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Design of A Direct Driven Permanent Magnet Synchronous Generator for Small Horizontal Axis wind Turbines

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ABSTRACT: *Electric power stability has been a major challenge in Nigeria thus the need for harnessing renewable energy sources like wind. Wind energy is so abundant and available at near zero cost, this makes wind easily exploitable using wind turbine. Electricity generation works on the principle of electromagnetic induction. Permanent magnets are used to produce the magnetic field flux. The permanent magnets were placed on a 10mm thick steel plate to concentrate on one side of the plate to prevent flux leakage and used as the rotor. The operation of the wind turbine electric generator depends on the flow of electrons passing over electric coils or the other way round where the coils of wire (stator) move through electromagnetic field. The shaft was designed to carry the rotor and was capable of having smooth rotation. A permanent magnet series motor was used to test the fabricated generator and the test was done in two phases. First test was run on no load, second test was run on a load of 10w 12v and results were obtained. Graphs of speed versus emf for the two tests were plotted and compared. From the graph, it was deduced that voltage produced in the on load condition even at highest speed for all test carried out is lower than that of the no load condition. Permanent magnet wind turbine generator has been successfully designed and the design has adopted minimum air gap to enhance magnetic flux generation.*

KEYWORDS: *Permanent Magnets,Stator,Rotors, No Load Condition.*

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I. INTRODUCTION

The permanent magnet generator is an important component in a wind turbine since it converts the mechanical energy in the rotating wind turbine to electricity. PM machines are a well-known class of rotating and linear electric machines used in both motoring and generating modes. They have been used for decades in applications where simplicity of structure and low cost were of primary importance. Recently, PM machines have been applied to more demanding applications, primarily as a result of the availability of low-cost power electronic control devices and the improvement of permanent magnet characteristics. Generally, modern PM machines are competitive both in performance and cost with many types of machines . PM generators are well suitable for low-speed applications since their performance, such as efficiency and power factor, does not depend on the rotation speed.

II. LITERATURE REVIEW

Types of PM Generators

There are different types of generators available for wind turbines, but they are basically of two types. They are the geared and direct driven PM Generators both of which were widely used in industrial applications such as in wind turbines. They both have advantages as well as disadvantages.

Geared PM Generators:

Most wind turbines manufacturers built constant-speed wind turbines with power levels below 1.5 MW using a multistage gearbox from the early time till the 1990s. Later in that decade, they have changed to variable speed wind turbines for power levels from roughly 1.5MW up, mainly in order to enable more flexible matching with requirements on audible noise, power quality and energy yield where multistage gearboxes of relatively low cost standards were built. The gearbox brings additional weight and costs, demands regular maintenance, generates noise and incurs losses. Most of the turbines failed due to wear and fatigue in the gearboxes.

Direct Driven PM Synchronous Generator:

The turbine manufacturers later proposed gearless generator systems with direct-driven generators, mainly to reduce failures of gearboxes and to decrease the quantity of maintenance problems. The low-speed high-torque generators and the fully rated converters for gearless wind turbines are usually expensive. The synchronous generators have their magnetic fields rotate in same speed with their rotors thus the name synchronous and are mostly used as commercial electrical energy source.

Most synchronous generators are usually permanent magnet generators, as such they do not require a DC supply for their excitation, they also don't have slip rings and contact brushes. The synchronous generator uses Neodymium-Iron-Boron (NdFeB) magnets not only for small wind power generators, but also for large wind power generators as it has the advantage of having no excitation loss . The development of the permanent-magnet synchronous generator has been fast since the invention of the high-performance (NdFeB) permanent magnet material in 1983 .

