Performance Enhancement of PMSG Based Wind Energy Conversion System: Experimental Analysis

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Abstract: Wind energy is a hopeful renewable energy which is used to generate electricity. The kinetic energy present in the wind is converted into electrical energy by the principle of Wind Energy Conversion System. This effort approaches the performance enhancement by re-design, re-fabrication, and re-implementation of Permanent Magnet Synchronous Generator-based wind energy conversion system and data logging system. PMSG connected to the wind turbine converts wind power into electricity. The proposed hardware design of PMSG aims to achieve the overall improved efficiency of the wind turbine by 7-10% of the existing hardware design. In the proposed design of PMSG overall efficiency was improved by increasing the magnet grade, reducing the air gap, and changing the winding type. A web dependent supervising system has been recognized. A data logging system was used for collection of data on wind speed, generating power, and other related data. Besides, the stored data can be observed through the website depend on data showed by the Global System for Mobile Communications. So, the user can monitor related data through the website. The Load Management System was used to balance the supply of electricity.

KEYWORDS: Magnet grade, Gauss value, Airgap, Permanent Magnet Synchronous Generator (PMSG), Global System for Mobile Communication (GSM).

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INTRODUCTION

In power production for the past era the Wind power generation has been under the attention and an incredible amount of exploration exertion is working on renewable energy, specifically on wind power generation. Wind energy offers an ecological power generation.

The proposed work was about enhancing the performance of the Permanent Magnet Synchronous Generator (PMSG) set up with a new hardware design. Similarly, the data logging system interconnected with the generating system has also to be modified.

Sintered Neodymium Iron Boron (NdFeB) magnet was used in PMSG design. Sintered NdFeB magnets are strong permanent magnets made of an mixture of Neodymium, Iron, and Boron. NdFeB magnets will oxidize rapidly, so an anti-corrosive coating is needed to protect the substrate. Neodymium magnets are graded by the maximum strength they can be magnetized to. If the magnet grade number is higher, then the magnet is more stronger. So, the performance of PMSG can be enhanced by using a higher-grade magnet.

The Gauss value of magnet also increased in the proposed design. Gauss denotes the number of magnetic field lines emitted by a magnet per square cm. Since the value of Gauss is higher, the additional lines of magnetic field produced by the magnet. So, EMF induced by the PMSG was increased.

The air gap is one of the important factors in designing a machine. The air gap is nothing but a space between the outer surface of the rotor and the inner surface of the stator. In the proposed design, the air gap value of PMSG was reduced when compared to the existing design. If the air gap is reduced, resistance to flux flow decreased, flux distribution increased and so EMF induced by PMSG was increased. It is understood that the air gap is inversely proportional to power factor and efficiency. So, a reduced air gap increases the power factor and efficiency.

Windings used in the proposed design were lap winding whereas in the existing design concentric winding was used. In lap winding, the number of poles is equal to the number of parallel paths in the armature circuit. The conductors are in many slots under a single pole due to this arrangement smooth sinusoidal EMF waveform is obtained. Even though distributed armature winding diminishes EMF, still it is worth due to weakens harmonic EMF and so the waveform is enhanced. Armature reaction also reduced by distributed winding. Uniform spreading of conductors supports for improved cooling. Lap winding is usually required for large current applications because it has a more parallel path. The turns and thickness of the winding wire were increased to increase the turbine efficiency.

The Data loggers are electronic devices that routinely screen and store ecological limitations over time, permitting the condition to be calculated, recorded, examined, and authenticated. A sensor is present inside the data logger to receive the information and a chip is used to hold it. Then the information stored in the data logger is transported to a computer for examination. An electronic data logger is more real, exact, and consistent when compared to a episodic physical reading. Load management is the process of balancing the supply of electricity.

LITERATURE SURVEY

Raja Ram Kumar, et al [1] have proposed an Enhanced Magnetic Circuit model for the optimum design and the Five-Phase, Permanent Magnet Synchronous Generator (FP-PMSG) based wind power features are estimated. For quicker result generation capabilities, the IMC model was favored along with the Finite Element Method. The optimal designing and performance estimation of FP-PMSG was proposed by considering limitations such as leakage fluxes, rotor and stator material properties, properties of sleeve material of rotor permanent magnet, armature reaction, and the effect of saturation.

