles are each wound with 79.5 turns. The data for the open-circuit characteristic are:

Field ampere turns per pole	Open-circuit terminal voltage
6,000	4330
10,000	5460
12,000	5800
14,000	6060

What is the regulation of this generator when delivering 30 per cent. overload current at unit power factor?

(a) Assume that the cross-magnetizing and demagnetizing ampere turns act on magnetic circuits of the same reluctance as that of the resultant field. This is a modification of the general method.

(b) Assume that the cross-magnetizing ampere turns act on a magnetic circuit whose reluctance is determined by the lower part of the saturation curve, and that the demagnetizing ampere turns act on the same magnetic circuit as do the impressed field ampere turns. This is the Blondel method.

58. A 3-phase, Y-connected alternating-current generator is rated to deliver 1000 kv.-a. at 13,800 volts. The armature has an effective resistance of 2.18 ohms per phase. The data for the open-circuit characteristic and the full-load current saturation curve at zero power factor are:

Field current	Open-circuit terminal voltage	Saturation curve 42 amp., at zero P.F.
41.2	....	0
50	8,800	....
110	15,600	10,750
140	17,250	13,250
180	18,900	15,600

What is the regulation for an inductive load of 50 amperes at 0.85 power factor?

59. A 3-phase, water-wheel generator is rated to deliver 5000 kv.-a. at 6600 volts. The armature winding is Y-connected and has an effective resistance of 0.081 ohm per phase. The data for the open-circuit characteristic and the full-load current saturation curve at zero power factor are:

Field current	Open-circuit terminal voltage	Saturation curve 438 amp. at zero P.F.
64	3050	0
100	4800	1800
150	6500	4200
200	7400	5700
275	8150	6900

What is the regulation for an inductive load of 500 amperes at 0.8 power factor?

60. A 3-phase, Y-connected alternating-current generator is rated to deliver 1640 kv.-a. at 13,500 volts. The armature has an effective resistance of 1.52 ohms per phase and a synchronous reactance of 31.4 ohms per phase.

(a) What is the regulation of this alternator on an inductive load taking 1500 kw. at 0.85 power factor?

(b) What is the regulation on a condensive load taking 1500 kw. at 0.85 power factor?

61. A 2-phase alternating-current generator is rated to deliver 3500 kw. at 10,000 volts. The armature has an effective resistance of 0.64 ohm per phase and a synchronous reactance of 13.7 ohms per phase.

(a) What is the regulation of this alternator on a non-inductive load taking the rated kv.–a.?

(b) What is the regulation on an inductive load taking the rated kv.-a. at zero power factor?

(c) What is the regulation on a condensive load taking the rated kv.-a. at zero power factor?

62. A 760-kv.-a, 2200-volt, 3-phase alternating-current generator has an effective armature resistance of 0.17 ohm per phase. The armature winding is connected in Y. With the armature short-circuited the armature current is 338 amperes when the field current is 60 amperes. The open-circuit characteristic data are:

Field current	Open-circuit terminal voltage
50	1060
80	1650
100	1950
120	2160
150	2420
200	2650

(a) What is the regulation of this generator, calculated by the magnetomotive-force method, for an inductive load which requires full-load current at 0.5 power factor?

(b) What is the regulation for a condensive load which requires full-load current at 0.5 power factor?

63. A 3-phase, Δ-connected alternating-current generator has a full-load capacity of 15 kv.-a. at 230 volts. The effective armature resistance and synchronous reactance are respectively 0.302 and 4.36 ohms per phase. Three reactors each of which has an effective resistance of 2.5 ohms and a reactance of 10 ohms are connected in Δ across the terminals of the generator. If the terminal voltage is adjusted to its rated value to what will it rise when the coils are removed?

(b) If the coils are connected in Y and the terminal voltage adjusted as before to what will it rise when the coils are removed?

(c) What is the power output of the generator in each case?

64. In problem 63 if the open-circuit voltage of the generator is adjusted to 300 volts to what will it fall when the coils are connected in Δ across the terminals? What is the power output of the generator?

65. A 3-phase, 1500-kv.-a., 5500-volt alternating-current generator delivers full-load current to an inductive load at 0.85 power factor. The effective resistance and synchronous reactance of this alternator are respectively 0.36 and 6.5 ohms per phase. The armature winding is Y-connected. With the field excitation unchanged what will be the terminal voltage if the alternator delivers its rated current to a condensive load at 0.85 power factor?

66. A special 6-pole, 60-cycle alternating-current generator has six similar and independent armature windings. The windings are equally spaced so that their voltages differ by 30 degrees.

On the basis of equal armature and field heating losses and of equal frequencies compare the rated outputs—kilovolt-amperes and terminal voltage—of this alternator when the windings are connected (1) for an open-coil single-phase winding and (2) for a 2-phase winding.

67. (a) In problem 66 compare the rated outputs on the same basis when the windings are connected (1) for an open-coil single-phase winding and (2) for a 3-phase mesh winding.

(b) Compare the rated outputs on the same basis when the windings are connected (1) for an open-coil single-phase winding and (2) for a 3-phase star winding.

68. In problem 66 compare the rated outputs on the same basis when the windings are connected (1) for a 2-phase winding and (2) for a 3-phase star winding.

69. Concerning the alternator described in problem 51 the following additional data are given. The field current is supplied at 110 volts. The friction and windage loss is 310 watts at normal speed, and the core loss due to rotation is 480 watts for an armature generated voltage of 240. Assume that the core loss is constant. What is the efficiency of this alternator at the load described in problem 51? (1) Calculate the field current by the synchronous impedance method, (2) by the magnetomotive-force method.

70. Concerning the alternator described in problem 52 the following additional data are given. The resistance of the field circuit is 0.516 ohm. The friction and windage loss is 6.2 kw. at normal speed. The core loss due to rotation is 11.0 kw. at 2200 volts and may be assumed to vary as the square of the generated armature voltage.

(a) What is the efficiency of this generator at the load described in problem 52?

(b) What is the efficiency of this generator when delivering the same current at 0.80 power factor?

Calculate the field current (1) by the general method and (2) by the magnetomotive-force method.

71. Concerning the alternator described in problem 53 the following additional data are given. The resistance of the field circuit is 0.376 ohm. The friction and windage loss is 8.4 kw. The core loss due to rotation is 20.2 kw. at 5500 volts, and should be assumed to vary as the square of the generated armature voltage.

(a) What is the efficiency of the generator at the load described in problem 53?

(b) What is the efficiency of this generator when delivering the same power at unit power factor?

Calculate the field current (1) by the synchronous impedance method, and (2) by the magnetomotive-force method.

72. The full-load capacity of a 3-phase, 25-cycle alternating-current generator is 850 kv.-a. at 5000 volts. The armature windings are connected in Y and have an effective resistance of

0.398 ohm per phase. The synchronous reactance is 8.4 ohms per phase. With the armature short-circuited the armature current is 108 amperes when the field current is 50 amperes. The resistance of the field circuit is 0.82 ohm. The friction and windage is 7.6 kw. The core loss due to rotation is 20.2 kw. at 5200 volts and may be assumed to be constant. The open-circuit characteristic is given by the following data:

Field current	Open-circuit terminal voltage
125	5460
150	5800
175	6060

What is the efficiency of this generator when delivering 10 per cent. overload current at 0.80 power factor (inductive)?

Calculate the field current (1) by the synchronous impedance method, and (2) by the magentomotive force method.

73. Concerning the alternator described in problem 54 the following additional data are given. The resistance of the field circuit is 0.37 ohm. The friction and windage is 19 kw. The core loss is given by:

Terminal voltage on open circuit	Core loss
1360	18.0 kw.
2000	36.5 kw.
2480	60.0 kw.

What is the efficiency of this generator for the load described in problem 54? Calculate the field current (1) by the general method, (2) by the synchronous impedance method, and (3) by the magnetomotive-force method.

74. Concerning the alternator described in problem 58 the following additional data are given. The resistance of the field circuit is 0.541 ohm. The friction and windage loss is 9.2 kw. The core loss is given by:

Terminal voltage on open circuit	Core loss
8,800	7.5 kw.
13,000	16.6 kw.
15,600	25.4 kw.
17,250	33.5 kw.

What is the efficiency of this generator for the load described in problem 58?

75. Concerning the alternator described in problem 59 the following additional data are given. The resistance of the field circuit is 0.549 ohm at 25° C. The temperature of the field under load conditions is 68° C. The friction and windage loss is 38 kw. The core loss is given by:

Terminal voltage on open circuit	Core loss
4800	45 kw.
6000	73 kw.
6600	90 kw.
7500	123 kw.

What is the efficiency of this generator for the load described in problem 59?

76. Two alternators of the same design are operating in parallel. The first delivers 980 kw. at 0.95 power factor, and the second 720 kw. at 0.73 power factor. What adjustments should be made to have these alternators operate under the best conditions? When these have been made what power will each deliver and at what power factor will it operate?

77. Two 3-phase alternators connected in parallel are driven by shunt motors whose speed load characteristics for particular field excitations are given by the following data: The speed of the first motor falls uniformly from 600 rev. per min. at no load to 530 rev. per min. at full load of 100 kw. on the alternator. The speed of the second motor falls uniformly from 590 rev. per min. at no load to 550 rev. per min. at full load of 100 kw. on the alternator.

(a) For what load will the alternators divide the load equally?

(b) What will be the load on each alternator when their combined load is 200 kw.?

(c) What is the greatest load that can be delivered without overloading either alternator?

78. A 3-phase, 2200-volt alternator which is rated to deliver 760 kv.-a. is connected in parallel through transformers with a 3-phase, 5500-volt alternator which is rated to deliver 1500 kv.-a. The first alternator has 64 poles and is driven by an engine whose speed falls from 94 rev. per min. at no load to 91 rev. per min. at full load on the alternator. The second alternator has 72 poles and is driven by an engine whose speed falls from 83 rev. per min. at no load to 79 rev. per min. at full load on the alternator.

(a) What is the greatest combined load that the alternators can deliver without overloading either by more than 25 per cent.?

(b) What is the load on each alternator when the first is running at 91.6 rev. per min.?

(c) What is the frequency when they are delivering a combined load of 2000 kw.?

79. Two 3-phase, 60-cycle alternating-current generators are operating in parallel. The first has a capacity of 1000 and the second a capacity of 1500 kv.-a. The first is driven by a prime mover so adjusted that the frequency falls from 61 cycles at no load to 59.6 cycles at full load. The second has a different speed-load characteristic, the frequency falling from 61.4 cycles at no load to 59.2 cycles at full load.

When these alternators are jointly delivering 2000 kw. what is the load on each? What is the frequency? If the speed-load characteristic of the second is shifted parallel to itself until the alternators divide this load properly, what is the new value of the no-load frequency of this alternator? At what frequency will they now operate when delivering 2000 kw.?

80. Two 3-phase, 11,000-volt, 60-cycle alternating-current generators, operating in parallel, are driven by prime movers which have the same speed-load characteristic. The armature windings of the alternators are Y-connected and have an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase. The total load supplied is 1700 kw. at 0.83 power factor. The excitations are adjusted so that the terminal voltage is 11,000 volts and one of them is operating at unit power factor. What are the excitation voltages and the phase angle between them?

81. Two identical 3-phase, Y-connected alternators operating in parallel are driven by prime movers that have such dissimilar speed-load characteristics that when the first alternator is delivering 400 kw. at 0.8 power factor the second is running at no load. (a) If the excitations of the alternators are adjusted so that the terminal voltage is 5000 volts and the armature current of the second alternator is zero, what are the excitation voltages and their phase displacement? (b) If the excitations are adjusted so that the terminal voltage is 5000 volts and the total armature copper loss is reduced to its least value what current will each alternator deliver? The effective armature resistance and the synchronous reactance of each alternator are respectively 0.42 and 12.4 ohms per phase.

82. Two identical 3-phase alternators, connected in parallel, are driven by prime movers that have dissimilar speed-load characteristics. When the excitations of the alternators are equal the first delivers 100 amperes at 0.9 power factor (lagging) and the second, 75 amperes at 0.7 power factor (lagging).

(a) What per cent. of the total load does each alternator deliver?

(b) What is the power factor of the load?

(c) If the field excitations are adjusted so that both alternators operate at the same power factor what current will each deliver?

(d) If the field excitations are adjusted so that the total armature copper loss is reduced to its least value at what power factor will each alternator operate?

83. Two identical 2-phase alternators, connected in parallel, are driven by prime movers which have somewhat dissimilar speed-load characteristics. The first alternator delivers 3200 kw. at 2210 volts and has an armature current of 760 amperes, while the second delivers 3700 kw. at 2210 volts and has an armature current of 1100 amperes. The effective armature resistance and the synchronous reactance of each alternator are respectively 0.0256 and 0.72 ohms per phase. The excitations of the alternators are now adjusted so as to reduce the total armature copper loss to its least value, but the terminal voltage is maintained at 2210 volts.

(a) At what power factor will each alternator be operating?

(b) What is the reduction in the total armature copper loss?

(c) What is the change in the copper loss of each alternator?

84. Two identical 3-phase alternators, operating in parallel on a balanced load, are driven by prime movers with different speed-load characteristics. The power output of each alternator is measured by two wattmeters. Show that when the differences between the wattmeter readings for each alternator are the same the total armature copper loss is reduced to its least value for the given load.

85. Two dissimilar Y-connected alternators, operating in parallel, supply a load of 1500 kw. at 0.85 power factor and a terminal potential difference of 5000 volts. The alternators being of the same capacity are adjusted to deliver equal loads.

The effective armature resistances are respectively 0.40 and 0.52 ohm per phase.

What should be the armature current of each alternator in order that their combined armature copper loss will be reduced to its least value?

86. An alternator which has a capacity of 1650 kv.-a. is operated in parallel with one which has a capacity of 1000 kv.-a. Their armature resistances are 1.56 ohms and 2.08 ohms respectively. For a combined load of 2200 kw. at 0.83 power factor what load should each deliver and at what power factor should it operate if the current and power outputs are proportional to their ratings? With this division of the load the excitations are adjusted so that the combined armature copper loss is reduced to a minimum. At what power factor should each alternator operate for this latter condition?

87. Two identical 3-phase, Y-connected alternators are operating in parallel with a common potential difference of 2200 volts. The effective armature resistance and the synchronous reactance of these alternators are respectively 0.158 and 2.12 ohms per phase. The characteristics of the prime movers are so dissimilar that of the total load of 1500 kw. at 0.85 power factor the first alternator supplies 840 kw. The excitations of the alternators are adjusted so that both are operating at the same power factor. What are their excitation voltages and the phase displacement between them?

88. Two identical 3-phase, Y-connected alternators, operating in parallel, are driven by prime movers which have the same speed-load characteristic. The effective armature resistance and the synchronous reactance of the alternators are respectively 2.18 ohms and 62 ohms per phase.

The alternators supply 1830 kw. at 13,800 volts to an induction motor load that is operating at 0.83 power factor. The excitations of the alternators are adjusted so that the first supplies a current of 40 amperes, lagging.

(a) What current does the second alternator supply?

(b) What are the excitation voltages of the alternators and their phase displacement?

89. Two identical 3-phase, Y-connected alternators, operating in parallel, are driven by prime movers that have the same speed-load characteristic. The alternators are rated to deliver 1000 kv.-a. at 2400 volts. The effective armature resistance and the synchronous reactance are respectively 0.067 and 1.64 ohms per phase. Assume that the rotational losses, both core loss and friction, are constant and equal.

(a) If these alternators are delivering 2000 kw. at unit power factor and their rated voltage, by what amount can the load be shifted from one to the other if their field excitations are adjusted so that there is an interchange current equal to the full-load current, viz., 240 amperes?

(b) If these alternators are delivering 1500 kw. at 0.75 power factor and their rated voltage, by what amount can the load be shifted from one to the other if their field excitations are adjusted so that there is an interchange current equal to the full-load current, viz., 240 amperes.

90. The alternators described in problem 89 are operating in parallel with non-inductive resistances of 0.8 ohm inserted in each phase of each alternator.

(a) If the alternators are jointly delivering 2000 kw. at unit power factor and their rated voltage to a load by what amount can this load be shifted from one to the other if the excitations are adjusted so that there is an interchange current equal to the full-load current, viz., 240 amperes?

(b) If the alternators are jointly delivering 1500 kw. at 0.75 power factor and their rated voltage to a load, by what amount can this load be shifted from one to the other if the excitations are adjusted so that there is an interchange current equal to the full-load current, viz., 240 amperes?

91. Two identical 3-phase alternators, rigidly coupled together so that their excitation voltages are in phase, are driven by a shunt motor. The effective armature resistance and the synchronous reactance of each alternator are respectively 0.302 and 4.36 ohms per phase. The terminals of the alternators are electrically connected as they would be for parallel operation but no external load is supplied. When the field excitations are adjusted so that the excitation voltages are respectively 200 and 300 volts per phase, what is the armature current? If the armature windings are connected in delta what is the terminal voltage? What is the electrical output of the alternator which is acting as a generator? If the rotational losses are supplied by the shunt motor what is the mechanical output of the alternator which is acting as a motor? If the rotational losses are 1620 watts what power does the shunt motor supply?

92. If the alternators described in problem 91 are mechanically coupled together so that their excitation voltages differ in phase by 30 degrees what will be the armature current when the excitation voltages are each 300 volts? What is their terminal voltage? What is the electrical output of the alternator which is acting as a generator? If the rotational losses are supplied by the shunt motor what is the mechanical output of the alternator which is acting as a motor? What power does the shunt motor supply if the rotational losses are 1620 watts?

93. Two identical, Y-connected, 60-cycle alternators are rigidly coupled together and are driven at their rated speed of 1200 rev. per min. The alternators have revolving fields and the coupling is so made that the north poles of the first are 10 degrees (mechanical) ahead, *i.e.*, in the direction of rotation, of the corresponding north poles of the second. The corresponding terminals are connected through non-inductive resistances of 1.5 ohms each. The effective armature resistance and the synchronous reactance of each alternator are respectively 0.302 and 4.36 ohms per phase. The field currents are adjusted so that the excitation voltages are respectively 200 and 300 volts per phase. What is the current? What is the electrical output of the alternator which is acting as a generator? If the rotational losses are supplied by the driving motor what is the mechanical output of the alternator which is acting as a motor? If the rotational losses are 1620 watts what is the output of the driving motor?

94. Two identical, 3-phase, Y-connected alternators, rigidly coupled to the same prime mover, are operating in parallel and supply 1500 kw. at 0.83 power factor and a terminal potential difference of 5000 volts. The effective armature resistance and the synchronous reactance of each alternator are respectively 0.42 and 12.4 ohms per phase. The mechanical coupling is so made that the excitation voltages are in phase, and the field currents are adjusted so that one of these voltages is 50 per cent. greater than the other. What is the output of each alternator?

95. Two 3-phase, Y-connected alternators, each of which is rated to deliver 760 kv.-a. at 2200 volts, are rigidly coupled to the same prime mover. Each of these alternators has 64 field poles, an effective armature resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. With equal field excitations they operate at full load with undue heating and on examination it is found that their corresponding field poles are displaced by an angle of 1 degree and 6 minutes.

(a) When they deliver 1500 kw. at 0.87 power factor and their rated voltage, what is the output of each alternator if the field excitations are equal?

(b) If this displacement of the field poles is reduced to zero what will be the reduction in the armature copper loss of each alternator? The load delivered is still 1500 kw. at 0.87 power factor and their rated voltage.

96. Two identical, 2-phase, 3750-kv.-a. water-wheel generators, operating in parallel, are driven by prime movers which have the same speed-load characteristic. The effective armature resistance and the synchronous reactance of these alternators are respectively 0.0254 and 0.72 ohms per phase. The alternators are jointly delivering 7500 kw. at unit power factor and their rated terminal potential difference of 2200 volts. The excitations are equal.

Instantaneous records show that due to hunting the maximum displacement of their excitation voltages is 30 degrees. What is the synchronizing power at the time of maximum displacement? What is the maximum value of the effective armature current?

97. If the alternators described in problem 96 are jointly delivering 5250 kw. at 0.7 power factor and their rated voltage to an inductive load, what is the synchronizing power at the time the displacement of their excitation voltages is 30 degrees? What are the effective armature currents at this time?

98. If the alternators described in problem 96 are jointly delivering 5250 kw. at 0.7 power factor and their rated voltage to a condensive load, what is the synchronizing power at the time the displacement of their excitation voltages is 30 degrees? What are the effective armature currents at this time?

99. Two identical 3-phase, Y-connected alternators, each of which is rated to deliver 1640 kv.-a. at 13,500 volts are operating in parallel. The speed-load characteristics of the prime movers are the same and the load requires 70 amperes from each alternator at 0.83 power factor and the rated voltage. The effective armature resistance and the synchronous reactance of the alternators are respectively 1.52 ohms and 31.4 ohms per phase. Oscillograph records show that due to hunting the greatest value of the effective armature current is 87 amperes.

What is the maximum displacement between the excitation voltages?

What is the synchronizing power at this maximum displacement?

NOTE I. In calculating the armature reaction it is recommended to use $0.707k\frac{NI}{P}$ for turbo-alternators and $0.75k\frac{NI}{P}$ for salient pole machines. k is the total reduction factor for breadth and pitch, and $\frac{NI}{P}$ represents the armature ampere-turns per pole.

NOTE II. See "Principles of Alternating Current Machinery," by R. R. Lawrence, pages 106–115.

