A Review on Wind Energy Conversion Systems (Wecs) Generators

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Abstract - Wake effects cause the wind turbine generators (WTG) in a wind power plant (WPP) to produce different levels of active power and subsequent reactive power. In addition, the impedance between a wind turbine and the point of interconnection (POI) -which depends on the distance between them- affects the reactive power injection capacity from the WPP to the POI. This work proposes a voltage control scheme for a WPP based on the reactive power available from doubly-fed induction generators (DFIG) and its effects on the POI to improve the reactive power injection of the WPP. This article proposes a design strategy for changing the DFIG controller gain and examines the comprehensive properties of these control gains. In the proposed scheme, the WPP controller, operating in the voltage regulation mode, sends the control signal to the DFIGs according to the voltage difference at the POI. DFIG controllers, operating in voltage regulation mode, use a proportional controller with a limiter. The proportional controller gain is adjusted according to the available reactive current of the DFIG and the series impedance between the DFIG and the POI. The performance of the proposed scheme is validated for various faults, such as reactive load connection and network faults, using an EMTP-RV simulator. The simulation results show that the proposed scheme quickly restores the POI voltage by injecting more reactive power after a fault than the conventional scheme.

***Key Words*:** Doubly-fed induction generator, Voltage control, Wind power plant, Wake effect, Available reactive current, Point of interconnection.

1. INTRODUCTION

Wind energy system is becoming more and more popular due to technological development in recent years. In this situation wind energy is going to be a better option to fulfil the ever increasing demand of energy. It is the cleanest form of energy having no emission which is detrimental to the environment. Utilization of wind energy is mostly associated with conversion into electrical energy. After the oil crises in 1973 European countries started to find solution for their own renewable energy [1].Among the known energy sources like wind, solar and biomass, wind energy for electrical power generation has shown the fastest rate of growth in recent years [2].

Wind energy conversion is the process by which physical energy of wind is converted into electrical energy. Wind possesses kinetic energy which is first converted to mechanical power by the help of wind turbine, and that mechanical power is used to create electrical power. . Despite of the fact that wind turbine has some untoward environmental impact [3, 4], like noise, it is still more environment friendly when compared to fossil fuel. Due to excessive exploitation of conventional sources like coal, petroleum and natural gases for energy requirement, the emission of carbon dioxide is growing, that is expected to rise up to 36 billion metric tons globally in 2020 [5]. Due to rise of in the atmosphere, the average global temperature could rise between F and F by year 2100 [6].

The solution of these serious environment related issue lies in the use of clean, long term eco-friendly renewable energy sources. Several countries have come forward for the development of technology so that effective exploitation of renewables like wind, solar, tidal, geothermal, biomass, could be done. Among all these existing renewable source wind energy can be one of the most efficient energy source for the generation of power, having the ability to fulfil world's energy needs [7].

2. WIND TECHNOLOGIES

Power generation with the help of wind energy is one of the most viable solution for fulfilling energy demand. Due to erratic nature of wind, its forecasting is one of the fundamental necessity in wind energy systems [10]. The utilization of wind energy can be done in two ways. It can either be directly used as mechanical energy or by converting it into electrical energy indirectly. Wind turbine is the vital part of WECS which is used to capture physical energy of wind and converting it to mechanical energy by rotating rotor of generator with the help of gearbox [11]. Production of electricity by exploiting the abundantly available wind energy became possible only after advent of wind turbine [12]. In the Fig. 4, a detailed view of the inside of a wind turbine, its components, and their functionality is shown. The development of special type of generators, together with the help of power electronic devices, have made the scope for gearless turbine designs [14].

2.1 Wind turbine design

A wind turbine is a complex electromechanical system consisting of many components and subsystems. Selection of size and design of wind turbine is done according to demand, location, and wind profile with the prime motive of reduction in price and maximizing wind energy capture. From the last many decades research and advancement for the turbine technology has been rising.

