

# EDEXCEL NATIONAL CERTIFICATE/DIPLOMA

## UNIT 67 - FURTHER ELECTRICAL PRINCIPLES

### NQF LEVEL 3

#### OUTCOME 1

#### TUTORIAL 2 - DIRECT CURRENT GENERATORS

##### **Unit content**

**1 Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator**

**Direct current (DC) circuit theorems:** Thévenin's theorem e.g. application of theorem to a parallel circuit having two sources of electromotive force (EMF) and three resistors; Norton's theorem e.g. application of theorem to a parallel circuit having two sources of EMF and three resistors; maximum power transfer theorem e.g. application of theorem to a series circuit with a source of EMF, internal resistance and a load resistor; application to a more complex circuit where Thévenin needs to be applied first

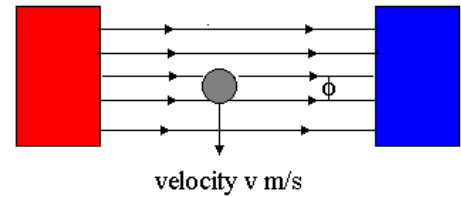
**Direct current (DC) motor:** type e.g. shunt, series, compound; construction e.g. windings, motor starter circuits, speed control (series resistance in the armature circuit); characteristics e.g. EMF generated, torque, back EMF, speed and power, efficiency

**Direct current (DC) generator:** type e.g. separately-excited, shunt, series compound; construction e.g. main frame or yolk, commutator, brushes, pole pieces, armature, field windings; characteristics e.g. generated voltage/field current (open circuit characteristics), terminal voltage/load current (load characteristic),  $V = E - I_a R_a$

You should have studied the basic principles of generators in the basic principles module.

## THE GENERATOR PRINCIPLE

Let's start by revising the basic principle. Consider a conductor crossing a flux as shown. As it moves a voltage is generated in it. If current is produced then the voltage will be reduced slightly by the resistance of the conductor. The ELECTRO MOTIVE FORCE or E.M.F. is the theoretical voltage as though the conductor had no resistance and this is denoted with the symbol  $e$ . Note that  $e$  is used for e.m.f. when the values are instantaneous and changing.  $E$  is used for a constant value.



The E.M.F. is directly proportional to the flux density  $B$ , the velocity  $v$  and the length of the conductor within the flux  $l$ . It follows that the e.m.f. is given by:

$$e = B l v$$

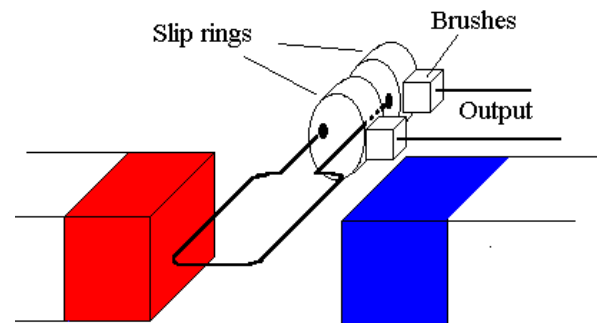
$B = \phi/A$  (tesla).  $\phi$  is the magnetic flux (Weber).  $A$  is the cross sectional area of the flux path (metres squared).

## CONSTRUCTION OF A SIMPLE GENERATOR

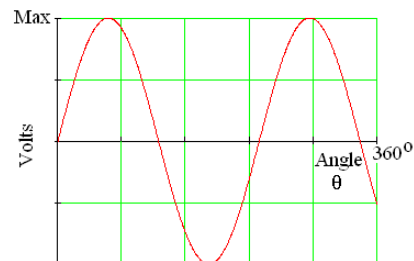
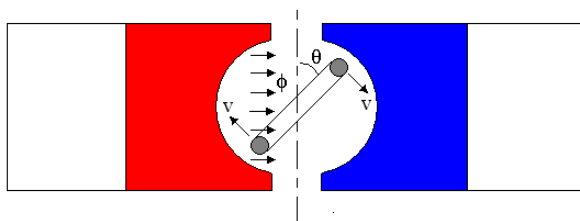
A simple generator may be produced by rotating a simple loop of conducting wire in magnetic field as shown. In the position shown one side of the loop is moving up and the other down cutting the flux at a right angle. A voltage is generated across the end of the loop. The current flowing from the terminals is governed by the resistance connected between them (e.g. the resistance of a light bulb). Two slip rings and brushes are needed to connect the loop to the external circuit. At any other position of the loop the conductors cut the flux at an angle. The voltage generated is directly proportional to the angle of the loop to the flux ' $\theta$ '. The output voltage is hence sinusoidal and alternating and given by the formula

$$V = V_{\max} \sin \theta$$

$V_{\max}$  is the maximum voltage and  $\theta$  is the angle of rotation.

