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Applications of Power Electronics for Wind and Solar Energy Conversion Systems

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***Abstract*— The whole world is focusing on the utilization of renewable energy sources in order to mitigate the world power crisis. Power electronics is being used in a large scale for the renewable energy conversion in a more efficient manner. It has a great impact on controlling as well as interfacing the renewable system with both the grid and standalone applications. Hence more and more emphasis is given on design and control of power converters. In this paper different renewable energy systems (wind, solar) with different aspects of their power conversion have been discussed. Some basic principles of their operations with their recent technology advancements are reviewed. It is the reality that power electronics plays a vital part on interfacing and hence increasing the overall performance.**

Keywords—*Power electronics; Renewable energy systems; Wind energy conversion system; Photo voltaic system.*

I. INTRODUCTION

Due to the rapid growth in global energy consumption and the negative impact of green house gas emissions into the environment, there is a transition towards utilization of renewable energy resources. Several research works is going on for utilization of non-conventional energy sources to compensate the present as well as future energy demand. According to world energy outlook 2015, the per capita electricity demand in worldwide (average) is 2500 KWh. Among which only about 18% of the world's energy demands is supplied from renewable energy sources [1]. But the technical potential to compensate the energy of renewable energy system is more than 18 times its current potential. Fig. 1. shows the estimated energy share of global electricity production of the year 2015.

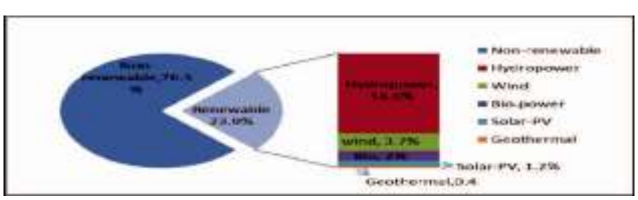

Fig. 1. The estimated energy share of global electricity production of the year 2015[2].

Among the available energy sources,wind and solar are the most challenging energy sources.The natural flow of air is taken as input source of power generation in case of Wind energy conversion system (WECS). Although wind power generation creates noise and effected by climatic conditions but these are ignored in comparison to negative effect associated with the conventional sources. The increased global wind power generation from the year 2004 to 2015 is shown in Fig. 2.Similar to wind,solar energy can also be used for electricity generation.Solar cells are connected in series and parallel to increase both the voltage and current rating. But as the output power of a PV module depends upon the solar irradiation, shading and temperature, its efficieny is low.

For the effective power conversion of both wind and solar energy systems, that is based on enhancement of power quality and reliability, grid management and control is essentially needed. In recent time with the advancement of power electronic technologies, the integration of renewable energy sources into electrical grid has become simpler. It is due to exploitation of new topologies of converter systems, low price with high performance devices along with smart energy management principles. For high level AC to DC MW power conversion of RESs, multi stage converters along with hybrid and matrix converters are widely used. In the grid side to convert power from DC bus to AC utility grid application multistage inverters are employed. Power electronics technologies are associated with various renewable energy systems to generate power in a very controlled manner [3]. General layout of a power electronics system is shown in Fig. 3. It gives an overview of various renewable energy systems and their interfacing with the power electronics converters in various stages to produce the desired output with the help of monitoring and control units.

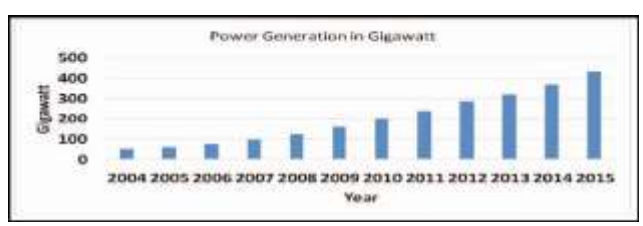

Fig. 2. Global cumulative installed wind power capacity from to 2004 to 2015[4].

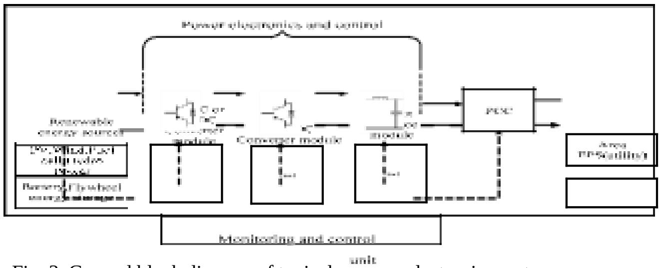

Fig. 3. General block diagram of typical a power electronics system.

