A Systematic Investigation on Electric Generators Adapted Wind Energy Conversion System

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Abstract - *The wind power conversion system convert the wind energy to an electric energy and make a part of the sources of renewable energies as an alternative to the conventional sources of energy. The main intention of this paper describes comparative study on electric generators fitted wind energy conversion system. The selection of the most suitable electrical generator machines for a wind turbine system is most important task. This study has made an over view of three main conventional electric generator in wind energy system that are the Squirrel-Cage Induction Generator (SCIG), the Doubly-Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG) for various wind speeds (8, 12 and 16 m/s). The analysis of output power (%) has been made in terms of generator speed and pitch angle. The conclusion shows the Permanent Magnet Synchronous Generator (PMSG) is able fulfills the major requirements of a wind energy system.*

Keywords:-*Electric generators, Wind energy, Conversion system*

1. Introduction of Wind power

The current scenario reveals the important to find an alternative form of energy before the world's fossil fuels are exhausted. It is predicted that oil and gas reserves will be depleted soon. Due to the combustion of fossil fuels, carbon dioxide is released into the atmosphere causing the atmosphere to trap solar radiation that then leads to global warming or the "green house effect". The Wind energy power has played an important role in the history of human civilization. Wind turbines have been used for at least 3000 years, mainly for grinding grain or pumping water. The wind has been an essential source of power for even longer.

Since from 19th century the wind power used to generate electricity. In 1888, Charles F. Brush built the first automatically operating wind turbine of 12 KW rotor blades made of cedar wood for electricity generation. The Danish Poul la Cour was another pioneer of electricity generating wind turbines, discovered fast rotating wind turbines with few rotor blades in1897 in Askov. It was more efficient for electricity. In the 1973, the oil crisis rekindled the interest of wind power in several countries and capacity of wind power increased to several thousand KW.

In many ways they suffered the same fate as their even larger colleagues like as extremely expensive and the high energy price. The clean technologies help reduce global carbon emissions, but they also add some much-needed flexibility to the energy resource mix by decreasing the dependence on limited reserves of fossil fuels

1.1. Wind Power Scenario

In present decade, there is much more attention and worldwide growth in the exploitation of wind energy. Wind power technology continues to improve in efficiency, reliability and cost performance, unprecedented growth, making wind the fastest growing from of electric generation in the world. The wind power scenario for this global and our country shown in Table 1.1 and fig 1.1.

Fig 1.1.Top 10 New Installation Countries – 2015

Table -1.1: Wind power generation

COUNTRY	GENERATION (MW)
PR China	1,45,362
USA	74,471
Germany	44,947
India	25,088
Spain	23,025
UK	13,603
Canada	11,205
France	10,358
Italy	8,958
Brazil	8,715

