SOLUTIONS
ELECTRICAL ENGINEERING (EE) PRACTICE PROBLEMS
FOR TECHNICAL MAJORS

Note: The text entitled "Applied Engineering Principles Manual" is used as the reference for the questions and problems below. Although only Section 1.3-"Three-Phase Systems and Transformers," Section 1.4-"Generators," and Section 1.5-"Motors" are explicitly needed to answer these questions and problems, students with weak or non-existent backgrounds in EE may first need to review portions of Section 1.1-"Fundamentals of Electricity" and Section 1.2-"Alternating Current Theory".

Section 1.3 – "Three-Phase Systems and Transformers"

1. State the advantages of three-phase systems over single-phase systems.

The advantages include a reduction in the size of machinery for the same capacity, simpler machine construction, reduced cost, and increased reliability of power transmission.

2. A balanced three-phase 60-Hz system is driven by a generator with a line voltage of 450 V.

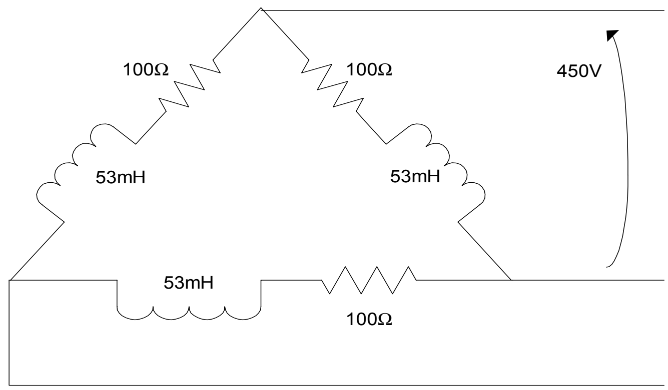
a. If the generator is wye-connected, what is the voltage across each of its phases?

$$V_{\varphi Y} = \frac{V_L}{\sqrt{3}} = \frac{450\ \text{V}}{\sqrt{3}} = 260\ \text{V}.$$

b. If the generator is delta-connected, what is the voltage across each of its phases?

$$V_{\varphi\Delta} = V_L = 450\ \text{V}.$$

c. If each phase of a delta-connected load can be represented by a $100\,\Omega$ resistor in series with a 53 mH inductor, find the line current and total real power. (See figure at the top of the next page.)



$$Z_R = 100\,\Omega \qquad Z_L = j\omega L = j\,(377\,\frac{\text{rad}}{\text{sec}})(53\text{x}10^{-3}\,\text{H}) = j\,20\;\Omega$$

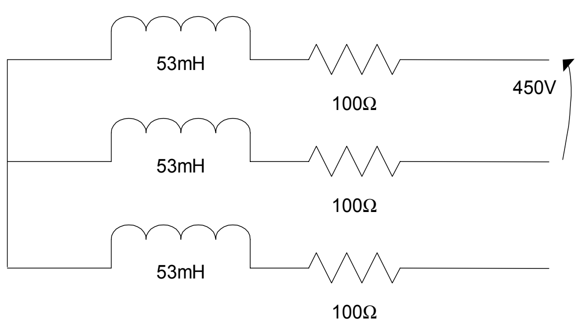
$$Z = Z_R + Z_L = 100\,\Omega + j20\,\Omega = 102\;\Omega\,\angle 11.3^{o}$$

$$I_{\varphi} = \frac{V_{\varphi}}{|Z|} = \frac{450\,\text{V}}{102\;\Omega} = 4.41\,\text{A}$$

$$I_L = \sqrt{3}(I_{\varphi Y}) = \sqrt{3}(4.41\,\text{A}) = \underline{7.64\ \text{A}}$$

$$P = \frac{3V_{\varphi}^{\,2}}{|Z|}\cos\theta = \frac{3(450\,\text{V})^2}{102\,\Omega}\cos(11.3^{o}) = \underline{5{,}840\,\text{W}}.$$

d. Repeat Part c. for a wye-connected load of the same phase impedance.



$$V_{\varphi Y} = \frac{V_L}{\sqrt{3}} = \frac{450\ \text{V}}{\sqrt{3}} = 260\,\text{V}$$

$$I_{\varphi} = \frac{V_{\varphi}}{Z} = \frac{260\ \text{V}}{102\,\Omega\,\angle 11.3^{o}} = 2.55\,\text{A}$$

$$I_L = I_{\varphi Y} = 2.55\,\text{A}$$

$$P = \frac{3V_{\varphi}^{\,2}}{|Z|}\cos\theta = \frac{3(260\ \text{V})^2}{102}\cos(11.3^{o}) = 1{,}950\ \text{W}.$$

