

Chapter 4

Wind Energy Conversion Systems

Learning Objectives

On completion of this chapter, the reader will have knowledge on:

- Characteristics of Wind Energy.
- Basic components of Wind Energy Conversion systems.
- Types of Wind Turbine Generator Configurations.
- Power Converter Topologies for Wind Turbine Generator.
- MATLAB/SIMULINK model of Wind Turbine.
- MATLAB/SIMULINK model of different types of turbines in WECS.
- Grid Integration and MATLAB/SIMULINK model of Grid Connected WECS.

4.1 Introduction

The wind is a free, clean, and inexhaustible type of solar powered energy. Winds originate from the uneven heating in the atmosphere from the sun, the irregularities from the earth's surface, and rotation of the earth. Wind flow patterns are modified through the land terrain, environmental conditions and buildings. This wind flow, or motion energy, when harvested by modern wind turbines, enable to generate electricity. The terms wind energy or wind generation describes the task where the wind is utilized to come up with mechanical power or electricity. Wind turbines convert the kinetic energy inside wind turbine into mechanical power. This mechanical power may be used for grinding grain or pumping water or perhaps a generator can convert this mechanical power into electricity energy. Wind turbines exactly like the aircraft propeller blades, converts the linear motion in the air into circular motion and powers a power generator that supplies a current. The wind turns the blades, high torque, low speed of the wind will result in low torque, high

speed using gearbox and through a shaft, which connects to a generator and in turn produces electricity. Wind turbines can be bought in different sizes, and as a consequence different power ratings. Utility-scale turbines range in size from 50 to 750 kW. Single small turbines, below 50 kW can be used for domestic applications. Wind turbines will often be grouped together in a single wind generation plant, alias wind energy facility. Electricity out there turbines is fed in to a utility grid and distributed to customers, just like conventional power plants.

The wind has been utilized to power wind-surfing ships for almost all centuries. Many international locations owed their success on their science in sailing. No doubt, wind was about the only actual power source intended for ships until W invented the water engine inside the actual 1700s. The first recorded English generator is dated at 1191. In this generation, the initial corn-grinding windmill was integrated. There were quite a few technological developments on the centuries, and furthermore during 1600 the most popular windmill was the actual tower mill. This phrase mill refers to the operation of grinding or milling texture. Based on this application, wind generators were categorised as windmills regardless in the event that these people moved water or performed some other work. Denmark was the primary country to work with the wind pertaining to generation of electrical energy. Denmark was the leading country to operate the wind for multiplication of electricity.

During 1925, commercial wind-electric plants using a couple of- and three-bladed propellers appeared for the American market. The most commonly encountered brands were Wincharger (200–1,200 W) as well as Jacobs (1.5–3 kW). These were applied to farms to charge hard drive batteries which were then used to operate receivers, lights, and small devices with voltage ratings involving 12, 32, or 110 volts. A good collection of 32 Vdc appliances was made by industry to meet this demand. Then the Rural Electric Administration (REA) was established by Congress in 1936. Low interest rate loans were provided and so the necessary transmission and circulation lines could be made to supply farmers using electricity. In the conception of the REA, approximately during 1940, electricity could follow supplied to the outlying customer at a tariff of 3–6 cents per kWh. The equivalent cost of wind created electricity was 12–30 cents per kWh when interest, accounting allowance, and maintenance were incorporated. After 1940, the price of utility generated electricity carried on a slow decline, sinking under 3 cents per kWh in the beginning 1970s. This ended up by using larger and more useful generating plants.

The Federal Wind Energy Program got its beginning in 1975 when a joint Solar technology Panel of the National Science Foundation (NSF) as well as the National Aeronautics and Space Administration (NASA) recommended that will wind energy be created to broaden the Region's energy options achievable energy sources. With 1973, NSF was given the responsibility for this Federal Solar Energy Plan, of which wind vitality was a part. The actual Lewis Research Center, any Federal Laboratory controlled by simply NASA, was selected to deal with the technology development and also initial deployment of prominent wind turbines. Early in 1974, NASA was financed by NSF to (1) design, build, and operate a wind turbine for research purposes, designated the MOD-0, initiate scientific studies of wind turbines pertaining to utility application, and (three or more) undertake a

program involving supporting research and engineering development for wind turbines. In 1975, the liability within the Federal governing for wind turbine development was assigned to the actual newly created Energy Analysis and Development Administration (ERDA). ERDA was after that by the United States DOE (DOE) in 1977. The actual NASA Lewis Research Center continued to direct the technology development of prominent turbines during this time.

In this chapter, the characteristics of Wind energy and components of Wind energy conversion systems are discussed. The types of wind turbine generators based on their electrical configuration are described. The power converter topologies used for wind turbine generators are elaborated in detail. The MATLAB/SIMULINK models for wind turbine and types of wind turbine generators are developed and the simulation results are analyzed. The concept of grid connection with SIMULINK model is presented in this chapter.

4.2 Wind Characteristics

The wind blows to the south and goes round to the north; round and round goes the wind, and on its circuits the wind returns. Ecclesiastes 1:6

The earth's air can be modeled as a gigantic heat engine. The item extracts energy from the sun in addition to delivers heat to yet another reservoir at a cheaper temperature (space). In the procedure, work is done within the gases in the ambience and upon the ground-atmosphere boundary. There will likely be regions where the atmospheric pressure is temporarily higher or perhaps lower than average. That difference in air pressure causes atmospheric gases or perhaps wind to flow through the region of higher pressure to that of reduced pressure. These regions are normally hundreds of kilometers in diameter. The wind relocating counter clockwise in the particular cyclone experiences a strain gradient force f_p inward, a Coriolis force f_c outward, and a centrifugal force f_g outward. For wind to go on moving in an antagonistic clockwise direction parallel for the isobars, the forces have to be balanced, so the stress gradient force for a cyclone is $f_p = f_c + f_g$. The pressure force inward is balanced well by the sum from the Coriolis and centrifugal aids. The wind that runs in such a product is called the gradient wind flow.

Mechanical designing of gears, shafts and brakes is performed. They possess effect on minimum energy required to start the equipment, cut-in-speed, potential to absorb variation within rotor torque by keeping in the form of strain energy, shaft rigidity for non-useful a good deal and flexibility for beneficial loads. Structural design is carried out for knives, root, hub, support anatomical structure, tower and foundation according to static, dynamic and tiredness loading. Blade root will be subjected to loads together with moments in all several direction. Further they change through-out the lifetime of the machine even whether it's in a shut-down condition. Soft designing techniques like coning and teetering of rotor works extremely well in rotor design. Collection of tower is also important in wind machine design the way it slows down the breeze and also imparts innervation loads on the device. Natural frequencies of distinct wind machine

components ought to be carefully designed considering how often these excitation loads exist. The wind machine also needs to be designed considering the requirements of transport and installation. Direct smooth highways are required to carry long blades and installation equipment to the installation site usually in remote parts. Similarly, heavy, sophisticated along with costlier material handling products are required to handle heavy and unwieldy machine pieces at site.

Characteristic parameters for wind machine are

- Rated power of the machine, is the maximum power developed by the rotor and is also the generator rating.
- Cut-in speed, u_c is the minimum wind speed at which the machine starts rotating.
- Rated speed, u_R is the minimum wind speed at which the machine develops rated power. This is the speed at which the blade regulation become active.
- Furling speed, u_F is the maximum wind speed at which the machine develops power. The machine is stopped beyond this speed.

4.3 Wind Turbine

The principle of wind turbines in power generation is transformation of the air kinetic energy into rotating mechanical power of the turbine rotor blades. At this moment soon enough the most common secondary wind turbine is the particular horizontal-axis propeller having 2 or 3 blades mounted on the top of a tower. The selection of number of blades of the wind turbine is not an easy design choice. Three blade systems cost in excess of two blade systems, yet two blade wind generators have to operate on higher rotational speeds than three blade ones. This way the individual blades of the two bladed wind generator need to be lighter and have bigger awkwardness and are therefore more pricey. The basic formulation for the power in the wind in a location A, perpendicular to the wind blowing direction is given by the formula:

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot C_p \cdot v^3 \quad (4.1)$$

where P is the power, ρ is the air density, v is the wind speed and C_p is the power coefficient, which describes the fraction of the wind captured by a wind turbine. According to Betz rules, the value of the power coefficient features a theoretic limit connected with 59.7 %.

Most wind power internet sites experience large wind speeds only for the few hours per evening. Hence different forms of power regulating schemes are necessary to be designed which in turn are cost effective. The design of wind mill elements is regulated by the ability to withstand physical loads. There are two basic aerodynamical blades types, which make it possible to reduce those loads. The wind generation can end up being regulated possibly by not function-regulation – scheming the knives to begin sleek stall above a specific wind speed level or even by message-control –

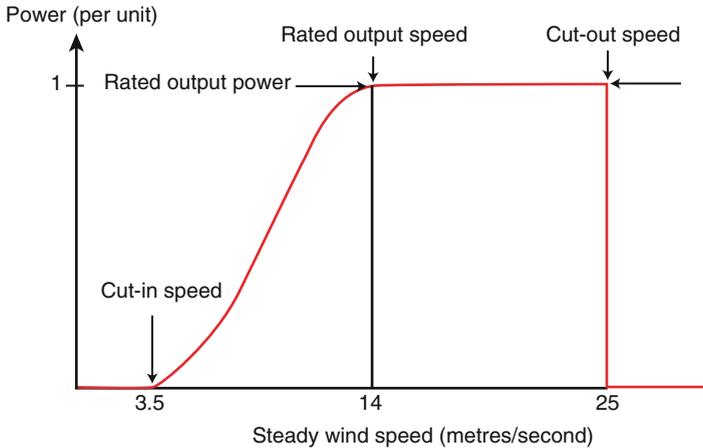


Fig. 4.1 Power from a pitch-regulated wind turbine

designing the rotor blades to generate the unnecessary power. A benefit involving stall-regulation is a simplified mechanized design of the rotor, that enables the blades for being affixed rigidly the generator hub. Additionally, stall-rules will definitely not permit strength excursions by very robust and gusty winds to pass on the thrust train. Additionally, it features disadvantages, as well: the requirement of a rotor coil brake, technological difficulties involving aerodynamic blades stall design, motor powered start along with stronger aerodynamic noise.

Figure 4.1 shows a comfortable wind speeding – power contour, which demonstrates the controlled power accomplishable from the particular wind generator. At very low wind rates of speed the developed power is too low to end up being utilized. With typical models the wind generators are started out when the wind swiftness exceeds three or more than four thousand. The turbine is started out at the cut-in wind pace and it's power will increase with another power on the wind rate, for the moment once the rated breeze speed is reached. On wind rates of speed range by 12 m/s around about 25 min the electricity is restricted to the ranked power on the wind turbine with the assistance of stall-regulations or pitch-control methods. When this wind pace exceeds 20–25 m/s the particular wind generators are commonly brought to be able to standstill avoiding high mechanically skillful loads within the turbine components. This wind flow speed is called the shortened-out breeze speed.

4.3.1 Fixed-Speed Wind Turbines

In early prototypes involving “fixed-speed wind turbines” “synchronous machines” have already been used, nevertheless the generalization machine was more broadly adopted to its lower charge, better environmental durability along with superior hardware compatibility along with rapid wind changes. That is why in preset-speed wind turbines, the power generator used may be the induction electrical generator type, connected towards the grid. Inside the majority associated with wind generators

designs the actual generator is definitely connected while using the hub using blades via a gearbox. They are placed within a nacelle on the top of the turbine system. The gear box is needed to change the lower rotational speed of the particular turbine to a high rotational speed within the generator. The rotational speed of induction power generators is typically 1,000 or even 1,500 revolutions. The rate of this turbine relies on their rotor dimension. For exercise a 330 kW turbine carries a rotational speed of around 18 – 1 out of 3 rpm, while rotational pace of the 1,670 kW turbine is around 10–19 rpm. A set-speed windmill is created to obtain greatest efficiency with one winding speed that will give this optimum tip speed with wind velocity ratio with the rotor aerofoil. To be able to capture far more wind energy, some set-speed wind turbines have a couple of different rotational speeds. This is achieved practically by positioning two power generators in this nacelle or by a single generator obtaining two freestanding windings.

4.3.2 Variable-Speed Wind Turbines

There are many similarities in variable speed wind turbine with respect to the components of fixed-speed wind turbines. These wind generators operating with a narrow variable-speed variety. Fixed-speeding wind mills operating inside a narrow velocity range unremarkably use a double-fed induction generator and possess a converter coupled to the rotor setup. The spinning speed on the double-fed induction motor is nearly 1,000 or 1,500 rpm, so a gear box implementation is necessary.

To reduce the nacelle design and style an unmediated-driven generator is employed. A unmediated-driven source using a huge turbine rotor blades diameter may operate for a very lower speeds and need a gearbox fitted to boost to pace. The usage of frequency convertor is to use a principal-driven power generator, so wind generators operating inside a broad adjustable-speed variety are equipped with a frequency converter. In the conventional fixed-speed wind generator, the gear box and the actual generator must be mounted on the stiff your bed plate and also aligned specifically in respect to each other. A direct driven generator can end up being integrated with the entire nacelle, so the generator unit and support structure can also be the main parts in the nacelle structure.

4.4 Components of WECS

Wind energy can follow harnessed with a wind power conversion organization, composed of wind generator blades, a generator, an power electronic converter tools and the related control system. Figure 4.2 indicates the block diagram involving different parts of WECS. Different WECS options based on synchronous or asynchronous machines, and stalling-regulated or even pitch controlled systems are available. The sensible objective of those systems is identical: converting the wind kinetic energy into electricity and inserting this energy into a utility grid.

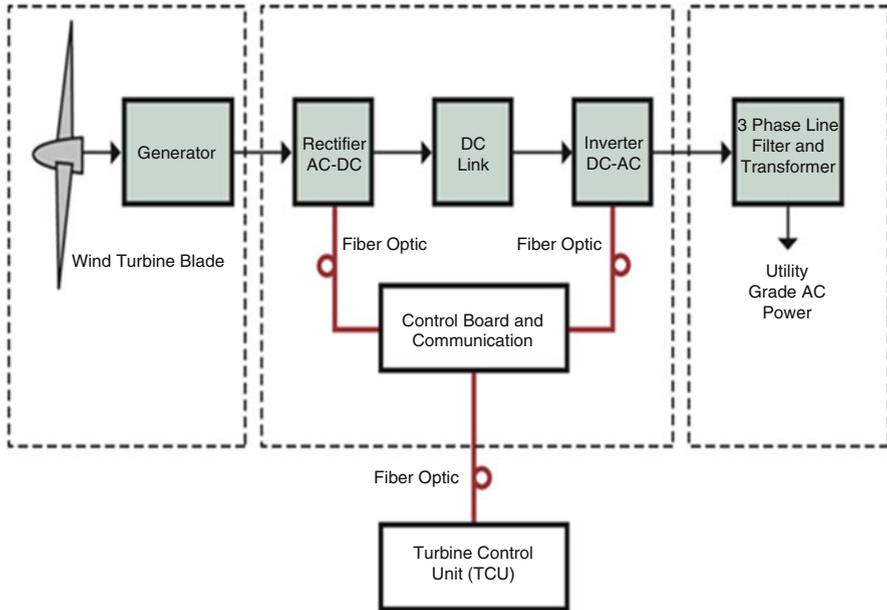


Fig. 4.2 Typical block diagram for a wind turbine power generation system

Figure 4.2 shows the normal block diagram of typical wind power generation system. The actual block demonstrates the wind generator and source selection represents a huge part in this wind energy conversion. Modern wind generators fall straight into two fundamental groups: the horizontal-axis wind turbine, like the original wind generator used for pumping water, and the vertical-axis wind turbine, like an eggbeater-fashion Darrieus product, named right after its France inventor. Many large modern-day wind mills are horizontal-axis wind generators.

Wind generators have being mounted in place where wind power is ample. Wind speed is higher up in the sky than the ground. The optimal site needs to be far by tall structures to keep off turbulences, which are the link between changing speed of wind when it hits the actual obstacles. Horizontal axis wind turbines harvest the wind energy against the actual direction associated with wind.

4.4.1 Description of Components

Horizontal turbine components include:

- blade or rotor, which converts the energy in the wind to rotational shaft energy;
- a drive train, usually including a gearbox and a generator;
- a tower that supports the rotor and drive train; and

- Other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.

4.4.1.1 Rotor

The area of the wind generator that accumulates energy on the wind is known as the blades. The rotor coil usually is made of two or even more wooden, fiberglass or steel blades which usually rotate an axis (horizontal or vertical) at a rate determined by the wind velocity and the design of your blades. The blades are attached to the center, which consequently is attached to the main base.

4.4.1.2 Drag Design

Knife designs run by using either drag or lift. With the drag design and style, the wind literally promotes the blades out of the way. Drag powered wind generators are seen as slower rotational speeds as well as high torque capabilities. They may be useful with the pumping, cutting or grinding work that will Dutch, grow and similar “work-equine” windmills perform. For exercise, a village-type wind turbine must develop high twisting at commence-up so as to pump, or lift, water system from the deep ground.

4.4.1.3 Lift Design

This lift edge design engages the same principle that makes it possible for airplanes, kites and also birds to fly. The particular blade is essentially control surface, or annex. When air travel flows past the blade, some sort of wind speed and force differential is produced between the top and lower blade section. The demand at the lower surface is greater and thus acts to be able to “lift” the blade. While blades attach to a main axis, like a wind turbine rotor, the lift is actually translated into rotational motions. Lift-power wind generators have much higher rotational data transfer speeds than move types and as a consequence well designed for electricity generation.

4.4.1.4 Tip Speed Ratio

The tip-speed would be the ratio in the rotational pace of the blade towards the wind speed. The greater this percentage, the more quickly the turning of the actual wind turbine rotor at the given winding speed. Energy generation calls for high rotational speeds. Lift-type wind generators have maximal tip-swiftness ratios of around 10, while drag-type ratios are generally approximately. Given this high rotational speed demands of electrical generators, it’s clear that this lift-type wind turbine is almost practical due to its application.

4.4.1.5 Number of Blades

The volume of blades comprises the total number of blades and the total area they will cover to aid wind generator performance. For a lift-type rotor to function effectively, the wind ought to flow effortlessly over these blades. In order to avoid turbulence, spacing between blades should be greater so that particular blade is not going to encounter the actual disturbed blade. Due to this reason, most of the wind turbines have only two or three blades on their rotors.

4.4.1.6 Generator

The generator converts the particular rotation of wind turbine blades directly into electricity. Inside this constituent, coils regarding wire tend to be rotated in the magnetic field to create electricity. Generator models produce often alternating current (AC) or perhaps direct current (DC), and they're available within a large range of output electrical power ratings. The generator's standing, or size of it, is influenced by the length of the wind generator blades. Generators that generate AC usually are equipped along with features to generate the accurate voltage (a 100 V and 20 V or 240 V) as well as constant consistency (50 series) of power, even if the wind speed is varying. DC power generators are normally used in battery pack charging applications and for operating Digicam appliances in addition to other equipments. They also can be used to produce Air conditioning electricity by using an inverter, which converts Direct current to Air conditioning.

