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DESIGN AND DEVELOPMENT OF AXIAL FLUX COMPACT PM WIND GENERATOR

[1]H. PRAVEEN, [2]Dr.U.K.CHOUDHURY,

[1]PG Scholar, Department of EEE, Chaitanya Bharathi Institute of Technology Gandipet, Hyderabad

[2]Professor,Department of EEE, Advisor- Innovations& Incubation, ChaitanyaBharathi Institute of Technology Gandipet, Hyderabad

Abstract: The technical paper proposed here covers the conceptual design, detailed design, simulation, and manufacturing aspects of a single stator sand witched between double rotor with axial-flux type construction with embedded permanent-magnet to form an Axial Flux generator. In addition, to magnets with magnetisation along the generator axis, the proposed structure is provided with magnets which were magnetized circumferentially i.e along thickness and pasted on the rotor surface. The electromagnetic design of the axial-flux generator was evaluated against the technical specification and design parameters. For designing the Axial Flux Generator the number of poles and coils, as well as the outer diameter was decided based on the frequency , Voltage and power output. It may be mentioned here that the axial length of the new generator is shorter compared to conventional generator. Simulations were carried out by comparing the generators parameters and out output such as air-gap flux density, torque, electromotive force, Current and power output etc. Testing was carried out on the prototype. It may be mentioned that the output of the calculated results were compared with the tested values. They compared reasonable well and we could find some differences due to air gap variation.

IndexTerms **-** Axial flux permanent magnet wind generator(AFPMWG), Axial flux, Simulation, Generator.

I. INTRODUCTION

Modern society's increasing energy demands have necessitated significant investments in renewable energy sources, involving substantial technological innovation and capital. Wind energy has recently emerged as a particularly appealing renewable energy source, with global wind energy power plant capacity reaching 158gigawatts by the end of 2009. The focus on electricity generation places specific requirements on electrical machinery and drives. Notably, the challenge of harnessing mechanical energy from renewable sources has driven technological advancements in induction machines and permanent magnet synchronous generators. The author underscores the substantial room for growth in renewable energy, given that wind energy currently accounts for a mere 0.3% of global energy consumption. The primary aim of this thesis is to develop a suitable permanent magnet synchronous generator (PMSG) for use in conjunction with a vertical axis wind turbine. This wind energy conversion system operates on the principle of variable speed. Unlike larger wind turbines, which often incorporate blade pitch mechanisms, small-scale wind turbines typically do not use such mechanisms. Instead, they employ power electronics converters to compensate for variations in wind speed, which ultimately enhances their power efficiency. The specific design of the PMSG in this system is a surface-mounted machine with a concentrated winding. This winding configuration is well-suited for low-speed applications, as it allows for the easy implementation of a high number of poles. The main advantage of having a high number of poles is that it eliminates the need for gearboxes. Gearboxes tend to reduce the overall system's reliability and generate a significant amount of user-unfriendly noise. The design also prioritizes reducing magnetic noise generated by the machine. Furthermore, the chosen PMSG topology can be readily scaled by increasing the machine's length. Importantly, the design process places a significant emphasis on minimizing manufacturing costs and the cost of active materials as part of the objective function.

II. DESIGN PARAMETERS

Table1. design parameters of AFPM wind generator.

SERIAL NO	PARAMETERS	CONSIDERED VALUE
1.	Power Rating	100 w
2.	Tip speed Ratio	6.25
3.	Frequency	66 hz
4.	Wind speed	5 m/s
5.	Outer diameter of stator	200mm
6.	Inner diameter of stator	40mm
7.	Outer diameter of rotor	200mm
8.	Inner diameter of rotor	85mm
9.	No of Poles/Magnets	8
10.	No of coils	6
11.	velocity	5
12.	Generator topology	Single stator double rotor
13.	Purpose	For M.E college project

III. DESINGN MATHEMATICAL CALCULATIONS

1.Calculating Turbine Rotor RPM(N): $N = \frac{120*frequency}{poles}$

$$N = \frac{120*66}{8}$$

Approximately 990 rpm is consider to design

Number of poles/magnets are = 8

for calculating flux of magnet A).Total flux(φ_T) = Total magnets area* flux density

Selected magnet sizes are

Length of magnet =21mm
Width of magnet = 13mm
Height of magnet = 5mm
Weight of magnet = 300gm
Ndfeb and N35 magnet type is used here
Flux density is 0.3

