Electrical Equipment - Course 230.2

GENERATORS: PART 1

ELECTRICAL AND MAGNETIC EFFECTS

1.0 OBJECTIVE

The student must be able to:

1. Explain the factors which determine and limit the output voltage, of a generator on no load.
2. Explain the operation of a generator when it is loaded onto an isolated 1.0 pf load.

2.0 INTRODUCTION

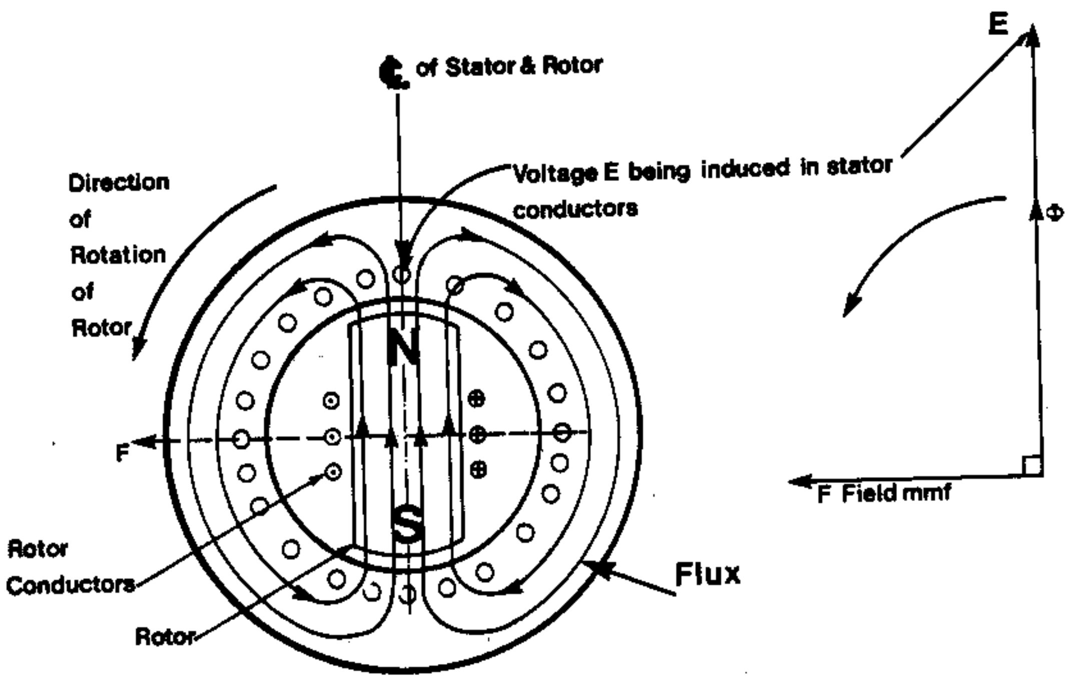
This lesson explains how a generator output behaves when it is off load and when it is loaded onto an isolated 1.0 pf load. An isolated 1.0 pf load is purely resistive and occurs when resistive components, (lamps, heaters, stoves) are supplied from an ac generator.

3.0 GENERATOR OFF LOAD

3.1 How the Voltage is Produced

Figure 1(a) shows an endview of a generator. When a current is passed through the rotor conductors, a magnetic flux Φ is produced by the rotor. This flux crosses the gap between the rotor and stator and passes around the stator iron as shown in Figure 1(a). When the flux is rotated, it cuts the conductors and induces a voltage E in the conductors.

Figure 1(b) shows the relationships between rotor current and turns (mmf, F), flux Φ, rotation and induced emf E.



(a) Induced off load emf E, field mmf F, flux Φ, and rotation.

(b) Relationships between:
- induced emf E
- flux Φ
- mmf F.

Figure 1: Diagrams Showing How a Generator Produces a a Voltage.

The magnitude of the **instantaneous** voltage 'e' induced in a generator is:

$$e = N \frac{d\Phi}{dt}$$

where e is the **instantaneous** value of induced voltage.

N is the number of turns.

$\frac{d\Phi}{dt}$ is the rate of change of flux.

However, the more convenient form of the above formula gives the voltage E in RMS values:

$$E = 4.44\ N\Phi_m f$$

ie, $E \propto N\ _m f$

where E is the RMS value of induced voltage.

N is the number of turns.

Φ_m is the maximum value of flux. (Φ is called "phi").

f is the frequency of the output voltage in hertz.