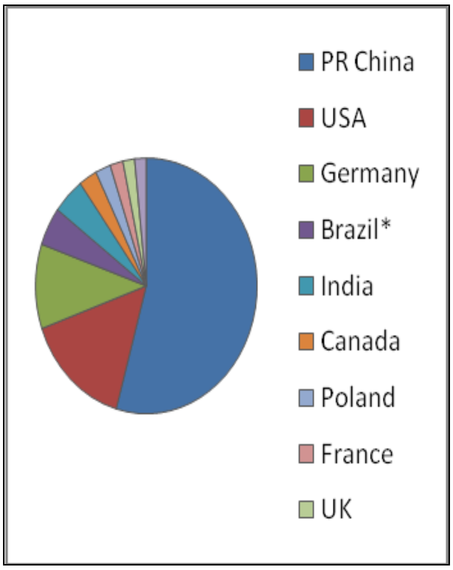


Fig 1.1.Total Installation in India -2015

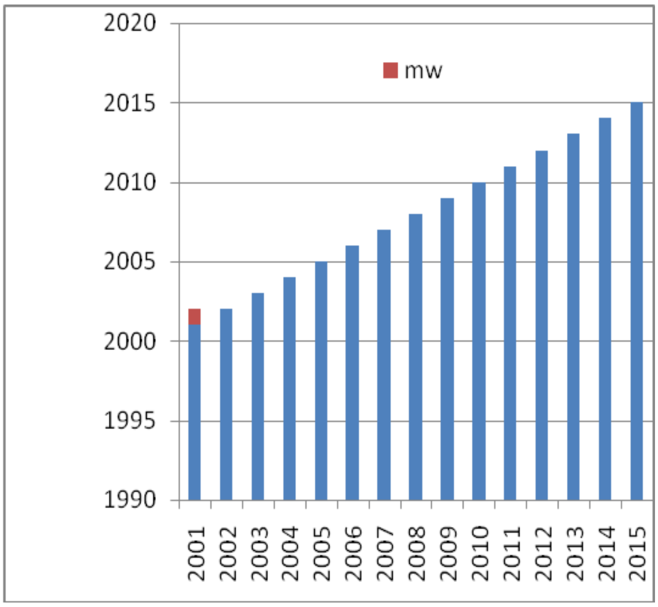


Table -1.2: Wind power generation

2. Wind Energy Conversion system (WECS)

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Passing over the blades, wind generates lift and exerts a turning force. The rotating blades turn a shaft inside a nacelle which goes into the gearbox. The gearbox adjusts the rotational speed to that which is appropriate for the generator. The generator converts the rotational energy to electrical energy. The power output goes to a transformer connected to the grid, which converts electricity from the generator at 700V to the appropriate voltage for the power collection system, typically 33kV.

A wind turbine extracts energy from the swept are of the blades. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time. That is,

$$P_w = \frac{1}{2} \rho A v_w^3$$

Where P_W is the power contained in the wind (in watts)

ρ is the air density (1.225 kg/m^3 at 15 ^{o}C),

A is the swept area (m^2),

Vw is the velocity of the wind without any rotor interference i.e wind speed at infinite distance from the rotor blades.

2.1. Types of Wind Turbines:

i. Horizontal Axis Wind Turbines (HAWTs): They are of the 'axial" flow type which means that wind flowing in a direction parallel to the axis is harnessed. These are mostly used in modern day electricity generation purposes. But their disadvantage is that they can harness speed only in a particular direction. As the direction of the wind can fluctuate quite routinely, this becomes a major drawback.

ii. Vertical Axis Wind Turbines (VAWTs): They are of the 'cross" flow type which means that wind flowing in a direction perpendicular to the axis is harnessed. Theoretically these should have better efficiency as compared to their horizontal counterparts, but they usually have very complex shapes and are therefore very difficult and economically unviable to manufacture.

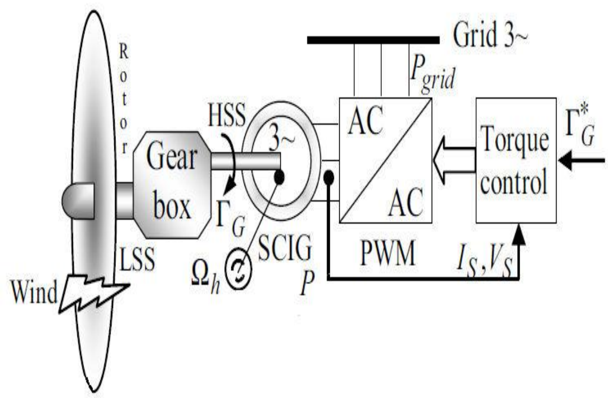


Fig 2.1.Variable-speed WECS

2.2. Generator characteristics versus wind power

The major requirements of generators for wind turbine, as mentioned in past literature, are summarized as follows.

- High torque and high power density;
- Reduction of the system parts;
- High efficiency;
- Lowest maintenance;
- High reliability and robustness for various wind operating conditions;
- Reasonable cost.

Moreover, in the extreme environments, the electric generator should be fault-tolerant Finally, in an industrial point of view, an additional selection criterion is the market acceptance degree of each generator type, which is closely associated with the comparative availability and cost of its associated power converter technology, in many different generator–converter combinations are compared on the basis of topology, cost, efficiency, power consumption and control complexity.

