Review and Comparison of Various Types of Generation Using WECS Topologies

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Abstract. Increasing in the power demand for day to day life, apart from fossil fuels wind energy conversion system (WECS) contributes largely, small wind turbines (SWT) and offshore installations become popular and with the continual research newly designed efficient generators and power converter design new wind turbine models are expected to launch in the recent years. At present WECS operates at fixed speed and variable speed drives using induction generator principle, such that Squirrel cage induction generators (SCIG) and Doubly fed induction generators have a geared operation, Permanent magnet synchronous generator (PMSG) goes gearless. In elaborate the comparisons, advantages and drawbacks of various WECS is discussed in this work.

Keywords: WECS, DFIG, SCIG, PMSG.

1. Introduction
Exponentially human population rise at an enormous number leads to more demand in energy [1]. To fulfil the requirement power generation becomes necessary and essential thing for national growth also. Energy consumption and development have a same state of art. Hence progressive power production is much awaited[2]. Dependency of fossil fuels for energy production leads to emission of pollutant gases like carbon mixture have a poisonous effect on natural world. Thereby, possible way of producing energy utilizing renewable sources like solar, wind will not emit hazardous gases[3]. In recent days wind is gaining more attentiveness due to its infrastructure, technological advancements and cost efficient[4].

In the developing countries almost one-third of human life’s proceeding their lives without power supply, since wind turbines is there for almost bicentennial to generate power, WES is a cost-effective mechanism for power demand[5][6]. Environmental friendly and being lucrative WES is considered as a precious source for energy production[7]. Even though wind attainability varies from place to place, it lacks in continual power supply[8]. Due to essential heavy requirement of power the turbine technology have a considerable change from the recent past[9]. Continual improvement in wind turbine modelling technology in the areas concern power converters, streamlined flowing sleek and...
mechanical power plant design approaches it an powerful source of energy[10]. In remote areas usually wind turbines are installed along with wind farms where power supply from grid is insufficient and the wind farm since energy supply from grid is insufficient and the produced energy from the farm is normally routed to storage[11][12]. For additional power requirement there exists a direct connection to grid from wind plants [13].

In the earlier decades, horizontal axis wind turbine (HWAT) have largely been used to produce electricity with higher capacity for power demand[14]. Since the major drawback in HWAT system is the power loss due to the use of gear mechanism which leads to huge maintenance cost, all these factors made the overall HAWT system costlier[15]. To overcome this issue Vertical axis wind turbine (VAWT) were introduced in early 19th century. However, VAWT resolved the issue by replacing the gear box to direct drive generator system which minimizes the maintenance cost by reducing power losses[16].

This paper is classified in to different sections. Section 2 discusses the different arrangement and numerous designs of a wind turbine. Next chapter 3 elaborates commonly used generators listed as Induction, Synchronous, Double Fed Induction (DFIG), Squirrel Cage Induction (SCIG) and Permanent Magnet Synchronous (PMSG). In Section 4 will enlighten the comparison of different generator topologies. Section 5 engages to the selection of best suitable generator as per the power demand.

![Figure 1. Predicted transformation in near future](image)

2. WIND TURBINE DESIGN AND TOPOLOGIES

Fixed and variable speed drive systems are commonly used wind turbine topologies in general[17]. In recent decades, wind turbine technology have rapid growth from older fixed speed WT to variable speed WT, mainly 1kw SCIG type are available[18]. Variable speed WT intended to aim maximum aerodynamic efficiency over a different range of wind speeds. Compared with horizontal axis wind generator with 3 rotor blades and mechanical parts and heavy generator mounted at the nacelle. The nacelle is placed very high up on a tower. The blades of large scale WTS diameters to a rotational speed between 5 and 25 rpm. Nowadays variable speed WT with pitch control systems replacing later
one. Fig 2. shows that wind turbine systems have the potential to transform kinetic (mechanical) energy of the wind into power[19]. The conversion process is derived from the following equations.

\[ P_M = C_p(\lambda, \beta) P_W \]  

(1)

\[ P_W = \frac{1}{2} \pi R^2 V^3 \rho_{AIR} \]  