A work presented at the international conference on renewable energies and power quality (ICREPQ) showed that the use of direct driven generators, instead of geared machines, reduce the number of drive components, which offers the opportunity to reduce costs and increase system reliability and efficiency . The turbine is connected through a shaft directly to the rotor of the generator, i.e. the generator is direct driven. The generator will have a slow rotational speed compared to conventional generators and it is therefore designed with a large number of poles in order to achieve good induction and high efficiency. Direct drive eliminates losses, maintenance and costs associated with a gearbox. A case studied has shown that the gearbox is the part in a wind turbine responsible for most downtime due to failures . The benefit of a direct driven PMG is produced by the elimination of the gear. As a result, the problems associated with the efficiency, oil maintenance, pollution, and positioning precision can be mitigated. The generator proposed for this thesis will therefore be a direct driven permanent magnet generator.

The PM generator is categorized into radial type and axial type in terms of the direction of the magnetic flux from the magnet and the generator.

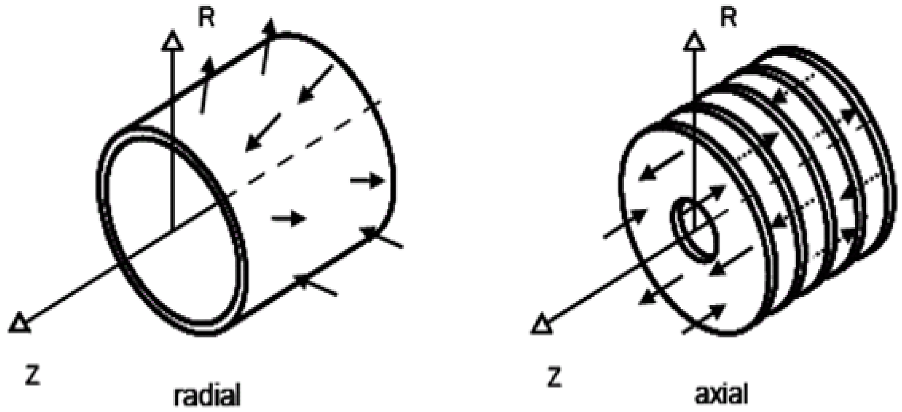

Fig 1: Radial and Axial types of PM Generators.

From fig 1, it could be seen that the magnet is positioned on the surface of the rotor that is coupled to the shaft, and the magnetic flux is generated is perpendicular to the shaft in the radial type. The magnetic flux is also directed towards the stator arranged on the outer side of the rotor. In the axial type, the magnet is positioned on the surface of the disk shaped rotor which is coupled to the shaft to generate the magnetic flux parallel to the shaft.

Induction Generators

The induction generators also known as asynchronous generators are used to generate alternating current. They operate by mechanically turning their rotors faster than the synchronous speed corresponding to the electric grid they are connected with. They are useful in applications such as mini hydro power plants, wind turbines, and in reducing high-pressure gas streams to lower pressure, because they can recover energy with relatively simple controls . They are particularly suitable for wind generating stations because their speed is always a variable factor.

Unlike synchronous motors, induction generators are load-dependent and cannot be used alone for grid frequency control .

A research carried out on world market share of wind turbine concepts (1998 to 2002) shows that induction machines dominated the market for wind power generation, but the fixed speed induction generator is slowly being replaced by the variable speed, doubly-fed induction generator. But the use of synchronous generators also increased by 20% by 2002 .

Wind Parameters for Kaduna State from year 1996-2000

The wind parameters for Kaduna state from 1996 to 2000 are presented below;

Month/year	1996	1997	1998	1999	2000
January	51	59	68	51	55
February	46	100	74	41	80
March	43	72	72	34	73
April	40	54	44	46	53
May	47	42	51	42	46
June	46	44	44	42	51
July	49	48	41	41	50
August	34	38	40	44	43
September	37	31	26	26	41
October	36	24	28	25	39
November	54	28	44	44	47
December	48	38	56	57	64

