Air Core Generator

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Abstract – *Due to environmental concerns arising from the frequent overuse of resources, attention has now shifted to non-renewable sources, especially solar and wind as these are environmentally cleaner and not environmentally friendly. Modern technologies incorporated in wind turbines have increased the limits of wind power generation to a greater extent in wind turbines. Thus, wind energy penetration has become increasingly important and requires robust, sophisticated and reliable networks.*

This paper presents the design and construction of a permanent magnet machine with an air core stator.

***Key Words:* Air-cored stator, PM machines, Radial Flux Permanent Magnet (RFPM), neodymium magnet. Faraday's law of electromagnetic induction.**

1. INTRODUCTION

GENERATION OF ELECTRICITY: -

In 1831-1832 Michael Faraday discovered that a potential difference is produced between the ends of an electrical conductor which moves perpendicular to a magnetic field. The first electromagnetic generator based on this effect, using a copper disc rotating between the poles of a horseshoe magnet which produces a small direct current. It is based on the principle that when a current carrying conductor coil or conductor is rotated in the permanent magnetic field, the e.m.f. is generated. *However, due to the low power intensity, we provide a low voltage that can be increased if larger drives are used.*

1. ALTERNATOR

1.1 An Alternator: An alternator is a generator that converts mechanical energy into electricity to produce alternating current. In theory any AC generator can be called an alternator, but the term generally refers to small rotating machines powered by internal combustion engines and other automotive.

1.2 Theory of operation

Alternators produce electricity on the same principle as DC generators. When magnetic field lines cross a conductor, a current is induced in the conductor. An alternator generally has a stationary (stator) and a rotating (rotor). The stator has a winding of conductors and a rotting magnetic field in the rotor. The field cuts across the conductors and generates electricity, while the mechanical input causes the rotor to rotate. The rotor magnetic field can be generated by induction (in "brushless" generators), permanent magnets, or rotor windings with direct current through slip ring brushes automotive alternators uses brushes and sliprings. Which is used to regulate the voltage produced by the alternator by varying the current in the rotor field windings. Permanent magnet devices avoid losses due to magnetizing current in the rotor but are restricted in size due to due to the cost of the magnet material. Brushless AC generators are generally larger devices than those used in automotive applications.

1.3 Automotive alternators

1.3.1 Alternators are used in vehicles to charge batteries and power all electrical systems when the vehicle engine is running. A major advantage of alternators over direct-current generators is that they do not use commuters, making them simpler, lighter and more robust than DC generators. The stronger construction of the alternator to turn at higher speed, allowing the automotive alternator to turn at twice the engine speed, improve when the engine is idling .Since about 1960, the availability of inexpensive solid-state diodes has enabled automakers to replace generators with alternators. Automotive alternators use a set of rectifiers (diode bridges) to convert AC to DC. Automotive alternators have three-phase windings which provide direct current with a low ripple.

1.3.2 Very large automotive alternators used in heavy equipment or emergency vehicles are capable of delivering 150 amps. Old automobiles with minimal lighting and electronics may only have a 30 amp alternator. Hybrid automobiles use a motor/generator combination that replaces the separate alternator and starter motor, running the internal combustion engine during start-up, providing additional mechanical energy for acceleration, bounce large battery storage when driving at constant speeds. A rotating magnetic field is a magnetic field that periodically changes direction. This is the basic principle of alternating current motors.

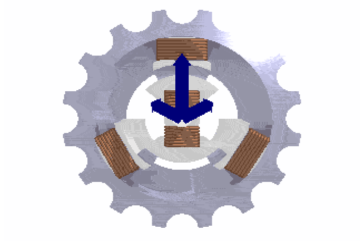

Fig 1: Sine wave current in each of the coils produces sine varying magnetic field on the rotation axis. Magnetic fields add as vectors.

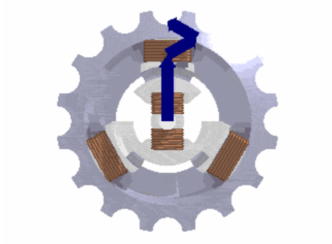

Fig 2: Vector sum of the magnetic field vectors of the stator coils produces a single rotating vector of resulting rotating magnetic field.

