

# ROLE OF POWER ELECTRONICS IN GRID INTEGRATION OF RENEWABLE ENERGY SYSTEMS

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**Abstract:** Advanced power electronic systems are deemed to be an integral part of renewable, green and efficient energy systems. Wind energy is one of the renewable means of electricity generation that is now the world's fastest growing energy source can bring new challenges when it is connected to the power grid due to the fluctuation nature of the wind and the comparatively new types of its generators. The wind energy is part of the worldwide discussion on the future of energy generation and use and consequent effects on the environment. However, this paper will introduce some of the requirements and aspects of the power electronic involved with modern wind generation systems, including modern power electronics and converters, and the issues of integrating wind turbines into power systems.

**Key words:** Power electronics, renewable energy, smart grid, green energy, power technology

## 1. Introduction

The global energy consumption has been continually increasing over the last century. Official estimates indicate a 44 percent increase in global energy consumption during the period 2006-2030. It can be said that fossil fuels (liquid, coal and natural gas) have been the primary energy source for the present day world. Sustained urbanization, industrialization, and increased penetration of electricity have led to unprecedented dependency on fossil fuels. Presently, the most important concerns regarding fossil fuels are the green house gas emissions and the irreversible depletion of natural resources. Based on the official energy statistics from the US Government, the global carbon dioxide emissions will increase by 39 percent to reach 40.4 billion metric tons from 2006 to 2030. Green house gas emissions and the related threat of global warming and depleting fossil fuel reserves have placed a lot of importance on the role of alternative and greener energy sources [1].

Many renewable energy technologies today are well developed, reliable, and cost competitive with conventional generators. The cost of renewable energy technologies is on a falling trend and is expected to fall further as demand and production increases [2]. Renewable energy power systems can be a cost effective alternative for areas with high electricity connection fees. It is also possible to connect renewable energy power systems to the grid, reducing the amount of electricity you need to purchase, or in some cases, allowing you to export surplus power into

the grid. There are many renewable energy sources (Fig. 1) such as biomass, solar, wind, mini-hydro, and tidal power.



Fig. 1. Most sources of renewable energy

The increasing number of renewable energy sources and distributed generators requires new strategies for the operation and management of the electricity grid in order to maintain or even to improve the power-supply reliability and quality. In addition, liberalization of the grids leads to new management structures, in which trading of energy and power is becoming increasingly important [3,14].

The quest for cleaner and more reliable energy sources has considerable implications to the existing power transmission and distribution system as well. Traditionally bulk of the power is generated and distributed to the large load centers via transmission lines. The transfer of power was always one way, from the utilities to the consumers [1]. Conventionally, important parameters of power delivered (frequency and voltage) are monitored and controlled by the large power generator units (usually consisting of synchronous generators).

The adoption of renewable energy is being promoted as a measure to help mitigate the problem of global warming. The generated power output from renewable energy, however, is often difficult to control, and if adopted in large quantities, may cause frequency fluctuations throughout the entire power system and local voltage fluctuations may occur [4]. The power electronics technology plays an important role in the realization of a compensating high-speed high-accuracy power supply system must be used to connect renewable energy, for which the generated output power is difficult to control, to the power system. In particular, many types of distributed power sources

generate DC power, and power electronics technology for performing power conversion is one of the most important technologies for integration of renewable energy in the electrical network.

Power electronics has developed continuously over the years and are finding increasing applications. There are many converter circuits some of which have become standard topologies and are available as modules from the manufacturers. Power electronics has evolved as a distinctive subject area in electrical engineering and it is making significant contributions towards the modern technological growth.

## 2. Modern power electronics

Power Electronics is an interdisciplinary field, which combines power, electronics and control theory for the control and conversion of electric power. It can be viewed as a branch of system engineering. Power Electronics has already found an important place in the modern technology and it is now being used in great variety of high power products. The rapid growth of the power electronics revolution has been caused due to the numerous benefits of power electronics for power control and processing of industrial applications [1]. This presentation reviews the chronological development of power electronic circuits and identifies the commonly used converters for renewable energy.

The power-electronic technology plays an important role in distributed generation and in integration of renewable energy sources into the electrical grid, and it is widely used and rapidly expanding as these applications become more integrated with the grid-based systems [3]. Power electronics has changed rapidly during the last thirty years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. For both cases higher performance is steadily given for the same area of silicon, and at the same time they are continuously reducing in price [5]. A typical illustration in figure 2 shown the power electronic system, consisting of a power converter and a control unit connect the renewable energy source in electrical network.

