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Theoretical Approach for Comparison of Various Types of Wind Generator Systems

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Abstract: **Presently the major energy requirements have fulfilling by conventional sources out of which coal based thermal power generation is having major contribution. But such facts like the rate at which conventional sources are being consumed and their impact on environments, it is necessary to adopt alternate energy technologies which are more consistent. Out of various renewable energy sources, wind generation is most cost effective in addition to its various advantages. Worldwide the share of wind generation connected to grid is increasing at faster rate and in near future will become one of the major sources of renewable energy. With rapid development of wind power technologies and significant growth of wind power capacity installed worldwide, various wind turbine concepts have been developed. The control capabilities of these wind power plants are continuously improving to satisfy grid code requirements, ensuring a safe operation under normal and fault conditions. Considering the challenges to be faced related to interfacing of large wind farms using Induction and Synchronous generators, it is necessary to study the different wind generator systems and their comparisons. This paper analyzes and compares various wind turbine generator connections, its control using various power electronic circuits and study of the power quality and reactive power issues considering voltage quality and stability. An overview of different wind generator systems and their comparisons are presented.**

Keywords: **Wind Energy, Wind Turbines, Wind Generator System, Grid Connection, Power Quality.**

1. INTRODUCTION

Winds are essentially caused by solar heating of the atmosphere; they carry enormous quantity of energy. This wind energy can be harnessed to drive a wind turbine, to which is coupled with an electrical generator. The kinetic energy of the moving air (wind) rotates the blades of the wind machine. The blades convert the wind energy to mechanical energy, which in turn, is converted to electrical energy by the generator. The power output of wind machine is affected by wind velocity, machine efficiency, blade design, blade pitch, cross-sectional area, etc. Wind turbines can either operate at fixed speed or variable speed. For a fixed speed wind turbine the generator is directly connected to the electrical grid. The most common type of wind turbine is the fixed-speed wind turbine with the induction generator directly connected to the grid. This system has a number of drawbacks, however. The reactive power and, therefore, the grid voltage level cannot be controlled. Most of the drawbacks of fixed wind turbine are avoided when variable-speed wind turbines are used. These turbines improve the dynamic behaviour of the turbine and reduce the noise at low wind speeds. For a variable speed wind turbine the generator is controlled by power electronic equipment. There are several reasons for using variable-speed operation of wind turbines; among those are possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. Most of the major wind turbine manufactures are developing new larger wind turbines in the 3-to-5-MW range. Out of these, doubly fed induction generator which is type of asynchronous generator is more preferable because of its several advantages. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator. Considering the increasing share of wind generation interfaced to grid it is necessary to

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study an overall perspective on various types of existing wind generator systems and possible generator configurations and their comparison.

2. TYPES OF WIND TURBINES

- ***Fixed-speed wind turbines:***

It is characteristic of fixed-speed wind turbines that they are equipped with an induction generator that is directly connected to the grid, with a soft-starter and a capacitor bank for reducing reactive power compensation. They are designed to achieve maximum efficiency at one particular wind speed. In order to increase power production, the generator of some fixed-speed wind turbines has two winding sets. The fixed-speed wind turbine has the advantage of being simple, robust and reliable and well-proven. And the cost of its electrical parts is low. Its disadvantages are an uncontrollable reactive power consumption, mechanical stress and limited power quality control. Owing to its fixed-speed operation, all fluctuations in the wind speed are further transmitted as fluctuations in the mechanical torque and then as fluctuations in the electrical power on the grid.

- ***Variable-speed wind turbines:***

Variable-Speed wind turbines are designed to achieve maximum aerodynamic efficiency over a wide range of wind speeds. It has more complicated electrical system than that of a fixed-speed wind turbine. It is typically equipped with an induction or synchronous generator and connected to the grid through a power converter. The power converter controls the generator speed. The advantages of variable-speed wind turbines are an increased energy capture, improved power quality and reduced mechanical stress on the wind turbine. The disadvantages are losses in power electronics, the use of more components and the increased cost of equipment because of the power electronics. The introduction of variable-speed wind-turbine types increases the number of applicable generator types and also introduces several degrees of freedom in the combination of generator type and power converter type.

