Performance Based Comparison of Asynchronous Generator Wind Turbine Model And Permanent Magnet Synchronous Generator Wind Turbine Model

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Abstract*- This paper present the performance based comparison of the Asynchronous generator wind turbine and permanent magnet synchronous generator wind turbine model. The asynchronous generator wind turbine model consists of wind turbine profiles which attribute to the mechanical power and torque characteristics of wind turbine. The AGWT-Model can work as induction generator. The performance of a variable speed wind turbine can be enhanced significantly by using a low speed permanent magnet synchronous generator (PMSG) without a gearbox. The main features of PMSG based wind turbines are; gearless operation, higher efficiency, enhanced reliability, smaller size, reduced cost and low losses.*

Keywords- Wind energy, pitch angle, Wind velocity, Turbine power, Power coefficient, AGWT-Model, PMSGWT-Modal, WECS, MATLAB/SIMULIK.

I. INTRODUCTION

A wind turbine is a machine for converting the kinetic energy in the wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator. Utility-scale turbines range in size from 100 kilowatts to several megawatts [1]. A wind turbine consists of a rotor mounted to a nacelle and a tower with two or more blades mechanically connected to an electric generator. The gearbox in the mechanical assembly transforms slower rotational speeds of the wind turbine to higher rotational speeds on the electric generator. The rotation of the electric generator's shaft generates electricity whose output is maintained by a control system.

There are two types of wind turbine technology:

(i) Fixed Speed Wind Turbine Technology:

Fig.1 show the fixed speed wind turbine which uses a squirrel cage induction generator (SCIG) directly connected to the grid through a coupling transformer. A capacitor bank is required for the compensation of reactive power requirement of induction generator [2].

ii) PMSG Based Gearless Direct Drive Variable Speed Wind Turbine Technology

In this configuration, the generator rotor is directly connected to the turbine rotor without any gearbox and the generator is interfaced with the grid/load using full scale AC-DC-AC power converters as shown in Fig.2. This configuration is most suited for full power control as it is connected to the grid through a power converter [2].

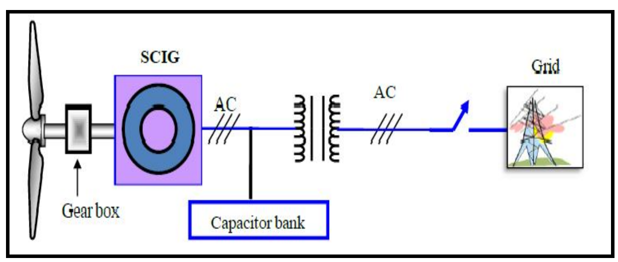

Fig. 1: Fixed Speed Wind Turbine With Induction Generator [2]

The permanent magnet synchronous generators (PMSGs) used in this configuration are low speed generators with suitable number of poles and able to produce higher torque at low speed. The main features of PMSG based wind turbines are [2] –

1. Gearless operation and enhanced reliability.
2. Simple structure, smaller size and reduced cost.
3. Low mechanical and electrical losses.
4. Higher power factor and efficiency.
5. No requirement for reactive power support.
6. Higher cost and power losses in the converters.
7. No need of external excitation.

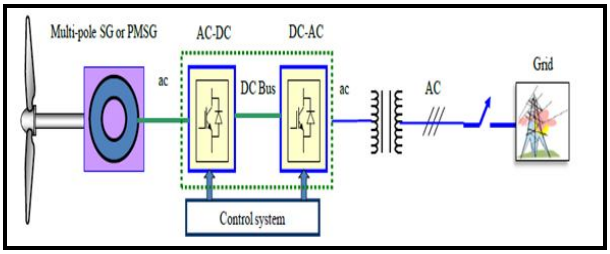

Fig. 2: Gearless Direct Drive Variable Speed Wind Turbine PMSG [2]