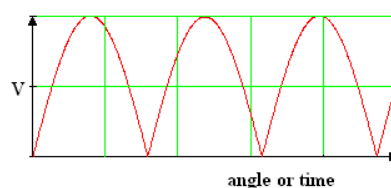
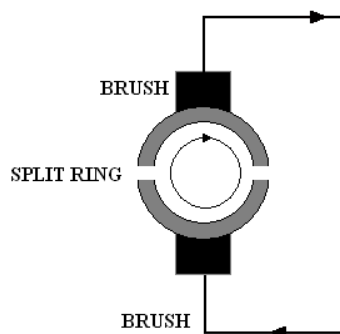


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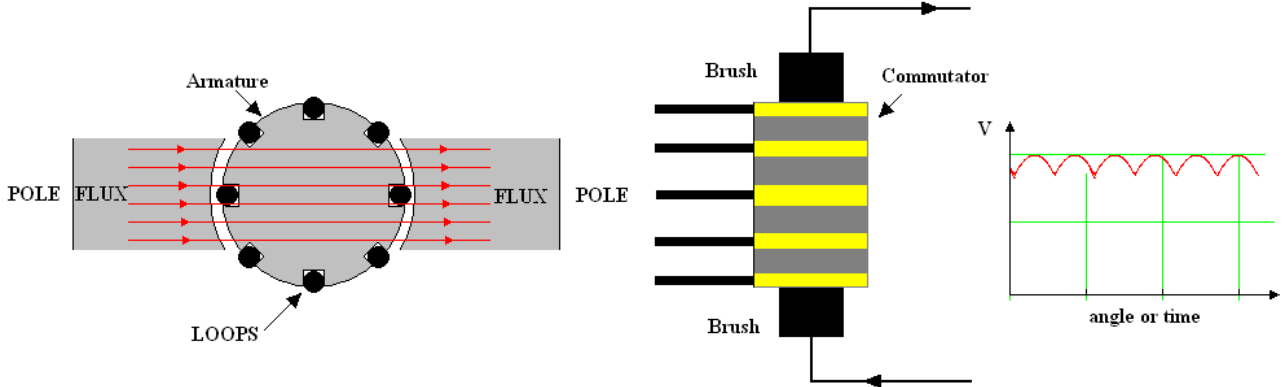


## D.C. GENERATION

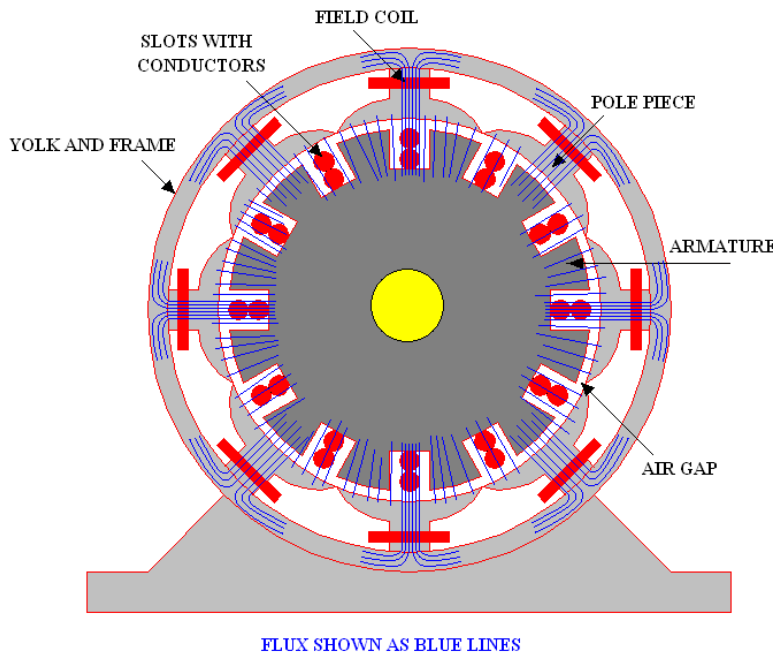
If the loop is connected to a split ring as shown, the polarity at the brushes is reversed every half revolution and the output is a series of half sinusoidal waves.