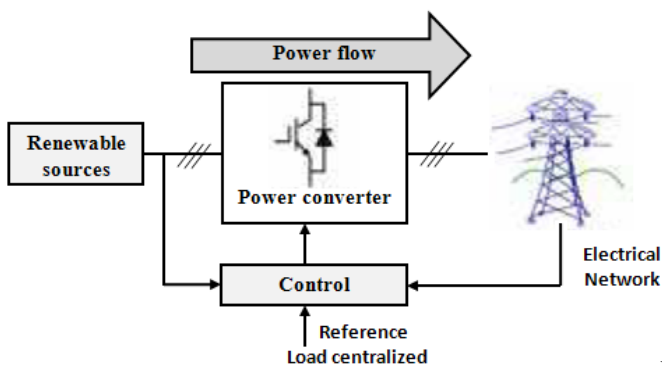


Fig. 2. Typical Renewable energy integrated in grid with power electronic system

The power converter is the interface between the generator and the grid. Typically, the power flow is uni-directional from the generator to the electrical network. Three important issues are of concern using such a system namely the reliability, the efficiency and last but not least the cost.

Currently, the cost of power semiconductor devices is decreasing 1-5% every year for the same output performance and the price for a power electronics system is also decreasing. The trend of weight, size, number of components and functions in a standard Danfoss Drives A/S frequency converter can be seen in figure 3.

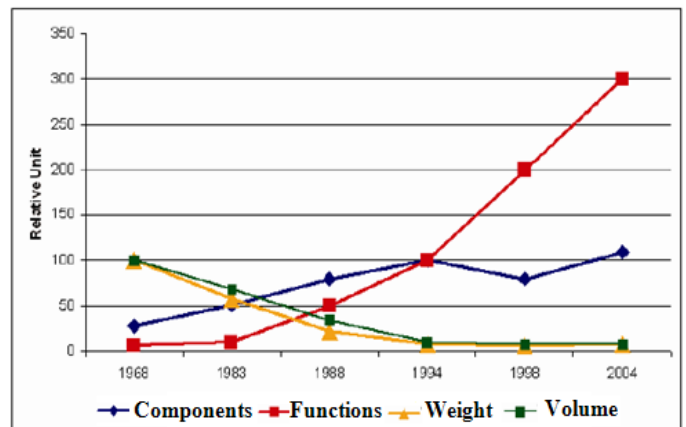


Fig. 3. Development of standard adjustable speed drives for the last decades

It clearly shows that power electronics conversion is shrinking in volume and weight. It also shows that more Integration is an important key to be competitive as well as more functions become available in such a product [5].

The key drive of this development is that the power electronic device technology is still undergoing important progress. An overview of different power device and the areas where the development is still going on is presented in figure 4.

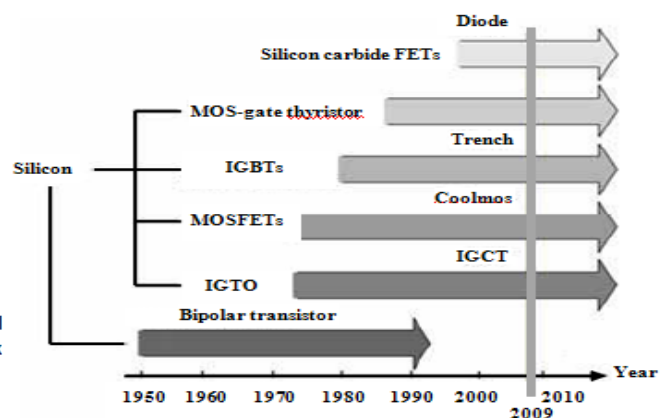


Fig. 4. Development of power semiconductor devices

Important research is going on to change the material from silicon to silicon carbide, which may dramatically increase the power density of power converters as well as their voltage capability [5, 6].

Power electronics find applications in most renewable energy systems technologies, solar and wind energy systems being the most important applications. During the last years, there is a constant effort to improve each part of a photovoltaic and wind turbine application. The efficiency of commercial photovoltaic modules now exceeds 17%, inverters have reached almost 99% European efficiency and there are new topologies found which make wind turbine systems more efficient and flexible in their operation. Due to the increased demand, each manufacturer is trying to find new concepts in order to achieve better system yield, which results in increased economic returns for the investor. Most of the systems used in such applications produce DC current, so inverters are required to convert this power to AC, which is needed in most applications and definitely for grid connection [10].

