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POWER ELECTRONIC TECHNOLOGIES IN RENEWABLE ENERGY SYSTEMS

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ABSTRACT
For supplying the demand of global electrical energy two major technologies will be important in future. First is to modify the electrical power generation sources from the traditional energy sources to renewable energy resources and the second is to use highly efficient power electronics circuits in power generation, power transmission and power distribution and end-user utilities. This paper discuss the some of the emerging renewable electric energy sources, which by using power electronics technologies are modifying renewable energy sources to work as important power sources in the electric energy system that will play very important role as future energy supplies in distributed generation. Power electronics technologies has got maturity after several years of dynamic development of power electronic components, converters, pulse width modulation techniques, electrical machines, electric motor drives, modern control, and simulation techniques. In the twenty first century, we expect to see the tremendous effect of power electronics not only in worldwide industrialization and energy systems, but also in energy conservation, renewable energy systems, and electric vehicles.

INTRODUCTION
In traditional power systems, large power generation plants installed at proper geographical places produce most of the electric power, which is then delivered towards large utilization centers over long distance transmission lines. The system controller regulates and monitors the power system continuously to ensure the quality of the power that is frequency and voltage. However, now the overall power system is changing, a large number of disperse generation (DG) units, including both nonconventional and conventional sources such as wind turbines, wave generators, photovoltaic (PV) generators, small hydro, fuel cells and gas/steam powered Combined Heat and Power (CHP) stations, are being developed and installed. A wide-spread use of renewable energy sources in distribution networks and a high penetration level will be seen in the near future many places. The main advantages of using renewable energy sources are the elimination of harmful emissions and inexhaustible resources of the primary energy. However, the main disadvantage, apart from the higher costs, e.g. photovoltaic, is the uncontrollability. The availability of renewable energy sources has strong daily and seasonal patterns and the power demand by the consumers could have a very different characteristic. Therefore, it is difficult to operate a power system installed with only renewable generation units due to the characteristic differences and the high uncertainty in the availability of the renewable energy sources. [1] Power electronics enables the efficient generation, use, and distribution of electrical energy because it substantially improves energy conversion efficiency. In order to realize the large electrical energy savings potential enabled by power electronics suitable technological solutions at acceptable cost levels are needed. Moreover, public policy and public acceptance must play an in- caressingly important role. An effective way to quantify the value of power electronics is needed and it must be presented in such a way that it is understood and appreciated by policymakers. In this paper, energy payback time is shown to be a powerful tool for weighing the value of energy savings achieved by using power electronics versus the energy needed to manufacture the systems. A life cycle analysis of two power electronic converters and their parts is performed. The benefits of energy savings versus energy invested in manufacturing and end-of-life management of power converters is analyzed. It is shown that power electronics systems have shorter energy payback time compared to other technologies. [2]

ROLE OF POWER ELECTRONICS
Let us now fall back to power electronics and explain why it is so important today not only for industrialization and general energy systems but also for energy saving and, thus, for mitigating climate change problems. As we know, power electronics deals with conversion and control of electrical power with the help of power semiconductor devices that operate in switching mode, and therefore, the efficiency of power electronic apparatus may approach as high as 98%–99%. With the advancement of technology, as the cost of power electronics decreased significantly, size became smaller, and the performance improved; power electronics

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A. Power Electronics in Energy Saving

Saving of energy gives the economical benefit directly, particularly where the energy cost is high. The extra cost of power electronics can be recovered within a reasonable period. In addition, reduced consumption means reduced generation that indirectly mitigates the environmental pollution and climate change problems. Power electronic control instead of classical rheostat or motor/ generator set control is obviously more efficient.

B. Power Electronics in Renewable Energy Systems

As earlier discussed, renewable energy resources, such as wind, solar, bio-fuels, hydro, geothermal, wave, and tidal powers, are eco-friendly and abundant in nature and therefore are getting tremendous emphasis all over the world. Scientific American has recently published a paper by Stanford University professors that predicts that renewable energies only with adequate storage can supply all the energy needs of the world. Another study by UN IPCC reports that 50% of the total world energy can be met by renewable resources by 2050. The wind and solar resources, which are heavily dependent on power electronics for conversion and control, are particularly important to meet our growing energy needs and mitigate the climate change problems. Note that solar energy can be two types: One is thermal through solar concentrators that generates steam and operates turbo generators to generate electricity. (Like traditional steam power plant), and the other is PV generation of electricity by silicon semiconductor. [3]