Warda Gul, et al [2] discussed the simulation model of a double-stator single-rotor permanent magnet synchronous generator (DSSR PMSG). A 5MW DSSR PMSG was developed in proposed model with the second-generation double-layered fractional slot concentrated winding (FSCW), which diminishes huge primary funding, size, and weight, in contrast to the regular huge direct drive (DD) generators for wind turbines.

Mohammad Jahanpour, et al [3] studied the Permanent Magnet Synchronous Generator-based Wind Energy

Conversion Systems. In this the basic features of both the vector control and direct torque control methods are combined into a consistent and efficient control system to deliver enhanced machine performance.

Shengquan Li, Juan Li [4] discussed a direct-driven Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion System (WECS) with variable speed. In this proposed work the external and internal disturbances are considered in Wind Energy Conversion System to provide a Predictive Active Disturbance Rejection Control (PADRC) strategy for a direct driven PMSG based WECS, for widen the wind power evocation.

Y. Liu, et al [5] have designed a 10 MW DC generator with the copper-based armature winding on the rotor. The comparison and analyzation were carried out between double layer lap winding and concentric winding for an appropriate configuration of the armature winding. The 2-pole was used on commutation to clarify the difference between the lap winding and concentrated winding.

Hongwei Fang, Dan Wang [6] discussed a new design of permanent magnet synchronous generator (PMSG). In this proposed work the whole design procedure was unchanged from old-style design, material cost also remain same but the output power of PMSG was obviously improved and, an improved output power scheme is determined by adjusting the Permanent magnets shape with the change of mechanical pole-arc coefficient.

Chun-Chieh Wang, et al [7] discussed about the NdFeB magnets property like corrosion resistance. It was upgraded by direct thin film treatment of NiCrAlV and NiCrAlVN in a sintered NdFeB magnet surface. To study the microstructure of the thin films X-ray diffraction and transmission electron microscopy are used. The other properties of the thin film were examined.

EXISTING DESIGN OF PMSG BASED WIND ENERGY CONVERSION SYSTEM

In the existing design of PMSG based wind energy conversion system, NdFeB Neo Dymium Iron Boron magnet of the grade N35 was used. As I mentioned early Neodymium magnets are graded by the maximum strength they can be magnetized. Grades of NdFeB magnets are N35, N40, N42, N45, N48, N50, N52. Among these N35 grade was used in the existing design. Since it is a lower grade when compared to others the strength of the magnet is reduced and so, magnetic flux is also reduced.

The properties of magnet N35 are discussed below. Residual flux density measured in Kilo Gauss Br (KG) value is 11.7-12.2, External force required to demagnetize measured in Kilo Oersteds HCB (KOe) value is ≥ 10.9, Intrinsic Coercive force of the material HCI (KOe) value is ≥12. 0, Maximum Energy product measured in Mega Gauss Asteroids BH Max (MGOe) value is 33-36 and the Maximum Operating Temperature measured in Celsius/Fahrenheit Tmax value is 80C/176F. Magnets are rated by Gauss. The Gauss value of this magnet was 15000-16000T. Since the value is lower compared to the proposed design, lines of magnetism emitted by the magnet were reduced.

In the existing design, the Airgap value is 5.0 mm which is higher than the proposed design. Increased airgap leads to increased leakage flux, increased reluctance, reduced flux distribution, and reduced EMF induced.

In the existing design windings used were concentric winding. The concentric winding has the drawbacks like even when supplied with ideal current, harmonic fields are produced at the machine air gap which is capable of inducing losses due to eddy current in permanent magnet and consequent overheating. This winding provides determined output voltage, but not precisely sinusoidal since independent of pitch factor and distribution factor. In the existing design, the generator magnets are fixed with glues in the rotor with equal distance.

Table 1: Parameters of existing PMSG based WECS

Number of poles	48
Rated speed	300 rpm @ 11m/s
Rated current	35 A
Rated power	1.8 KW

Table 1 denotes the parameters of the existing PMSG based Wind Energy Conversion System. In this table, the value of rated speed, rated current, rated power, and the number of poles is given.

3.1 TEST RESULTS OF EXSISTING PMSG

The following tables represent the test results of the existing PMSG.

Table 2: Star connection under no- load condition

Speed(RPM)	V_L(RY)	V_L(YB)	V_L(BR)
75	43.74	42.66	42.12
100	64.8	63.2	62.4
125	80.5	78.21	78.78
150	96.39	94.8	92.82
175	107.73	109.81	107.64
200	129.6	124.82	124.8
225	145.8	142.99	141.18
250	161.19	158	156
275	178.2	173.8	172.38
300	194.4	188.02	185.64

Table 2 shows the test result of existing PMSG during star connection under no-load condition.

