A Review on Power Electronics in Renewable Source of Energy

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Abstract: ***With Renewable Energy (RE) production becoming the talk of the globe due to the concern about the environment and the end of tradition fuels, India has aligned itself with the changing tide with a herculean target of 450 GW by 2030. Owing to the large scale penetration of RE, the role of power electronics becomes more important. Power Electronics is increasingly becoming popular in the applications of sustainable energy sources such as Solar, Wind due to its vast characteristics over conventional electronic components. In this paper an overview of some of the most emerging renewable energy sources like solar energy, wind energy and hydro power are presented along with a qualitative description of the role of power electronics in solar, wind, and hydro power systems.***

Keywords: Renewable energy systems, Power electronics, Solar energy, Wind energy, Hydro power

1. Introduction

In the last decade, renewable energy systems have experienced the largest growths in percentage with more than 30% per year, similar to the growth of coal and lignite energy systems, because of the exhaustion of natural resources and the increasing pollution levels caused by the use of fossil fuels and nuclear energy [1]. The ever-increasing demand for energy can lead to problems for power distributors, such as grid instability and outages [2]. The importance of producing more energy and the interest in clean technologies has provoked increased development of renewable energy systems. One driving force in Europe was initiated in March 2007, when EU Heads of State adopted a binding target of 20 % of energy generated by renewable sources by 2020.

According to the GWEC (Global World Energy Council) [4], the cumulative worldwide installed wind power by the end of 2011 was 237.7GW. In 2011, the wind power grew by about 6% compared to 2010, and the 40.6 GW wind power brought on line. The China (26.2 %), USA (19.7%), and Germany (12.2%) comprise the large proportion of world cumulative wind power capacity.

The world-wide cumulative and annual installed photovoltaic power in 2011, according to the EPIA, was 69.68 GW and 29.7 GW, respectively [4]. It can produce 85 TWh of electricity every year and this energy volume is sufficient to cover the annual power supply needs of over 20 million households. In terms of cumulative installed capacity, Europe still leads the way with more than 51 GW installed as of 2011. Next are Japan (5 GW) and the USA (4.4 GW), and then China (3.1 GW) is followed. The overall PV penetration is quite low but the EPIA estimated it could be as high as 12 % in 2020.

The increasing use of renewable energy systems requires new strategies for the operation and management of the electricity grid in order to maintain or to improve power-supply reliability and quality. Additionally, regulation of the grid leads to new management structures in which trading of energy and power is becoming increasingly important. Power electronics, the technology to convert electric power efficiently from one stage to another, is essential for distributed renewable energy systems to achieve high efficiency and performance. The power electronics field has grown during the last decades for two main reasons. Firstly, the development of fast semiconductor switches that are capable of switching quickly and handling high power. Secondly, the production of microcontrollers that can implement advanced and complex control algorithms. These factors have led to the development of cost effective and grid-friendly power converters [3].

1.1 Solar Energy

Solar energy is the most readily available and free source of energy since prehistoric times. It is estimated that solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year. India receives solar energy in the region of 5 to 7 kWh/m2 for 300 to 330 days in a year. This energy is sufficient to set up 20 MW solar power plant per square kilometer land area. While the world's energy demand is steadily increasing, PV power supply to the utility grid is gaining more and more visibility. With reductions in system costs, such as for PV modules, inverters, cables, fittings and man power, the PV technology has the potential to become one of the main renewable energy sources for future electricity supply [9].Without moving parts to break and replace, after the initial costs of installing the solar panels, maintenance and repair costs are very reasonable. It may be noted that photovoltaic solar panels are the only source considered with the potential to satisfy existing demand.

1.2 Wind Energy

The wind is a free, clean, and renewable energy source on our planet. It has served mankind for centuries to pump water, grind grain, and move ships. With the discovery of electricity and development of electric power, wind energy found new applications in human society in the form of providing clean and inexhaustible electric power in a wide range of scales and capacities. Nowadays, wind powered generation operates at variety of sizes between small residential and utility scales. Modern utility-scale wind power is the fastest growing energy sector in the world. At the end of 2009, worldwide nameplate capacity of wind power generators was 159.2 GW producing about 2% of worldwide electricity usage [6].Despite this growth, the technology used in wind turbines has not yet coalesced around one particular design. A wide variety of designs, especially for power conversion, are in use and on the drawing board. This makes wind turbines and WPPs an interesting study from the power conversion point of view. The upward trend in wind turbine installation worldwide is shown in Fig. 1.2.1