This paper presents an overview of current trends in power electronics in wind and solar energy conversion systems. Section II gives an overview of wind energy conversion system along with various converter topologies. Different PV inverter configurations along with recently developed inverter topologies are viewed in section III. In section IV, smart grid technology to improve performance of overall system is proposed. Conclusion is presented for these two main energy sources at the end.

II.WIND ENERGY CONVERSION SYSTEM (WECS)

Wind Energy Conversion System covers a large boundary in compensating the energy demand in distribution networks. Denmark is the emerging country in the world for utilizing the wind power.Irrespective of the minor issues like creation of noise, visual and climatic effects that are associated with a wind farm, it has increased its size from KW to MW in few decades. Squirrel Cage induction generator (SCIG) was introduced in 1980 for electrical power conversion but reactive power compensation with voltage and frequency control were the biggest challenges associated with it. Hence in order to control reactive power and high mechanical stress variable speed wind turbines were came into picture. They have the advantage of maintaining constant speed irrespective of the variable wind speed such that mechanical stress can be reduced and more wind power can be extracted. But controlling the voltage and frequency of variable wind turbine are the two major issues. PE network has a great contribution for these purposes [5].

A. Wind Energy Conversion System (WECS) and PE Network

The nature of wind energy is versatile in nature.The mechanical energy of wind is converted to generator and the generator converts this torque into electricity and feeds it into the grid. A WECS is a combination of wind turbine, generators and power electronics converters for ac-dc-ac conversion.

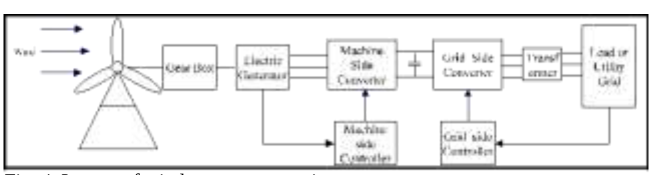

Fig. 4. Layout of wind energy conversion system .

For a complete and efficient conversion of wind power knowledge of aerodynamics, mechanical, electrical and control system are the requirement. Normally in a wind farm wind turbines are connected in parallel. These turbines are connected to the common DC bus and with the help of current controlled voltage source inverters, the DC power is delivered to the grid. The WECS interfaced with PE networks is shown in Fig. 4. Based on the operation , the wind energy conversion system is categorized into two types, fixed speed and variable speed operating systems. The variable speed systems are cost effective and produced more power as compared to the fixed speed system. Two different types of AC generators are mostly in practice. These are asynchronous generator and synchronous generator.

1. Asynchronous Generator

These are commonly called as fixed speed wind turbines and operated for narrow speed range for slightly more than the synchronous speed. A transformer connects a Squirrel Cage Induction Generator (SCIG) to the supply grid shown in Fig. 5(a). The grid supplies the reactive power required to energize the magnetic circuit of the SCIG and it is controlled by switching capacitor bank connected to it. In order to limit the effect of inrush current at the starting, current limiter/soft starter is normally used. Irrespective of the control mechanism made for the aerodynamics, the wind fluctuation has the direct impact on the electrical power generated. Variable speed induction generators are used to reduce the wind fluctuation caused by high mechanical stress shown in Fig. 5(b) and it is associated with full scale power converters. Recent technology is based on the development of multi-stage gearbox connected to a variable speed wind turbine system with a Doubly Fed Induction Generator (DFIG) shown in Fig. 5(c).This type of WECS mainly uses a doubly fed induction generator where stator winding is connected directly to the three phase constant frequency grid and a partial scale back to-back converter is used to connect its rotr winding. It has nearly 25-30% of power conversion efficiency[6].

2. Synchronous Generator

Power electronics contribute in eliminating the gear-box as it is associated with power loss and hence causes failure of the whole systems. Permanent Magnet Synchronous Generator (PMSG) shown in Fig. 5(d) provides an alternative way for this application. Due to the absence of slip ring, it has low maintenance cost and higher efficiency [7]. For a gearless PMSG system, multiple numbers of poles are selected to generate power at lower rotational speed. The efficiency of power conversion has been increasing due to the advancement of fixed speed to variable speed generators and now PMSG gives the most reliable solution and the different converter topologies used for its grid integration is presented in the next section.