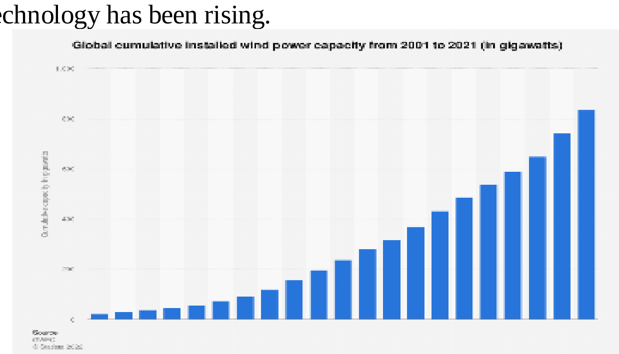

Fig. 1. The cumulative global wind power growth from theyear 2001 to 2021

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 08 | August - 2022 Impact Factor: 7.185 ISSN: 2582-3930

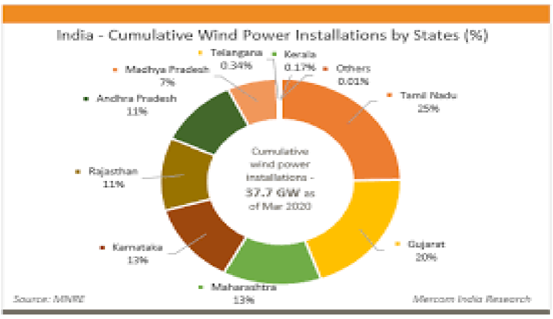

Fig. 2. Distribution of different renewable energy sources inIndia.

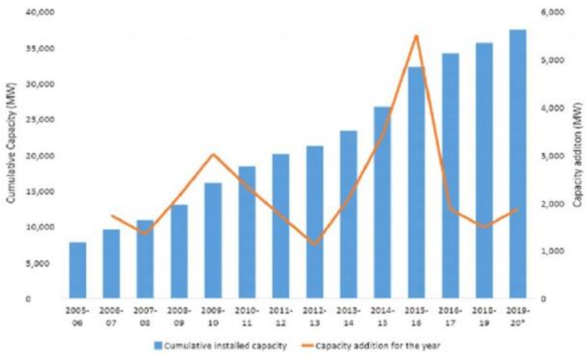

Fig. 3. Wind power growth in India.

As a result of continuous research and development, now wind turbine of rating varying from several kilowatts to megawatts is available. Super conductor based power equipment has been the subject of intensive research from the last two decades [15]. Due to the use of High temperature superconductor (HTS) technology, size and cost of 10 MW – class generator for wind turbine system is reduced [16]. The one of the most important parameter of the wind turbine is its diameter. Nowadays the emphasis is being given on turbine with long turbines blades, as longer blades have the capacity to sweep wind energy from a larger area and generate greater amount of output energy.

Rotor Hub and Blade- The interaction between wind and rotor blade is the important factor for the production of power. The rotor consists of large turbine blades and hub. Blades resemble the wings of an aeroplane. Blades are normally large in size. Generally three bladed wind turbines are used in practice. Another component of rotor is pitch drive, which is used to keep the rotational speed of rotor blades at desired operational range of 1000-3600 RPM (revolution per minute).

Gearbox- Gear and bearings are two main components of gearbox. The rotor speed in wind turbine (Variable speed wind turbine with pitch system) is ranging from 7-30 rpm and gear box ratio is typically of ratio 1: (100-150), for 6 pole generator rated RPM is 1000, 4 pole rated RPM is 1500, and for 2 pole generator RPM 3000. In general 4 or 6 pole generator is used with gear box. The rotor speed of wind turbine is not sufficient to produce electricity as most generators need the speed of 1000-3600 RPM. Therefore gearbox increases the speed of the generator rotor to 1000- 3600 RPM to render generator functional.

Generator- The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity. Thus generator converts mechanical energy of wind turbine rotor into electrical energy.

A voltage control mode was used for both WPP and WTG controllers in[10, 11]. In[10], a WPP controller used the reactive power to voltage (Q-V) characteristic of a WPP to generate the voltage reference signal for each WTG. In contrast, the Q-V characteristic of a DFIG was used in the WTG controller in[11]. This scheme is capable of providing better performance in terms of voltage support than that described in[10]. However, these conventional schemes use the fixed Q-V characteristic based on the rated power irrespective of the reactive power capability, and thus their available reactive power is unable to be fully injected.

Air creates two type of dynamic forces when it flows over any surface, one is drag force (in the same direction of air flow) and another is lift force (in the normal to air flow).These two forces are responsible for generating the driving torque needed to rotate the turbine blades.

$P_{wind} = 0.5\rho\pi R^2 V$ ....(1)

Where ρ is the air density, R is the turbine radius in the wind speed and ω_r Is the rotational speed of wind.