One of the major factors affecting the performance of a wind power is its power response to different wind speeds. This is usually given by the ideal power curve of the wind turbine, which reflects the aerodynamic, transmission and generation efficiencies of the system in an integrated form. In this example, the rated power of the turbine is 2 MW. The performance characteristic depending on the wind speed comprises three distinct zones:

3. Comparative Study on WECS

3.1. Squirrel-Cage Induction Generator (SCIG)

The squirrel cage induction generator has a unique construction with the rotor having solid bars of conducting material placed in rotor slots and shorted through end rings on each side. In large machines alloyed copper bars are driven in the slots and are brazed onto the copper end-rings, while smaller ones have die cast aluminium bars. The rotor circuit cannot be tempered with and the machine has a low starting torque, while it has excellent running performance. Another important aspect of construction is that the number of stator slots must be a non-integral multiple of the number of rotor slots so as to prevent magnetic locking of rotor and stator teeth at the time of starting. For the same purpose the rotor teeth are skewed slightly.

The first production of electrical energy with wind power was 1887 by Charles Brush in Cleveland, Ohio. The rated Power of the used dc-generator was 12kW and was designed to charge batteries. The induction machine was used at the first time in 1951 But, in wind power using squirrel-cage induction generators must be operated at a constant speed, which is not favored at the varied wind speed application. However, SCIG drives have bulky construction, low efficiency, low reliability and need of maintenance, also the existing of slip ring, brush and three-stage gearbox increases the system mass and cost, also electrical and mechanical loss. Recently, squirrel-cage induction generators are dropping in this application. The figure 3.1 illustrates the process of squirrel cage induction generator.

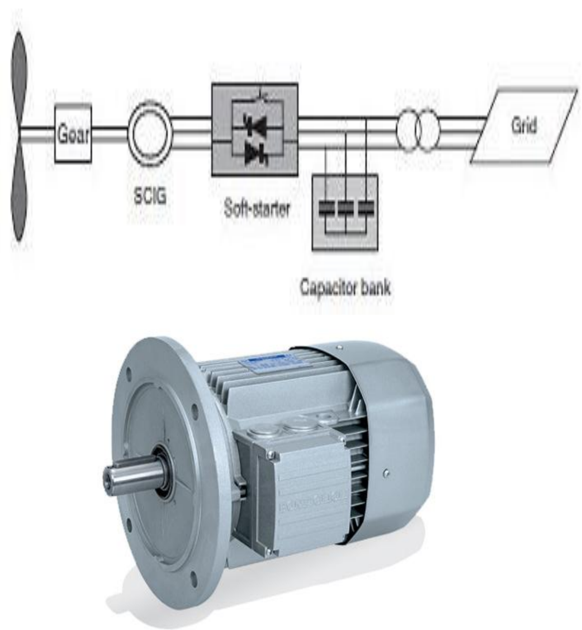


Fig 3.1.Squirrel-Cage Induction Generator (SCIG)

3.2. Doubly Fed Induction Generator (DFIG)

The Doubly Fed Induction Generator with a power controller is a simple and highly controllable way to transform the energy from the variable speed rotor to a constant frequency electrical utility grid. The main reason for the popularity of DFIG connected to the national networks is their ability to provide power at constant voltage and frequency while the rotor speed varies.

Today over 70% of the wind turbines are build up with Doubly-Fed Induction Generator (DFIG). Many manufacturers, such as Vestas, Gamesa, GE and Repower, have provided the wind turbine system with this concept. In fact, DFIG has great improvement comparing with the SCIG concept, in This system consists of a wind turbine with DFIG. This means that the stator is directly connected to the grid while the rotor winding is connected via slip rings to a converter. As also seen in the Fig 3.2 the DFIG can operate both in motor and generator operation with a various rotor speed.

