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Review on Power Electronics Circuits in Renewable Energy Systems

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Abstract - **The rapid increase in global energy consumption and the impact of greenhouse gas emissions has accelerated the transition towards greener energy sources. The need for distributed generation (DG) employing renewable energy sources such as wind, solar and fuel cells has gained significant momentum. Advanced power electronic systems, affordable high performance devices, and smart energy management principles are deemed to be an integral part of renewable, green and efficient energy systems. This paper briefly describes the attributes of DG. An overview of wind, fuel cell, solar based energy conversion systems has been presented. A qualitative description of the role of power electronics in wind, solar, and photovoltaic systems has been presented.**

Keywords - Fuel cell, Photovoltaic, Wind energy conversion, Wind Turbines, Z- source converter

I. 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 greenhouse 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 [1]. 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. In the immediate future, renewable energy sources cannot support the entire grid by themselves [1]. They have to be connected to the main grid acting as auxiliary power sources reducing the burden on the primary power generation units. They could also be employed to serve load units isolated from the main grid. A power system employing wind powered turbines, fuel cell based sources, micro generators, and photovoltaic systems augmenting the main power lines will constitute a distributed power generation (DG) system. In a DG system end users need not be passive consumers, they can be active suppliers to the grid. Conventionally, important parameters of power delivered (frequency and voltage) are monitored and controlled by the large power generator units (usually consisting of synchronous generators). In case of DG systems, the power electronic interface has to regulate the voltage, frequency, and power to link the energy source to the grid. The focus will be on high power density, robust dc-ac and ac-ac modules with complex control and safety requirements. This paper presents some of the requirements of the power electronic interface as applicable with respect to wind, fuel cell, and photovoltaic power generation units and qualitatively examines the existing power electronic topologies that can be employed. Energy storage is also very important for DG, however, this paper focuses solely on the power electronics aspects of DG. Section II presents an overview of wind power generation and the associated challenges. Section III and IV present overviews on power generation based on fuel cells and photovoltaic and its implication on the associated power electronic circuits respectively. Section V presents the conclusion.

II. WIND ENERGY SYSTEMS

Wind energy has the biggest share in the renewable energy sector [1], [3]. 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 [3]. The important 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 employed for interfacing with the grid.

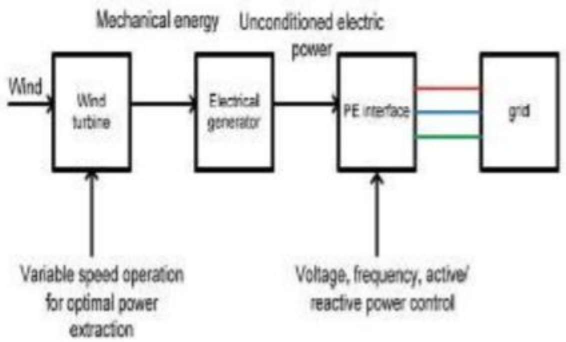

Figure 1: Variable speed wind energy conversion system

Wind energy – Wind speeds, air pressure, atmospheric temperature, earth surface temperature etc., are highly inter-linked parameters. Due to the inherent complexity, it is unrealistic to expect an exact physics based prediction methodology for wind intensity/sustainability. However, distribution based models have been proposed, and employed to predict the sustainability of wind energy conversion systems [4]. Detailed explanation of the wind energy resources is beyond the scope of this paper. Based on studies it has been reported that the variation of the mean output power from a 20 year period to the next has a standard deviation of less than 0.1 [4]. It can be concluded with reasonable confidence that wind energy is a dependable source of clean energy. 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 [2], [3]. Power electronic circuits play a crucial enabling role in variable speed based wind energy conversion systems. Fixed speed wind turbines are simple to operate, reliable and robust. However the speed of the rotor is fixed by the grid frequency. As result, they cannot follow the optimal aerodynamic efficiency point. In case of varying wind speeds, fixed speed wind turbines cannot trace the optimal power extraction point. 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. 1 depicts a variable speed wind energy conversion system. The electrical generator popularly e m p l o y e d for partially v a r i a b l e speed wind energy conversion systems are doubly- fed-induction generators [5]. Fig. 2 depicts a doubly- fed induction- generator where the rotor circuit is controlled by the power converter system via the slip rings and the stator circuit is connected to the grid. This method is advantageous as the power converter has to handle a fraction ~ 25% - 50 % of the total power of the system [5]. The power converter system employs a rotor side ac- dc converter, a dc link capacitor, and a dc- ac inverter connected to the grid as shown in Fig.