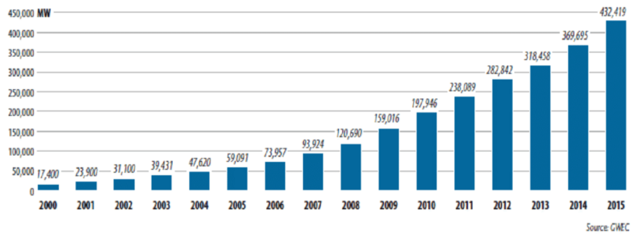

Figure 1.2.1: Global cumulative installed wind capacity

1.3 Hydro Power

Hydropower is a major energy source among the renewable energy sources. According to "BP Statistical Review of World Energy, June 2013", 16.34 percentage of global power generation acquire from hydropower [24].

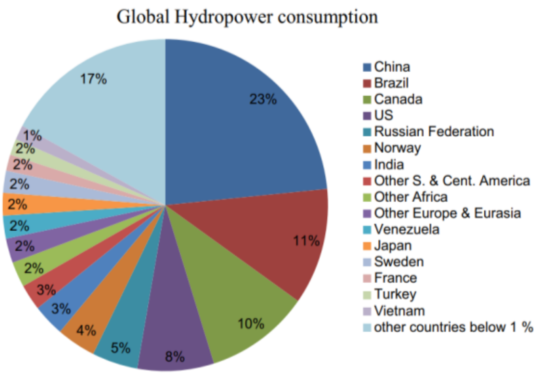

Figure 1.3.1: Global hydropower consumption.
Source: BP Statistical Review of World Energy, June 2013

According to the law of energy conservation, the hydroelectric energy systems are extracting electricity from water. Globally, 3673.1 Terawatt-hours of energy are consumed from hydropower in various countries as shown in Fig. 1.3.1. [25] It is a clean and renewable energy source. Most countries give priority to development of hydropower considering the economic, technical and environmental benefits of its. It is important to develop hydropower to overcome the energy crisis and environmental pollution resulting from the rapid economic growth of China and other countries in the 21st century [7]. Hydropower is generated when mechanical energy of flowing water force it through piping called a penstock, which then turns a generator in order to generate electricity. Water power also consists of wave and tidal energy, which are both in the infant stage of research [8]. Hydropower has much potential over other electrical power generating sources such as a high level of reliability, proven technology, high efficiency, less operating and maintenance costs, and easily adjustable load variations. In general, many hydropower plants are located in conjunction with reservoirs, which provide water, flood control, and recreation benefits for the community. Additionally, hydropower does not produce waste products that cause acid rain, and greenhouse gases.

2. Role of Power Electronics

Power Electronics (PE) deals with conversion and control of electrical power with the help of electronic switching devices. One advantage of the switching mode of power conversion is its high efficiency, which can be 96% to 99% [5]. High efficiency saves electricity. In addition, PE devices are more easily cooled than analog or digital electronics devices. PE is often defined as a hybrid technology that involves the disciplines of power and electronics.

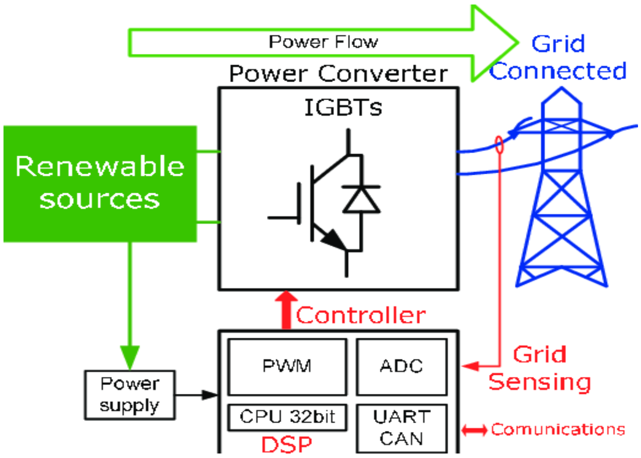

Figure 2.1: Power electronics grid connected system with the grid, load/source, power converter and controller

The power converter is an interface between the load/generator and the grid. The power may flow in both directions depending on the topology and applications. There are three important issues are of concern using such a system: reliability, efficiency and cost.