(2)

\[ P_M = C_p(\lambda, \beta) P_W \]  

\[ T_{mec} = \frac{1}{2} \pi R^2 V^3 \rho_{AIR} \]  

(4)

Figure 2. Power Generation from Wind energy system

Where \( P_W \) and \( P_M \) denotes the wind and mechanical power of the wind. Performance coefficient is referred as \( C_p \) of the turbine, \( R \) represents the radius of the rotor, and the wind speed \( V \) and air density represents as \( \rho_{AIR} \). In \( C_p(\lambda, \beta) \) coefficient is in function of \( \lambda \) that is the tip speed ratio (TSR) and \( \beta \) refers the pitch angle of the blade in degrees. \( C_p \) is at its peak value when \( \beta=0 \) and \( \lambda=8.1 \) the \( T_{mec} \) (mechanical torque) can bedetermined in the below relationship, where torque coefficient (\( C_m \)) can be written as.

\[ C_M = C_p / \lambda \]  

(3)

3. Various Types of Generators

3.1 Induction generator (IG)

The principle of induction motor to produce electric power is adopted by the induction generator (IG) and synchronous generator is of alternating type. IG rotates the rotor above the synchronous speed by mechanically turning their rotor. In generator working, turbine or engine rotates the rotor far beyond the synchronous speed (negative slip). The stator flux induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motor now operates as a generator, sending power back to the electrical grid.
3.1. Application and advantages

Wind turbines, small wind turbine and micro hydro installations are often uses Induction generators (IG) which have the potential to generate useful power at varying rotor speeds. Comparison to the other generator types IG are mechanically and electrically simpler. Even which it is also much rugged, hence it need not require brushes or commutators.

3.2. Synchronous generator (SG)

One of the generator used for variable speed turbine application is synchronous generator, it can be a suitable selection for variable speed operation since it has low rotational synchronous speed that produces the voltage at grid frequency. It does not require a pitch control mechanism since cost cutting of turbine is possible and occur stress on generator and turbine. SG will generate variable voltage and variable frequency power. Utilizing automatic voltage regulator (AVR) to excite field voltage so as the output voltage of the SG can be controlled.

3.3. DFIG (Doubly Fed Induction Generator)

Another popular series in this type of generator is DFIG, maximum energy is captured in variable speed winds through which power electronic interface controls the rotor currents, the matching between the rotor and generator speed ranges should be achieved by a coupled gearbox. Since the process of the rotor is driven by the power electronics switches it captures less than quarter of the complete output power. The power switching converter is to make conversion from AC to DC to AC usually of variable frequency drive.
Normally the soft switches with high stability like IGBT converters are made: A DC-link connects the grid side converter and rotor side converter. The decoupling between the grid frequency and rotor mechanical frequency is also achieved by the power switching converter which progresses variable speed operation. Since the rotor power is from the power switching converter, The Rotor side power converter topology holds the control of active and reactive powers with controlled harmonics at the generator, at the Grid side power converter topology maintains the power factor to high enough. The main advantage of DFIG is reduced power losses with minimal cost is achieved. The working representation of DFIG is as below in Fig.5.

![DFIG Diagram](image)

**Figure 5.** RSC and GSC Representation in DFIG

### 3.3.1. DFIG Advantages
- Compared with the earlier generator type it is simpler in mechanical design and electrical structure.
- Seam is Rugged and brushless produces higher efficiency and higher energy.
- Three stage geared DFIG is weightless for cost effective solution,
- Power switching converter topologies matches the reactive power and ensures smooth integration of grid.
- Power Conversion Rating is only about 25%-30% in DFIG as compared to 100 % of maximum true power of the generator, it possible Can reach to about 30% of synchronous speed, thus have a wide speed range.

### 3.3.2. DFIG Disadvantages
- In these type, gearboxes are still essential, prior in multiple pole DFIG achieving lower speed is technically not possible.
- Grid side faulty conditions are not simpler to assemble
- Since produces upper than lower reliability and have limited life because of gear faults and bearing fault.