B) Magnet area =$l_m * w_m$

$= (21*10^{-3})*(13*10^{-3})$

=0.000273 m

C).All magnets area = One magnet area *number of magnets

= 0.000273*8

= 0.0021sq.m

D).Total flux= all magnets area *flux density

= 0.0021*0.3

= 0.0006 wb

E).No of turns per coil (Nc) = 300 (assumed)

2.Calculation of voltage : by using the below formula we can calculate the average voltage

induced emf = number of turns*4.44*frequency*winding factor*flux density

=300*4.44*66*0.95*0.0006

= 50 v (ac voltage)

for dc voltage =50*$\sqrt{2}$

=70.71v

Resistance (ohm) = 50 0hm

a) from ohms law V=IR

$$\mathbf{I} = \frac{V}{R}$$

$= \frac{70.71}{50}$ =1.42 A

b) Output power(P) = V*I

= 70.71*1.42

= 100.40watts

IV. MANUFACTURING PROCESS

for making of the stator, follow these steps

A .Wind Coils: Wind six coils of enameled copper wire according to the design specifications outlined in the Auto-CAD drawing. Enamel-coated copper wire is used due to its electrical insulation properties.

Fig1.single winding coil

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Fig2.winding coils

B. Apply Cotton Tape: Wrap each coil with cotton tape. The purpose of this step is to achieve tightness and provide mechanical strength to the coils. This tight winding is crucial to maintain the coil's shape and integrity during operation. Then connect the 6 coils in series star connection and then test in the laboratory after the testing of coils you can assembly in the stator as per calculation.

for making rotor follow these steps:

1) Start to place the magnets on the rotor disk with the help of aralditeglue and feviquick perfectly balancing the rotor.

2) Now place the magnets on the rotor based on the calculation process.

3) Generator Assembly Process:

Using the workshop drill machine, begin drilling holes in two MS flat pattis to secure the stator and rotor to the shaft. To ensure smooth disc spinning, take the rotor magnet disc and place a bushing in its centre and on its rear. After that, attach the base MS flat patti to the shaft-fixed bottom bearing. Next, install the rotor and discount the shaft before testing the generator. took the plywood surround and cut it to a diameter that is significantly larger than the outside diameter of the stator disc. Next, the surround is attached to the base piece. The star-connected coil assembly is then inserted into the newspaper-covered hole in the surround. Subsequently, araldite epoxy resin and hardener are combined in a cup and applied to the coil assembly inside the surround until every coil is fully submerged in the resin. Condense it Using a drill machine in the workshop, start by drilling holes in two flat steel plates so that the stator and rotor are attached to the shaft. To ensure smooth spinning, take the magnetic disc of the rotor and mount a bush to the backside, centering it over the disc. Place the rotor disc on the shaft after attaching one of the flat steel plates to the bottom bearing that is connected to the shaft. Let's test the generator now. Next, cut a plywood surround so that its diameter is more than the stator disc's outer diameter. Line up the surround with the base component. After that, carefully place the star-connected coil assembly into the surround's hole and cover it with newspaper. Lastly, combine the hardener and Araldite epoxy resin in a cup and pour the mixture onto the coil assembly inside the surround, making sure that every coil is well submerged in the resin.

The next step in the manufacturing process of the AFPM generator involves assembling the stator and rotor components on the shaft, using bearings, MS flat patti (metal plates), and nuts and bolts.

V. ASSEMBLE PROCESS

Allow the Castings to Dry: After the stator and rotor discs have been prepared, let them dry for an entire day to ensure that any adhesives or materials used are fully set and cured. Once dry, proceed with the assembly process.

Fix Castings to MS Flat Patti: Create holes in the castings to allow them to be securely fixed to the MS flat patti (metal plates). This ensures a stable connection between the stator and rotor components and the supporting structure.

Install Bearings: Attach bearing to the base of the shaft and another bearing to the top of the rotor disc. The bearings are critical for smooth rotation and support of the rotor disc on the shaft.

Position Stator Disc: Place the stator disc onto the shaft, ensuring that the stator and rotor discs are positioned with a balanced mechanical distance of 5mm between them.

Fix Stator Disc to Base Plywood Piece: To secure the stator disc in a stationary position, attach it to a rectangular plywood piece, This plywood piece serves as a stable base for the stator disc.