4.4.1.7 Transmission

The amount of revolutions per minute (rpm) of wind turbine rotor range between 45 rpm along with 400 rpm, depending on the model plus the wind velocity. Generators generally require rpm's of just 200 to at least 800. Consequently, most wind turbines require some sort of gear-pack transmission to raise the rotation of the generator to the speeds necessary for efficient electricity production. A few DC-form wind turbines do not use transmissions. Instead, they have a direct online link between the particular rotor and generator. These are generally known as direct thrust systems. While transmission is not performed, wind turbine complexity and maintenance specifications are decreased, but a larger turbine is necessary to deliver the identical power output in this AC-type wind turbines.

4.4.1.8 Towers

The structure on which usually a wind generator is installed is not just a support framework. It in addition raises the particular wind turbine so that it is blades safely and securely clears the floor and then it can attain the stronger winds at increased elevations. Maximum tower level is optional in many cases, except in which zoning restrictions apply. Deciding exactly what height tower system should be mounted will be based on the cost regarding taller towers versus the amount of the increase in power production caused by their work. Studies have established that the added cost connected with increasing podium height is often justified through the added power generated in the stronger gusts of wind. Larger wind generators are unremarkably mounted about towers between 40 and 70 m tall. Podiums for small wind methods are generally “guyed” styles. This means that there are guy wires anchored to the floor on 3 or 4 sides of the tower to carry it erect. These podiums cost lower than freestanding systems, but require more acreage to ground tackle the man wires. A few of these guyed towers are built by tilting them upwards. This function can possibly be quickly achieved using just a winch. This shortens not only installation, but maintenance as well. Towers could be constructed of a simple tubing, a wood pole or a lattice connected with tubes, supports, and angle bracket. Large wind generators may be mounted in lattice towers, tube towers or guyed aim-up systems. Installers can suggest the better type connected with tower on wind turbine. It must be strong and ample to offer the wind turbine and to be able to sustain shake, wind packing and the complete weather components for the lifetime of the wind generator. Tower expenses will change widely as being a function associated with design as well as height. A few wind turbines are marketed complete having tower. More often, however, podiums are marketed separately.

Advantages of the Horizontal axis Wind turbine:

- Higher efficiency,
- Ability to turn the blades, and
- Lower cost-to-power ratio.

Disadvantages of horizontal-axis:

- Generator and gearbox should be mounted on a tower, thus restricting servicing, and
- More complex design required due to the need for yaw or tail drive.

4.5 Types of Wind Turbine Generators

Over four decades the advancement of wind generation conversion engineering has generated development of several different adjustments of wind generators, which employ a wide selection of electric turbines. The group of most popular electric source types utilized in megawatt variety wind energy conversion systems (WECS) is presented in Fig. 4.3.

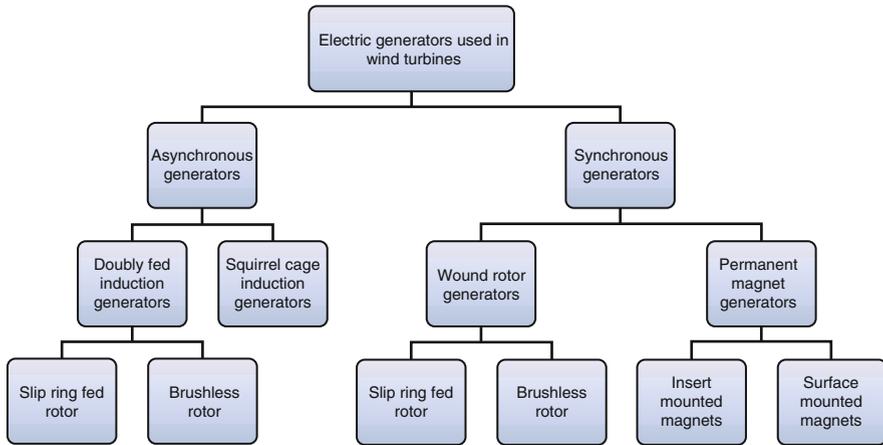


Fig. 4.3 Types of generators in WECS

Nowadays the direct current generators are usually found in low-voltage and very low-power standalone systems with small size wind strength applications. The alternating stream generators existing in present scenario are the most common solution for large scale wind flow energy conversion process systems. This alternating current generators are usually divided in two main groups, depending on the construction along with operating theory: synchronous generators (SG) and also the induction generators (IG). Each synchronous and induction generators can always be constructed using wounded rotors, that is fed with slip rings through hair brushes or by way of brushless electro-magnetic exciter. In the matter of non-harmed induction generator rotor designs, the rotor coil alternating current needs to develop the magnetic field from a different source compared to externally given current. With regards to the generalization generators it is performed via induction phenomena. The most commonly used induction generator through the years is the squirrel cage induction turbine. If the particular induction power generator rotor gets injured, it becomes doubly fed induction generator (DFIG), becoming one of the extremely commonly utilized generator used in wind generators applications. In case there is synchronous turbines the rotor magnetic flux can be also created because of the rotor rotation and also through the usage of permanent magnets mounted on the blades. This results in permanent magnet synchronous generator (PMSG). A few types regarding permanent magnet synchronous generators can be distinguished, determined by how the magnets are mounted on the rotor: wound rotor generators, permanent magnet generators. The classification of generators used in WECS is shown in Fig. 4.3.

4.5.1 Type 1 WTG

Squirrel-cage Induction generator (SCIG) connected directly to the step up transformer is referred to as the Type I Wind Turbine Generator. The turbine speed is fixed (or practically fixed) towards electrical grid frequency. The item generates real power when the turbine shaft rotates faster than the electrical grid frequency developing a negative (positive slip and power is due to motoring convention). For any given wind flow speed, the actual operating velocity of the turbine under steady problems is a practically linear purpose of torsion. For abrupt changes within wind speed, the kinetic inertia with the drive will control the pace of change in electrical output. Figure 4.4 shows the standard configuration connected with type 1 wind turbine generators.

Figure 4.5 shows the power flow on the SCIG terminals. Since there is a deviation in the output due to the slip of the machine, Type 1 generators typically work at or perhaps very close to a rated speed. An important drawback in the induction generator is the reactive energy it consumes for its excitation subject and the massive currents the machine can bring when running “across-the-line.” To remove these outcomes the turbine typically engages a delicate starter in addition to discrete ways of capacitor banks from the turbine.

4.5.2 Type 2 WTG

Wound rotor motor induction generators are connected to the WTG step-up transformer in a way similar to Type 1 with respect to the machines stator coil circuit, but also include a variable resistor in the actual rotor signal as found in Fig. 4.6. This can be accomplished with a set of resistors and power electronics components added external to the rotor along with currents going between the resistors as well as rotor through slip rings. Alternately, the resistors as well as electronics components can be mounted within the rotor, eradicating the slip rings. The variable resistors are generally connected to the rotor routine softly and can control the rotor voltages quite quickly, thus maintaining continuous power.

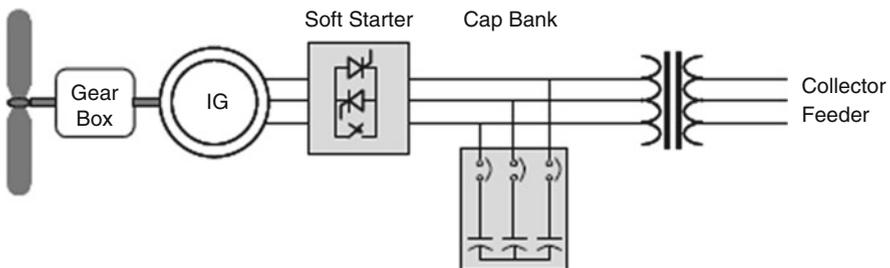


Fig. 4.4 Configuration of Type 1 WTG

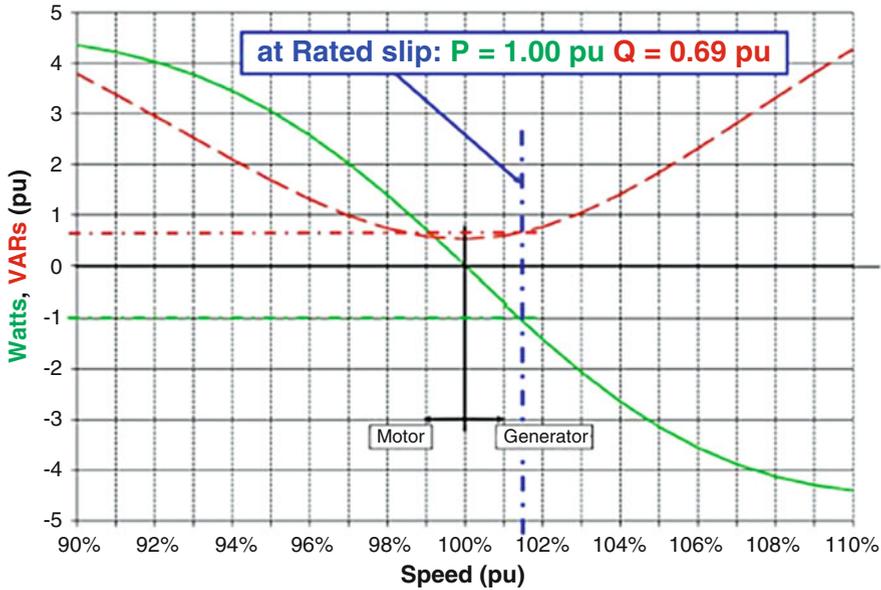


Fig. 4.5 Variation of real and reactive power for SCIG

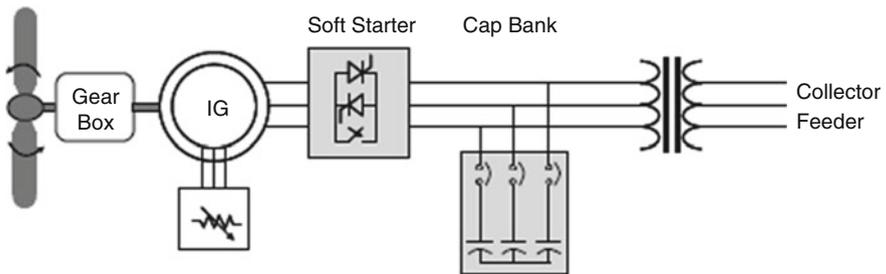


Fig. 4.6 Configuration of type 2 WTG

By including resistance for the rotor signal, the actual power curve can become varied on the higher slip and speed ranges as shown in Fig. 4.7. The generator should spin faster to create the very same output strength, for an added rotor opposition. This allows some ability to control the pace, with the particular blades’ pitching mechanisms and also move the actual turbines based on tip-speed ratio to achieve the best energy output. It is typical in which speed versions of nearly 10 % tend to be possible, taking into account some degree of freedom towards energy capture and self protective torque control.

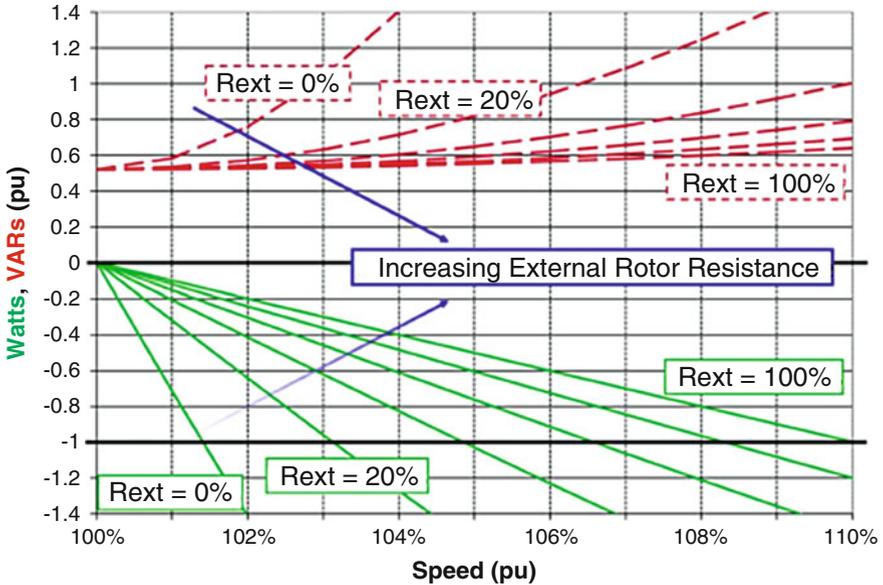


Fig. 4.7 Variation of real and reactive power with an external rotor resistor in a type 2 WTG

4.5.3 Type 3 WTG

The Type 3 turbine, known normally as the Doubly Fed Induction Generator (DFIG) or Doubly Fed Asynchronous Generator (DFAG), improves the type 2 design to one stage further, by adding or changing frequency to the AC excitation (instead of purely resistance) to the actual rotor circuit shown in Fig. 4.8. The extra rotor excitation is supplied via slip happens to be by a latest regulated, voltage-resource converter, which in turn adjust the windmill currents' magnitude and phase. This rotor-side converter is connected back-to-rear with a grid side converter, that exchanges power immediately with the grid.

A small volume of power is injected into the rotor circuit to make a large difference in the control of power in the stator circuit. This is a major advantage in the DFIG. A great deal of control of the output is available with the presence of user to set converters that commonly are only 30 % of the status of the machine. In addition on the real power that is certainly delivered to this grid from this generator's stator circuit, power will be delivered to the grid through the grid-connected inverter when the generator is shifting faster than synchronous speed. When the particular generator is going slower than synchronal speed, electricity flows from the grid, through the two converters, and via rotor to stator. These two modalities, made possible from the four-quadrant nature of the two converters, allows a significantly wider speed array, both in addition to below synchronous velocity by an increase of 50 %, although smaller ranges are more widespread.

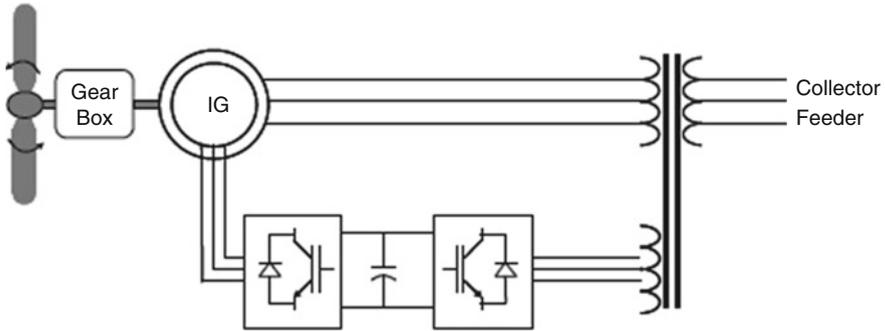


Fig. 4.8 Configuration of type 3 WTG

The major benefit from the DFIG, is it offers separate real and reactive power controller, much like a regular synchronous generator, even though being able to run asynchronously. The industry has produced as well as matured the ideas of vector or field oriented control over induction machines. Using these control techniques, the torque providing components of this rotor flux can be created to respond fast enough that the appliance remains under control, even for the duration of significant grid disturbances. Indeed, cost is higher than the Type 1 or 2 machines, the Type 3 is turning into popular due to its advantages.

4.5.4 Type 4 WTG

The Type 4 turbine offers a great deal of flexibility in design and style and operation because the output of the rotating machine will be sent to the grid through a complete-scale back-to-back frequency rippling tools as shown in Fig. 4.9. The turbine is permitted to rotate at its optimal aerodynamic speed, resulting in a “wild” AC productivity from the machine. In addition, the gearbox may always be eliminated, such that the machine spins for the slow turbine rate and generates an electric frequency well at a lower place that of the grid. The rotating machines of this type have been made as wound rotor synchronous machines, comparable to conventional generators seen in hydroelectric plants together with control of area of current and higher pole numbers, equally permanent magnet synchronous machines, or seeing that squirrel cage induction machines. However, based on the ability of the machine, an inverter is used to control real and reactive power flow. Advances in power electronic devices as well as controls in the last decade have built the converters both equally responsive and useful. It does carry mentioning, however, that this power electronic converter have to get sized to pass the entire output of the spinning machine, plus any kind of capacity to provide for reactive compensation.

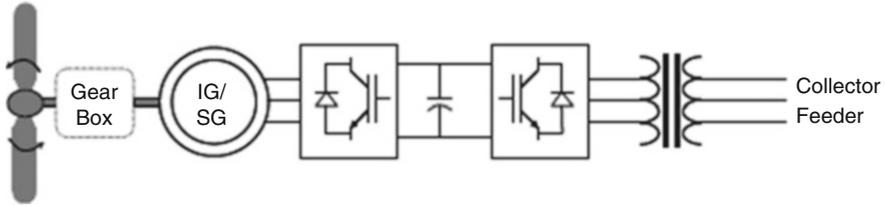


Fig. 4.9 Configuration of type 4 WTG

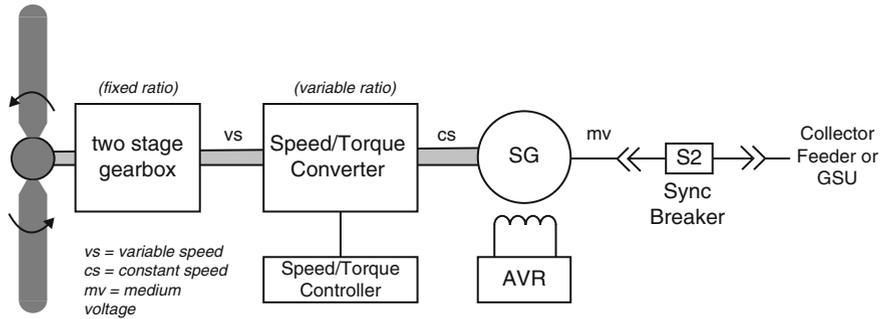


Fig. 4.10 Configuration of type 5 WTG

4.5.5 Type 5 WTG

Type 5 turbines consist of a regular WTG variable-speed drive train attached to a Speed/Torque converter coupled with a synchronous generator as shown in Fig. 4.10. The Speed/Torque converter alters the variable pace of the rotor head to a continuous output shaft speed. The closely coupled synchronous generator, functioning at a set speed (corresponding to the grid frequency), might be directly attached to the grid through any synchronizing circuit breaker. The synchronous source can be designed appropriately for virtually any desired speed (commonly 6 pole as well as 4 pole) and also voltage (typically moderate voltage for greater capacities). This approach requires speed in addition to torque control with the Speed/Torque converter along with the average voltage regulator (AVR), synchronizing process, and generator protection system using a grid-connected synchronous generator.

