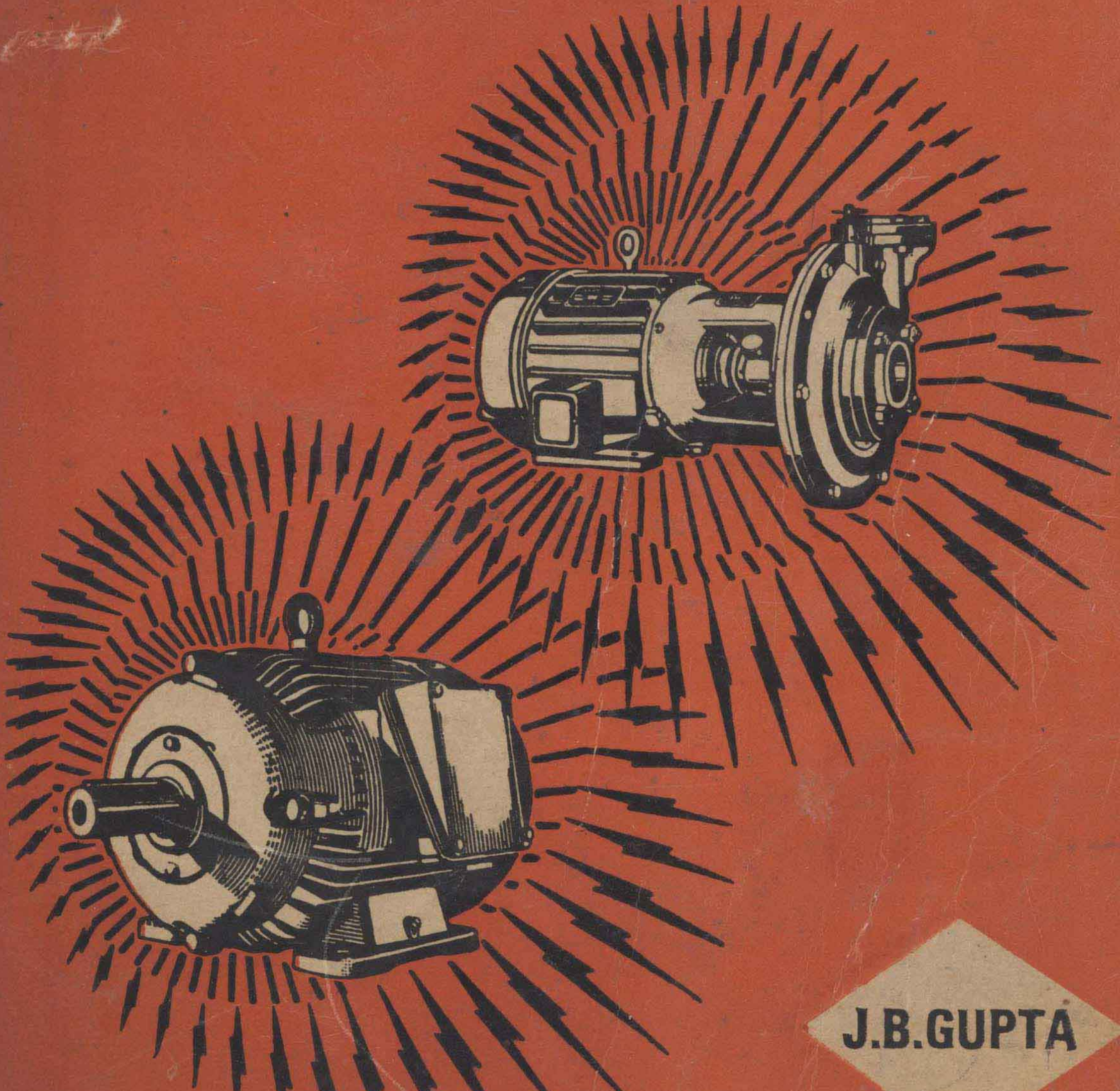
THEORY & PERFORMANCE OF

ELECTRICAL MACHINES



J.B.GUPTA

Theory and Performance of

ELECTRICAL MACHINES

(D.C. Machines, A.C. Machines and Polyphase Circuits)

IN

S.I. UNITS

FOR

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BY

J. B. GUPTA

B.Sc. Elec. Engg. (B.H.U.) ; M.I.E. (India)

Author of : A Course in Electrical Power ; Utilization of Electric Power & Electric Traction ; Electrical Measurements and Measuring Instruments ; Electrical Installation, Estimating and Costing ; Elements of Electrical Engineering ; Electrical Machines.