The formula $E \propto N\Phi_m f$, shows that the magnitude of the induced voltage is proportional to the number of turns, the strength of the flux and speed or frequency. The number of turns in a generator is fixed and the speed is usually fixed so the only way of varying the voltage is to vary the flux Φ_m. This is done by varying the excitation, ie, the field current I_f.

3.2 Factors Limiting the Output Voltage

For a given generator operating at its rated speed the voltage output is limited by:

(a) Insulation considerations. The insulation is designed to operate at its rated voltage. Operating the insulation above its rated voltage may shorten its life and in the worst case may cause it to fail.

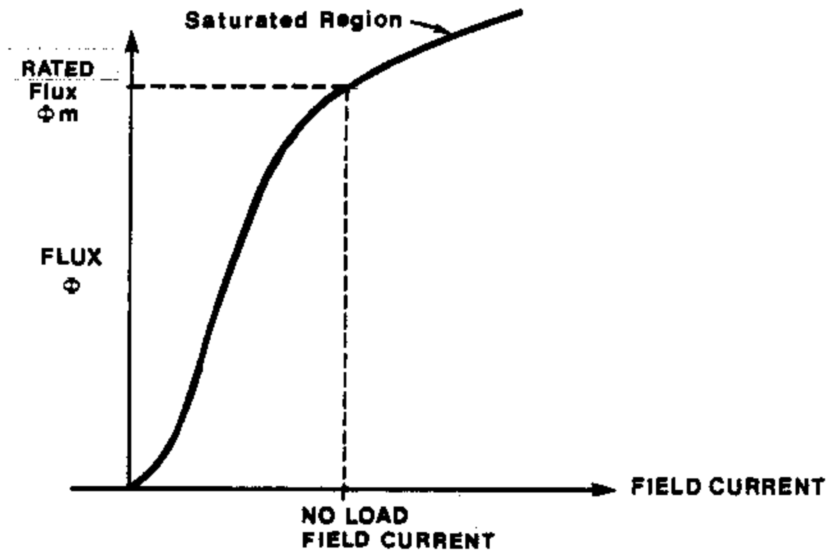


Figure 2: Diagram showing the relationship between generator flux Φ and field current I_f at rated speed.

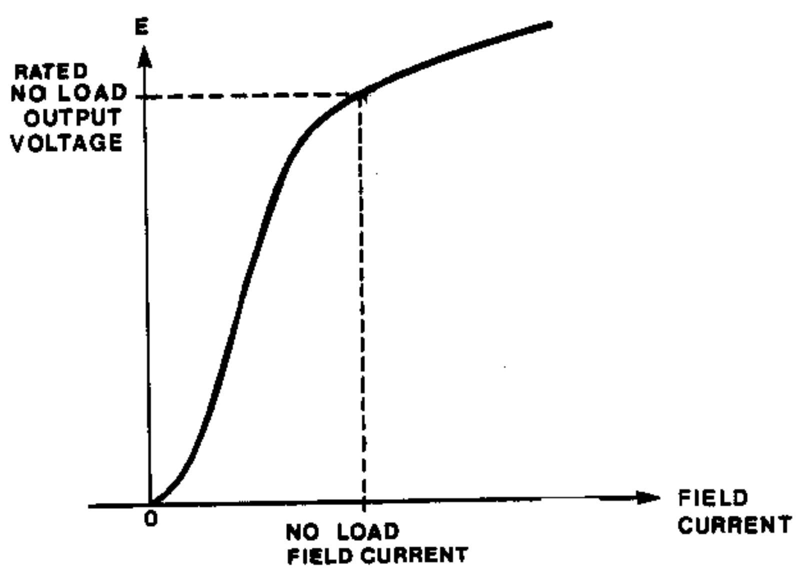


Figure 3: Diagram showing the relationship between generator no load output voltage E and rotor current I_f at rated speed.

(b) Magnetic considerations. Figure 2 shows the *relationship between field current and flux* and Figure 3 shows the relationship between field current and induced voltage E. Note how iron saturation limits the amount of flux and hence the value of voltage that can be produced. If the generator is operated with the iron in a saturated condition, a very large rotor current is required (which produces excess rotor *conductor heating*). Excessive heating also occurs in stator iron due to eddy currents and hysterisis within the iron. Lesson 230.25-7 explains this problem in more detail.