II. MODELLING OF THE ASYNCHRONOUS GENERATOR

It is assumed that the asynchronous generator, also called induction generator, has three-phase stator armature winding (A_S, B_S, C_S) and a three-phase rotor winding (A_R, B_R, C_R) as shown in Fig. 3. The stator is the outer stationary member and the rotor is the inner rotating member of the machine. The rotor is mounted on bearings fixed to the stator. In the electromagnetic structure of the induction generator, when the stator winding is supplied with three-phase current (waveforms of equal amplitude, displaced in time by one-third of a period), a rotating magnetic field is produced. The angular speed of the rotating magnetic field is called the synchronous speed, ω_s. The relative speed between the rotating field and the rotor induces a current in the rotor. The resulting magnetic field interacts with the stator field to make the rotor rotate in the same direction. In this case, the machine acts as a motor since, in order for the rotor to rotate; energy is drawn from the electric power source. However, if an external mechanical torque (in this case the wind torque) is applied to the rotor to drive it beyond the synchronous speed, then electrical energy is pumped to the power grid, and the machine will act as a generator [1].

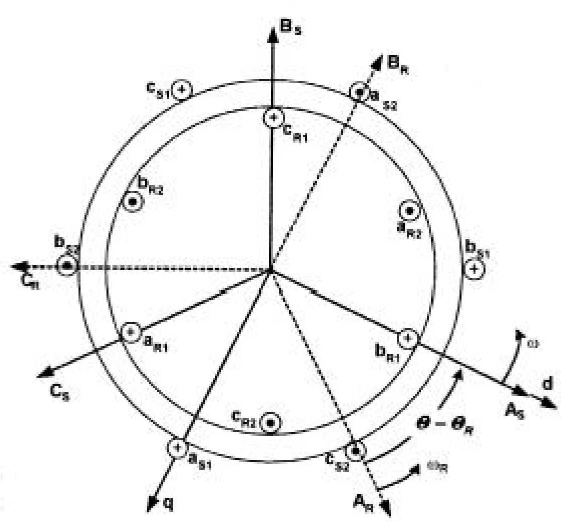

Fig. 3: The Windings in the Asynchronous Generator [1]

The mathematical model of an asynchronous generator for power system analysis is usually based on the following assumptions [1]

- The stator currents are positive when flowing towards the network.
- The real and reactive power is positive when fed into the grid.
- The stator and rotor windings are placed sinusoidal along the air-gap as far as the mutual effect with the rotor is concerned.
- The stator slots cause no appreciable variations of the rotor inductances with rotor position.
- The rotor slots cause no appreciable variations of the stator inductances with rotor position.
- Magnetic hysteresis and saturation effects are negligible.
- The stator and rotor windings are symmetrical.
- The capacitance of all the windings can be neglected.

III. MODELING OF THE PMSG WIND TURBINE

The Permanent Magnet Synchronous Generator (PMSG) offers better performance than other generators because of its higher efficiency and of less maintenance since they don’t have rotor current and can be used without a gearbox, which also implies a reduction of the weight of the nacelle and a reduction of costs. VSWT wind turbine generator consists of another three parts: wind speed, wind turbine and drive train.

Fig.4 shows a three phase two poles PMSG. It has 3 phase Y-connected stator windings and a permanent magnet in the rotor. The stator windings are identical windings displaced 1200, each with a turns number of *Ns* and resistance *Rs*. For our analysis we assume that the stator windings are sinusoidal distributed. Damper windings are neglected because the permanent magnet is a poor electrical conductor and the eddy current that flow in the nonmagnetic materials securing the magnets are small. Hence large armature current can be tolerated without significant demagnetization [2].