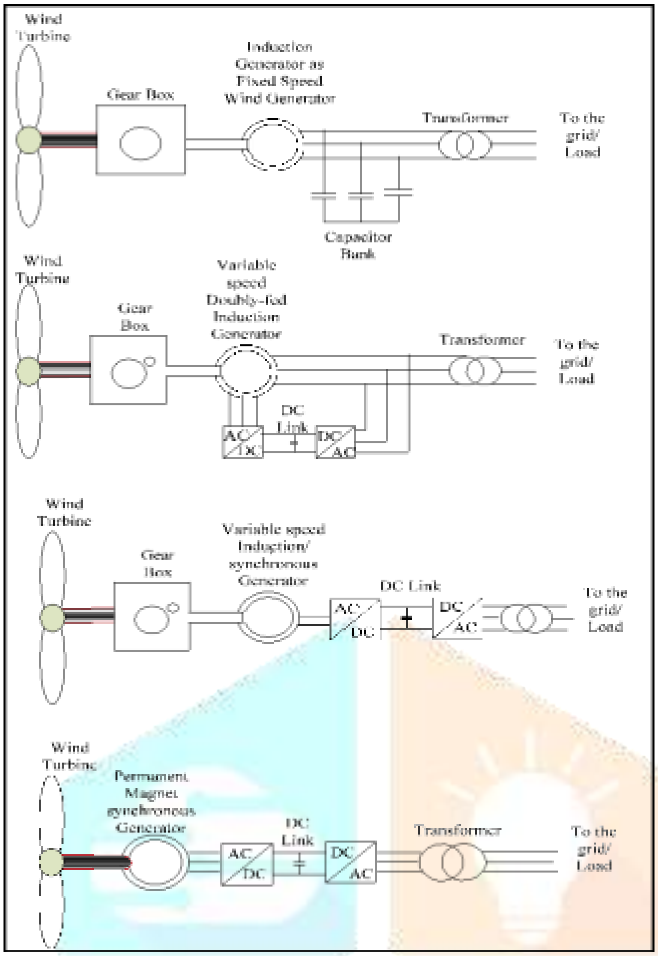

Fig.5. Different types of wind generators connected to the grid.

B. Electrical Aspect of Power Electronics Converters

It is essential that all the devices connected to a network should be operated in a stable operating region and there is a continuous flow of power from source to load .Two major outcomes associated with this are [8]:
1.Output waveform must be sinusoidal with small distortion
2.Grid must be opertated at 50 Hz for safety of its other equipments.

Power electronic converters used to meet the above demandsin year in wind energy conversion system are discussed below:

1. Back to Back Power Converter

These converters are mostly used in variable speed wind energy conversion systems and are also known as ‘Two level PWM converter’.The system comprises of two level voltage source converter (2L-VSC) connected through a DC-link capacitor to control both the grid side and generator side that is shown in Fig. 6.It has the advantage of lower cost of DC-link capacitor.But switching loss and requirement of filters to eliminate the high frequencies harmonics are its biggest disadvantages [9].

2 . Multi-level Power Converters

In order to mitigate the drawbacks of back to back power converter multilevel converter was introduced in 1975 as shown in Fig. 7. With the help of more and more voltage levels it can reduce the total harmonics distortion (THD) at the cost of complexicity of the circuit and control. Regardless of its contribution in high voltage and power rating ,the major disadvantages associated with this configuration are high cost,circuit complexity due to more number of switches used and the voltage imbalance associated with the dc-link capacitor.The different configuration of multi-level converter are[10]:

• Neutral Point Clamped (NPC)
• Cascade Half-Bridge (CHB)
• Flying-capacitor (FLC)

Now a days multicell converter topologies shown in Fig. 8. And matrix converter as shown in Fig. 9. are used in wind industry for faster growth .