### 3.4. SCIG (Squirrel cage Induction Generator)
The SCIG is an strongly a better consideration in the category of variable drive wind power turbine and SCIG is in fully coordination with the power converter to adjust the voltage generated and frequency for load side in an standalone loads. Extraction of more power from wind is limited since it
causes overload at the generator. So as to grasp an optimal power, blade pitch angle is required. Since SCIG prolongs as a replacement energy resource by having simpler design structure, requires much lesser maintenance, excellent power to weight ratio so it is robust.

3.4.1. **SCIG Advantages**
- The construction is sturdy and simpler mechanism makes this machine very popular.
- Brushes are not required in SCIG compared to DFIG.
- Rotor bars are designed to be impervious to quivering smut
- Suitable for variable speed operations since grid is absolutely decoupled.
- Protection from the grid side is higher to avoid short circuit power to the generation side.

3.4.2. **SCIG Disadvantages:**
- Grid side and load side converters are required for operating.
- Compared with DFIG for variable speed operation it requires more number of power converter switches which makes more switching losses.
- SCIG is not suitable for gearless operation in multiport.

![SCIG working model blocks](image)

**Figure 6.** SCIG working model blocks

3.5. **PMSG (Permanent magnet synchronous generator)**
PMSG drive does not require gearbox since it does not have a rotor current with minimum rotational speed, since the drive is gearless small wind turbines are easily possible at consumer side with high efficiency at low maintenance cost. The principle of pmsg is that it generates torque from wind power. The developed torque is shifted to the rotor shaft of the generator. The mechanical rotation of the rotor acceleration depends on the produced electrical torque from the generator difference to the mechanical torque.

![PMSG structure representation](image)

**Figure 7.** PMSG structure representation
3.5.1. PMSG Advantages:
- Maintenance cost will cut down due to no gearbox.
- Possibility of faults in the generators will be eliminated since there is no gears and bearings, thus produces higher reliability.
- Minimum weight that produces higher energy yield.

3.5.2. PMSG Disadvantages:
- Compared with the SCIG, the outer diameter of the PMSG is almost double in size.
- It is a new technology drive, the cost being higher.
- Wind turbine capacity over 4MW leads to a critical proportions and have increased mass and weight.

Table 1 Comparison of Different Generator Topologies

| Generator Type                  | STRENGTHS                                                | WEAKNESS                                           |
|--------------------------------|----------------------------------------------------------|----------------------------------------------------|
| Induction Generator            | • Maximum speed capacity range                           | • power converter is must                          |
|                                | • Generator do not require brushes                        | • Gears are unavoidable                            |
|                                | • Reactive and active power are in full control          |                                                    |
| Synchronous Generator          | • Maximum speed range                                    | • Compact converter for field is enough           |
|                                | • Gear can be avoided                                    | • AC/DC/AC power converter is required            |
|                                | • Reactive and active power are of complete control      | • Multipole generator in case of direct driven topology |
| Doubly-fed Induction Generator | • Speed range limited from -30% to 30% around synchronous speed | • Slip rings are unavoidable                       |
|                                | • PWM inverter are of small capacity and inexpensive    | • Gears required                                   |
|                                | • Reactive and active power are of complete control      |                                                    |
| Permanent Magnet Synchronous Generator | • Maximum speed range                              | • AC/DC/AC power converter is required            |
|                                | • Gear can be avoided                                    | • Multipole generator (big and heavy)             |
|                                | • Reactive and active power are of complete control      | • Permanent magnets are necessary                  |
|                                | • No Brushes ensures low maintenance                     |                                                    |
|                                | • Field has no power converter                           |                                                    |
Figure 8. Wind energy power global and annual additions, around 60 GW increased till 2019.

4. Conclusion
This paper has intended to review the various technology for generators used in WECS. Due to the fact that the variable speed machines are in demand that produces lower mechanical stress and higher power capture. DFIG plays a key role in the current market by comparing with the variable speed wind turbine DFIG have the advantage of only 30% of the power generated passes through the converter topology this factor leads to a sensible cost cutting advantage compared with the cheap cost of nearby converters and power switches. Grid faults occurrence possibility is more in DFIG due to large peak currents, and SCIG suffers to a short circuit problems at grid. The parameters consideration of overall efficiency, long lasting and reliability and market availability, the PMSG wind turbine generator without the gearbox leads the top. Since they are larger in size, can be still installed at offshore where there is enough wind speed.

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