2.1 In Solar Energy/Photovoltaic System

Solar Energy systems are of two types: active and passive. So, for PE point of view we discuss here on photovoltaic or (PV) solar cell. PV technology involves converting solar energy directly into electrical energy by means of a solar cell. A solar cell is typically made of semiconductor materials such as crystalline silicon and absorbs sunlight and produces electricity through a process called the PV effect. The efficiency of a solar cell is determined by its ability to convert available sunlight into usable electrical energy and is typically around 10%–15%. Therefore, toproduce significant amount of electrical energy, the solar cells must have large surface areas. Individual solar cells are usually manufactured and combined into modules that consist of 36 to 72 cells, depending on the output voltage and current of the module. The modules vary in size by manufacturer, but are typically between 0.5 to 1 m^2 and generate around 100 W/m^2 of energy during peak solar conditions for a 10% efficient module [10].

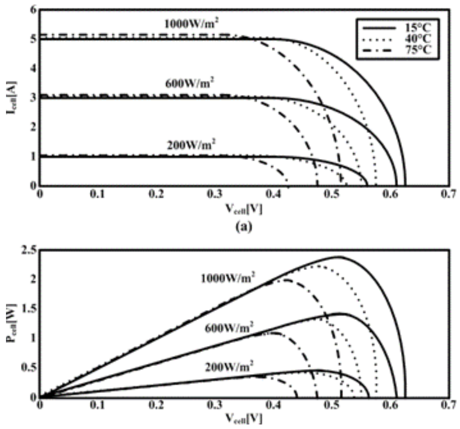

Figure 2.1.1: Characteristics of PV Cell
(A) V-I curve
(B) V-P curve

Additionally, the modules can also be grouped together in following section to form arrays with unique voltage and current characteristics.

2.1.1 PV System Configuration

PV modules are connected together into arrays to produce large amounts of electricity. The array is then connected with system components such as inverters to convert the DC power produced by the arrays to AC electricity for consumer use. The inverter for PV systems performs many functions. It converts the generated DC power into AC power compatible with the utility. It also contains the protective functions that monitor grid connections and the PV source and can isolate the PV array if grid problems occur. The inverter monitors the terminal conditions of the PV module(s) and contains the MPPT for maximizing the energy capture. The MPPT maintains the PV array operation at the highest possible efficiency, over a wide range of input conditions that can vary due to the daily (morning-noon-evening) and seasonal (winter-summer) variations [11].

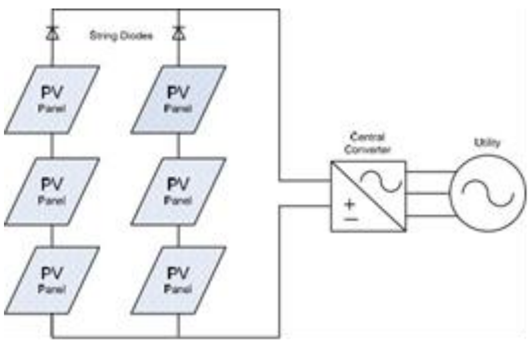

Figure 2.1.2: Centralised PV configuration

Centralised PV configuration has been the most common type of PV installation in the past. PV modules are connected in series and/or parallel and connected to a centralised DC-AC converter. The primary advantage of this design is the fact that if the inverter is the most costly part in the installed PV system, this system has the lowest cost design because of the presence of only one inverter. The primary disadvantage of this configuration is that the power losses can be high due to the mismatch between the PV modules and the presence of string diodes [11]. Another disadvantage is that this configuration has a single point failure at the inverter; therefore, it has less reliability [12].

Other configurations of PV systems are:

- Module inverter configuration: Here, each PV module is connected to the separate inverters and then these inverters are paralleled which gives AC as the resultant output.
- String inverter configuration: Here, each set of PV modules connected in series is connected to a string inverter.
- Multi-string inverter configuration: This is a modified form of the string inverter in which string inverters are replaced by DC-DC converters.

In an AC-module, PV module has its own inverter. Advantages of this type of system are that it is easy to add modules because each module has its own DC-AC inverter and the connection to the utility is made by connecting the inverter AC field wirings together. There is also an overall improvement in system reliability because there is no single-point failure for the system [11] [12]. It is a highly flexible and configurable design topology; however, prior examples of this configuration are still more costly than the conventional PV systems because of the increased number of inverters. The power loss of the system is lowered due to the reduced mismatch among the modules, but the constant losses in the inverter may be the same as for the string inverter. The PEs are typically mounted outside together with the PV panel and need to be designed to operate in an outdoor environment.

