Experiment 5 —

Generation of AC Power

Objectives

To generate AC power and control the frequency and the voltage generated.
Specifically, the objectives are to experimentally:
1. Understand the operation of a synchronous generator
2. Understand the phase relationships between the generated voltages in the various armature windings.
3. Understand the factors that affects the generated voltage
4. Obtain the magnetization characteristics (no-load) of an alternator.

Prelab

Read this experiment to the end. Review starting of DC motors. Determine if the rheostat for the DC machine field circuit should be turned to the minimum resistance or maximum resistance when starting the motor.

Theory

1. Construction of the synchronous machine

A cross section of an alternator is shown below.

![Diagram of an alternator](image)

Fig 1. A cross section of a four salient pole alternator (1)

The synchronous machine (alternator) consists of two main parts:
a- Stator, which carries the three phase winding,
b- Rotor, with one DC winding or permanent magnets, the excitation winding is generally supplied with DC through slip rings.
There must be also a source of mechanical energy (prime mover) and a source of excitation (usually an exciter).

The armature windings are placed (not shown) in the slots (shown) at the inner surface of the stator. When the prime mover rotates the rotor,

The alternator that you will be using is especially designed to give you better insight on the phasor relations and three-phase power. The machine is equipped with six similar armature windings equally spaced around the periphery of the armature.

2. Operation

The prime mover (the DC motor in this experiment) is coupled to the shaft of the alternator. When the prime mover rotates the shaft of the alternator, the magnetic flux of the rotor that is linking the armature will be changing. The change of the flux generates an emf in the armature windings according to Faraday’s Law. The voltage generated depends on this flux and, therefore, on the field current. The prime mover imparts mechanical power to the alternator.

If the number of poles is P, then the frequency of the generated voltages in the stator depends on the speed:

\[ N(\text{rpm}) = \frac{120f}{P} \]

Thus, the frequency of the machine is influenced by the rotational speed of the prime mover (the DC machine in this case), while the voltage magnitude is influenced by the excitation current, according to:

\[ E_{\text{rms}} = 4.44f \times \text{(number of turns)} \times \varphi_{\text{pole}} \]

The stator currents produce a rotating magnetic field in the air-gap. A constant torque can be produced only if the stator field and the DC excited rotor field rotate synchronously.

The equivalent circuit of one phase of an alternator is shown

![Equivalent circuit per phase](image)

Fig. 2. Equivalent circuit per phase (2)
Procedure

Important Note: Always make certain that there is field current flowing in the DC machine before pushing the starter button. Also be sure to turn the field rheostat all the way one direction to the starting position. Ask the instructor if you’re not certain which position this is

1. Read the name plate data of the DC machine and the alternator and record these data.
2. Connect the supply to the DC motor through a circuit breaker. The relative position of the various modules and machines terminals on the bench is shown below (A refers to the armature, F to the shunt field, and S to the series field):

   DC Field Rheostat       Supply       DC Machine       AC Machine
   DC Starter             Circuit Breakers    AC Field Rheostat

3- Ask the instructor to check the circuit.
4- Run the DC machine and familiarize yourself with speed control using the field current. Note the range of speed you can obtain using this method and record the corresponding field currents. **Make certain the field current stays within the rating on the nameplate.**
5- With the AC field not energized, measure and record the generated voltage across each of the AC machine armature winding.
6- Connect an analog DC Ammeter in the field circuit of the alternator.
7- Ask the instructor to check the circuit and then record the possible range of the field current in the AC machine.
8- With the AC field current at minimum, start the DC machine.
9- Measure the generated voltages across the armature windings of the AC machine.
10- Observe the phase difference between those voltages. Determine the number of poles in your machine, from the generated electrical frequency and the rpm speed of the prime mover. Compare it with the nameplate data.
11- Keeping the field current of the AC machine constant, vary the speed and record the generated voltage.
12- Switch off the DC machine and then connect the windings of the AC machine to obtain a 3-phase Y-connected supply.
13- Start the DC machine as before. Vary the field current of the alternator and measure the line to neutral generated voltage, record this voltage and the corresponding field current for enough values to plot the no-load characteristic of this generator. These data are needed to plot the no-load characteristic.
14- Turn the machine off and add a three-phase resistive load box. Arrange to measure the load current. Start the DC machine as before and vary its speed to drive the generator at its rated speed. Choose a value of the field current that is somewhere in the middle of the range. Measure the output voltage as a function of the load. If you have insufficient load capabilities in one load cart you may try paralleling two. Take enough data to plot the output voltage as a function of the resistive load.
15- Repeat Step 14 but with a three-phase variable capacitive load. Take enough data to plot $V_{out}$ as a function of the capacitive load.
16- If possible repeat step 14 with a three-phase inductive load (IMs, Transformer…?)

Report
Your report should include a detailed circuit diagrams.

In addition to reporting on the data you obtained, and creating the plots of the no-load and loaded characteristics ($V_{out} \text{ vs } I_{out}$), answer the following questions:

0- Plot the loaded characteristics for both resistive and capacitive load on one graph if possible. Can you explain the difference in the curves for resistive and capacitive loads?
1- When starting the DC motor, should the DC field rheostat be maximum or minimum.
2- If there is a starting rheostat in the armature circuit of the DC machine, should it be all-in or all-out.
3- Does the alternator you used have a round rotor (cylindrical) or salient-pole rotor?
4- What factors affects the decision to design a machine with salient or round rotor?
5- If the voltage induced in the first stator winding is: $v_1(t) = 50\cos(\omega t)$, write the equations of the voltages of the other five windings.
6- Represent the voltages of the previous question in a phasor diagram.
7- Each winding can be thought of as a voltage source as shown:

How would you connect these sources to obtain a 3-phase, Y-connected source.
8- Use Matlab to obtain a smooth $V = f(\text{If})$.
9- Plot $E$ as a function of $\text{If}$ with constant speed. This is the no-load characteristics. Explain the shape of this characteristics.

Bibliography

1- [http://cnx.org/content/m30028/latest/](http://cnx.org/content/m30028/latest/), licensed by NGUYEN Phuc under a Creative Commons Attribution License (CC-BY 3.0)
2- “Power System Analysis,” by Saadat (permission requested).