### 3. Power Electronics for WT applications

Wind generation has emerged as most promising among these generation technologies. Wind energy has matured to a level of development where it is ready to become a generally accepted utility generation technology. Wind exists almost everywhere on the earth, and in some places with considerable energy density. Wind turbines can make a major contribution to the production of renewable energy and it may experience large variation in its output power under variable weather conditions. When the oil crisis occurred in the 1970s in Europe, the emerging was awareness of the finiteness of the fossil fuel reserve and the adverse effects of burning those fuels for energy has made us look for alternatives. This awareness is hastening the deployment of eco-friendly wind generator systems. One method to overcome the above problem is to integrate Wind Generator with other reliable power sources [3, 8, 10]. The wind power is starting to play (contribute in) an important role in the electric generation in several countries.

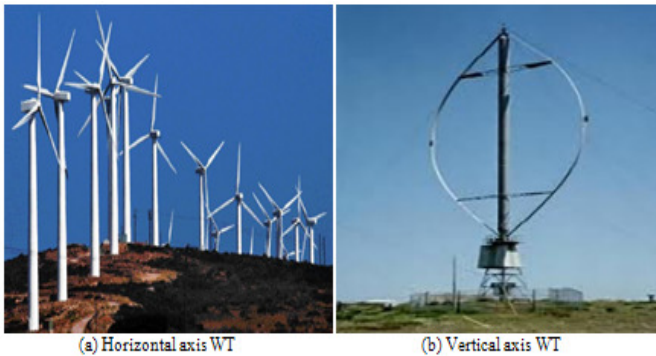


Fig. 5. Different types of wind turbines

There are two types of wind turbines (WT), the horizontal axis and the vertical axis. They are both shown on Figure 5. However, the horizontal axis wind turbines are by far the most popular design.

A large number of designs are available, ranging from 50W up to 7MW size. The number of blades can vary but the most commonly seen are with 2 or 3 blades. The grid connected wind turbines are connected to the utility grid either directly or through power electronics, feeding the produced energy to the grid. On this type of wind turbines all manufacturers are trying to increase the size and efficiency of the machines.

Wind energy is transformed into mechanical energy by means of a wind turbine whose rotation is transmitted to the generator by means of a mechanical drive train [3, 8]. A simplified relation is used between mechanical power and wind speed to avoid this complexity when the electrical behavior of the system is the main point of interest [7]. The mechanical power output ( $P_m$ ) that a turbine produces is given by:

$$P_m = \frac{1}{2} \rho \pi r^2 v^3 C_p(\lambda, \beta) \quad (1)$$

The equations for the modeling of the wind turbine are described as follows:

$$C_p(\lambda, \beta) = \frac{1}{2} (\Gamma - 0.022\beta^2 - 5.6) e^{-0.17\Gamma} \quad (2)$$

$$\lambda = \frac{w \cdot r}{V} \quad (3)$$

$$\Gamma = \frac{r \cdot (3600)}{\lambda \cdot (1609)} \quad (4)$$

Where,  $P_m$  is the extracted power from the wind,  $\rho$  is the air density [kg/m<sup>3</sup>],  $r$  is the turbine radius [m],  $v$  is the wind speed [m/s],  $\beta$  is blade pitch angle [deg],  $w$  is the rotational speed [rad/s] and  $C_p$  is the turbine power coefficient which represents the power conversion efficiency and it is a function of the ratio of the rotor tip-speed to the wind speed.

The torque coefficient and the turbine torque are expressed as follows:

$$C_t = \frac{C_p \cdot (\lambda)}{\lambda} \quad (5)$$

$$T_M = \frac{1}{2} \rho C_t(\lambda) \pi r^3 V^2 \quad (6)$$

Where,  $\lambda$  is tip speed ratio,  $T_M$  is the wind turbine output torque [Nm].

In case of varying wind speeds, fixed speed wind turbines cannot trace the optimal power extraction point  $CP_{max}$ . In variable speed wind turbines, power electronic circuitry partially or completely decouples the rotor mechanical frequency from the grid electrical frequency, enabling the variable speed operation. The

type of electric generator employed and the grid conditions dictate the requirements of the power electronic (PE) interface. Fig. 6 depicts a variable speed wind energy conversion system. The electrical generator popularly employed for partially variable speed wind energy conversion systems are doubly fed induction generators [8].

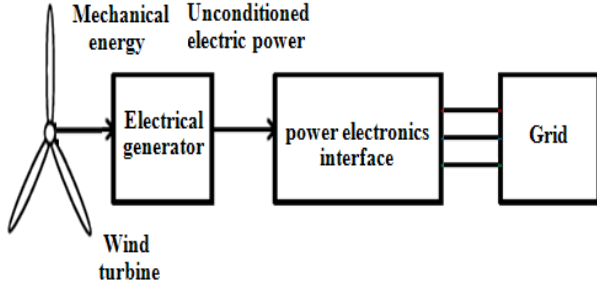


Fig. 6. Variable speed of wind energy conversion system.