Table 1: Wind speed data in km/hr

Month/year	1996	1997	1998	1999	2000
January	1013.7	1015.1	1015.8	1014.5	1013.4
February	1012.2	1016.7	1015.5	1012.9	1043.4
March	1010.9	1012.2	1013.4	1009.8	1004.1
April	1010.2	1012.2	1010.5	1010.8	1009.9
May	1011.8	1013.9	1012.4	1012.4	1011.8
June	1014.0	1013.7	1015.1	1013.3	1014.3
July	1015.3	1015.8	1014.4	1014.7	1013.9
August	1015.1	1016.1	1014.1	1014.8	1015.0
September	1014.3	1014.5	1014.3	1013.8	1013.9
October	1014.0	1013.7	1014.1	1014.4	1014.3
November	1015.1	1014.8	1014.1	1014.2	1014.2
December	1015.5	1016.4	1015.6	1015.4	1016.2

Table 2: wind pressure data in mlbar

From the tables above, it can be deducted that the turbine performance would be highest in February because the speed and the pressures are higher in February but the other months are pretty good too.

III. MATERIALS AND METHOD

Materials

The material selection was made based on engineering criteria which emphasize cost effectiveness, economy of space and utilization of materials to reduce wastage, these materials are:

a) 24 pieces of neodymium iron (NdFeB) magnets of 50x25x10mm size having 24kg pull magnetic strength each.
b) Two 220mm diameter mild steel rotor discs,
c) A 310mm long steel shaft with 26mm outer diameter,
d) Ball bearings
e) Epoxy for holding the magnets on the rotor discs.
f) Resin for casting the stator and the rotor.
g) #14 American Wire Gauge (AWG) wire

IV. METHOD

Principle of Electromagnetism:

The operation of the wind turbine electric generator depends on the flow of electrons passing over electric coils or the other way round where the coils of wire move through electromagnetic field. Faraday's Law states that the induced electromotive force (emf) in any closed circuit is equal to the negative of the time rate of change of the magnetic flux enclosed by the circuit . It is represented as

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}$$

Where $\mathcal{E}$ is the electromagnetic force (emf)
N is the number of turns of wire
Φ_B is the magnetic flux and
$\frac{d\Phi_B}{dt}$ is the rate of change of flux.

The law shows that the polarity of the induced emf is such that it produces a current whose magnetic field opposes the change that produces it thus the negative sign. The induced magnetic field inside any loop of wire always acts to keep the magnetic flux in the loop constant as shown in fig 3.1