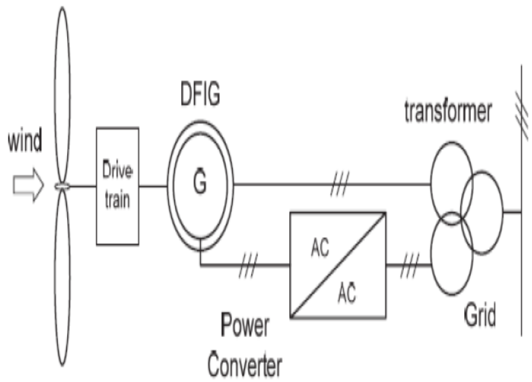


Fig 3.2.Doubly Fed Induction Generator (DFIG)

The dynamic behavior model and their control system of the DFIG are considered. Moreover, new types of generators which may change the configuration of the wind energy are being developed, where this new concept eliminates most of the mechanical parts, such as brush, slip ring and gearbox that are considered drawbacks to this concept, as a result, reducing the mass and cost of the system and achieving high reliability and availability.

Finally, it should be noticed that most research works tend to use the DFIGs in wind energy, as they have excellent performance. Such as in adjustable speed operation of the DFIG offers many advantages to reduce cost and has the potential to be built economically at power levels above 1.5 MW for off-shore applications.

3.3. Permanent magnet synchronous generators (PMSG)

Permanent magnet synchronous generators (PMSG)s consists of a rotor and a three- phase stator similar to an induction generator, is shown in Fig.3.3, are most capable of competing with induction generators for the wind power applications. In fact, they are adopted by well-known small wind turbine. These generators have a number of advantages, which are:

(a) Simple and more effective configuration in the rotor with permanent magnet.
(b) Overall weight and volume significantly reduced for a given output power (high power density).
(c) Higher efficiency and self excited.
(d) Heat efficiently dissipated to surroundings.

A Permanent Magnet Synchronous Generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The rotor contains the permanent magnet and the stator is the stationary armature that is electrically connected to a load. A set of 3 conductors make up the armature winding in standard utility equipment, placed 120^o apart in space, this provides for a uniform force or torque on the generator rotor. The uniformity of the torque arises because the magnetic field resulting from the currents in the three conductors of the armature winding combine spatially in such a way as to resemble the magnetic field of a single rotating magnet. The stator magnetic field appears as a steady rotating field and spins at the same frequency as the rotor when the rotor contains a single dipole magnetic field. The two fields move in 'synchronicity' and maintain a fixed position with respect to each other as they rotate. The armature mmf combines vectorically with the persistent flux of the permanent magnets, which leads to higher *air-gap* flux density and eventually core saturation. In PMSG, the output voltage is proportional to the speed.

In the PMSG the air-gap flux density can be increased by increasing the thickness of the magnets. The air-gap flux density in the PMSG machine is approximated by the following equation, although the PM machine can achieve a larger air-gap flux density and the stator bore diameter is smaller. Moreover, the advantage of the PM machine design is that it has a much higher efficiency (97 %) than the induction machine (85 %).

Due to their excellent performance especially, efficiency and reliability, the general trend in wind industry is to go for higher powers, which is especially relevant with harsh environment. it has become more and more popular during this year's. where several companies have been tried this concept:

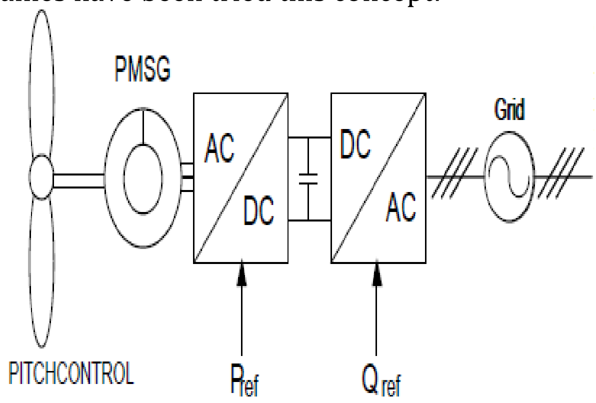


Fig.3.3. Industrial permanent magnet synchronous generator.

Many authors examine the benefits and the physical and economic limitations of PMSGs and consider their appropriateness as a key piece in the overall wind turbine system design. The reported results are promising.