4.6 Power Converter Topologies for Wind Turbine Generators

4.6.1 Permanent Magnet Synchronous Generators

Permanent magnet excitation is generally popular in newer smaller scale turbine types, since it enables higher efficiency in addition to smaller wind generator blade

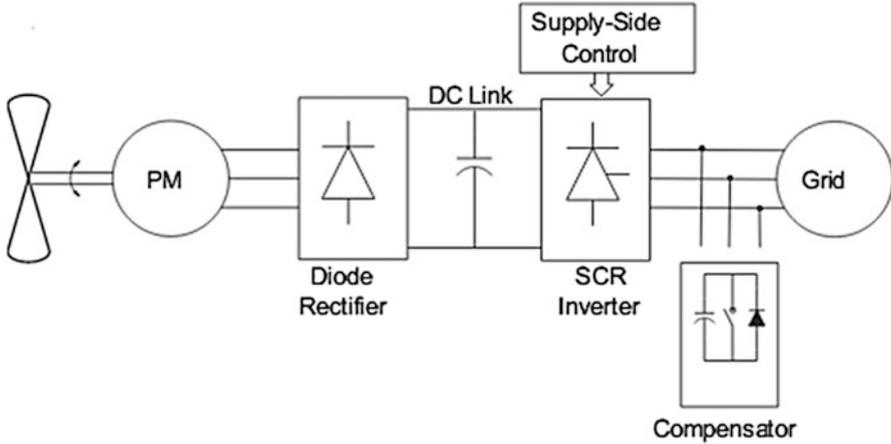


Fig. 4.11 Configuration of thyristor supply-side inverter

diameter. Though recent research has considered larger scale patterns, the economics of huge volumes of large volume material has constrained their practical use. The primary benefit from permanent magnet synchronous generators (PMSG) is that they do not require any external excitation current. A major cost benefit in using the PMSG is a diode bridge rectifier that may be used at the generator devices since no external excitation current should be used. A variety of research has been performed using a diode rectifier.

4.6.1.1 Thyristor Supply-Side Inverter

On applying thyristor-based grid-side inverter as shown in Fig. 4.11, continuous control on the inverter firing angle, regulating the turbine speed is possible with the DC-link voltage; hence, capturing optimum energy. Advantages with this scheme include cheaper device cost and improved power than hard-switching inverters. A major drawback in this inverter is the need for an active compensator for the reactive power demand and to reduce harmonic distortions. A voltage source converter (VSC) can be used for the compensator and the error signal between the reference and compensator is utilized to drive the actual pulse width modulated (PWM) controller.

4.6.1.2 Hard-Switching Supply-Side Inverter

A recommended control involves the particular manipulation of the modulation index in the reference sinusoidal signal applied to the particular PWM generator. This is achieved by determining the actual DC-link voltage by an electrical power mapping technique which has the maximum electricity versus DC-link

characteristic. The control system is additionally improved by using a derivative control around the stator frequency, mainly because it also changes along with change in DC-link voltage. This control is compared to maximum power point tracking (MPPT), which includes an anemometer, a wind prediction scheme and a fixed-voltage scheme. The anemometer measures the actual wind speed along with aids in providing the wind power reference to the MPPT controlled. The reference electrical power is compared with the actual DC energy extracted and the result is used to determine the new operating DC voltage drop. The current control loop of this inverter receives the brand new operating DC voltage and outputs a great instantaneous driving indication for the PWM. In breeze prediction methods, autoregressive statistical types are commonly utilized. The system views energy captured within the previous time shape to predict the actual wind speed importance for the next time frame set. With reference to the fixed voltage the voltage on the inverter is fixed at a precise optimum wind velocity. In comparing some control methods, the fixed voltage output was used as the reference. The actual MPPT with wind gage setup proved being superior, obtaining 56–63 % of energy available.

4.6.1.3 Intermediate DC/DC Converter Stage

The use of a voltage source inverter (VSI) that has a DC/DC converter is depicted in Fig. 4.12. This kind of setup is also compared to the converter shown in Fig. 4.13. Incorporating an extra DC/DC converter gives the following advantages:

1. control over generator-side Power-voltage through deviation of the switching ratio,
2. retains appropriate inverter-side DC-voltage,

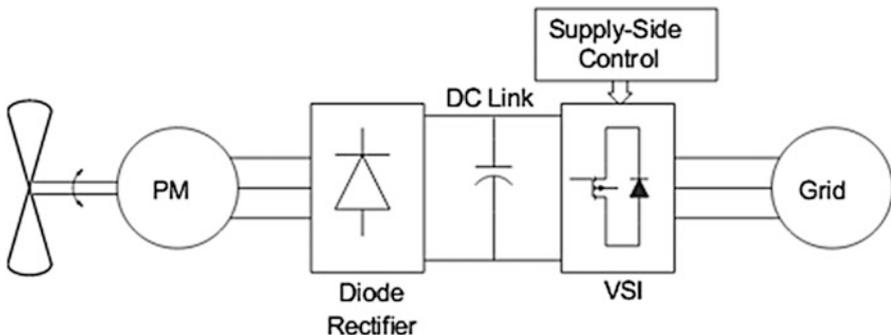


Fig. 4.12 Configuration of VSI using DC/DC converter

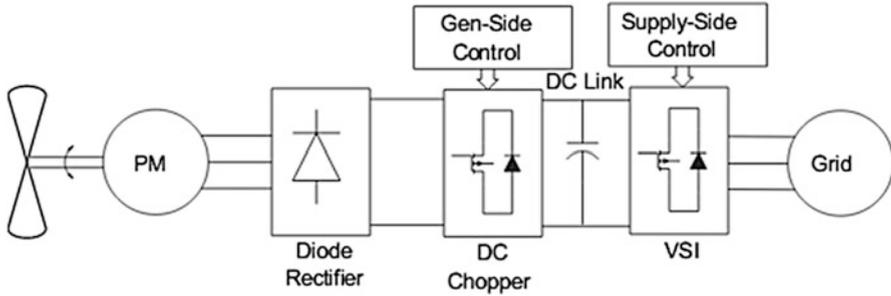


Fig. 4.13 Configuration using VSI

3. allows for selective harmonic elimination (SHE) switching, resulting in reduced losses,
4. inverter no longer needs to command DC-voltage, possesses more flexible power.

The inverter control can be achieved by regulating the particular magnitude of the basic line current and the phase angle between line current and also line voltage. The controller can be configured such that the VSI is switched at the absolute frequency of the three-sided carrier signal and its output harmonics are well defined. For each shaft speed, optimal values of electric voltage can be recognized corresponding to the most available turbine power. The DC/AC voltage percentage and power are used while control variables which can be tuned to control the power are used upon necessity. The inverter handle can also possibly be implemented to keep the DC-link continuous and vary the active power in a fashion so that it attains maximum real power transfer towards grid. Effects show that the thyristor-based inverter with active compensator is most suitable for strong HVAC systems since the inverter relies on the device to ensure substitution. However, the two VSI and Direct current/DC-VSI devices are capable of integrating with equally strong AC systems. Various other control strategies have been also adopted for this convertor. The specific DC/AC inverter can control the active as well as reactive power brought to the grid by means of control of the q-axis in addition to the existing d-axis. The q-axis reference point current is determined by the error inside DC-link voltage, and is subsequently compared with the current. The phase angle of this utility, used in power factor command, is detected using phase locked loop (PLL) mechanism in a d-q synchronous reference frame. Power factor control makes the d-axis of rotation as the reference current, thus it can be compared while using the actual d-axis current. The error in both coordinate system currents are utilized to create the d-q-axis voltages used inside space vector PWM control. While using voltage equation control a boost-controlled DC/DC chopper and a proportional-integral (PI) controlled, the duty ratio of the chopper switch may be determined for any kind of specific optimum location. The inverter-side DC-link voltage remains constant set by the actual grid voltage giving the advantage of involving flexible

transfer of active and reactive power to the particular grid. A bit of a modification to the particular DC-link is included by means of including a battery power. The battery allows charging during night when load demand is usually lower. An advantage due to the continuous DC-link voltage, leads to controlling the chopper output to its maximum value thus resulting output power. To perform the control, a human relationship between the output power and duty cycle of this chopper is utilized. Starting from an arbitrary point, the obligation cycle can become continuous and slow adjusted between a unique ranges searching to the maximum power distributor point. It is found that the system began losing efficiency at large speeds; this had been due to the phase lag relating to the DC current in addition to duty ratio.

4.6.1.4 Back-to-Back PWM Converters

The use of, 6-switch, hard-switched converters, with a DC-link capacitor, had been existing so far. The source side rectifier is definitely controlled through a PI controller in ways that the d-axis current is held to zero to obtain maximum electrical torsion with minimum stream. A MPPT is used in determining this optimum rotor speed for each winding speed to get maximum rotor power. In contrast, this grid side inverter controls the line current to end up being sinusoidal through a hysteresis controller. The DC-link voltage is also controlled by a PI controller, via the grid side inverter.

Recently a converter using two B-4 converters and two DC-link capacitors has been developed, shown in Fig. 4.14. Yet again MPPT calculates the actual output power involving the generator by measurement the DC-link current and potential drop, and then alters the operating point through increasing or decreasing the reference current magnitude. The MPPT control is performed on the generator side rectifier. The error in current is used to drive the inverter switching responses. A PLL is employed on each section to ensure power factor is maintained throughout the complete system.

4.6.1.5 Unconventional Schemes

A rather unconventional scheme using a PMSG has been recently discussed. The system relies on a rotary phase shifter (RPS) as a frequency converter. This RPS can adjust the angular velocity of the turbine at a affordable price in comparison into a power electronic device. A flywheel is also used as an electricity stabilizer; it includes a lifetime that is just not limited unlike the use of a battery. Recently, researches have been performed in order to resolve DC-link voltage problems under low wind speed ailments. By placing 3 switches between the diode rectifier and middle point on the DC-link capacitor, the voltage at low winds might be increased.

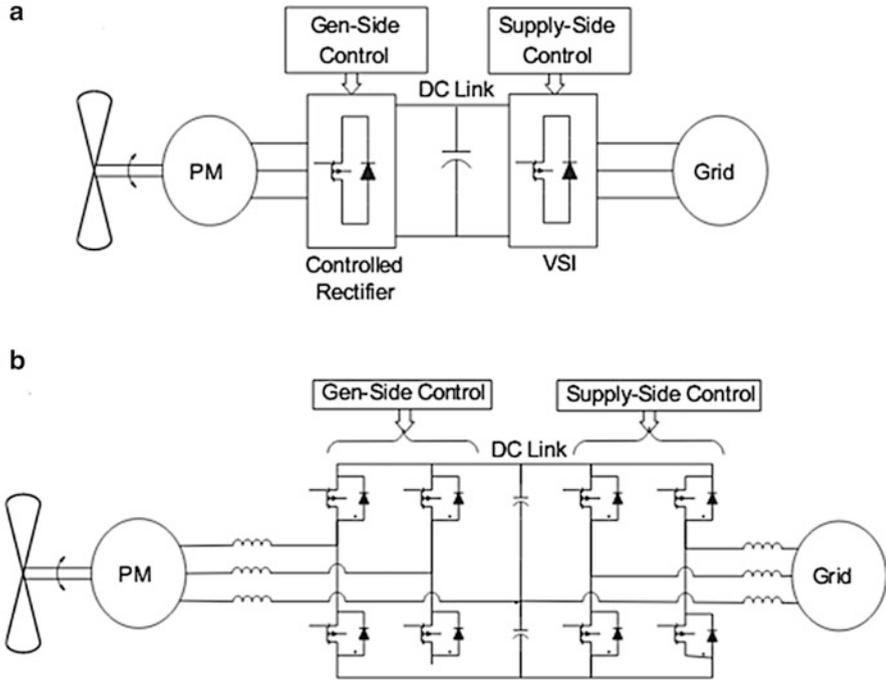


Fig. 4.14 PMSG with back-to-back PWM converter schemes

During reduced wind speeds, the switches are switched on and off instead, keeping the program symmetrical while increasing the voltage. The knobs are not utilized during high winds to avoid haunt over-voltages. Another modification to converter system is presented in Fig. 4.12, can be done to ensure constant flow from generator to grid by placing a straightforward diode in between capacitive DC-link and the inverter, flow of energy is restricted as a result of reverse blocking functions of the diode.

4.6.2 Doubly Fed Induction Generators

As the PMSG has acquired much attention throughout wind energy transformation, the doubly fed induction generator has brought just as very little consideration. If a wound rotor induction unit is used, the user will be able to control the generator by accessing this rotor circuits. A tremendous advantage in utilizing doubly fed generalization generators (DFIG) could be the ability to produce output more than their rated power without getting overheated. It is able to transfer maximum power over a wide space range in the two modes of operation. The DFIG along with

induction generators are extremely useful for high power applications in particular in the MW range. Furthermore, converter power evaluation is reduced since it is connected to the actual rotor, while almost all of the power flows through the stator.

4.6.2.1 Static Kramer Drive and SCR Converter Methods

The static Kramer drive is made up of diode rectifier within the rotor side and a line commutated inverter connected to the supply side as shown in Fig. 4.15. With this converter, a sliding mode control is developed which provides the ideal compromise between alteration efficiency and smoothing of torque oscillation. The controller regulates the thyristor inverter discharge angle to attain the ideal compromise. This sliding mode control law forces the generator torque to become linear function with the generator speed across the operating point of maximum power transfer. This converter is only able to provide power from each stator and windmill circuits, under excellent-synchronous operation. To solve this problem, methods replace this diode rectifier using thyristor rectifier (SCR). The supplement of a minute SCR allows the particular generator reactive power demand to be satisfied by the rotor-side converter system. When coupled to the wind turbine, it is shown that ideal performance is attained by adjusting the apparatus ratio, of the gear box, to the optimum value. In comparison for the Kramer drive, this product produces more power due to the lack of reactive power available with a diode rectifier. More descriptive control of the two rectifiers is succumbed. A variety of both firing angles for each mode of operation is given like a plot showing the particular optimum firing angle at different the wind speeds resulting in ideal power transfer. It is discovered that between 7.5 as well as 8.5 m/hydrates, maximum

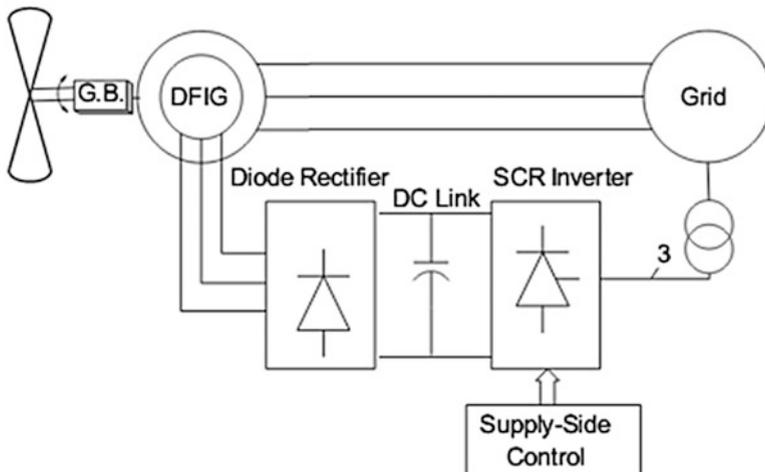


Fig. 4.15 DFIG with static Kramer drive

power is usually generated in both sub-and super-synchronous modes. Major drawbacks on this approach include firing off and commutation problems with the rotor-side converter and consonant distortion to the grid, created with the supply-side thyristor converter.

4.6.2.2 Back-to-Back PWM Converters

A more highly advanced method applying back-to-back converters has also been developed, as shown in Fig. 4.16. Although the convertor used in most of these works are extremely similar, great differences lie within the control strategy and complexity. One option is to employ vector control on the supply-side ripper tools, with a frame of reference orientated with the actual d-axis along the stator voltage vector. The supply-side converter is definitely controlled to maintain the DC-link electric potential constant through regulation of the d-axis current. It can be responsible for reactive power control by means of alteration of the actual q-axis stream. As for the rotor side, choosing decoupled control in the electrical torque in addition to the rotor excitation current is displayed. The machine is controlled in a very synchronously rotating coordinate system with the n-axis orientated over the stator-flux transmitter, providing maximum power transfer. Conversely, inwards, the rotor coil current was decomposed into d-q components, in which the d-axis current is used to manage the electromagnetic torque and the q-axis current controls the power factor. Both kinds of rotor-side convertor control are used in the application of PI controllers. PWM switching techniques can be utilized, or additionally space vector machine (SVM) is found to obtain a better inflection index.

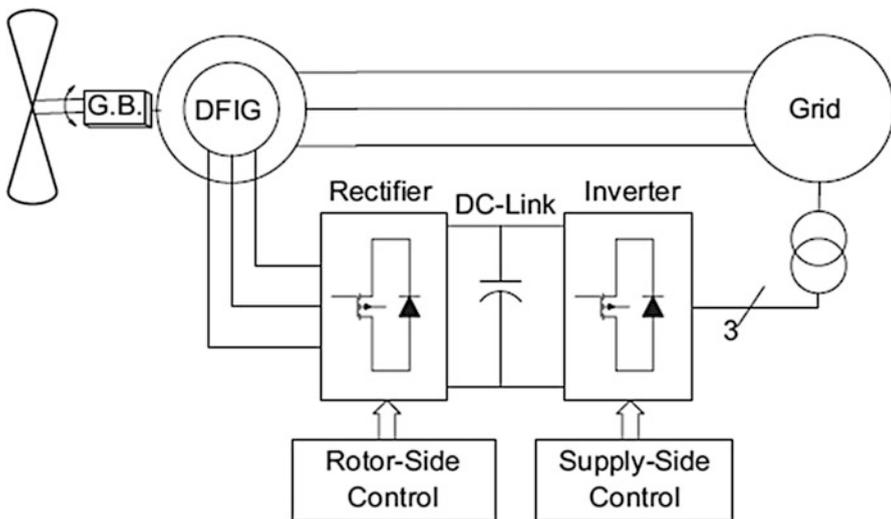


Fig. 4.16 DFIG with back-to-back PWM converters

Typically control schemes aided by a windmill speed encoder attain excellent tracking outcomes. However these encoders are high priced and the charge due to dropped accuracy without the encoder may not be as large as possible. The application of speed sensors has been described. To go along with the capacitor within the DC-link, a cell may be employed as a storage device. With the additional storage device, the supply-side converter controls the movement of real energy between the power grid and the battery, as the DC-link voltage is at this point is fixed. The supply side controller comprises three PI controllers, one for outside loop power control, and the other two for the d–q-axis inner current controller loop. Energy can be stored during large winds and is exported to the actual grid during silent conditions to compensate for the drop in the stator power. Throughout long periods connected with high or lower wind speeds, the control algorithm will be modified to manage the bus current until the ailments change. In this example, the rotor-side converter is used to control the real and reactive power of the equipment. Another different pick for rotor command has been identified. The algorithmic rule searches for the peak power by means of varying the rotor coil speed, and the actual peak power factors are recognized with zero slopes for the power-speed shape. The control algorithm works continuously, as a substantial shift in power causes the controller to shift the rate at which it causes the power to shift once more. Once the alternation in power no change exceeds the minimal set value, the particular controller takes no more further action. Once again, d–q-axis control is utilized to control the real and reactive power of the machine. It is crucial that the user ensures that this dynamics of the speed controller are not necessarily extremely fast, more large transients with generator torque may occur. The standard control objectives identified above can end up being attained through handle theory based on voltage space vectors (VSV). The use of certain voltage vectors may accelerate the rotor flux, in addition to increase the lively power generated by the stator. Other voltage vectors may also increase or decrease the actual rotor flux value, resulting in a reduction in the reactive power drawn by the stator and an increased power factor. The direct power command method requires a series of tables to determine which of the six sectors the operator is operating on. From the choice of sector, the employed voltage vectors can be discovered from a controller table. A concluding control scheme, with the back-to-back again PWM converter plan, uses information on base speed and turbine output power to estimate the wind speed. This turbine output power can be described as a function of TSR. The sources of the equation are solved to look for the optimum TSR in a specific range. Using the estimated wind velocity and optimal TSR, the revolutionary reference of the particular generator output power and shaft speed is obtained. The machine is commanded towards desired shaft pace and the production power is over again measured, regurgitating the control. This control is applied to a brushless DFIG, giving reduced cost when compared with machines with brushes and slip-rings.