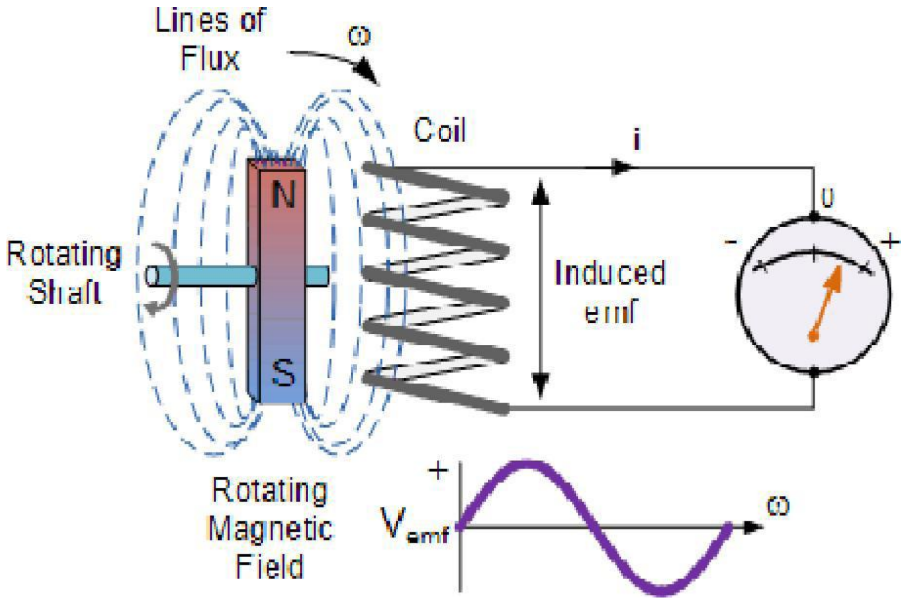

Fig 2: Principle of electromagnetic induction

The interaction between the electromagnetic field and coils of wire induces emf. For a given magnetic flux, the voltage generated increases as the number of turns on the coil increases and for a given number of turns, the emf induced is proportional to both the strength of magnetic flux and speed of rotation . The direction of the magnetic lines of flux and the direction of conductor movement are used to determine the polarity of the generated voltage.

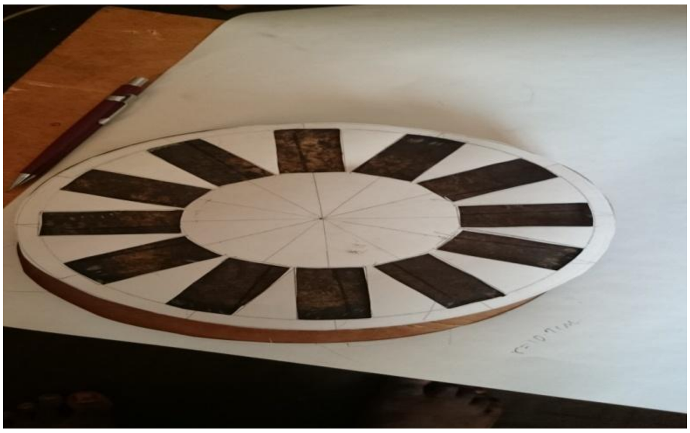

Fig 3: Template for forming the base for mounting the magnet

Fig4: Progressive mounting of the magnets

Fig5: Magnets mounted with poles opposing each other

Fig6: The shaft before the attachment of peripherals.

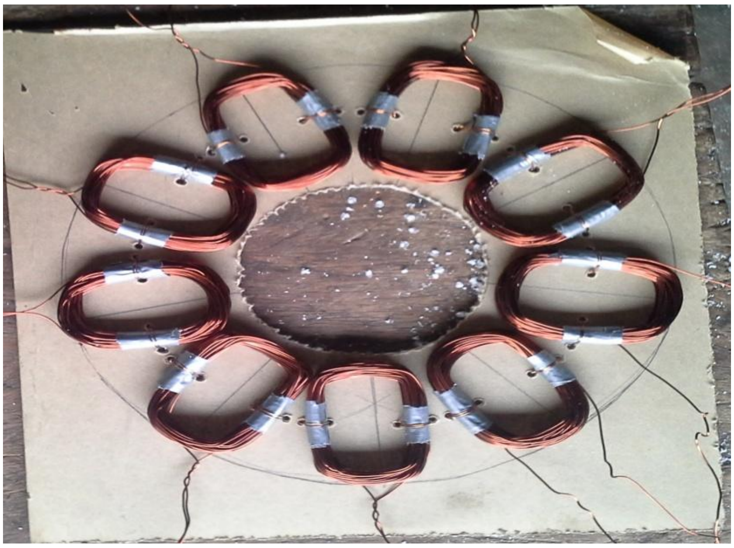

Fig7: The stator coils before attachment on the shaft

Fig8: The assembly of the wind turbine generator with tachometer to measure speed

V. Results

Tables 3 and 4 show the results of the test carried out on the generator. Table 4 shows that of no load test while table 5 shows that of 10w load test. Figures 4.1 and 4.2 are graphs deduced from the tables of results respectively.