3. A three-phase 450V system is supplying a delta-connected 100hp load (746W = 1hp) at a power factor of 0.92 lagging. Find:

a. The real power

$$P = 100\ \text{hp}\left(\frac{746\ \text{W}}{1\ \text{hp}}\right) = 74.6\ \text{kW}.$$

b. The apparent power

$$P_{app} = \frac{P}{pf} = \frac{74.6\text{kW}}{0.92} = 81.1\ \text{kVA or } 81.1\text{x}10^{3}\ \text{VA}.$$

c. The line current

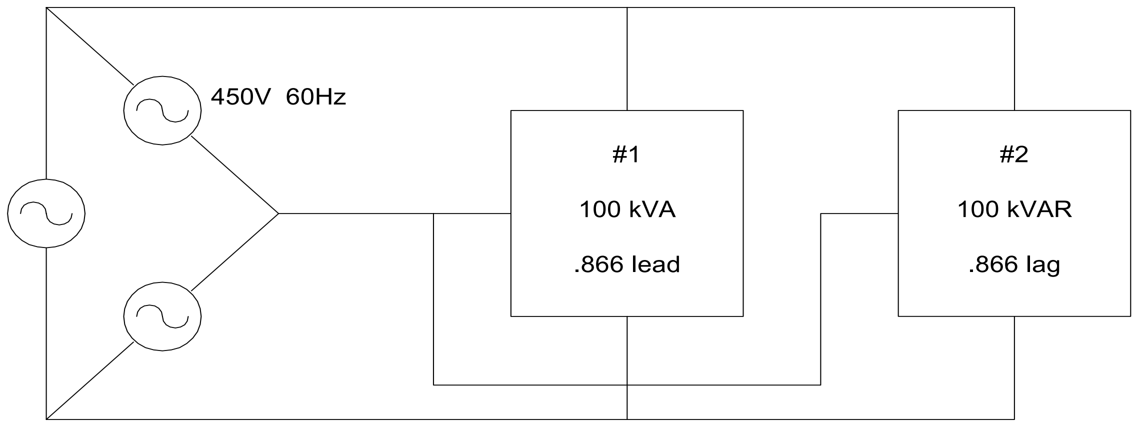
$$P_{app} = \sqrt{3}\,V_L I_L$$

$$I_L = \frac{P_{app}}{\sqrt{3}\,V_L} = \frac{81.1\text{x}10^{3}\ \text{VA}}{\sqrt{3}\,(450\,\text{V})} = 104\ \text{A}.$$

d. The phase current

$$I_{\varphi\Delta} = \frac{I_L}{\sqrt{3}} = \frac{104\ \text{A}}{\sqrt{3}} = 60\ \text{A}.$$

4. **Given the following balanced 3∅ system, find the <u>apparent</u> power delivered by the generator.**



LOAD #1

$$\theta_Z = \cos^{-1}(pf) = \cos^{-1}(0.866) = -30^o$$
$$P_1 = P_{app}\,pf = (100\,kW)(0.866) = 86.6\ kW$$
$$Q_1 = P_{app}\sin\theta = (100\,kW)\sin(-30^o) = -50\ kVAR.$$

LOAD #2

$$\theta_Z = \cos^{-1}(pf) = \cos^{-1}(0.866) = 30^o$$
$$Q_2 = 100\ kVAR$$
$$P_2 = \frac{Q_2}{\tan\theta} = \frac{100\,kW}{\tan(30^o)} = 173.2\ kW.$$

TOTAL

$$P_T = P_1 + P_2 = 86.6\,kW + 173.2\,kW = 259.8\ kW$$
$$Q_T = Q_1 + Q_2 = -50\ kVAR + 100\ kVAR = 50\ kVAR$$
$$P_{app} = \sqrt{P_T{}^2 + Q_T{}^2} = \sqrt{(259.8)^2 + (50)^2}$$
$$P_{app} = 264.57\ kVA.$$

Section 1.4 – "Generators"

D-C Generators

1. Describe briefly the construction and operation of a d-c generator.

The field windings of a d-c generator, located on the stator, generate a fixed and nearly uniform magnetic field through which the rotor rotates. As the armature windings (located on the rotor) pass through the magnetic field, an a-c voltage is induced in each armature winding. The resulting current is effectively converted to direct current and carried to the load by means of the commutator and brushes.

2. Describe the problems with commutation in d-c generators.

First, the orientation of the "neutral plane," the plane in which an armature winding produces zero output voltage, is shifted from the no-load position. This results in sparking across the commutator-brush connection each time the armature connection is reversed. Second, the distorted flux across the pole gap causes a gradual reduction in output voltage with increasing generator load.

3. Describe how problems with commutation are compensated for in a d-c generator.

The commutation problem is usually solved by the addition of two small poles called "interpoles" in the no-load neutral plane. The armature current is passed through the interpole windings to produce a flux exactly equal to the armature field but opposite in direction. This technique assures that the neutral plane remains fixed and that commutation always occurs in the neutral plane regardless of load.

The distorted flux near the air gap between pole tips and rotor may be corrected, if desired, by the addition of "compensating windings" connected in series with the armature windings. The compensating windings develop a flux which opposes the armature flux in the air gap. This compensating flux varies with load in the same manner as the armature reaction. Thus, the field flux in the air gap remains uniform regardless of load. However, compensating windings add to the cost of a generator and are not usually employed.