CHAPTER III

SYNCHRONOUS MOTORS

1. A 3-phase, 60-cycle, Δ-connected alternating-current generator is rated to deliver 15 kv.-a. at 230 volts. The field structure has 6 poles each of which is wound with 398 turns. The armature core has 4 slots per pole per phase with 8 inductors in series per slot. Each inductor is 5 in. long. The hot resistance of the armature measured between any two terminals is 0.126 ohm. The effective resistance is 1.6 times the ohmic resistance. In calculating the leakage reactance assume 8 leakage lines per ampere per inch of inductor. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
2.0	104	22
4.0	199	44
5.0	240	55
6.0	275	....
7.5	315	....

This generator is running as an overexcited synchronous motor and receives 15 kw. at its rated voltage and 0.8 power factor.

(a) Calculate the field current by the general method.

(b) Calculate the field current by the synchronous-impedance method.

(c) Calculate the field current by the magnetomotive-force method.

2. A 3-phase, 5000-volt, 25-cycle synchronous motor has a full-load capacity of 1100 h.p. The field structure consists of 32 poles each of which is wound with 79.5 turns. The armature core has 192 slots with 14 inductors in series per slot. The armature winding is Y-connected. The effective resistance of the armature winding is 0.38 ohm per phase. In calculating the leakage reactance, assume 75 leakage lines per ampere per inductor. The open- and short-circuit characteristics are given by the following data:

Field ampere-turns per pole	Open circuit	Short circuit
	Terminal voltage	Armature current
4,000	3200	108
6,000	4330	162
10,000	5460	....
12,000	5800	....
14,000	6060	....

This motor receives 760 kw. at its rated voltage and 0.83 power factor. The excitation is less than normal.

(a) Calculate the field current by the general method.

(b) Calculate the field current by the synchronous-impedance method.

(c) Calculate the field current by the magnetomotive-force method.

3. A 3-phase, 5500-volt, 50-cycle synchronous motor has a full-load capacity of 2000 h.p. The field structure has 72 poles each of which is wound with 35 turns. The armature core has one slot per pole per phase with 12 inductors per slot. The armature winding is connected in Y. The armature resistance measured between any two terminals is 0.536 ohm, and the ratio of effective to ohmic resistance is 1.35. In calculating the leakage reactance assume 67 leakage lines per inductor per ampere. The data for the open- and short-circuit characteristics are:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
150	5100	300
200	5900	400
250	6500	....
300	6800	....
350	7100	....

This motor receives 960 kw. at its rated voltage and 0.68 power factor. The excitation is greater than normal.

(a) Calculate the field current by the general method.

(b) Calculate the field current by the synchronous-impedance method.

(c) Calculate the field current by the magnetomotive-force method.

4. A 3-phase, 2200-volt, 50-cycle synchronous motor is rated to deliver 1000 h.p. when operating at unit power factor. The field structure has 64 poles each of which is wound with 50 turns. The resistance of the field circuit is 0.516 ohm. The armature core has 384 slots with 3 inductors in series per slot. Each inductor is 10 in. long. The hot resistance of the armature measured between terminals is 0.264 ohm. The ratio of effective to ohmic resistance is 1.3. In calculating the leakage reactance assume 6.5 lines per ampere per inch of inductor. The armature windings are connected in Y. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
40	1450	225
50	1840	280
60	2220	....
80	2860	....
100	3380	....

The rotational losses at normal voltage are 17.2 kw.

This motor deliveres 1000 h.p. and the excitation greater than normal and is adjusted so that it is operating from a 2200-volt circuit at a power factor of 0.93.

(a) Calculate the voltage impressed on the field circuit. Use the general method.

(b) Calculate the voltage impressed on the field circuit. Use the synchronous-impedance method.

(c) Calculate the voltage impressed on the field circuit. Use the magnetomotive-force method.

5. A 2-phase, 10,000-volt synchronous motor is rated to deliver 4500 h.p. when operating at unit power factor. The armature has an effective resistance of 0.64 ohm per phase. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
100	7,700	220
200	10,200	430
250	10,900	....
300	11,500	....
375	12,200	....

This motor is delivering 3760 h.p. with an efficiency, exclusive of field loss, of 95.6 per cent., and the field current is adjusted so that it takes a leading current at 0.91 power factor.

(a) Calculate the field current by the synchronous-impedance method.

(b) Calculate the field current by the magnetomotive-force method.

6. The full-load capacity of a 3-phase, 13,500-volt, synchronous motor is 2200 h.p. The armature windings, which are connected in Y, have an effective resistance of 1.52 ohm per phase. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
50	7,500	75
100	10,100	155
150	14,700	227
200	15,800	....
250	16,700	....

Calculate the field current by the synchronous impedance method when this motor receives 1640 kv.-a. at 0.75 power factor, (a) with excitation greater than normal, (b) with excitation less than normal.

7. The synchronous motor described in problem 6 receives 1250 kw. at 0.75 power factor.

Calculate the field current by the magnetomotive-force method (a) with excitation greater than normal, (b) with excitation less than normal.

8. Concerning the alternator described in problem 1 the following additional data are given: The field current is supplied at 110 volts. The friction and windage loss is 310 watts at normal speed. The core loss is 280 watts, 480 watts, and 610 watts for generated armature voltages of 199 volts, 240 volts, and 275 volts respectively.

What is the efficiency of this generator when it is running as an overexcited synchronous motor and receives 15 kw. at 0.8 power factor?

Calculate the field current (a) by the general method, (b) by the synchronous-impedance method, and (c) by the magnetomotive-force method.

9. Concerning the synchronous motor described in problem 2 the following additional data are given: The resistance of the field circuit is 0.82 ohm. The friction and windage loss at normal speed is 7.6 kw. The core loss due to rotation is 22.3 kw. at 5460 volts and may be assumed to vary as the square of the generated armature voltage. What is the efficiency of this motor under the conditions described in problem 2?

Calculate the field current (a) by the general method, (b) by the synchronous-impedance method, and (c) by the magnetomotive-force method.

10. Concerning the synchronous motor described in problem 3 the following additional data are given. The field circuit has a resistance of 0.376 ohm. The friction and windage loss is 8.4 kw. The core loss due to rotation is 20.2 kw. at 5500 volts and may be assumed to vary as the square of the generated armature voltage. What is the efficiency of this motor under the conditions described in problem 3?

Calculate the field current (a) by general method, (b) by the synchronous-impedance method, and (c) by the magnetomotive-force method.

11. A 3-phase, 2200-volt synchronous motor is rated to deliver 1000 h.p. when operating at unit power factor. The armature windings, which are connected in Y, have an effective resistance of 0.172 ohm per phase. The resistance of the field circuit is 0.576 ohm. The friction, windage and core losses are 17.2 kw. and may be assumed constant. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
40	1450	225
50	1840	280
60	2220	....
80	2860	....
100	3380	....

What is the efficiency of this motor when it delivers 960 h.p. and is operating at 0.83 power factor from a 2200-volt circuit (a) if the excitation is greater than normal, (b) if the excitation is less than normal?

Calculate the field current by the synchronous impedance method.

12. A 2-phase, 2200-volt synchronous motor has a full-load capacity of 5000 h.p. when operating at unit power factor. The armature has an effective resistance of 0.0255 ohm per phase.

The resistance of the field circuit is 0.37 ohm. The friction and windage loss is 19.0 kw. The core loss due to rotation is 45.2 kw. at 2200 volts and may be assumed constant. The open- and short-circuit characteristics are given by the following data:

Field current	Open circuit	Short circuit
	Terminal voltage	Armature current
66.7	680	606
133.0	1360	1210
200.0	2000	....
267.0	2480	....
300.0	2660	....

What is the efficiency of this motor when it receives 3200 kw. at 0.80 power factor (a) if the excitation is greater than normal, (b) if the excitation is less than normal?

Calculate the field current by the magnetomotive-force method.

13. The following test data are given on a 1340-h.p., 11,000-volt, 3-phase synchronous motor. The armature effective resistance is 0.94 ohm per phase, and the resistance of the field winding is 3.11 ohms. The armature windings are connected in Y.

Field current	Open circuit terminal voltage (V)	Core loss and V	Terminal voltage for $I_a = 60$, $PF = 0$
20	8,400	11,600	....
30	11,000	19,400	....
40	12,700	25,600	....
50	13,800	....	9,800
60	14,700	....	11,100
70	15,500	....	12,100

The friction and windage loss is 12.1 h.p.

What is the efficiency of this motor when it receives 68 amperes per terminal at 11,550 volts if the excitation is greater than normal and is adjusted so that the power factor is 78.4 per cent.?

14. The following test data are given on a 6500-h.p., 6600-volt, 3-phase synchronous motor. The effective resistance of the armature winding is 0.081 ohm per phase, and the resistance of the field winding is 0.549 ohm. The armature windings are connected in Y.

Field current	Open circuit terminal voltage (V)	Core loss and V	Terminal voltage $I_a = 438$, $PF = 0$
100	4800	45 kw.	1750
150	6470	85 kw.	4200
200	7400	120 kw.	5700
250	7930	....	6600
275	8150	....	6900

The friction and windage loss is 62.8 h.p.

What is the efficiency of this motor when it receives 450 amperes at unit power factor, and its rated voltage?

15. The following test data are given on a 1340-h.p., 13,800-volt, 3-phase synchronous motor. The armature windings, which are connected in Y, have an effective resistance of 2.18 ohms per phase. The resistance of the field circuit is 0.541 ohm.

Field current	Open circuit terminal voltage (V)	Terminal voltage $I_a = 42$, $PF = 0$	Core loss and V
50	8,800	....	7.5
80	13,000	....	16.6
110	15,600	10,750	25.4
140	17,250	13,250	33.5
180	18,900	15,600	....

The friction and windage loss is 11.2 h.p.

What is the efficiency of this motor when it delivers 1200 h.p. if the excitation is greater than normal and is adjusted so that the motor takes an armature current of 47.6 amperes at a terminal voltage of 13,500 volts?

16. A synchronous motor, whose armature windings are connected in Y, has an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase. This motor receives a line current of 60 amperes at a terminal potential difference of 11,000 volts and the excitation is adjusted so that the power factor is 0.85.

What power does the motor receive? What is the excitation voltage (a) if the excitation is greater than normal, (b) if the excitation is less than normal?

17. A 2-phase synchronous motor has an effective armature resistance of 0.64 ohm and a synchronous reactance of 13.7 ohms per phase. The motor receives 3000 kw. at a line potential difference of 10,000 volts and the excitation adjusted so that the line current is 200 amperes.

At what power factor is this motor operating? What is the excitation voltage (a) if the excitation is greater than normal, (b) if the excitation is less than normal?

18. A 5000-h.p. synchronous motor is operated from a 2200-volt, 2-phase circuit. The effective resistance of the armature is 0.0254 ohm per phase. The field winding has 60 turns per pole and a total resistance of 0.37 ohm.

Ampere turns per pole	Open circuit terminal voltage	Short circuit armature current
4,000	680	606
8,000	1360	1210
12,000	2000	....
16,000	2480	....
18,000	2660	....

At no load this motor takes 67.5 kw. at 2200 volts when the excitation is adjusted so that it operates at 0.86 power factor. How much must the excitation be increased in order that the motor will deliver its rated load and operate at this same power factor? Use the magnetomotive-force method for calculating the field current.

19. A 3-phase synchronous motor, whose armature windings are connected in Δ, has an effective resistance of 0.302 ohm and a synchronous reactance of 4.36 ohms per phase. This motor receives a line current of 40 amperes at 230 volts and the field current is adjusted so that the excitation voltage is 310 volts.

What power does the motor receive? At what power factor is it operating?

20. A 2400-volt, 3-phase, synchronous motor has a full-load capacity of 1340 h.p. The effective resistance of the armature is 0.067 ohm per phase and the synchronous reactance is 1.64 ohms per phase. The armature windings are connected in Y. The resistance of the field circuit is 0.427 ohm. The rotational losses at normal voltage are 26.6 kw.

This motor is operated from a 2400-volt circuit at 0.82 power factor and is delivering 1220 h.p. What is the line current, and what is the necessary excitation voltage? Calculate the excitation voltage for both under- and overexcitation.

21. A 135-h.p. synchronous motor is operated from a 480-volt, 2-phase circuit. The effective resistance of the armature is 0.135 ohm per phase at normal running temperature. The rotational losses at normal voltage are 5.7 kw.

Field current	Terminal voltage on open circuit	Armature current on short circuit
10	397	158
17	527	....
25	600	....
35	655	....

With the greatest allowable excitation the motor takes a current of 135 amperes when delivering its rated load. At what power factor does it then operate? What is the field current? Use what you consider the best method for calculating the field current.

22. A 3-phase synchronous motor, whose armature windings are connected in Y, has an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. This motor receives 750 kw. at a line potential difference of 2200 volts, and the field current is adjusted so that the excitation voltage is 2800 volts.

What is the line current? At what power factor is the motor operating?

23. A 2200-volt, 2-phase synchronous motor has a full-load capacity of 5000 h.p. The full-load efficiency of the armature, with the field current adjusted for unit power factor, is 96.1 per cent. The armature winding has an effective resistance of 0.025 ohm and a synchronous reactance of 0.72 ohms per phase. The motor receives a constant power of 3000 kw. at 2200 volts. If the current is limited to 130 per cent. of its full-load value, what is the greatest allowable excitation voltage? At what power factor would the motor be operating?

24. A 3-phase, 13,500-volt synchronous motor is rated to deliver 2200 h.p. when operating at unit power factor. The armature has an effective resistance of 1.52 ohms per phase. The armature windings are connected in Y.

Field current	Open circuit terminal voltage	Short circuit armature current
50	7,500	75
100	10,100	155
150	14,700	227

The rotational losses at normal voltage are 68 h.p.

If the maximum allowable current is 125 per cent. of the full-load current over what range should it be possible to vary the field current when the motor is delivering a constant load of 2000 h.p.? Use the magnetomotive-force method for calculating the field current.

25. A 3-phase, 230-volt, synchronous motor, whose armature windings are connected in Δ, has an effective resistance of 0.302 ohm and a synchronous reactance of 4.36 ohms per phase. The rotational losses are 750 watts and may be assumed constant. The motor delivers a constant load of 20 h.p. What is the least excitation voltage with which the motor will run? What is the armature current at the instant of breakdown?

26. A 1340-h.p., 3-phase synchronous motor receives a constant power of 860 kw. from an 11,000-volt circuit. The armature windings, which are connected in Y, have an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase.

Over what range can the excitation voltage be varied so that the current will not exceed 135 per cent. of its full-load value, which is 62.5 amperes?

27. A 3-phase, 5000-volt synchronous motor, whose armature windings are connected in Y, has an effective resistance of 0.40 ohm and a synchronous reactance of 10.4 ohms per phase. The rotational losses are 30 kw. and may be assumed constant. The greatest excitation voltage that can be obtained is 3520 volts per phase.

When the motor is delivering its full load of 1100 h.p. over what range can the power factor be varied? What is the armature current at each of the limiting conditions? Compare these with the full-load armature current.

28. Neglecting the field copper loss, the efficiency of a 2200-h.p., 3-phase synchronous motor is 96.0 per cent. at full load when the motor is operating at unit power factor. Assume that the rotational losses are constant. The armature windings, which are connected in Y, have an effective resistance of 1.52 ohms and a synchronous reactance of 37.4 ohms per phase. With the motor delivering 2000 h.p. the field current is adjusted so that the motor takes a leading current of 85 amperes from a 13,500-volt constant potential circuit.

(a) At what power factor is the motor operating? What is the excitation voltage?

(b) If this load is thrown off what current will the motor take, and at what power factor will it be operating? The excitation is unchanged.

29. The rotational losses of a 1340-h.p., 2400-volt, 3-phase synchronous motor are 43 h.p., and may be assumed constant. The armature windings, which are connected in Y, have an effective resistance of 0.067 ohm and a synchronous reactance of 1.64 ohms per phase.

(a) What is the least power factor at which the motor can be operated at no load so that the current will not exceed 135 per cent. of its full-load value? If the motor is overexcited what is the excitation voltage?

30. When operating at unit power factor the full-load losses of a 1100-h.p., 5000-volt, 3-phase synchronous motor are: Armature copper loss = 13.9 kw: Field copper loss = 18.6 kw: Rotational losses = 27.8 kw. Assume that the rotational losses are constant. The armature windings, which are connected in Y, have a synchronous impedance of 12.4 ohms per phase.

If the current is limited to 130 per cent. of its full-load value what is the least power factor at which this motor can be operated when it is delivering full load? What is the necessary excitation voltage if the motor is overexcited?

31. The synchronous motor described in problem 14 is rated to deliver 6500 h.p. when operating at unit power factor. If the maximum allowable current is 130 per cent. of its full-load value what is the least power factor at which it can operate when delivering its rated load? What is the greatest allowable value of the field current at full load under this condition?

32. A 20-h.p., 230-volt, 3-phase synchronous motor has an effective resistance of 0.302 ohm and a synchronous reactance of 4.36 ohms per phase. The armature windings are connected in $\triangle$. The rotational losses are 750 watts and may be assumed constant.

With the maximum excitation voltage of 315 volts at what load will this motor break down? Compare the current at breakdown with the full-load current for normal excitation.

33. If the ratio of resistance to synchronous reactance is increased to 0.30 by inserting equal resistances in series with each phase of the synchronous motor what will be the results called for (a) in problem 25; (b) in problem 26; (c) in problem 27; (d) in problem 29; (e) in problem 30; (f) in problem 32.

34. A 3-phase synchronous motor receives line currents of

226 amperes at a terminal potential difference of 2180 volts and delivers 812 h.p. The no-load rotational losses are 23 h.p., and may be assumed constant. The armature windings, which are Y-connected, have an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase.

At what power factor is the motor operating? Neglecting the field copper losses, what is the efficiency?

35. At no load a 3-phase synchronous motor takes line currents of 1.52 amperes at 11,000 volts if the field current is adjusted for a minimum armature current. The armature windings, which are connected in Y, have an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms.

When the motor receives 960 kw. at 11,000 volts and the excitation is adjusted so that the line current is 72 amperes, what is the output? If the excitation is greater than normal, what is the excitation voltage?

36. The no-load rotational losses of a 1340-h.p., 3-phase synchronous motor are 34.6 kw. The armature windings are connected in Y and have an effective resistance of 0.067 ohm and a synchronous reactance of 1.64 ohms per phase. This motor is operated from a 2400-volt circuit and when delivering its rated output the excitation is adjusted so that the motor takes a leading current of 0.83 power factor.

What is the power input? What is the excitation voltage?

37. At no load a 150-h.p., 2-phase synchronous motor takes 7.6 kw. at 480 volts when the excitation is adjusted for a minimum armature current. Under load this motor takes 108 amperes at 485 volts when the excitation is adjusted so that the power factor is 0.78. The effective resistance of the armature is 0.118 ohm and the synchronous reactance is 2.13 ohms.

What is the output? What is the excitation voltage (a) if the field current is greater than normal? (b) if the field current is less than normal?

38. A 3-phase, 6600-volt synchronous motor is operated at its rated voltage and delivers its rated output of 6500 h.p. In order that the motor shall take a large leading current the field current is adjusted for an excitation voltage of 8100 volts. The no-load rotational losses are 138 kw. and may be assumed constant. The armature windings are connected in Y and have an effective resistance of 0.081 ohm and a synchronous reactance of 2.2 ohms.

What is the power factor? What current does the motor take?

39. A 2-phase, 10,000-volt synchronous motor has a rated capacity of 4500 h.p. The armature has an effective resistance of 0.64 ohm and a synchronous reactance of 13.7 ohms per phase. At no load with an excitation greater than normal the motor takes 74 kw. at 10,000 volts and the line current is 41 amperes.

With the field excitation unchanged what current will the motor take when it is delivering its rated output? At what power factor will the motor be operating?

40. At the end of a 3-phase transmission line are induction motors which take a total load of 1200 kw. at 0.87 power factor. An additional load of 600 h.p. should be provided for. Find the kilovolt-ampere capacity of a synchronous motor that will supply this load and will at the same time make it possible to adjust the power factor of the entire load to unity. Assume that the efficiency of the synchronous motor is 92 per cent.

41. An induction motor load at the end of a 3-phase transmission line takes 6000 kw. at 0.60 power factor. A synchronous motor is operating in parallel with the induction motors in order to improve the power factor. The motor has a full-load capacity of 6500 h.p. when operating at unit power factor from a 6600-volt circuit. The armature windings, which are connected in Y, have an effective resistance of 0.081 ohm per phase. The synchronous impedance is 2.57 ohms per phase. The friction and windage losses are 62.8 h.p. and the core losses at normal voltage are 86 kw. The latter may be assumed to be constant. The synchronous motor is operated so that the resultant power factor of the load is 0.90, and the line voltage is 6600 volts. If the current is limited to 125 per cent. of its full-load value what is the greatest power that the synchronous motor can supply? What is the necessary excitation voltage of the synchronous motor at this time?

42. Induction motors at the end of a 3-phase transmission line deliver a total power of 3500 h.p. and operate at a resultant efficiency and power factor of 90.6 per cent. and 0.65 respectively. The line voltage is 13,200 volts. A 1640-kv.-a. synchronous motor is operated in parallel with these motors to improve the power factor of the load, and to supply an additional load of 1000 h.p. The armature windings of this synchronous motor are connected in Y and have an effective resistance of 1.52 ohms per phase. The rotational losses at normal voltage are 57 h.p. and may be assumed to be constant.