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PREFACE TO THE SEVENTH EDITION

The author feels great pleasure in presenting the seventh edition of the book with marked improvement on the previous one in several aspects. The book has been revised and enlarged on one side and has been reset in an entirely new and attractive form as per desire of both the teachers and the students on the other side. Almost all the old blocks have been replaced by new ones and innumerable new diagrams have been added to make the subject more illustrative and clear. Worked out examples, exercises and numerical problems have been replaced by latest ones with thorough checked answers. Objective type questions have been added at the end of every chapter to make the readers familiar with the new trend adopted by various examining bodies for setting of examination papers. Mistakes and misprints, as they were noticed, have been corrected.

My sincere thanks are due to my publishers for their sincere labour and efforts in bringing out this seventh edition in very short time.

The author is thankful to the teachers and students, who sent their valuable suggestions for the improvement of the book.

The author is most anxious to receive criticism and suggestions from the readers for further improvement of the book.

2nd. January, 1981

J. B. GUPTA

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1.1. INTRODUCTION

A dynamo is a machine that converts either mechanical energy into electrical energy or electrical energy into mechanical energy. When a dynamo is driven mechanically by a prime mover such as by a diesel engine, steam engine, steam turbine or water turbine and supplies electrical energy, it is called a *generator*. When the dynamo draws electrical energy, from supply mains and drives mechanical devices such as line shafts and machine tools it is called a *motor*. In this chapter dynamos used as generators, although much of what is said concerning generators is equally applicable to motors, are dealt with.

The term "generator" denotes that it generates electrical energy but actually it does not. It simply converts mechanical energy supplied to it into electrical energy. A dynamo may be compared with water force pump to make operation of dynamo more clear.

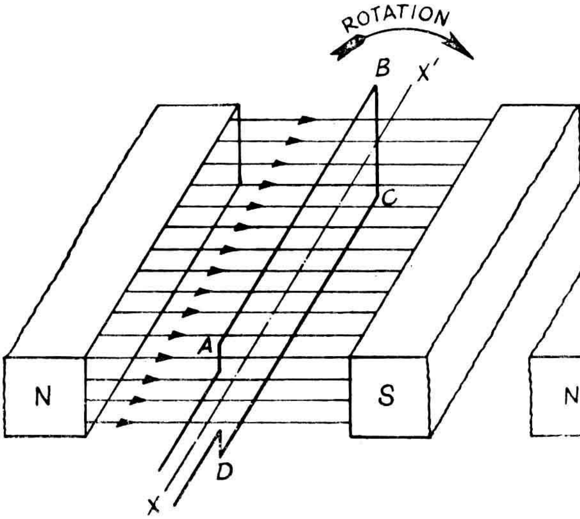
As the force pump does not produce water but causes a mechanical pressure which forces the existing water into an elevated reservoir against the back pressure due to its weight, in the same way the generator does not produce electricity but creates potential difference, which causes the electric current to flow from low pressure terminal to high pressure terminal in the machine and from high pressure terminal to low pressure terminal in the external circuit against the resistance of the circuit.

The generator operates on the principle of the production of dynamically induced e m.f. *i.e.* whenever flux is cut by the conductor, dynamically induced e.m.f. is produced in it according to the laws of electro-magnetic induction, which will cause a flow of current in the conductor if the circuit is closed.

For production of dynamically induced e.m.f., three things are necessary, a magnetic field, a conductor and motion of the conductor with respect to the field. In d.c. generators the field is produced by the field magnets which are stationary. Permanent magnets are used for very small capacity machines and electro-magnets are used for large machines to create magnetic flux. The conductors are situated on the periphery of the armature being rotated by the prime-mover.