The stator of a PM synchronous generator is similar to the wound rotor synchronous generator and the back emf produced by the permanent magnets is the same as that produced by an excited coil. In developing mathematical model for a PMSG we will assume the following;

1. The stator windings are sinusoidal distributed along the air gap
2. Magnetic saturation is negligible

3. The back emf is sinusoidal.
4. The variation of phase inductance is sinusoidal [2].

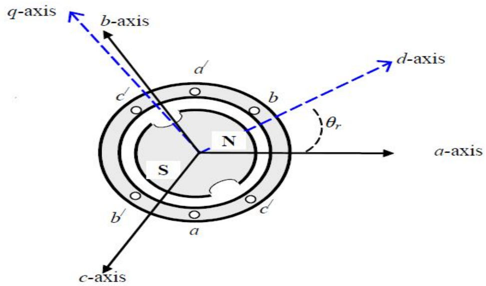

Fig.4 : Three Phase, Two Pole PMSG [2]

The generator is connected to the grid via an AC/DC/AC con¬verter, which consists of an uncontrolled diode rectifier, boost chopper circuit and a PWM voltage-source inverter. For this topology of con¬verter, operation at relatively low wind speeds is possible due to the inclusion of the boost circuit. The boost circuit can maintain the DC bus link voltage at a constant value. A transformer is located between the inverter and the Point of Common Connection (PCC) in order to raise the voltage by avoiding losses in the transport of the current.

IV.SIMULATION RESULTS FOR ASYNCHRONOUS GENERATOR WIND TURBINE MODEL (AGWT-MODEL)

Study is done by keeping following parameters as

Fixed parameters = pitch angle in degree, Variable parameter = Wind speed in meter per second (m/s). The value of power for asynchronous generator wind turbine model is shown in Tables-1 [3].

Table-1 : Simulation Results of Generated Power (P) in Watts for AGWT-Model [3]

Wind Speed (m/s)	P at Pitch angle =0	P at Pitch angle =1	P at Pitch angle =2	P at Pitch angle =3	P at Pitch angle =4	P at Pitch angle =5
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	-122.3	-81.1	-64.08	-64.02	-66.01	-68.31
2	-52.12	17.3	41.67	34.32	23.29	11.09
3	341.7	338.8	312.5	292	273.4	254.9
4	823.5	705.8	613.9	586.2	570.1	553.9
5	1182	978	840.7	818.1	812.4	808
6	1347	1110	961	953.3	956.6	981
7	1347	1126	994.8	1005	1038	1073
8	1253	1081	980.3	1009	1058	1111
9	1138	1019	954.2	995.3	1055	1121
10	1049	978.7	942.9	989.7	1054	1127
11	1009	972.9	957.8	1006	1070	1143
12	1020	1006	1004	1049	1109	1180
13	1077	1075	1080	1121	1175	1240
14	1171	1175	1184	1218	1265	1324
15	1294	1299	1309	1338	1378	1429
16	1439	1446	1455	1478	1512	1556
17	1603	1608	1616	1635	1663	1701
18	1780	1785	1792	1807	1830	1862
19	1971	1974	1980	1992	2010	2038
20	2172	2175	2179	2188	2204	2226
21	2382	2385	2388	2395	2407	2427
22	2601	2603	2605	2611	2621	2637
23	2828	2829	2831	2835	2843	2857
24	3062	3062	3064	3068	3074	3086
25	3302	3303	3304	3306	3311	3322

The simulation results for AGWT model as shown in the Table-1. These results are achieved by different operating condition of AGWT model. To achieve the results as shown in the colomn-2 by measuring the generated power by keeping pitch angle zero-degree as a fixed parameter and vary the wind speed from 1 m/s to 25 m/s, in steps 1 m/s as an increment. The maximum power 3302 Watts is achieved at fixed pitch angle zero-degree, wind speed is 25 m/s. Similarly to achieve the results as shown in the colomn-3 by measuring the generated power by keeping pitch angle one-degree as a fixed parameter and vary the wind speed from 1 m/s to 25 m/s, in steps 1 m/s as an increment. The maximum power 3303 Watts is achieved at fixed pitch angle one-degree, wind speed is 25 m/s. Now to achieve the results as shown in the colomn-3 to 7 by varying pitch angle and wind speed [3].

V. GRAPHICALLY REPRESENTATION OF AGWT-MODEL RESULT

The graphs between power and wind speed for asynchronous generator wind turbine model are shown in figures 5 to 10.