Table 3: Star connection under load condition

Speed (RPM)	V_L (RY)	V_L (YB)	V_L (BR)	V_{DC} (V)	I_{DC} (A)
80	26.4	26.73	26.4	34.15	0.129
100	31.2	31.59	31.2	41.1	5.52
125	36	36.45	36	47.12	9.9
150	40	40.5	40.8	53.19	14.97
175	42.4	42.93	42.4	55.74	21.70

Table 3 shows the test result of existing PMSG during star connection under a load of 48V DC bank.

Table 4: Delta connection under no-load condition

Speed(RPM)	V_L(RY)	V_L(YB)	V_L(BR)
75	27.65	27.65	28
100	33.18	33.18	33.6
125	44.24	43.45	44.8
150	52.14	53.72	53.6
175	59.25	57.67	58.4
200	70.31	70.31	70.4
225	79	79.79	81.6
250	88.48	88.48	89.6
275	98.75	98.75	100
300	106.65	106.65	108

Table 4 shows the test result of existing PMSG during Delta connection under no-load condition.

Table 5: Delta connection under load condition

Speed (RPM)	V_L (RY)	V_L (YB)	V_L (BR)	V_{DC} (V)	I_{DC} (A)
50	27.65	27.65	28	36.36	0.127
75	36.34	36.34	36.8	47.57	5.298
100	37.92	38.71	39.2	49.71	10.622
125	41.08	41.08	41.6	53.98	15.88
150	42.66	42.66	43.2	56.11	16.90
175	43.45	43.45	44.8	57.18	20.84

Table 5 shows the test result of existing PMSG during delta connection under a load of 48V DC bank.

PROPOSED DESIGN OF PMSG BASED WIND ENERGY CONVERSION SYSTEM

The proposed design of PMSG has a NdFeB Neo Dymium Iron Boron Magnet of N45 grade. The grade of the magnet was increased in the proposed model. Since the grade is higher the stronger the magnet was increased. The properties of magnet N45 are discussed here.

Residual flux density measured in Kilo Gauss Br (KG) value is 13.2-13.8, External force required to demagnetize measured in Kilo Oersteds HCB (KOe) value is ≥ 11.6, Intrinsic Coercive force of the material HCI (KOe) value is ≥12. 0, Maximum Energy product measured in Mega Gauss Oersteds BH Max (MGOe) value is 43-46 and the Maximum Operating Temperature measured in Celsius/Fahrenheit Tmax value is 80C/176F. The advantages of using higher grade magnets were material's ability to retain a magnetic field after being magnetized, resistance to external and internal magnetic force without being changed, materials maximum magnetic strength after the magnet is fully saturated by external magnetic field all these factors were increased due to higher grade magnet.

The Gauss value of the proposed design was 17500-19000T. Gauss value was increased in the proposed design, so higher magnetism was emitted by a magnet. Since the proposed design has a higher-grade magnet and increased gas value, the magnetic flux increased by 5-10% increase the turbine efficiency.

In the proposed design the air gap between stator and rotor was reduced to 4.1mm. It is well known that a reduced air gap leads to reduced reluctance, increased flux distribution, increased EMF production, and improved power factor.

In the proposed design, windings used were lap winding whereas in the existing design windings used were concentric winding. All the above-mentioned drawbacks in concentric winding were overcome by lap winding. Lap winding is usually required for large current applications because it has a more parallel path. The turns and thickness of the winding wire will increase to increase the turbine efficiency.

In the proposed design, magnets were fitted into the rotor with equal distance from specially designed laser-cutting magnet holding rings. The possibility of dislocation of magnets was almost nil by making this alteration. So, the output of the generator was reliable and guaranteed. In the proposed design, slip ring assembly was fitted on the yaw top to take the output from the wind turbine whereas in the existing design slip ring assembly was fitted on the yaw center middle to take the output from the wind turbine. Due to this arrangement, we have the advantage of easy servicing and replacement.

Table 6: parameters of proposed PMSG based WECS

Number of poles	48
Rated current	35 A
Rated power	1.8 KW
Rated speed	225 rpm @ 10.4m/s
Cut in speed	4.5 m/s
Cut out speed	16 m/s

Table 6 signifies the parameters of the proposed PMSG based Wind Energy Conversion System. In this table, the value of rated speed, rated power, rated current, the number of poles, cut-in speed, and cut-out the speed of the wind turbine is given. Figure 1 represents front view of the re-designed PMSG.