The role of PE is mainly two-fold:

- To interconnect the individual solar panels – two solar panels cannot be identical hence a dc-dc converter interfacing the two will help maintain the required current and voltage, and with regulation improve the overall efficiency.
- To interface the DC output of the PV system to the grid or the load: This includes the DC-DC-AC and DC-AC-AC conversion. The topologies considered for fuel-cell system grid interconnection is depended on the grid interconnection of PV based system.

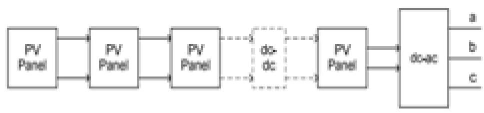

Figure 2.1.3: PV system with dc-dc module

2.2 In Wind Energy

The first wind powered electricity was produced by a machine built by Charles F. Brush in Cleveland, Ohio in 1888. It had a rated power of 12kW(DC). Direct current electricity production continued in the form of small-scale, stand-alone (not connected to a grid) systems until the 1930's when the first large scale AC turbine was constructed in the USA. Modern wind turbine generators are highly sophisticated machines, taking full advantage of state-of-the- art technology, led by improvements in aerodynamic and structural design, materials technology and mechanical, electrical power and control engineering and capable of producing several megawatts of electricity. Large wind farms or wind power stations have become a common sight in many countries on the globe. In fact, the grid connected wind capacity is undergoing the fastest rate of growth of any form of electricity generation.

Wind energy has the biggest share in the renewable energy sector [13], [14]. Over the past 20 years, grid connected wind capacity has more than doubled and the cost of power generated from wind energy based systems has reduced to one-sixth of the corresponding value in the early 1980s [14].

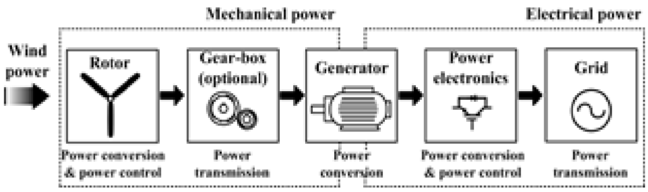

Figure 2.2.2: Basic power conversion principle in a wind power system

The necessary features associated with a wind energy conversion system are:

- Available wind energy
- Type of wind turbine employed
- Type of electric generator and power electronic circuitry which are employed for interfacing with the grid.

In spite of the fact that, wind power suffers from disadvantages such as, fluctuating nature, poor power quality, and lack of active and reactive power control, there is substantial growth in the wind based electricity generation. This is due to the fact that; today's wind power generation systems could overcome the above disadvantages due to PE. In this way PE is playing vital role in the development and improvement in the wind power generation systems.

There are number of applications of PE in the field of wind power generation systems. However, mainly, PE is used for power conditioning and control in wind power generation systems.

Based on the aerodynamic principle utilized, wind turbines are classified into drag based and lift based turbines. Based on the mechanical structure, they are classified into horizontal axis and vertical axis wind turbines. With respect to the rotation of the rotor, wind turbines are classified into fixed speed and variable speed turbines. Presently the focus is on horizontal axis, lift based variable speed wind turbines [9], [14].

Though the fixed speed wind turbines are simple to operate, reliable and robust, the speed of the rotor is fixed by the grid frequency. As result, they cannot provide the optimal aerodynamic efficiency point and also cannot trace the optimal power extraction point in case of varying wind speeds.

In variable speed wind turbines, power electronic circuitry partially or completely decouples the rotor mechanical frequency from the grid electrical frequency which enables the variable speed operation. The type of electric generator employed and the grid conditions dictate the requirements of the power electronic interface. The electrical generator popularly employed for partially variable speed wind energy conversion systems are doubly fed induction generators [16].

This method is advantageous as the power converter has to handle a fraction ~ 25% - 50 % of the total power of the system [16]. The power converter system makes use of a rotor side AC- DC converter, a DC link capacitor, and a DC-AC inverter connected to the grid.

The rotor side converter controls the rotor's speed and torque whereas the stator side convertor maintains a constant voltage across the DC link capacitor, irrespective of the magnitude of the rotor power. This method is more efficient than the fixed speed system; but it does not reflect the possible optimal efficiency.