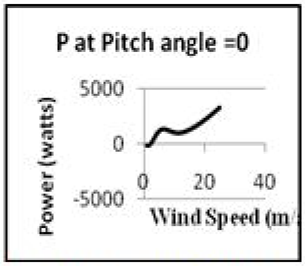

Fig.5: Power v/s Wind Speed Curve

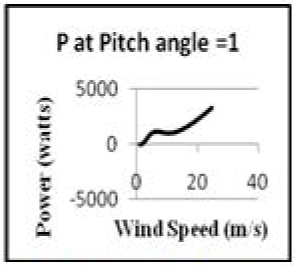

Fig.6: Power v/s Wind Speed Curve

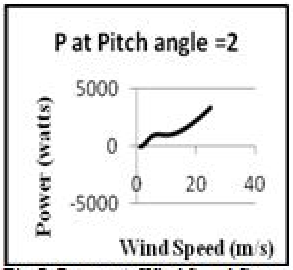

Fig.7: Power v/s Wind Speed Curve

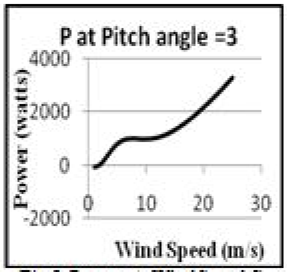

Fig.8: Power v/s Wind Speed Curve

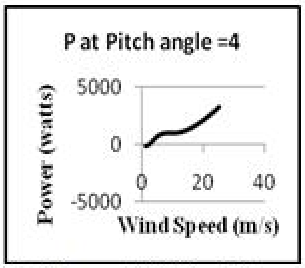

Fig.9: Power v/s Wind Speed Curve

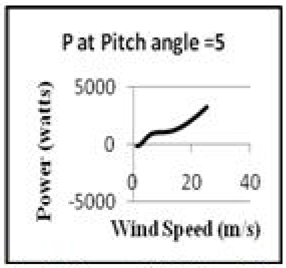

Fig.10: Power v/s Wind Speed Curve

VI .SIMULATION RESULTS FOR PMSG WIND TURBINE MODEL (PMSGWT-MODEL)

Study is done by keeping following parameters as Fixed parameters = pitch angle in degree, Variable parameter = Wind speed in meter per second (m/s). The value of power for permanent magnet synchronous generator wind turbine is shown in Table-2.

Table-2: Simulation Results of Generated Power (P) in Watts for PMSGWT-Model

Wind Speed	P at Pitch angle =0	P at Pitch angle =1	P at Pitch angle =2	P at Pitch angle =3	P at Pitch angle =4	P at Pitch angle =5
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	3564	3563	3563	3563	3563	3563
2	3563	3563	3563	3563	3563	3563
3	3564	3563	3562	3562	3562	3562
4	3565	3563	3562	3561	3562	3562
5	3568	3563	3561	3561	3561	3561
6	3573	3565	3561	3561	3561	3561
7	3580	3567	3561	3561	3561	3562
8	3591	3571	3562	3562	3562	3563
9	3604	3577	3564	3563	3564	3565
10	3622	3585	3567	3566	3567	3568
11	3644	3595	3571	3569	3571	3573
12	3670	3606	3576	3574	3576	3579
13	3701	3621	3583	3580	3582	3586
14	3738	3638	3590	3587	3590	3594
15	3780	3658	3600	3596	3600	3605
16	3827	3681	3611	3607	3611	3617
17	3882	3708	3624	3619	3624	3632
18	3943	3738	3639	3633	3639	3648
19	4011	3771	3656	3649	3656	3666
20	4086	3808	3675	3667	3675	3687
21	4169	3849	3696	3686	3696	3710
22	4259	3894	3719	3708	3719	3735
23	4357	3943	3745	3732	3745	3763
24	4464	3996	3773	3759	3773	3793
25	4579	4053	3803	3787	3803	3826

The simulation results for PMSGWT model as shown in the Table-2. These results are achieved by different operating condition of PMSGWT model. To achieve the results as shown in the colomn-2 by measuring the generated power by keeping pitch angle zero-degree as a fixed parameter and vary the wind speed from 1 m/s to 25 m/s, in steps 1 m/s as an increment. The maximum power 4579 Watts is achieved at fixed pitch angle zero-degree, wind speed is 25 m/s. Similarly to achieve the results as shown in the colomn-3 by measuring the generated power by keeping pitch angle one-degree as a fixed parameter and vary the wind speed from 1 m/s to 25 m/s, in steps 1 m/s as an increment. The maximum power 4053 Watts is achieved at fixed pitch angle one-degree, wind speed is 25 m/s. Now to achieve the results as shown in the colomn-3 to 7 by varying pitch angle and wind speed.

