Low Conversion Loss Dual Generator

Dr Manilal D Amipara
Professor
Department of Electrical Engineering
Balaji Institute of Engineering & Technology, Junagadh, India

Jayesh B. Ruchandani
Student
Department of Electronics & Communication Engineering
Babaria Institute of Technology, India

Abstract

This paper explains losses associated with conventional generators due to armature reaction and self-induced emf and introduces a new design, dual generators, to scale down these losses. In the following paper, it will be shown how dual generators can offer better conversion of energy from mechanical to electrical and also reduce the above mentioned losses.
Keywords: Dual Generator, Conventional Generator, Armature Reaction, Cross-Magnetization, De-Magnetization and Armature Winding

I. INTRODUCTION

An inductive generator has various losses associated with it. Armature reaction and reactance voltage in armature windings affects severely the performance of a generator and reduce its terminal voltage and efficiency. The main cause of armature reaction, reactance voltage losses in a generator is due to "armature flux". The term "armature flux" represents flux ϕ_1 produced by the current flowing in the armature conductors when armature rotates under the magnetic poles of a generator.

Consider a basic working operation of a generator in figure. 1. Conductor ABCD is rotating in a clockwise direction in a magnetic field B supplying a load R_L. Since the conductor is cutting flux ϕ' of the magnetic field B, an emf E_1 is induced in the armature conductor and current flows through it $I_1=E_1/R_L$ as shown in figure 1.'N' and 'S' represent the poles of a magnet and the conductor ABCD is wound on an armature.

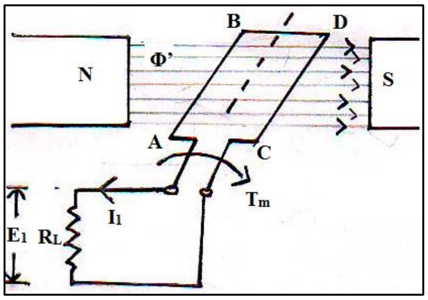

Fig. 1: Basic Operation of a Generator

II. FLUX CANCELLATION OF TWO SIDE-BY-SIDE PLACED WIRES

A current carrying conductor generates flux around it. When two enamel coated copper wires carrying current of equal amplitude but in opposite directions are placed side-by-side as shown in figure 2, they tend to cancel the flux of each other. This can be proved with Ampere's Circuital Law. It states that the line integral of magnetic field $\overline{H}$ about any closed path is exactly equal to the current enclosed by that path.[4]

$$\oint \overline{H}.\overline{dL} = I_{encl}$$

Where I_{encl}= Enclosed current by the closed path

$\overline{dL}$ = Unit length element

Consider two wires placed together carrying currents of equal magnitude but in opposite directions. The two wires remain insulated from each other as they are enamel coated.

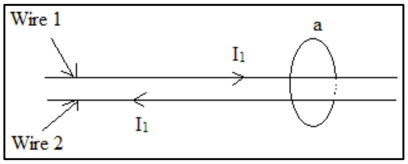

Fig. 2: Enameled Copper Wires

Applying Ampere's Circuital Law around the path 'a'

$$\oint \overline{H}.\overline{dL} = I_1 - I_1 = 0$$

$$\therefore \overline{H} = 0$$

Hence, the region around the wires has no magnetic field. Note that the flux in the region between the two wires is not zero which is not of importance here.

This can be more clearly understood that currents in two wires are equal in amplitude but differ in phase by 180° as shown in figure 3.

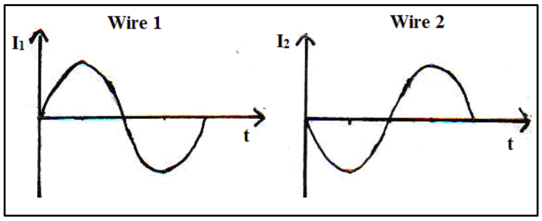

Fig. 3: Current Waveform in the two copper wires

There is phase shift of 180° in the currents. Flux produced by the currents in the form of waveform is shown in figure 4.

