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A Review on Power Electronics in Renewable Energy Systems

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Abstract - *The global energy consumption is still rising and there is a demand to double the power capacity within 20 years. This rapid increase in global energy consumption and the impact of greenhouse gas emissions has accelerated the transition towards greener energy sources. For this reason there is growing interest in the renewable energy around the world. Today, the world is very much focused on renewable energy systems (RESs) and their improvements due to the concern about the environment and the end of tradition fuels. That is why it is interesting to have the knowledge and the understanding of the RESs and this study aims at the same. 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/photovoltaic, 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.*

***Key Words*: Renewable energy systems, Power electronics, Solar energy, Wind energy, Hydro power**

1. INTRODUCTION

Power electronics deals with the conversion and control of electrical power in different energy systems. Last few years, power electronics are increasingly growing field due to well developed, more reliable and cost effective components in comparison with conventional electronic components. Increasing demand and production makes power electronics Components (PEC) cheaper. In addition, for extracting power from sustainable energy sources such as Solar, Wind, and Hydro, power electronics is widely known as efficient technology. Since, primary energy sources in the world are mostly from fossil fuels. As a result, emission of carbon dioxide (CO2) increases rapidly and it is seen that emitting CO2 relating to world energy augments from 32.3 billion metric tons (bmts) in 2012 to 35.6 billion metric tons (bmts) in 2020 and in 2040, it would be to 43.2 billion metric tons (bmts)[1].

The sources of electricity production such as coal, oil, and natural gas have a contribution to one-third of global greenhouse gas emissions. It is essential to raise the standard of living by providing cleaner and more reliable electricity [2].

Renewable Energy is defined as the type of energy the sources of which can be constantly replenished or the sources are limitless [3], [4]. It is derives directly from natural sources such as the sun, wind, rain, tides of ocean, biomass and geothermal resources from heat generated deep within the earth. It also reduces emissions of conventional air pollutants, such as sulfur dioxide, that result from fossil fuel combustion. Though there are various types of renewable energy sources, the paper is mainly focused on the solar, wind and hydro power systems.

1.1 Solar Energy

Solar energy is a true and the most abundant renewable resource on our planet [5]. It is pollution free, does not create greenhouse gases, such as oil based energy does, nor it creates waste that must be stored, such as nuclear energy. It is also far quieter to create and harness, drastically reducing the noise pollution required and converts energy to a useful form. Residential size solar energy systems also have a very little impact on the surrounding environment compare to other renewable energy sources such as hydro and wind electric power systems. 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 [6], [7]. Photovoltaic cell offers clean, noise- free, emission-less energy conversion, without involving any active mechanical system [8].

1.2 Wind Energy

Wind is free, abundant, and sustainable energy that has the biggest share in the renewable energy sector [9], [10]. The electricity generated by using wind power is clean, non-polluting because wind power plants do not emit any air pollutants. The operation cost of them is almost zero if the turbine is once built [1]. A wind turbine converts the kinetic energy (motion) of wind into mechanical energy that is used to generate electricity; which is fed through a generator, converted a second time into electrical energy, and then fed into the grid to be transmitted to a power station.

Wind energy has many advantages such as reduces greenhouse gas emissions by using turbines, which produce energy and electricity when moved by the wind, and can reduce electricity costs. All the turbines need wind in order to function, which is just natural air, and air is everywhere.

Wind power is an option that works in accord with nature to promote social progress by rejecting the gloomy forecast of a world that has exhausted oils and fuels [11].

Wind power has been harnessed for thousands of years, but only in the last decade has it generated significant amounts of commercial energy. The irregular and unpredictable nature of the wind power would limit its contribution to any region, unless large-scale energy storage or intercontinental transmission is available. Environmental constrains, such as the presence of forests and protected areas, further limit the location of the wind turbines, as would simple public acceptance [12].

1.3 Hydro Power

Hydropower 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 [13].

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 [14].

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.

Although there is some disadvantages including high initial costs of facilities; precipitation dependency (no control over amount of water available); variations in stream regimens (can affect fish, plants, and wildlife by varying stream levels, patterns of flow, and temperature); inundation of land and wildlife habitat (creation of reservoir); and displacement of people living in the reservoir area [15].

2. ROLE OF POWER ELECTRONICS

During the last thirty years Power electronics has changed rapidly and their applications have been increasing which is 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 as well as they are continuously reducing in price. A typical power electronic system consists of a power converter, a load/source and a control unit as shown in Fig-1

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 [16].