Field current	Open circuit terminal voltage	Short circuit armature current
50	7,500	75
100	10,100	155
150	14,700	227
200	15,800	....
250	16,700	....

At what per cent. of its rated capacity must the synchronous motor be operated so that the power factor of the entire load shall be 0.95 and the line voltage 13,200 volts? Calculate the necessary field current of the motor for this condition by the magnetomotive-force method.

43. A 1000-h.p. synchronous motor is operating at the end of a 3-phase transmission line which has a resistance of 0.58 ohm and a reactance of 0.64 ohm per conductor. The motor is overexcited so that it takes a line current of 216 amperes at a power factor of 0.82, and with a line potential difference of 2210 volts.

What is the line voltage at the generating station? What is the efficiency of transmission?

44. A synchronous motor operating at the end of a 3-phase transmission line takes a constant power of 1500 kw. The resistance and reactance of the line are respectively 2.2 ohms and 2.6 ohms per conductor. The line voltage at the generating station is maintained at 5740 volts. The excitation of the motor is adjusted so that the line loss has its least possible value.

What is the terminal voltage at the motor? What is the efficiency of transmission?

45. A synchronous motor operating at the end of a 3-phase transmission line which has a resistance of 3.6 ohm and a reactance of 4.1 ohm per conductor takes a constant power of 720 kw. from the line and the excitation is adjusted so that the line voltage is 5000 volts. The line voltage at the generating station is also maintained at 5000 volts.

(a) What current does the motor take? At what power factor is it operating?

(b) If the motor is Y-connected and has an effective resistance of 0.40 ohm and a synchronous reactance of 10.4 ohms per phase, what is the necessary excitation voltage?

46. A 1200-h.p. synchronous motor is operated at the end of a 3-phase transmission line which has a resistance of 3.3 ohms and a reactance of 3.7 ohms per conductor. The line voltage at the generating station is 5000 volts, and the motor delivers energy to a constant load of 1000 h.p. The rotational losses of the motor are 29.8 kw. and may be assumed constant. The armature windings are connected in Y and have a resistance of 0.40 ohm and a synchronous reactance of 10.4 ohms per phase.

If the maximum allowable line current is 135 amperes what is the greatest possible terminal voltage at the motor? What is the necessary excitation voltage of the motor?

47. At the end of a transmission line which has a resistance of 12.2 ohms and a reactance of 17.4 ohms per conductor there is a synchronous motor which delivers a constant load of 1300 h.p. The armature windings of the motor, which are connected in Y, have an effective resistance of 0.94 ohm and a synchronous reactance of 36 ohms per phase. At no load with an impressed voltage of 11,000 volts the motor takes a current of 1.52 amperes when the field current is adjusted for unit power factor. The line voltage at the generating station is maintained constant at 11,500 volts.

If the line current is limited to 120 per cent. of its full-load value, which is 62.5 amperes, what is the least additional reactance that should be inserted in each line so that a terminal potential difference of 12,000 volts may be obtained at the motor? What is the necessary excitation voltage of the motor in this case?

48. A 13,800-volt, 3-phase synchronous motor has a full-load capacity of 1350 h.p. The armature windings are connected in Y and have an effective resistance of 2.18 ohms and a synchronous reactance of 62 ohms per phase. At no load with an impressed voltage of 13,800 volts the motor takes 28.2 kw. at unit power factor when the excitation is normal. This motor is operated at the end of a transmission line which has a resistance of 22 ohms and a reactance of 28 ohms per conductor. The line voltage at the generating station is maintained constant at 14,000 volts.

When the motor is delivering 1200 h.p. what is the greatest potential difference at the motor if the armature current is limited to 125 per cent. of its full-load value? What is the necessary excitation voltage of the motor?

49. At the end of a 3-phase transmission line which has a resistance of 0.62 ohm and a reactance of 0.64 ohm per conductor there is a synchronous motor whose armature windings are connected in Y and have an effective resistance of 0.172 ohm and a synchronous reactance of 2.12 ohms per phase. The rotational losses of the motor are 17.2 kw. and may be assumed constant.

When instruments in the generating station indicate that the transmission line is receiving 780 kw. at 2250 volts and a power factor of 0.88 (leading), what is the output of the motor? What is the line voltage at the motor?

50. A 3-phase transmission line has a resistance of 12.6 ohms and a reactance of 16.4 ohms per conductor. The generating station which delivers energy to this line maintains a constant line potential difference of 14,000 volts. At the end of the line there is a synchronous motor whose armature windings are connected in Y and have an effective resistance of 1.52 ohms and a synchronous reactance of 37.4 ohms per phase. The rotational losses of this motor are 36.8 kw. and may be assumed constant. When the motor is delivering 2000 h.p. and the excitation voltage is adjusted to its greatest value of 16,700 volts what is the terminal voltage of the motor? At what power factor is the motór operating?

CHAPTER IV

INDUCTION MOTORS

1. A 2-phase induction motor has a stator with 2 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 4 slots. The effective value of the current in each phase of the stator winding is 7.07 amperes, and the current in phase two lags behind the current in phase one by 90 electrical degrees. Place the first slot in phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 2 in. Use the following scales in these plots.

Abscissæ	Pole pitch = 3 in.
Ordinates	40 ampere turns = 1 in.

(a) Plot the distribution of the magnetomotive force in the air-gap due to the stator currents at the time that the current in phase one is a maximum.

(b) Plot the distribution of magnetomotive force in the air-gap at one-eighth of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at one-quarter of a period later than in (a).

2. A 2-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 8 slots. The effective value of the current in each phase of the stator winding is 7.07 amperes, and the current in phase two lags behind the current in phase one by 90 electrical degrees. Place the first slot in phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 3 in. Use the following scales in this plots:

Abscissæ	Pole pitch = 3 in.
Ordinates	40 ampere turns = 1 in.

(a) Plot the distribution of the magnetomotive force in the air-gap due to the stator currents at the time that the current in phase one is a maximum.

(b) Plot the distribution of magnetomotive force in the air-gap at one-eighth of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at one-quarter of a period later than in (a).

3. A 3-phase induction motor has a stator with 2 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 6 slots. The effective value of the current in each phase of the stator winding is 7.07 amperes, and the current in phase two lags behind the current in phase one by 120 electrical degrees and leads the current in phase three by the same amount. Place the first slot in phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 2 in. Use the following scales in these plots:

Abscissæ................................	Pole pitch = 3 in.
Ordinates..........................	40 ampere turns = 1 in.

(a) Plot the distribution of the magnetomotive force in the air-gap due to the stator currents at the time that the current in phase one is a maximum.

(b) Plot the distribution of the magnetomotive force in the air-gap at one-eighth of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at one-quarter of a period later than in (a).

4. A 3-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors in series per slot. The coil pitch is 12 slots. The effective value of the current in each phase of the stator winding is 7.07 amperes, and the current in phase two lags behind the current in phase one by 120 electrical degrees and leads the current in phase three by the same amount. Place the first slot in phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 4 in. Use the following scales in these plots:

Abscissæ................................	Pole pitch = 3 in.
Ordinates..........................	40 ampere turns = 1 in.

(a) Plot the distribution of the magnetomotive force in the air-gap due to the stator currents at the time that the current in phase one is a maximum.

(b) Plot the distribution of the magnetomotive force in the air-gap at one-eighth of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at one-quarter of a period later than in (a).

5. A 3-phase induction motor has a stator with 4 slots per pole per phase. There are 4 inductors per slot, two of which are in one coil and two in another. The coil pitch is 10 slots. There are two coil sides in each slot. The effective value of the current in each phase of the stator winding is 7.07 amperes, and the current in phase two lags behind the current in phase one by 120 electrical degrees and leads the current in phase three by the same amount. Place the first slot in phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 4 in Use the following scales in these plots:

Abscissæ..................................	Pole pitch = 3 in.
Ordinates..........................	40 ampere turns = 1 in.

(a) Plot the distribution of the magnetomotive force in the air-gap due to the stator currents at the time that the current in phase one is a maximum.

(b) Plot the distribution of the magnetomotive force in the air-gap at one-eighth of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at one-quarter of a period later than in (a).

6. Assume that the stator winding of a 3-phase induction motor is uniformly distributed. The coil pitch is unity and the phase spread is one-third the polar pitch. The current in phase two lags behind the current in phase one by 120 degrees and leads the current in phase three by the same amount. Place the beginning of phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 3 in. As ordinates let 1 in. equal the maximum ampere turns per pole per phase, and as abscissæ let 3 in. equal the pole pitch.

(a) Plot the distribution of the magnetomotive force in the air-gap at the time that the current in phase one is a maximum.

(b) Plot the distribution of the magnetomotive force in the air-gap at one-eight of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at a time one-quarter of a period later than in (a).

7. Assume that the stator winding of a 3-phase induction motor is uniformly distributed. The coil pitch is unity and the phase spread is two-thirds the polar pitch. The current in phase two lags behind the current in phase one by 120 degrees and leads the current in phase three by the same amount. Place the beginning of phase one at the extreme left of the paper and draw the zero lines to allow for a maximum ordinate of 3 in. As ordinates let 1 in. equal the maximum ampere turns per pole per phase, and as abscissæ let 3 in. equal the pole pitch.

(a) Plot the distribution of the magnetomotive force in the air-gap at the time that the current in phase one is a maximum.

(b) Plot the distribution of the magnetomotive force in the air-gap at one-eighth of a period later than in (a).

(c) Plot the distribution of the magnetomotive force in the air-gap at a time one-quarter of a period later than in (a).

8. At no load a 25 h.p. induction motor takes 865 watts at 0.18 power factor from a 250-volt, 3-phase circuit. The effective resistance of the stator winding is 0.3 ohm between terminals. Neglect the leakage reactance. What would have been the no-load power and power factor if the motor had been designed with an air-gap which would have made the reluctance of the magnetic circuit 25 per cent. greater?

9.[1] A 200-h.p. induction motor is designed to operate from a 3-phase, 980-volt, 20-cycle circuit. Under this condition the no-load power and power factor are 6.62 kw. and 0.086. The friction and windage loss is 4.0 kw. The stator winding is delta-connected and has an effective resistance of 0.387 ohms per phase. What will be the no-load power and power factor if this motor is operated from a 3-phase, 1100-volt, 25-cycle circuit? Neglect the leakage reactance and assume that the core losses vary as $B^{1.7}f^{1.3}$ $(F+W)$ varies as (speed)^2.

10.[1] At no load a 570-h.p., 1900-volt 3-phase induction motor takes 15.1 kw. at 0.081 power factor. The friction and windage loss is 12.0 kw. The effective resistance of the stator winding is 0.757 ohm per phase. The windings are connected in delta. There are 8 inductors in series per slot. If the motor is rewound with the same size wire but with 6 inductors in series per slot, what no-load current and power will it take from the same circuit? Neglect the leakage reactance and assume that the core losses vary as $B^{1.7}f^{1.3}$.

11.[1] Both the stators and rotors of two 150-h.p., 3-phase induction motors are of the same design except that one is wound for 6 poles and the other for 8 poles. Each stator has the same number of slots with the same number of inductors per slot. The six-pole motor takes 5.7 kw. from a 500 volt, 38-cycle circuit

[1] For saturation curve, see page 92.

at no load and the line current is 46 amperes. The friction and windage loss is 2.9 kw. The effective resistance of the stator winding is 0.082 ohm per phase. The effective resistance of the stator winding of the 8-pole motor is 11 per cent. less than this. The windings are connected in Y. What current and power will the 8-pole motor take at no load from the same circuit? Assume that the friction and windage loss varies as the square of the speed and neglect the leakage reactance. Where approximations are made state what they are.

12.[1] At no load a 335-h.p., 3-phase induction motor takes a line current of 15.5 amperes and absorbs 10.1 kw. from a 2000-volt, 50-cycle circuit. The effective resistance and the leakage reactance of the stator winding are respectively, 0.248 and 0.76 ohm per phase. The windings are connected in Y. The friction and windage loss is 2.5 kw. What current and power will this motor take at no load from a 2200-volt, 60-cycle circuit? Assume that the core losses vary as $B^{1.7}f^{1.3}$ and that the generated voltage due to the air-gap flux is equal to the impressed voltage less the magnetizing current multiplied by the leakage reactance.

13.[1] At no load a 150-h.p., 3-phase induction motor takes a line current of 46 amperes and absorbs 5.65 kw. from a 500-volt, 38-cycle circuit. The friction and windage loss is 3.1 kw. The stator has 12 slots per pole and the winding pitch is 12 slots. If this motor is rewound with the same number of turns using a pitch of 10 slots, what current and power will it take at no load from the same circuit? Neglect the resistance and the leakage reactance, and assume that the core losses vary as $B^{1.7}f^{1.3}$

14.[1] The stator of a 150-h.p., 3-phase, 500-volt induction motor has 108 slots, and in each of the following cases it is wound for 6 poles with 4 inductors per slot. With a winding pitch of 18 slots the core losses are 2.9 kw. and the magnetizing current is 45 amperes. If a winding pitch of 14 slots is used what will be the core losses and the magnetizing current at the same voltage and frequency? Assume core losses vary as $B^{1.7}$.

15.[1] The stator of a 25-h.p., 3-pease, 250-volt induction motor has 72 slots, and in each of the following cases it is wound with 8 inductors per slot. If this motor is wound for 8 poles with a winding pitch of 8 slots the core losses are 590 watts, the friction and windage loss is 220 watts, and the magnetizing current is 11 amperes. What current and power will this motor take from the same circuit at no load if it is wound for 6 poles

[1] For saturation curve, see page 92.

with a winding pitch of 10 slots? Neglect the resistance and leakage reactance and assume that the friction and windage loss varies as the speed and that the core losses vary as $B^{1.7}f^{1.3}$.

16.[1] The stator of a 25-h.p., 3-phase, 50-cycle induction motor is wound for 250 volts. With an impressed voltage of 110 volts the starting current is 61 amperes at 0.336 power factor. The effective resistance and leakage reactance of the stator winding are respectively 0.159 ohm and 0.46 ohm per phase. The stator has 72 slots with 9 inductors per slot and the rotor has 120 slots with 2 inducters per slot. Both the stator and rotor windings connected in Y. The ohmic resistance of the rotor winding is 0.015 ohm per phase.

What is the leakage inductance of the rotor winding per phase? What is the ratio of effective to ohmic resistance for the rotor winding at 50 cycles?

If the stator is rewound for 500 volts by using twice as many turns of wire of one-half the size, what voltage should be impressed to have a starting current of 30 amperes?

17.[1] The full-load line current taken by a 200-h.p., 3-phase, 980-volt induction motor is 101 amperes. The stator has 216 slots with 5 inductors per slot, and the ohmic resistance of the winding is 0.246 ohm per phase. The rotor has 288 slots with 1 inductor per slot and the ohmic resistance of the winding is 0.010 ohm per phase. Both the stator and rotor windings are connected in delta. The leakage inductances of the stator and rotor windings are respectively 3.9 mil-henrys and 0.19 mil-henry per phase. At the rated frequency of 20 cycles the ratios of effective to ohmic resistance are respectively 1.6 and 1.9 for the stator and rotor.

(a) What voltage should be impressed on this motor in order that the starting current will be twice the full-load current?

(b) If the stator winding is reconnected in Y what voltage should be impressed on the motor in order that the starting current will be twice the full-load current? In this case the rated voltage becomes 1700 volts.

18. At full load the stator and rotor copper losses of a 500-h.p., 3-phase, 2000-volt induction motor are respectively 4.14 per cent. and 1.82 per cent. The core loss is 2470 watts and the friction and windage loss is 11.0 kw. The magnetizing component of the line current is 23 amperes. At the rated frequency of 60 cycles the ratio of effective resistance to ohmic resistance is 1.55 for the stator winding and 1.85 for the rotor winding. At the

[1] Assume that the ratio of transformation equals the ratio of turns.

rated frequency the leakage reactances of the windings are 3.2 times their effective resistances. What line voltage should be impressed on this motor when starting to give a line current of 200 amperes?

19.[1] The ohmic resistances of the stator and rotor windings of an induction motor are respectively 0.04 ohm and 0.01 ohm. At normal frequency the ratios of effective resistance to ohmic resistance are respectively 1.5 and 1.8 for the stator and rotor windings and the leakage reactances are 3.1 times their effective resistances. The stator winding has 108 inductors per phase and the rotor winding has 54 inductors per phase. Assume that the core loss due to leakage flux and the increase in the resistance due to a non-uniform distribution of current over the cross-section of the inductors both vary directly as the frequency.

(a) If the voltage impressed on this induction motor when starting is increased 30 per cent., how much is the starting current increased? How much is the starting torque increased?

(b) If the frequency of the voltage impressed on this induction motor when starting is increased 10 per cent., how much is the starting current decreased? How much is the starting torque decreased.

20.[1] A 570-h.p. induction motor is designed to receive power from a 3-phase, 1900-volt, 22.5-cycle circuit. The ohmic resistances of the stator and rotor windings are 0.488 ohm and 0.0138 ohm per phase, and at the rated frequency the effective resistances are 1.3 and 1.5 times as great. The leakage reactances at the rated frequency are three times the effective resistances. The stator has 864 inductors per phase and the rotor 144 inductors per phase. The motor is wound for 36 poles, and both of the windings are connected in delta. The friction and windage loss is 12 kw.

What is the slip at full load if the generated voltage in the stator winding due to the air-gap flux is 93 per cent. of the impressed voltage? What is the starting torque with full voltage impressed on the stator windings?

21.[1] The effective resistances of the stator and rotor windings of a 3-phase inducton motor are 0.071 ohm and 0.0218 ohm per phase, and the leakage reactances at normal frequency are 0.22 ohm and 0.066 ohm per phase. The stator has 108 slots with 5 inductors per slot, and the rotor has 126 slots with 2 inductors per slot. Both of the windings are connected in Y. At starting,

[1] Assume that the ratio of transformation equals the ratio of turns.

with full impressed voltage, the current is 3.6 times the full-load value and the torque is 0.62 of the full-load torque. What will be the starting current and the starting torque with full impressed voltage if resistances of 0.2 ohm are inserted in each phase of the rotor winding?

22. With full-load current the slip and brake torque of a 500-h.p., 3-phase, 60-cycle induction motor are 1.82 per cent. and 16,300 pound-feet. The ohmic resistance and leakage inductance of the rotor winding are 0.24 ohm and 3.1 mil-henrys per phase. What will be the slip, the brake torque and the output when the current has its full-load value if resistances of 2 ohms are inserted in each phase of the rotor winding?[1] Estimate the copper loss in each of these additional resistance units.

23. The resistance and leakage inductance of the rotor windings of a 3-phase, 38-cycle induction motor are 0.013 ohm and 0.27 mil-henry per phase. The full-load torque and slip are 2,190 lb.-ft. and 2.6 per cent.

(a) To what per cent. of its normal full-load value should the air-gap flux be reduced so that the motor will deliver its full-load torque at one-half the full-load speed?

(b) What resistance should be inserted in each phase of the rotor so that the motor will deliver its full-load torque at one-half the full-load speed? Assume that the air-gap flux has its normal value.

(c) Compare the rotor currents in (a) and (b).

24. The full-load distribution of losses in a 10-h.p., 220-volt, 3-phase induction motor is:

Stator copper loss	3.9 per cent.
Rotor copper loss	4.8 per cent.
Core loss	3.1 per cent.
Friction and windage loss	4.0 per cent.

(a) What are the slip and efficiency at full load?

(b) What are the slip and efficiency at one-half of full load?

25.[2] At full-load the slip of a 335-h.p., 2000-volt, 50-cycle, 6-pole induction motor is 1.8 per cent. The ohmic resistances of the stator and rotor windings are 0.165 ohm and 0.0127 ohm per phase, and the leakage inductances are 2.4 mil-henrys and 0.22 mil-henry per phase. Both of the windings are connected in Y. The stator has 72 slots with 10 inductors per slot, and the rotor has 90 slots with 2 inductors per slot. The ratios of effective

[1]The air-gap flux has its full-load value.

[2]Assume that the ratio of transformation equals the ratio of turns.

resistance to ohmic resistance at 50 cycles are 1.45 and 1.75 for the stator and rotor windings. At full load the voltage generated in the stator winding by the mutual flux is 93 per cent. of the impressed voltage.

To what per cent. of its full-load value should the air-gap flux be reduced so that the starting current will be 175 amperes? What is the starting torque for this condition? What are the full-load torque and rotor current?

26. In problem 25 what resistance should be inserted in each phase of the rotor winding so that when starting with full impressed voltage the rotor current will be twice its full-load value? What is the starting torque for this condition? What is the running torque with full-load current?

27. In problem 25 what reactance should be inserted in each phase of the rotor winding so that when starting with full impressed voltage the rotor current will be twice its full-load value? What is the starting torque for this condition? What is the running torque with full-load current?

28.[1] At the instant of starting on a reduced voltage of 500 volts a 500-h.p.,, 3-phase, 60-cycle induction motor takes a line current of 152 amperes at 0.31 power factor. The motor is wound for 44 poles. The ohmic resistance of the rotor winding is 0.0306 ohm measured between terminals—when the winding is not short-circuited. The effective resistance is 1.7 times as great at the rated frequency. The stator winding has 704 inductors per phase and the rotor winding has 220 inductors per phase. The friction and windage loss is 11. kw. What is the starting torque? With an impressed voltage of 2000 volts what brake torque would be delivered when the slip is 1.8 per cent? Assume that the voltage drop in the stator winding at no load is 3.5 per cent. of the impressed voltage.