$P_{blade} = 0.5\rho\pi R^2 * (V_w)^3 C_p(\lambda,\beta)$ ....(2)

where, λ is tip-speed ratio (TSR) and β is the pitch angleof turbine blade. C_p is the power coefficient. It is given by,

$C_p(\lambda,\beta) = 0.5176((116/\lambda_i) - 0.4\beta - 5))^{21/\lambda_i} + 0.0068\lambda$ ....(3)

λ may be expressed by the relationship,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$ …………..(4)

On the basis of above written equations, a MATLAB program has been written to analyse the relationship between tip to speed ratio (TSR) and power coefficient at varying pitch angle as depicted in Fig. 5. It can be concluded that at lowest pitch angle value of turbine blade, power coefficient is maximum at given wind speed. It is evident that only oneparticular value of TSR yields the highest efficiency. It may also be verified from the figure that theoretical maximum power coefficient cannot exceeds a certain value 0.59(Betz limit). The graph between the power coefficients versus tip- speed ratio is very important tool in the characterization of converters used in wind electrical system.

3. Wind Energy Conversion System

Electricity is generated by converting physical energy of wind with the help of rotor. The kinetic energy of wind is captured by wind turbine with the help of especially aerodynamically designed blades. The mechanical energy of rotating blades is transferred to generator rotor and electricity is generated with the rotation of rotor. This electrical energy can be used to fulfil standalone demand or sent to grid through a transformer for more widespread applications.

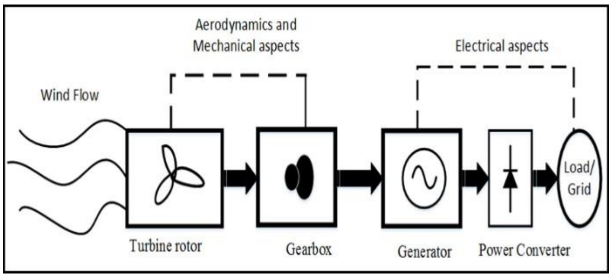

Fig. 6. A general layout of wind energy conversion system.

The connection between turbine and grid is done at different level of voltages. According to rotational speed of aero turbines WECS is basically categorized into two types, fixed speed and variable speed. Fixed speed system operates at almost constant speed. It concludes that irrespective of the speed of wind turbine, the rotor maintains a fixed angular speed, which is determined by supply frequency at grid and gear ratio. The drawback of such system is that any fluctuation in wind power has a direct impact on grid. In variable speed system the generator torque is kept fixed and generator speed is varied [23]. The generator speed can be adjusted to maximize the power extraction from the wind using rotor side power converter. A general layout of wind energy conversion system is shown in Fig. 6.

3.1. Generator system

Although several types of generators are employed in wind electricity market, but the permanent magnet synchronous generator(PMSG) and double fed induction generator(DFIG) are getting more and more attention day by day, due to their ability of being more reliable, and capturing more wind energy [24],[25]. Between the ac and dc generators, ac generator are more popular and mostly dominate the market due to lower expenditure, less maintenance, and higher rating. A classification of the different types of generators employed in WECS is given in the Fig. 7.

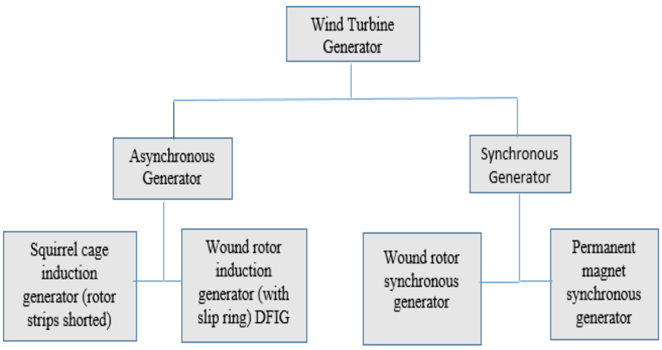

Fig. 7. Various commonly used wind turbine generator

3.1.3. Future Scope for Wind Generator System

There is serious concern about the impact of erratic wind power on the power system stability especially during grid fault. Therefore, one of the most attentional subject for researcher community is to develop ability for wind power generator system to protect itself during grid fault without being disconnected. Therefore, in the future, to design the generator with low weight & maintenance having fault ride through capability will be one of the main motive. Moreover, reduction in prices of generator system will be also great issue in the future. Therefore, not only being dependent upon commonly used wind turbine generators i.e. PMSG, DFIG or