4. GENERATOR ON LOAD

4.1 Fluxes, Voltages and Currents

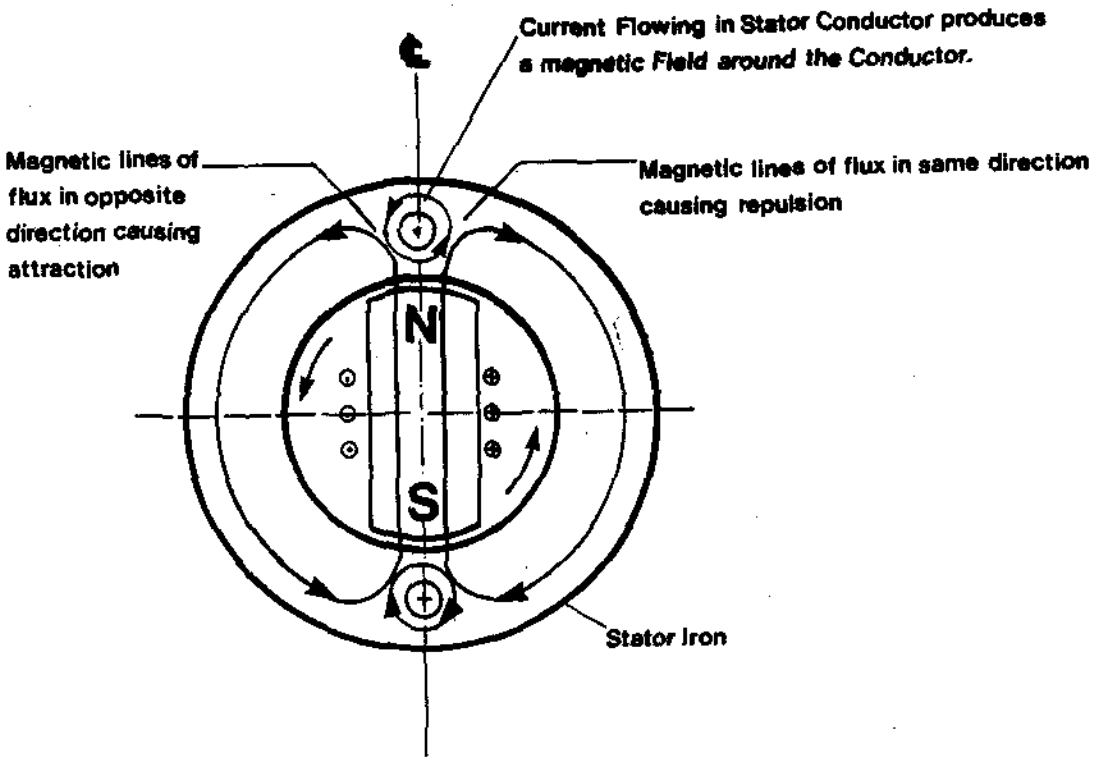


Figure 4: Diagram showing how current flowing in a stator conductor affects the magnetic fields in a generator.

When a load is connected to the generator terminals, the same current flows in the load and in the stator conductors. Figure 4 shows the effects that are produced. The load current in each stator conductor produces a magnetic flux which surrounds each conductor. This flux interacts with the flux produced by the rotor and produces two effects:

(a) Repulsion or **opposition to rotor turning counterclockwise** when the fluxes flow in the **same direction.**

(b) Attraction or **oppositon to rotor turning counterclockwise** where the fluxes flow in **different directions.**

Examination of Figure 4 shows that both these forces produce opposition to the rotor being turned and consequently a torque is required to drive the generator. This torque is supplied by the turbine.

Figure 5(a) shows the fluxes in a generator on full load, 1.0 pf, ie, a purely resistive load. The load current in each of the stator conductors produces a magnetic field which surrounds each conductor. These individual magnetic fields, when combined produce a magnetic field Φ_A. This magnetic field Φ_A interacts and distorts the field Φ_F produced by the rotor. This distortion **effect is called armature reaction.** With 1.0 pf loads, the flux Φ_A weakens the rotor field Φ_F and produces the resultant flux Φ_R. It is this resultant flux Φ_R which produces the terminal voltage V_T. Consequently, as the generator loading is increased, the field current has to be increased to keep output voltage V_T constant.

Figure 3(a) shows that with the generator off load and at an instant in time, the rotor and stator centre lines are coincident. When the generator is loaded, torque is applied by the turbine. This torque stretches the magnetic lines of force coupling the rotor to the stator, seeFigure 5(a). The magnetic centre line of the rotor **will now** lead the stator magnetic centre line by an angle. This angle is known as the **load** angle, δ (delta). The stator and rotor magnetic fields will continue to rotate at the same speed, ie, they will remain in synchronism but will be displaced by the load angle δ. It follows that increasing load increases the stretching effect and hence the load angle. A generator, when on full load typically operates with a load angle of 20-30°. The significance of this load angle is covered in subsequent lessons.