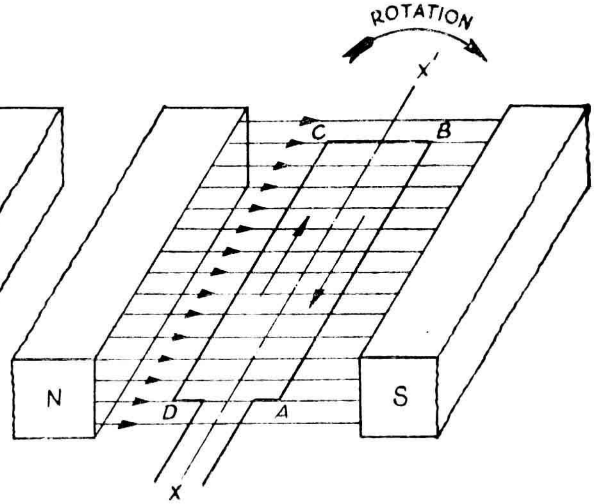
1.2. SIMPLE LOOP GENERATOR

A single turn rectangular copper conductor loop A B C D rotating in clockwise direction about its own axis XX′ in the uniform magnetic field is shown in fig. 1 1. As the coil is rotated in the magnetic field by some mechanical means (not shown in the fig.) the flux linking with the loop changes continually, therefore, an e.m.f. is induced in it. The



Armature Coil in Neutral Plane

Fig. 1.1 (*a*)



Armature Coil in the 90° Position

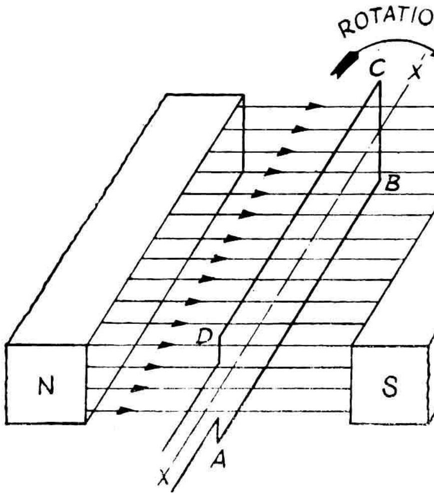
Fig. 1.1 (*b*)

magnitude of e.m.f. induced at any instant is proportional to the rate of change of linking flux at that instant and its direction is given by Fleming's right hand rule.

While rotating at the instant, the loop of wire A B C D assumes the position shown in fig. 1.1 (*a*) *i.e.* when the loop A B C D is just parallel to the faces of field magnets **N** and S, the flux linking with the loop is maximum but the rate of change of linking flux is zero, as at this instant no flux is cut by the coil sides AB and CD which are just moving parallel to them. Hence induced e.m f. is zero when the loop is in this position. This position of the loop is known as *neutral position* and let it be taken starting position and angle of rotation be measured from this position.

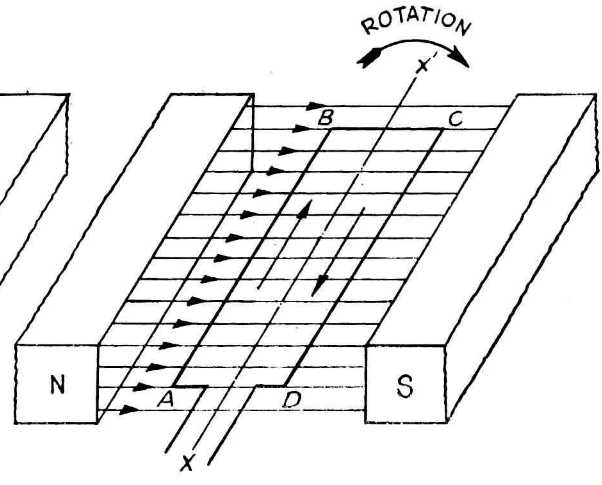
As the coil is turned in clockwise direction at a constant speed, the coil sides begin to cut across the field, slowly at first but at gradually increasing rate. Thus the magnitude of e.m.f. induced gradually increases as the loop moves and becomes maximum when the loop assumes the position shown in fig. 1.1 (*b*). During this period the loop rotates through $\frac{\pi}{2}$ radians or 90° and induced e.m.f. in the loop increases following the sine law, as shown in fig. 1.2. The direction of e.m.f. induced in the coil, as given by Fleming's right hand rule, is from B to A and from D to C. In the position of the loop shown in fig. 1.1 (*b*) the coil sides are moving at right angles to the field and are therefore cutting across the field at maximum rate, consequently, the e.m.f. induced at this instant is of maximum value.