29. A 570-h.p., 3-phase induction motor is arranged so that it may be connected to the line through a compensator at starting. The motor is wound for 36 poles and a line voltage of 1900 volts at 22.5 cycles. When the compensator reduces the impressed to 600 volts the line current is 200 amperes and the power is 58.8 kw. at the instant of starting. The stator and rotor ohmic resistances are equal when reduced to the same side and the effective resistances are 1.5 times as great as the ohmic. The friction and windage loss at full load is 12. kw.

[1] Assume that the ratio of transformation equals the ratio of turns.

The no-load line current is 56.6 amperes. What is the slip when the motor delivers its rated load? What is the starting torque with 600 volts impressed on the motor?

30. At full load the slip of a 500-h.p., 3-phase induction motor is 1.80 per cent. The motor is wound for 12 poles and an impressed voltage of 2200 volts at 25 cycles. When the rotor winding is not short circuited the hot resistance—referred to the stator—measured between terminals is 0.431 ohm, and the effective resistance is 1.65 times as much. What is the starting torque when the impressed voltage is adjusted so that the rotor current is twice its full-load value?

31. At full load the slip of a 1000-h.p., 3-phase induction motor is 1.72 per cent. The motor is wound for 12 poles and an impressed voltage of 2200 volts at 25 cycles. When the rotor winding is not short circuited the hot resistance measured between terminals is 0.0895 ohm, and the effective resistance is 1.6 times as great. The ratio of transformation from stator to rotor is 2200 to 1500. The effective resistance and leakage reactance of the stator winding between terminals are 0.195 ohm and 0.59 ohm. The leakage reactance of the rotor between terminals is 0.29 ohms at 25 cycles.

What voltage should be impressed on this motor so that the starting torque will be the same as the full-load torque? What is the starting current for this condition and how does it compare with the full-load current?

32. In problem 31 what resistance should be inserted in each phase of the rotor winding in order that the starting torque for the rated voltage will be equal to the full-load torque? What is the starting current for this condition and how does it compare with the full-load current?

33. The ohmic resistances of the stator and rotor windings of a 500-h.p., 3-phase induction motor are 0.24 ohm and 0.0153 ohm per phase, and the effective resistances at the rated frequency are respectively 1.5 and 1.6 times as great. The leakage reactances at the rated frequency are respectively 1.1 ohms and 0.075 ohm per phase. The motor is wound for 44 poles and an impressed voltage of 2000 volts at 60 cycles. The stator has 2112 inductors and the rator 660 inductors. Both windings are connected in Y. At full load the voltage drop in the stator winding due to the no-load current is 4 per cent. of the impressed voltage.

What resistance should be inserted in each phase of the rotor in order that the starting torque with full impressed voltage may have its maximum value? What is this torque? What is the starting current for this condition and how does it compare with the full-load current?

34. The ohmic resistances of the stator and rotor windings of a 150-h.p., 3-phase railway induction motor are 0.054 ohm and 0.014 ohm per phase, and the effective resistances at the rated frequency are respectively 1.45 and 1.65 times as great. The leakage reactances at the rated frequency are respectively 0.24 ohm and 0.071 ohm per phase. The motor is wound for 6 poles and an impressed voltage of 500 volts at 38 cycles. The ratio of transformation from stator to rotor winding is 15 to 7, and both windings are connected in Y. With full impressed voltage the measured slip for a brake torque of 1470 pound-feet is 2.26 per cent.

What resistance should be inserted in each phase of the rotor winding so that the starting torque with full impressed voltage will have its maximum value? What is this torque?

INDUCTION MOTOR DATA

		A	*B*	*C*	*D*	*E*
Horse-power		25	120	200	335	570
Line voltage		250	500	980	2000	1900
Type of winding		Y	Y	Δ	Y	Δ
Frequency		50	38	20	50	22.5
Poles		8	6	24	6	36
Ohmic resistance per phase.	Stator	0.096	0.04	0.246	0.165	0.488
	Rotor	....	0.01	....	0.0127	0.0138
Ratio of transformation		....	2 : 1	....	4 : 1	6 : 1
Magnetizing current (line)		11	....	39	....	....
Core loss		590	....	1120	....	....
Friction and windage loss		220	....	4000	....	....
No load	Line voltage	....	500	....	2000	1900
	Line current	....	34.5	....	15.3	57.6
	Power	....	4400	....	10,100	17,200
Blocked	Line voltage	100	500	220	440	600
	Line current	57	800	173	170	200
	Power	3,100	220,000	20,400	40,500	65,000

35. Draw the Heyland diagram for motor No. *A*. (a) What are the full-load power factor, slip and efficiency. (b) What is the break-down torque? (c) At what load is the power factor a maximum?

36. Draw the Heyland diagram for motor No. *B*. (a) What are the power factor, the slip, and the efficiency at full load? (b) at one-half of full load? (c) What is the break-down torque? (d) At what load is the power factor a maximum?

37. Draw the Heyland diagram for motor No. *C*. (a) What are the power factor, the slip and the efficiency at full load? (b) What is the break-down torque? (c) At what load is the power factor a maximum?

38. Draw the Heyland diagram for motor No. *D*. (a) What are the power factor, the slip and the efficiency at full load? (b) at one-half full load? (c) What is the break-down torque?

39. Draw the Heyland diagram for motor No. *E*. (a) What are the power factor, the slip and the efficiency at full load? (b) What is the break-down torque? (c) At what load is the power factor a maximum?

40.[1] The following data are given on a 5-h.p., 110-volt, 8-pole, 60-cycle, 3-phase induction motor. The stator and rotor windings are both connected in delta, and the former has an effective resistance of 0.24 ohm and a leakage reactance of 0.70 ohm per phase. The ohmic resistance of the rotor winding referred to the stator is 0.36 ohm per phase. At no load the motor takes 300 watts at 110 volts and a power factor of 0.15.

When this motor takes 5100 watts at 110 volts and a power factor of 0.835 what are the slip, the power output and the torque?

41.[1] A 3-phase, 1000-h.p. induction motor is taking 916 kw. from a 2200-volt circuit at a power factor of 0.914. At no load with an impressed voltage of 2200 volts the line current is 75.1 amperes and the power is 15.2 kw. The effective resistance and the leakage reactance of the stator winding, which is Y-connected, are 0.118 ohm and 0.32 ohm per phase. The ohmic resistance of the rotor winding referred to the stator is 0.10 ohm per phase. What is the output for the specified load? What is the slip?

42.[1] A 3-phase, 2600-h.p. induction motor is taking 2272 kw. from a 6470-volt circuit, and the line current is 245 amperes. At no load with an impressed voltage of 6400 volts the line current is 89.5 amperes and the power is 47.5 kw. The ohmic resistance of

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem. See "Principles of Alternating Current Machinery," R. R. Lawrence, page 454.

the stator winding between terminals is 0.561 ohm at 25° C. The ohmic resistance of the open-circuited rotor winding between terminals is 0.0766 ohm at 25° C.[2] The leakage reactance of the stator winding is 3.64 ohms between terminals. With the rotor blocked 375 kw. is supplied when the line current is 369 amperes. The temperature of the windings at this time is 25° C. Assume that the ratios of effective resistance to ohmic resistance are the same for the stator and rotor windings at 25° C.

What is the output for the specified load? What is the slip? What is the distribution of the losses? The temperature at this time is 73° C.

43.[1] A 3-phase, 2000-volt, 60-cycle induction motor has a full-load capacity of 500 h.p. The stator winding has an effective resistance of 0.36 ohm and a leakage reactance of 1.1 ohms per phase. The rotor winding has an ohmic resistance of 0.157 ohm and a leakage inductance of 1.96 mil-henrys per phase referred to the stator. Both of the windings are connected in Y. The magnetizing current is 23 amperes, the core loss is 2470 watts, and the friction and windage is 11 kw.

What are the slip, the power factor, and the efficiency when the motor delivers its rated output?

44.[1] A 3-phase, 1900-volt, 22.5 cycle, 36-pole induction motor has a full-load capacity of 570 h.p. The ohmic resistances of the stator and rotor windings are 0.488 ohm and 0.0138 ohm per phase, and their effective resistances at the rated frequency are respectively 1.4 and 1.6 times as great. Both of the windings are connected in delta, and the ratio of transformation of stator to rotor is 6 to 1. The magnetizing component of the line current is 57.2 amperes, the core loss is 2.8 kw., and the friction and windage loss is 12 kw. With the rotor blocked the line current is 200 amperes when the impressed voltage is 600 volts. Assume that the ratios of leakage reactance to effective resistance at the rated frequency are the same for both stator and rotor windings.

What are the slip, the power factor, and the efficiency when the motor delivers its rated output?

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem. See "Principles of Alternating Current Machinery," R. R. Lawrence, page 454.

[2] For ratio of transformation see Motor *J*, page 83.

45.[1] A 3-phase, 500-volt, 38-cycle, 6-pole railway induction motor has a full-load capacity of 120 h.p. The ohmic resistances of the stator and rotor windings are 0.04 and 0.01 ohm per phase, and their effective resistances at the rated frequency are respectively 1.45 and 1.60 times as great. Both of the windings are connected in Y, and their ratio of transformation is 2 to 1. The magnetizing component of the line current is 34 amperes, and the total no-load losses are 4400 watts. With the rotor blocked the line current is 800 amperes when the impressed voltage is 500 volts. Assume that the leakage reactances of the stator and rotor windings at the rated frequency are equal when reduced to the same side.

What are the slip, the power factor and the efficiency when the motor delivers a torque of 1200 pound-feet?

46.[1] The full-load capacity of a 3-phase, 2000-volt, 50-cycle induction motor is 335 h.p. The motor is wound for 6 poles, and both the stator and rotor windings are connected in Y. The effective resistance of the stator winding is 0.23 ohm and the ohmic resistance of the rotor winding referred to the stator is 0.203 ohm per phase. At 50 cycles the leakage reactances of the windings, referred to the stator, are respectively 0.70 ohm and 0.83 ohm per phase. At no load the motor takes 15.2 amperes from a 2000-volt circuit at a power factor of 0.187. The core loss is 7400 watts at this time. The motor is operating with a slip of 1.43 per cent., and the terminal voltage has its rated value. What is the output of the motor? What is the power factor? What is the efficiency?

47.[1] A 3-phase, 500-volt, 38-cycle railway induction motor has a full-load capacity of 150 h.p. The ohmic resistances of the stator and rotor windings are 0.052 ohm and 0.013 ohm per phase, and the effective resistances are respectively 1.40 and 1.55 times as great at the rated frequency. The motor is wound for 8 poles. Both stator and rotor windings are connected in Y and have a ratio of transformation of 9 to 5. At no load with an impressed voltage of 500 volts the motor takes a current of 46.6 amperes at a power factor of 0.141. With the rotor blocked the motor takes

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem. See "Principles of Alternating Current Machinery," R. R. Lawrence, page 454.

a current of 610 amperes when the impressed voltage is 500 volts. Assume that the leakage reactances are in the same ratio as the effective resistances at the rated frequency.

What are the slip, the power factor and the efficiency when the motor delivers a torque of 1950 pound-feet?

48.[1] At no load when the line voltage has its rated value of 1900 volts, a 3-phase, 570-h.p. induction motor takes a line current of 57.2 ampers at a power factor of 0.091. The speed of the rotor is 74.6 rev. per min., and the slip is one revolution in 23 minutes. The ohmic resistances of the stator and rotor winding are 0.488 ohm and 0.0138 ohm per phase. The motor is wound for 36 poles and both the stator and the rotor windings are connected in delta, and have a ratio of transformation of 6 to 1. With the rotor blocked the line current is 200 amperes and the power supplied is 59.2 kw. when the impressed voltage is 600 volts. Assume that the ratios of effective to ohmic resistance are the same for the stator and rotor, and that the ratios of leakage reactance to effective resistance are also the same for each winding.

What is the friction and windage loss? What is the core loss?

49.[1] A 3-phase, 2000-volt, 60-cycle induction motor is rated to deliver 500 h.p. at full load. The ohmic resistances of the stator and rotor windings are respectively 0.24 ohm and 0.0153 ohm per phase, and the ratios of effective to ohmic resistance are respectively 1.5 and 1.6. With the rotor blocked the power factor is 0.29. Assume that the ratios of leakage reactance to effective resistance at the rated frequency are the same for the stator and rotor. The motor is wound for 44 poles, and both the stator and rotor windings are connected in Y and have a ratio of transformation of 16 to 5. The friction and windage loss is 11.0 kw. and the core loss is 2470 watts at the rated voltage.

What is the slip in revolutions per minute at no load? What are the power factor, the current and the power for this condition?

50.[1] The full-load capacity of a 3-phase, 980-volt, 20-cycle induction motor is 200 h.p. The effective resistance and leakage

[1] Use either the transformer diagram or the equivalent circuit in the solution of this problem. See "Principles of Alternating Current Machinery," R. R. Lawrence, page 454.

reactance of the stator winding are 0.342 ohm and 1.08 ohms respectively. The ohmic resistance and leakage inductance of the rotor winding referred to the stator are 0.141 ohm and 5.1 milhenrys. The motor is wound for 24 poles and both the stator and rotor windings are connected in delta. At no load the motor takes a line current of 39.4 amperes and absorbs 6680 watts when the impressed voltage has its rated value. The friction and windage loss is 4.0 kw.

If the air-gap flux is assumed to be constant the maximum torque occurs when the slip equals the ratio of the resistance of the rotor winding to its leakage reactance at the rated frequency. In this case how much must the impressed voltage be increased in order that the air-gap flux will have its no-load value when the torque is a maximum?

		F	*G*	*H*	*I*	*J*
Horse-power		50	150	500	1000	2600
Line voltage		2200	500	2200	2200	6400
Frequency		60	60	25	25	25
Connection		Y	Δ	......	......	......
Poles		......	......	12	12	36
Ohmic resistance between terminals.	Stator	6.307	0.050	0.357	0.130	0.561
	Rotor	......	......	0.0286	0.0772	0.0766
At temperature		hot	hot	25° C.	25° C.	25° C.
Ratio of transformation		......	......	2200 : 610	2200 : 1500	6400 : 2076
No load, temp. = 25°C.	Voltage (line)	2200	500	2200	2200	6400
	Current (line)	4.14	36.7	39.9	75.1	89.5
	Power	1620	7550	13,600	15,200	47,500
Blockedtemp. = 25°C.	Voltage (line)	620	80	750	400	2200
	Current (line)	25	245	288	346.5	369
	Power	10,600	12,500	116,000	68,000	375,000
Blocked with full impressed voltage.	Current (line)	......	......	935	1960	1210
	Power, (kw.)	......	......	1050	1960	2950

51.[1] What are the power factor, the output, and the efficiency of the induction motor No. *F* when the slip is 1.55 per cent. Assume that the ratios of effective to ohmic resistance are respectively 1.1 and 1.20 for the stator and rotor windings and that the leakage reactances are equal when reduced to the same side.

52.[1] What are the slip, the power factor, and the efficiency of the induction motor No. *G* when it delivers full load and the

[1] Use the transformer diagram in the solution of this problem. See "Principles of Alternating Current Machinery," R. R. Lawrence, page 454.

voltage generated in the stator winding by the air-gap flux is the same as at no load? Assume that the ratios of effective to ohmic resistance are respectively 1.4 and 1.6 for the stator and rotor windings, and that the ratio of the leakage reactances at the rated frequency is equal to the ratio of the effective resistances. What is the impressed voltage?

53.[1] What are the power factor, the torque and the efficiency of the induction motor No. *H* when the slip is 1.86 per cent. Assume that the ratios of effective to ohmic resistance are the same for the stator and rotor windings at 25° C., and that the ratio of the ohmic resistances is equal to the ratio of the leakage reactances of the two windings at the rated frequency. The temperature under the running condition is 65° C.

54.[1] What are the power factor, the slip, and the efficiency of the induction motor No. *I* when it delivers a torque of 22,000 pound-feet? Assume that the ratios of the ohmic resistances, the effective resistances, and the leakage reactances of the stator and rotor windings are equal at the rated frequency and a temperature of 25° C. The running temperature is 70° C.

55.[1] What are the power factor, the slip and the efficiency when the induction motor No. *J* delivers 2750 h.p. Assume that the ratio of the effective to the ohmic resistance for the rotor is 20 per cent. greater than for the stator, and that the ratios of the leakage reactances and of the effective resistances are equal at the rated frequency and a temperature of 25° C. The running temperature is 70° C.

56. What are the power factor, the torque and the efficiency for the induction motor No. *I* when the slip is 1.6 per cent. and the impressed voltage has its rated value? Make the same assumptions in regard to the resistances and reactances as were made in problem 54.

57. What are the power factor, the slip and the efficiency when the induction motor No. *J* delivers a torque of 164,000 pound-feet and the impressed voltage is 6400 volts? Make

[1] Use the transformer diagram in the solution of this problem. See "Principles of Alternating Current Machinery," R. R. Lawrence, page 454.

the same assumptions in regard to the resistances and reactances as were made in problem 55.

58. What are the power factor, the slip and the efficiency when the induction motor No. *H* delivers 560 h.p. and the impressed voltage has its rated value? Make the same assumption in regard to the resistances and reactances as were made in problem 53.

59. Two 3-phase, 220-volt, 60-cycle induction motors are connected in concatenation across a 220-volt circuit. Each is rated to deliver 10 h.p. and is wound for 6 poles. What is the no-load speed? When they deliver 10 h.p. what is the torque developed by each motor?

60. Two 3-phase, 220-volt, 60-cycle induction motors are connected in concatenation across a 220-volt circuit. Each is rated to deliver 10 h.p. but one is wound for 6 poles and the other for 8 poles. What is the no-load speed? When they deliver 10 h.p. what is the torque developed by each motor? What per cent. of its full-load current does each motor carry?

61. Two 3-phase, 220-volt, 60-cycle induction motors are connected in concatenation across a 220-volt circuit. One is rated to deliver 10 h.p. and the other 15 h.p., but both are wound for 6 poles. What is the no-load speed? What load is delivered when the 15-h.p. motor takes its full-load current? What per cent. of its full-load value is the current in the 10-h.p. motor? What is the torque developed by each?

62. Two 3-phase, 220 volt 60-cycle induction motors are connected in concatenation across a 220-volt circuit. One is rated to deliver 10 h.p. and is wound for 6 poles, and the other is rated to deliver 15 h.p. and is wound for 4 poles. What is the no-load speed? What is the greatest load that can be delivered and have neither motor take more than its full-load current? When they deliver 15 h.p. what torque does each develop?

63. The two induction motors, *M* and *P*, are connected in concatenation. The stator of the first receives power at its rated voltage and frequency, and the stator of the second is short-circuited. Neglect the no-load component of the current and the core loss due to the leakage flux.

(a) What is the total output when the slip of the first motor is 51.3 per cent.?

(b) What is the power developed by each motor?

(c) What are the copper losses in the stator and rotor of each motor?

INDUCTION MOTOR DATA

Number		K	L	M	N	P
Horse-power		500	570	150	150	120
Line voltage		2000	1900	500	500	500
Connection (both stator and rotor)		Y	Δ	Y	Y	Y
Frequency		60	22.5	38	38	38
Poles		44	36	6	8	6
Magnetizing current (per phase.)[1]		23	33	45	46	34
Core loss at no load[1,2]		2470	2800	1300	1360	1200
Ohmic resistance per phase	Stator	0.24	0.488	0.054	0.052	0.04
	Rotor	0.0153	0.0138	0.014	0.013	0.01
Ratio of effective resistance to ohmic resistance at the rated frequency.	Stator	1.3	1.35	1.25	1.25	1.2
	Rotor	1.4	1.55	1.4	1.35	1.4
Leakage inductance per phase (mil-henry).	Stator	2.6	13.	0.091	0.086	0.068
	Rotor	0.17	0.37	0.024	0.022	0.018
Ratio of transformation		16 to 5	6 to 1	15 to 7	9 to 5	2 to 1

64. The two induction motors, N and P, are connected in concatenation. The stator of the first receives power at its rated voltage and frequency, and the stator of the second is short-circuited. Neglect the no-load component of the current and the core loss due to the leakage flux. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density.

(a) What is the total output when the slip of the second motor is 4.0 per cent.?

(b) What is the power developed by each motor?

(c) What are the copper losses in the stator and rotor of each motor?

(d) What are the core losses in the stator and rotor of each motor?

65. The two induction motors, M and N, are connected in concatenation. The stator of the first receives power at its rated voltage and frequency, and the stator of the second is short-circuited. Neglect the no-load component of the current. Assume that the loss caused by the leakage flux varies as the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density.

(a) What is the total output when the speed is 228 rev. per min.?

[1] At the rated voltage.

[2] Assume that the ratio of the core loss in the stator to that in the rotor for the same mean flux density and frequency is 4 to 3.

(b) What is the power developed by each motor?

(c) What are the effective resistance losses in the stator and rotor of each motor?

(d) What are the core losses in the stator and rotor of each motor?

66. The two induction motors, K and L, are connected in concatenation. The stator of the first receives power at its rated voltage and frequency, and the stator of the second is short-circuited. Neglect the no-load component of the current. Assume that the loss caused by the leakage flux is proportional to the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the frequency and the square of the flux density.

(a) What is the total output when the slip of the second motor is 1.55 per cent.?

(b) What is the power developed by each motor?

(c) What are the effective resistance losses in the stator and rotor of each motor?

(d) What are the core losses in the stator and rotor of each motor?