Terminate Electrical Connections: Ensure that the three electrical terminals (R, Y, B) and a neutral terminal are brought out from the casted stator disc. These terminals are essential for testing and electrical connections to the generator. The electrical connections can be made at this stage to complete the generator's electrical circuit.

Balance the Generator: To maintain stability and balance in the generator assembly, fix a rubber bush (black bush) to the base plywood piece. This bush helps absorb vibrations and ensures proper alignment of the components. This assembly process is a critical step in the manufacturing of the AFPM generator, as it establishes the mechanical and electrical connections necessary for its operation. Following the correct procedures and maintaining precise measurements is crucial to ensure the generator's efficiency and reliability.

Fig3**.**Final assemble of generator

VI .TESTING AND RESULTS

A) BLOWER TEST: In the blower test, a blower system is utilized to generate a controlled wind stream. The generator is exposed to the wind generated by the blower, simulating wind turbine conditions.

Data is collected to evaluate the generator's performance in generating electricity under varying wind speeds. This test allows for an assessment of the generator's efficiency in harnessing wind energy.

Table2. blower test results.

Frequency	Open Mode			Under Load			
	RPM	m/s	Voc(v)	RPM	Vload(v)	Iload(mA)	Power(W)
12	134	1.8	19.5	27	1.7	25	0.0425
20	300	2.2	37	91	5.7	80	0.456
30	440	3.6	59	183	15.2	150	2.28
40	630	4.6	80	300	29.5	250	7.375
50	790	5.7	105	410	38.8	370	14.356
Flap Mode	980	11.9	135	636	58.5	580	33.93

B) FORCED ELECTRIC DRIVE TEST

The forced electric drive test involves using an external electric drive mechanism. A prime mover, such as a drill machine, known for its high torque and low-speed operation, provides mechanical input to the generator.

This test measures the generator's electrical output when driven by the drill machine. It helps assess the generator's capability to produce electricity under artificial mechanical input condition

Table3. forced electric drive test results.

GENERATOR PERFORMANCE REPORT(Open Ckt Model)		GENERATOR PERFORMANCE REPORT(Resistance-50E)-100Watt Load			
RPM GS(WOL)	VDC	RPM GS(WL)	Vload (Volts)	Iload (Amp)	Power (Watts)
105	15.5	100	6.9	0.12	0.828
202.7	27.6	192	14	0.26	3.64
300	40.1	282	21	0.4	8.4
401	53.3	377	28	0.59	16.52
504	67.5	472	35.3	0.68	24.004
604	81.2	563	42.1	0.82	34.522
705	95.1	655	48.7	0.96	46.752
800	109	748	55.2	1.08	59.616
904.5	122.5	835	61.2	1.2	73.44
1002	136	921	66.9	1.32	88.308
1103	150	1021	72.4	1.42	102.808

By conducting these tests in a professional factory environment, it ensures a comprehensive evaluation of the generator's performance under different conditions, both as a wind-driven device and as a mechanically-driven generator. The results of these tests provide valuable insights into its functionality and efficiency.

VII. RESULT GRAPHS

A) No load test results.