4.1 TEST RESULTS OF PROPOSED PMSG

The following tables represent the test results of the proposed PMSG.

Table 7: Star connection under no-load condition

Speed(RPM)	V_L(RY)	V_L(YB)	V_L(BR)
75	54	54	54
100	80	80	80
125	100	99	101
150	119	120	119
175	133	139	138
200	160	158	160
225	180	181	181
250	199	200	200
275	220	220	221
300	240	238	238

Table 7 represents the test result of re-designed PMSG during star connection under no-load condition.

Table 8: Star Connection Under Load Condition

Speed (RPM)	V_L (RY)	V_L (YB)	V_L (BR)	V_{DC} (V)	I_{DC} (A)
80	33	33	33	50	0.1
100	39	39	39	52	4.8
125	45	45	45	57	9.1
150	50	50	51	60	15.3
175	53	53	53	63	21.7

Table 8 represents the test result of re-designed PMSG during star connection under a load of 48V DC bank.

Table 9: Delta Connection Under No-load Condition

Speed (RPM)	V_L (RY)	V_L (YB)	V_L (BR)
75	35	35	35
100	42	42	42
125	56	55	56
150	66	68	67
175	75	73	73
200	89	89	88
225	100	101	102
250	112	112	112
275	125	125	125
300	135	135	135

Table 9 represents the test result of re-designed PMSG during delta connection under no-load condition.

Table 10: Delta Connection Under Load Condition

Speed (RPM)	V_L (RY)	V_L (YB)	V_L (BR)	V_{DC} (V)	I_{DC} (A)
50	35	35	35	51	0.1
75	46	46	46	55	5.1
100	48	49	49	58	10.1
125	52	52	52	61	14.1
150	54	54	54	63	17.9
175	55	55	56	64	21

Table 10 represents the test result of re-designed PMSG during Delta connection under a load of 48V DC bank.

Figure 1: Front view of Redesigned PMSG

Figure 2: Final setup of PMSG based WECS

Figure 3 Connection of Brake, microcontroller, Dump load, Battery, and Inverter

Figure 2 represents the final setup image of PMSG based WECS. Figure 3 represents the connection of brake, micro-controller, battery, and inverter system used in PMSG based Wind Energy Conversion System. Brakes are used in WECS in the case of power transmission maintenance or power generator rest, and in an emergency. The micro-controller in WECS has the diode rectifier inside. The generated output power from WECS is AC in nature, this AC power is transformed into DC power by the diode rectifier. The converted DC power is stored in a 48V DC battery bank. The inverter connected to the battery will convert the stored DC power into AC power and give supply to the load. If the battery is fully charged, then the remaining power is flowing to the dump load, here the power is emitted as heat.

Figure 4 Data logger and Load Management System

Figure 4 denotes the data logger system and load management system used in the PMSG based Wind Energy Conversion System. In this work wind speed, generated voltage, generated power, frequency, and other related data are monitored, stored, and recorded. It can routinely calculate the electrical output from any kind of transducer and record the value. The physical data is converted into electronic signals through the sensor present in a data logging system. These electronic signals are then transformed into binary data, then it is simply evaluated by software and kept for future study.

Load management is the process of organize the loads to decrease the electric energy consumption and or the extreme demand. In the proposed work, the load management system is programmed to give supply automatically to the certain load during the time of evening 6 PM to morning 6 AM. After that supply is automatically cut off to that load.

RESULTS

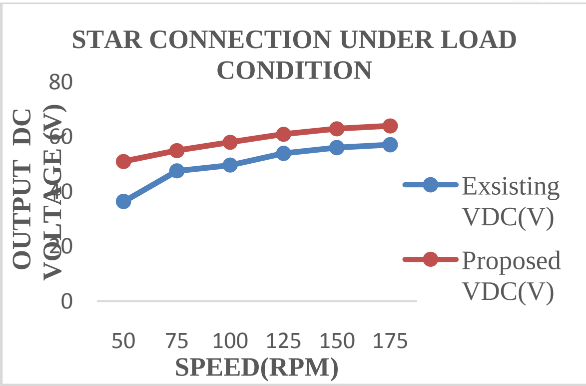

Figure 5 Speed VS Output DC Voltage of Star Connection

Figure 5 depicts the graph between the speed and output DC voltage of star-connected wind generators under load conditions. From the graph, it is inferred that the output DC voltage of the proposed design is higher than the existing design during star connection under load conditions.