In the next quarter of the revolution of the loop *i.e.* between $\frac{\pi}{2}$ radians and π radians (or 90° to 180°), the rate at which the conductors cut across the magnetic field gradually decreases, causing the magnitude of induced e.m.f. to fall gradually with the angular movement of the loop and becomes zero at the instant, the loop becomes again parallel to the faces of the field magnets but with the sides AB and CD's position interchanged with respect to zero position [fig. 1.1 (*c*)].



Armature Coil in the 180° Position

Fig. 1.1 (*c*)

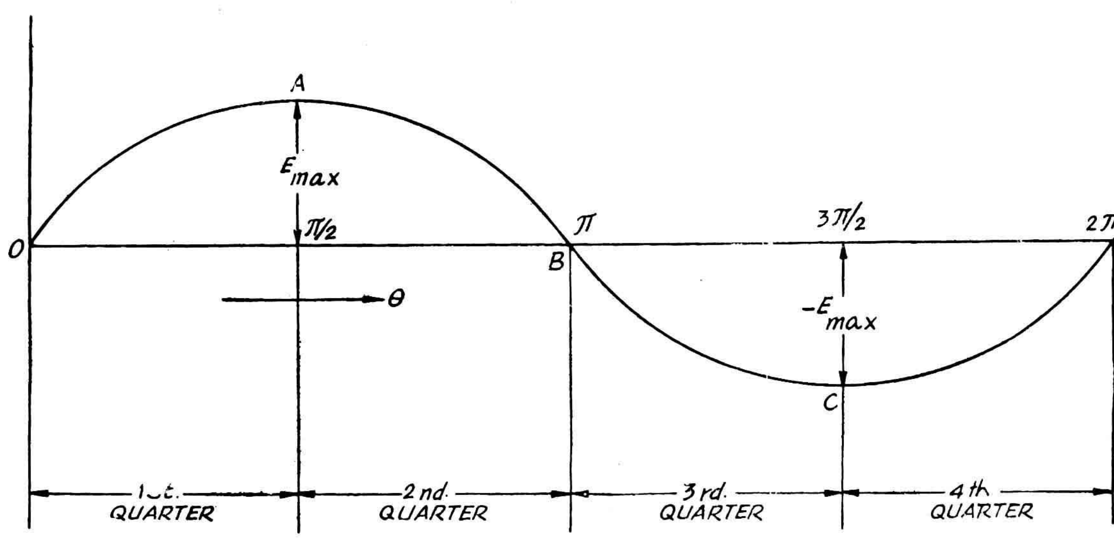


Armature Coil in the 270° Position

Fig. 1.1 (*d*)

In the third quarter of the revolution of loop *i.e.* between π and $\frac{3\pi}{2}$ radians (or 180° to 270°), the rate at which the conductor cut across the magnetic field hence induced e.m.f. gradually increases as the loop moves and become maximum at the instant, the loop assumes the position shown in fig. 1.1 (*d*). However, the direction of e.m.f. in the loop is now from A to B and from C to D *i.e.* opposite to that in the first two quarters.

In the fourth quarter of the revolution of the loop *i.e.* between $\frac{3\pi}{2}$ and 2π radians (or