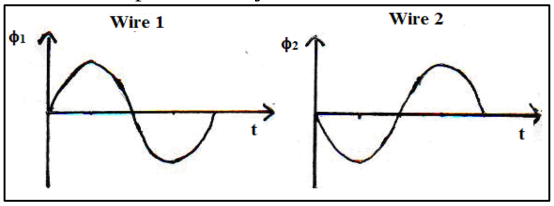

Fig. 4: Flux waveform due to current in the two copper wires

Since the wire 1 and 2 are close to each other, the flux produced by wires 1 and 2, ϕ_1 and ϕ_2 respectively, will be 180° out of phase and cancel out each other. The absence of the flux was confirmed by a magnetic compass. Thus, we are able to remove the flux of both wires without affecting the transmission of signals through wires. Because fluxes are reduced to zero, the effects caused by the self-induced emf e', armature reaction and skin effect are removed in both the wires.

III. LOSSES IN CONVENTIONAL GENERATOR

A. Armature reaction in generators [1][2][3]

Armature reaction is the effect of the magnetic field set up by the armature current on the distribution of flux under the main poles of a generator. To illustrate the effects of armature current on the distribution of flux under the main poles, consider an armature rotating in clockwise direction in the bipolar field.

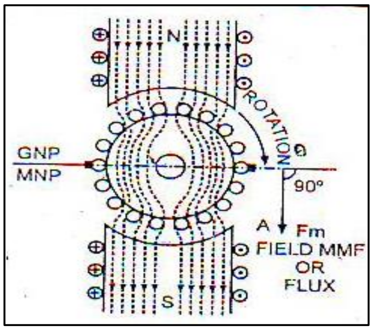

Fig. 5: Distribution of main flux under the poles when supplying no load

Geometric neutral plane (GNP) and magnetic neutral plane (MNP), plane through axis along which no emf is induced in the armature conductors is also shown in figure 5.

The main field flux is represented by vector OA in magnitude as well as direction is shown in fig. 6

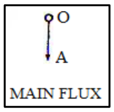

Fig. 6: Vector representation of the main flux as OA

When generator is supplying load, current flows through the armature conductors. Distribution of flux due to current carrying armature conductors is shown in figure 7. Field flux is not shown for now.

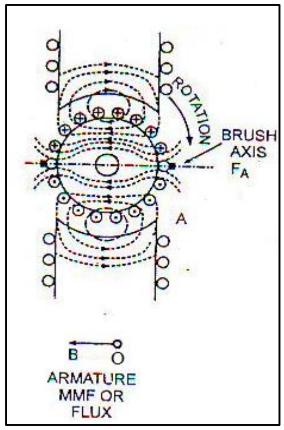

Fig. 7: Flux distribution due to current in armature conductors and vector representation of armature mmf as OB. Main Flux is not shown

'+' sign indicates that current is flowing inward in conductors under N-pole and '.' sign indicates that current is flowing outward in armature conductors under S-pole. Current flowing in the armature conductors creates a magnetizing effect or mmf that acts at right angle to the main field flux. This magnetizing action of the armature current is known as cross magnetization. Distribution of the resultant field formed by the simultaneous action of the main field windings and the field produced by the cross magnetizing action of the armature current when the generator is rotating in clockwise direction is shown in figure 8.

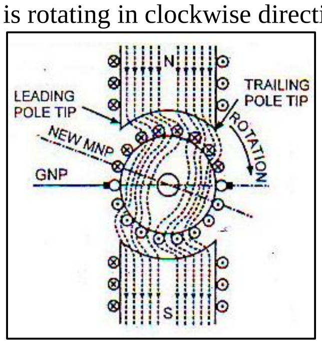

Fig. 8: Resultant flux distribution when generator is supplying a load

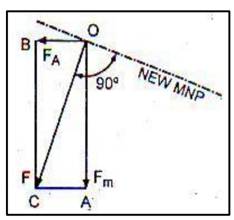

Fig. 9: Vector representation of the resultant mmf and new Magnetic Neutral Plane (MNP)

When the generator is supplying load, the main mmf is downwards represented by vector OA and mmf produced due to armature current is from right to left represented by vector OB. The resultant mmf is OC. Thus MNP which is always perpendicular to the resultant mmf OC will be shifted through an angle θ. This overall effect is termed as cross magnetization. Flux density in the air gap when the generator is supplying no load and on load is shown in figure 10.