Note the following on Figures 5(a) and 5(b):

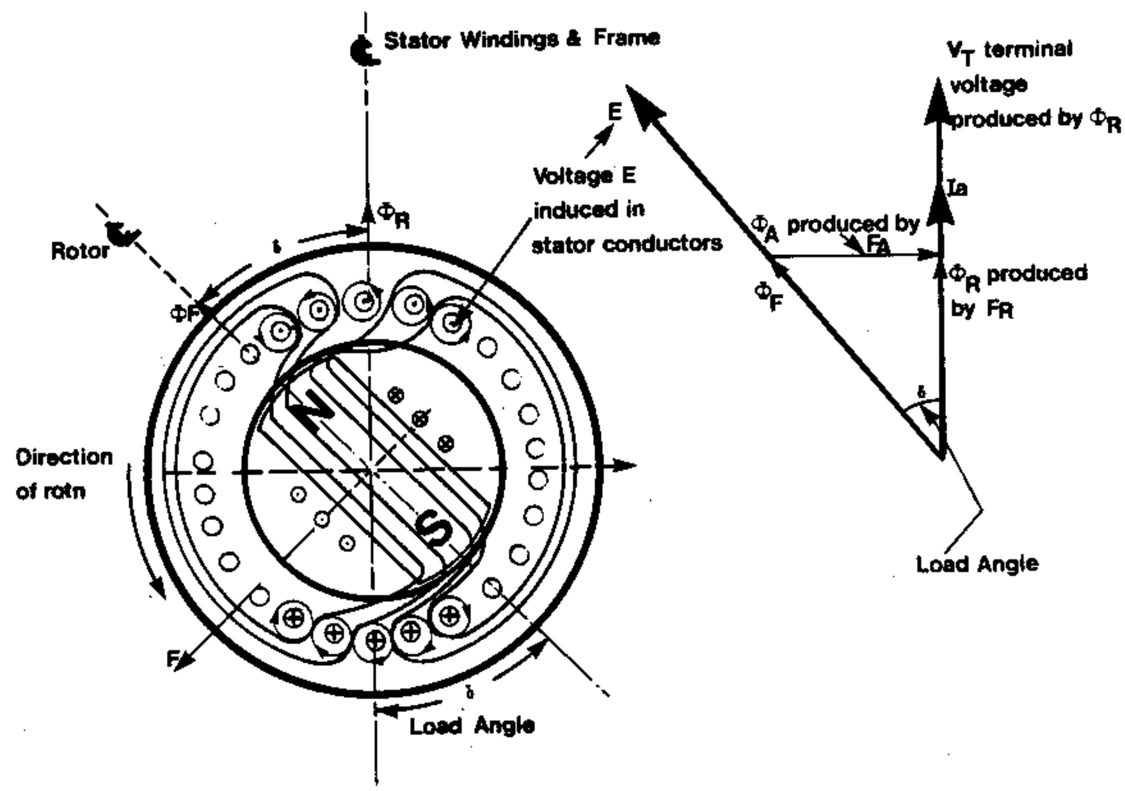
(a) The rotor produces a flux Φ_F.

(b) The armature reaction produces a flux Φ_A.

(c) The combination of the fluxes Φ_F and Φ_A gives the resultant flux Φ_R.

(d) The flux Φ_F causes a voltage E to be **induced** in the generator.

(e) The resultant flux Φ_R causes a voltage V_T to be **produced** at the generator terminals.



(a) Diagram showing the fluxes in a generator on full load, 1.0 pf. Note how the fluxes produced by the load current distorts the fluxes produced by the field and cause the generator load angle δ.

(b) Relationships between
- fluxes Φ_F, Φ_A, Φ_R
- E, V_T, I_a
- load angle δ

Figure 5(a) & (b): Diagrams showing generator fluxes, voltages and current for a generator on full load, 1.0 pf.

ASSIGNMENT

1. A generator is being rotated at its rated speeds and is off load. Explain the two factors which limit the output voltage.

2. Draw and label a diagram showing the rotor current, the flux and the output voltage for a generator which is off load.

3. Explain, using labelled diagrams, how a loaded generator produces:

   (a) a voltage.
   (b) a current.
   (c) a torque.
   (d) a load angle.

4. Explain why, as a generator is loaded, the field current has to be increased to keep the terminal voltage constant.

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