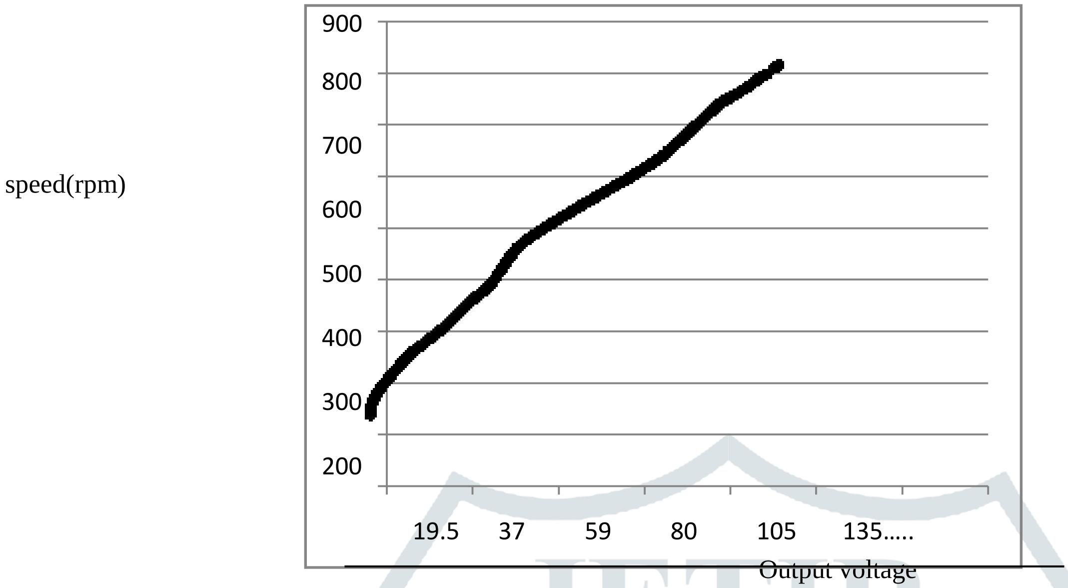

Fig 4.output voltage Vs speed

B**) Under load test results.**

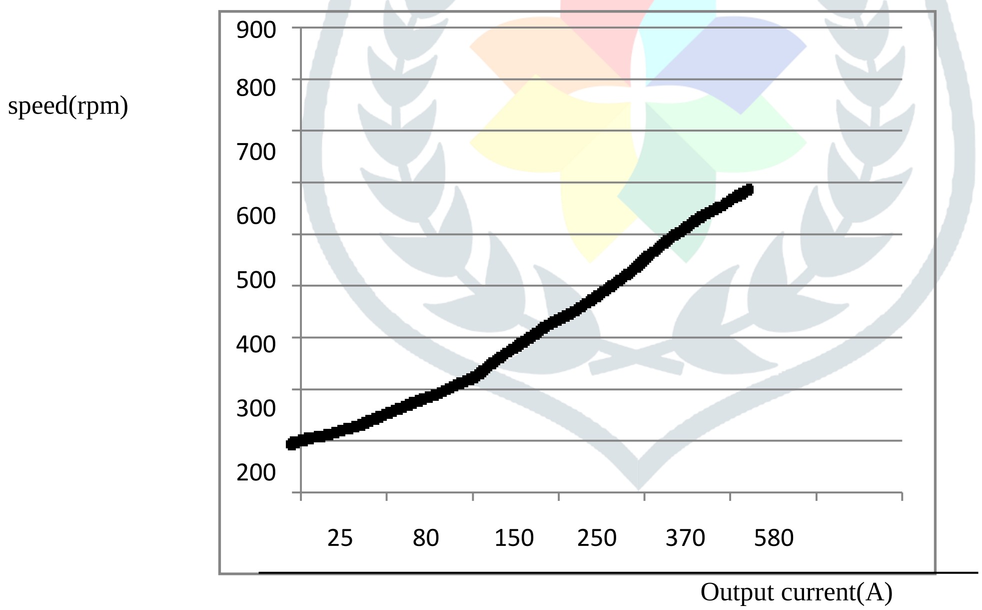

Fig 5.output current Vs Speed graph

C) **Power graph**

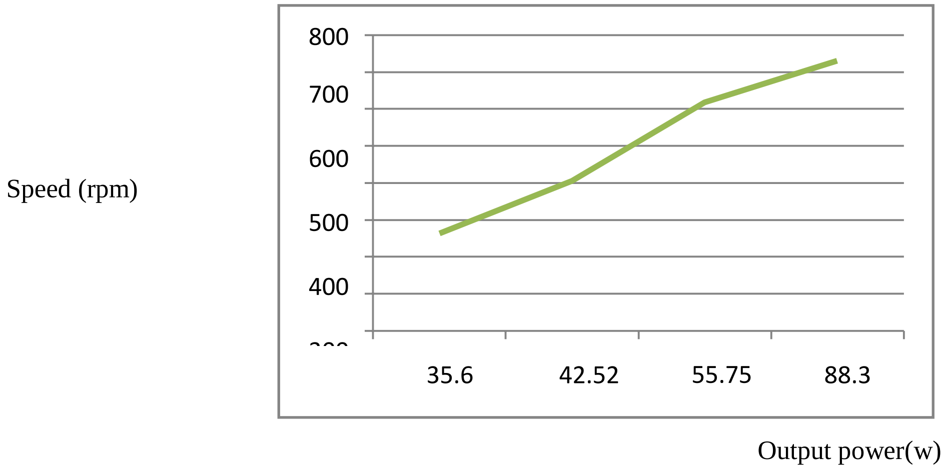

Fig 6.output power Vs Speed

VIII .SIMULATION BLOCK DIAGRAM AND RESULTS

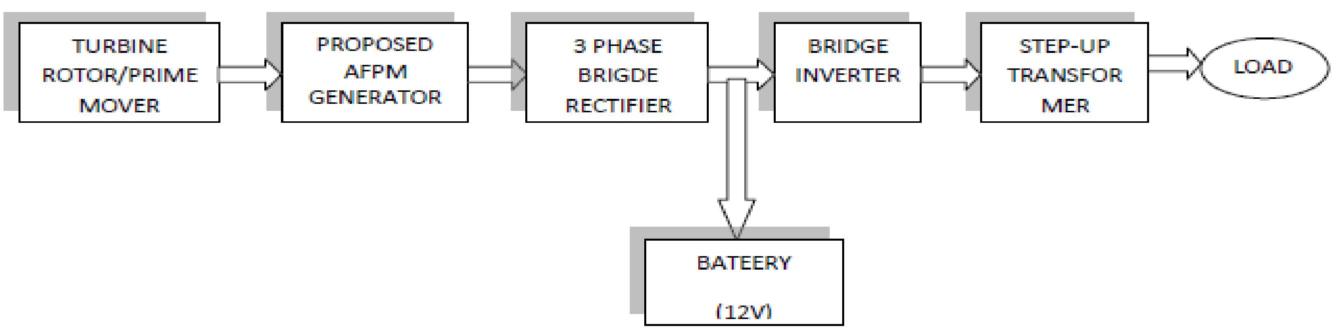

Fig 7.block diagram of AFPM wind generator.