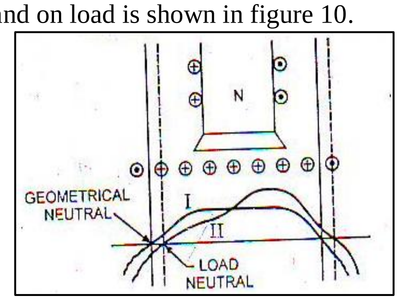

Fig. 10: Flux distribution due to main flux when generator is on no load and Flux distortion in the air gap when generator is supplying load

Thus, because of cross magnetization, the distribution of flux density in the air gap becomes non uniform and contorted. The effect of action of armature mmf makes necessary a shifting of the brushes through angle θ with changes in load to secure sparkles commutation. However, shifting of brushes results in a component of armature mmf that is not at right angle to the main field but directed against the main field i.e. it is demagnetizing in its nature. The demagnetizing component of armature mmf results in a weakened field flux, which in turn results in a lowered generated emf in the generator.

This can be summarized as below:

- Cross Magnetization: This distorts the main field flux distribution in the air gap as shown in fig.5
- De-Magnetization: This causes the field flux to weaken which in turn results in a lowered generated emf in armature. This overall effect of cross-magnetization and de-magnetization is known as armature reaction.

B. Effects and losses due to armature reaction in generator [1]

- The demagnetizing effect of armature reaction reduces the total flux per pole from its no-load value. The decrease in the main field flux on-load due to armature reaction may be around 10%. Therefore, the decrease in the flux due to armature reaction on-load reduces the magnitude of the generated emf E in a generator by around 10%.
- The cross magnetizing effect of armature reaction distorts the field in the air gap. The two principal effects of these are:
  1) Creation of magnetic field in the interpolar region. Where he brushes are place for commutation.
  2) Weakened field strength in the air gap under leading pole tips and strengthened field under trailing pole tips.

The above two effects, caused by the distortion of the main field under load leads to increased iron losses, poor commutation or even sparking at commutator surface.

- Iron Losses: Iron losses depend on the maximum value of flux density B in the air gap. Since the flux density in the air gap is not uniform, the increase in iron losses due to increase in flux density under one-half of the pole arc is much more than the decrease in losses in other half pole arc.
- Poor Commutation: For good commutation, the coils short-circuited by the brushes should have zero induced emf in them. However, because of armature reaction, since mmf is shifted through angle θ, brushes short-circuit the coil which may cause sparking at the brushes. Under heavy load, if voltage between adjacent commutator segments exceeds 30volts or 40volts, spark may occur between these commutator segments. Sometimes this spark may be too large that it may spread around *commutator in the form of a ring wire.*

C. Remedies and methods used to overcome Armature Reaction in conventional generators [1]

To overcome the effects and losses due to armature reaction in conventional generators, the brushes are shifted along the Magnetic Neutral Plane (MNP) and high resistance carbon brushes are used. Interpoles/ commutating poles are also used to compensate for the effect of demagnetization. This all add to the cost of the machine. Also in generators, which are required to supply heavy currents, compensating windings are used extensively because provision of interpoles and use carbon brushes do not suffice to afford sparkles commutation. Compensating winding adds considerably to the cost and doubles the armature copper loss. Compensating winding is used extensively in generators at power stations.

D. Self-Induced emf e', skin effect and their losses

When an emf E_1 is induced in the armature conductors due to rotation of armature under poles and current flows through it, flux ϕ_1 is also associated with the armature conductors. In case of AC generators, the current waveform I_1 and the corresponding flux ϕ_1 generated by the armature conductors due to current I_1 is shown in figure 11.

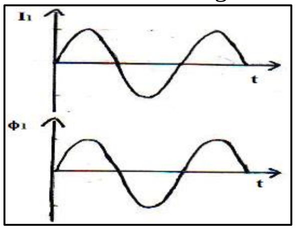

Fig. 11: Current and flux waveform due to current in the coils

This flux ϕ_1 also gets linked with the armature conductors itself and since it is a varying flux, it induces an emf in the conductor, self-induced emf e_1', which is directed against the cause that produces it i.e. induced emf E_1 according to Lenz's law. Therefore, self-induced emf e_1' lowers the emf E_1 in the conductor induced due to rotation of armature.

IV. DUAL GENERATORS

A. Conventional Generator [3]

A simple construction of the generator is shown in figure 12. 'N' and 'S' represent the two poles of the magnet. ABCD is the coil which is rotating in the magnetic field of the magnets.