From analysis of the commercially available wind turbine generators, the elimination of the gearboxes and the power electronic converters will significantly increase the system reliability. The overall system efficiency will increase because the losses in the gearbox and power electronic converters are eliminated, it is concluded that direct drive, grid connected generators indicate a future trend in the wind generation. Finally, the reported results are promising, however, the requirement of PM materials restricts the applications of PMSG, either for high cost or potential to demagnetization in harsh environment.

4. Discussion

Generator is one of the most important components of a wind energy conversion system (second important component), generator of a wind turbine has to work under fluctuating power levels. Different types of generators are being used with wind turbines. These generators can either be induction (asynchronous) generators or synchronous generators and recently appeared innovative machine.

Pitch Mechanism

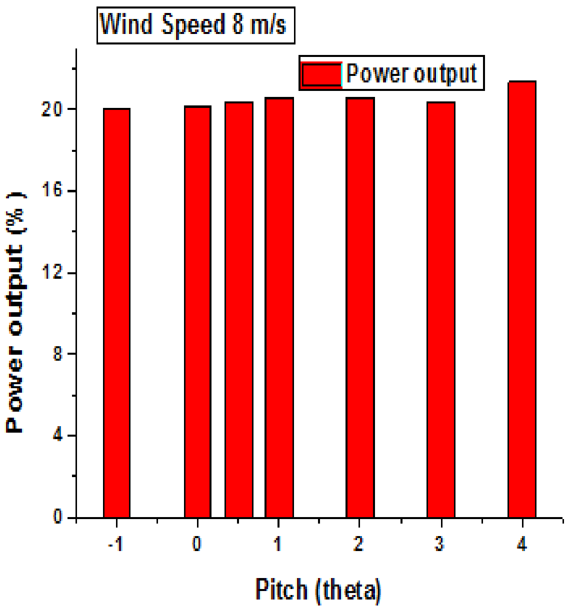
The pitch mechanism in large wind turbines enables the rotation of the blades on their longitudinal axis. It can change the angle of attack of the blades with respect to the wind, by which the aerodynamic characteristics of the blade can be adjusted. This provides a degree of control over the captured power to improve conversion efficiency or to protect the turbine. When the wind speed is at or below its rated value, the angle of attack of the blades is kept at an optimal value, at which the turbine can capture the maximum power available from the wind. When the wind speed exceeds the rated value, the pitch mechanism is activated to regulate and limit the output power, thus keeping the power output within the designed capability. For this purpose, a pitch range of around 20 to 25 degrees is usually sufficient. When the wind speed increases further and reaches the limit of the turbine, the blades are completely pitched out of the wind (fully pitched or feathering), and no power will be captured by the blades. The pitch mechanism can be either hydraulic or electric. Electric pitch actuators are more common nowadays since they are simpler and require less maintenance. Traditionally, all blades on the rotor hub are pitched simultaneously by one pitch mechanism. Modern wind turbines are often designed to pitch each blade individually, allowing an independent control of the blades and offering more flexibility. The pitch system is usually placed in the rotor hub together with a backup energy storage system for safety purposes (an accumulator for the hydraulic type or a battery for the electric type).

4.1. Squirrel-Cage Induction Generator (SCIG)

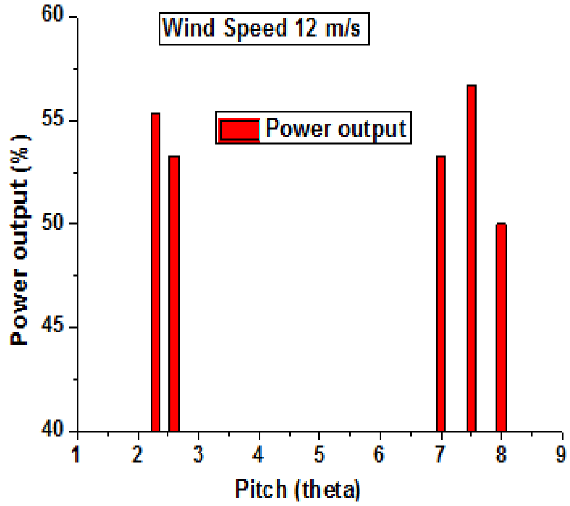
In squirrel cage induction generator wind power analysis has been made for various wind speed such 8, 12 and 16 m/s. The output power in terms of percentage was tailored by various pitch angle and generator speed. The output power for various wind speed such 8, 12 and 16 m/s clearly shown in table 4.1. In that the pitch angle influenced more than expected level of output power. On the whole, the condition of 8 m/s wind velocity gives very minimum of output power.