3. TYPES OF GENERATORS

Basically, a wind turbine can be equipped with any type of three-phase generator. Today, the demand for grid-compatible electric current can be met by connecting frequency converters, even if the generator supplies alternating current (AC) of variable frequency or direct current (DC). Several generic types of generators may be used in wind turbines:

- Synchronous Generator
- Asynchronous or Induction Generator

1. Synchronous generator (SG):

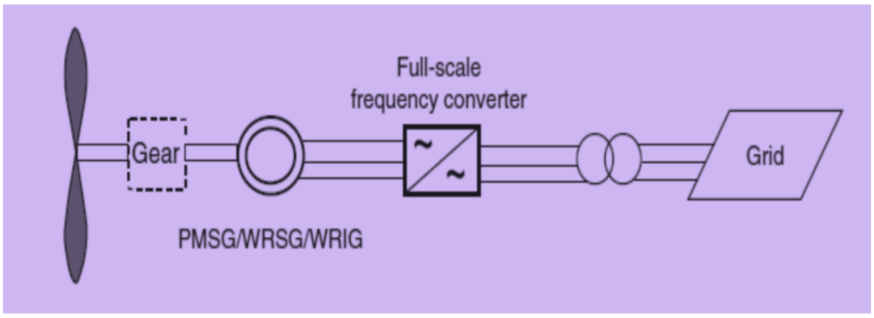

Figure 1 SG

A synchronous generator (figure 1) operates at the synchronously rotating speed of an alternating current system to which it is connected. A synchronous generator requires direct current to be supplied to the rotor winding via slipping to produce the rotor's magnetic flux. The prime mover (wind) drives the generator rotor forming a rotating magnetic field that induces a voltage in the stator windings of the unit. The windings of the stator are arranged so that a three-phase voltage is produced. Interactions of rotating magnetic field of synchronize rotation, which inducts a three-blade voltage. The induction voltage of alternating current is given by the following equation-

$E = K\phi\omega syn$

Where,

K-electrical coefficient of generator

ϕ- rotor magnetic flux (Wb)

ωsyn: Angular velocity of rotor rotating at synchronous speed.

Synchronous generator applies to wind-powered units when the rotating blades directly drive the rotor without any gearbox, avoiding the noise and wear of meshing drive gears.

Types of synchronous generator-

- wound rotor synchronous generator (WRSG)
- Permanent magnet synchronous generator (PMSG)

Wound Rotor Synchronous Generator (WRSG):

The stator windings of WRSGs are connected directly to the grid and hence the rotational speed is strictly fixed by the frequency of the supply grid. The rotor winding is excited with direct current using slip rings and brushes or with a brushless exciter with a rotating rectifier. It has the advantage that it does not need a gearbox. But the price that has to be paid for such gearless design is a large and heavy generator and a full-scale power converter that has to handle the full power of the system.

Permanent Magnet Synchronous Generator (PMSG):

In the permanent magnet machine, the efficiency is higher than in the induction machine, as the excitation is provided without any energy supply. However, the materials used for producing permanent magnets are expensive, and they are difficult to work during manufacturing. Additionally, the use of PM excitation requires the use of a full scale power converter in order to adjust the voltage and frequency of generation to the voltage and the frequency of transmission, respectively. The stator of PMSGs is wound, and the rotor is provided with a permanent magnet pole system. The synchronous nature of the PMSG may cause problems during start-up, synchronization and voltage regulation. It does not readily provide a constant voltage. Another disadvantage of PMSGs is that the magnetic materials are sensitive to temperature. Therefore, the rotor temperature of a PMSG must be supervised and a cooling system is required. Because the rotating magnetic field is fixed and the rotor rotating speed varies with wind velocity, the output voltage and frequency are variable and cannot provide a stable power supply. Due to the small capacity and higher cost per kilowatt of output, this type is not suit-able for commercial applications. It is only suitable for remote areas without a grid power supply.