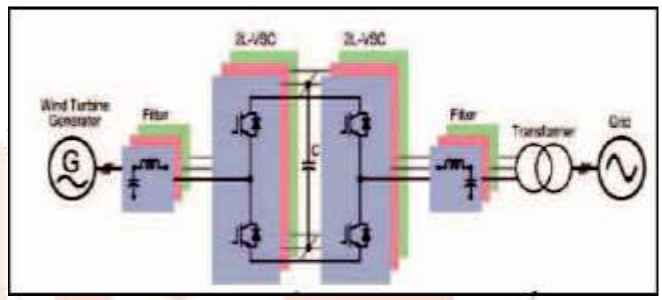

Fig. 6. 2L-VSC BTB voltage source converter for WTSs.

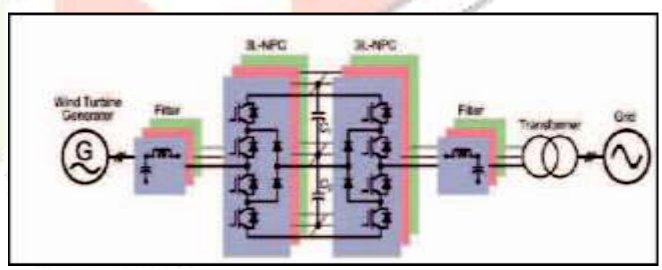

Fig. 7. 3L-NPC BTB topology for WTSs.

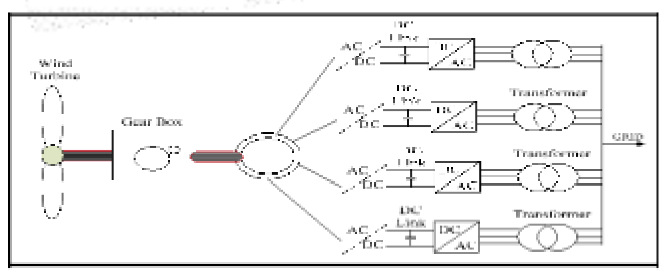

Fig. 8. Multi-cell full power structure.

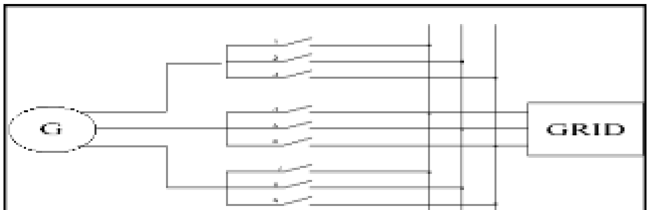

Fig. 9. Circuit configuration of a matrix converter.

3. Matrix Converters

These converters uses single stage conversion. It utilizes bidirectional controlled switch to achieve automatic conversion of power from AC to AC. Fig. 9. shows the nine switch based matrix converter.While operating this converter, a proper time interval should be maintained when the three switches in a common output leg are turned on and all the three outputs must be connected to an input phase constantly.

III. PHOTOVOLTAIC SYSTEM

A PV cell produces electrical power when it exposes to sun light . Due to static nature, it has maximum life time of about 25 years.A typical PV module consists of about 36 or 72 cells connected in series [11]. PV system may be grid connected type or can be standalone type. PE acts as an interface between the PV system and the utility grid. A PV system connected to grid consists of a PV array, DC-DC boost converter, DC-AC converter and a controller stage followed by the utility grid shown in Fig. 10.

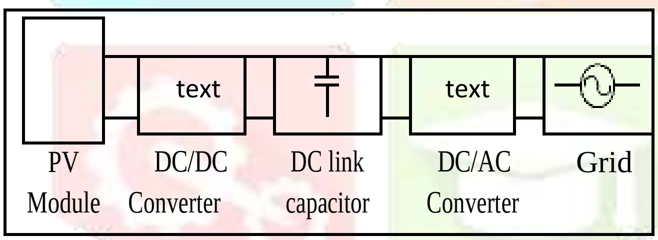

Fig. 10. Typical structure of PV system

A. PV system and PE network:

1.Different PV inverter configurations Cost-to-efficiency ratio is a major aspects of PV system. In order to decrease this ratio new inverter design is being continuously improved. The PV inverters are classified as follows [12]:

- central inverters
- string inverters
- module integrated inverters
- multi-string inverters
- cascaded dc/dc inverters