4.6.2.3 Matrix Converter

The matrix converter is capable of converting the variable quantity AC from the generator into continuous AC to the actual grid in a single stage (Fig. 4.17). Two distinct advantages arise from this type of topology, the converter requires no bulky energy storage or perhaps DC-link in addition to control. The simply using a matrix converter with a DFIG has already been explored. The use of stator-flux oriented control was applied to the rotor coil matrix converter. This type of d-axis current was aligned with the entire stator-flux linkage vector. Simple PI controllers can be used to control the d-axis currents. The regulation of the actual d-axis steady current allows for control of the stator-part reactive power flow, where as the q-axis current helps regulate the stator-side dynamical power.

A recent option is to control the rotor winding voltage, that therefore manipulates the power factor of the DFIG. The particular matrix converter incorporates nine bi-directional switches (18 in total), arranged in a fashion such that an input cycle could possibly be connected to virtually almost any output phase according to the user need. Each specific switch is capable of connecting with correction and upending. The matrix converter is controlled making use of double space vector PWM, employing use of input current along with output voltage SVM. One of the major drawbacks associated with the matrix converter is that 18 total switches are required, creating an increase in the converter semiconductor cost.

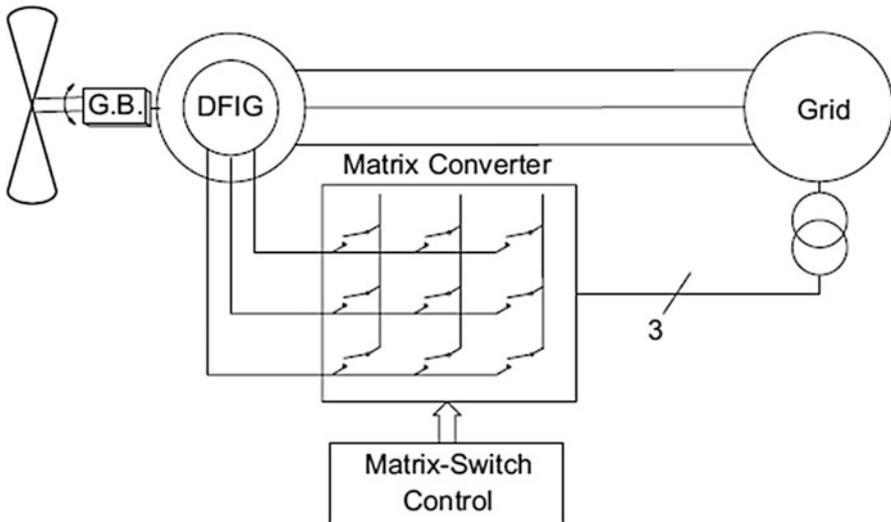


Fig. 4.17 DFIG with matrix converter

4.6.3 Induction Generators

The use of induction generators (IG) is advantageous since they are usually relatively inexpensive, and they call for low maintenance. The type of IG can be unlike that associated with PMSG, they have to possess bi-directional power flow in the particular generator-side convertor since the induction generator requires external reactive power assistance from the grid. The use of back-to-back PWM converters (Fig. 4.18), along with the implementation of one or more fuzzy logic remote controls is a constant converter-control combination. The advantages of fuzzy logic command are parameter insensitivity, fast convergence as well as acceptance of imprecise and inaccurate alerts. A PI based fuzzy logic operator takes in the DC voltage error and change in DC voltage error. The controller outputs the d-axis reference current used in actual power flow control. In a similar manner, the Q-axis current is definitely kept zero to maintain unity power element. A control program using three fuzzed logic controllers has been investigated. The first controller tracks the generator speed with the actual wind velocity to be able to extract maximum power. The second controller programs the machine flux for lighting load efficiency progress. More specifically, the rotor flux might be reduced from the particular rated value to lessen the core losses and thereby improve the efficiency. The rotor coil flux may be reduced by constantly decreasing the magnetizing current until the maximum power output is obtained. The third controller gives robust speed control versus wind gust and turbine oscillatory torque. Unlike the second controller, the third fuzzy logic controller is always effective.

In another control strategy, a PI controller is additionally used; nevertheless, rotor slot harmonics (RSH) cause speed estimation. The rotor slots get connected to the magnetizing element of the air-space magneto-motive force (MMF), generating harmonics that are dependent on the rotational speed. Once the algorithmic program locates the consistency of the RSH through a look-up table, the rotational speed can be found through a series of calculations. While using RSH, the control system also utilizes sensor-less command through a model reference adaptive

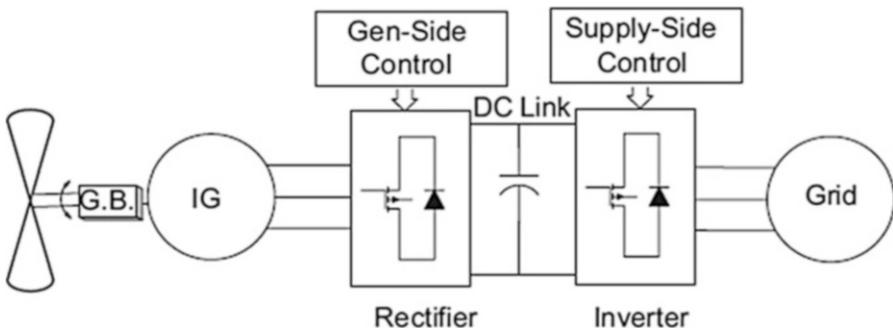


Fig. 4.18 Induction generator with back-to-back converter

system (MRAS) based observer to help estimate the spinning speed. Some sort of control option to the supply-side convertor includes real along with reactive power control. A reference shape orientated along the supply voltage rotating vector allows for real power control via d-axis current control and Q-axis manipulation regulates the reactive power. The above mentioned control results in rotational speed with high accuracy, a positive characteristic for methods employing a stall controlled wind turbine. This control protocol can react speedily to wind gusts and will be utilized to manage the amount regarding mechanical power in addition to torque input to the generator. They are common concerns intended for stall controlled wind turbines as operation over rated power could potentially cause damage to this generator and power electronic converter. Rather than the usual back-to-back PWM converters scheme, the generators use a fixed-capacitor thyristor-governed reactor and a static Volt-ampere compensator at the actual generator terminals to manage its voltage. The mechanical input power is controlled while using blade pitch angle. The design methods used for this control systems are based on the state infinite linearized model of the system. Two remote controls, a state feedback controller and output feedback controller are designed. The output feedback control is preferred since each of the output signals are available for measurement and the observer is not needed due to their state feedback control. A comparison between the wound rotor induction machine plus a caged rotor induction machine, both regarding identical size, has been performed. Both the squirrel cage induction motor and wound rotor six pole slip ring generalization machine have a rated voltage of 415 V. The coupled generators are identically rated for 300 kW and have a rated speed of 1,000 rpm. The comparison ensures validity with the use of identical converter sorts in each of the systems. The separate designs were tested individually under the exact variable wind problems. A variable wind speed profile was made to model an area with a normal wind speed of 12 m/s for the duration of peak wind period. It is found, under the like wind conditions, which the wound rotor induction machine outputs 35 kWh of electricity over 10 min, while the caged induction machine produces only 28.5 kWh inside 10 min. The higher cost of the injure rotor induction machine, due to potential need of slip rings, is reimbursed by the reduction in the sizing of the power converters along with the increase in electricity output. The DFIG is more advanced than the caged induction machine, due to its ability to create above rated power.

4.6.4 Synchronous Generators

Finally, the application of synchronous generators (SG) in residential wind power generation has also recently been researched. A brief description of one possible converter-command scheme is given for a small wind energy the conversion process system. The application of a diode rectifier along with a DC/DC boost stage and inverter as an energy electronic interface pertaining to grid connection

have been discussed. The converter is similar to, except a SG replaces the actual PMSG. In this particular scheme, the DC-link voltage is actually controlled while using the amplitude of the three-phase inverter voltages and the particular phase displacement angle of the inverter. The linearized currents and DC-link potential drop of the inverter can always be obtained by ways of state equations. Controller performance improvements are usually achieved over the original power angle control. For low power systems, the existence on a winding circuit in the rotor coil may be a drawback as compared to PMSG. Although PMSG are frequently used for low-electricity application, larger systems utilize SG. In big systems, the energy from the SG is most often converted through back-to-back PWM voltage source inverters, similar to Fig. 4.18. The supply side PWM inverter allows control of genuine and reactive power transferred to the actual grid. The source side converter is utilized for electromagnetic torque regulation. The controllers found in these systems are designed to achieve maximum power transfer to the grid. These generation devices have a large efficiency since the full stator current is utilized during electromagnetic torque production. Another advantage is the minimization of stator current over the direct control of generator power. In comparison to IG, the application of SG is useful since they are generally self-excited machines and the magnetic pole pitch of the machine can be more compact. As a result both DFIG and SG are preferred for high power applications.

A comparison of different generator converter topologies available for the Wind Energy Conversion Systems is summarized in Table 4.1.

4.7 Economics of Wind Energy Conversion Systems

The cost-effective goal of maximizing the energy output per dollar of expenditure has been pointed out several times. We have discussed the matter of determining the entire capital investment along with operating cost intended for wind electric power generators, so that we can determine the device cost of power. The fuel wind may be no cost, but the equipment essential to use the fuel tends to be expensive, so economic scientific tests are quite important. The unit expense of electricity can be determined in an easy manner from knowledge of capital investment and operating expenses. The value on the electricity is fairly more difficult to view, but must end up being calculated before capital investment decisions can be achieved. The value ought to exceed the cost before the purchase of wind equipment can be validated. The ratio of worth to cost need to be as good equally that for choice sources of power before wind is usually justified over these kind of alternatives. The price of wind generated electrical power to an electric utility is driven by its fuel savings and also its capacity credit ratings. When the breeze is blowing, less oil and coal need to be burned, which represents a savings on the utility. Also, when the utility is able to delete or delay payments on some new traditional generation as a consequence of adding wind devices, then this represents additional savings to the utility.

Table 4.1 Summary of generator converter topologies

Generator	Converter options	Control schemes
PMSG (kW)	Diode bridge/SCR inverter/compensator	Simple firing angle control of one converter
	SCR rectifier/SCR inverter	Simple firing angle control of both converters
	Diode bridge/hard-switching inverter	Power mapping technique including stator frequency derivative control MPPT, wind prediction control
	Diode bridge/DC boost/hard-switching inverter	Vector control of supply side inverter DC Voltage control via chopper duty ratio
	Back-to-back hard-switching inverters	MPPT, vector control of both converters
	Back-to-back hard-switching inverters (reduced switch)	Generator controlled through MPPT inverter current controlled through PI controllers
DFIG (kW–MW)	Diode bridge/SCR inverter	Sliding mode control
	SCR rectifier/SCR inverter	Dual thyristor firing angle control
	Back-to-back hard-switching inverters	Vector control of rotor and supply side space vector modulation or PWM MPPT, space vector control
	Matrix converter	Vector control of rotor and supply side double space vector PWM switching
IG (kW–MW)	Back-to-back hard-switching inverters	Vector control, use fuzzy logic controllers use rotor slot harmonics and model reference adaptive system
SG (kW–MW)	Diode bridge/DC boost/hard-switching inverter	Phase angle displacement control supply voltage control
	Back-to-back hard-switching inverters	Supply real and reactive power control generator electromagnetic torque control

There are nearly one thousand million people living in scattered rural regions of developing countries inside continents of Japan, Africa, and South USA who have very poor living conditions. Most of these conditions are explaining a massive exodus to the elegant slums, which helps make the overall situation more painful in many conditions. Most of the developing countries are poor in ceremonious fossil fuel resources and have to import them making use of their meager foreign exchange reserves. There are only two feasible solutions from a technical perspective to their energy problems. One is a commitment to use large central atomic power plants and an electrical transmission and distribution network. The other is a decentralized system of PV and wind gear installed at the village level. A tough estimate of the energy needs of a typical village of 190 families is as follows: 88,500 kWh per calendar year for cooking food, 1,000 kWh per class for pumping water, and 26,000 kWh per year for lighting. The specific average 315 kWh per 24 h, most of which should be delivered during a few hour period at night. The energy needed for cooking food is about three-fourths in the total, and just about any resource must be able to satisfy the load even in case all the villagers choose to cook at the same time

frame. The most noticeable solution is a diesel engine and 100-kW or 150-kW generator, even so the cost of gas makes this unaccepted. This energy consumption style also puts many difficult constraints about solar or wind systems that will be used. The production of a solar panel will be nearly zero by the time of the optimum load and the winding may be quiet at that time period also. Thus it is necessary to store satisfactory energy to meet one days requirement. This storage can be in the way of storage batteries regarding wind and solar electric systems.

Yet another possibility for the power system is biogas. Plant, animal, and human waste materials can be accustomed to produce methane, which may be stored and used directly for cookery. It is not functional to use methane directly with regard to lighting so the actual methane can use in a car engine driving a generator to supply electricity for lights. The investment is very less but requires extensive labor to maintain biogas facility along with the operating internal combustion engine. The real amount of electricity consumed per person is not large, so costs every kWh can follow relatively high but still be acceptable. One problem is that people look at the costs of gear, the lack connected with transportation, the insufficient trained people, as well as the centuries-old cultures and customs in addition to conclude that it isn't economically feasible to supply electricity to these kinds of villages. The towns are left in poverty and hopelessness. City slums are perceived as being a better location to live, with enormous migrations of individuals. The country grows more unstable and ripe for revolution as this process continues. It can be concluded that the genuine costs to the developing country and in many cases to the human race community of international locations is greater if these basic electricity needs are certainly not met than when they are required. An enhancing standard of coping with the rural areas would relieve quite a lot of human misery and also improve the political stability of the planet.

4.8 Grid Connection

4.8.1 *Unique Configurations for Linking Wind Turbines on the Grid*

The association of the windmill to the grid depends on the electrical generator as well as power electronic converters used. Based about the application of PE converters in the WECS, the turbine configurations can be divided into a few topologies: directly connected to the grid without any PE converter, connected via full-scale the PE converter, and connected via partially-rated PE converter. In the following, the generator in addition to power electronic converter configurations most widely used in wind turbine systems are discussed.

As a basic, robust and reasonably low-cost program, a squirrel-cage induction generator (SCIG), as an asynchronous machine, will be connected directly towards the grid, as represented in Fig. 4.19. For a good induction generator, using a gearbox

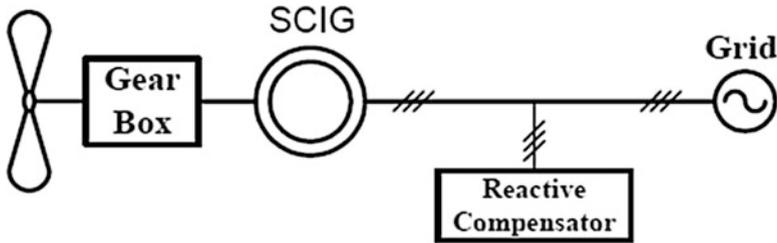


Fig. 4.19 Wind turbine system with SCIG

is required in order to interface the turbine speed and generator speed. The electrical condenser bank (for responsive power compensation) as well as soft-starter (regarding smooth grid link) are also necessary. The speed and also power are minimal aerodynamically by stall or pitch handle. The variation of slip is within the range of 1 %–2 %, but there are several wind turbines determined by SCIG in marketplace with increased rotor resistance and, thus, increased slip (2 %–3 %). This program is used to allow for a little bit of speeding up for the duration of wind gusts in order to reduce the physical stresses. However, the configuration based with almost fixed pace is not suitable for a windmill in an increased power range as well as for locations together with widely varying the wind velocity.