2. Asynchronous or Induction Generator:

The three-phase induction generator uses magnetic induction theory to transfer the electrical energy in the form of magnetic flux from stator to rotor, without any wire connection. Power from an external source energizes the stator, causing the rotor to turn, just like an induction motor. The rotating speed of the rotor is slightly lower than the rotating magnetic flux in the stator. This type generator is also called an asynchronous machine. When the rotor speed of an induction generator exceeds the speed rotating magnetic field in the stator, and the rotor direction is consistent with rotating magnetic field, the rotor will tend to pull the stator field faster. This action causes a reverse torque in the rotating direction, thus causing the induction generator to operate as a generator at the frequency and voltage of the initial power supply to the stator. In a properly designed machine, the magnetic link between the rotor and stator is strong enough to prevent the rotor going into over speed, regardless of the energy input from the blades. The definition of rotating difference ratio for an induction generator is

$$S = \left(\frac{Nsyn - Nm}{Nsyn}\right) * 100$$

Where,

Nsyn=synchronous speed of magnetic field (rpm)

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Nm= rotating speed of rotor (rpm)

Induction generators can be classified according to their rotor construction and type of excitation process.

Classification on the basis of their rotor construction-

-Squirrel cage induction generator (SCIG)

-Wound rotor induction generator (WRIG)

I. OptiSlip induction generator (OSIG)

II. Doubly-fed induction generator (DFIG)

Squirrel Cage Induction Generator:

For the squirrel cage type induction generator, the rotor winding consists of un-insulated conductors; in the form of copper and aluminium bars embedded in the semi closed slots. These solid bars are short circuited at both ends by end rings of the same material. Without the rotor core, the rotor bars and end rings look like the cage of a squirrel. The rotor bars form a uniformly distributed winding in the rotor slots.

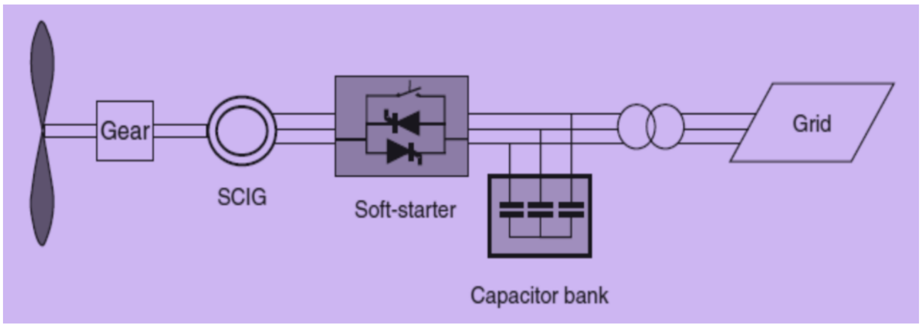

Figure 2 SCIG

As illustrated in Figure (2) the SCIG is directly grid coupled. The SCIG speed changes by only a few percent because of the generator slip caused by changes in wind speed. Therefore, this generator is used for constant-speed wind turbines. The major problem is because of the magnetizing current the full load power factor is relatively low. Too low a power factor is compensated by connecting capacitors in parallel to the generator. In the case of a fault, SCIGs without any reactive power compensation system can lead to voltage instability on the grid. The wind turbine rotor may speed up, for instance, when a fault occurs, owing to the imbalance between the electrical and mechanical torque.

Wound rotor induction generator:

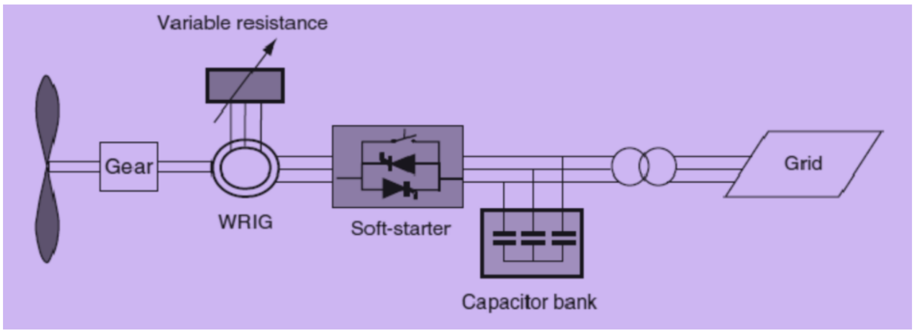

Figure 3 WRIG

Wound rotor induction generator has two subcategories-

I. OptiSlip induction generator

The OptiSlip feature allows generator to have a variable slip and to choose the optimum slip, resulting in smaller fluctuations in torque and power output. The variable slip is a very simple, reliable and cost-effective way to achieve load