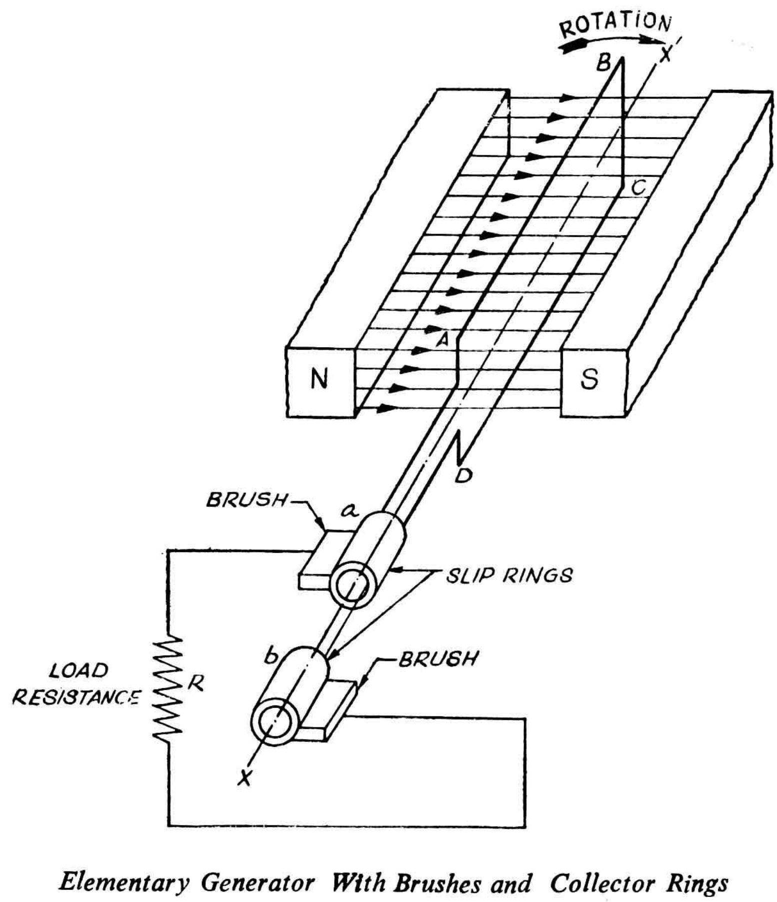
Curve Showing Variation of Induced E.M F. in a Coil Rotated in a Uniform Magnetic Field

Fig. 1.2

270° to 360°), the induced e.m.f. decreases as the coil moves and becomes zero, when it completes 2π radians or 360° from the starting instant. At this instant the loop comes to its absolute original position and hence the loop is said to have completed one cycle. The cycle then repeats for each revolution of the armature.

The e.m.f. thus generated in the loop is of the form shown in fig. 1.2 from which it is obvious that e.m.f. induced in armature conductors is of pulsating nature. Such an e.m.f. is known as an *alternating e.m.f.*

The current induced in the coil is collected and conveyed to the external load circuit by connecting the coil terminals to two continuous and insulated rings, known as *slip rings or collector rings,* mounted on the generator shaft and making the two stationary brushes

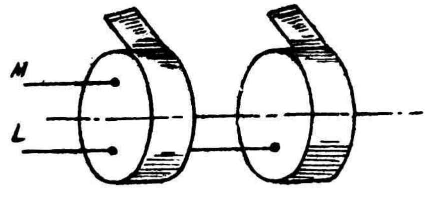


Elementary Generator With Brushes and Collector Rings

Fig. 1.3

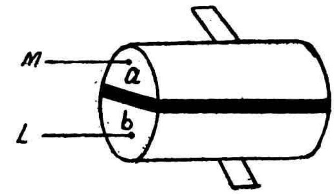
pressing against the slip rings, one brush bearing on each ring, as shown in fig. 1.3. When the coil is rotated, the generated alternating e.m.f. causes a current to flow first in one direction and then in the other through the coil and external circuit. Such a current is called an *alternating current.*

To obtain the uni-directional or direct current in the external circuit, the collecting arrangement is modified, as shown in fig. 1.4. In this arrangement, the slip rings are replaced by split rings made of a conducting material and splitted into two halves separated from each other by insulation and brushes are placed diametrically opposite instead of being side by side.