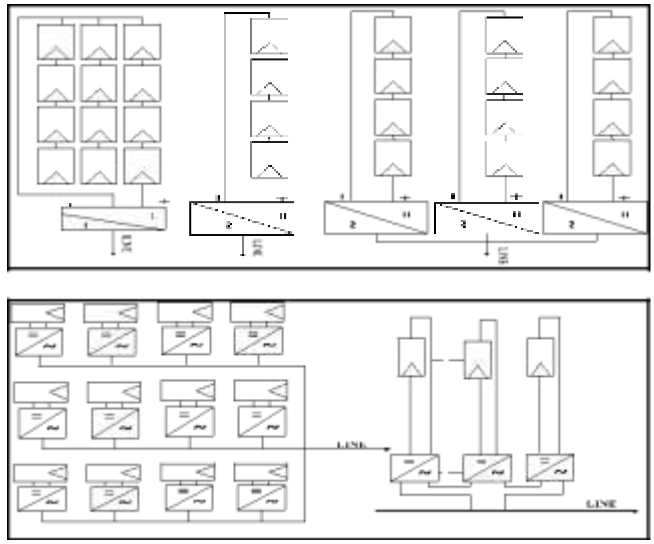

Fig. 11. Configuration of different PV inverters : (a) Central PV inverter (b) String Inverter (c) Multistring Inverter. (d) AC Module Inverter (e) Cascaded dc/dc Inverter.

A central inverter topology shown in Fig. 11(a), is used for a solar plant of large scale (more than 10 kWP) .In this system, PV plants are arranged parallely and connected to a central inverter. The major issue related with this, is the need of high voltage DC panel between the cables and the inverter. Different power losses associated here are the losses due to common Maximum Power Point Tracking (MPPT), module mismatch and due to shedding for which the reliability of the whole system is disturbed. To overcome these drawbacks, string inverter, module integrated inverter and multistring inverters topologies were developed. In string inverter configuration, shown in Fig. 11(b), series connected solar panels form a PV string and each string is connected to a separate inverter. These string inverters are connected in parallel and finally they are connected to the grid. Due to the use of separate MPPT for each string, power loss in this configuration is reduced. But if the string voltage is low enough, DC-DC converter or line frequency transformer is used to increase the voltage level. In multistring inverter, shown in Fig. 11(c), several DC-DC converters are connected with their individual MPPT technique to control the individual PV string connected to it, henceforth the conversion efficiency is high due to less power loss. the solar panel is connected to grid through its own inverter .AC module inverter shown in Fig. 11(d),achieve highest MPPT efficiency and eliminate the DC cabling.Another recently developed configuration is cascaded dc/dc converter shown in Fig. 11(e) where the modules with their associated converters are connected in series to provide a high dc voltage.A comparison of different PV inverter configurations is shown in table–I.Their power rating, conversion efficiency and features are briefly presented.

TABLE I

AN OVERVIEW OF DIFFERENT GRID CONNECTED PV INVERTER CONFIGURATION

	AC MODULE	STRING	MULTISTRING	CENTRAL
POWER RATING	<350W	<10KW	<500KW	<850KW
SWITCHES USED	MOSFET	MOSFET,IGBT	MOSFET,IGBT	MOSFET
MPPT EFFICIENCY	High	Good	High	Good
EFFICIENCY OF COVERTER	Lowest (up to 96.5%)	High (up to 97.8 %)	High (up to 98 %)	Highest (up to 97.8 %)
CHARACTER-ISTICS	Modular in structure Highest MPPT efficiency Easy to install Loss is less Per watt cost is higher Two stage of conversion	MPPT efficiency is good DC wiring is reduced No need of transformer High component count One string, one inverter	Flexible/Modular Highest MPPT efficiency Low cost for multiple string system Two stage of conversion	Stucture is very simple High converter efficiency Blocking diode is needed MPPT is poor Not flexible