Many studies have been made on the speed control part and on ways to reduce the cost of the unit. There are several types of inverters which are used on wind turbine installations, such as PWM-VSI converters and matrix converters. However the PWM-VSI converter is widely used. The back to back PWM-VSI is a bi-directional power converter consisting of two PWM-VSI inverters [10]. The topology of this inverter is shown in Figure 7.

To achieve full control of the grid current, the DC link voltage must be boosted to a level higher than the amplitude of the grid line voltage.

The power flow of the grid side converter is controlled in order to keep the DC-link voltage constant, while the control of the generator is set to suit the magnetization demand and the reference speed.

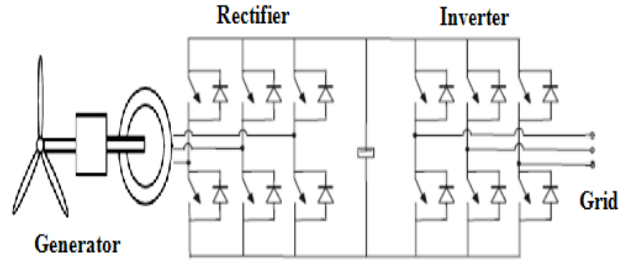


Fig. 7. Topology of wind power generation system using Three-Phase Boost Rectifier.

The voltage and torque equations of a no salient permanent magnet generator in the rotor reference frame can be written as follows:

$$P \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{E_s}{L_s} & \omega_r \\ -\omega_r & -\frac{E_s}{L_s} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_s} \begin{bmatrix} -V_d \\ -V_q + \omega_r \lambda'_m \end{bmatrix} \quad (7)$$