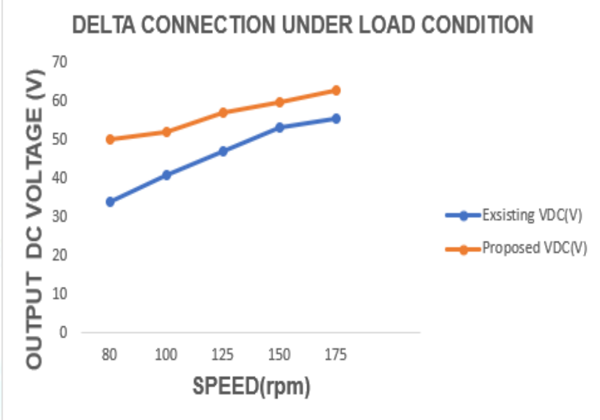

Figure 6 Speed VS Output DC Voltage of Delta Connection

Figure 6 depicts the graph between the speed and output DC voltage of delta connected wind generator under load condition. From the graph, it is inferred that the output DC voltage of the proposed design is higher than the existing design during delta connection under load conditions.

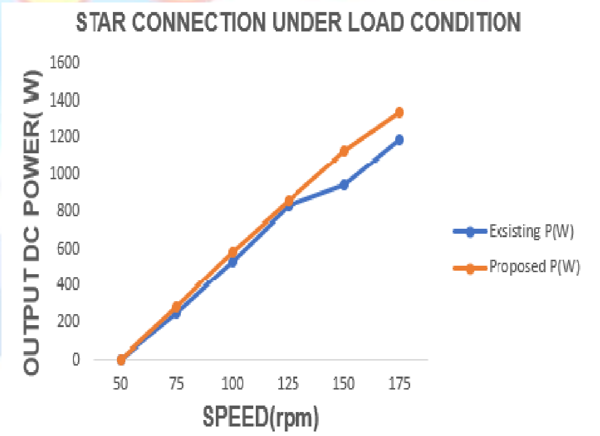

Figure 7 Speed VS Output DC Power of Star Connection

Figure 7 depicts the graph between the speed and output DC power of star-connected wind generators under load conditions. From the graph, it is inferred that the output DC power of the proposed design is higher than the existing design during star connection under load conditions.

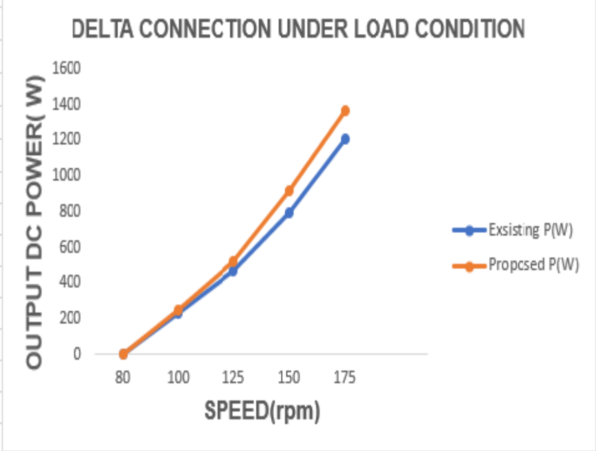

Figure 8 Speed VS Output DC Power of Delta Connection

Figure 8 depicts the graph between the speed and output DC power of delta connected wind generator under load condition. From the graph, it is inferred that the output DC power of the proposed design is higher than the existing design during delta connection under load conditions.

CONCLUSION

The re-design, re-fabrication, and re-implementation of Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion System (WECS) and data logging system was installed. In the proposed hardware design magnet with a higher grade was used, the air gap was reduced, and the winding type was changed from concentric to lap winding. All these factors lead to an increase in the magnetic flux, increase the induced EMF and current rating from the existing design. In the proposed design, slip ring assembly was fitted on yaw top to take the output from the wind turbine

Due to magnet holding rings. The possibility of dislocation of magnets was almost nil. So, the output of the generator was reliable and guaranteed. Due to slip ring assembly fitted in yaw top, we have the advantage of easy servicing and replacement. The overall efficiency was enhanced in proposed design when compared to the existing design. Data on wind speed, generating power, and other related data were collected by using data logging system.

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