Table 4.1.Output power for various wind speeds (SIG)

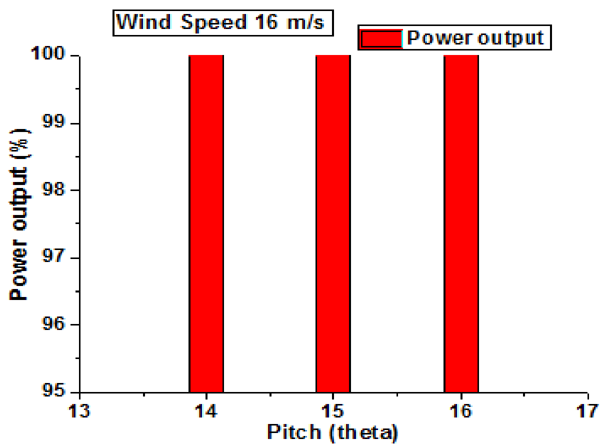
SIG (Wind speed 8 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	-1	1502	20.00
2	0	1503	20.10
3	0.5	1502	20.40
4	1	1501	20.60
5	2	1502	20.54
6	3	1503	20.34
7	4	1503	21.34



SIG (Wind speed 12 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	8	1504	50.0
2	7	1503	53.3
3	7.5	1503	56.7
4	2.6	1504	53.3
5	2.3	1502	55.3



SIG (Wind speed 16 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	15	1504	98.7
2	14	1505	100.0
3	15	1504	100.0
4	16	1503	100.0



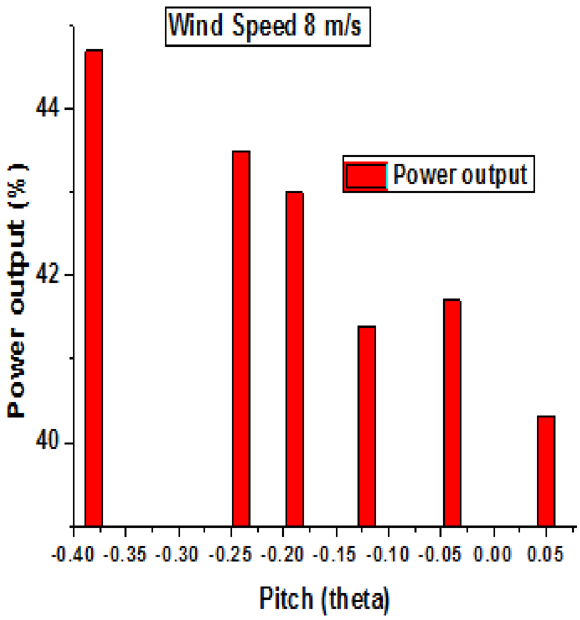
4.2. Doubly Fed Induction Generator (DFIG)

The Doubly Fed Induction Generator wind power analysis has been made for various wind speed such 8, 12 and 16 m/s. In this, the output power for 8 m/s wind speed is very minimum with respective pitch angle. The output power in terms of percentage was tailored by various pitch angle and generator speed.

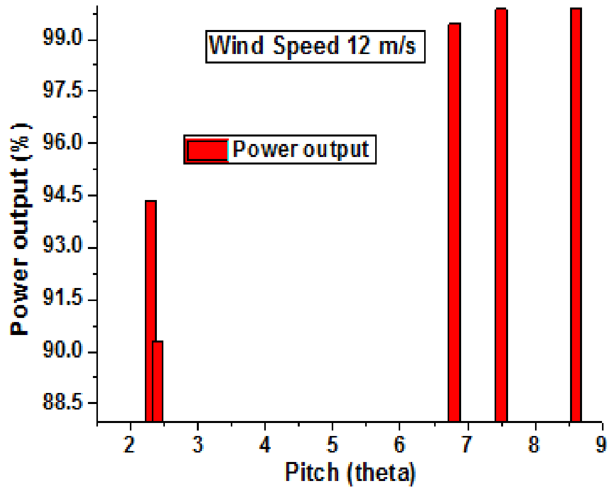
The output power for various wind speed such 8, 12 and 16 m/s clearly shown in table 4.2. In that the pitch angle again influenced more than expected level of output power for doubly fed induction generator.