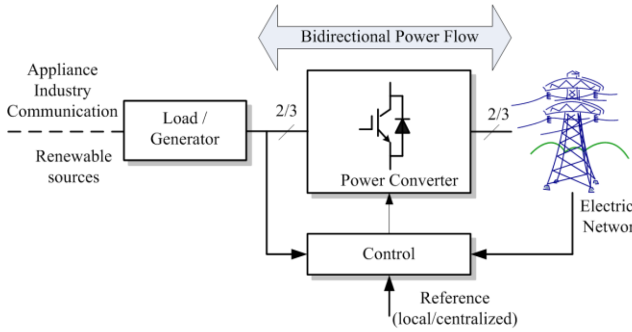


Fig -1: Power electronic system with the grid, load/source, power converter and control [16].

2.1 In Solar Energy System (SES)

Solar Energy Systems are mainly divided into passive and active systems which are further classified into different types [17], [18]. From power electronics perspective, the main focus will be on the photovoltaic (PV) solar cell, which is a type of active SES.

Photovoltaic energy systems consist of arrays of solar cells which produce electricity from irradiated light. The yield of the PV systems is primarily depending on the intensity and duration of illumination [8].

The PV cell is an all-electrical device, which produces electrical power when exposed to sunlight and is connected to a suitable load [16]. The designed SES includes PV cells as the main source of energy, electric storage (battery), maximum power point tracking (MPPT) and protection circuitries. An MPPT algorithm based on measuring the slope of the PV power-voltage curves is presented that can be implemented with simple analog electronic circuits [19].

Without any moving parts inside the PV module, the tear-and-wear is very low and thus it has a high life time (> 20 years) [8]. To enhance the efficiency of the solar cell, a lot of work is being done which focus is mainly on electro-physics and materials domain.

A certain number of solar cells are connected in series to form PV panels. Since the cells are connected in series to build up the terminal voltage, the current flowing through the panel is decided by the weakest solar cell [8], [20]. Parallel connection of the cells would solve the low current issue but it produces very low (< 5 V). To enhance the power handling capacity, these panels are further connected in series. To improve the efficiency and reliability of the system the entire PV system can be seen as a network of small dc energy sources with power electronics conditioning interfaces employed.

Here the role of power electronics is mainly:

I. To interconnect the individual solar panels: Two solar panels cannot be identical; therefore a DC-DC converter interfacing the two will help maintain the required current and voltage, and with regulation improve the overall efficiency. For this purpose several non-isolated DC-DC converters have been employed. Buck, Boost, Buck-Boost, and Cuk topologies with suitable modifications can be employed for this purpose [20].

II. 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 which includes the usage of the Z- source inverter.

In Fig-2, PV modules are connected in series and/or in parallel and then connected to a centralized DC/AC converter. There are also string-array PV systems in which a series of PV panels are connected in the form of a single string and connected to the grid with one inverter per string. PV strings have a DC-DC converter plus and inverter offering the possibility of maximum power point tracking for maximizing the power production of the PV system [19].

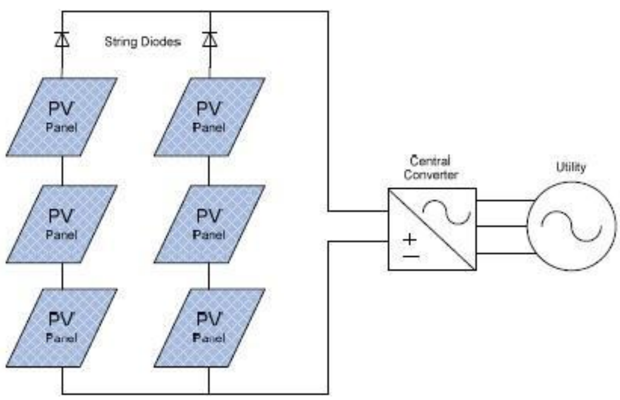


Fig-2: Photovoltaic configuration with a centralized power electronic coupling

In wind and hydroelectric energy power generation systems, the energies are converted to AC by generators but in SES photovoltaic panels convert solar energy to DC that is why the discussion of DC-DC and DC-AC conversion is significant in PV systems. Various types of useful inverters are described below [21]:

A. String Inverter: Here, each set of PV modules connected in series is connected to a string inverter. Further, the string inverters are connected in a parallel configuration and resultant output is obtained in the form of AC.

B. Module Inverter: Here, each PV module is connected to the separate inverters and then these inverters are paralleled which gives AC as the resultant output.

C. Multi-String Inverter: This is a modified form of the string inverter in which string inverters are replaced by DC-DC converters. After connecting these in parallel combination, an inverter is connected before the resultant output.

2.2 In Wind Energy System

The basic principle of wind turbine is the opposite of a Fan where electricity is used to make wind. On the other hand, wind is used to generate electricity [1]. Here by the mechanical power this is wind through the wind turbine blades converted to the electrical power and used for the other purpose. As multi-pole generator systems are also can be used gear box are optional here. A power converter can be inserted between the grid and the generator. The electrical output of the system can either be AC or DC. At the end a power converter will be used as interface to the grid. High frequency direct AC-AC converter and Matrix converters have been proposed as coupling of wind energy conversion systems to the grid and wind energy generation systems respectively. In addition, the presence of power converters in wind turbines also provides a high potential control abilities for both large modern wind turbines and wind farms to fulfill the high technical demands imposed by the grid operators such as: controllable active and reactive power (frequency and voltage control); quick response under transient and dynamic power system situations, influence on network stability and improved power quality [19].