67. The two induction motors, M and P, are connected in concatenation. The stator of the first receives power at its rated frequency, and the stator of the second is short-circuited. Do not neglect the no-load component of the current, but assume that it is proportional and wattless with respect to the generated voltage. Assume that the loss caused by the leakage flux varies as the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density.

(a) What is the total output when the speed is 268 rev. per min. and the voltage generated by the air-gap flux in the rotor winding of the second motor is 68 volts per phase?

(b) What power do they receive from the line and at what power factor do they operate?

(c) What is the power developed by each motor?

68. The two induction motors, K and L, are connected in concatenation. The stator of the first receives power at its rated frequency, and the stator of the second is short-circuited. Do not neglect the no-load component of the currrent, but assume that it is proportional and wattless with respect to the generated voltage. Assume that the loss caused by the leakage flux varies as the frequency and the square of the current. Assume that the core loss due to the mutual flux varies as the product of the frequency and the square of the flux density.

(a) What is the total output when the slip of the second is 1.55 per cent. and the voltage generated by the air-gap flux in the rotor winding of the second motor is 430 volts per phase?

(b) What power do they receive from the line and at what power factor do they operate?

(c) What is the power developed by each motor?

69. A 1000-h.p. induction motor is operated as an induction generator in parallel with a synchronous generator having a full-load capacity of 1000 kv.-a. The induction machine, which is wound for 12 poles, is driven at a constant speed of 250.5 rev. per min. The speed of the synchronous generator falls uniformly from 1530 rev. per min. at no load to 1500 rev. per min. at full load, when the frequency is 25 cycles. The load delivered by the induction generator is proportional to the slip which at full load is 1.7 per cent.

When the total load supplied is 1500 kw. what is the load delivered by each? At what speed should the induction generator be driven so that both will deliver their rated loads at the same time?

70. An induction generator and a synchronous generator, each rated to deliver 2500 kv.-a., are operated in parallel. The speed of the induction generator falls from 1520 at no load to 1498 at full load, and the speed of the synchronous generator falls from 1525 at no load to 1490 at full load. The load on the induction generator is proportional to the slip which at full load is 1.8 per cent.

What is the greatest load that can be delivered without over loading either generator? To what value should the full-load speed of the synchronous generator be adjusted so that both generators will deliver their rated loads at the same time?

71. A 4-pole induction generator and a 2-pole synchronous generator are operating in parallel. The induction generator is driven at a constant speed, but the speed of the synchronous generator falls from 3660 rev. per min. at no load to 3590 at full load of 2000 kw. The resistance of the rotor windings between terminals refered to the stator is 0.73 ohm. Neglect the stator resistance and reactance, the rotor reactance, and the losses. The excitation of the synchronous generator is adjusted so that the terminal voltage is 6400 volts at all loads. The speed of the induction generator is adjusted so that when the synchronous machine is delivering no power the load on the induction generator is 500 kw. What is the division of the load when 3500 kw. is required? What is the frequency at this time? At what speed should the induction generator be driven so that both will deliver their rated loads, viz., 2000 kw., at the same time?

72. A 500-kw., 3-phase induction generator is operated with a synchronous motor floated across its terminals. At no load, when running as an induction motor, it takes a line current of 31 amperes at 2000 volts. The resistance of the rotor winding between terminals is 0.0228 ohm, and the ratio of transformation from stator to rotor is 16 to 5. Neglect the resistance and reactance of the stator and the reactance of the rotor windings of the induction generator, and all of the losses in both machines. The excitation of the synchronous motor is adjusted so that the terminal voltage is 2000 volts. The load supplied by these machines is 450 kw. at a power factor of 85 per cent. What is the line current supplied by the induction generator? What is the frequency of this system if the induction generator is wound for 44 poles and is driven at 165 rev. per min.? If the synchronous motor has a synchronous reactance of 6.2 ohms between terminals what is its necessary excitation voltage?

73. An induction generator supplies power to a load and to an over-excited synchronous motor. At no load as an induction motor it takes a line current of 98 amperes at 2200 volts. The resistance of the rotor winding between terminals is 0.058 ohm and the ratio of transformation from stator to rotor is 22 to 15. Neglect the resistance and reactance of the stator winding and the reactance of the rotor winding of the induction generator and all of its losses. The rotational losses of the synchronous motor are 23.3 kw. and the resistance and synchronous reactance are respectively 0.26 ohm and 3.04 ohm between terminals. The induction generator delivers 1150 kw. of which the synchronous motor receives 450 kw. The excitation of the latter is adjusted so that the terminal voltage is 2200 volts. The power factor of the load exclusive of the synchronous motor is 0.83. The induction generator is wound for 12 poles and is driven at a speed of 254 rev. per min.

What is the frequency of the system. At what power factor is the synchronous motor operating? What is the excitation voltage of the synchronous motor? What is the power output of the synchronous motor?

74. A 2000-kw. induction generator is operated in parallel with a synchronous generator of the same capacity. At no load, when running as an induction motor, it takes a line current of 90 amperes at 6400 volts. The resistance of the rotor winding between terminals is 0.0766 ohm and the ratio of transformation from stator to rotor is 6400 to 2076. Neglect the resistance and reactance of the stator and the reactance of the rotor winding and all of its losses. The resistance and synchronous reactance of the synchronous generator between terminals are respectively 0.65 ohm and 14.2 ohms. The induction generator delivers 1800 kw. and the synchronous generator 1200 kw. The excitation of the latter is adjusted so that the terminal voltage is 6400 volts, and the power factor of the load is 0.85. The induction generator is wound for 36 poles and is driven at a speed of 82.4 rev. per min.

What is the frequency of the system? At what power factor does the synchronous generator operate? What is the excitation voltage of the synchronous generator?

75. An induction generator and a synchronous generator are operated in parallel and supply a load of 700 kw. at 0.86 power factor. Data concerning the induction generator are: 370 kw., 2000 volts, 44 poles, Y wound. The magnetizing current is 23 amperes at the rated voltage, and the core loss is 2.47 kw. For values of stator and rotor resistance and reactance see Motor K, page 86. Data concerning the synchronous generator are: 500 kw., 2200 volts, 64 poles, Y wound. The effective resistance and synchronous reactance of the armature winding are respectively 0.224 ohm and 2.76 ohms per phase. The induction generator is driven at 166.4 rev. per min. and the synchronous generator at 113.0 rev. per min. What is the division of the load if the excitation of the synchronous machine is adjusted so that the terminal voltage is 2200 volts? What is the necessary excitation voltage of the synchronous generator?

76. An induction generator and a synchronous generator are operated in parallel and supply a load of 950 kw. at 0.83 power factor. Data concerning the induction generator are: 450 kw., 2000 volts, 36 poles, Δ wound. The magnetizing current is 33 amperes per phase and the core loss is 2.8 kw. For values of stator and rotor resistance and reactance see Motor *L*, page 86. Data concerning the synchronous generator are: 850 kw., 2000 volts, 32 poles, Y wound. The effective resistance and synchronous reactance are respectively 0.064 ohm and 2.40 ohms per phase. The induction generator is driven at 85.0 rev. per min. and the synchronous generator, at 94.0 rev. per min. What is the division of the load if the excitation of the synchronous generator is adjusted so that the terminal voltage is 2000 volts? What is the necessary excitation voltage of the synchronous generator?

77.[1] The induction motor No. *G* is operated as a generator on a 60-cycle circuit in parallel with synchronous apparatus. What are the slip, the power factor and the efficiency when it receives 150 h.p. from the prime mover and the terminal voltage is 500 volts? Assume that the ratios of effective to ohmic resistance are respectively 1.4 and 1.6 for the stator and rotor windings, and that the ratio of the leakage reactances at the rated frequency is the same as ratio of the effective resistances.

78.[1] The induction motor No. *H* is operated as a generator on a 2200-volt, 25-cycle circuit in parallel with synchronous apparatus. What are the output, the power factor and the efficiency when the slip is 1.86 per cent.? Assume that the ratios of effective to ohmic resistance are the same at 25° Centigrade, and that the ratio of the ohmic resistances is equal to the ratio of the leakage reactances of the two windings at the rated frequency. The temperature under the running condition is 65° C.

79.[1] The induction motor No. *I* is operated as a generator on a 25-cycle circuit in parallel with syncrohnous apparatus. What are the slip, the power factor and the efficiency when it receives 1000 h.p. from the prime mover and the terminal voltage is 2200 volts? Assume that the ratios of the ohmic resistances, the effective resistances and the leakage reactances of the stator and rotor windings are equal at the rated frequency and a temperature of 25° C. The running temperature is 70° C.

80.[1] The induction motor No. *J* is operated as a generator

[1] See page 83.

on a 6400-volt, 25-cycle circuit in parallel with synchronous apparatus. What are the output, the power factor, and the efficiency when the slip is 1.9 per cent.? Assume that the ratio of the effective to the ohmic resistance for the rotor is 20 per cent. greater than for the stator, and that the ratios of the leakage reactances and of the effective resistances are equal at the rated frequency and a temperature of 25° C. The running temperature is 70° C.

SATURATION CURVE

Per cent. Normal voltage	Per cent. Normal Magnetizing Current
68.2	66.9
79.5	78.3
90.9	90.2
100.0	100.0
109 0	111.4
118.1	143.2
127.2	168.3

CHAPTER V

ROTARY CONVERTERS

1. Assume that the graph representing the flux density in the air-gap of a rotary converter is rectangular and is constant over the entire pole pitch. Also assume that the armature winding is uniformly distributed. Calculate the ratio of the single-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch and phase spread are each unity.

2. In problem 1 calculate the ratio of the four-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-half.

3. In problem 1 calculate the ratio of the three-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is two-thirds.

4. In problem 1 calculate the ratio of the six-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-third.

5. In problem 1 calculate the ratio of the twelve-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-sixth.

6. Assume that the air-gap flux density in a rotary converter is constant under the poles and is zero between them. The ratio of pole arc to pole pitch is two-thirds. Also assume that the armature winding is uniformly distributed. Calculate the ratio of the single-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch and the phase spread are each unity.

7. In problem 6 calculate the ratio of the four-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-half.

8. In problem 6 calculate the ratio of the three-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is two-thirds.

9. In problem 6 calculate the ratio of the six-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-third.

10. In problem 6 calculate the ratio of the twelve-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-sixth.

11. The graph representing the flux density in the air-gap of a rotary converter is a simple harmonic function. Assume that the armature winding is uniformly distributed. Calculate the ratio of the single-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch and the phase spread are each unity.

12. In problem 11 calculate the ratio of the four-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-half.

13. In problem 11 calculate the ratio of the three-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is two-thirds.

14. In problem 11 calculate the ratio of the six-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-third.

15. In problem 11 calculate the ratio of the twelve-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-sixth.

16. The graph representing the flux distribution in the air-gap of a rotary converter is $B = B_1 \sin x + B_3 \sin 3x$. x is the angular displacement measured from the neutral point. Take the third harmonic component of the flux density as 0.3 of the fundamental. Assume that the armature winding is uniformly distributed. Calculate the ratio of the single-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch and the phase spread are each unity.

17. In problem 16 calculate the ratio of the four-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-half.

18. In problem 16 calculate the ratio of the three-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is two-thirds.

19. In problem 16 calculate the ratio of the six-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-third.

20. In problem 16 calculate the ratio of the twelve-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-sixth.

21. The graph representing the flux distribution in the air-gap of a rotary converter is $B = B_1 \sin x - B_3 \sin 3x$. x is the angular displacement measured from the neutral point. Take the third harmonic component of the flux density as 0.3 of the fundamental. Assume that the armature winding is uniformly distributed. Calculate the ratio of the single-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch and the phase spread are each unity.

22. In problem 21 calculate the ratio of the four-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-half.

23. In problem 21 calculate the ratio of the three-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is two-thirds.

24. In problem 21 calculate the ratio of the six-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-third.

25. In problem 21 calculate the ratio of the twelve-phase alternating-current voltage to the direct-current voltage. Assume that the coil pitch is one and that the phase spread is one-sixth.

26. In a single-phase rotary converter, assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the rotary is operating at unit power factor. (b) Calculate this ratio when the rotary is operating at 0.9 power factor.

27. In a four-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the rotary is operating at unit power factor. (b) Calculate this ratio when the rotary is operating at 0.9 power factor.

28. In a three-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the rotary is operating at unit power factor. (b) Calculate this ratio when the rotary is operating at 0.9 power factor.

29. In a six-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the rotary is operating at unit power factor. (b) Calculate this ratio when the rotary is operating at 0.9 power factor.

30. In a twelve-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the ratio of the average heating in a conductor at one of the alternating-current taps to that in a conductor midway between the taps when the rotary is operating at unit power factor. (b) Calculate this ratio when the rotary is operating at 0.9 power factor.

31. In a single-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal and neglect all of the losses in calculating their relative values. (a) Calculate the relative outputs when operating as a rotary converter at unit power factor and as a direct-current generator on the basis of the same armature copper loss. (b) Calculate the relative outputs when the rotary is operating at 0.9 power factor. (c) Calculate the relative outputs when operating as a rotary converter and as a synchronous generator at unit power factor on the basis of the same armature copper loss. (d) Calculate the relative outputs when both are operating at 0.9 power factor.

32. In a four-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the relative outputs when operating as a rotary converter at unit power factor and as a direct-current generator on the basis of the same armature copper loss. (b) Calculate the relative outputs when the rotary is operating at 0.9 power factor. (c) Calculate the relative outputs when operating as a rotary converter and as a synchronous generator at unit power factor on the basis of the same armature copper loss. (d) Calculate the relative outputs when both are operating at 0.9 power factor.

33. In a three-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the relative outputs when operating as a rotary converter at unit power factor and as a direct-current generator on the basis of the same armature copper loss. (b) Calculate the relative outputs when the rotary is operating at 0.9 power factor. (c) Calculate the relative outputs when operating as a rotary converter and as a synchronous generator at unit power factor on the basis of the same armature copper loss. (d) Calculate the relative outputs when both are operating at 0.9 power factor.

34. In a six-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal, and neglect all of the losses in calculating their relative values. (a) Calculate the relative outputs when operating as a rotary converter at unit power factor and as a direct-current generator on the basis of the same armature copper loss. (b) Calculate the relative outputs when the rotary is operating at 0.9 power factor. (c) Calculate the relative outputs when operating as a rotary converter and as a synchronous generator at unit power factor on the basis of the same armature copper loss. (d) Calculate the relative outputs when both are operating at 0.9 power factor.

35. In a twelve-phase rotary converter assume that the currents on the direct- and alternating-current sides are respectively steady and sinusoidal and neglect all of the losses in calculating their relative values. (a) Calculate the relative outputs when operating as a rotary converter at unit power factor and as a direct-current generator on the basis of the same armature copper loss. (b) Calculate the relative outputs when the rotary is operating at 0.9 power factor. (c) Calculate the relative outputs when operating as a rotary converter and as a synchronous generator at unit power factor on the basis of the same armature copper loss. (d) Calculate the relative outputs when both are operating at 0.9 power factor.

36. A 5-kilowatt single-phase rotary converter supplies power on the direct-current side at 110 volts. It receives energy on the alternating-current side through a transformer from a 2200-volt circuit. What should be the transformer's ratio of transformation? If the rotary has an efficiency of 85 per cent. what should be the current rating of the high-tension winding of the transformer?

37. A 100-kilowatt, 4-phase rotary converter supplies power on the direct-current side at 230 volts. It receives energy on the alternating-current side through two single-phase transformers from a 2-phase circuit. The voltage between adjacent high-tension conductors is 1555 volts, and between alternate conductors is 2200 volts. The high-tension windings of the transformers are connected across the 2200-volt lines and the low-tension windings are connected in star with the neutral point grounded. The efficiency of the rotary at full load and unit power factor is 94 per cent. What should be the full-load current and voltage ratings of the high- and low-tension windings of the transformers?

38. A 4-phase, 50-kilowatt rotary converter supplies power on the direct-current side at 220 volts. It receives energy on the alternating-current side from a 2-phase line through two single-phase transformers which have double primary and secondary windings. The voltage between the adjacent high-tension conductors is 1625 volts and between alternate conductors is 2300 volts. The high-tension windings of the transformers are connected in star and the low-tension windings in mesh. The efficiency of the rotary at full-load output and 0.90 power factor is 90.2 per cent. What are the primary and secondary currents and voltages when the rotary delivers its rated load at 0.90 power factor?

39. A 4-phase 100-kilowatt rotary converter delivers power on the direct-current side at 220 volts. It receives energy from a three-phase, 11,000-volt circuit through Scott-connected transformers. The low-tension windings are connected in star. The efficiency of the rotary at full load and unit power factor is 92.5 per cent. What are the ratios of transformation of each of the transformers? What are the full-load current ratings of the primary and secondary windings of each transformer?

40. A 4-phase, 100-kilowatt, 230-volt rotary converter receives its power from a three-phase, 6600-volt circuit through Scott-connected transformers. The low-tension windings are double and are connected in mesh. The efficiency of the rotary at full load and 0.90 power factor is 91.8 per cent. What are the high- and low-tension currents and voltages of the transformers when the rotary delivers its rated load and operates at 0.90 power factor?

41. A three-phase, 200-kilowatt rotary converter supplies direct current at 110 volts. It receives power from a three-phase, 6600-volt circuit through three single-phase transformers which have their high-tension windings connected in delta and their low-tension windings connected in Y. At full load and unit power factor the rotary has an efficiency of 93 per cent. What should be the full-load current and voltage ratings of the high -and low-tension windings of the transformers?

42. A three-phase, 250-kilowatt, 220-volt rotary converter receives power through three single-phase transformers from a 3-phase, 2200-volt circuit. The high-tension windings of the transformers are connected in Y and the low-tension windings in delta. The rotary has an overload current capacity of 5 per cent. when operating at 0.9 power factor and at this time the efficiency is 91.8 per cent. What should be the overload current and voltage ratings of the high- and low-tension windings of the transformers?

43. A three-phase, 300-kilowatt, 500-volt rotary converter receives power through three single-phase transformers from a three-phase, 11,000-volt circuit. Both the high- and low-tension windings of the transformers are connected in Y. When delivering its rated load and operating at 0.90 power factor the rotary has an efficiency of 91.6 per cent. What is the ratio of transformation of the transformers? What should be the full-load current ratings of the high- and low-tension windings of the transformers?

44. A three-phase, 150-kilowatt, 230-volt rotary converter receives power through two single-phase transformers from a three-phase, 2200-volt circuit. Both the primary and secondary windings of the transformers are connected in V. Neglecting the losses what should be the current and voltage ratings of the high- and low-tension windings of the transformers?

45. A 6-phase, 1500-kilowatt, 650-volt rotary converter delivers power to a railway system. It receives power through three single-phase transformers from a three-phase, 13,200-volt transmission line. The transformers are connected in Y on the high-tension side and diametrically on the low-tension side. In order to maintain a constant line voltage of 13,200 volts at the substation the rotary is over-compounded so that when delivering 10 per cent. overload current at 650 volts it operates at 0.95 power factor with an efficiency of 92.7 per cent. What is the ratio of transformation for each transformer? What should be the overload current ratings of the high- and low-tension windings of the transformers?

46. A six-phase, 1000-kw., rotary converter receives power through three transformers from a three-phase, 11,000-volt circuit. The rotary delivers power at 650 volts to a railway system. The transformers are connected in Y on the high-tension and in double delta on the low-tension side. What should be the current and voltage ratings and the ratio of transformation for each of these transformers? In determining the rating neglect the losses.

47. A 6-phase, 2000-kw., rotary converter receives power from a 3-phase, 13,000-volt transmission line. The transformers are connected in delta on the high-tension and in double Y on the low-tension side. The rotary delivers power at 650 volts to a railway system. It has an overload current capacity of 10 per cent. and an efficiency of 92.8 per cent. when delivering this load and operating at 0.95 power factor. What should be the overload current and voltage ratings of the high- and low-tension windings of the transformers? What should be their ratio of transformation?

48. A 12-phase, 3000-kw., 650-volt rotating converter receives power from a three-phase transmission line through three single-phase transformers, whose high-tension windings are connected in Y and whose low-tension windings are connected in double chord. The high-tension line voltage is 22,000 volts. Neglecting the losses what should be the current and voltage ratings of the high- and low-tension windings of the transformers?

49.[1] A 6-phase, 25-cycle, 600-volt rotary converter has an efficiency of 92.5 per cent. when delivering 750 kw. and operating at 0.90 power factor. The armature winding has 4 inductors

[1] In calculating the armature reaction do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

in series per slot and 24 slots per pole. Neglect the resistance and the leakage reactance of the armature winding. What are the demagnetizing ampere turns per pole for the specified load?

50.[1] A 3-phase, 25-cycle rotary converter has a full-load capacity of 300 kw. at 600 volts. The armature has 96 slots with 6 inductors in series per slot. The field structure has 4 poles. Neglect the resistance and leakage reactance of the armature winding. When this rotary receives a line current of 540 amperes at 367 volts and is overexcited so that it operates at a power factor of 0.90 what are the demagnetizing ampere turns per pole?

51.[1] A 6-phase, 60-cycle, 600-volt rotary converter has a full-load capacity of 1000 kw. when operating at unit power factor. The armature has 180 slots with 6 inductors in series per slot. The field structure has 12 poles each of which is wound with 864 turns. When this rotary is overexcited so that it operates at 0.95 power factor and is delivering its rated output on the direct-current side the efficiency is 92.9 per cent. How much greater is the field current than its normal value, *i.e.*, if the power factor were unity?