A. Power Electronics in Energy Consumption

Over the last 40 years, there has been an overwhelming trend to provide all electric energy to the final load equipment through fast and precise electronic power converters in order to improve load performance and energy efficiency. Most of the electric motors used in elevators, ventilation, pumping, heating, air-conditioning, refrigeration, food processing, fabric care, etc. are today being powered through electronic motor drives. With the already widespread use of electronic ballasts for fluorescent, HID, and LED lighting, and with the forthcoming elimination of incan- descent lights, soon all electrical energy for lighting will also be processed electronically. Finally, with the traditional cook- ing equipment being replaced with microwaves and induction heating, over 80% of the total energy usage in newly equipped commercial and residential buildings will be processed through power electronics. Similar percentages of the total electric energy consumed in industry and transportation are already being processed by power electronics converters.

B. Power Electronics in Distributed Generation

Although distributed generation (DG) was the rule rather than an exception in the early days of electric energy production it has been almost completely replaced by the large- scale centralized generation in the second half of the 20th century. Recently, rapid commercialization of the renewable energy sources has resulted in increased deployment of low, medium and high power DG sources as well as Energy storage (ES) systems. Invariably, renewable DG and ES sources are interfaced to the grid with the assistance of power electronics converters. Fast, digitally controlled converters offer endless possibilities for the most optimal utilization of renewable resources. Moreover, power electronics-based DG can enhance power system controllability due to the fast dynamic response to the power system disturbances and deviations of the voltage and frequency. Although future energy sources will unavoidably represent a mix of different technologies, wind generation is most likely to remain the dominant segment of the renewable industry.

C. Power Electronics in Power Transmission

There are two major types of HVDC systems: the older, thyristor-based line-commutated, current source HVDC is usually used with the overhead lines, and the newer, IGBT-based force-commutated, voltage source converter (VSC) HVDC is often employed for cable and multi-terminal transmission. The line-commutated HVDC is used for long-distance very high power transmission, up to 6.5 GW through the lines with up to ±800 KV whereas the VSC HVDC systems have been used for transmission up to 1.2 GW with the ±320 kV cables and could be suitable even for some distribution-level applications, e.g. through underwater or underground cables. Similarly to the HVDC technology, flexible ac transmission systems (FACTS) have been offering new solutions and opportunities for controlling power and improving the trans- mission capacity utilization. In the form of the thyristor- based static VAr compensators (SVC) and VSC-based static synchronous compensators (STATCOM) and universal power flow controllers (UPFC), FACTS devices are opening numerous possibilities in controlling the power and improving the performance and reliability of the centralized bulk power transmission systems.[4]

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MODERN POWER ELECTRONICS TECHNOLOGIES

The present state-of-the-art in power electronics has been characterized as mature. However, when power electronics is characterized as mature, it is important to realize that this refers to how the technology is practiced at present—as it is seen from inside.

A. Characterizing Power Electronics Technology

1) Fundamental Functions in Power Electronics

For our purposes, a converter will be taken as the total of the equipment between source and load that have the objective of the conversion and control of electromagnetic energy flow between an electric source and the load. The power electronic converter has internal fundamental functions that characterize the different aspects of its functioning.

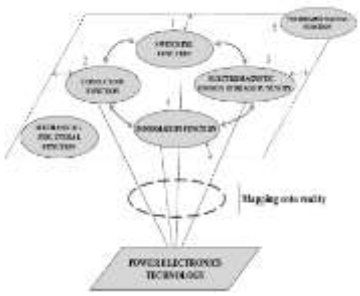

Fig.1. Internal functions of a power electronic converter

These functions, shown in Fig. 1, relate to the propagation, conversion and control of the flow of electromagnetic energy, and are found at all power levels, in all types of converters for all applications:

1) The switching function controls electromagnetic energy flow/average power;
2) The conduction function guides the electromagnetic energy flow through the converter;
3) The electromagnetic energy storage function enables energy continuity when interrupted by the switching function;

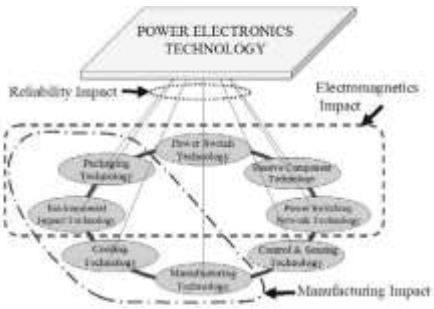

Fig. 2. Interrelationships in power electronics constituent technologies.