Three wind turbine systems based on induction generators, while using the capability of variable-speed operation are shown in Fig. 4.20. The wind turbine system in Fig. 4.20a uses a wound-rotor induction turbine (WRIG). The concept of this model is the rotor resistance might be varied electronically having a variable external rotor resistance and a PE converter. Simply by controlling the rotor coil resistance, the output of the unit will be improved over a 10 % range (speed range 2–4 %). In normal operations, the rotor level of resistance is low, related to low slip, yet during wind gusts the rotor opposition is increased to allow speeding up. Figure 4.20b shows a setting employing a Doubly-Fed Induction Source (DFIG) and power electronic converters that connects this rotor winding towards grid directly. On this configuration, it is quite possible to extend the speed range further without affecting the efficiency. The reason behind speed control without having loss of productivity is that fall power can follow back to the grid by the particular converter instead to be wasted in the rotor resistance. Note that the power standing of the electrical power converter is sP_{nom} , where 's' would be the maximum possible elusion and P_{nom} would be the nominal power in the machine. The windmill slip (s) is usually positive or adverse because the rotor coil power can stay positive or negative, due to the bidirectional nature connected with power electronic ripper tools. For example, when the power rating from the converter is 12 % of the electricity rating of the generator, the speed control range is definitely from 90 % to 110 % of the synchronous speed. It implies at 110 % rate, $s = -0.1$ and power can be fed from this rotor to the particular grid, whereas from 90 % speed, your slip is $s = +0.1$, as well as 10 % of the energy is fed on the grid to the rotor through the converter. With these kind of attributes, a larger control range

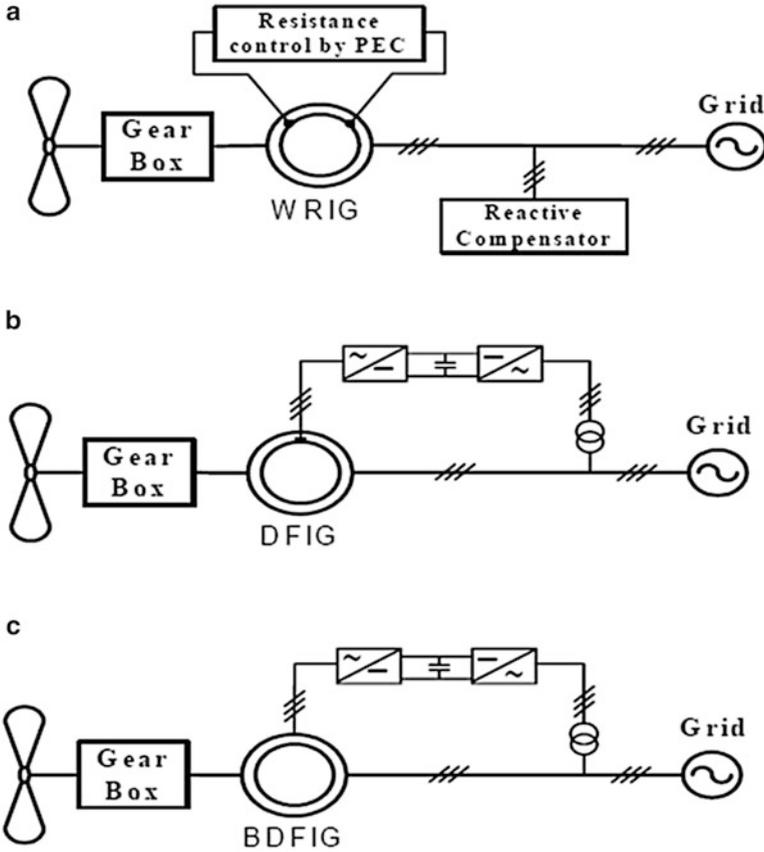


Fig. 4.20 Wind turbine systems based on induction generator with capability of variable-speed operation: (a) Wound-Rotor, (b) Doubly-Fed, and (c) Brushless Doubly-Fed induction generators

and more compact losses, the shape in Fig. 4.20b is a lot more attractive than this configuration in Fig. 4.20(a).

In the configurations shown in Fig. 4.20a, b, together with wound-rotor induction generator, the access to the rotor is achievable through the slip rings and brushes. Slip rings as well as brushes cause hardware problems and electric losses. In order to solve the difficulties of using get rings and brushes one alternative is utilizing the Brushless Doubly-Fed induction generator (BDFIG), shown in Fig. 4.20c. In this scheme, the stator coil windings (main winding) are directly connected to the grid, while three-phase auxiliary winding is connected on the electrical grid by having a PE converter. When using the appropriate control within the auxiliary winding, the user possibly can control the trigger machine at any speed virtually.

In this category, the electro-mechanical machine is coupled to the electrical grid using a fully-rated converter. It means that this whole power interchanged between the particular wind turbine and also the electrical grid has to be passed through any

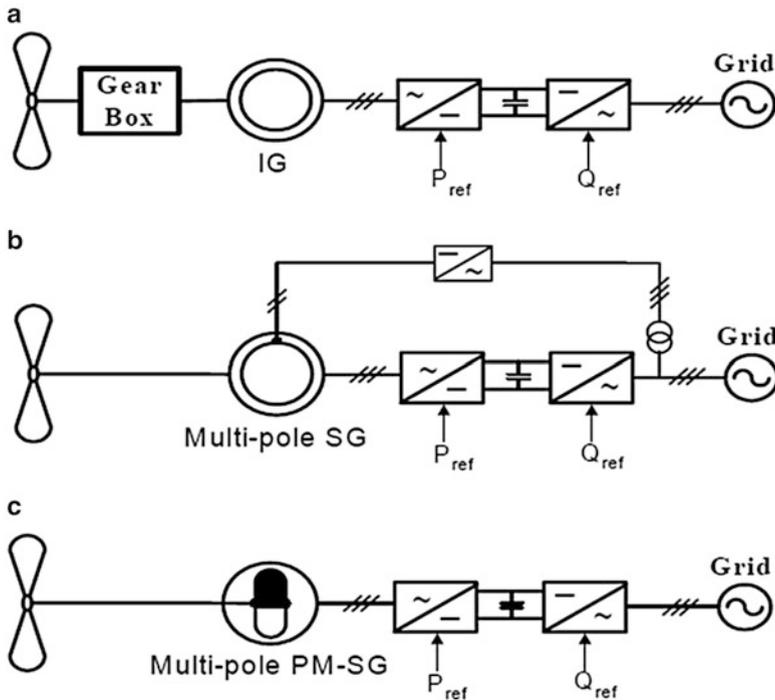


Fig. 4.21 Wind turbine systems with fully-rated power converter between generator terminals and the grid: (a) induction generator with gearbox, (b) synchronous and, (c) PM synchronous generator

PE converter. This suggests extra losses in the power conversion. Nonetheless this configuration can improve the technological performance. In this kind of configuration, as an electrical machine, it may be possible to use induction machine or synchronous machine, as demonstrated in Fig. 4.21. Note the system of Fig. 4.21a uses a gear box together with a SC induction generator. The systems associated with Fig. 4.21b, c use synchronous machines without a gear case. In Fig. 4.21b the synchronous generator needs power electronic converter tools for field excitation, and slip speed. An advantage of utilizing the synchronous generator is the chance of eliminating the gear case in the wind generator (direct-drive turbine). Direct drive machines essentially have a big diameter due to the high torque. Within gearless drives, induction machines cannot supply because of the excitation losses in these large machines as a result of large air break. However, synchronous machines can be utilized in direct-drive wind turbines, with either electrically excited or permanent-magnet blade structures (Fig. 4.21c). Direct-drive systems with permanent magnet excitation are more costly, because of the high price regarding magnets, but results in lower losses. Nowadays, the price connected with permanent magnets is definitely decreasing dramatically. Yet another disadvantage of using permanent magnet synchronous machine is the actual uncontrollability of their

excitation. All configurations shown in Fig. 4.21 have the same control characteristics because the power converter relating to the generator and the grid enables fast control of lively and reactive electrical power. Also, the power generator is isolated through the grid by a new DC-link capacitor. But, using fully-rated power automated converter is the particular disadvantage of these configurations. Different wind turbine manufacturers produce different configurations. Comparing different systems from various points of check out shows a trade-off between price and performance.

4.9 Modeling of Wind Turbine Using MATLAB/SIMULINK

This section presents the simulation of a wind turbine connected to a synchronous generator and a rectifier. The torque of the wind turbine is given as the input to the synchronous generator and the three phase AC output is given to the rectifier. The electromagnetic torque, stator current and the base speed of the synchronous generator are also analyzed.

4.9.1 SIMULINK Models

The SIMULINK blocks of the permanent magnet synchronous machine, wind turbine and asynchronous machine are discussed below:

4.9.1.1 Permanent Magnet Synchronous Machine

Model the dynamics of three-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back electromotive force (back EMF). The sinusoidal machine is modelled in the dq rotor reference frame and the trapezoidal machine is modelled in the abc reference frame. Stator windings are connected in wye to an internal neutral point.

Library

The Permanent Magnet Synchronous Machine block shown in Fig. 4.22 is available in the *Machines* library.

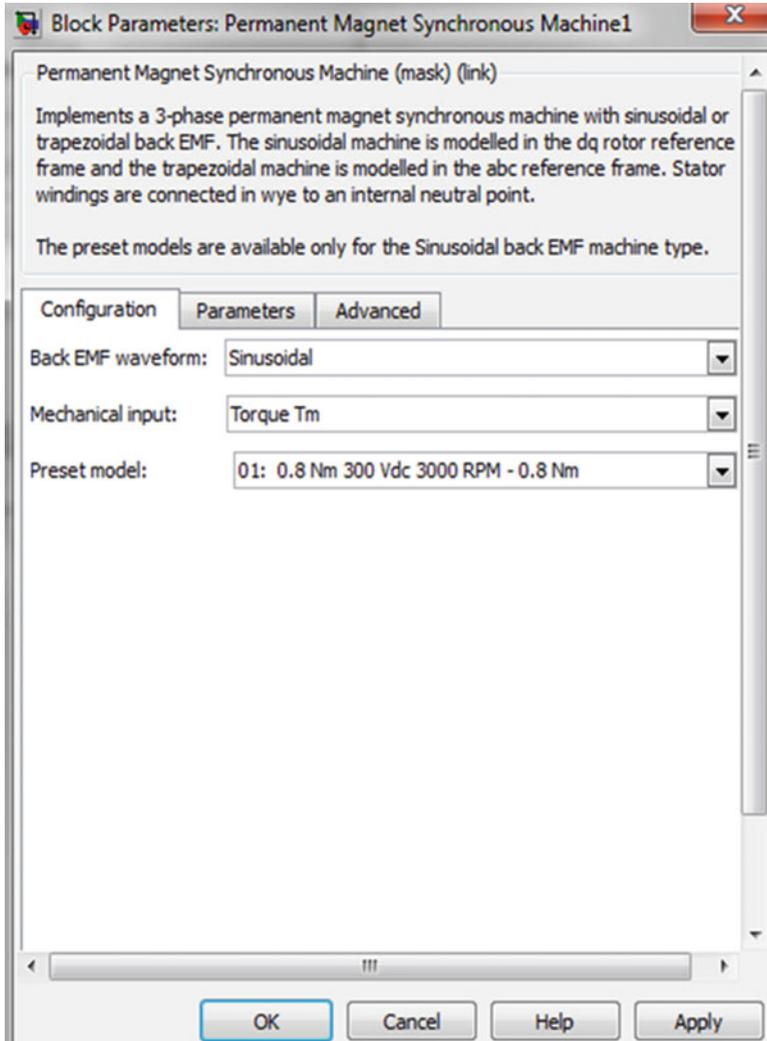


Fig. 4.22 Permanent magnet synchronous machine block

Description

The Permanent Magnet Synchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque (positive for motor mode, negative for generator mode). The electrical and mechanical parts of the machine are each represented by a second-order state-space model. The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal. For the trapezoidal machine, the model assumes that the winding distribution and flux established by the permanent magnets produce three trapezoidal back EMF waveforms.

Table 4.2 Parameters of the permanent magnet synchronous machine block

Parameters	Value
Stator phase resistance R_s (ohm)	2.8750
Inductance L_d (H)	8.5e-3
Inductance L_q (H)	8.5e-3
Flux linkage established by magnets (V.s)	0.175
Voltage constant V -peak (V)	126.966
Torque constant	1.05
Inertia J (kg.m ²)	0.0008
Friction factor F (N.m.s)	0.001

Parameters

The parameters of the Permanent Magnet Synchronous Machine block for sinusoidal back emf machine are shown in Table 4.2:

4.9.1.2 Wind Turbine

This block implements a variable pitch wind turbine model. The performance coefficient C_p of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (β). C_p reaches its maximum value at zero β . Select the wind-turbine power characteristics display to plot the turbine characteristics at the specified pitch angle.

The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (β) in degrees. The third input is the wind speed in m/s.

The output is the torque applied to the generator shaft in per unit of the generator ratings. The turbine inertia must be added to the generator inertia.

Library

The wind turbine block shown in Fig. 4.23 is available in the Distributed Resources/ Wind Generation library.

Description

The model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine.

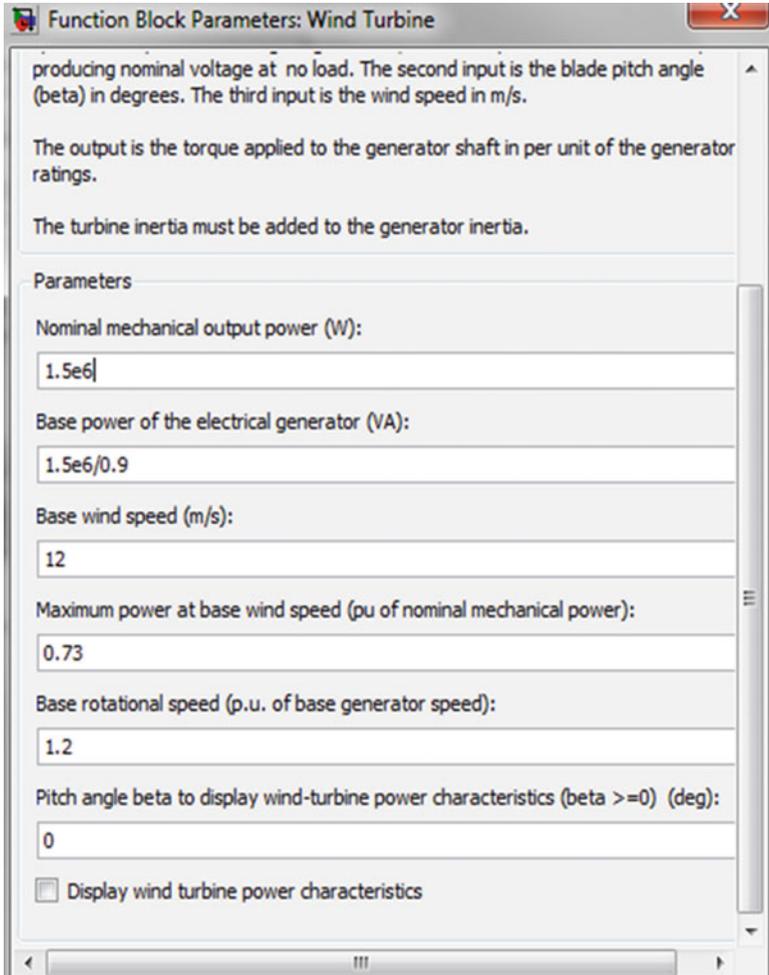


Fig. 4.23 Wind turbine block

Parameters

The parameters of the Wind Turbine block are shown in Table 4.3.

The SIMULINK model of the turbine is illustrated in the following Fig. 4.24. The three inputs are the generator speed (ω_r _pu) in pu of the nominal speed of the generator, the pitch angle in degrees and the wind speed in m/s. The tip speed ratio λ in pu of λ_{nom} is obtained by the division of the rotational speed in pu of the base rotational speed (defined below) and the wind speed in pu of the base wind speed. The output is the torque applied to the generator shaft. The parameters are described below:

Nominal Mechanical Output Power

The nominal output power in watts (W).

Table 4.3 Parameters of the wind turbine block

Parameters	Value
Nominal mechanical output power (W)	1.5e6
Base power of the electrical generator (VA)	1.5e6/0.9
Base wind speed (m/s)	12
Maximum power at base wind speed (pu of Nominal mechanical power)	0.73
Base rotational speed (kpu of base generator speed)	1.2

Base Power of the Electrical Generator

The nominal power of the electrical generator coupled to the wind turbine, in VA. This parameter is used to compute the output torque in pu of the nominal torque of the generator.

Base Wind Speed

The base value of the wind speed, in m/s, used in the per unit system. The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.

Maximum Power at Base Wind Speed

The maximum power at base wind speed in pu of the nominal mechanical power. This parameter is the power gain k_p already defined.

Base Rotational Speed

The rotational speed at maximum power for the base wind speed. The base rotational speed is in pu of the base generator speed.

Pitch Angle Beta to Display Wind Turbine Power Characteristics

The pitch angle beta, in degrees, used to display the power characteristics. Beta must be greater than or equal to zero.

Display Wind Turbine Power Characteristics

If this parameter is checked, the turbine power characteristics are displayed for different wind speeds and for the specified pitch angle beta.

4.9.1.3 Inputs and Outputs**Generator Speed (pu)**

SIMULINK input of the generator speed in pu based on the nominal speed of the generator.

Pitch Angle (deg)

SIMULINK input of the pitch angle.

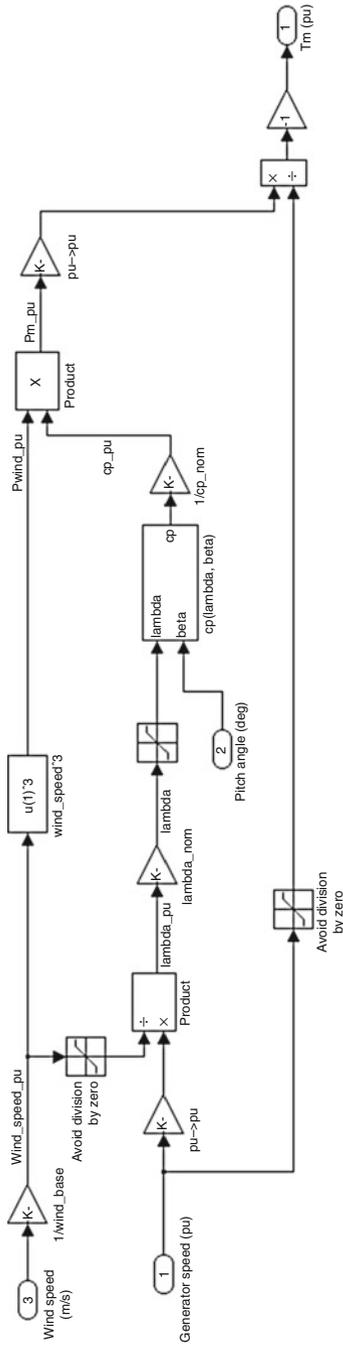


Fig. 4.24 SIMULINK model of the turbine

Wind Speed (m/s)

SIMULINK input of the wind speed in m/s.

T_m (pu)

SIMULINK output of the mechanical torque of the wind turbine, in pu of the nominal generator torque. The nominal torque of the generator is based on the nominal generator power and speed.

4.9.1.4 Characteristics of Wind Turbine

A wind turbine as power source leads to special conditions. The shaft speed power function is pre-determined because aerodynamic efficiency of the turbine depends on the ratio between the blade tip speed and the wind speed, called tip speed ratio. Maximum aerodynamic efficiency is obtained at a fixed tip speed ratio. To keep the turbine efficiency at its maximum, the speed of the turbine should be changed linearly with the wind speed. The wind power is proportional to the cube of the wind speed. If a turbine control program that is designed to optimize the energy production is used the wind speed turbine power function is also a cubic function. The turbine power curve is shown in Fig. 4.25 together with the turbine speed curve. In this report the turbine speed is assumed to be controllable above the rated wind speed by blade pitch control. The generator speed can then be considered nearly constant at wind speeds above the rated wind speed. An ordinary wind turbine has a rated wind speed of about 13–14 m/s but the median wind speed is much lower, about 5–7 m/s. Therefore, the power of the turbine is most of the time considerably less than the rated power.