By employing a full scale AC-AC converter system the wind turbine can be completely decoupled from the grid and enables a wider range of optimal operation. From the turbine the variable frequency AC is fed to the three phase AC-DC-AC converter. The generator side AC-DC converter is controlled to obtain a predetermined value at the end of the DC link capacitor. Using a six-switch DC-AC inverter the dc voltage is then inverted. Since Inversion is buck operation hence the turbine side AC-DC converter has to provide sufficient voltage level to integrate with the grid. For additional boosting of the voltage, an additional DC-DC boost converter can be employed. This increases the overall cost and complexity. To overcome the shortcomings a Z source inverter based conversion system can be employed [17].

Z source inverter is a relatively new topology. It has the following advantages over the conventional voltage source/current source inverters:

- Buck boost ability
- Inherent short circuit protection due to its configuration
- Improved EMI as dead bands are not needed

2.3 In Hydro Energy

These hydroelectric energy systems are classified according to the accessibility of sources. The traditional hydroelectric plants are capable to produce power up to few GW. Small hydro plants are also available without dam or water storage. According to the plant rating, the small hydro plants are further classified into mini (rated up to 1000 kW), micro (rated up to 100 kW) and Pico (rated up to 5 kW). Pumped storage plant stores electrical energy in the form of potential energy by raising the water to the highest level and utilizes during demand period. This generated power is utilized by the consumers directly or once after synchronizing with the grid, which depends upon their location and rating. In the above process, the voltage and frequency should maintain constant and it can be achieved by controlling the generating machines through PE converters in various aspects like excitation control, dump load control, etc., In pumped storage plants, same machine is operated for both pumping and generation at variable speed to provide more efficiency.

This effective operation of the machine can attain through PE converter adapted with different control technique. Hydroelectric generation enabled with the advanced power electronics and proper control strategies possess superior performance in their technical characteristics like voltage and frequency regulation, active and reactive power control, short circuit control, fault ride through, etc., [18].

Therefore, above all generation, conversion and transmission controls would fulfill only with the help of PE technology.

Large-scale hydropower plants are normally used for generation of electricity. The basic schematic diagram for hydroelectric power generation system is shown in Fig-2.3.2.

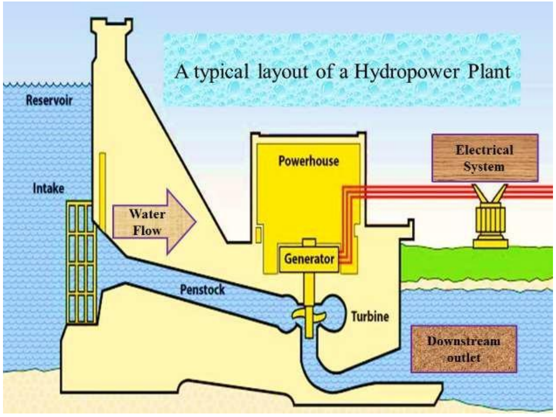

Figure 2.3.2: A schematic view of a hydropower plant [25]

To produce electricity, output shaft of the turbine is coupled to the generator. The generator is principally made up of electromagnetic rotor that is located inside a cylinder (known as stator) containing a winding of electric wires (known as conductor). During operation, the rotor in the stator turns and generates electricity by the principle of electromagnetic induction.

The generated electricity is transmitted to load points through a transmission system that consists of components such as switch yard, transformers, and transmission lines. For a well-planned and well-operated hydropower project, hydropower electricity generation technology is stated as one of the cheapest in terms of electricity generation costs [19]. It may be because the fuel (falling water) is available without direct costs associated with fuel purchase [20].

The relatively low cost of electricity generation may be one of the reasons why hydroelectricity is recommended as base load for most of the power utility companies. Hydroelectric power plants are able to respond to power demand fluctuations much faster than other electricity generation systems such as thermal electric power stations [21], [22].

This makes hydropower a flexible energy conversion technology and also explains the reason of use of hydroelectric power stations for peaking purposes. Further, hydroelectric power technology converts directly mechanical work into electricity, both of which are high forms of energy. Therefore, it is called as a high efficient energy conversion process The energy conversion system efficiency for a well operated hydroelectric power plant can be around 85%, while the system efficiencies for thermal-electric plants are less than 50% [23].

3. Conclusion

With the very rapid consumption of fossil fuels and the thought to protect our environment it has become the need of the hour to rely more on Renewable Energy production.
Renewable Energy can contribute to local economy by creating create jobs and opening new markets as well as it can be used as a hedge against price fluctuations of fossil fuels. Power Electronics is concerned with the efficient conversion and control of electrical power and the next focus point now due to their inherent characteristics of automation. So some of the uses of PE technologies have been listed in this paper.

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