52.[1] At full load and when operating at unit power factor a 3-phase, 25-cycle rotary converter receives a line current of 499 amperes at 367 volts and delivers on the direct-current side 500 amperes at 600 volts. The armature has 96 slots with 6 inductors in series per slot. The field structure has 4 poles with 2340 turns in the shunt windings per pole. The resistance of this field circuit with the regulating rheostat cut out is 120.5 ohms. When this rotary receives its rated current what is the least power factor at which it can be operated and still maintain its rated voltage? Normal excitation, *i.e.*, when operating at unit power factor, is 3.25 amperes.

53.[1] At full load and when operating at unit power factor a 6-phase, 25-cycle compound rotary converter receives a line current of 840 amperes at a voltage of 212 volts between adjacent slip rings and delivers on the direct-current side 1667 amperes at 600 volts. The armature has 168 slots with 6 inductors in series per

[1] In calculating the armature reaction do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

slot. The field structure has 8 poles with 1501 turns in the shunt winding and 2 turns in the series winding per pole. A current of 5.6 amperes in the shunt field winding alone is the normal excitation and produces a voltage of 600 volts on the direct-current side at no load when running as a generator.

When this rotary delivers 1500 amperes at 600 volts what should be the shunt field current in order that the current on the alternating-current side shall be leading and not exceed its full-load value and the power factor have its least value? What is this power factor? Neglect any change in the efficiency.

54.[1] At full load and when operating at unit power factor a 6-phase, 60-cycle rotary converter receives a line current of 840 amperes at a voltage of 424 volts between diametrical points of the armature and delivers on the direct-current side a current of 1667 amperes at 600 volts. The armature has 15 slots per pole with 6 inductors in series per slot. On each field pole there are 864 turns in the shunt winding and 2 turns in the series winding. A current of 9.3 amperes in the shunt field winding alone is the normal excitation and produces a voltage of 600 volts on the direct-current side at no load when running as a generator. When this rotary delivers 1460 amperes at 600 volts what are the limits of the shunt field current in order that the current on the alternating-current side shall not exceed its full-load value and the power factor have its least value? What are these limiting power factors? Neglect any change in the efficiency. The rotary has 12 poles.

55.[1] At full load and when operating at unit power factor a 6-phase, 25-cycle rotary converter takes a line current of 840 amperes at a voltage of 424 between diametrical points and delivers 1667 amperes at 600 volts. The armature has 21 slots per pole with 6 inductors in series per slot. Each field pole is wound with 1501 turns. The resistance of the field circuit with the regulating rheostat cut out is 76.6 ohms. A current of 5.6 amperes in the field winding is the normal excitation: *i.e.*, for full load and unit power factor. With an output of 850 kw. at 600 volts what is the least power factor at which this rotary can be operated when overexcited? What per cent. is the current

[1] In calculating the armature reaction do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

on the alternating-current side of its full-load value? Neglect any change in the efficiency.

56.[1] At full load and when operating at unit power factor a 6-phase, 60-cycle rotary converter takes a line current of 840 amperes at 212 volts per phase and delivers 1000 kw. at 600 volts. The armature has 180 slots with 6 inductors in series per slot. The field structure has 12 poles with 864 turns in the shunt winding and 2 turns in the series winding per pole. The resistance of the shunt field circuit is 39.65 ohms with the regulating rheostat cut out. A current of 9.3 amperes in the shunt field alone is the normal excitation, *i.e.*, for full load and unit power factor. With an output of 800 kw. at 600 volts what is the least power factor at which the rotary can be operated when overexcited? What per cent. is the current of its full-load value? Neglect any change in this efficiency.

57.[1] A 3-phase, 25-cycle rotary converter has a full-load capacity of 300 kw. at 600 volts. The armature has 96 slots with 6 inductors in series per slot. The field structure has 4 poles with 2340 turns in the shunt winding per pole. The resistance of this field circuit with all of the regulating rheostat cut out is 120.5 ohms. A current of 3.25 amperes in the shunt field winding alone gives the normal excitation, *i.e.*, for full load at unit power factor. In order to maintain the terminal voltage on the direct-current side at 600 volts when full load is delivered, it is necessary to overexcite the rotary so that it takes a line current of 600 amperes at a power factor of 86 per cent.

Calculate the least number of series field turns that must be added in order that this excitation may be produced. What should be the current in the shunt field winding?

58.[1-2] Calculate the efficiency of the rotary A when it receives 300 kw. at a power factor of 0.90 and with a line voltage of 380 volts. The excitation is greater than normal. Assume that the running temperature is 70° C.

59.[1-2] Calculate the efficiency of the rotary A when it delivers 300 kw. at 625 volts and the excitation is greater than normal and is adjusted so that the line current on the alternating-current side is 520 amperes. Assume that the running temperature is 70° C.

[1] In calculating the armature reaction do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch. [2] As a first approximation it may be assumed that the efficiency is 95 per cent.

DATA ON ROTARY CONVERTERS

	A	*B*	*C*
Kilowatt	300	1000	1000
Voltage (D.C.)	600	600	600
Current (D.C.)	500	1667	1667
Phases	3	6	6
Frequency	25	25	60
Poles	4	8	12
Armature slots	96	168	180
Inductors per slot	6	6	6
Turns per pole:			
Shunt	2340	1501	864
Series	9	2	2
Resistance at 25° C.:			
Armature between D.C. brushes	0.030	0.00688	0.00589
Shunt field[2] (alone)	120.5	76.6	39.65
Series field	0.00248	0.00042	0.0006095
Friction and windage (kw.)	3.2	6.7	9.1

D. C. SATURATION CURVES AND CORE LOSSES

Ordinates	Abscissæ					
D. C. voltage	Shunt field currents			Core losses		
	A	*B*	*C*	*A*	*B*	*C*
550	2.70	4.90	7.9	1.96	4.68	12.4
600	3.25	5.60	9.3	2.52	5.50	14.7
650	4.00	6.36	11.2	3.25	6.40	17.7
700	5.00	7.44	14.0	4.23	7.70	21.6

60.[1-3]Calculate the efficiency of the rotary *B* when it delivers 1000 kw. at 650 volts and the shunt field rheostat is cut out. Assume that the running temperature is 70° C. What are the line current and power factor on the alternating-current side?

61.[1-3]Calculate the efficiency of the rotary *C* when it delivers 1000 kw. at 650 volts and the excitation is greater than normal and is adjusted so that the power factor is 0.95. Assume that the running temperature is 70° C.

[1] In calculating the armature reaction do not neglect the distribution of the winding, and assume that the constant usually given as 0.707 is 0.75. This makes an approximate correction for the effect of the ratio of pole arc to pole pitch.

[2] The shunt field has a regulating rheostat in series with it, the loss in which should be included in calculating the efficiency.

[3] As a first approximation it may be assumed that the efficiency is 95 per cent.

CHAPTER VI

POLYPHASE CIRCUITS

1. Three equal impedance units, each of which has an equivalent resistance of 2.0 ohms and a reactance of 1.25 ohms are connected in delta across a three-phase 220-volt circuit. What current does each unit take? What is the line current? What is the total power supplied?

2. The three impedance units described in problem 1 are connected in Y across a three-phase, 220-volt circuit. What current does each unit take? What is the total power supplied?

3. Six equal impedance units each of which has an equivalent resistance of 2.5 ohms and a reactance of 1.5 ohms are connected across a three-phase, 220-volt circuit—three in delta and three in Y. What is the line current? What is the total power supplied?

4. Three equal impedance units each of which has an equivalent resistance of 2 ohms and a condensive reactance of 1 ohm are connected in delta across a three-phase, 220-volt circuit. At the same point three other equal impedance units, each of which has an equivalent resistance of 1.5 ohms and an inductive reactance of 1 ohm, are connected in Y across the circuit. What is the line current? What is the total power supplied?

5. Three equal resistances are connected in delta across a three-phase circuit. What should be the relative value of three other equal resistances which will take the same power when connected in Y across the circuit?

6. Three equal impedance units, each of which has an equivalent resistance of 2.0 ohms and a reactance of 1.0 ohm are connected in delta across a three-phase, 220-volt circuit. Three other equal impedance units are connected in Y across the same circuit. What should be their equivalent resistance and reactance in order that they will take the same line current and the same total power?

7. Three equal impedance units each of which has an equivalent resistance of 2.0 ohms and an inductive reactance of 1.0 ohm are connected in delta at the end of a transmission line, each conductor of which has a resistance of 0.2 ohm and an inductive reactance of 0.3 ohm. If the line voltages at the generating station are each 2200 volts what is the line current? (b) What is the voltage at the load? (c) What is the efficiency of transmission?

8. In problem 7 if the reactance of the impedance units had been condensive instead of inductive what would have been (a) the line current, (b) the voltage at the load, and (c) the efficiency of transmission?

9. Two equal resistances of 100 ohms each are connected in series across two mains of a three-phase 220-volt circuit and from their junction a resistance of 50 ohms is connected to the neutral conductor of the system. The line voltages are balanced and the voltages from the lines to the neutral conductor are equal. (a) What are the line currents? (b) What is the neutral current? (c) What is the total power absorbed?

10. Two equal impedances, each of which has an equivalent resistance of 2.0 ohms and an inductive reactance of 1.0 ohm are connected in series across two mains of a three-phase, 220-volt circuit, and from their junction another unit which has a resistance of 1.0 ohm and a condensive reactance of 1.0 ohm is connected to the neutral conductor of the system. The line voltages are balanced and the voltages from the lines to the neutral are equal. (a) What are the line currents? (b) What is the neutral current? (c) What is the total power absorbed?

11. Three non-inductive resistances of 5, 10 and 15 ohms are connected in delta across the lines of a three-phase, 220-volt circuit. (a) What is the total power absorbed? (b) What are the line currents?

12. Three impedance units which are represented by the expressions, $z_1=5+j5$, $z_2=5+j10$, $z_3=5-zj10$, are connected in delta across the lines 1–2, 2–3, 3–1 respectively of a three-phase, 220-volt circuit. If V_{12} leads V_{23} by 120 degrees (a) what is the total power absorbed? (b) What are the line currents?

If V_{12} lags V_{23} by 120 degrees, (c) what is the total power absorbed? (d) What are the line currents?

13. Three non-inductive resistances of 5, 10 and 15 ohms are connected in Y across the lines of a three-phase, 220-volt circuit. (a) What is the total power absorbed? (b) What are the line currents?

14. Three impedance units which are represented by the expressions, $z_1=5+j5$, $z_2=5+j10$, $z_3=5-j10$, are connected in Y from the mains 1, 2 and 3 respectively of a three-phase, 220-volt circuit to a common point. If V_{12} leads V_{23} by 120 degrees, (a) what are the line currents? (b) What is the total power absorbed? (c) What is the voltage between the "common point" and the true neutral of the system?

15. In problem 14 if V_{23} leads V_{12} by 120 degrees a what are the line currents? (b) What is the total power absorbed? (c) What is the voltage between the "common point" and the true neutral of the circuit?

16. Three impedance units which are represented by the expressions $z_1 = 10 + j0$, $z_2 = 0 + j10$, $z_3 = 0 - j10$, are connected in Y from the mains 1, 2 and 3 respectively of a three-phase, 220-volt circuit to a common point. If V_{12} leads V_{23} by 120 degrees (a) what are the line currents? (b) What is the total power absorbed? (c) What is the voltage between the "common point" and the true neutral of the system?

17. In problem 16 if V_{23} leads V_{12} by 120 degrees (a) what are the line currents? (b) What is the total power absorbed? (c) What is the voltage between the "common point" and the true neutral of the system?

18. Three voltmeters are connected in Y from the mains of a three-phase, 220-volt circuit to a common point. The resistances of the voltmeters are R_1 ohms and R_2 ohms and R_3 ohms respectively. What does each instrument indicate?

19. Three unequal lamp loads are connected between the mains and neutral conductor of a three-phase transmission line. The mains and neutral conductor each have a resistance of 0.1 ohm and negligible reactance. The resistances of the lamp loads are 1.0 ohm, 1.5 ohms and 2.0 ohms respectively. At the generating station the line voltages are each 220 volts and the voltages between the mains and neutral conductors are equal. (a) What are the line and neutral currents? (b) What is the voltage across each lamp load? (c) What is the efficiency of transmission?

20. Three unequal lamp loads are connected in delta at the end of a three-phase transmission line which has a resistance of 0.1 ohm per conductor and negligible reactance. The resistances of the lamp loads are 1.0 ohm, 1.5 ohms and 2.0 ohms respectively. If the line voltages at the generating station are each 220 volts, (a) what are the line currents? (b) What are the line voltages at the load? (c) What is the efficiency of transmission?

21. Three impedance units whose values are represented by the expressions, $z_1 = 2.0 + j\ 1.0$, $z_2 = 1.5 + j\ 0.5$, and $z_3 = 2.5 + j\ 1.0$, are connected in delta at the end of a three-phase transmission line each conductor of which has a resistance of 0.1 ohm and a reactance of 0.15 ohm. If the line voltages at the generating station are each 11,000 volts, (a) what are the line currents? (b) What are the line voltages at the load? (c) What is the efficiency of transmission?

22. The power supplied to a three-phase induction motor is measured by the two-wattmeter method. One wattmeter indicates 5770 watts and the other 2930 watts. What is the power supplied? At what power factor is the motor operating?

23. The only instrument available for measuring the power taken by a three-phase, 230-volt induction motor is a wattmeter of suitable range. Measurements are made as follows: The current coil of the wattmeter is inserted in main 1 and the potential coil, first between mains 1 and 2 and then between mains 1 and 3. If the two wattmeter readings thus obtained are 5760 and 3380 watts respectively what is the power supplied to the motor? If the line voltage is 230 volts what is the line current? At what power factor is this motor operating?

24. The power taken by a balanced three-phase load is measured by two wattmeters. The current coils of the wattmeters are connected to current transformers which are in lines 1 and 2 respectively. The potential coils are connected to potential transformers which are across lines 2 and 3 and lines 1 and 3 respectively. The line voltages are each 230 volts and the line currents are each 150 amperes. The wattmeters each indicate 19.6 kw. What is the power supplied? What is the power factor?

25. The power taken by an unbalanced three-phase load is measured by two wattmeters. The current coils of the wattmeters are connected to current transformers which are in lines 1 and 2 respectively, and the potential coils are connected to potential transformers which are across lines 2 and 3 and lines 1 and 3 respectively. The line voltages are each 230 volts. The currents in lines 1 and 2 are 150 amperes and 200 amperes respectively. The first wattmeter indicates 21.2 kilowatts and the second indicates 18.1 kilowatts. What is the power supplied to the load?

26. A 3-phase, 500-volt, Y-connected alternating-current generator with equal line voltages and a grounded neutral supplies energy to an unbalanced Y-connected load, the neutral of which is not grounded. The line currents are, $I_1 = 141.4$ amperes, $I_2 = 100$ amperes and $I_3 = 100$ amperes. One wattmeter is used and it is connected with its current coil in line 1 and its potential coil across lines 1 and 2. If this wattmeter indicates 70.7 kw. what is the total power supplied to the load? If the power factors of each of the three phases are equal what is the voltage between the neutral of the load and the neutral of the generator? What is the power factor?

27. An unbalanced lamp load, consisting of 115-volt lamps, is connected in Y across the lines of a balanced 3-phase, 200-volt circuit. The line currents are 70.7 amperes, 50 amperes and 50 amperes respectively. What is the power supplied to this load? What is the voltage across each phase of the load?

28. In problem 27 if the resistances of the lamp load are assumed to be constant, what will be the currents in the lines and neutral when the neutral point of the load is connected to the neutral conductor of the circuit? The voltages between the neutral conductor and the lines are equal.

29. An unbalanced lamp load is connected in delta across the lines of a balanced 3-phase, 230-volt circuit. The resistances of these loads between lines 1 and 2, 2 and 3, and 3 and 1 are 10 ohms, 8 ohms and 6 ohms respectively. (a) What are the line currents? (b) If the power is measured by two wattmeters which have their current coils in lines 1 and 2 what will each instrument indicate?

30. An unbalanced lamp load, consisting of 115-volt lamps, is connected between the lines and neutral conductor of a balanced 3-phase, 200-volt circuit. The resistances of the loads between lines 1, 2, and 3 and the neutral conductor are 6, 8, and 10 ohms respectively. The line voltages are equal and the voltages from the lines to the neutral conductor are also equal. What would two wattmeters indicate which have their current coils in lines 1 and 2 and their potential coils across lines 1 and 3 and lines 2 and 3 respectively? What is the total power supplied? What is the current in the neutral conductor?

31. Three single-phase transformers each of which has a ratio of transformation of 2.5 to 1 are connected in delta on the high-tension side. The low-tension windings are not connected but supply three separate single-phase loads. The first of these loads is 90 kilowatts at unit power factor, the second is 60 kilowatts at 0.7 power factor, and the third is 30 kilowatts at unit power factor. The high-tension line voltages are 600 volts. Neglect the losses in the transformers. What are the high-tension line currents?

32. Three unequal single-phase motor loads are connected across the lines of a balanced 3-phase, 230-volt circuit. The first takes 106 amperes at 0.78 power factor, the second takes 142 amperes at 0.82 power factor, and the third takes 28.4 kilowatts at 0.77 power factor. What are the line currents?

33. Three unequal single-phase motor loads are connected between the lines and neutral conductor of a balanced 3-phase, 350-volt circuit. The voltages from the lines to the neutral are each 202 volts. The first load takes 20 kilowatts at 0.82 power factor, the second takes 28 kilowatts at 0.75 power factor, and the third takes 36 kilowatts at 0.79 power factor. What is the current in the neutral conductor?

34. From the terminals of a 3-phase, 550-volt, 60-cycle alternating-current generator runs an artificial transmission line which has a resistance of 0.1 ohm and an inductance of 1.0 millihenry per conductor. At the end of this line is a balanced load of three reactors connected in Y. The equivalent resistance and reactance of these reactors should be assumed to be constant. The power output of the generator is measured by the two-wattmeter method with the current coils of the instruments in lines 1 and 2. The first wattmeter indicates 40 kw. and the second, 100 kw.

If line 3 is opened at the load what power will the instruments indicate? The terminal voltage of the generator is constant.

35. In problem 34 if line 3 is opened between the terminal of the generator and the potential coils of the wattmeter, what power will the instruments indicate?

36. From the terminals of a 3-phase, 500-volt, 25-cycle alternating-current generator runs an artificial transmission line which has a resistance of 0.3 ohm and an inductance of 3 millihenrys per conductor. At the end of this line is a balanced load of three reactors connected in delta. The equivalent resistance and reactance of these reactors should be assumed to be constant. The power output of the generator is measured by the two-wattmeter method with the current coils of the instruments in lines 1 and 2. The first wattmeter indicates 50 kw. and the second, 25 kw.

If line 3 is opened what power will the instruments indicate? The terminal voltage of the generator is constant.

37. In problem 36 if line 3 is opened between the terminal of the generator and the potential coils of the wattmeters what power will each instrument indicate? The terminal voltage of the generator is constant.

38. Two alternating-current generators, operating in parallel, deliver power to a balanced, 3-phase load. The output of each generator is measured by the two-wattmeter method. The terminal voltage is 2210 volts. The wattmeter readings are:

First generator	Second generator
$W_1 = 196$ kw.	$W_1 = 172$ kw.
$W_2 = 312$ kw.	$W_2 = 88$ kw.

The similarly numbered instruments are connected in the same lines. What is the total power supplied? What is the power factor of the load?

39. Two alternating-current generators, operating in parallel, deliver power to a balanced 3-phase load. The output of each generator is measured by the two-wattmeter method. The terminal voltage is 6650 volts. The wattmeter readings are:

First generator	Second generator
$W_1 = 412$ kw.	$W_1 = 183$ kw.
$W_2 = 626$ kw.	$W_2 = 457$ kw.

The similarly numbered instruments are connected in the same lines. What is the total power supplied? What is the power factor of the load?

40. It is desired to transform 200 kw. from 2-phase to 3-phase by Scott-connected transformers. The two-phase line voltage is 2200 volts and the three-phase line voltage is 230 volts. What should be the current and voltage rating, and the ratio of transformation of each transformer?

41. It is desired to transform 100 kw. from 3-phase at 6600 volts to 2-phase at 110 volts by the means of Scott-connected transformers. What should be the current and voltage rating, and the ratio of transformation of each transformer?

42. Three single-phase transformers are connected in delta on both the primary and secondary sides. With a primary voltage on open circuit of 22,000 volts the secondary voltage is 440 volts. The short-circuit characteristic data of each transformer are:

$V = 1020$ volts, $I = 1.136$ amperes, $P = 351$ watts. If the secondary terminal voltage is 440 volts when there is a single-phase load taking 40 kw. at 0.8 power factor connected across one phase of the secondary, what will be the percentage rise in this voltage when the load is thrown off?

43. (a) On the basis of the same heating loss compare the full-load kilowatt output at unit power factor of two single-phase transformers connected in open delta with their name-plate rating. (b) On the basis of the same heating loss compare the full-load kilowatt output at 0.87 power factor—both lagging and leading—of two single-phase transformers connected in open delta with 87 per cent. of their name-plate rating. In each case the load is balanced.

44. (a) Three single-phase transformers with both primaries and secondaries connected in delta supply a balanced load of 100 kw. at unit power factor. If it is necessary to remove one of these transformers from the line by what per cent. will the copper loss in each of the other two transformers be increased? (b) If the load had been a balanced one taking 87 kw. at 0.87 power factor—both leading and lagging—what would have been the per cent. increase in the copper loss in each of the other transformers?