Wind turbines capture power from the wind by means of aerodynamically designed blades which is then convert it to rotating mechanical power. The number of blades is normally three. As the blade tip-speed should be lower than half the speed of sound the rotational speed will decrease as the radius of the blade increases. The most weight efficient way to convert the low speed, high-torque power to electrical power is to use a gear-box and a standard fixed speed generator as illustrated in Fig-3 [16].

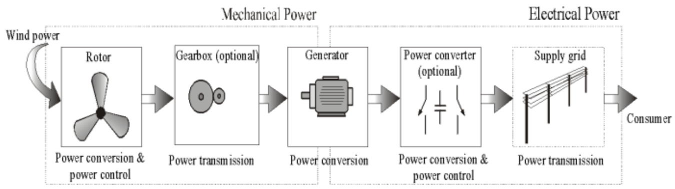


Fig -3: Converting wind power to electrical power in a wind turbine [22].

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.

Wind energy includes wind speeds, air pressure, atmospheric temperature, earth surface temperature etc., are highly inter- linked parameters. Due to the inherent complexity, it is difficult to obtain an exact physics based prediction methodology for wind intensity/sustainability. However, distribution based models have been proposed, and employed to predict the intensity/sustainability of wind energy conversion systems [23].

Based on the aerodynamic principle, wind turbines are classified as: drag based and lift based turbines. Based on the mechanical structure, they are classified as: 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 [8], [10]. Power electronic circuits play a significant role in variable speed based wind energy conversion systems.

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 [24].

This method is advantageous as the power converter has to handle a fraction ~ 25% - 50 % of the total power of the system [24]. 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 maintain 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.

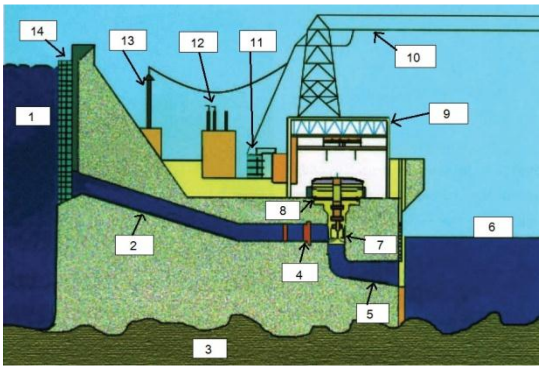
By employing a full scale AC-AC converter system the wind turbine can be completely decoupled from the grid and enables a wider range of optimal operation. From the turbine the variable frequency AC is fed to the three phase AC-DC-AC converter. The generator side AC-DC converter is controlled to obtain 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 [25]. 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

Z-source inverter based wind power conversion systems are comparatively new, although the researches are investigating its applicability.

2.3 In Hydro Power

Hydropower is the rate at which hydraulic energy is extracted from a specific amount of falling water as a result of its velocity and position. The rate of change of angular momentum of falling water and its pressure on the turbine blade surfaces creates a differential force on the turbine runner thereby causing rotary motion. As a working fluid, water in a hydropower system is not consumed; which is thus available for other uses. Hydropower can be used to power machinery or electricity generation or both at the same time. The mechanical application is mainly applicable for small-scale hydropower plants where the power generated is used to power small-scale mechanical tools and machines for pressing, milling, grinding, and sawing applications. In some instances, the output shaft from the small-scale hydropower turbine is extended in both the directions to provide space for both mechanical power provision and electricity generation [26].



(1) Reservoir (2) Penstock (3) Bed rock (4) Valve (5) Draft tube (6) Tailrace water (7) Turbine (8) Generator (9) Power house (10) Transmission lines (11) Transformer (12) Insulators (13) Transmission tower (14) Trash rack

Fig-4: A schematic view of a hydropower station along its basic parts, source: International Energy Agency [27].

Large-scale hydropower plants are normally used for generation of electricity. The basic schematic diagram for hydroelectric power generation system is shown in Fig-4. 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 [28]. It may be because the fuel (falling water) is available without direct costs associated with fuel purchase [29]. 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 [30], [31]. 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% [32].

3. CONCLUSION

It is necessary to protect our planet by embracing renewable, eco-friendly energy sources in our daily lives. A growing number of local governments are turning to renewable energy as a strategy to reduce green house gases, improve air quality and energy security, boost the local economy, and pave the way to a sustainable energy future. 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.

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