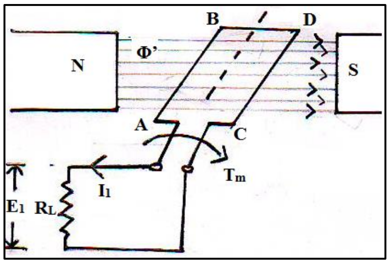

Fig. 12: Basic working principle of generator

Due to the flux cut by the coil ϕ', emf E_1 is induced in the coil which is equal to (N*dϕ')/dt

Where N= Number of turns in the coil.

ϕ'= Magnetic flux of the magnet.

T_m= Mechanical Torque.

Let the current through the coil be I_1. The current I_1 through coil produces an additional flux ϕ_1, that gets linked with coil 'ABCD' itself which in turn gives rise to the self-induced emf e_1'. This self-induced emf e_1' is in the direction opposite to the induced emf E_1 in the coil 'ABCD' which is undesirable. This self-induced emf e_1' is called reactance voltage. This additional flux ϕ_1 produced by the armature conductor 'ABCD' is also responsible for armature reaction and skin effect, the detailed severe effects of which on performance of generator is reviewed later. This flux ϕ1 also opposes the rotation of coil in magnetic field B as per Lenz's Law.

B. Low Conversion Loss Dual Generator

To remove this self-induced emf e_1' in the coil 'ABCD', consider figure 13.

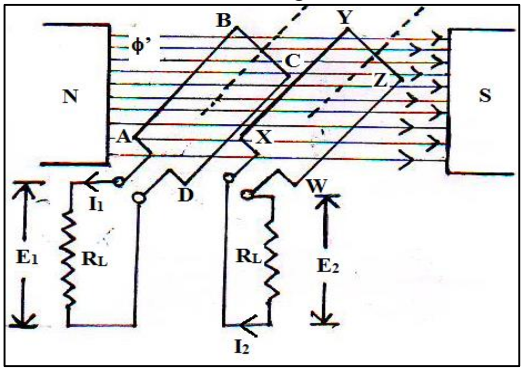

Fig. 13: Simple construction of a dual generator

'N' and 'S' are two poles of the magnet,ϕ' is the flux due to the magnet. ABCD and XYZW are two coils with equal number of turns N/2 and N/2 respectively. The coils are rotated in the magnetic field and change of flux with the coil is dϕ'/dt.

Emf induced in the coil 'ABCD', e_{ABCD} = (N/2)*(dϕ'/dt) and emf induced in the coil 'XYZW', e_{XYZW} = (N/2)*(dϕ'/dt)

The coil 'XYZW' is wounded in such a way that $e_{XYZW} = - e_{ABCD}$ i.e. the emf's in the two coils are 180° out of phase with each other which is shown in figure 14.

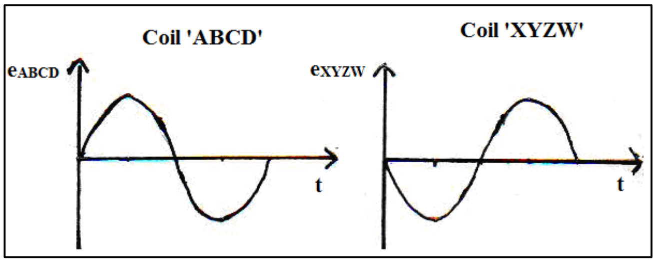

Fig. 14: Voltage Waveform in the two coils

Assuming the two coils each are supplying equal load R_L, the magnitude of currents in the two coils I_{ABCD} and I_{XYZW} is same in magnitude but 180° out of phase with each other as shown in figure 2. Fluxes due to the currents I_{ABCD} and I_{XYZW}, ϕ_{ABCD} and ϕ_{XYZW} respectively in two coils 'ABCD' and 'XYZW' are also shown in figure 15.