A rotating symmetric magnetic field can be created with just a few three coils. The symmetrical 3-phase AC sine-current system must include three coils, so each phase will be shifted 120 degrees to the others. For the purposes of this example, the magnetic field is assumed to be a linear function of the current in the coil. Adding three 120-degree phased sine waves to the axis of the motor is a single rotating vector. A rotor (with a constant magnetic field driven by a DC current or a constant magnet) attempts to adopt a position such that the N pole of the rotor adjusts the S pole of the stator magnetic field, and vice versa. This magneto-mechanical force will drive rotor to follow rotating magnetic field in a synchronous manner. In such a field, a permanent magnet will rotate so as to maintain its alignment with the external field. This effect was applied in early alternating current electric motors. Two orthogonal coils with a phase difference of 90 degrees in AC currents can be used to generate a rotating magnetic field. In practice, however, such a system would be provided by a three-wire system with non-uniform flow. This inequality will cause serious problems in standardizing the size of the conductor and is overcome by using a three phase system where three currents are equal in magnitude and have a phase difference of 120 degrees three identical coils whose mutual geometric angles are 120 degrees will give a rotating magnetic field in this case. The ability of the three phase system to produce a rotating field applied in electric motors is one of the main reasons why three phase systems are dominated in the world electric power supply systems. Because magnets degrade with time, synchronous motors and induction motors use short-circuited rotors (instead of a magnet) following rotating magnetic field of multicoiled stator. (Short circuited turns of rotor develop eddy currents in rotating field of stator which (currents) in turn move the rotor by Lorentz force).*Note that the rotating magnetic field can actually be produced by two coils, with phases shifted about 90 degrees, but such field would not be symmetric due to difference between magnetic susceptibility of ferromagnetic materials of pole and air. In case two phases of sine current are only available, four poles are commonly used.*

1.4 Marine alternators

1.4.1 Marine alternators as used in boats are usually automotive alternators, adapted to the saltwater environment. They can be 12 or 24 volts depending on the type of system installed. Larger marine fuels may have two or more transformers to meet the high power requirements of a modern boat. In a single alternator circuit, power is divided between the engines starting battery and the household battery (or batteries) by split charge diodes or mechanical switches because the alternator powers only then when driven engine control panels usually provide directly from the alternator via auxiliary terminals. Other specific connections are made for charge control circuits.

1.5 Brushless Alternators

1.5.1 Terminology

The stationary part of the motor or alternator is called the stator and the rotating part is called the rotor. The wires used to generate the magnetic field are called fields, and the coils that generate energy are called armatures. The field and armature wires are sometimes called "windings".

1.5.2 Construction

A brushless alternator consists of two alternators built end-to-end on the same shaft. Smaller brushless alternators look like one unit but in larger ones, the two parts are easily identifiable. The larger of the two parts is the main alternator and the smaller exciter. The exciter has stationary field coils and a rotating armature (power coils). The main alternator uses a reverse configuration with a rotating field and a stationary armature.

1.6 Exciter

The excited field coils are on the stator and its armature is on the rotor. The AC output from the exciter armature is supplied by a series of diodes which are also mounted on the rotor to provide a DC voltage. This goes directly to the field coils of the main alternator, which is also on the rotor. With this arrangement brushes and slip rings are not required to flow current through the rotating field coils. This can be compared to a simple car alternator where brush slip rings are used to flow current to the rotating field.

1.7 Main Alternator

The main alternator has a rotating field as described above and a stationary armature (Power generating winding). If the armature is stable, high current should not pass through the brush and slip rings. Although the electrical system is more complex, it makes for a very reliable alternator because the only parts that can fail are the bearings.

1.8 Control System

The strength of the magnetic field in the exciter is controlled by varying the amount of current flowing through the stationary excited field coils. This also controls the exciter output. The exciter output is injected with a rotating field for which the main alternator generates a magnetic field. The strength of the alternator's magnetic field in the main then controls the output. The result of all this is that a small current, controls the main alternator output indirectly at the location of the exciter and does not have to go through any brush slip rings.

1.9 AVR

AVR is an abbreviation for Automatic Voltage Regulator. An AVR serves the same function as the "voltage regulator" in an automobile or the "regulator" or "controller" in a home power system.

1.10 Hybrid automobiles

Hybrid automobiles replace the separate alternator and starter motor with a combined motor/generator that performs both functions, cranking the internal combustion engine when starting, providing additional mechanical power for accelerating, and charging a large storage battery when the vehicle is running at constant speed. These rotating machines have considerably more powerful electronic devices for their control than the simple automotive alternator described above.

1.11 Radio alternators

With the expansion of Tesla's work on high-frequency alternators, high-frequency alternators of the variable reluctance type have been used commercially for radio transmission on low-frequency radio bands.