Table 3: No load test

Speed (RPM)	Volt (V)
146.5	1.5
200.1	1.8
302.1	3.5
405.7	4.3
507.1	5.6
600.1	6.5
705.4	7.0
813.2	9.2
900.1	10.6

Table 4:10w load test

Speed (RPM)	Volt (V)
213.6	1.6
307.2	2.7
400.3	3.7
506.1	5.0
603.2	5.9
700.1	6.9
812.2	8.0
905.0	8.5

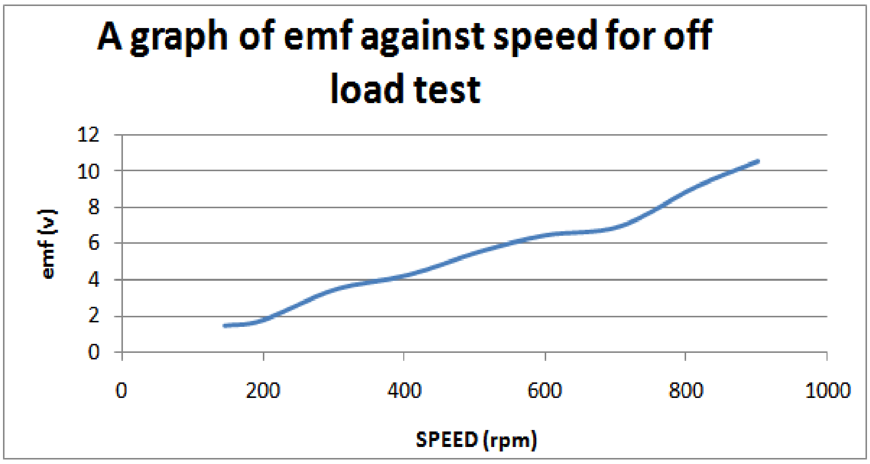

Fig 9: A graph of EMF-speed test result for the off load test

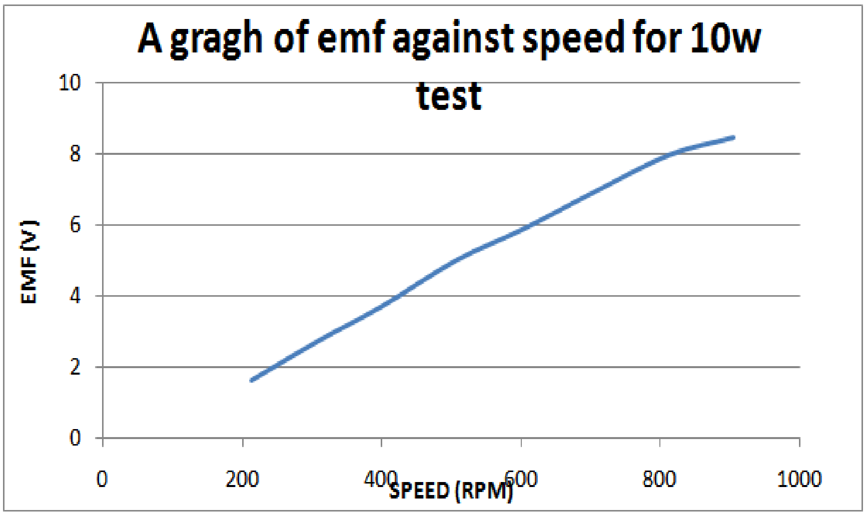

Fig 10: A graph of EMF-speed test for the load test

VI. DISCUSSION

During the no load test as shown in the result table, it was observed that at speed of 146.5 rpm, a voltage of 1.5 was recorded, at 200.1 rpm, 1.8 was recorded up to 900.1 rpm which was the highest speed recorded for the shaft with a corresponding voltage of 10.6v. At the on load test, it was also observed that at the speed of 213.6 rpm, an emf of 1.6v was recorded. At 307.2 rpm, 2.7v was produced up to the maximum speed of 905.1 rpm with an emf value of 8.5v.

From the graphs in fig 9 and 10, the voltage is seen to have been increasing with the speed for both tests. Generally, the test showed that the voltage produced in the on load condition even at highest speed for all test carried out is lower than that of the no load condition.