If many loops are used, the rotor becomes an armature. The split ring becomes a commutator. Each loop is connected to a segment of a commutator. The output from the brushes will be a series of peaks from successive loops and the output is a direct current with a ripple.



The single loops illustrated may be replaced by more complex arrangements of conductors in slots connected to the segments of the commutator.



CROSS SECTION THROUGH TYPICAL GENERATOR AND A TYPICAL SMALL ARMATURE.

The diagram shows the construction and main parts of a d.c. generator. The yolk and frame form the body. End caps have bearings in them to support the rotor shaft. In most cases the armature contains the slots and conductors. The poles produce the flux and this could be from permanent magnets but much more likely that they have field coils to produce the flux. The yolk carries the pole pieces and the field coils. There are many types of construction and it is quite possible for the yolk to contain the conductors and the armature the poles which may be permanent magnets or have field coils.

### **POWER LOSS**

There are four internal losses that contribute to lower efficiency of a DC generator. - Copper losses - Eddy-current losses - Hysteresis losses - Mechanical losses. The pole pieces and the armature are constructed from laminated steel sheets to reduce energy loss through the generation of eddy currents in the iron.

## THEORY SECTION

In theory the e.m.f. generated is  $e = B \ell v$

Consider the simplified diagram right. Each length of the coil lies in a slot of length  $\ell'$ . For each loop there must be two slots.

The number of lengths in each slot is  $s$

In the simplified diagram  $s = 1$  for 1 loop and  $s = 2$  for 2 loops and so on.

The flux only cuts the length  $\ell'$  so we do not consider the rest of the loop in the derivation.

The total length of the conductors in the flux is  $\ell' s$  - per slot

Next we suppose that the entire circumference of the rotor is covered in slots all cutting the flux. If the total number of slots is  $n$  then the total length cutting the flux is  $\ell' s n$

$Z$  is the number of conductors connected in series cutting the flux at any instant.  $Z = sn$  for the arrangement so far described.

Total length =  $\ell' Z$

Suppose that more than one set of loops is placed in each slot and they are connected in parallel. Let this number be  $c$ .

Note that the emf is not changed by having more loops in parallel.

Since  $s$  is the total number of conductors in the slot the number in each loop is  $s/c$

The total length per loop is then  $\ell = \ell' Z/c$  and this the length to be used to calculate the emf.

If the number of pole pairs is denoted  $P$  then each pole has a circumferential length of  $\pi D/2P$ . This is called the pole pitch and denoted  $p$ . If the diameter of the rotor is  $D$  then  $p = \pi D/2P$

The cross sectional area of the flux at each pole is  $A = \pi D \ell'/2P = p \ell'$

The flux density is  $B = \phi/A = \phi/p \ell'$

$N$  = speed in rev/min and  $D$  = mean diameter of the path of the conductor.

$v$  = velocity of the conductor = circumference x speed =  $\pi DN/60$

$$e = B \ell v = \frac{\phi}{A} \times \frac{\ell' Z}{c} \times \frac{\pi DN}{60}$$

$p = \pi D/2P$  so  $\pi D = 2Pp$  and  $A = p \ell'$

$$e = \frac{\phi}{p \ell'} \times \frac{\ell' Z}{c} \times \frac{2pPN}{60} = \frac{\phi Z}{c} \times \frac{2PN}{60}$$

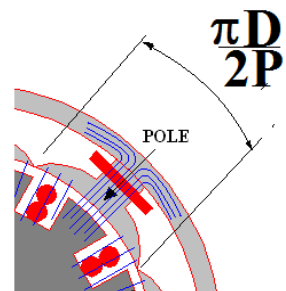
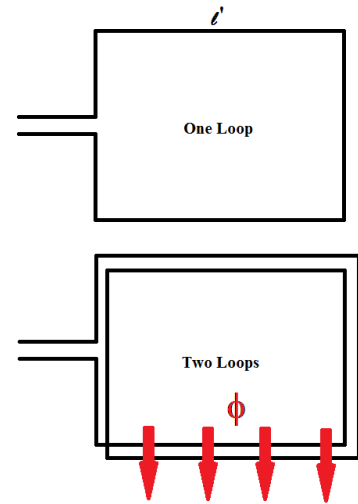
The total emf is usually shown as  $E$ :