3.1.1 Synchronous Genrator

Wind turbine using synchronous generator are often termed as gearless or direct drive wind turbine generator system. Nowadays, PMSG supported with different power electronics converter topology is getting huge attention to generate power from gearless wind turbine [26], [27]. Magnetic field in PMSG is produced by permanent magnet. It has received much focus due to its self-excitation capacity [28]. PMSG can be run with or without the gear. The power of gearless PMSG wind turbine system can be enhanced with using multiple number of poles. This arrangement can be directly connected to the grid without the gearbox, hence minimizing the mechanical loss, reducing the construction, maintenance and operation costs of the wind turbine generator system[29],[30]. The relatively lower weight ofPMSG and its gearless wind turbine system design makes an attractive choice for its selection for variable speed windpower generator system. Due to their small size and weight PMSGs are particularly useful in low-power wind energy applications [31]. Thus the huge advantage of synchronous generator over induction generator in WECS is the absenceof gearbox resulting an increase of system efficiency and reliability. Though absence of gearbox can be cost effective, it requires more number of poles to match the speed of gearless wind turbine with that of wind turbine with gear, making the direct drive generator larger and heavier. Therefore, indirect drive synchronous generator with lesser number of poles is still an acceptable choice in wind energy market [25].

3.1.2 Asynchronous Genrator

Due to simple operation, brushless structure, good dynamic response, and less price Induction generator (IG) are also vastly used as wind turbine generator [32]. They have robust structure and provide protection against short circuit. For its operation, IG needs reactive power to be fed to generate the magnetic field. A grid tied IG draw reactive power from grid. However, in standalone application, this reactive power can be supplied by external sources such as, power electronics converter, or bank of capacitors, called SEIG (self-excited induction generator) [33]. Owing to high cost of capacitors and maintenance requirement, SEIG is economically appropriate for small power plant [34], [35]. On the basis of rotor two type of induction generator is used as wind turbine generator, wound rotor induction generator (WRIG) and squirrel cage induction generator (SCIG). WRIG can be configured as DFIG which is widely used wind turbine generator nowadays. Variable speed operation using DFIG can be achieved by connecting the rotor circuit of DFIG by an external variable voltage through slip rings and controlled by external means [33]. The stator of DFIG is coupled with grid via transformer whereas rotor is connected through the grid via harmonic filter, power converter and the transformer. Connection of the stator with grid has a disadvantage that DFIG based WECS is more likely to be subjected to grid fault. The stator flux cannot follow abrupt change in stator voltage.

SCIG, focus should be given on the invention of other new types of generators. With light weight and about near zero resistivity superconductor based power devices has been area of intensive research nowadays. Size and weight are greatly reduced in high temperature superconductor (HTS) direct drive generator. Superconductors have high current carrying capability. Moreover it shows characteristics of permanent magnet, hence it may be the preferred choice for PMSG. The stator and rotor of synchronous generator made out of HTS have huge advantages.

3.2 Development of Power Electronics

The nature of wind flow is very erratic in nature. It has varying daily and seasonal pattern. Therefore, it is not easy to operate a power system installed only with wind power generation unit. The power electronics helps the WECS to enhance its reliability and improve performance of the system by decreasing the mechanical stress and raising energy yield, because of which the whole WECS acts like controllable generation unit and enabling itself for better integration of wind power to grid . Variable speed operation is more advantageous than fixed speed system for numbers of reasons, like reduced mechanical stress, greater power capture, better controllability and power quality, which are extremely needed for grid integration . Thus variable speed wind turbines (WTs) has got better market penetration than fixed speed. The power electronics plays an important role in variable speed WTs (Fig. 8) . It is evident that even in the fixed speed WTs, where power generator is directly linked with grid, thyristors-(power electronic semiconductor device), are used as soft starter. Though use of such power electronics converter mayincrease the cost of the system, this expense may be toleratedas it helps to reduce mechanical complexity, absorb mechanical stress minimizing the effect of wind gust. Inmany cases it eliminate the need of gearbox (Fig. 8(d)) whichis main reason for losses and failure in wind turbine system. For wind electrical system many converter technologies are being employed. To overcome this drawback a new back to back current source inverter (CSI) topology has been presented, in which switches are protected from overvoltage during commutation as in case of commonly used CSI .