1.12 Dynamo

2.13.1 The dynamo was the first electric generator capable of powering industry, and remains the most important electrical generator used in the 21st century. The dynamo uses the principle of electricity to convert rotating machinery into alternating current.

1.13 Gramme dynamo

But both of these systems had the same problem: they gave a "spike" of current that neither followed at all. The Italian scientist Antonio Pacinotti remedied this by replacing the spinning wires with a toroidal coil, using metal rings to fasten them. This means that part of the coil was in motion with the magnets, smoothing the current flow.

2. Concepts

It is important to understand that a generator generates electricity, but not electricity, which is already in the conductors of its windings similar to a water pump that makes water flow but not the water itself. There are other types of electrical generators, based on other electrical properties such as piezoelectricity and magnetic hydrodynamics. The design of a dynamo is similar to that of an electric motor, all of which can operate as conventional dynamo motors. Furthermore, all conventional electric motors could act as generators. The generator rotor is turned by a device called a prime mover, usually a gasoline engine, steam turbine, water turbine or gas turbine connected to the rotor-shaft.

Equivalent circuit

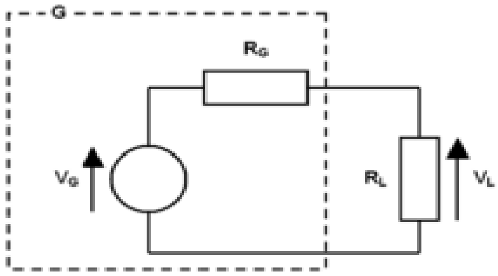

Fig 3: Equivalent circuit of generator and load.

G=generator
V_G=generator open-circuit voltage
R_G=generator internal resistance
V_L=generator on-load voltage
R_L=load resistance

2.1 The equivalent circuit of a generator and load is shown in the diagram. To determine the generator's V_G and R_G parameters, follow this procedure:

- Before starting the generator, measure the resistance across its terminals using an ohmmeter. This is its DC internal resistance R_{GDC}.
- Start the generator. Before connecting the load R_L, measure the voltage across the generator's terminals. This is the open-circuit voltage V_G.

- Connect the load as shown in the diagram, and measure the voltage across it with the generator running. This is the on-load voltage V_L.
- Measure the load resistance R_L, if you don't already know it.
- Calculate the generator's AC internal resistance R_{GAC} from the following formula:

$$R_{GAC} = R_L \left(\frac{V_G}{V_L} - 1 \right)$$

Note 1: The AC internal voltage of a generator when it is running is usually slightly higher than its DC resistance at idle. The procedure above allows you to measure two values. For more complex calculations, you can skip the RGAC measurement and assume that RGAC is equal to RGDC.

Note 2: If the generator is an AC type (not a dynamo), use an AC voltmeter for the voltage measurements.

3. CONSTRUCTION DIAGRAM

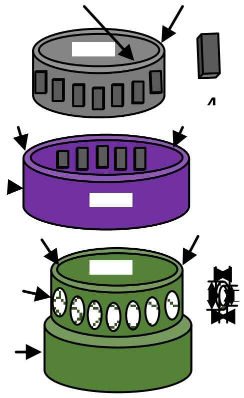

Fig 4: Constructional diagram

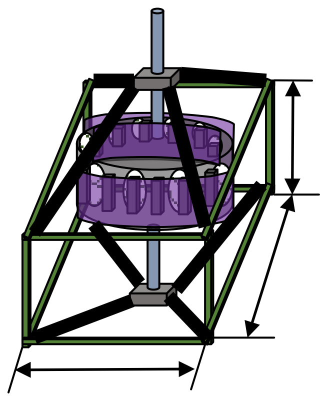

Fig 5: Assembly diagram

3.1 Metallurgy is fundamental and yet it overflows into areas of knowledge and remains closed to the general reader. Knowledge of materials and their properties is very important for the designer. Mechanical components must be a material with properties suitable for operating conditions. In addition to this, the designer must be familiar with manufacturing processes, material properties and operating temperatures. In designing the parts of a machine, he determines how the material will perform in service. For some of those properties or mechanical properties commonly used in industrial applications, they are usually derived from standard tensile tests. In engineering practice, the machine parts are subjected to various forces, which may be due to either one or more of the following.