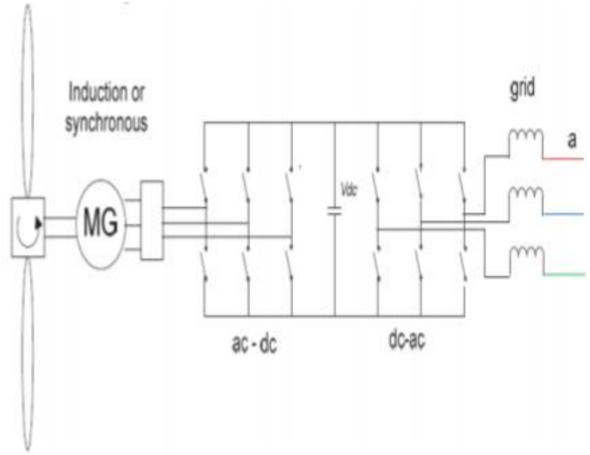

Figure 2: Fully variable wind energy conversion system

III. FUEL CELL SYSTEMS

Fuel cells offer clean, non-toxic energy at relatively good energy densities (higher than lead-acid battery) and high reliability. Fuel cells cannot store energy as opposed to a battery; however, they can continually produce electricity. Presently the fuel cells being popularly used are:

- Solid oxide
- Molten carbonate
- Proton exchange membrane
- Phosphoric acid
- Aqueous alkaline

The efficiency of fuel cell systems are ~ 50 %. Along with heat recovery systems the efficiency can be as high as ~ 80 % [2]. Description of the electrochemical process involved in the power generation process of a fuel cell is beyond the scope of this paper. This section briefly describes the electrical characteristics of fuel cells and their implications on the power electronic interface circuitry. Fig. 3 shows the typical V-I characteristics of a full cell.

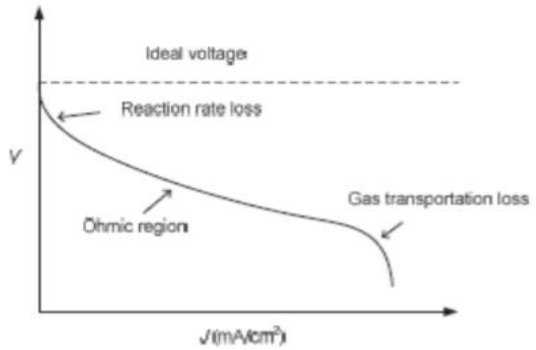

Figure 3: Typical terminal voltage and current characteristics of a fuel cell [11].

IV. PHOTOVOLTAIC ENERGY CONVERSION SYSTEMS

Photovoltaic energy systems consist of arrays of solar cells which create electricity from irradiated light. The yield of the photovoltaic systems (PV) is primarily dependent on the intensity and duration of illumination. PV offers clean, emission-less, noise- free energy conversion, without involving any active mechanical system. Since it is all electric it has a high life time (> 20 years) [2]. A lot of work is being done to enhance the efficiency of the solar cell which is the building block of PV. In this regard the focus is mainly on electro-physics and materials domain. Some of the existing PVs and their efficiencies are [2]:

- Crystalline and multi-crystalline solar cells with efficiencies of ~11 %.
- Thin film amorphous Silicon with an efficiency of ~10%. •
- Thin- film Copper Indium Dieseline with an efficiency of ~12%.
- Thin film cadmium telluride with an efficiency of ~9%.

PV panels are formed by connecting a certain number of solar cells in series. Since the cells are connected in series to build up the terminal voltage, the current flowing is decided by the weakest solar cell [2], [13]. Parallel connection of the cells would solve the low current issue but the ensuing voltage is very low (< 5 V). These panels are further connected in series to enhance the power handling ability. The entire PV system can be seen as a network of small dc energy sources with PE power conditioning interfaces employed to improve the efficiency and reliability of the system. The role of PE is mainly: I. 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. Several non-isolated dc-dc converters have been employed for this purpose. Buck, buck-boost, boost, and Cuk topologies with suitable modifications can be employed for this purpose [13]. II. To interface the dc output of the PV system to the grid or the load - This includes the previously discussed topics of dc-dc-ac and dc-ac-ac conversion. The topologies considered for fuel-cell system grid interconnection correlates to the grid interconnection of PV based system as well including the usage of the Z- source inverter.

V. CONCLUSION

The importance of renewable energy, renewable energy based energy conversion systems, and distributed power generation has been reiterated. A brief overview of the wind energy basics and the existing PE interface requirements and techniques have been addressed qualitatively. The basic electrical characteristics of fuel cell and photovoltaic based systems have been presented. The different methods of integrating these systems to the grid have been briefly described. The advantage of employing a Z- source inverter over a conventional dc- ac VSI has been emphasized. It can be concluded that with the advancements being made in the area of renewable energy and distributed power generation power electronics has a demanding and critical role in the future of efficient power generation and distribution.

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