Table 4.1.Output power for various wind speeds (SIG)

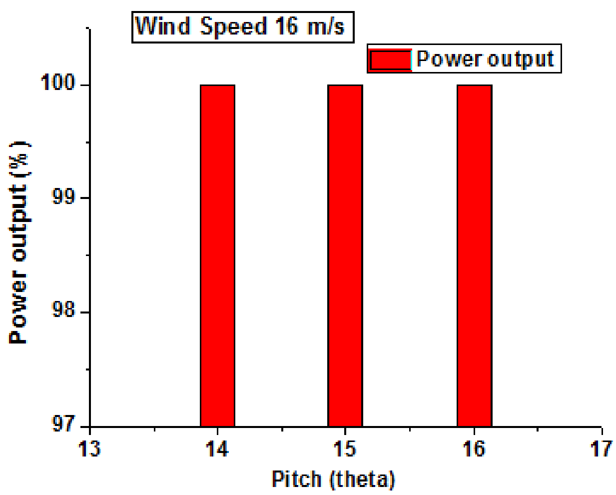
DFIG (Wind speed 8 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	-0.24	1468	43.50
2	-0.38	1482	44.70
3	0.05	1440	40.30
4	-0.19	1471	43.00
5	-0.04	1462	41.70
6	-0.12	1434	39.90
7	-0.12	1445	41.40



DFIG (Wind speed 12 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	8.6	1679.6	99.90
2	6.8	1680.1	99.46
3	7.5	1679.3	99.87
4	2.3	1681.4	94.32
5	2.4	1678.4	90.31



SIG (Wind speed 16 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	15	1504	98.7
2	14	1505	100.0
3	15	1504	100.0
4	16	1503	100.0



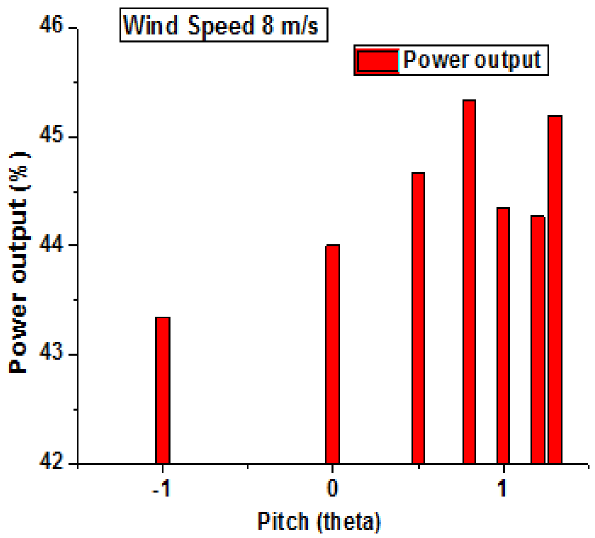
4.2. Permanent magnet synchronous generators (PMSG)

The amplitude and frequency of the voltage can be fully controlled by the power electronic converter at the generator side, so that the generator is fully controllable over a very wide range, even to very low speeds. The permanent magnet synchronous generator wind power analysis has been made for various wind speed such 8, 12 and 16 m/s. In this, the output power for 8 m/s wind speed is very minimum with respective pitch angle.