From the above test, the maximum power generated was

$P=IV$

$P=6.25x10.6$

$= 66.25w$

Percentage of obtained result was calculated as;

Obtained power/expected power x 100

(66.25/300) x100 =22.1%

From the data collected during the testing, the efficiency of the turbine was found to be 22.1% of the expected power which means that the power generated is less than the expected power. The power generated was not enough to explore the magnetic strength of the magnets maximally; this is because the windings in the coils were relatively low compared to the magnetic strength of the magnet. The choice of materials was made based on the properties of the materials and their intended use. Mild steel used for the rotor disc was chosen because it is weldable, very durable (although it rusts), it is relatively hard and is easily annealed. It is also a less expensive kind of steel and magnetizes well. The mild steel was 10mm thick to concentrate all the magnetic flux on one side of the plate thereby preventing flux leakage and wastage through the back.

There are several errors observed while test running this project work. These errors are mostly technical errors in machining and unavoidable human errors. Again, one of the rotor wheels is seen to be wobbling while running and rolling back in the opposite direction when it is about to halt. The rolling back of the rotor causes the generator to require high starting torque from the driving device to start the rotors.

VII. CONCLUSION

The design and construction of permanent magnet synchronous generator for small horizontal axis wind turbines was carried out and tested successfully. The power generated was less than expected because the number of windings in the stator coil is relatively small compared to the strength of the magnet. A three phase stator was constructed which allows voltage output using electromagnetic flux interaction.The shaft was successfully designed to carry the rotor and was capable of having smooth rotation. As a cost reduction measure, the quantity of neodymium permanent magnet used was significantly reduced by reducing the air gap to the barest minimum before the rotor discs start rubbing on the stator coils.

The generators under steady conditions with constant AC frequency (f), the machine speeds (n) is equal to the synchronous speed (ns) and are related by:

$n = n_s = 120f/p$ where p = no of poles of the magnets.

The voltage generated by the permanent magnet generator was determined by a number of factors including the magnetic field strength of the permanent magnet, the number of turns of the stator and the rotational speed of the rotor. Also, as the rotor is provided with sealed permanent magnets by casting, it is resistant to the effects of possible dirt ingress. However, if not fully sealed, the permanent magnets will attract ferromagnetic dust and metallic swarf which may cause internal damage.

Permanent magnets were used because they produce a high magnetic field with a low mass, and are stable against the influences which would demagnetize them. The permanent magnet generator is a good choice for small scale wind turbine systems as they are reliable can operate at low rotational speeds and provide good efficiency especially in light wind conditions as the cut-in point is fairly low. In the absence of commutating brushes and slip rings, the permanent magnet generator does not require regular maintenance as the other versions that carry carbon brushes which not only require regular replacement as they wear out but also have the tendency to produce electrically conductive carbon dust in the machine.

Part of the simplicity in the design of the permanent magnet generator is the mounting of the turbine blades directly on the generator shaft without the complication of gearing and the associated losses. With brushless permanent magnet generator, there is no need for DC current excitation as in the synchronous machine. However, magnets are still quite expensive and to reduce the quantity required for a given design, the air gap between the two rotor plates is minimized for maximum efficiency and cost reduction. Although the permanent magnet design is simpler, more durable, it does not allow control of magnetic flux production hence excitation because the rotor flux attains its maximum efficiency at one pre-defined wind speed.

It is advisable to place a wooden wage on the rotor disc resting on the table with the magnets facing up as a precaution against the two discs carrying opposite magnetic poles jamming together and smashing the fingers as a safety measure in handling of neodymium magnets because they are very strong and can cause serious personnel injuries during the generator assembling, It is as well necessary to remove all sharp steal objects within the vicinity that the assembling is taking place. The neodymium magnets are very brittle that they break by a simple knock or drop so it is necessary to handle with care. Ensure that two of the magnets never get near each other otherwise one may never pull them apart. If accidentally they glue together pulling them apart may not work is not the best approach rather twisting them carefully may separate them.

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