$$E = \frac{2\phi ZPN}{60c}$$

The loops or coils placed in the slots is either wave or lap formation (not described here). For wave winding there are 2 parallel conductors in each slot so  $c = 2$ . For lap winding there  $c = 2p$

$$E = \frac{ZPN\phi}{60} \text{ for wave winding.} \quad E = \frac{ZPN\phi}{60p} \text{ for lap winding.}$$

For both, the only variables for a given generator are the speed  $N$  and the flux  $\phi$ . We could say  $E = k N \phi$



### **WORKED EXAMPLE No. 1**

A d.c. generator has 8 poles and the armature is wave wound. There are 48 slots in the armature with 6 conductors in each slot. The flux per pole is 0.02Wb. Calculate the e.m.f. produced at 300 rev/min.

### **SOLUTION**

$$Z = 6 \times 48 = 288 \qquad P = 4 \qquad E = \frac{Z P N \phi}{60} = \frac{288 \times 4 \times 300 \times 0.02}{60} = 115.2 \text{ V}$$

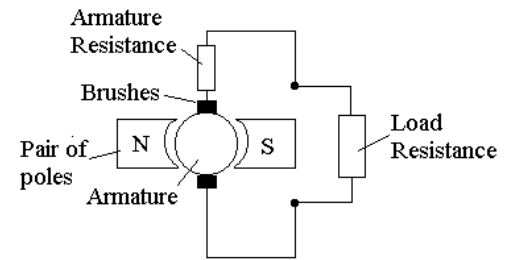
### **SELF ASSESSMENT EXERCISE No.1**

1. A wave wound d.c. generator has 8 poles and it is required to produce an e.m.f. of 260 V at 350 rev/min. The flux per pole is 0.05 Wb and the armature has 120 slots. Calculate the number of conductors required in each slot. (Answer 2 rounded up)
2. A 4 pole d.c. generator with separate excitation gives 410 V when on no load (open terminals) and running at the design speed of 145 rev/min. Calculate the flux per pole if the armature is wave wound with 39 slots each with 16 conductors. (0.044 Wb)

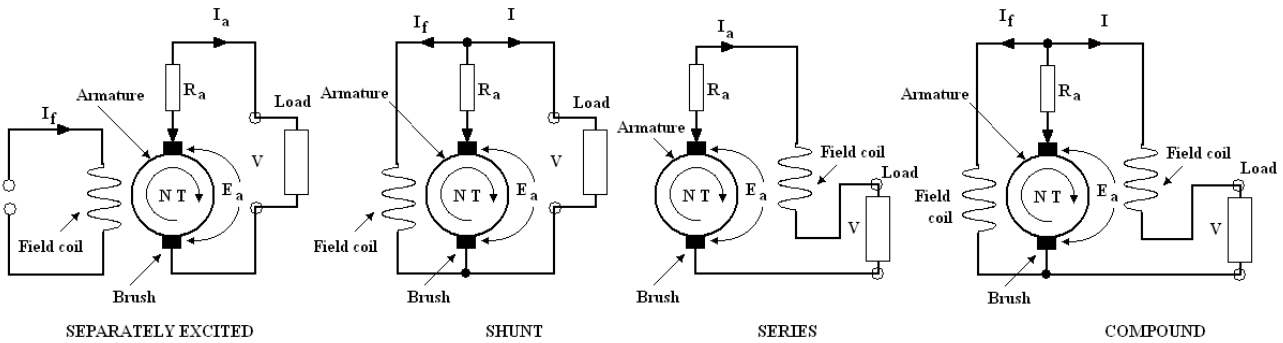
## GENERATOR CONFIGURATIONS

The schematic for a basic dc generator is shown with a load across the terminals. The armature resistance represents the resistance of the loops or coils and the brushes.

The magnetic flux may be created by a permanent magnet but field coils are the normal for large generators. The current to energise the field coils could be supplied by the generator but this means that a certain amount of permanent magnetism would be needed to get the process started; otherwise an external source of electricity would be needed.