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reductions. WRIG includes a variable external rotor resistance by means of which slip can be controlled. The converter is optically controlled, which means that no slip rings are necessary. The stator of the generator is connected directly to the grid. The advantages of this generator concept are a simple circuit topology, no need for slip rings and an improved operating speed range compared with the SCIG. However, it still requires a reactive power compensation system. The disadvantages include the speed range is typically limited to 0–10 %, poor control of active and reactive power is achieved and the slip power is dissipated in the variable resistance as losses.

II. Doubly fed induction generator:

The term 'doubly fed' refers to the fact that the voltage on the stator is applied from the grid and the voltage on the rotor is induced by the power converter. This system allows a variable-speed operation over a large, but restricted, range. The converter compensates the difference between the mechanical and electrical frequency by injecting a rotor current with a variable frequency. Both during normal operation and faults the behaviour of the generator is thus governed by the power converter and its controllers.

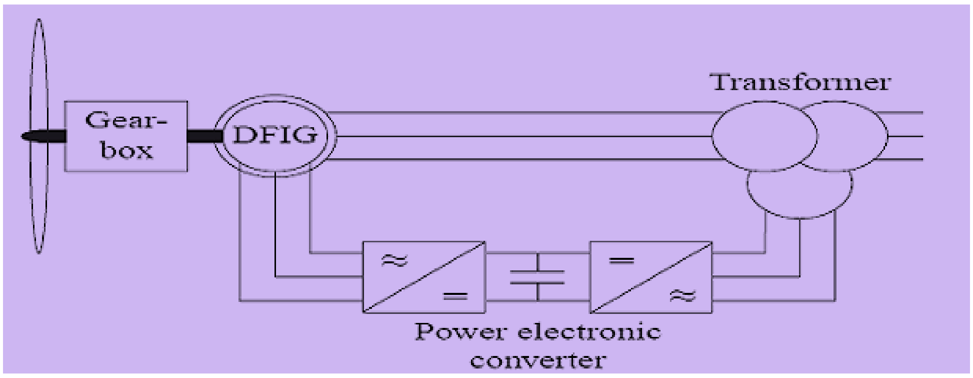

Figure 4 DFIG

The power converter consists of two converters, the rotor-side converter and grid-side converter, which are controlled independently of each other. The rotor-side converter controls the active and reactive power by controlling the rotor current components, while the line-side converter controls the DC-link voltage and ensures a converter operation at unity power factor. In both cases – sub synchronous and over synchronous – the stator feeds energy into the grid. The DFIG has several advantages. The DFIG has not necessarily to be magnetized from the power grid; it can be magnetized from the rotor circuit, too. It is also capable of generating reactive power that can be delivered to the stator by the grid-side converter. In the case of a weak grid, where the voltage may fluctuate, the DFIG may be ordered to produce or absorb an amount of reactive power to or from the grid, with the purpose of voltage control. The converter used in DFIG is back to back converter the back-to-back converter is highly relevant to wind turbines today.

Classification on the basis of their excitement process-

- Grid connected induction generator
- Self-excited induction generator

Grid Connected Induction Generator (GCIG):

The grid-connected induction generator (GCIG) takes the reactive power from the grid, and generates real power via slip control when driven above the synchronous speed, so it is called grid connected induction generator. It is also called autonomous system. The operation is relatively simple as voltage and frequency are governed by the grid voltage and grid frequency respectively. The GCIG results in large inrush and voltage drop at the time of connection, and its operation makes the grid weak.

Self-Excited Induction Generator (SEIG):

The self-excited induction generator takes the power for excitation process from a capacitor bank, connected across the stator terminals of the induction generator. This capacitor bank also supplies the reactive power to the load. The excitation capacitance serves a dual purpose for standalone induction generator: first ringing with the machine inductance in a negatively damped, resonant circuit to build up the terminal voltage from zero using only the permanent magnetism of the machine, and then correcting the power factor of the machine by supplying the generator reactive power.