45. (a) On the basis of the same copper loss in each transformer compare the full-load kilowatt output at unit power factor of two equal single-phase transformers connected in T with their name-plate rating. (b) On the basis of the same copper loss in each transformer compare the full-load kilowatt output at 0.87 power factor of two equal single-phase transformers connected in T with 87 per cent. of their name-plate rating.

46. On the basis of the same copper loss in each transformer compare the full-load kilowatt output of two equal single-phase transformers connected in open delta with the full-load output of the same transformers connected in T (a) at unit power factor, (b) at 0.87 power factor—both lagging and leading.

47. Compare the regulation of three 100-kv.-a. transformers whose primaries and secondaries are connected in delta with rhat of two 100-kv-a. transformers whose primaries and secondtaies are connected in open delta when a single-phase load of 100 kw. at 0.8 power factor is delivered on the secondary side. The secondary or low-tension voltage under load conditions is 2200 volts and the ratio of transformation is 5 to 1. The short-circuit of each transformer are: $V = 310$ volts, $I = 9.1$ amperes (full-load) $P = 1000$ watts. In the case of the open delta the load is connected across one transformer.

48. In problem 47 compare the regulation in the two cases when a single-phase load of 150 kw. at 0.8 power factor is supplied, which in the case of the open delta is connected across the terminals of the two transformers, *i.e.*, across the open side.

49. Three transformers whose primaries are connected in Y and whose secondaries are connected in delta are in parallel on the primary side with three others whose primaries and secondaries are both connected in Y. If one secondary terminal of the first set is connected to one corresponding terminal of the second set what are the greatest and least voltages that can exist between the other secondary terminals of the two sets? The line voltages on the secondary sides are 1100 volts for the two sets of transformers.

50. Three transformers whose primaries and secondaries are both connected in delta are in parallel on the primary side with three others whose primaries are connected in delta and whose secondaries are connected in Y. If one secondary terminal of the first set is connected to a corresponding terminal of the second set, what are the greatest and least voltages that can exist between the other secondary terminals of the two sets. The line voltages are 1100 volts for the two sets of transformers.

51. Three transformers whose primaries and secondaries are both connected in delta are in parallel on the primary side with three others whose primaries are connected in Y and whose secondaries are connected in delta. If one secondary terminal of the first set is connected to a corresponding terminal of the second set what are the greatest and least voltages that can exist between the other secondary terminals of the two sets. The line voltages are 1100 volts for the two sets of transformers.

52. Three auto-transformers are connected as shown in Fig. 3 to receive power from a 3-phase, 11,000-volt circuit. The ratio of transformation for each transformer from high tension to low tension is 2 to 1. What is the secondary line voltage, and what is the phase relation of the corresponding primary and secondary line voltages on open circuit?

53. Three auto-transformers are connected as shown in Fig. 4 to receive power from a 3-phase, 11,000-volt circuit. The ratio of transformation fron high tension to low tension is 2 to 1. What is the secondary line voltage, and what is the phase relation of the corresponding primary and secondary line voltages on open circuit?

54. Three auto-transformers are connected as shown in Fig. 5 to receive power from a 3-phase, 11,000-volt circuit. The ratio of transformation for each transformer from high tension to low tension is 2 to 1. What is the secondary line voltage, and what

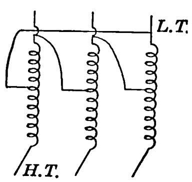

FIG. 3.

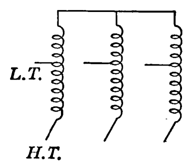

FIG. 4.

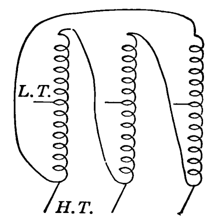

FIG. 5.

is the phase relation of the corresponding primary and secondary line voltages on open circuit?

55. A 1500-kw., 5500-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which have their low-tension windings connected in delta and their high-tension windings connected in Y. The following data on this generator and the transformers are given:

GENERATOR

Field current	Open-circuit terminal voltage	Short-circuit armature current
150	5100	300
200	5900	400
250	6500	....
300	6800	....
350	7100	....

The core loss at the rated voltage is 20.2 kw. and the friction and windage is 8.4 kw. Both of these losses may be assumed constant. The effective resistance of the armature is 0.362 ohm per phase. The resistance of the field winding is 0.376 ohm. The armature windings are connected in Y.

TRANSFORMER

Kv.-a	Voltage		Short circuit		
	High tension	Low tension	Amperes[1]	Volts	Watts
500	12,700	5500	39.4	332	4680

[1] Full-load current.

The core loss at the rated voltage is 3330 watts and may be assumed constant.

(a) When the power delivered to the transmission is 1280 kw. at a power factor of 0.83 and a line voltage of 22,300 volts, what is the combined efficiency of the generator and transformers? Calculate the generator field current by the magnetomotive-force method.

(b) If this load is removed from the line and the field excitation of the generator is unchanged, what is the high-tension line voltage?

56. A 1640-kw., 13,500-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which are connected in Y on both the high- and low-tension sides. The following data are given on this generator and transformers:

GENERATOR

Field current	Open-circuit terminal voltage	Short-circuit armature current
50	7,500	75
100	10,100	155
150	14,700	227
200	15,800	....
250	16,700	....

The core loss at the rated voltage is 21.3 kw., and the friction and windage is 8.8 kw. Both of the losses may be assumed constant. The effective resistance of the armature is 1.52 ohms per phase. The resistance of the field circuit is 0.392 ohms. The armature windings are connected in Y.

TRANSFORMERS

Kv.-a	Voltage		Short circuit		
	High tension	Low tension	Amperes[1]	Volts	Watts
500	38,000	7800	13.15	1190	3375

The core loss at the rated voltage is 2960 watts, and may be assumed constant.

(a) When the output of the generator is 1460 kw., at 0.92 power factor and a terminal voltage of 13,600 volts what is the combined efficiency of the generator and transformers? Calculate field current of the generator by the magnetomotive-force method.

[1] Full-load current.

(b) If this load is removed from the line and the field excitation of the generator is unchanged what is the high-tension line voltage?

57. A 1000-kw., 2400-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which are connected in delta on the low-tension and in Y on the high-tension side. Each transformer has a ratio of transformation of 5.29 to 1. The resistances of the high- and low-tension windings are 2.02 ohms and 0.072 ohm respectively. The effective resistance of the generator is 0.067 ohm per phase. The armature windings are connected in Y. With the high-tension windings of the transformers short circuited and with a field excitation of 100 amperes for the generator the armature current is 458 amperes. With this same excitation the open-circuit terminal voltage of the generator is 2220 volts. The rotation losses in the generator are 31.2 kw. at normal voltage and the core losses in each transformer are 1.8 kw.

(a) What is the combined efficiency of the generator armature and the transformers when a balanced load of 954 kw. at 0.91 power factor is delivered on the high-tension side of the transformers at a line voltage of 22,400 volts?

(b) What would be the high-tension line voltage if this load were removed and the excitation of the generator unchanged?

58. A 760-kw., 2200-volt, 3-phase generator delivers power to a transmission line through three single-phase transformers which have both their high and low-tension windings connected in Y. With the high-tension windings of the transformers short-circuited the output of the generator is 37.8 kilowatts, the armature current is 450 amperes when the terminal voltage is 133 volts. With the transformers on open circuit and with the same field excitation, the terminal voltage of the generator is 1780 volts. The effective resistance of the armature is 0.172 ohm per phase. The armature windings are connected in Y. The rotation losses of the generator are 17.2 kw. at normal voltage and the core loss in each transformer is 1670 watts. The transformers have a ratio of transformation of 10 to 1.

(a) What is the combined efficiency of the generator armature and the transformers when a balanced load of 680 kw. at 0.9 power factor is delivered to the transmission line at 22,400 volts?

(b) What would be the high-tension line voltage if this load were removed and the excitation of the generator unchanged?

59. A 1000-kw., 11,000-volt, 3-phase generator delivers power to a transmission line at the end of which is a 1200-h.p. induction motor. With the induction motor running at no load the excitation of the generator is adjusted so that the terminal voltage, the line current and the total power measured at the motor are 10,600 volts, 20.2 amperes and 20.4 kilowatts respectively. At the same time the terminal voltage and the total power measured at the generator are 10,980 volts and 29.8 kw. The field excitation of the generator is adjusted so that, when the motor is delivering full load, its terminal voltage is 11,000 volts. The efficiency and power factor of the motor at full load are 0.921 and 0.906 respectively.

What is the terminal voltage of the generator when the motor delivers full load? What is the efficiency of transmission at this time?

60. A 1000-kw., 13,800-volt, 3-phase generator delivers power directly to a transmission line at the end of which is an induction motor load. The resistance and reactance of the transmission line are 16.8 ohms and 17.2 ohms per conductor. The generator has an effective armature resistance of 2.18 ohms per phase. The field current is supplied at 120 volts.

Field current	Open-circuit terminal voltage[1]	Terminal voltage with an armature current of 42 amp. at zero power factor
50	8,800	....
80	13,000	....
110	15,600	10,750
140	17,250	13,250
180	18,900	15,600

On open circuit the rotational losses are 16.6 kw. and 25.4 kw. when the terminal voltages are 13,000 and 15,600 volts respectively.

What should be the field excitation of the generator so that the line voltage at the motor load will be 13,200 volts when the motors take 926 kw. at 0.91 power factor? What is the efficiency of the generator and the line?

61. At the end of a 3-phase transmission line is a motor load requiring 3000 kw. The line voltage at the load should be 32,000 volts and the power factor of the load is 0.90. What should be

[1] The generator is Y-connected.

the resistance and reactance of the line per conductor so that the efficiency of transmission will be 90 per cent. and the voltage regulation, 12 per cent?

62. A 1640-kv.-a., 13,500-volt, 3-phase generator delivers power directly to a transmission line which has a resistance of 30.2 ohms and a reactance of 24 ohms per conductor. With the far end of the line short-circuited and with a field excitation of 150 amperes the line current is 138 amperes. With the same field excitation the open-circuit terminal voltage of the generator is 14,700 volts. The effective resistance of the armature is 1.52 ohms per phase. The generator is Y-connected.

What is the combined electrical efficiency of the armature of the generator and the transmission line for a load of 1500 kw. at 0.90 power factor if the line voltage at the load is 13,200 volts? To what value will the line voltage rise if this load is removed and the field excitation of the generator is unchanged?

63. A 1000-kv.-a., 11,000-volt, 3-phase generator delivers power directly to a transmission line which has a resistance of 8.42 ohms and a reactance of 6.8 ohms per conductor.

Field current	Open-circuit terminal voltage	Rotational losses
20	8,400	11,600
30	11,000	19,400
40	12,700	25,600
50	13,800	....
60	14,700	....
70	15,500	....

The armature has an effective resistance of 0.94 ohm per phase, and the windings are connected in Y. The field current is supplied at 260 volts. With the far end of the line short-circuited and with a field current of 40 amperes the line current is 115 amperes.

If the load at the end of the line requires 940 kw. at 0.92 power factor what must be the excitation of the generator in order that the line voltage at the load shall be 11,000 volts?

64. A 1000-kw., 13,800-volt, 3-phase alternating-current generator delivers power over a transmission line to a synchronous motor load. The resistance and reactance of the line are 16.5 and 17.1 ohms per conductor respectively. The armature of the generator has an effective resistance of 2.18 ohms per phase. The field current is supplied with 120 volts.

Field current	Open-circuit terminal voltage[1]	Core loss at open circuit
50	8,800	7.5
80	13,000	16.6
110	15,600	25.4
140	17,250	33.5
180	18,900	....

With the synchronous motor running at no load and with under excitation the line current has its full-load value of 42 amperes, the line voltage at the motor is 13,200 volts and the power supplied to the motor is 28.6 kw. At this time the field excitation of the generator is 161 amperes.

When the motor load requires 1000 kw. what must be the excitation of the generator in order that it shall operate at unit power factor[2] and the line voltage at the load shall be 13,200 volts? What is the power factor of the load?

65. A 3500-kw., 10,000-volt, 2-phase alternating-current generator delivers power through Scott transformers to a three-phase transmission line. With the far end of this line short-circuited the output of the generator is 490 kw. and the armature current and terminal voltage are 220 amperes and 1630 volts. On open circuit the high-tension line voltage is 33,000 volts when the terminal voltage of the generator is 10,000 volts. The armature has an effective resistance of 0.64 ohm per phase The open- and short-circuit characteristics are:

Field current	Open-circuit terminal voltage	Short-circuit armature current
100	7,700	220
200	10,200	430
250	10,900	....
300	11,500	....
375	12,200	....

If there is a load requiring 3200 kw. at 0.91 power factor at the end of the line, what must be the excitation of generator in order that the line voltage at the load shall be 30,000 volts? (Use the magnetomotive-force method when dealing with the generator.)

66. A 1000-kw., 13,800-volt, 3-phase alternating-current generator delivers power over a transmission line which has a

[1] The armature windings are connected in Y.

[2] The excitation of the motor must also be properly adjusted for this to occur.

resistance of 16.4 ohms and a reactance of 17.2 ohms per conductor to a 1340-h.p. synchronous motor. Both generator and motor have their armatures connected in Y. This motor is rated for 11,000 volts and has an effective armature resistance of 0.94 ohms and a synchronous reactance of 46 ohms per phase. The effective resistance and synchronous reactance of the generator are respectively 2.18 ohms. and 82 ohms per phase. The rotation losses of the motor are 22 kw. and may be assumed constant. For certain excitations of generator and motor the line current and power factor at the motor are respectively 48 amperes and 0.92 (lagging) when the motor delivers 1140 h.p.

If the excitations are unchanged what will be the line current and the terminal voltages of the generator and motor if the load on the motor is thrown off?

67. A 1500-kv.-a., 5500-volt alternator delivers energy to a high-tension transmission line through step-up transformers, the low-tension windings of which are connected in delta and the high-tension windings in Y. The neutrals of the generator and of the high-tension transformer windings are grounded. The transformers have a ratio of transformation of 6.3 to 1.0.

GENERATOR CHARACTERISTICS

Field current	Terminal voltage on open circuit	Armature current on short circuit
100	3500	200
150	5100	300
200	5900	400
250	6500	....
300	6800	....
350	7100	....

The effective resistance of the armature is 0.36 ohm per phase. The reisstance of the field circuit is 0.386 ohm. The power required to drive the generator on open circuit with a terminal voltage of 5500 volts is 28.6 kw.

TRANSFORMER CHARACTERISTICS

With the high-tension winding short-circuited and 170 volts impressed on the low-tension winding the current supplied to a transformer is 91 amperes and the power is 4.26 kw. At no load and with 5500 volts impressed on the low-tension winding the power is 3.12 kw.

With a balanced load of 1360 kw. at 0.83 power factor delivered to the high-tension line at 60,000 volts what must be the generator's excitation? What is the combined efficiency of the generator and the transformers at this load? If this load were removed what would be the high-tension line voltage if the excitation of the generator were unchanged? Use (a) the synchronous impedance method and (b) the magnetomotive-force method when calculating the field current of the generator.

68. A 1000-kv.-a., 2400-volt alternator delivers energy to a high-tension transmission line through step-up transformers both the low- and high-tension windings of which are connected in Y. The armature windings of the generator which are connected in delta have an effective resistance of 0.20 ohm per phase. The resistance of the field circuit is 0.427 ohm.

GENERATOR CHARACTERISTICS

Field current	Open-circuit terminal voltage	Terminal voltage $I_a = 139$. $P.F. = 0$	Core loss on open circuit
60	1470	....	7.6
100	2220	....	17.9
140	2700	1920	28.5
180	2980	2370	37.0
220	3180	2630	....

The friction and windage loss is 8.2 kw.

TRANSFORMER CHARACTERISTICS

The transformers have a ratio of transformation of 1390:12,700 volts. With the low-tension winding short-circuited and with 332 volts impressed on the high-tension winding the current is 26.2 amperes and the power is 3120 watts. The core loss at the rated voltage is 2220 watts.

The heaviest load that the high-tension line requires is 1000 kw. at 0.88 power factor and the necessary line voltage is 24,500 volts. What must be the terminal voltage of the exciter for this load? What is the combined efficiency of the generator and the transformers at this load?

69. A 1500-kv.-a., 5500-volt alternator delivers energy to a high-tension transmission line through three step-up transformers, the low-tension windings of which are connected in delta and the high-tension windings in Y. The neutrals of the generator and of the high-tension transformer windings are grounded. The transformers have a ratio of transformation of 3.2 to 1.0. The calculated resistance and reactance of the high-tension line are

48.6 ohms and 59.4 ohms per conductor respectively. The generator has an effective armature resistance of 0.36 ohm per phase. The open- and short-circuit characteristic data for the generator are:

Field current	Terminal voltage on open circuit	Armature current on short circuit
100	3500	200
150	5100	300
200	5900	....
250	6500	....
300	6800	....
350	7100	....

With the far end of the transmission line short-circuited the generator supplies a current of 165 amperes at a terminal potential of 860 volts, and the power delivered to the transformers and line is 146 kw.

If, when the far end of this transmission line delivers a balanced load of 1450 kw. at a power factor of 0.93, the line potential difference at the load is 30,000 volts, to what value would this voltage rise if the load were removed? Use what you consider the most exact method of calculation.

70. A 1000-kv.-a., 13,800-volt generator delivers power over a transmission line and through step-down transformers which are connected in delta on both the high- and low-tension sides. The armature windings of the generator, which are connected in Y, have an effective resistance of 2.18 ohms per phase. The resistance of the field circuit is 0.541 ohm.

GENERATOR CHARACTERISTICS

Field current	Terminal voltage on open circuit	Terminal voltage $I_a = 42$ $P.F. = 0$	Core loss on open circuit
50	8,800	....	7.5
80	13,000	....	16.6
110	15,600	10,750	25.4
140	17,250	13,250	33.5
180	18,900	15,600	....

The friction and windage loss is 7.9 kw.

TRANSFORMER CHARACTERISTICS

Each transformer has a ratio of transformation of 425:13,200 volts. With the low-tension winding short-circuited and with 1100 volts impressed on the high-tension winding the current is 25.2 amperes and the power is 3070 watts. The core loss at the rated voltage is 2130 watts.

The calculated resistance and reactance of the transmission line are 15.7 ohms and 16.2 ohms per conductor.

With the low-tension windings of the transformers short-circuited what must be the terminal voltage of the generator in order that it will deliver its full-load current? When the transformers deliver a load of 1000 kv.-a. at 0.90 power factor and a line voltage of 420 volts what is the necessary excitation of the generator, and what is the combined efficiency of the generator, line and transformers?

71. An 850-kv.-a., 11,000-volt, Y-connected generator delivers energy over a transmission line and through transformers, that are connected in Y on the high-tension and in delta on the low-tension sides, to a load of induction motors and a synchronous motor. The resistance and reactance of the line are 11.4 ohms and 10.6 ohms per conductor respectively. The transformers are each rated to deliver 300 kw. with a ratio of transformation of 6600:660 volts.

GENERATOR CHARACTERISTICS

Field current	Open-circuit phase voltage	Short-circuit armature current
25	2200	72
50	4070	....
75	5500	....
100	6270	....
125	6930	....
150	7370	....
175	7700	....

The ohmic resistance of the armature between terminals is 3.32 ohms at the running temperature. The effective resistance is 1.45 times the ohmic resistance. The field resistance is 0.723 ohm. The core and friction losses are 26 kw. at the rated voltage.

TRANSFORMER CHARACTERISTICS

With the low-tension winding short-circuited and with 240 volts impressed on the high-tension winding the current is 47 amperes and the power, 2.8 kw. The core loss at the rated voltage is 2.6 kw.

The induction motors take a constant load of 220 kw. at 0.83

power factor. The synchronous motor takes a constant load of 460 kw., and, with the greatest allowable field excitation, its line current is 610 amperes and the terminal voltage is boosted to 650 volts.

Calculate the terminal voltage of the generator's exciter and the combined efficiency of the generator, line and transformers. Use what you consider the most exact method.

72. A constant induction motor load taking 2500 kw. at 0.55 power factor and with a line voltage of 13,200 volts is at the end of a short transmission line. For this load the efficiency of transmission is 91.3 per cent. and the voltage regulation of the line is 11.2 per cent. A synchronous motor of suitable capacity is added at the load so that when running light with full-load current the resultant power factor at the load is increased to 0.93. Assume that the efficiency of this synchronous motor at full load and unit power factor is 0.93. The voltage at the load is maintained constant.

What is the necessary capacity of the synchronous motor? What are the efficiency of transmission and the voltage regulation of the line after the synchronous motor is added?

73. An induction motor load at the end of a three-phase 25-cycle transmission line takes 7600 kw. at 0.65 power factor and with a line voltage of 11,000 volts. The resistance and inductance of the line are respectively 1.4 ohms and 6.5 millihenrys per conductor. A synchronous motor, running light and taking full-load current, is added at the generating station to improve the power factor and thus increase the capacity of the line at the load. Assume that the full-load efficiency of this motor is 94 per cent. when operating at unit power factor. The voltage at the load is maintained constant. Induction motors, operating at the same power factor as do the others, are added at the load and the synchronous motor is adjusted so that the generating station operates at 0.95 power factor. For the same line current in the station as was required before the addition of the synchronous motor calculate the permissible increase in the induction motor load. What is the kilovolt-ampere capacity of the necessary synchronous motor? What is the line voltage at the generating station before and after the synchronous motor is added?