It can be seen that the wind speed usually is about half of the rated wind speed. Only during a small fraction of the time, less than 10 % of the year, the turbine

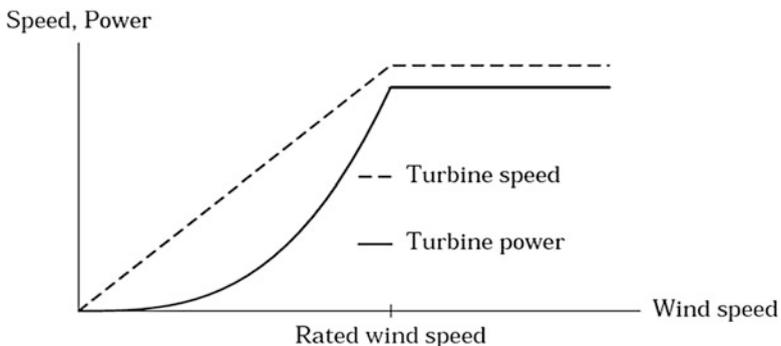


Fig. 4.25 Wind turbine characteristics

produces rated power. Therefore, a generator system for a wind turbine benefits more of low losses at low power than it does of low losses at rated power. At high power a variable-speed generator and converter have higher losses than what a similar generator connected directly to the network has. However, at low power the variable-speed system can have lower losses than the network-connected generator. Therefore, the annual average efficiency can be almost the same for both the systems.

4.9.1.5 Asynchronous Machine

Model the dynamics of three-phase asynchronous machine, also known as induction machine.

Library

The Asynchronous Machine block with corresponding parameters and their values is shown in Fig. 4.26. This block is available in the Machines library.

Description

The Asynchronous Machine block (Fig. 4.26) operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque. If T_m is positive, the machine acts as a motor and if T_m is negative, the machine acts as a generator. The stator terminals of the Asynchronous Machine block are identified by the A, B, and C letters. The rotor terminals are identified by a, b, and c letters. The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. The input to the block is the mechanical Torque T_m . The output is the rotor speed in p.u.

4.9.2 Simulation and Results

The SIMULINK model of a wind energy system with AC/DC converter is constructed as shown in Fig. 4.27. The output of the model is obtained in terms of DC output voltage, stator current, and rotor speed and the curves are plotted with respect to time as shown in Figs. 4.28, 4.29 and 4.30. The wind turbine is connected with a three-phase load (Fig. 4.31) and the DC output voltage and rotor speed are shown in Figs. 4.32 and 4.33.

This section presents a novel conversion method of wind energy for achieving maximum benefits from the inverters when installed in three-phase four-wire

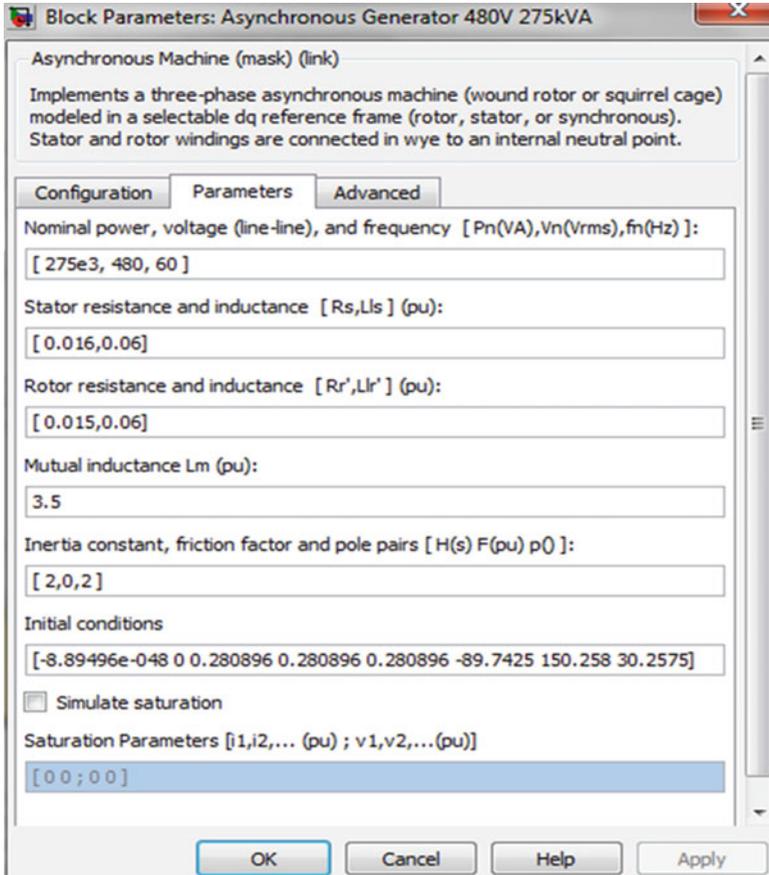


Fig. 4.26 Asynchronous machine block

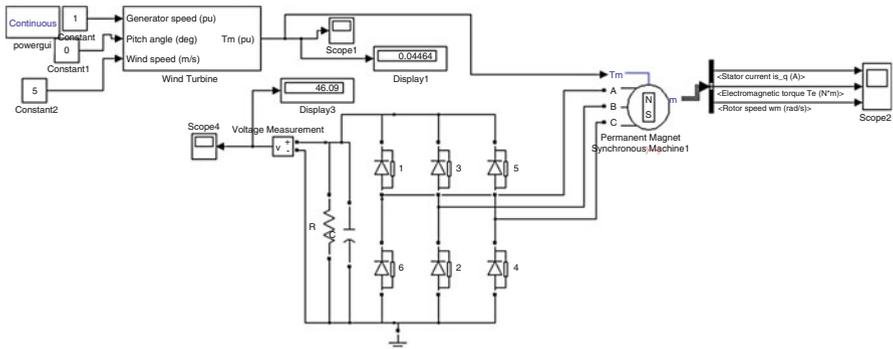


Fig. 4.27 SIMULINK model of wind energy system with AC/DC converter

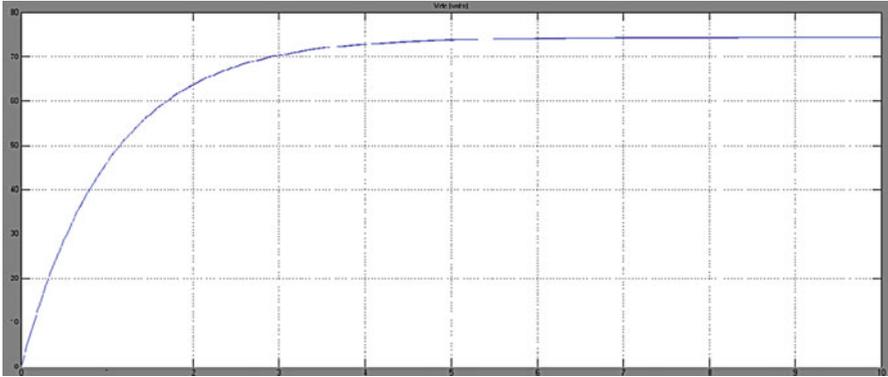


Fig. 4.28 DC output voltage (v_{dc}) versus time

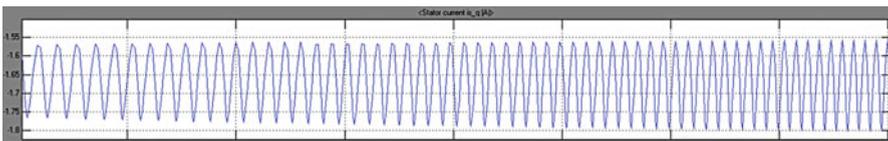


Fig. 4.29 Stator current versus time

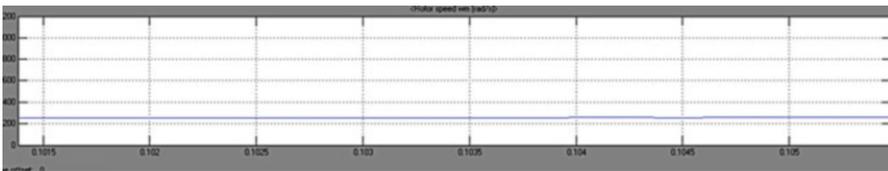


Fig. 4.30 Rotor speed versus time

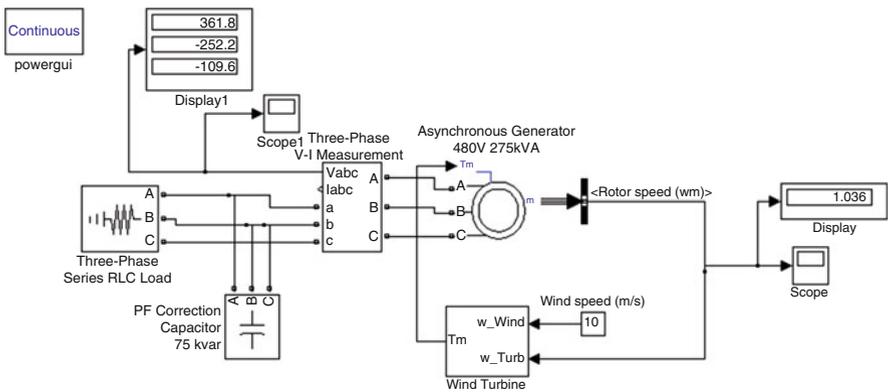


Fig. 4.31 SIMULINK model of wind energy system with three phase load

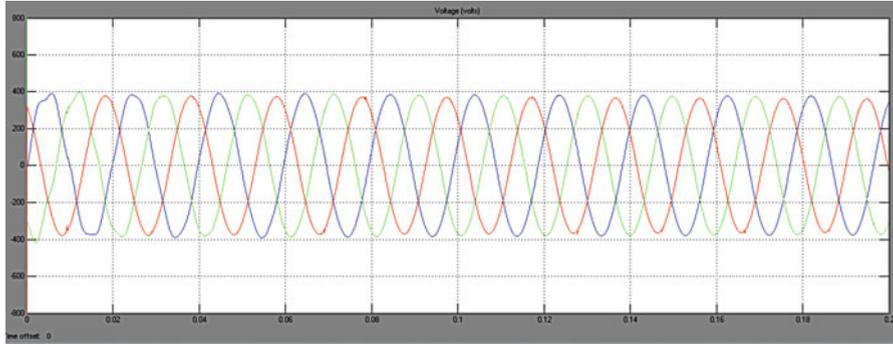


Fig. 4.32 Output voltage (v_{dc}) versus time

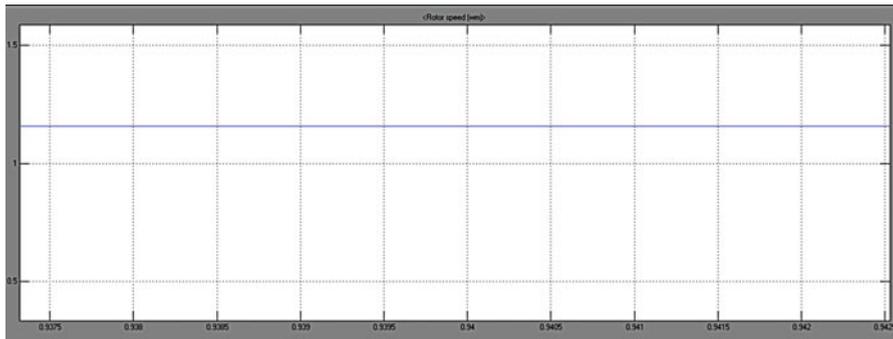


Fig. 4.33 Rotor speed versus time

distribution systems in the grid connected wind conversion system. The inverter can thus be utilized as: power converter to inject power generated from RES to the grid. All of these functions may be accomplished either individually or simultaneously. With such a control, the combination of grid-interfacing inverter and the three-phase four-wire linear/non-linear unbalanced load at point of common coupling appears as balanced linear load to the grid. This new control concept is demonstrated with extensive MATLAB/SIMULINK simulation and its results.

4.10 MATLAB/SIMULINK Model of Type 1 WTG

The stator winding of generator is connected directly to the grid and the rotor is driven by the wind turbine model. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to

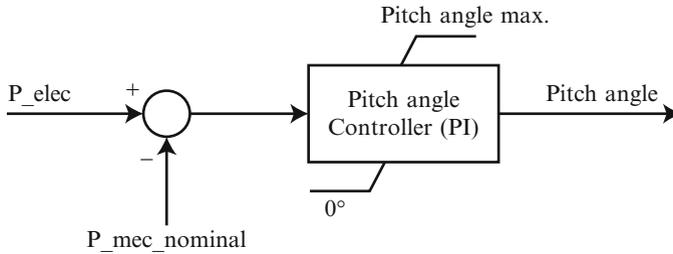


Fig. 4.34 Model of PI controller

generate power the induction generator speed must be slightly above the synchronous speed. But the speed variation is typically so small that the WTIG is considered to be a fixed-speed wind generator. The reactive power absorbed by the induction generator is provided by the grid or by some devices like capacitor banks, SVC, STATCOM or synchronous condenser.

4.10.1 Pitch Angle Control System

A Proportional-Integral (PI) controller shown in Fig. 4.34 is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value.

4.10.2 Parameters

The parameters to be considered are the nominal power in VA, the nominal line-to-line voltage in Vrms, the nominal system frequency in hertz, the stator resistance R_s , leakage inductance L_l in pu based on the generator ratings. The rotor resistance R_r' and leakage inductance $L_l r'$, both referred to the stator, in pu based on the generator ratings. The magnetizing inductance L_m in pu based on the generator ratings. Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator ratings and number of pole pairs p . The initial slip s , electrical angle Θ in degrees, stator current magnitude in pu and phase angle in degrees. Figure 4.35 shows the SIMULINK model of type 1 wind turbine generator. The generation and transmission of power in the wind farm model is simulated.

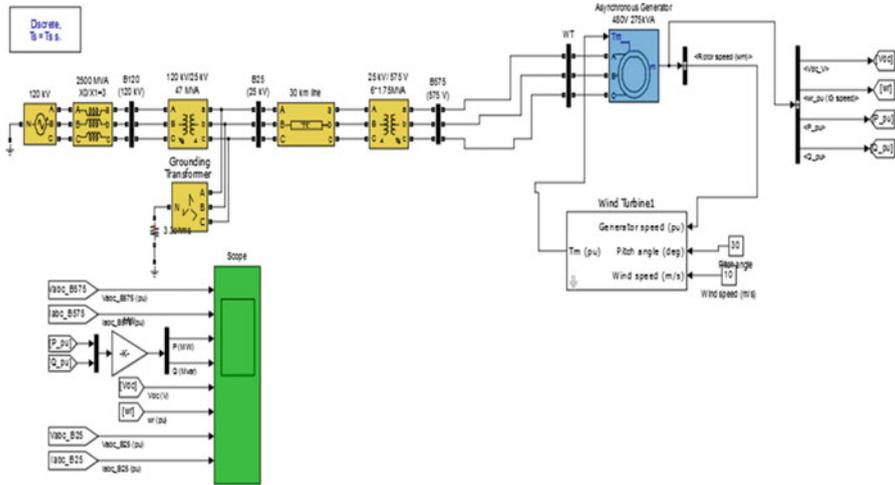


Fig. 4.35 SIMULINK model of type 1 WTG

The wind turbine is operated with a constant wind speed (13 m/s). This wind speed is chosen to be the rated value. Voltage sag on the grid is simulated, and the real and reactive power response of the wind turbine is observed. The grid voltage drops from 1 to 0.8 p.u. at $t = 15$ s, and the sag persists for 18 cycles (0.3 s). The intent of the test is to show that the model does indeed respond to events occurring in the dynamic timescale and that the response of the machine to this event is realistic. The grid voltage, rotor speed, real power, and reactive power during the event are shown. As expected, the step changes in the grid voltage magnitude when the sag begins and ends cause an immediate response. Note that the speed does not change by much (approximately 2 %), as expected from a fixed-speed wind turbine. The real power and reactive power outputs experience a disturbance too, and the outputs show that a mechanical oscillation occurs after the sag ends, and that the oscillation eventually damps out.

Figure 4.36 shows the simulation result obtained from the type 1 WTG. Three phase power is supplied to the load the output power is maintained nearly constant with respect to time.

4.11 MATLAB/SIMULINK Model of Type 2 WTG

The basic principle behind the IM operation is electromagnetic induction. Voltages applied to a multiphase AC stator winding result in currents which produce a rotating magnetic field. This field induces voltages (and therefore currents) in the rotor circuit. The interaction between the stator produced field and the rotor induced currents produces torque. If the induction machine is driven by a prime mover at a

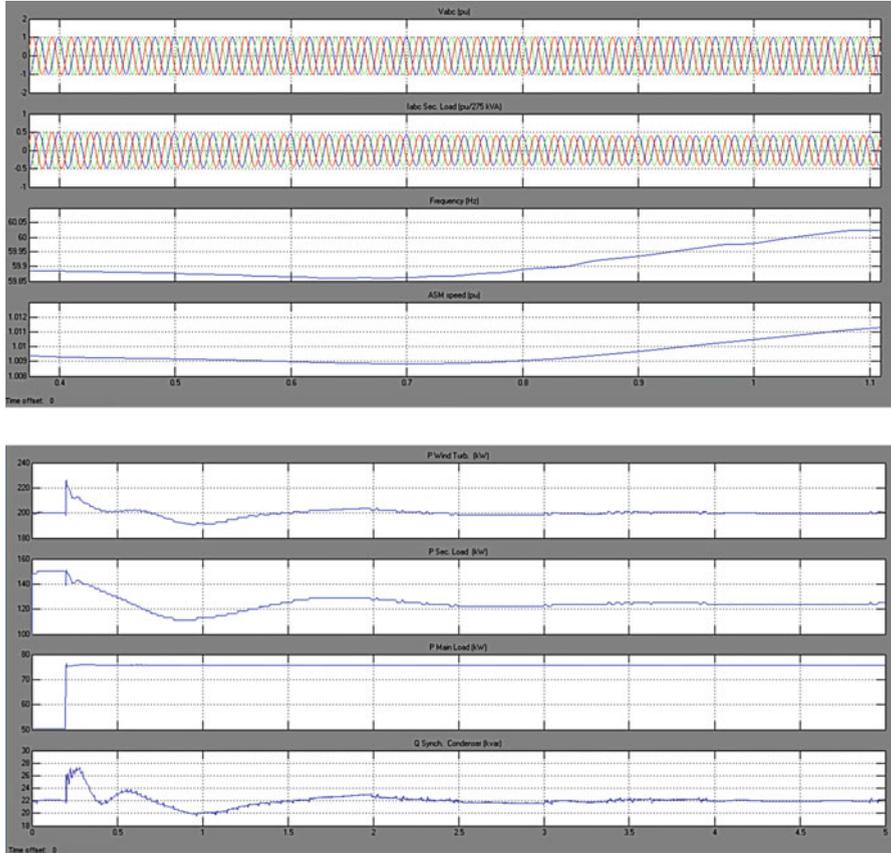


Fig. 4.36 Simulation results of type 1 WTG

speed greater than its synchronous speed, it acts as a generator. The rotor circuit may consist of bars short-circuited through end rings in the case of squirrel cage machines, or in the case of wound-rotor machines, multiphase windings accessible through slip rings and brushes. Only wound-rotor machines are used widely in all applications. Since the rotor windings are accessible, modifications to the rotor circuit are possible. One of these possible modifications is changing the rotor resistance. Revisiting the induction machine equivalent circuit is necessary to evaluate the impact of changing the rotor resistance on the torque and power associated with the machine.