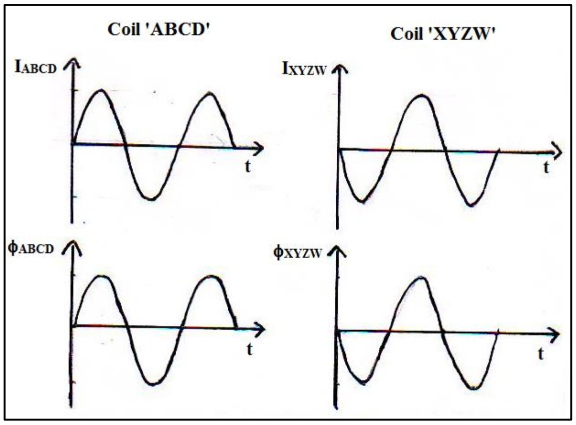

Fig. 15: Current and Flux waveform in the two coils 'ABCD' and 'XYZW'

Since the fluxes are 180° out of phase with each other, they cancel out each other and only flux from the magnet ϕ' is linked with the coils. Since the armature flux is completely eliminated, no self-induced emf is produced in both coils, skin effect is reduced and effects and losses due to armature reaction are eliminated.

Hence much power is saved with "Low Conversion Loss Dual Generator" in comparison to the conventional design of the generators.

V. DESIGN, IMPLEMENTATION AND USE OF DUAL GENERATORS

This model dual generator can be extremely useful for parallel operation of generators in power stations. Parallel operation of generators is almost universally adopted, in which all the generators operate on the same voltage and load on any unit of generator is proportional to the current delivered by it. Dual Generators will exhibit the best possible performance if both the armature windings in this generator deliver the same current to their respective loads.

The two coils 'ABCD' and 'XYZW' in the Dual Generators will be referred by the term "Armature winding 1" and "Armature winding 2". Since two windings are used in dual generators, two commutators will be required, one for each coil, and the armature winding can be done in the following ways shown in figure 16 and figure 17.

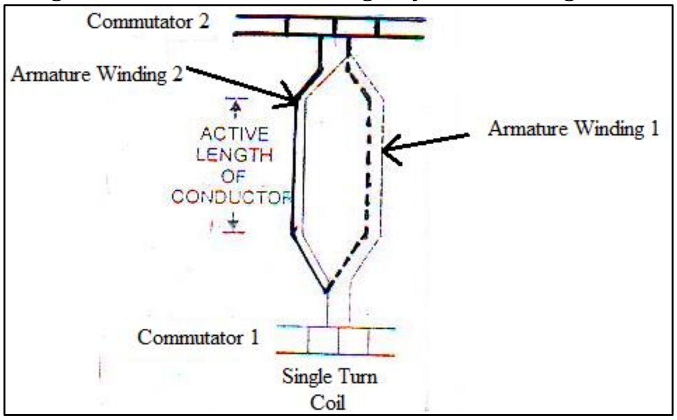

Fig. 16: Armature winding arrangement in dual generator

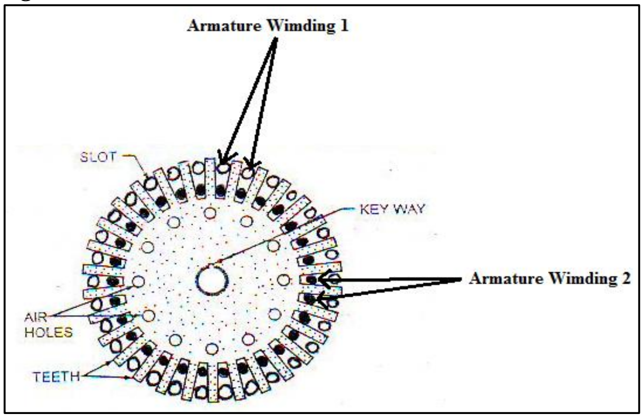

Fig. 17: Armature winding arrangement in dual generator

Thus, dual generators can be used with multi-turn winding, progressive lap winding, retrogressive lap winding, wave winding and gramme-ring winding type of armature employing generators. Hence little changes are required in construction design of generators.

The two windings "Armature Winding 1" and "Armature Winding 2" should be so wound on the armature core, so that that the direction of emf e_{ABCD} and e_{XYZW} induced in both coils and hence the current flowing through the two windings is opposite to each other, then only they will cancel out each other's flux, ϕ1 and ϕ2 respectively.

VI. CONCLUSION

With this model of dual generator, there is no need of compensating winding and interpoles used in power station generators which dramatically increase the cost. This generator improves commutation, decreases armature reaction and reactance voltage. Hence, dual generators can be better replacement to conventional generators used at power stations and to high power rating generators. Dual generators will exhibit better performance and efficiency.

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