2. PV inverter topologies

In all the mentioned configurations, a low frequency (LF) or high transformer (HF) is needed for the grid isolation purpose. PV inverter is equipped with LF-transformer that helps in boosting the input voltage. No DC voltage is injected to the grid and distorted output current is low. But due to heavy weight, big size and low efficiency it is not preferable. Hence to increase the efficiency by 2% HF-transformer is used. Being compact, it introduces losses hence power electronic circuits are used. To further increase the efficiency a new inverter configuration is adopted [13]. Recent technology is concerned with the development of H-bridge or Neutral-Point-Clamped (NPC) inverter topology that is used as the DC/AC section. It reduces the direct current injection and helps in achieving a better MPPT.To design PV-inverter, isolation and the leakage current are the two major issues associated with. Hence recent technologies are related with the development of transformer less PV inverter [14]. Hence the H6 inverter was developed where isolation is provided by four extra devices in order to disconnect PV string from the inverter as shown in Fig. 12(a). For more efficient and reliable operation high efficient and reliable inverter (HERIC) inverter was invented that shown in Fig. 12(b).AC can be bypassed in this structure. Moreover ,many other topologies like multilevel topologies and flying inductor topologies are recently developed.

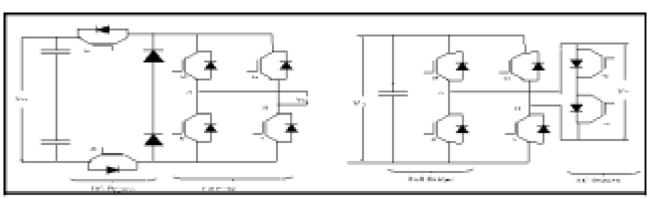

Fig. 12. Two transformers less PV inverters (a) H6 and (b) HERIC

MPPT is a technique used to extract maximum power from solar panel. The various MPPT methods that are used are:

- Perturbation –Observation (P&O)/Hill-climbing
- Incremental Conduction Control
- P/V or P/I Feedback Control
- Fuzzy Network Control
- Neural Network Control

These methods are distinguished from each other with respect to their circuit complexity, speed of convergence and cost. These MPPT techniques are used to control the DC/DC conversion stage or in DC/AC inverter stage [15][16].

IV. Proposals for Future Devices to Improve Performance of Overall System

Both wind and solar energy are the most freely available source of energy. But wind energy is quietly unpredictable than solar energy. Hence hybrid energy system is preferred that associated with two or more energy sources, a power conditioning equipment, controller and battery energy storage system to challenge the sudden fault condition in a network [17][18]. Hence research works are being carried out in academic institutions and the research labs to improve the issues like the grid integration standard, communication and protection. Moreover,some technical issues like reduction of transmission losses and fulfillment of peak demand while connecting with grid must be taken into consideration. The whole hybrid system can be integrated with a smart grid as shown in Fig 13. It is a smart technology for the renewable energy sources to improve their power quality and reliability in order to mitigate the consumer demand. It provides the real time information and improves the efficiency in a cost effective manner. Power electronics associated with smart control strategies will be adopted for this new transformation [19][20].

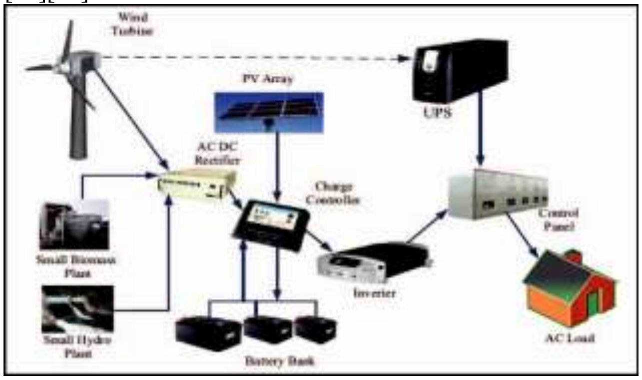

Fig. 13. Example of smart grid system.

V. CONCLUSION

Recent developments in power electronics technology has the greatest contribution towards the generation, integration, and transmission of renewable energy upto a greater extent. Advancement of high power rating devices has made the energy conversion easier. This paper is based on the current trends of power electronics on the renewable energy systems. Renewable energy sources like wind and PV with their energy conversion system have been discussed. The different PV topologies and configuration of different wind turbines to the grid have been briefly summarized. An overview of integration of solar and wind conversion systems with the smart grid technologies have been discussed. As classical control is based on state-space principle, renewable energy sources can not be described in terms of state equations. Hence there is need of intelligent systems for prediction and control. This paper is an attempt to cover the current technology related to wind and solar energy system and future research direction.

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