4) The information function enables the required time inter- relationship between the previous three functions to execute the fundamental function of the power electronic converter;

5) The heat exchange function stabilizes the thermal operation of the converter;
6) The mechanical/structural function guarantees the physical stability of the converter. [5]

2) Mapping the Fundamental Functions onto Reality:

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When the fundamental functions of power electronics are mapped onto reality by any type of technology, a number of constituent technologies can be identified, as shown in Fig. 2, independent of the type of converter, power level, or type of application. These constituent technologies are now identified as:

1) Power switch technology (covering device technology, driving, snubbing, and protection technology);
2) Power switching network technology (i.e., what is classically termed converter technology, covering the switch- ing technologies, such as hard switching, soft switching, resonant transition switching, and all the topological arrangements);
3) Passive component technology (covering magnetic, capacitive, and conductive components);
4) Packaging technology (covering materials technology, interconnection technology, layout technology, and mechanical construction technology);
5) Electromagnetic environmental impact technology (covering harmonics and network distortion, EMI and EMC);
6) Physical environmental impact technology (covering acoustic interaction, physical material interaction i.e., recycling, pollution);
7) Cooling technology (cooling fluids, circulation, heat extraction and conduction, and heat exchanger construction);
8) Manufacturing technology;
9) Converter sensing and control technology;

POWER ELECTRONICS FOR SOLAR ENERGY SYSTEMS

Photovoltaic (PV) cell is an all-electrical device, which produces electrical power when exposed to sunlight and connected to a suitable load. Block diagram of a singale-phase grid connection PV system including controlis shown below in fig.3. Without any moving parts inside the PV module, the maintenance is very low. Thus, lifetimes of more than 25 years for modules are easily reached. However, the power generation capability may be reduced to 75% ~ 80% of nominal value due to ageing. A typical PV module is made up of around 36 or 72 cells connected in series, encapsulated in a structure made of e.g. aluminum and tedlar.

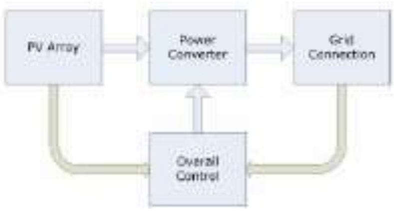

Fig. 3. Block diagram of a singale-phase grid connection PV system including control.

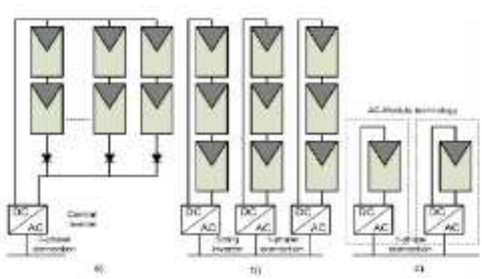

Fig. 4. Structures for PV systems:a) Central inverter,b) String inverter and c) Module integrated inverter.

1) Central inverters

In central inverters topology the PV plant (typical > 10 kW) is arranged in many parallel strings that are connected to a single central inverter on the DC-side (Fig. 4a). Central inverters are categorized by high efficiency and low cost pr. kW. However, the energy yield of the PV plant is out of operation. This causes reduction in the available power, which to some extent can be mitigated by the use of bypass diodes, in parallel with the cells. The parallel connection of the cells solves the 'weakest-link' problem, but the voltage seen at the terminals is rather low.

A. Structures for PV systems

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A schematic block diagram of a grid connected photovoltaic (PV) system is shown in Fig. 3. It consists of a PV array, a power converter with a filter, a controller and the grid.The PV array can be a single panel, a string of PV panels or a multitude of parallel strings of PV panels. Centralized or decentralized PV systems can be used as depicted in Fig. 4. Central inverter system uses one inverter for each module (Fig. 4c). This method optimizes the adaptability of the inverter to the PV characteristics, since each module has its own Maximum Power Point (MPP) tracker. Although the module-integrated inverter optimizes the energy yield, it has a lower efficiency than the string inverter. Module integrated inverters are characterized by a more extended AC-side cabling, since each module of the PV plant has to be connected to the available AC grid (e.g. 230 VI 50 Hz). Also, the maintenance is so complex plicated, especially for facade-integrated PV systems. This concept can be implemented for PV plants of about 50 - 400 W peak.