1. Energy transmitted.
2. Weight of machine
3. Frictional resistance
4. Inertia of reciprocating parts
5. Change of temperature
6. Lack of balance of moving parts

3.2 The selection of materials depends on the stresses during operation. The selected material will endure. Another factor in steel selection depends on the type of load to be applied because the mechanical component resists machine parts loads more than live loads and live loads more elastic than shock loads.

4. RAW MATERIAL & STANDARD MATERIAL

Table -1: Raw material

Sr no	Part name	Mat	Qty
1	Frame	Ms	20kg
2	Magnet	Ferite	40 nos
3	Cu coil	Cu	10 nos
4	Coil ring	Ms	1 nos
5	Magnet ring	Ms	2 nos
6	Bearing	Std	2nos
7	Shaft	En8	1 nos
8	Diode	Std	20 nos
9	Handel	Ms	1 nos
10	Led light	Std	1 nos
11	Nut bolt washer m 10	Ms	8 nos
12	Welding rod	-	1 50 nos
13	Colour	-	2 lit

5. COST ESTIMATION

5.1 The cost estimation can be defined as a method of forecasting the costs that must be incurred to produce a product. These costs consider all costs associated with design and manufacture including all related service activities such as sampling, equipment, manufacturing and a portion of all administrative and selling costs

6. BASICALLY THE BUDGET ESTIMATION IS OF TWO TYPES:

1. material cost
2. Machining cost

6.1 MATERIAL COST ESTIMATION:

Material cost estimation gives the total amount required to collect the raw material which has to be processed or fabricated to desire size and functioning of the components. These materials are divided into two categories: Material for fabrication: Materials obtained in this raw state are processed or processed to a finished size for product efficiency.

1. Standard purchased parts:

This includes the parts which was readily available in the market like allen screws etc. A list is forecast by the estimation stating the quality, size and standard parts, the weight of raw material and cost per kg. For the fabricated parts.

6.2 MACHINING COST ESTIMATION:

This cost estimate is an attempt to determine the total costs that may be included in production in addition to material costs. The cost of manufactured parts can be considered as a decision period after careful consideration including the labor, materials and factory services required to produce the required part.

7. DESIGN CALCULATION

7.1 Design concept of generator : For the concept of generator design is following to these steps:

7.1.1 Coil turns calculation

This section is determined number of coil turns for armature winding.

$$f = \frac{NP}{120} \quad (1)$$

$$Bmax = Br * [\frac{Lm}{Lm+\delta}] \quad (2)$$

$$\emptyset = Bmax * A\text{magnet} \quad (3)$$

$$Nc = \frac{Ea}{4.44 f \delta max} \quad (4)$$

When N is generator speed (rpm), f is generator frequency (Hz) and P is numbers of pole (poles), Bmaxis the maximum magnetic density in air gap per pole (Wb/m^2), Br is the magnetic density per pole(Wb/m^2), Ømax is the maximum flux in air gap (Wb), Lm is the thickness of permanent magnet (m.), $\emptyset max$ is theair gap between stator and rotor (m.), Amagnetis the cross sectional area of pole (m^2) that can find by usingthe product of width and length of permanent magnet, EA is induced voltage (V) or requirement voltagefrom generator, NC is coil turns (turns).

Name	Symbol	Design
Output Voltage	Ea	24v
Roof Ventilator average Speed	N	30 rpm
Poles	P	6 poles
Air gap	δ	3 mm.
Permanent Magnet size	$W \times L \times T$	
Permanent Magnet Magnetic density	Br	0.05 Wb/m2
Turns per coil	Nc	223 turns

Table 3: shows the generator parameters for calculation

7.1.2 Coil span calculation

This section is determined the coil span for all installation winding on stator core.

$$Coil\ Group = \frac{Total\ Slot}{Pole \times Phase} \quad (11)$$

$$\gamma = \left(\frac{360°}{Total\,slot}\right) \times \left(\frac{P}{2}\right) \quad (12)$$

$$coil\ span = 1 + \frac{Angle}{\gamma} \quad (13)$$

When Coil Span is the range between first coil-side and end coil-side that count from first coil-side in first slot to the end coil-side in the other slot (unit measurement maybe use slot or degree), Coil group is number of sub coil that distributed in coil span of a big coil, Total Slot is total numbers of slot on stator core (slots), Pole or P is magnetic pole (poles), Phase is number of phase system, γ is slot angle in each slot, (electrical degree), Angle is the angles for installation coil at each slot that use 2 angles as

- Pole Pitch is 180°
- Phase Initial, Phase A is 0°, Phase B is 120° and Phase C is 240°.