Control of power output of a Type-2 turbine can be accomplished by varying the rotor resistance. The MATLAB/SIMULINK model is shown in Fig. 4.37. The objective of a rotor resistance controller in this situation is to seek the operating point at which power extraction from the wind is maximized, and also prevent the power extracted from exceeding the machine’s ratings. The wind turbine is operated with a constant wind speed (13 m/s). This wind speed was chosen to be the

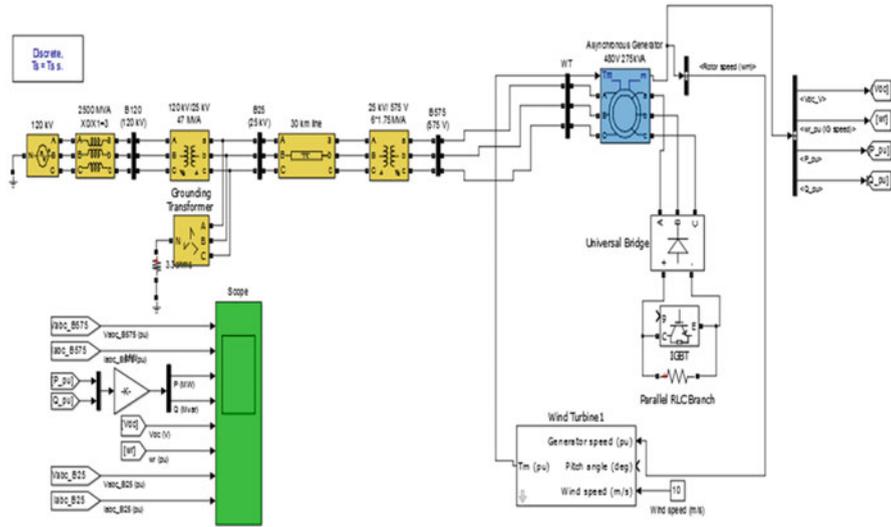


Fig. 4.37 SIMULINK model of type 2 WTG

rated value. Voltage sag on the grid was simulated, and the real and reactive power response of the wind turbine was observed. The grid voltage drops from 1 to 0.8 p.u. at $t = 15$ s, and the sag persists for 18 cycles (0.3 s). The grid voltage, rotor speed, real power, and reactive power during the event are shown in Fig. 4.38. As expected, the step changes in the grid voltage magnitude when the sag begins and ends cause an immediate response. Note that the speed experiences a greater change (approximately 5 %) as compared to the fixed-speed wind turbine. The real power and reactive power outputs experience a disturbance too; however, the disturbance is once again qualitatively and quantitatively different from the response of the fixed speed wind turbine due to the rotor resistance controller. As in the previous case, the outputs also show that a mechanical oscillation occurs after the sag ends, and that the oscillation eventually damps out.

4.12 MATLAB/SIMULINK Model of Type 3 WTG

Type 3 is the model with generic doubly-fed induction generator (DFIG) for a wind turbine. A set of three-phase currents is injected into the grid such that the real and reactive power of the generator can be independently controlled. The behavior of a DFIG control system to independently control the real and reactive power allows the use of a regulated current source in the dynamic model to represent the induction generator and power electronics. The main concern is to ensure that the model was suitably general and since the ultimate purpose of the model is use in load flow and dynamic stability studies, a highly detailed representation of the

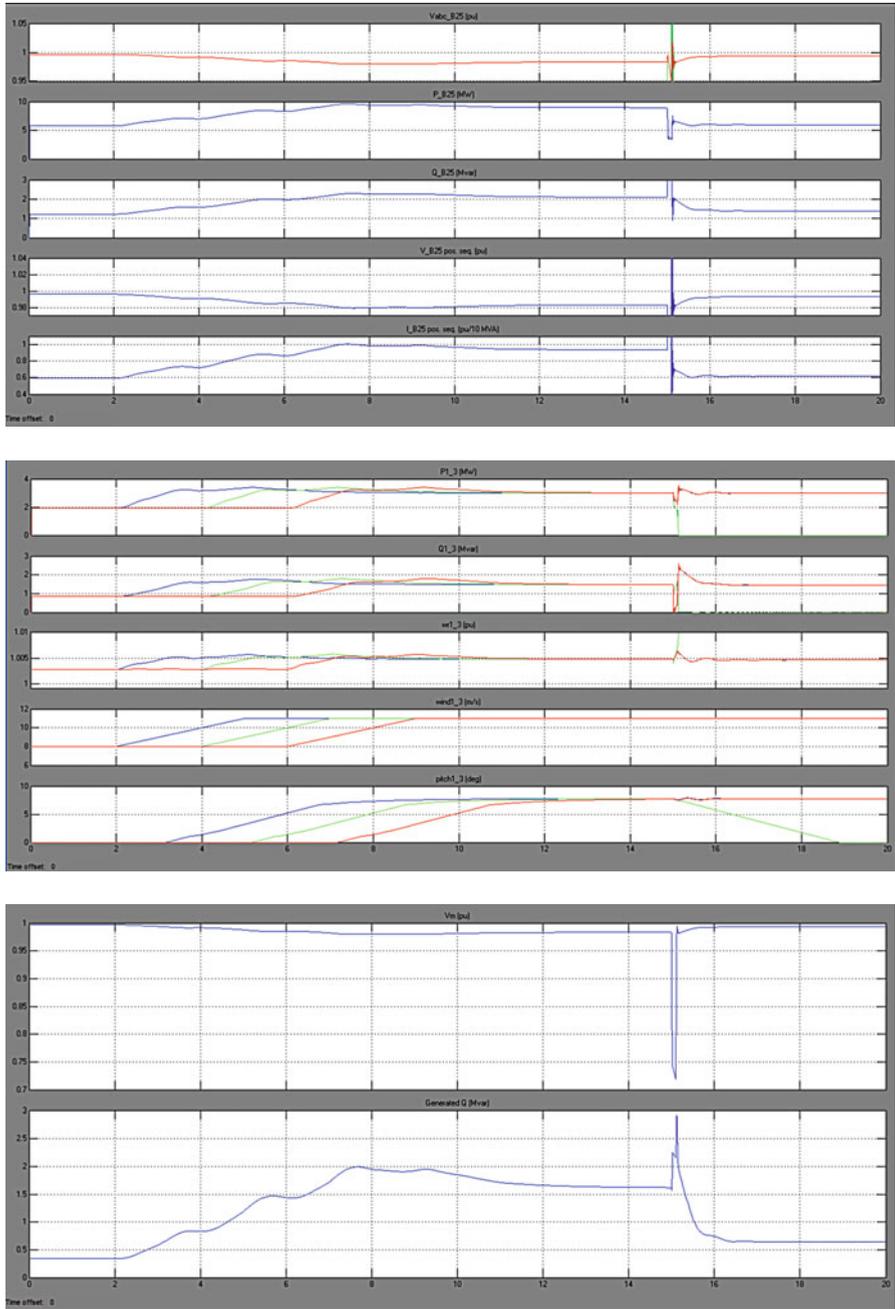


Fig. 4.38 Simulation results of type 2 WTG

machine and converter is not necessary. This subsection presents the analysis behind the approximations of using a regulated current source representation instead of explicitly modeling the generator and power electronics. A simplified model of the device dynamics is adequate. The mechanical modeling of the system has also been considerably simplified, with a one-mass model being used to represent the numerous rotating masses (the turbine, gearbox, and generator). Let the wound rotor induction machine be represented in a synchronously rotating $qd0$ reference frame. The currents flowing in the stator are assumed to be balanced. These currents produce a resultant stator magnetic field which has a constant magnitude and is rotating at synchronous speed. Since the angular speeds of 39 the stator magnetic field and the $qd0$ rotating frame are identical, the vector of the stator magnetic field is fixed with respect to the q - and d - axes of the $qd0$ rotating frame. In an actual WPP, a local grid collects the output from each wind turbine into a single point of connection on the grid. As a WPP is usually made up of several identical machines, it is a reasonable approximation to parallel all the turbines into a single equivalent large turbine behind single equivalent impedance. The rated power rating of the single equivalent wind turbine is equal to the combined rated power ratings of all wind turbines. The model developed is a simplified generic model intended for bulk power system studies where a detailed representation of a wind turbine generator is not required. The model is intended for transient stability analysis of grid disturbances. The actual device dynamics have been greatly simplified. To be specific, the very fast dynamics involved with the control of the generator-converter have been modeled as algebraic approximations of their response. This makes the generator-converter dynamics instantaneous.

Simplified turbine mechanical controls along with blade aerodynamic characteristics are included in the model. Generator-Converter sub-system: The generator-converter system is represented by a regulated voltage source. It injects three-phase voltage into the power system in response to the control commands from the Converter Control sub-system. Converter Control sub-system consists of the Reactive Power Control and Real Power Control sub-systems. These subsystems emulate power electronics controllers in regulating real and reactive power. Wind Turbine sub-system is represented by a single-mass model and it determines the mechanical input power and the angular speed of the wind turbine based on the specified pitch angle. Pitch Control sub-system is used to determine the desired blade pitch angle based on desired angular speed and real power. Figure 4.39 shows the SIMULINK model of type 3 WTG and Fig. 4.40 shows the corresponding simulation results obtained from MATLAB/SIMULINK model.

4.13 MATLAB/SIMULINK Model of Type 4 WTG

Full Converter Wind Turbine (FCWT) effectively decouples the generator from the grid, improving fault response. It allows the turbine to operate over a wide speed range, leading to improved power extraction from the wind. The converter

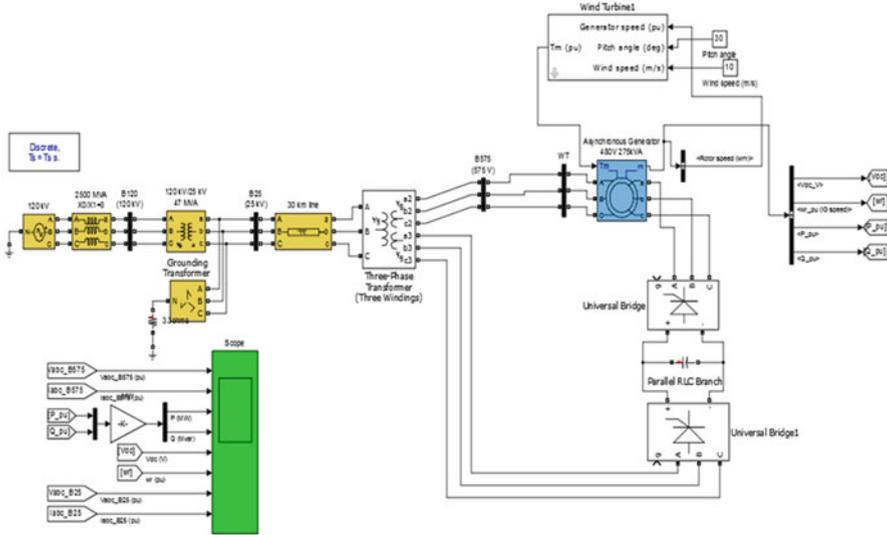


Fig. 4.39 SIMULINK model of type 3 WTG

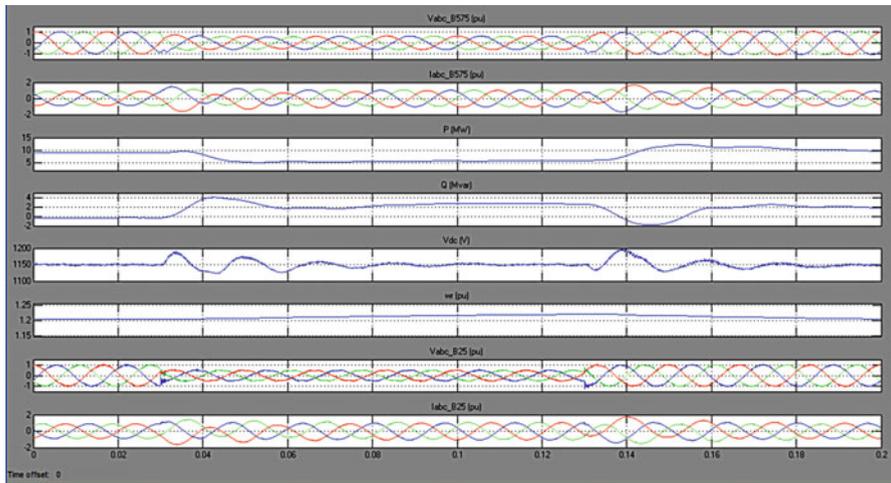


Fig. 4.40 Simulation results of type 3 WTG

interfacing the turbine to the grid has to handle the entire output of the generator (unlike in a DFIG turbine where the converter handles only 30–40 % of the generator output) and hence is more costly and lossy, but also provides more headroom to supply reactive power to the grid. The Permanent Magnet Alternator (PMA) itself has no rotor windings, reducing excitation losses and reducing the size of the generating unit with respect to competing technologies. Absence of rotor slip

rings reduces maintenance requirements. This combination of factors is driving the increasing penetration of FCWTs, especially for offshore wind power plants. The popularity of FCWTs has led to a search for reliable models to evaluate the impacts of integrating these FCWTs into the existing grid. The model presented in this report is a generic, manufacturer-independent model for a PMA-based FCWT, with no restrictions on its use. The PMA is interfaced to the grid through an AC-DC-AC conversion system. The AC-DC converter is comprised of a diode-bridge rectifier and a buck-boost converter which controls the DC-link voltage. The DC-AC conversion is accomplished using a current-controlled inverter which controls the real and reactive output power. Universal bridge is used for conversion purpose in the MATLAB model.

Figure 4.41 shows the SIMULINK model of type 4 WTG. Converter model is included in between for voltage conversion. Figure 4.42 shows the simulation results obtained for type 4 WTG.

4.14 MATLAB/SIMULINK Model of Grid Connection

The turbine rotor, gear box and generator are the main three components for energy conversion. The rotor, being the driving component in the conversion system, converts the wind energy into mechanical energy. In case of variable speed wind turbines also an electronic inverter absorbs the mechanical power from the rotor, converting it into electrical energy, which is then fed into a supply grid. The gear box is used to adapt the rotor speed to the generator speed, if it is necessary. The main components of the grid for connection of the wind turbines are the transformer and the substation with safety equipment (circuit breaker) and the electricity meter inside. Due to relatively high losses in low voltage lines, each of the turbines in the wind farm has its own transformer, converting the voltage level of the turbine to the medium voltage line of the distribution system. To avoid long low voltage cabling the transformers are located directly beside the turbine. Only in case of small wind turbines it is possible to connect them directly to the low voltage level of the grid without using a transformer. A wind farm of small wind turbines can use one transformer to connect to the grid. For very large wind farms with high powers a separate substation is necessary for transformation from the medium voltage system to the high voltage system. Between a single wind turbine or a wind farm and the grid, at the point of common coupling (PCC), a circuit breaker has to be installed to provide disconnection possibility in case a fault. The circuit breaker is usually located at the medium voltage system side, inside a substation, together with the electricity meter. The meter has its own voltage and current transformers. Depending on the individual conditions of the existing supply system the connection to the grid can be performed as a radial feeder or as a ring feeder (Fig. 4.43).

Figure 4.44 shows the generation part of the wind farm. The generator is a wound rotor induction machine. The stator winding is directly connected to the grid. The rotor supply is connected through an AC-DC-AC converter for the P and