VII. GRAPHICALLY REPRESENTATION OF PMSGWT-MODEL RESULT

The graphs between power and wind speed for permanent magnet synchronous generator wind turbine model are shown in figures 11 to 18.

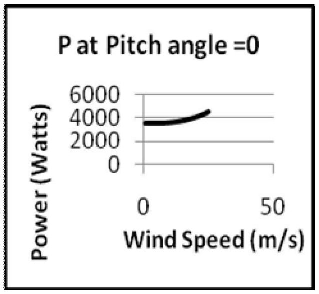

Fig. 11: Power v/s Wind Speed Curve

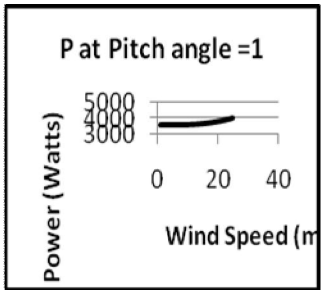

Fig. 12: Power v/s Wind Speed Curve

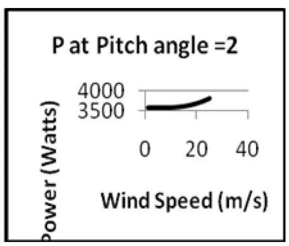

Fig. 13: Power v/s Wind Speed Curve

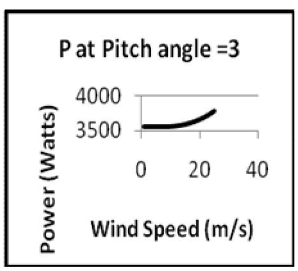

Fig. 14: Power v/s Wind Speed Curve

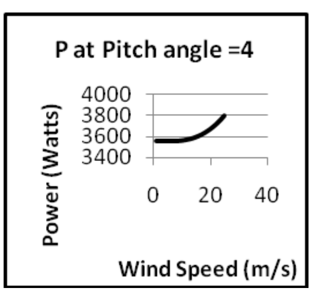

Fig. 15: Power v/s Wind Speed Curve

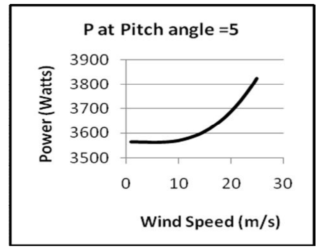

Fig. 16: Power v/s Wind Speed Curve

VIII. COMPARATIVE RESULT OF AGWT-MODEL AND PMSGWT- MODEL

The comparative results are achieved by above method, for asynchronous generator wind turbine model (AGWT-Model) and permanent magnet synchronous generator wind turbine (PMSGWT-Model) by finding the maximum power at same pitch angle and different wind speed. These comparative results are shown in below Table-3

Table-3 : Comparative results of Maximum Power for AGWT-Model and PMSGWT-Model at Different Wind Speed and Same Pitch Angle

Pitch Angle (degree)	AGWT Model		PMSGWT Model	
	Wind Speed (m/s)	Max. Power (Watts)	Wind Speed (m/s)	Max. Power (Watts)
(1)	(2)	(3)	(4)	(5)
0	25	3302	25	4579
1	25	3303	25	4053
2	25	3304	25	3803
3	25	3306	25	3787
4	25	3311	25	3803
5	25	3322	25	3826
6	25	3336	25	3852
7	25	3362	25	3878
8	25	3400	25	3904
9	25	3453	25	3931
10	25	3528	25	3958
11	25	3630	25	3985
12	25	3761	25	4012
13	24	3723	25	4039
14	23	3733	25	4066
15	22	3786	25	4094
16	20	3686	25	4121
17	19	3776	25	4148
18	17	3649	25	4175
19	16	3664	25	4203
20	15	3620	25	4230
21	15	3797	25	4257
22	14	3637	25	4285
23	13	3395	25	4312
24	13	3468	25	4339
25	13	3524	25	4367