7. Working principle of air core generator.

7. 1 when a conductor moves in a magnetic field, an emf is induced across the conductor. This is the basis of any rotating electrical system. Let us consider the topic in some detail so that it is easier to understand how an electric generator actually works. According to Faraday's law of electromagnetic induction, when a conductor is connected to a changing flux, an emf will be generated to cause it to cancel. The value of the emf produced across the conductor depends on the rate of change associated with the flux along the conductor. The direction of the emf applied to the conductor can be determined by Fleming's right-hand rule. This rule states that in the right hand if you extend the first thumb and second finger perpendicular to each other, and if you extend the thumb of the right hand to the direction of the conductor in the magnetic field are aligned, and your first finger points in the direction of the magnetic field then you second finger indicates the direction of emf in the conductor.

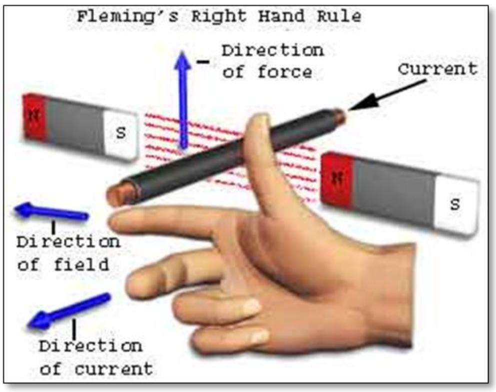

Fig 6 : Fleming's Right Hand Rule

7.2 A generator is a device that converts mechanical energy into electricity. It works based on the principle of Faraday's law of electromagnetic induction. The faradays law states that whenever a conductor is placed in a varying magnetic field, EMF is induced and this induced EMF is equal to the rate of change of flux linkages. This EMF can be produced when there is either relative space or relative time variation between the conductor and magnetic field.

7.3 D.C Generators are classified according to the way their magnetic field is developed in the stator of the machine.

- permanent-magnet DC generators
- Separately-excite DC generators and
- Self-excited DC generator.

7.4 A permanent magnet DC generator does not require external field excitation because it has permanent magnets to generate current. These are used in low voltage applications such as dynamos. Especially excited DC generators need external field excitation to generate magnetic flux. We can also change the excitation to get variable output power. These are used in electroplating and electro refining applications. Because of the residual magnetism present in the poles of the stator, self-excited DC generators may be able to generate their own magnetic field it starts. These are simple in design and do not require external circuitry to change the field excitation. Moreover, these self-interested DC generators are classified as shunt, series, and compound generators. They are used in applications such as battery charging, welding, and simple lighting.

8. Advantages of DC Generator:

Mainly DC machines have the wide variety of operating characteristics which can be obtained by selection of the method of excitation of the field windings .The output voltage can be smoothed by regularly arranging the coils around the armature .This leads to less fluctuations which is desirable for some steady state applications. No shielding need for radiation so cable cost will be less as compared to AC. The air core generator is core less generator in which there is no iron core in winding so that force required to rotate the rotor is going to reduced very low. We had design it for vertical axis wind turbine to generate power in low air velocity.

9. ADVANTAGES

i) The cost of the generator is very low as no stamping is required.
ii) Generate power at a lower speed because the number of poles is more.
iii) The coil can be arranged in series and parallel so we can generate voltage in many ranges.
iv) We can manufacture generators up to 5 kw capacity.

10. FUTURE SCOPE

i) In future by designing proper winding and use of neodymium magnet we generate more power from same set up.

11. RESULT AND CONCLUSION

11.1 RESULT:

Table -2: Output table.

SR. NO.	AIR VELOCITY m/s	SPEED RPM	TORQUE N-m	POWER Watt
1	2	8	0.65	0.5
2	2.5	11	0.85	1.0
3	3	13	1.56	2.1
4	3.5	15	2.4	3.8
5	4	22	3.2	7.4
6	4.5	24	4.5	11.3
7	5	26	5.8	15.8
8	5.5	27	6.9	19.5
9	6	30	8.2	25.7
10	6.5	32	9.5	31.8
11	7	34	10.9	38.8
12	7.5	35	13.2	48.4
13	8	38	14.5	57.7

11.2 CONCLUSION

The air core generator is very much useful for low speed power generation for wind turbine. The initial cost of the system is quite high, but if we go for a one-time investment for making a die, the cost of production will be lower and the efficiency & reliability will be higher.

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