B. Topologies for PV inverters

The PV inverter technology has evolved quite a lot during the last years towards maturity still there are different power configurations possible as shown in Fig. 5.

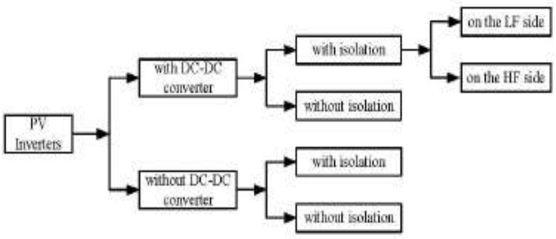

Fig.5. Power configurations for PV inverters.

The question of having a dc-dc converter is not first of all related to the PV string configuration. Having more panels in series and lower grid voltage, like in US and Japan, it is possible to avoid the boost function with a dc-dc converter. Thus a single stage PV inverter can be used leading to higher efficiencies. The issue of isolation is mainly related to safety standards and is for the moment only required in US. The drawback of having so many panels in series is that MPPT is harder to achieve especially during partial shading. In the following, the different PV inverter power configurations are described in more details.

1) PV inverters with DC-DC converter and isolation

The isolation is typically achieve using a transformer that can be placed on either the grid frequency side (LF) as shown in Fig. 6a or on the high-frequency (HF) side in the dc-dc converter as shown in Fig.6b. The HF transformer leads to more compact solutions but high care should be taken in the transformer manufacturing in order to minimize the losses.

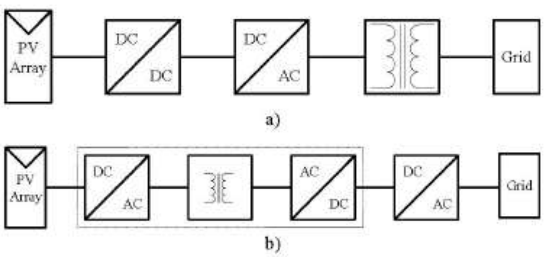

Fig. 6. PV inverter system with chopper and isolation transformer: (a) on the Low Frequency (LF) side and (b) on the High Frequency(HF)side

In Fig. 7 PV inverter with an HF transformer using an isolated push-pull boost converter is presented. In this technique the dc-ac inverter is a low cost inverter switched at the line frequency. The new technique on the market are using PWM dc-ac inverters with IGBT's switched typically at 10-20 kHz leading to a improve power quality performance.

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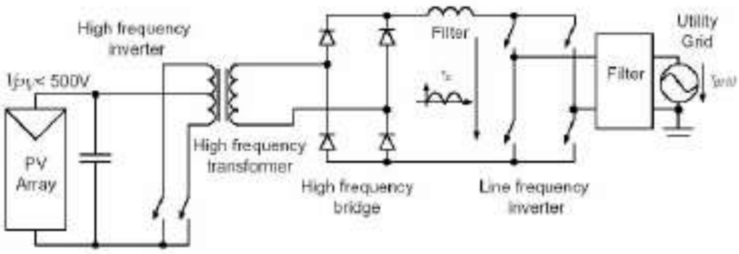

Fig.7 PV inverter with a high frequency transformer in the dc-dc converter.

To maintain the magnetic components small high switching frequencies in the range of 20 - 100 kHz are typically used. The full-bridge converter is usually utilized at power levels above 750 W. The merit of this technique is: good transformer utilization - bipolar magnetization of the core, good performance with current programmed control - reduced DC magnetization of transformer. The main demerits in comparison with push-pull topology are the higher active part count and the higher transformer ratio needed for boosting the dc voltage to the grid level.

Boosting function on both boosting inductor and transformer can provided by the single inductor push-pull converter by reducing the transformer ratio. Hence higher efficiency can be achieved together with smoother input current. On the negative side higher blocking voltage switches are required and the transformer with tap point puts some construction and reliability problems. Those shortcomings can be alleviated using the double inductor push-pull converter (DIC) where the boost inductor has been split in two. Actually this topology is equivalent with two inter-leaved boost converters leading to lower ripple in the input current. The transformer construction is easy not requiring a tap point. The single demerit of this topology remains the need for an extra inductor.