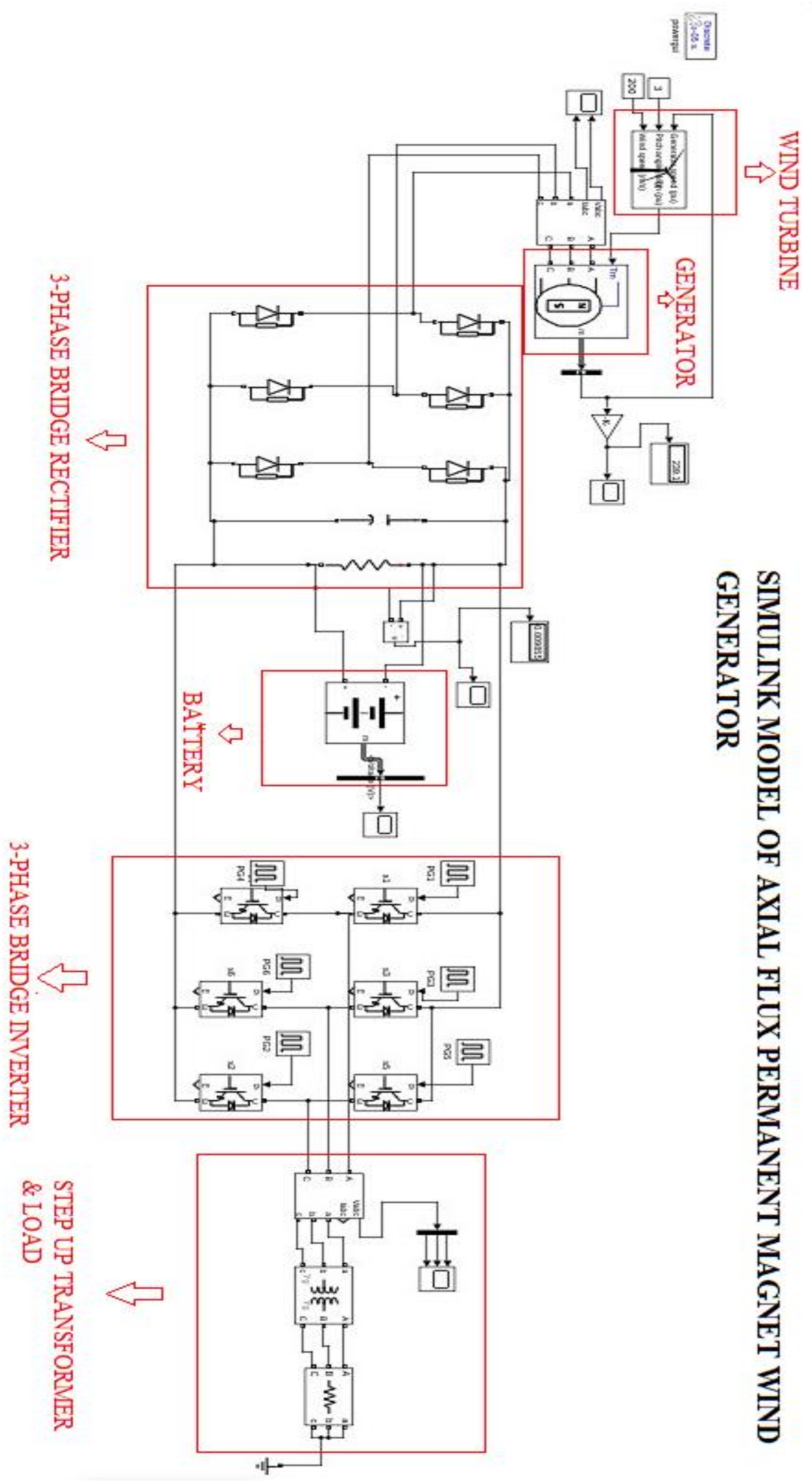

Fig 8.simulation block diagram of afpm wind generator.

IX. SIMULATION RESULTS