Slip Rings

Fig. 1.4 (*a*)



Split Ring

Fig. 1.4 (*b*)

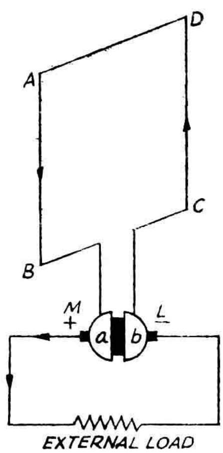


Fig. 1.4 (*c*)

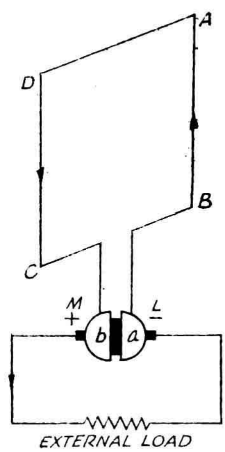


Fig. 1.4 (*d*)

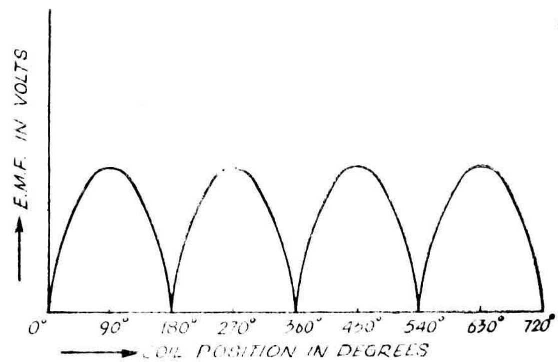
It will be observed that in the first half revolution current flows along ABMLCDA *i.e.* the brush M in contact with segment '*a*' acts as the +ve pole of the supply and brush L in contact with segment '*b*' acts as the —ve pole.

In the next half revolution, the direction of induced currents in the coil is reversed, but at the same time the positions of segments '*a*' and '*b*' are also reversed, with the result that brushes M and L again come in contact with +ve segment '*b*' and —ve segment '*a*' respectively. Thus the direction of current in the external load circuit remains the same.

The position of the brushes shall be so arranged that the change of segments from one segment to the other takes place when the plane of the rotating coil is perpendicular to the plane of field, since in this position the induced e.m.f. or induced current in the coil will be zero.

Thus the e.m.f. or current induced in the armature conductors of a d. c. generator is alternating which is rectified by the split-ring known as *commutator*.

Although after rectification the current through the load circuit is always in the same direction, but it is not a steady current, since the e.m.f. generated in the armature coil and applied to the brushes, varies from zero to maximum and back to zero twice each revolution. The variation in brush voltage is shown in fig. 1.5.



E.M.F. Curve of a Simple D.C. Generator
Fig. 1.5

A pulsating direct current such as given by a single coil generator is not suitable for most commercial purposes. However by employing a large number of coils and commutator segments, with the coils evenly distributed around the surface of the armature the brush voltage may be made practically constant.

The voltage generated by a single turn armature coil is small. For this reason, the coils employed in commercial generators consist of several turns in series thereby increasing the magnitude of generated e.m.f. in direct proportion to the number of the turns in the coil.

1.3. CONSTRUCTION OF D.C. MACHINES

D.C. machine (whether a generator or a motor) having 4 poles is shown in fig. 1.6.

In construction the d.c. machine consists of four parts mainly

(*i*) Field magnets (*ii*) Armature (*iii*) Commutator (*iv*) Brush and brush gear.

(*i*) *The Field System* : The object of the field system is to create a uniform magnetic field, within which the armature rotates.

Electro-magnets are preferred in comparison with permanent magnets on account of its greater magnetic effect and its field strength regulation, which can be achieved by controlling the magnetising current.

Field magnet consists of four parts given below.

(*i*) Yoke (*ii*) Pole cores (*iii*) Pole shoes and (*iv*) Magnetising coils.

Cylindrical yoke is usually used which acts as a frame of the machine and carries the magnetic flux produced by the poles. In small machines, cast iron yokes are used, because of cheapness but yoke of a large machine is invariably made of fabricated steel due to its high permeability. In case of small machines the cheapness is the main consideration, and not the weight but in large machines, weight is the main consideration. Since the permeability of cast steel is about twice of cast iron, therefore, the weight of cast steel required will be only half of the cast iron if used for the same reluctance.

Pole core is usually of circular section and is used to carry the coils of insulated wires carrying the exciting current.

The pole shoe acts as a support to the field coils and spreads out the flux in the air gap and also being of larger cross-section reduces the reluctance of the magnetic path.

The field poles are usually formed of laminations (thin sheets of steel) and are bolted to the frame or yoke to which are also fastened the end bells with their *bearings* and the