2) PV inverters with DC-DC converter without isolation

In few countries as the grid-isolation is not mandatory, more simplified PV inverter design can be used, like shown in Fig.8

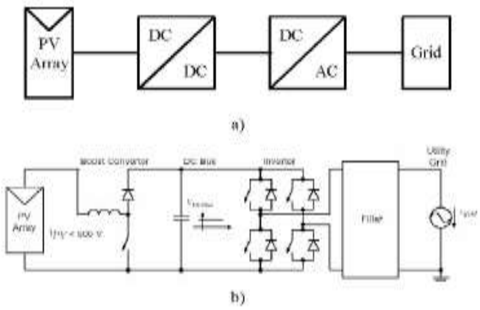

Fig. 8. PV inverter system with DC-DC converter without isolation transformer a) General diagram and b) Practical example with boost converter and full- brige inverter.

In Fig. 8b a practical example using a simple boost converter is shown.

3) PV inverters without DC-DC converter

The block diagram of this topology is shown in Fig 9-a

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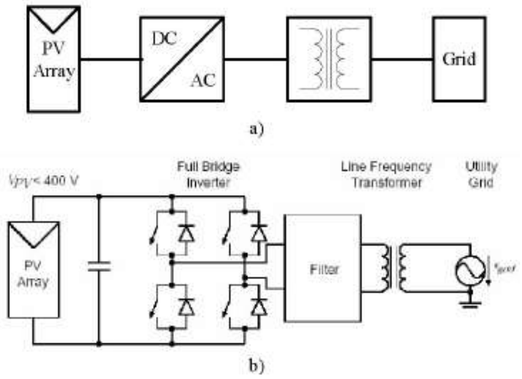

Fig. 9 (a) General diagaram of PV system without DC- DC converter and with isolated transformer (b) practical example with full bridge converter and gride side transformer

In Fig. 9-b are presented two topologies of PV inverters in which a line frequency transformer is used. For higher power levels, self-commutated inverters using thyristors may be used.

POWER ELECTRONICS FOR WIND ENERGY SYSTEMS

Until now, the configuration of DFIG equipped with partial-scale power converter is dominating on the market,but in very near future the configuration with synchronous generator (SG) with full- scale power converter is expected to take over. Actually, the solutions with full-scale power converter are becoming the preferred technology choices in the best selling power ranges of the wind turbines. In the following, these two state- of-the-art wind turbine concepts are going to be introduced.

A. DFIG with Partial-Scale Power Converter

This wind turbine concept is the most adopted solution nowadays and it has been used extensively since 2000s. As shown in Fig. 10, a PEC is adopted in conjunction with the DFIG. The stator windings of DFIG are directly connected to the power grid, whereas the rotor windings are connected to the power grid by the converter with normally 30% capacity of the wind turbine. In this concept, the frequency and the current in the rotor can be flexibly regulated and thus the variable speed range can be extended to a satisfactory level. The smaller converter capacity makes this concept attractive seen from a cost point of view. Its main drawbacks are however, the use of slip rings and the challenging power controllability in the case of grid faults— these disadvantages may comprise the reliability and may be difficult to completely satisfy the future grid requirements as claimed in and The two-level pulse width modulation voltage source converter (2L-PWM-VSC) is the widely used converter topology so far for the DIFG-based wind turbine concept as the power rating requirement for the converter is limited. Normally two 2L-PWM-VSCs are configured in a BTB structure in the WTS,

as shown in Fig. 11, which is called two-level BTB (2L-BTB) for convenience. A technical advantage of the 2L-BTB solution is the full power controllability (four quadrant operation) with a relatively simple structure and few components, which contribute to well-proven robust/reliable performances as well as advantage of cost. [6]

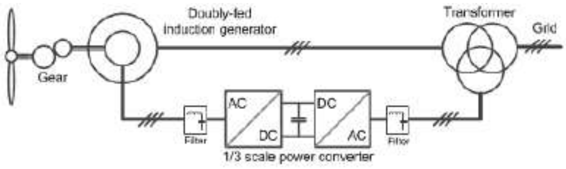

Fig. 10. Variable speed wind turbine with partial scale converter and a DFIG.

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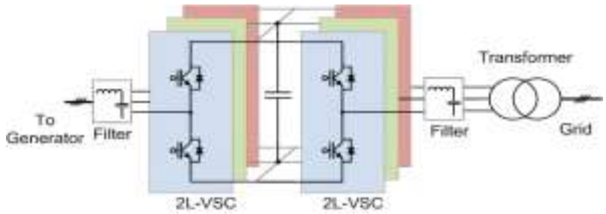

Fig. 11. 2L-BTB voltage source converter for wind turbine.