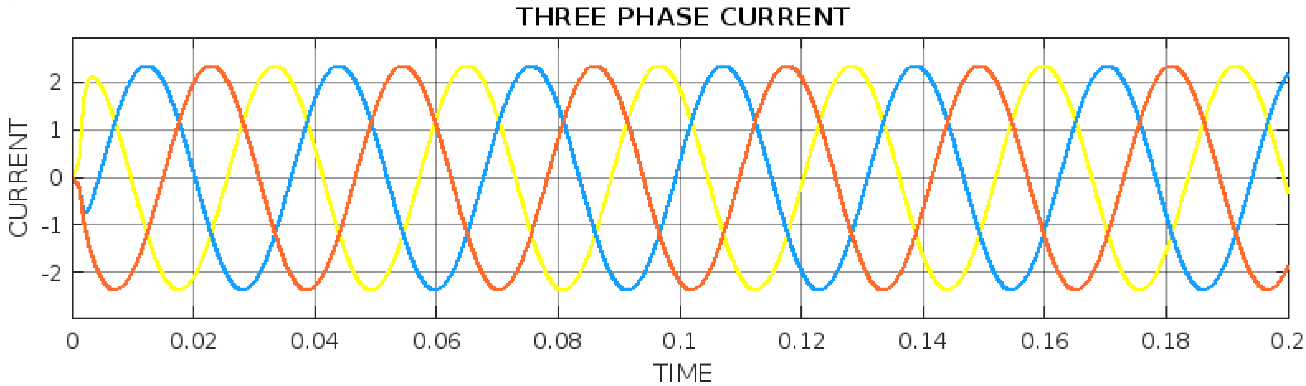

Fig 9.shows three phase current.

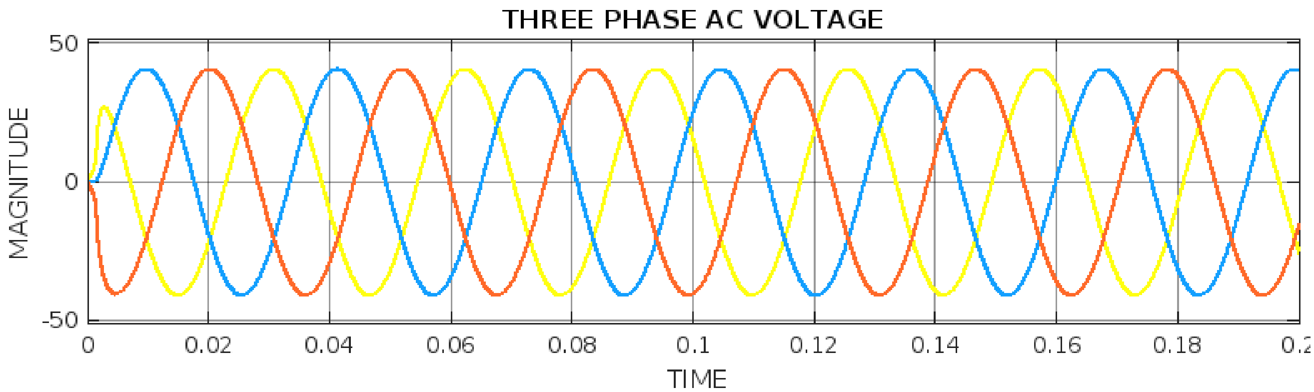

Fig 10.shows three phase ac voltage.