4. What is meant by compounding in a d-c generator?

Compound generators employ a series field winding in addition to the shunt field winding. The series field coils are made of a relatively small number of turns of large copper conductor, either circular or rectangular in cross section, and are connected in series with the armature circuit. These coils contribute a magnetic field that influences the main field flux of the generator.

5. Explain the concept of degree of compounding in a cumulatively compounded d-c generator.

If the ampere-turns of the series field act in the same direction as those of the shunt field, the combined magnetic field is equal to the sum of the series and shunt field components. If load is added to a compound generator, armature current and thus series field circuit current increases. The effect of the additive series field is to increase field flux with increasing load. The extent of the increased field flux depends on the degree of saturation of the field iron as determined by the shunt field current. Thus, the terminal voltage of the generator may increase or decrease with load depending upon the influence of the series field coils. This influence is referred to as the degree of compounding. A **flat-compounded** generator is one in which the no-load and full-load voltages have the same value. An **under-compounded** generator is one in which the full-load voltage is less than the no-load value. An **over-compounded** generator is one in which the full-load voltage is higher than the no-load value. The way the terminal voltage changes with increasing load depends upon the degree of compounding.

A-C Generators

1. Describe the construction and operation of a simple a-c synchronous generator.

The field winding is on the rotor and the armature winding on the stator. The rotating field winding is excited by direct current supplied through slip rings and brushes. The effect of the rotating field is the same as if a bar magnet was connected to the generator shaft. Rotating the field past the stationary armature winding causes a voltage to be induced in the armature. One complete cycle is generated for each revolution of the two-pole rotor.

2. **How fast should a 6-pole synchronous generator be rotated to provide an output frequency of 60 Hz?**

$$f = \frac{P\,N}{120}$$

$$N = \frac{120\,f}{P} = \frac{120(60)}{6} = 1200 \text{ rpm.}$$

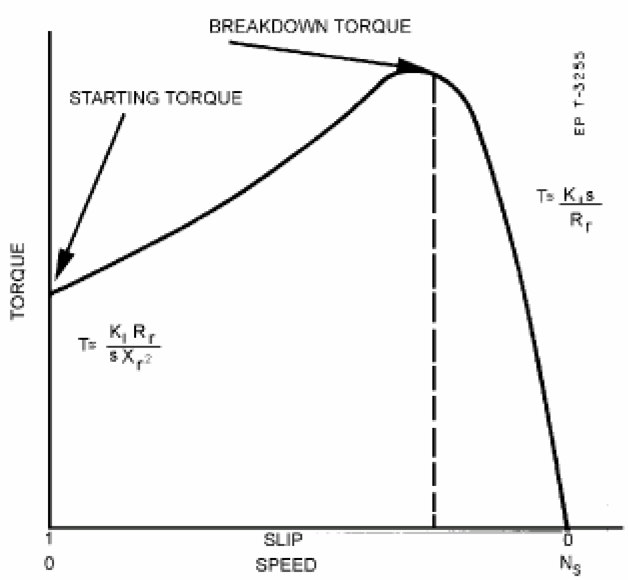
3. **List the requirements for paralleling a-c generators.**

Terminal voltages must be equal in magnitude.
Terminal voltages must be in phase with each other.
Terminal voltages must have the same frequency.
Both generators must have the same phase sequence.

<u>Section 1.5 – "Motors"</u>

<u>Induction Motors and Synchronous Motors</u>

1. **Draw the torque-speed characteristic curve for an induction motor. Label the horizontal axis with two physical quantities and give two names for the maximum torque the motor can produce. Describe the normal operating region for this motor.**



The maximum torque is called the "breakdown torque" or the "pull-out torque." The induction motor is normally operated to the right of the breakdown torque with slip values in the range of 3 to 10 percent.

2. **Describe the operation of a synchronous motor. Include construction and how the motor is started.**

A synchronous motor is the same in construction as a three-phase generator. An a-c current supplied to the stator winding of a synchronous motor produces a rotating magnetic field the same as in an induction motor. A direct current is supplied to the rotor winding, thus producing a fixed polarity at each pole. If it could be assumed that the rotor had inertia and that no load of any kind were applied, then the rotor would revolve in step with the revolving field immediately upon application of power to both windings. This, however, is not the case; the rotor has inertia and, in addition, there is a load. A synchronous motor has to be brought up to synchronous speed by special means [by including a squirrel-cage or “damper” winding in the rotor pole heads]. If the stator and rotor windings are energized, then as the poles of the rotating magnetic field approach rotor poles of opposite polarity, the attracting force tends to turn the rotor in the direction opposite to that of the rotating field. As the rotor starts in this direction, the rotating-field poles are leaving the rotor poles, and this tends to pull the rotor poles in the same direction as the rotating field. However, the rotor does not reach synchronous speed immediately because of its inertia: the rotating field passes it up and the rotor is again pulled in the reverse direction. Thus, the rotating field tends to pull the rotor poles first in one direction and then in the other, with the result that the average starting torque is zero.