There are four ways that the field coils may be arranged as shown in the diagram below.



The e.m.f. produced can be controlled by the current supplied to the field coils. To do this some way of controlling the field current is needed (such as a variable resistance). In the case of the series winding, the current in the field coil is the same as the load current and this implies that the e.m.f will vary with load.

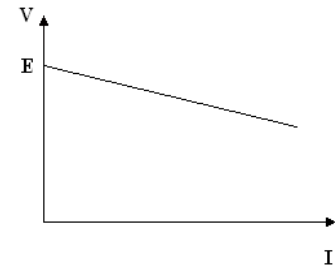
### SEPARATELY EXCITED

If the field current and speed is constant then  $E$  is a constant. The voltage over the load is smaller because of the voltage loss in the armature and brushes so the terminal voltage is:

$$V = E - I_a R_a$$

When  $I = 0$ ,  $E = V$  (the open terminal voltage).

The terminal voltage will fall with load current as shown.



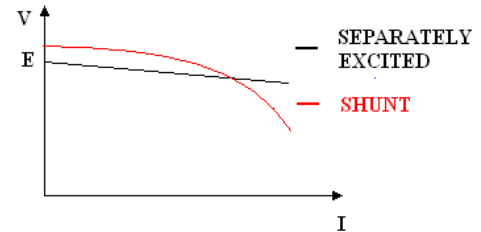
## SHUNT WOUND

The current supplied to field coil governed by the resistance of the field coil  $R_f$ . When the generator is running at constant speed an e.m.f. will be generated and the value depends on the current flowing in the field coil. This can be controlled by placing a variable resistance in series with the field coil.

$$V = E - I_a R_a = E - (I + I_f)R_a$$

At zero load when  $I = 0$ ,  $V = E - I_f R_a$

As load current is drawn,  $V$  will fall so the field current and flux will fall. This results in an even larger fall in  $V$ . The diagram shows how the voltage and current varies compared to the separately excited generator of the same rated capacity.

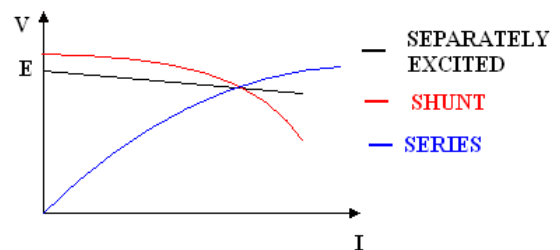


## SERIES WOUND

When the field winding is connected in series the armature current, load and field current are the same.

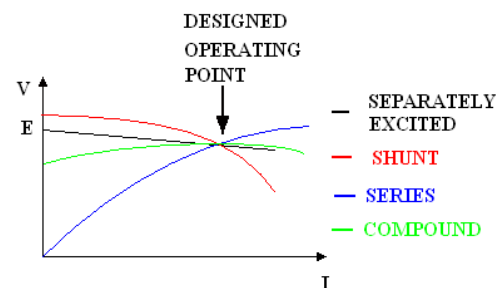
$$V = E - I_a R_a$$

At zero current  $V = E$  but if there is no current the flux is small so  $V$  is small. When the current is large, the flux is large and  $V$  is large. This form of winding is not suitable for most applications where a stable voltage is required.



## COMPOUND WINDING

This involves two sets of field windings, one in series and one in parallel (shunt). The shunt winding can be controlled by a series resistance. When load current increases we see a reduction in the flux from the shunt winding due to the drop in voltage but we get an increase in flux from the series winding. By careful design one can off set the other. The resulting characteristic is closer to a constant voltage. When the flux produced by the field winding at the rated load is just enough to keep the terminal voltage the same as at no load, the machine is said to be level compounded.



## WORKED EXAMPLE No. 2

A d.c. generator with level compound windings has a rated load of 200 A and 440 V. At no load, the shunt current is 4.1 A. The shunt has 1200 turns per pole. The series windings are shorted out and the machine is run full load at the same speed. The current to the shunt is then 5.8 A. Calculate the armature resistance and the number of turns per pole on the series winding for level compounding.