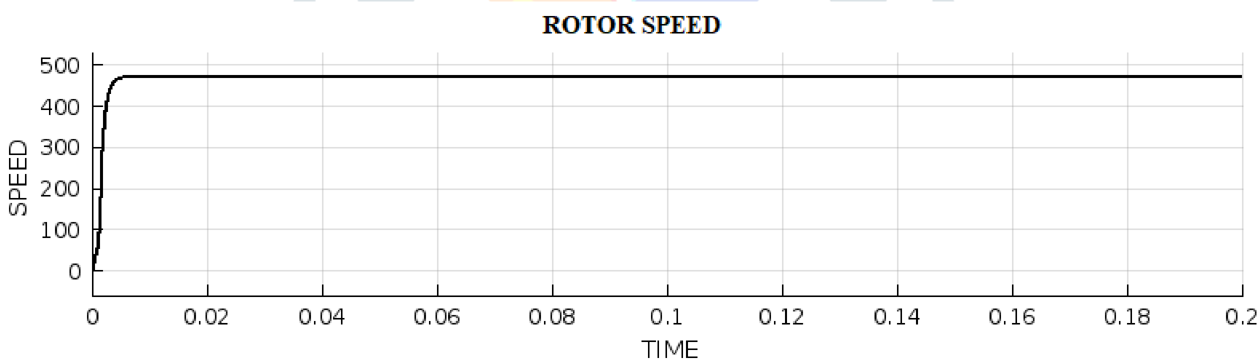

Fig11.shows rotor speed.

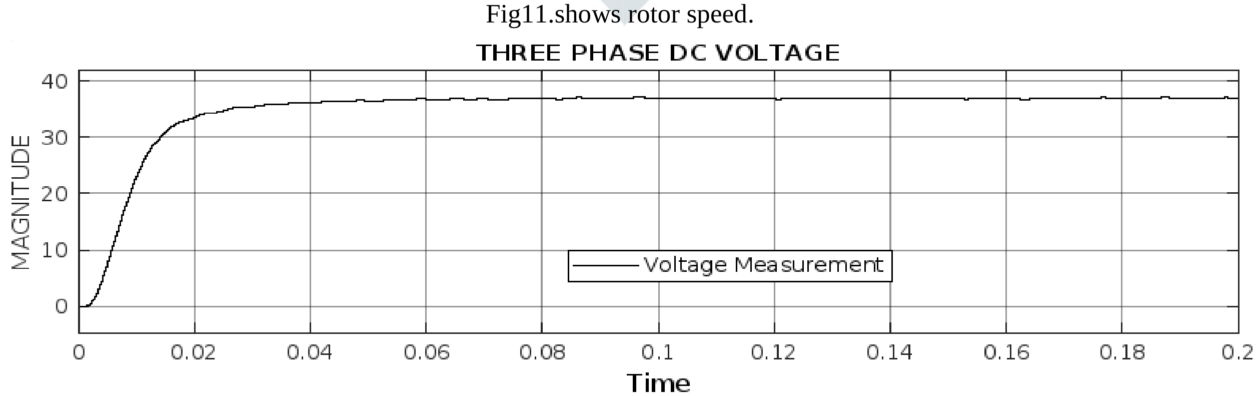

Fig12.shows three phase dc voltage.