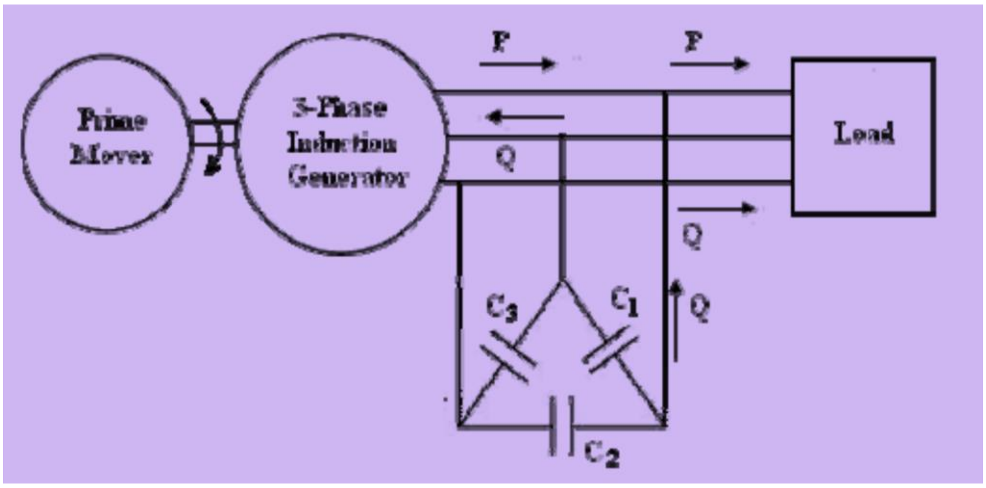

Figure 5 SEIG

4. COMPARISON OF SYNCHRONOUS GENERATOR AND INDUCTION GENERATOR

The stator construction is identical for a synchronous generator and an induction generator. The major difference is rotor design and construction. The winding of rotor of a synchronous generator need to have direct current (DC) for excitation to produce the rotor's magnetic field but the damper windings of the rotor of the induction generator need to be short-circuited to produce rotor magnetic field. **Table** shows the comparison of synchronous and induction generators.

Items	Synchronous Generator	Induction Generator
Stator structure	Three-phase winding	Three-phase winding
Rotor structure	Has evidenced and controlled pole rotor winding need to connect to DC source	Has cage rotor, winding doesn't need to connect DC
Speed	Operating at synchronize speed	Operating at over-synchronous speed
Reactive power compensation	Not needed	From system or connect to capacitor
End voltage control	Cause exciting system control	Can't control
Converter device	Needed	Not needed
Maintenance	Complicate and difficult	Simple and easy
Cost	Expensive	Cheap

5. HIGH EFFICIENCY DOUBLE-FED INDUCTION GENERATOR

The disadvantages and limitations of the self-exciting induction generator include the difficulty to adjust the output voltage and frequency, the need to be operated at over-synchronous speed, the small range of output power, etc. Currently, new developments in the windings of the induction generator and vector control theory as applied to controlling the rotor input voltage and frequency can modulate the power input and output characteristics of the generator rotor. With the advantages of operating in an sub-synchronous speed range, output can exceed rated power; closer control of output voltage and frequency is obtained.

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6. SIGNIFICANT POWER QUALITY ISSUES

Significant power quality issues related to incorporation of wind farms in weedy grids are as follows to differentiate the power quality:

1. Grid accessibility and capacity,
2. Reactive power,
3. Voltage disturbance,
4. Voltage limit violations,
5. Frequency violations,
6. Harmonics and interharmonics,
7. Voltage fluctuations.

Of these, reactive power is at the most important parameter, while other is the primary parameters influencing the wind turbine operation.

7. CONCLUSION

The paper provides an overview of different wind turbine concepts and generator types. The basic configurations and characteristics of various wind generator systems based on contemporary wind turbine concepts are described with their advantages and disadvantages. It is obvious that the introduction of variable-speed options in wind turbines increases the number of applicable generator types and further introduces several degrees of freedom in the combination of generator type and power converter type. A very significant trend for wind turbines is that large wind farms will have to behave as integral parts of the electrical power system and develop power plant characteristics. Power electronic devices are promising technical solutions to provide wind power installations with power system control capabilities and to improve their effect on power system stability.

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