Nowadays, huge effort is being given for improving the efficiency, capability as well as reducing the cost of ESS. The aim of research should be directed to make ESS economically feasible so as to make highest possible utilization of wind energy. To attain the future goal of higher wind electricity penetration into the market wakeful selection of storage technologies on the basis of desired operating condition, application, storage capacity and power rating is most sought after aspects for wind electricity generation. Life time and cost-effectiveness of present storage system need to be improved as much possible. The optimal size and their overall management together with the power system for obtaining the maximum economical advantage is going to be challenging task in future. Effective numerical optimization problem should be proposed in order to maximize the economical benefit from the storage device.

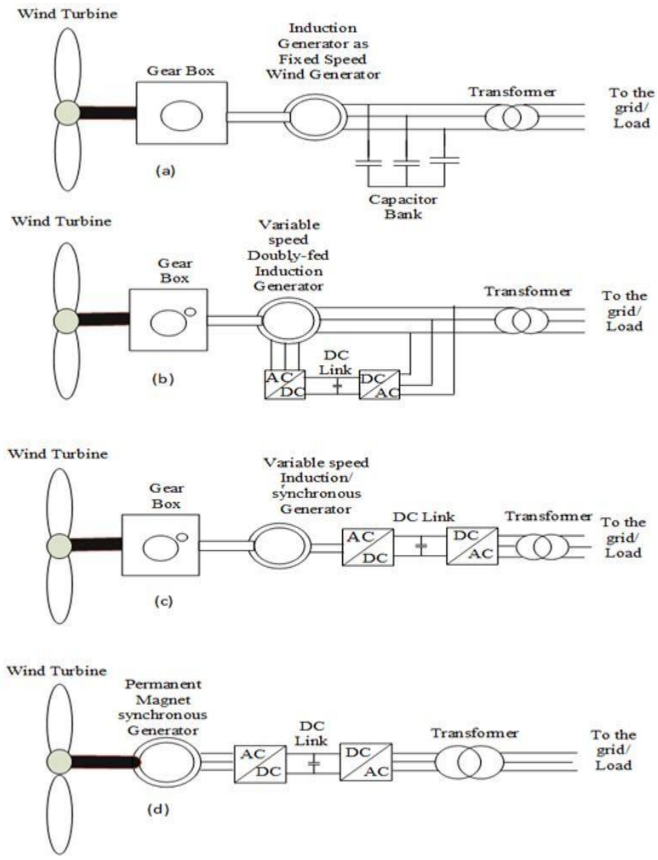

Fig. 8. Power electronics converters in WECS

T fulfil the fast growing demand and overcome the challenges present in wind energy conversion system some more advanced power electronic technologies can be expected to flourish in coming days where significant improvement could take place in power electronics converter to achieve power conversion at higher voltage level. A full scale power converter based back to back cascaded H-bridge converter, having galvanic insulated dc/dc converters as interface, may be one of the promising solution for future WECS. The dc-dc converter has medium frequency transformer operating at several kilohertz, reducing the transformer size significantly. The power semiconductor devices are linchpin in power converter design for wind electrical system. Nowadays, the potential silicon based power semiconductor devices used are pack-aged IGBT, press-pack packaged IGBT and the press packaging integrated gate commutated thyristor (IGCT). Recently, silicon carbide based devices which are primarily in the form of MOSFET as well as diode has gone through major development. From the above discussion it can be concluded that in the future, main aim of power electronics will be towards grid integration, enabling compatibility of wind power in the power system, lower cost and higher reliability.

4. Conclusion

This work is mainly study on different technical aspects for harnessing wind energy. Current trends and future possible research directions associated with energy conversion technology is presented. Need of the present hour is to exploit the available wind energy at every corner ofearth to meet our energy demand.

The variable speed DFIG based WECS is most popular. But, with the growing need of the system reliability and generator with fault ride through capability, the direct-drive system with full-scale converter and PMSG is also getting more attention as wind turbine generator. For reliable operation of WECS there is need of an efficient energy storage system (ESS) and hence developing a simple and the economical procedure for the same. Before setting up ESS, proper assessment on the commercial feasibility of the storage technology should be done. Intermittent nature of wind poses difficult task before the control techniques in WECS to obtain reliable and consistent power supply. Importance of power electronics in the wind electrical system has been demonstrated. Power electronics converters increase reliability and improve performance of the system by decreasing the mechanical stress and enhancing energy yield. There is need of more and more investigation in power electronics side for reliable and simplified grid integration. A review of technologies related to different control strategy found for MPPT, pitch control and GSC/MSC is presented. IEC standard and GL guidelines for the proper design, safety and operation are mentioned in brief.

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