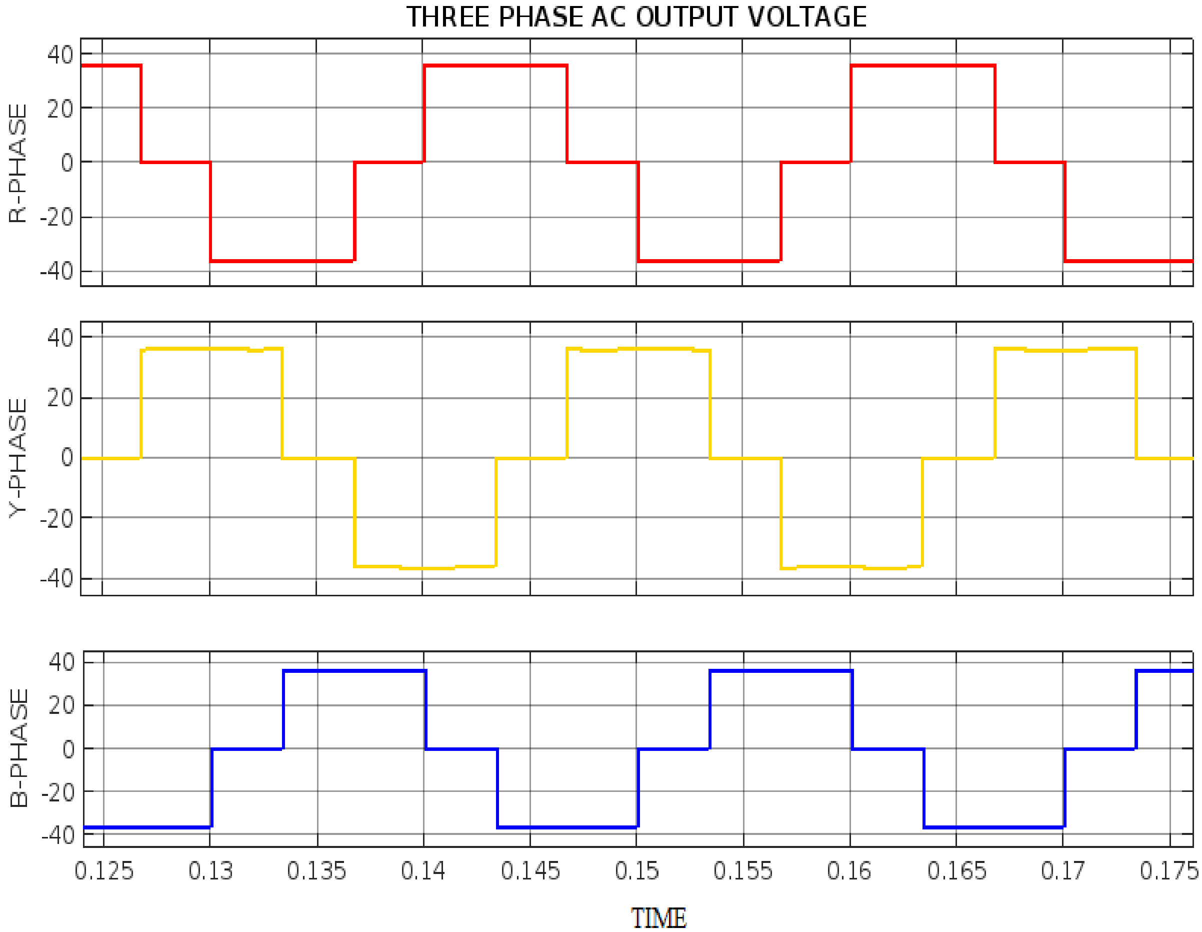

Fig13.shows three phase ac output voltage.

CONCLUSION

The process for developing a single stator double rotor AFPM (Axial Flux Permanent Magnet) generator begins with a theoretical design phase, where mathematical formulas are utilized to determine the generator's specifications. Subsequently, the generator is constructed in the Wind Stream factory with the aid of both electrical and mechanical tools. It is then operated by a prime mover at a calculated wind speed. Two distinct tests are conducted on the generator: the blower test and the forced electric drive test. The results are collected and analyzed through observation tables and graphs. However, the practical outcomes obtained from the project do not align precisely with the theoretical calculations and design. Several factors contribute to this disparity, Increased Air Gap, Imperfections in Cutting,Improper Resin Pouring.

FUTURE SCOPE

The future prospects for the single stator double rotor axial flux permanent magnet (AFPM) generator show promise for large-scale electrical energy generation with specific modifications. These adjustments includeAdvancements in Mechanical Design , Utilizing High-Quality Epoxy Resin ,Addition of an Extra Motor Rotor Magnet disc.

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