### SOLUTION

The flux produced by is directly proportional to the ampere turns per pole. For a given speed and set of constants it follows that  $E = k (I T)$ .  $I$  = current in the winding and  $T$  the number of turns.

$$\begin{aligned} \text{With no load} \quad V &= E - I_a R_a & I &= I_a = 4.1 \text{ A} & T &= 1200 & V &= 440 \\ 440 &= k(4.1 \times 1200) - 4.1 R_a \\ 440 &= 4920 k - 4.1 R_a \dots\dots\dots(1) \end{aligned}$$

$$\begin{aligned} \text{At full load with the field coils shorted} \quad I &= 5.8 \quad I_a = 205.1 \text{ A} \quad T = 1200 \quad V = 440 \\ V &= E - I_a R_a \\ 440 &= k(5.8 \times 1200) - 205.1 R_a \\ 440 &= 6960 k - 205 R_a \dots\dots\dots(2) \end{aligned}$$

$$(2) - (1) \quad 0 = 2040 k - 209.2 R_a \quad R_a = 9.951 k$$

$$\begin{aligned} \text{Substitute into (1) and} \quad 440 &= 4920 k - 4.1(9.951k) \\ 440 &= 4879.2 k \quad k = 0.0902 \text{ and hence } R_a = 0.897 \Omega \end{aligned}$$

This should be confirmed by substituting into (2)

With the shunt and series coil in use and level compound achieved, the current in the shunt coil will be 4.1 A.  $I = 4.1 \text{ A}$   $I_a = 204.1 \text{ A}$  The ampere turns is unknown.

$$\begin{aligned} V &= E - I_a R_a \\ 440 &= (0.0902)(I T) - 204.1 (0.897) \\ 440 &= (0.0902)(I T) - 183.08 \end{aligned}$$

$$IT = 623.08/0.0902 = 6908 \text{ Ampere turns per pole.}$$

The shunt winding takes  $1200 \times 4.1 = 4920 \text{ AT}$  per pole.

The series winding must provide  $6908 - 4920 = 1988 \text{ AT/pole}$

The number of turns must be  $1988/200 = 9.94$

Note we could have arrived at this answer quickly by just saying :

$$\text{No load ampere turns} = 1200 \times 4.1 = 4920$$

$$\text{Full load ampere turns} = 1200 \times 5.8 = 6960$$

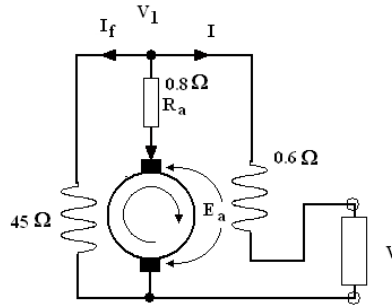
$$\text{The ampere turns to be added by the series winding} = 6960 - 4920 = 2000 \text{ AT}$$

$$\text{No of turns} = 2000/200 = 10$$

### WORKED EXAMPLE No. 3

A dynamo uses compound winding. The armature resistance is  $0.8 \Omega$ , the shunt winding has a resistance of  $45 \Omega$  and the series winding has a resistance of  $0.6 \Omega$ . The machine supplies  $5 \text{ kW}$  at  $250 \text{ V}$ . Calculate the e.m.f. of the armature.

### SOLUTION



$$I = 5000 \text{ W} / 250 \text{ V} = 20 \text{ A}$$

$$\text{The voltage before the field coil} = V_1 = 250 + (20 \times 0.6) = 262 \text{ V}$$

$$I_f = 262 / 45 = 5.822 \text{ A} \quad I_a = 25.822 \text{ A}$$

$$E = 262 + (25.822 \times 0.8) = 282.66 \text{ V}$$

### SELF ASSESSMENT EXERCISE No. 2

1. Describe the construction and purpose of the following parts of a d.c. generator.

Commutator  
Armature  
Yoke  
Pole piece

2. With the aid of suitable circuit sketches, explain the difference between d.c. generators that are:

Shunt wound  
Series wound  
Compound wound

Show with the aid of suitable graphs how the terminal voltage varies with load current for a given running speed.

3. How may the flux per pole be changed in a shunt wound d.c. generator? Why would such control be used?
4. A dynamo uses compound winding. The armature resistance is  $1.2 \Omega$ , the shunt winding has a resistance of  $40 \Omega$  and the series winding has a resistance of  $1 \Omega$ . The machine supplies  $8 \text{ kW}$  at  $400 \text{ V}$ . Calculate the e.m.f. of the armature. ( $456.6 \text{ V}$ )