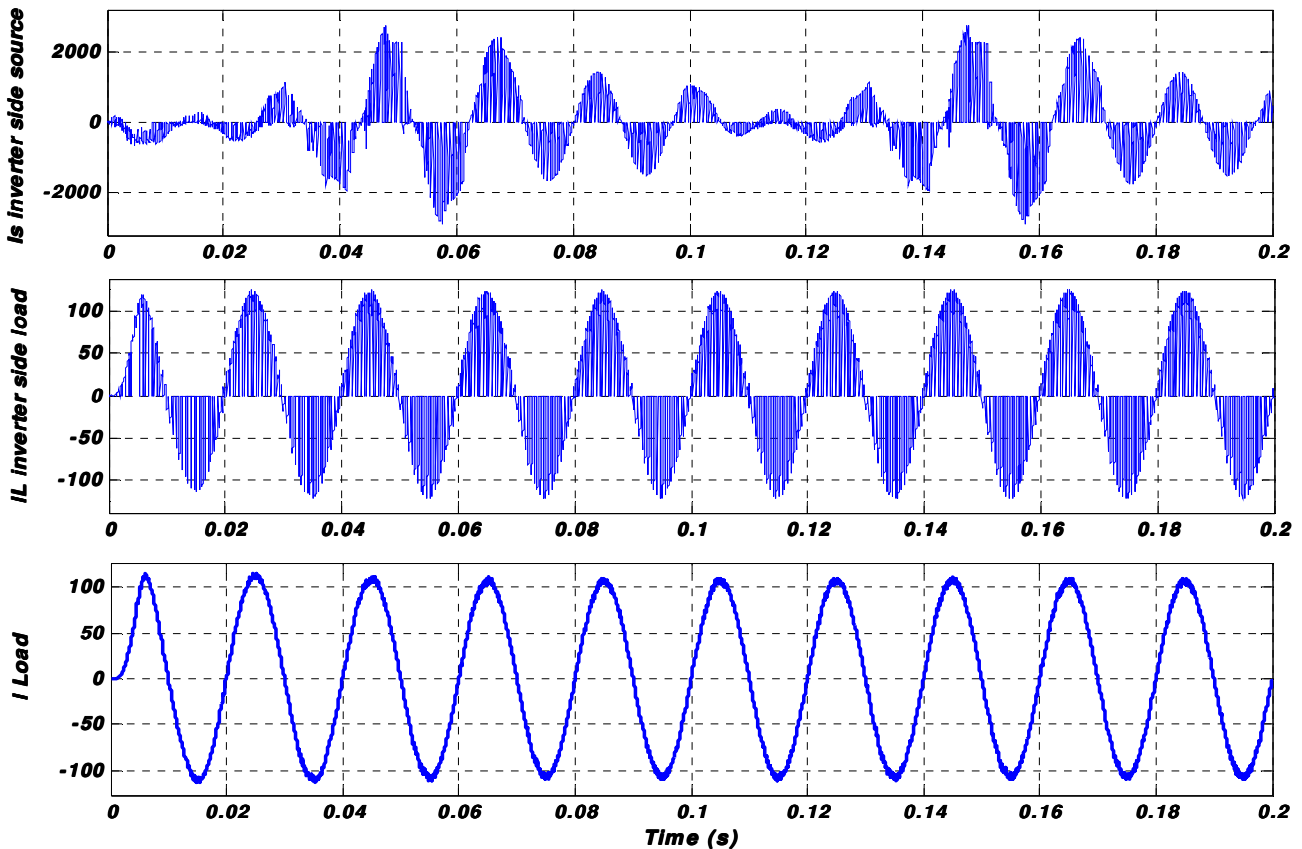


Fig. 8. The PWM-VSI converter steady state



$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = A \cdot \frac{1}{L_s} \begin{bmatrix} -V_d \\ -V_q + \omega_r \lambda'_m \end{bmatrix} \quad (8)$$

$$\text{Where: } A = \left( \begin{bmatrix} P \\ Q \end{bmatrix} - \begin{bmatrix} -\frac{R_s}{L_s} & \omega_r \\ -\omega_r & -\frac{R_s}{L_s} \end{bmatrix} \right)^{-1} \quad (9)$$

$$\text{And: } T_s = \left( \frac{3}{2} \right) \left( \frac{P}{2} \right) i_q \lambda'_m \quad (10)$$

The inclusion of a boost inductance in the dc-link circuit increases the component count, but a positive effect is that the boost inductance reduces the demands of the grid side harmonic filter, and offers some protection of the converter against abnormal conditions on the grid. One of the drawbacks of the back-to-back circuit topology is the switching losses. Every commutation in both the grid inverter and the generator inverter between the upper and lower dc-link branch is associated with hard switching and natural communication.

Since the back-to-back topology consists of two inverters, the switching losses might be even more pronounced. The high switching speed to the grid may also require extra EMI-filters, as well [ 8]. Controlled rectifiers offer distinct advantages over typically used uncontrolled diode, or phase-controlled thyristor rectifiers in ac-dc-ac converters for variable speed drive applications. These advantages include unity power factor and greatly reduced input line current harmonic distortion due to the nearly sinusoidal input line current attainable with controlled rectifiers. There is a duty cycle factor that can be adjusted to regulate the ratio of output to input voltage, up to a maximum value. Finally, the output is passed through a filter to eliminate high frequency harmonics [12].

The PWM-VSI inverters can efficiently convert the three phase electrical output of the wind turbine to the requested electrical grid characteristics for a proper connection. They use an array of controlled bidirectional switches to convert AC power from one frequency to another. They produce a variable output voltage with unrestricted frequency. The general operation of the inverter is to convert the AC current of the wind turbine to the AC current that the utility grid demands. The result of the conversion is shown on Figure 8.

In PWM type rectifiers, when the switching frequency increases, the power loss becomes high during the deactivation of the switching element and the commutation diode. This case limits the usage of an IGBT with 50 kHz as the switching element.

A common application of the static converters is the

switching to the grid of wind turbine equipped with induction generators (soft starting). Direct connection of the wind turbine to the grid causes high inrush currents which are undesirable especially for weak grids, also severe torque pulsations and damage to the gearbox. For this reason the soft starter is used which regulates the applied stator voltages.

Wind Energy Conversion Systems are playing an increasingly important role in electricity generation. According to the way they are connected to the electricity grid, the wind energy systems can be classified as systems without power electronics, systems with partially rated power electronics and systems with full scale power electronics. Systems without power electronics use induction generators and they require reactive power compensation to operate. This reactive power can be supplied by the grid, by capacitor banks or by power electronics based reactive current injection. Systems with full scale power electronic converter use a conventional or permanent magnet synchronous generator or induction generator [9]. This design allows the wind turbine to operate in variable speed mode allowing more energy of the wind to be captured and control of torque to smooth it during abnormal operation.

#### 4. Conclusion

In this paper the main trends of the power electronics used in applications of the wind turbine technology are presented. Due to the high demand for renewable energy sources applications, there is a continuing research for improving the total efficiency of these applications and by improving each electronic part included. The development of modern power electronics has been briefly reviewed, showing that the wind turbine behavior/performance is very much improved by using power electronics. Also it can be concluded the power scaling of wind turbines is important in order to be able to reduce the energy cost.

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