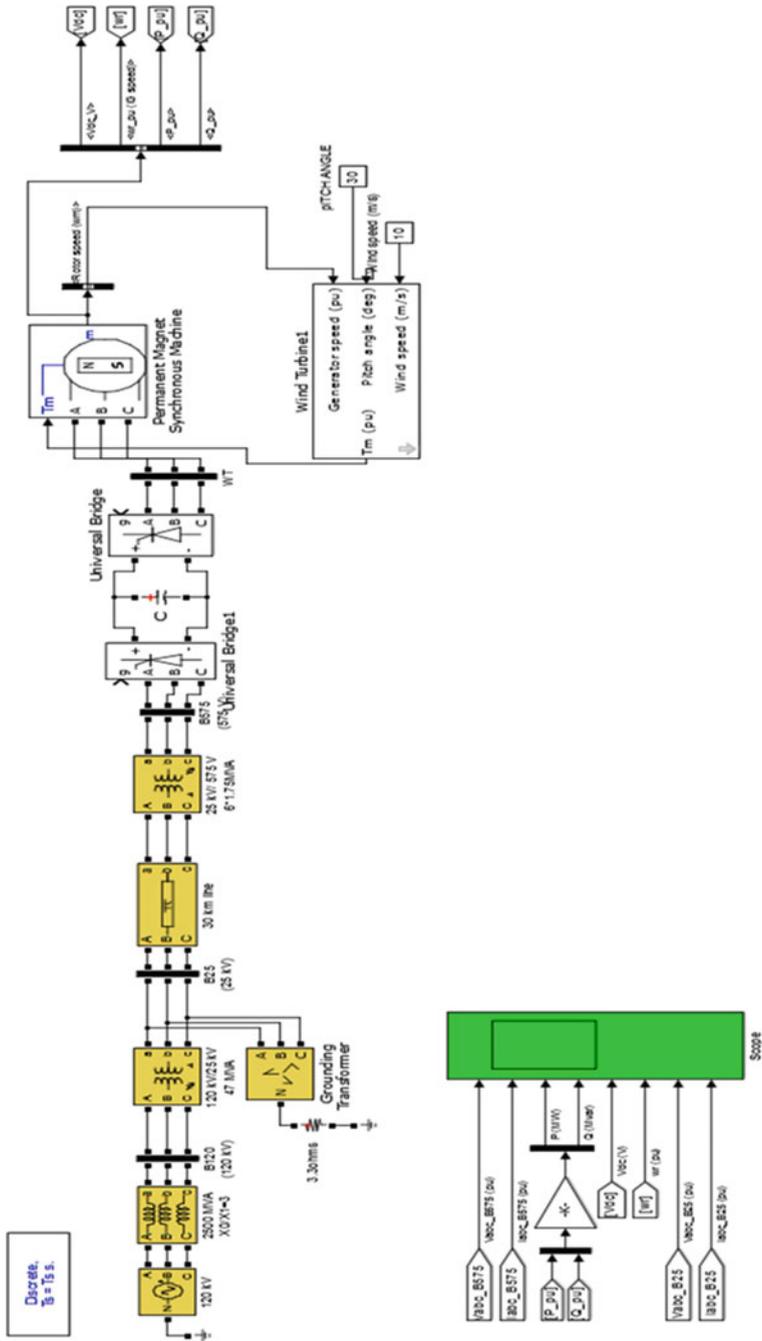


Fig. 4.41 SIMULINK model of type 4 WTG

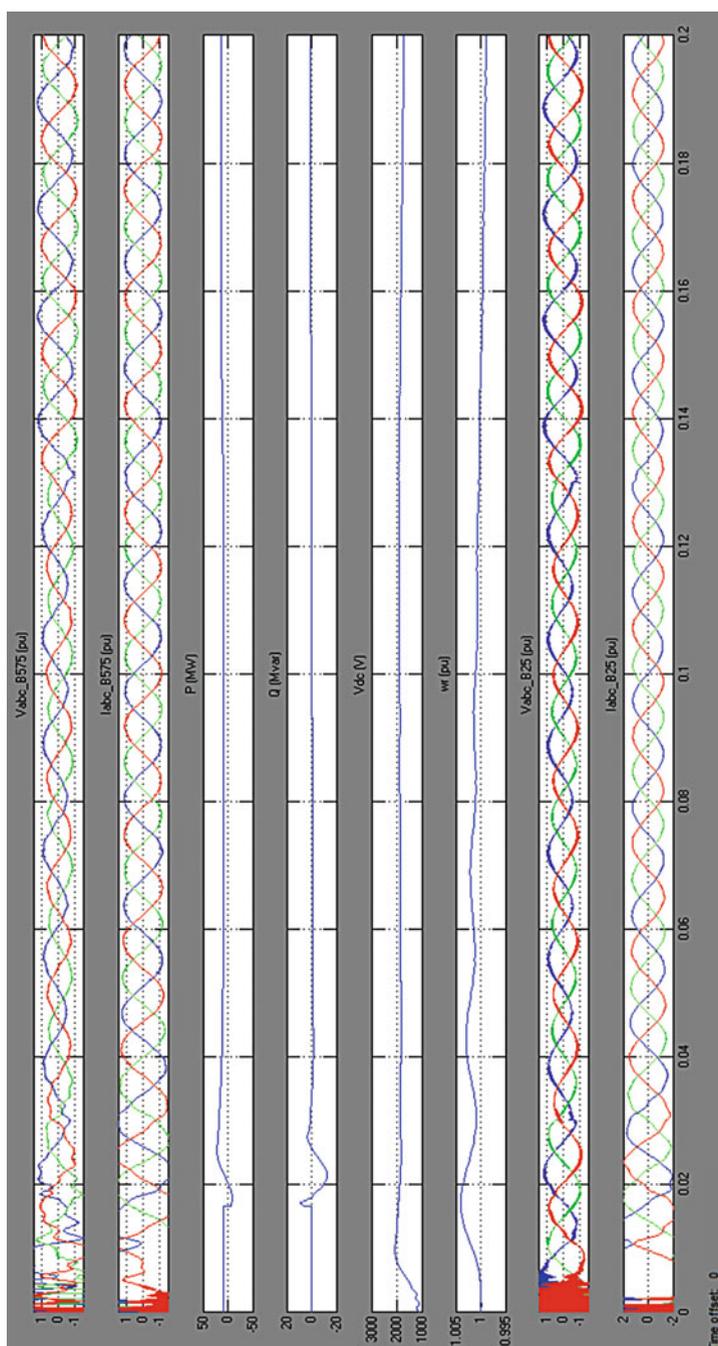


Fig. 4.42 Simulation results of type 4 WTG

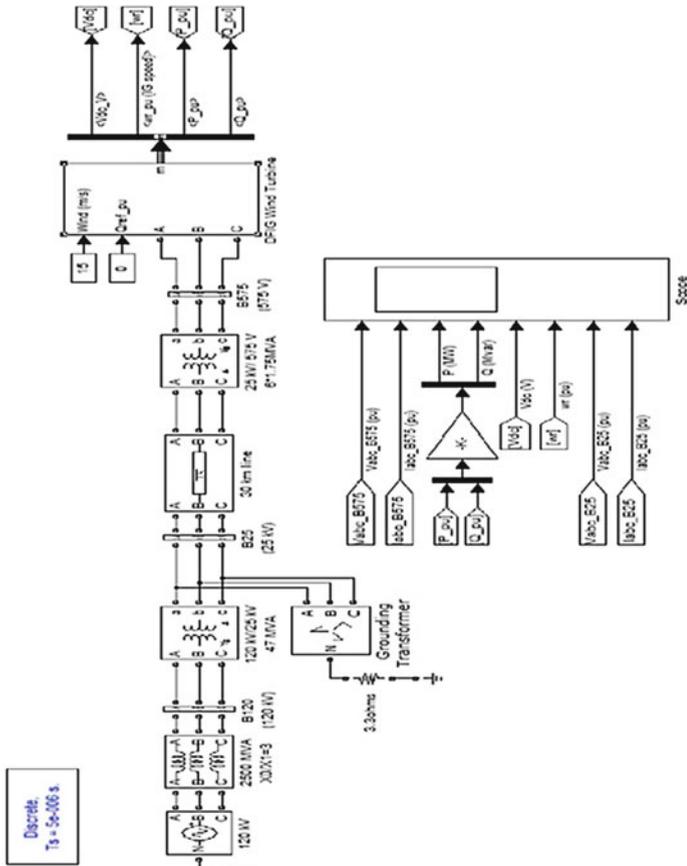


Fig. 4.43 SIMULINK model of grid connection

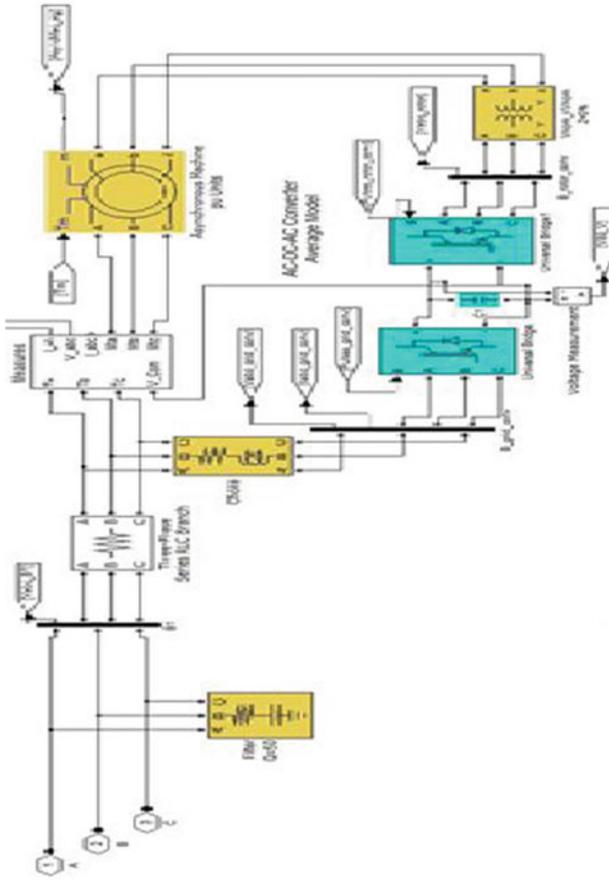


Fig. 4.44 SIMULINK model of the generating system

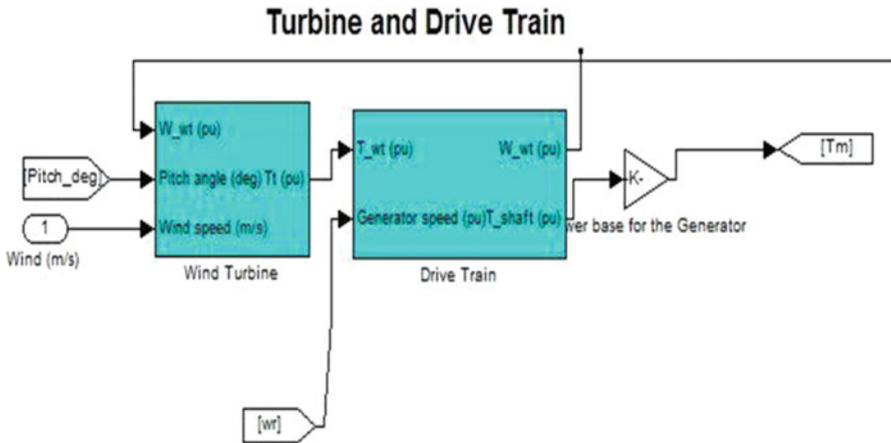


Fig. 4.45 Simulation diagram of the turbine and drive train

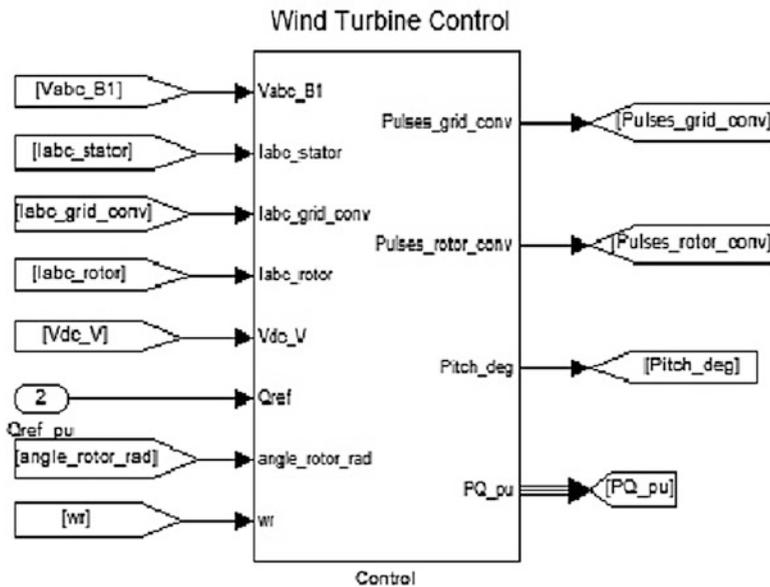


Fig. 4.46 Model of the wind turbine control

Q levels control. The two converters will get the control pulses from respective controllers i.e. grid side converter. Figure 4.45 shows the SIMULINK model of the turbine and drive train. Turbine control plays a major role in effective power generation. Figure 4.46 shows the Wind turbine control SIMULINK model.

Figures 4.47, 4.48, 4.49, and 4.50 shows the simulation results obtained for grid connected wind farm for variable speed. The grid is a 25 kv system. That shows the generation at one end which is step up to the grid voltage by using the step up transformer. The fault protection also provided with a grounding transformer.

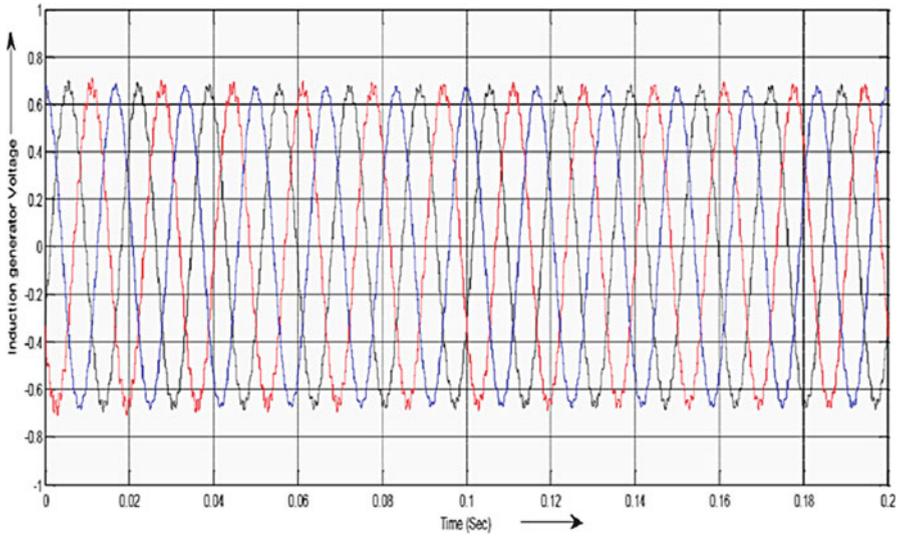


Fig. 4.47 Three phase voltage waveforms from Induction generator

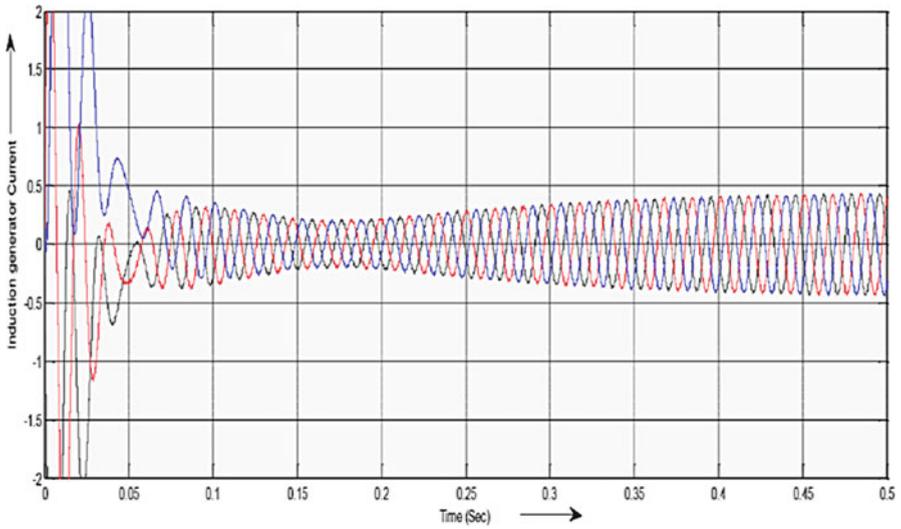


Fig. 4.48 Three phase current waveforms from Induction generator

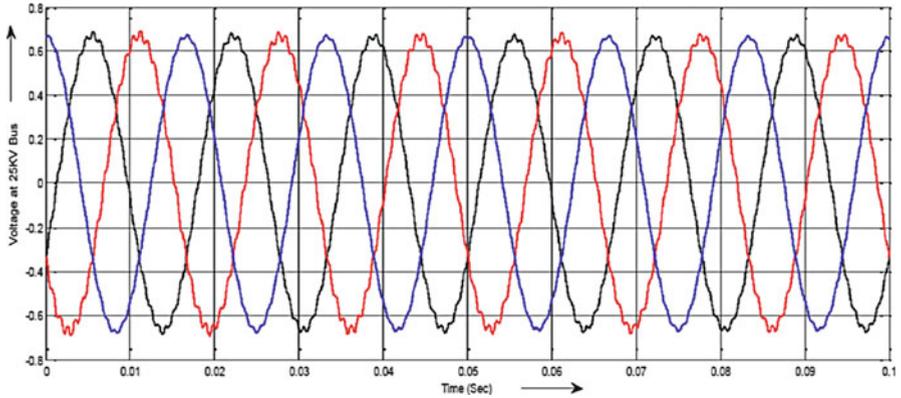


Fig. 4.49 Three phase voltage waveforms at 125KV Bus

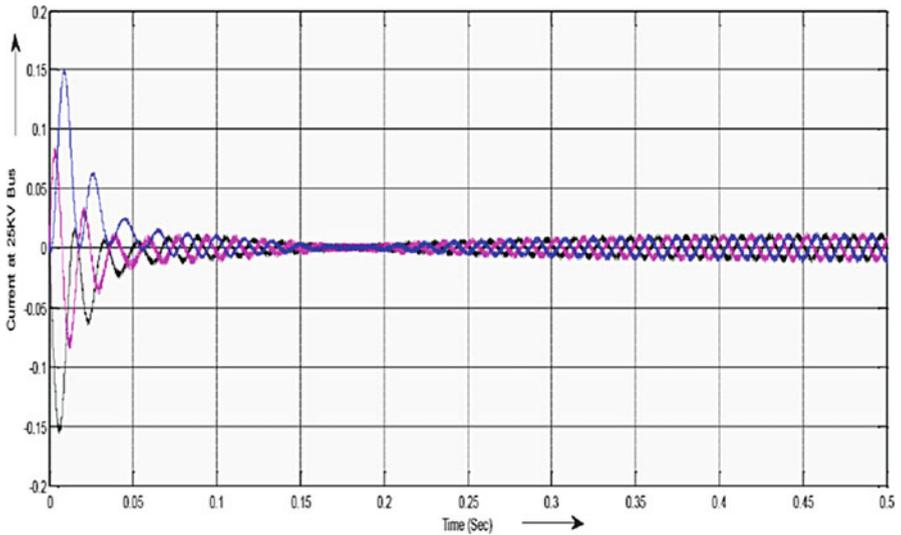


Fig. 4.50 Three phase current waveforms at 125KV Bus

4.15 Summary

Wind energy generation has become a highly researched area. A concise review of various WECS has been achieved through this chapter. Converter topologies used in combination with PMSG, DFIG, IG and SG, along with different control schemes has been described in detail. All control methods described, attempt to obtain maximum energy transfer from the wind turbine to the grid. There is a continuing effort to make converter and control schemes more efficient and cost

effective in hopes of an economically viable solution to increasing environmental issues. Wind power generation has grown at an alarming rate in the past decade and will continue to do so as power electronic technology continues to advance. In addition, development of MATLAB/SIMULINK models has aided to practical implementation of the models discussed in this chapter.

Review Questions

1. During high wind speeds, what are the approaches to regulate the power?
2. How is the energy in the wind captured?
3. What are the different types of anemometers used to measure wind?
4. How much electricity can one wind turbine generate?
5. How many turbines does it take to make one megawatt (MW)?
6. The wind doesn't blow all the time. How much can it really contribute to a utility's generating capacity?
7. What are the environmental benefits of wind power?
8. A wind turbine is being operated in a variable speed mode with an optimum load. If the wind speed doubles, what is the change in (a) output power? (b) torque? (c) rotor speed?
9. A three-phase load draws 250 kW at a power factor of 0.707 lagging from a 440-V line. In parallel with this load is a three-phase capacitor bank which draws 60 kVA. Find the magnitude of the line current and the overall power factor.
10. A 500-kW Darrieus wind turbine is equipped with a synchronous generator rated at 480 V line to line and 625 kVA at 0.8 power factor. Rated current is flowing and the current leads the voltage by 40° . What are the real and reactive powers being supplied to the load?
11. What are the economic obstacles to greater wind power usage?
12. Differentiate between back-to-back inverter with matrix inverter used for DFIG based WTG?
13. How are power quality issues addressed in WECS?
14. Develop a MATLAB/SIMULINK model for Hard switching inverter with vector control of supply side inverter DC voltage control using chopper duty ratio.
15. Develop a MATLAB/SIMULINK model for Matrix inverter for DFIG WTG.

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