74. An induction motor load taking 5400 kw. at 0.65 power factor and with a line voltage of 13,200 volts is at the end of a three-phase transmission line, which has a resistance of 2.38 ohms and an inductance of 7.6 millihenrys per conductor. The full-load capacity of the generating station is 320 amperes per line. A synchronous motor is to be added at the load both to compensate for power factor and to supply additional power. Assume that the efficiency of this synchronous motor and its exciter is 92 per cent. at full load and with unit power factor. The voltage at the load is maintained constant. The frequency is 60 cycles.

Calculate the kilovolt-ampere capacity of the synchronous motor so that the generating station can deliver its full-load current at 0.95 power factor. What additional power can the synchronous motor supply? At what power factor does the synchronous motor operate? What is the necessary line voltage at the generating station before and after the synchronous motor is added?

75. An induction motor load taking 26.000 kw. at 0.68 power factor and with a line voltage of 6600 volts is operated at the end of a high-tension transmission line. At the ends of the line there are step-up and step-down transformers, which have the same ratio of transformation. The total equivalent resistance and reactance of the line and transformers referred to the low-tension sides are 0.21 ohm and 0.25 ohm at 25 cycles respectively.[1] Synchronous motors, running light, but taking their full-load current, are added at the load to improve the power factor and thus increase the capacity of the generating station. Assume that the full-load efficiency of the synchronous motors and their exciters is 0.92 at unit power factor. The voltage at the load is maintained constant. Induction motors operating at the same power factor as do the others are added at the load and the synchronous motors are adjusted so that the resultant power factor of the load is increased to 0.94.

For the same line current as required before the addition of the synchronous motors calculate the permissible increase in the induction motor load. What is the necessary kilovolt-ampere capacity of the synchronous motors? At what power factor was the generating station operating before and after the synchronous motors were added? What was the line voltage at the generating station before and after the synchronous motors were added?

[1] Per line.

CHAPTER VII

NON-SINUSOIDAL WAVES

1. The equations for the open-circuit phase voltages of a three-phase, Y-connected, alternating-current generator are:

$$e_1 = 180 \sin \omega t + 60 \sin 3\,\omega t$$
$$e_2 = 180 \sin \left(\omega t - \frac{2\pi}{3}\right) + 60 \sin 3\left(\omega t - \frac{2\pi}{3}\right)$$
$$e_3 = 180 \sin \left(\omega t - \frac{4\pi}{3}\right)\ 60 \sin 3\left(\omega t - \frac{4\pi}{3}\right)$$

What is the equation of the line voltage, e_{12}? What would a voltmeter indicate when connected across one phase? When connected across the line terminals?

2. The equations for the open-circuit phase voltages of a three-phase, Y-connected, alternating-current generator are:

$$e_1 = 5300 \sin \omega t + 1200 \sin 3\,\omega t$$
$$e_2 = 5300 \sin \left(\omega t - \frac{2\pi}{3}\right) + 1200 \sin 3\left(\omega t - \frac{2\pi}{3}\right)$$
$$e_3 = 5300 \sin \left(\omega t - \frac{4\pi}{3}\right) + 1200 \sin 3\left(\omega t - \frac{4\pi}{3}\right).$$

What is the equation for the line voltage e_{12}? What would a voltmeter indicate when connected across one phase? When connected across the line terminals?

3. The equation for the voltage between line and neutral of a four-phase generator is:

$$e_1 = 1600 \sin \omega t + 500 \sin 3\,wt.$$

What is the equation for the voltage between adjacent line terminals? What would a voltmeter indicate when connected between line and neutral? Between adjacent lines?

4. The equation for the voltage between line and neutral of a four-phase generator is:

$$e_1 = 1600 \sin wt + 400 \sin 5\,wt.$$

What is the equation for the voltage between adjacent line terminals? What would a voltmeter indicate when connected between line and neutral? Between adjacent lines?

5. The phase voltage of a three-phase, Y-connected, alternating-current generator is 3750 volts. This consists of a fundamental and a third harmonic which is 30 per cent. of the fundamental. What is the line voltage?

6. The phase voltage of a three-phase, Y-connected, alternating-current generator is 2900 volts. This consists of a fundamental and a fifth harmonic which is 25 per cent. of the fundamental. What is the line voltage?

7. The phase voltage of a 3-phase, Y-connected, alternating-current generator is 3980 volts, while the line voltage is 6600 volts at the same time. If it is assumed that the phase voltage contains no harmonic higher than the seventh, what is the magnitude of the third harmonic in the phase voltage?

8. The phase voltage of a three-phase, Y-connected, alternating-current generator is 3010 volts while the line voltage (at the same time) is 5000 volts. What is the greatest value that a third harmonic component of the phase voltage can have?

9. The phase voltage of a three-phase, Y-connected, alternating-current generator is 138 volts while at the same time the line voltage is 230 volts. If the phases of this generator were connected in delta, what would be the unbalanced voltage tending to set up a circulating current in the windings?

10. Two transformers are arranged after the Scott method of connection to transform power from two-phase to three-phase. Their ratios of transformation are 1:10 and 1:8.66.

If there are impressed on the two-phase side electromotive forces whose equations are

$$e_1 = 1550 \sin \omega t + 500 \sin 3\,\omega t,$$

and $$e_2 = 1550 \sin \left(\omega t - \frac{\pi}{2}\right) + 500 \sin 3\left(\omega t - \frac{\pi}{2}\right),$$

what are the equations for the line voltages on the three-phase side?

11. In problem 10 if there are impressed on the two-phase side electromotive forces whose equations are,

$$e_1 = 1550 \sin \omega t + 300 \sin 5\,\omega t,$$

and $$e_2 = 1550 \sin \left(\omega t - \frac{\pi}{2}\right) + 300 \sin 5\left(\omega t - \frac{\pi}{2}\right)$$

what are the equations for the line voltages on the three-phase side?

12. In problem 10 there are impressed on the two-phase side equal electromotive forces which contain a third and a fifth harmonic. The effective value of these electromotive forces is 1100 volts and the harmonics are respectively 0.3 and 0.2 of the fundamental. What are the effective values of the three-phase line voltages? What per cents. of the fundamental components are each of the harmonics in these line voltages?

13. The line voltage and the voltage to neutral of a balanced three-phase circuit are respectively 230 volts and 139 volts. The voltage to neutral contains a fundamental and a third harmonic only. Three equal resistance units of 10 ohms each are connected in Y across the lines of this circuit.

(a) What is the line current? What are the line and neutral currents when the neutral point of the resistance units is connected to the neutral of the circuit.

(b) If the power is measured by the two-wattmeter method what would be the indicated power before and after the connection to the neutral is made? If a wattmeter were connected in the circuit with its current coil in the neutral and its potential coil between the neutral and one of the lines, what would this wattmeter indicate in the second case?

14. The voltage to neutral of a balanced three-phase circuit is 134 volts, and it contains a fundamental and a fifth harmonic which is 0.2 of the fundamental. Three equal resistance units of 10 ohms each are connected in Y across the lines of this circuit. What is the line current? If the neutral point of the resistance units and the neutral of the circuit are connected what is the current in the neutral conductor? What is the total power supplied in each case?

15. The line voltage and the voltage to neutral of a balanced three-phase, 60-cycle circuit are respectively 230 volts and 139 volts. The voltage to neutral contains a fundamental and a third harmonic only. Three equal air-core reactors, each having a resistance of 5 ohms and an inductance of 0.015 henry, are connected in Y across the lines of this circuit.

(a) What is the line current? What are the line and neutral currents when the neutral point of the reactors is connected to the neutral of the circuit?

(b) If the power is measured by the two-wattmeter method what is the indicated power before and after the connection to the neutral is made? If a wattmeter is connected in the circuit with its current coil in the neutral and its potential coil between the neutral and one of the lines, what would this wattmeter indicate in the second case?

16. The voltage to neutral of a balanced, three-phase, 60-cycle circuit is 134 volts, and it contains a fundamental and a fifth harmonic which is 0.2 of the fundamental component. Three equal air-core reactors, each having a resistance of 5.0 ohms and an inductance of 0.015 henry, are connected in Y across the lines of this circuit. What is the line current? If the neutral point of these reactors and the neutral of the circuit are connected what is the current in the neutral conductor? What is the total power supplied in each case?

17. The line voltage and the voltage to neutral of a balanced three-phase, 60-cycle circuit are 230 volts and 139 volts respectively. The voltage to neutral contains a fundamental and a third harmonic only. Three equal impedance units, each consisting of a resistance of 5 ohms in series with a capacity of 25 microfarads are connected in Y across the lines of this circuit.

(a) What is the line current? What are the line and neutral currents when the neutral point of this load is connected to the neutral point of the circuit?

(b) If the power is measured by the two-wattmeter method what is the indicated power before and after the connection to the neutral is made? If a wattmeter is connected in the circuit with its current coil in the neutral and its potential coil between the neutral and one of the lines, what will it indicate in the second case?

18. The voltage to neutral of a balanced three-phase, 60-cycle circuit is 134 volts, and it contains a fundamental and a fifth harmonic which is 0.2 of the fundamental component. Three equal impedance units, each consisting of a resistance of 5 ohms in series with a capacity of 25 microfarads, are connected in Y across the lines by this circuit. What is the line current? If the neutral point of this load is connected to the neutral point of the circuit what is the current in the neutral conductor? What is the total power supplied in each case?

19. Three unequal lamp loads are connected between the lines and neutral of a balanced three-phase circuit. The line voltage is 230 volts and the voltage to neutral is known to contain a third harmonic which is 0.3 of the fundamental component. The resistances of the lamp loads are 5, 8, and 10 ohms. What are the line currents, the neutral current, and the total power supplied?

20. Three equal lamp loads are connected in Y across the lines of a balanced three-phase circuit. The line voltages are 230 volts and the voltage from line to neutral is 139 volts. The latter voltage is known to contain harmonics. The resistance of each of the lamp loads is 5.0 ohms. What will be the effect on the line current if the neutral point of the load is connected through a resistance of 2 ohms to the neutral of the circuit? By what amount is the power supplied to the lamps increased? What is the loss in the 2-ohm resistance?

21. The voltages from the lines to the neutral conductor of a balanced three-phase circuit are each 140 volts. Three equal resistance units of 10 ohms each are connected in Y across this circuit. A voltmeter connected between the neutral point of this load and the neutral conductor indicates 40 volts. What power will these resistance units take if the neutral point of the load is directly connected to the neutral conductor? What will be the current in the neutral conductor?

22. The line voltages of a three-phase circuit are equal and maintained constant. The voltages from the lines to the neutral conductor, which are known to contain third harmonics, are also maintained constant and are each equal to 140 volts. Three equal resistance units of 10 ohms each are connected in Y across this circuit. The measured voltage from the neutral of this load to the neutral conductor is 40 volts. What current will exist in the neutral conductor if a resistance unit of 5 ohms is connected between these two points? What is the effective voltage across each of the equal resistance units before and after this additional resistance is inserted in the circuit?

23. Three hypothetical impedance units, a resistance, a reactor, and a condenser are so constructed that at 60 cycles the values of their impedances may be represented in the complex notation by: $z_1 = 10 + j0$, $z_2 = 0 + j10$ and $z_2 = 0 - j10$. These impedance units are connected between the mains and neutral of a balanced three phase, 60-cycle circuit The line voltages are each 230 volts, and the voltages between the lines and the neutral are equal and consist of a fundamental and a third harmonic which is 0.3 of the fundamental component. The first impedance unit is connected from line (1), the second, from line (2), and the third, from line (3) to the neutral.

If the cyclic order of the line voltages is such that the fundamental component of V_{12} leads V_{23} by 120 degrees what are the line currents? What is the neutral current? What is the total power supplied?

24. In problem 23 if the cyclic order of the line voltages is such that the fundamental component of V_{12} lags V_{23} by 120 degrees what are the line currents? What is the neutral current? What is the total power supplied?

25. Three hypothetical impedance units, a resistance, a reactance, and a condenser are so constructed that at 60 cycles their values may be presented in the complex notation by: $z_1=10+j0$, $z_2=0+j10$, $z_3=0-j10$. These impedance units are connected between the mains and neutral of a balanced three-phase, 60-cycle circuit. The line voltages are each 230 volts, and the voltages between the lines and the neutral are equal and consist of a fundamental and a fifth harmonic which is 0.25 of the fundamental component. The first impedance is connected from line (1), the second, from line (2), and the third, from line (3) to the neutral. If the cyclic order of the line voltages is such that the fundamental component of V_{12} leads V_{23} by 120 degrees what are the line currents? What is the neutral current? What is the total power supplied?

26. In problem 25 if the cyclic order of the line voltages is such that the fundamental component of V_{12} lags V_{23} by 120 degrees what are the line currents? What is the neutral current? What is the total power supplied?

27. Three hypothetical impedance units, a resistance, a reactor, and a condensor are so constructed that at 60 cycles their values may be represented in the complex notation by: $z_1=10+j0$, $z_2=0+j10$, $z_3=0-j10$. These impedance units are connected in delta across the lines of a balanced three-phase, 60-cycle circuit. The line voltages are each 230 volts and consist of a fundamental and a fifth harmonic which is 0.25 of the fundamental component. The first impedance is connected between lines 1–2, the second, between lines 2–3, and the third, between lines 3–1.

If the cyclic order of the line voltages is such that the fundamental component of V_{12} leads V_{23} by 120 degrees what are the line currents?

28. In problem 27 if the cyclic order of the line voltages is such that the fundamental component of V_{12} lags V_{23} by 120 degrees what are the line currents?

29. Three equal resistance units of 50 ohms each are connected in Y across the mains of a balanced three-phase, 230-volt circuit. An air-core reactor which has a resistance of 0.5 ohm and an inductance of 5 millihenrys is connected from neutral point of this load through a switch to the neutral conductor of the circuit. The voltage across the open switch is 40 volts. There is no higher harmonic than a third present.

(a) With the switch open what is the line current? What is the total power supplied?

(b) With the switch closed what is the line current? What is the neutral current? What is the total power supplied? What are the voltages across the resistance units before and after the switch is closed? What is the voltage across the reactor after the switch is closed?

30. In problem 29 if the air-core reactor is replaced by a condenser which has a capacity of 50 microfarads what are the line currents before and after the switch is closed? What is the neutral current after the switch is closed? What is the total power supplied with the switch open? With the switch closed? What are the voltages across the resistance units before and after the switch is closed? What is the voltage across the condenser after the switch is closed?

31. The voltages between the lines and neutral conductor of a balanced three-phase, 60-cycle circuit are each 140 volts. Three equal condensers each of 50 microfarads capacity are connected in Y across the lines of this circuit, and from their common junction a non-inductive resistance unit of 10 ohms' resistance is connected through a switch to the neutral conductor. The voltage across the open switch is 45 volts. There is no higher harmonic than a third present. (a) With the switch open what is the line current? What is the total power supplied? (b) With the switch closed what is the line current? What is the neutral current? What is the total power supplied?

32. In problem 31 if the non-inductive resistance unit is replaced by an air-core reactor which has a resistance of 0.5 ohm and an inductance of 5 millihenrys what are the line currents before and after the switch is closed? What is the neutral current after the switch is closed? What is the total power supplied with the switch closed? What are the voltages across the condensers before and after the switch is closed? What is the voltage across the reactor after the switch is closed?

33. Three equal lamp loads each of which has a resistance of 5 ohms are connected in Y across the lines of a balanced 230-volt, 3-phase circuit. Due to harmonics the voltages from the lines to the neutral conductor of the circuit are each 140 volts. The power supplied is measured by the two-wattmeter method.

(a) What are the line currents and the wattmeter readings?

(b) If the neutral point of the load is connected to the neutral conductor what will the wattmeters read? What is the power supplied? Compare the true power factor of this load with that calculated from the wattmeter, voltmeter, and ammeter readings.

34. Three unequal lamp loads are connected between the lines and the neutral conductor of a balanced 230-volt, 3-phase circuit Due to third and fifth harmonics, which are respectively 0.3 and. 0.25 of the fundamental, the voltages from the lines to the neutral conductor are each 140 volts. The effective line currents are 20 amperes, 30 amperes and 40 amperes respectively. What is the current in the neutral conductor?

35. In problem 34 if fuses in the third line and in the neutral conductor blow, what current will the lamp loads take, and what will be the voltage across each of them? Assume that the resistance of each lamp circuit is constant.

36. By mistake three equal air-core impedance units are connected in delta across two of the mains and the *neutral* conductor of a three-phase, 60-cycle circuit. Each of these impedance units has a resistance of 5 ohms and reactance of 2 ohms at 60 cycles. The voltages between the mains and neutral conductor are each 140 volts, and the voltage between any two of the mains is 230 volts. Assume that there are no harmonics higher than the third present. What are the currents in each of the impedance units? What are the currents in the mains and in the neutral conductor?

37. Two suitable transformers are arranged after the Scott method of connection to transform from 2-phase to 3-phase. Each of the two-phase line voltages is 2200 volts and consists of a fundamental and a third harmonic which is 30 per cent. of the fundamental. The 3-phase line voltages each have an effective value of 230 volts. The frequency of the fundamental is 60 cycles. Neglect the resistance and the leakage reactance of the transformers.

(a) If three equal lamp loads, each of which has a resistance of 5 ohms, are connected in delta across the 3-phase lines what current does each take?

(b) If three equal lamp loads, each of which has a resistance of 3 ohms, are connected in Y across the 3-phase lines what current does each take?

38. In problem 37 three equal air-core reactors, each of which has a resistance of 5 ohms and an inductance of 7.5 mil-henrys, are connected in delta across the 3-phase lines. What current does each take? What is the line current?

(b) If these reactors are connected in Y what current will each take?

39. In problem 37 three equal impedance units, each consisting of a resistance of 20 ohms in series with a condenser of 50 microfarads' capacity, are connected in delta across the 3-phase lines. What current does each unit take? What is the line current?

(b) If these impedance units are connected in Y what current will each take?

40. In problem 37 three hypothetical impedance units are connected in delta across the 3-phase lines. The values of these units at 60 cycles may be represented in the complex notation by: $z_1=10+j0$, $z_2=0+j10$, $z_3=0-j10$. What current does each unit take? What are the line currents?

41. In problem 37 the smaller transformer is tapped at a point two-thirds from its line terminal to give a neutral on the 3-phase side. The three hypothetical impedance units described in problem 40 are connected in Y between the lines and neutral. What are the line currents? What is the neutral current?

42. A 3-phase, 60-cycle alternating-current generator supplies power to a transmission line through step-up transformers whose low tension windings are connected in Y and whose high-tension windings are connected in delta. These transformers are rated at 3333 kv.-a., and have a voltage ratio of 3,800 to 80,000 volts. With the high-tension winding short-circuited and with 162 volts at 60 cycles impressed on the low-tension winding full-load current exists in each winding and 18.85 kw. is supplied. The neutral points of both the generator and the low-tension windings of the transformers are connected to the same ground bus. When the transformers are delivering no load on the high-tension side and the excitation of the generator is adjusted so that its terminal voltage is 6600 volts the voltage from line to neutral is found to be 3850 volts. A third harmonic in the phase voltage is suspected, and the oscillograph shows that one with a magnitude of 14 per cent. of the fundamental does exist.

What is the copper loss in each transformer when there is no load delivered to the high-tension line. Compare this with the full-load copper loss that would be produced in the transformers if their neutral point was not grounded.

43. A 1000-kw., 6-phase, 25-cycle, 600-volt rotary converter is supplied with power from a 3-phase, 13,200-volt transmission line. The high-tension windings of the transformers are connected in delta and the low-tension windings are connected to diametrical points of the armature of the rotary. With the low-tension winding of a transformer short-circuited and with 345 volts at 25 cycles impressed on the high-tension winding, full-load current, or 25.2 amperes exists in the winding and 3070 watts is supplied. When the rotary is delivering about full load and the excitation is adjusted for near unit power factor receive the transformer 1120 kw. and the line voltage and current are 13,200 volts and 49.8 amperes. Oscillograph records show that at this time there exists across diametrical points of the armature of the rotary a voltage which practically consists of a fundamental and a third harmonic that is 8.5 per cent. of the fundamental.

Calculate the total copper loss in each transformer. If the low-tension windings had been divided and connected in double Y with no connection between their neutral points what would have been the copper loss in each transformer under the same load condition?

44. A 3000-kw., 5000-volt, 60-cycle alternating-current generator supplies power to a 3-phase transmission line through three 1000-kv.-a. transformers which are connected in Y on the low-tension and in delta on the high-tension sides. With the low-tension winding short-circuited and with 3240 volts at 60 cycles impressed on the high-tension side full-load current exists in the windings and 7490 watts is supplied. The ratio of transformation is 2890 to 66,000 volts. Both the neutral point of the armature winding and the neutral point of the low-tension windings of the transformers are directly connected to the same bus. When the transformers are delivering 2650 kw. at 0.875 power factor and with a line voltage of 66,000 volts they become unduly hot. Oscillograph records show that at this time the terminal voltage of each phase of the generator practically consists of a fundamental and a third harmonic which is 12 per cent. of the fundamental.

What is the copper loss in each transformer? If the neutral point of the transformer windings is disconnected from the ground bus what will be the copper loss in each transformer for the same load condition?

GWYNN E. BISHOP.

write a report on impulse
turbine
where used, speeds etc.