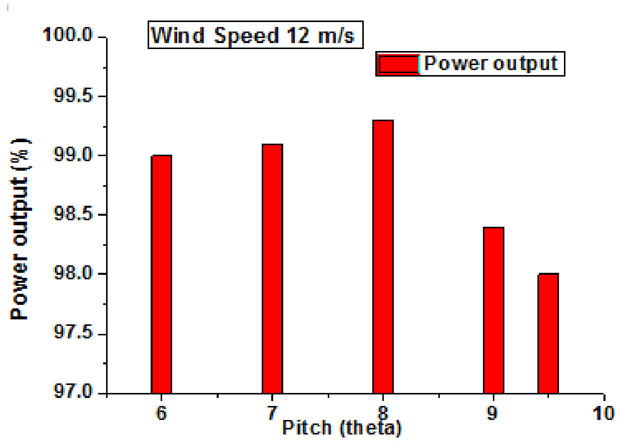
The output power in terms of percentage was tailored by various pitch angle and generator speed. The output power for various wind speed such 8, 12 and 16 m/s clearly shown in table 4.3. In that the pitch angle again influenced more than expected level of output power for doubly fed induction generator.

Table 4.3.Output power for various wind speeds (SIG)

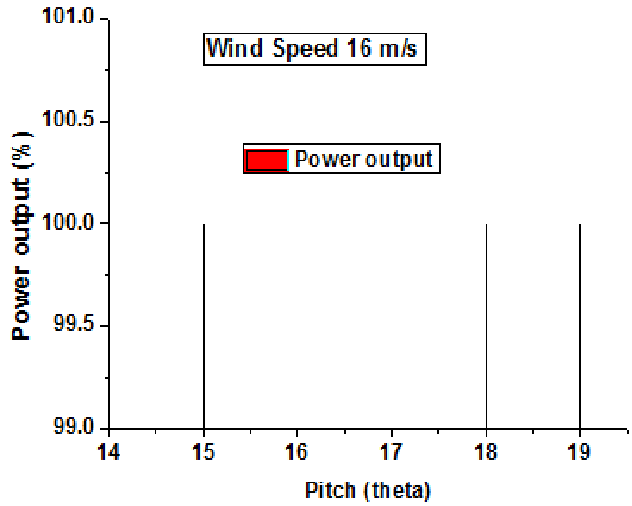
PMSG (Wind speed 8 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	-1.0	1500	43.34
2	0.0	1500	44.00
3	0.5	1500	44.67
4	0.8	1500	45.34
5	1.0	1500	44.34
6	1.2	1500	44.27
7	1.3	1500	45.20



PMSG (Wind speed 12 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	6	1500	99.0
2	7	1500	99.1
3	8	1500	99.3
4	9	1500	98.4
5	9.5	1500	98.0



PMSG (Wind speed 16 m/s)			
S.No	Pitch Angle (ɵ)	Generator Speed (RPM)	Power output (%)
1	18	1500.0	100.0
2	19	1500.0	100.0
3	15	1500.0	100.0
4	18	1500.0	100.0



The permanent magnet synchronous generator seems to be the most adapted candidate for the wind power systems. In fact, this solution is a consensual one as illustrated by the evaluation summarized in and based on the main characteristics of the wind power systems, each of them is graded from 1 to 10 points, where 10 points means the best. In our comparative study we have implicitly given the same weight to all the characteristic factors so as to cover a wide range of wind turbine applications, Otherwise, some of these factors should be weighted according to the application. For an example, in the generator choice is determined by four criteria: reliability and ease of maintenance; total weight of the nacelle; energy yield and grid integration issues and cost. Another example is nacelle in the harsh and variable environment where reliability and technological maturity are much more important than efficiency. In some cases, this could lead to another classification.

Table 4.4. Specification of wind generator

Generation Systems Characteristics	**IG**	**DFIG**	**PMSG**
Power	7	9	10
Density	7	8	10
Controllability	8	10	10
Reliability	6	8	8
Technological maturity	10	10	8
Weight	7	7	10
Cost	8	8	6
∑ *Total*	53	60	62

5. Conclusion

In this paper, the wind energy conversion process have been presented and evaluated according to the wind speed of 8, 12 and 16 m/s. The comparative study has revealed that the permanent magnet synchronous generator is better one that has good power output values comparatively with other to doubly-fed induction generator and squirrel cage induction generator. Moreover, this paper reveals permanent magnet synchronous generator is high efficient and most promising generator for any sort of most optimized wind condition.

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