The comparative result which consists of AGWT-Model and PMSGWT-Model are shown in Table-3. Looking to the colomn-3 of Table-3, Maximum power is achieved by AGWT-Model is 3797 Watts with respect to wind speed is 15 m/s and pitch angle is 21-degree. Now Looking to the colomn-5 of Table-3, Maximum power is achieved by PMSGWT-Model is 4579 Watts with respect to wind speed is 25 m/s and pitch angle is zero-degree.

IX. RESULT

In this paper, several aspects of modelling and simulation of Asynchronous generator and permanent magnet synchronous generator based grid connected variable speed wind turbines with maximum power extraction are considered.

The comparison between the asynchronous and synchronous generator is shown that which wind turbine is used in particular conditions. Which particular wind turbine is suitable in particular situation is decided by the comparison at same pitch angle and variable wind speed of wind generators. In permanent magnet synchronous generator wind turbine model, gearbox is not necessary so cost of gear box and its maintenance is eliminated.

REFERENCES

[1] Jasmin Martinez, “Modeling and Control of Wind Turbines”, Department of Chemical Engineering and Chemical Technology, Imperial College, London, September 21, 2007.

[2] Mujaddin Morshed Chowdhury, “Modelling and Control of Direct Drive Variable Speed Wind Turbine with Interior Permanent Magnet Synchronous Generator”, PhD Thesis, University of Tasmania, June 2014.

[3] Deepak Bohra, M.K.Bhaskar, Dharmendra Jain, Manish Parihar , “Modelling and Simulation of Asynchronous Generator Wind Turbine for Different Wind Speed”, International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 10, October 2017.

[4] Phlearn Jansuya and Yuttana Kumsuwan, “Design of MATLAB/Simulink Modeling of Fixed-Pitch Angle Wind Turbine Simulator”, Sciversa ScienceDirect, Energy Procedia , August, 2013.

[5] A. W. Manyonge, R. M. Ochieng, F. N. Onyango, and J. M. Shichikha,“Mathematical Modelling of Wind Turbine in a Wind Energy Conversion System: Power Coefficient Analysis”, Applied Mathematical Sciences,Vol.6,June 2012.

[6] Kuldipsinh. I. Rathod, Mahipalsinh.B.Jhala & A.D.Patel, “ Modeling and Simulation of Wind Turbine Connected to Pmsg for Wind Mill Application”, International Global Journal For Research Analysis, Volume : 3 | Issue: 3 | March 2014.

[7] Prerna Badoni, S. Bhanu Prakash, “Modeling and Simulation of 2 MW PMSG Wind Energy Conversion Systems”, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 9, Issue 4 Ver. I, Jul – Aug. 2014.

[8] S. Samanvorakij & P. Kumkratug, “Modelling and Simulation PMSG based on Wind Energy Conversion System in MATLAB/SIMULINK”, Proc. Of the Second Intl. Conf. on Advances in Electronics and Electrical Engineering — AEEE 2013.

[9] A. Honrubia-Escribano, F. Jiménez-Buendía, A. Molina-García, J.A. Fuentes-Moreno, E. Muljadi, and E. Gómez-Lázaro, “Analysis of Wind Turbine Simulation Models: Assessment of Simplified versus Complete Methodologies”, ISEF 2015 – XVII International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering Valencia, Spain, September 2015.

[10] D.johra Saheb-Koussa, Mourad Haddadi , Maiouf Belhamel, Mustapha koussa &Said noureddine, “Modeling and simulation of windgenerator with fixed speed wind turbine under Matlab-Simulink”, Sciversa ScienceDirect, Energy Procedia 18, November 2012