Boosting function on both boosting inductor and transformer can provided by the single inductor push-pull converter by reducing the transformer ratio. Hence higher efficiency can be achieved together with smoother input current. On the negative side higher blocking voltage switches are required and the transformer with tap point puts some construction and reliability problems. Those shortcomings can be alleviated using the double inductor push-pull converter (DIC) where the boost inductor has been split in two. Actually this topology is equivalent with two inter-leaved boost converters leading to lower ripple in the input current. The transformer construction is easy not requiring a tap point. The single demerit of this topology remains the need for an extra inductor.

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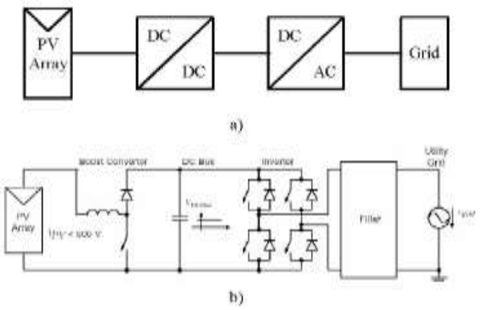

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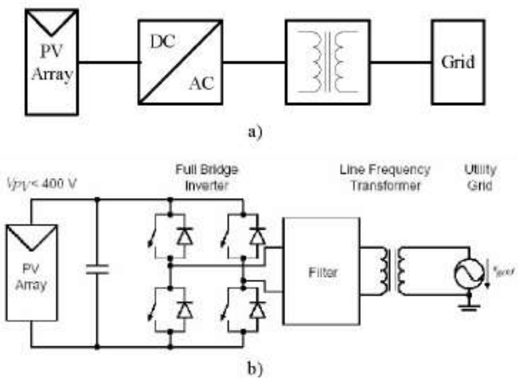

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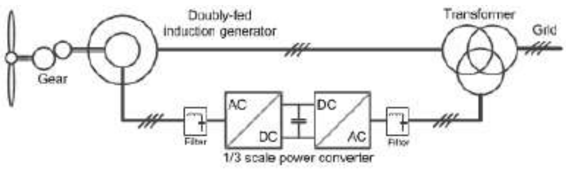

Fig. 10. Variable speed wind turbine with partial scale converter and a DFIG.

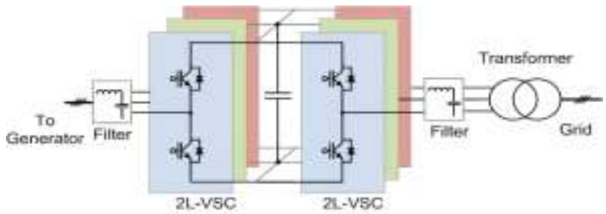

Fig. 11. 2L-BTB voltage source converter for wind turbine.

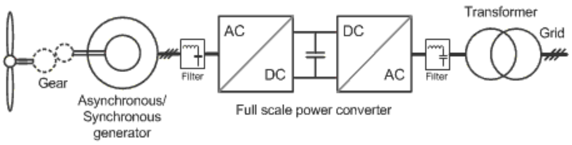

Fig.12. Variable-speed wind turbine with full-scale power converter.

B. A/SG with Full-Scale Power Converter

The second important concept that is popular for the newly developed and installed wind turbines is shown in Fig. 12. It introduces a full-scale power converter to interconnect the power grid and stator windings of the generator, thus all the generated power from the wind turbine can be regulated. The asynchronous generator, wound rotor SG (WRSG) or permanent magnet SG (PMSG) has been reported as solutions to be used. The elimination of slip rings, simpler or even eliminated gearbox, full power and speed controllability as well as

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better grid support ability are the main advantages compared with the DFIG-based concept. The more stressed and expensive power electronic components as well as the higher power losses in the converter are, however, the main drawbacks for this concept. To handle the growing power with the exiting 2L-BTB technology, some multi cell converter configurations are introduced (i.e., parallel/series connection of 2L-BTB converter cells). Fig. 13(a) shows a multi cell solution adopted by Gamesa in the 4.5-MW wind turbines, which have several 2L-BTB converters paralleled both on the generator and grid sides. Siemens also introduce the similar solution in their best selling multi megawatt wind turbines, as show in Fig 13(b). The standard and proven low voltage converter technologies as well as redundant and modular characteristics are the main advantages. This converter configuration is the state- of-the-art solution in the industry for the wind turbines with power level >3 MW.With the abilities of achieving higher voltage and power level, multilevel converters may become more preferred.

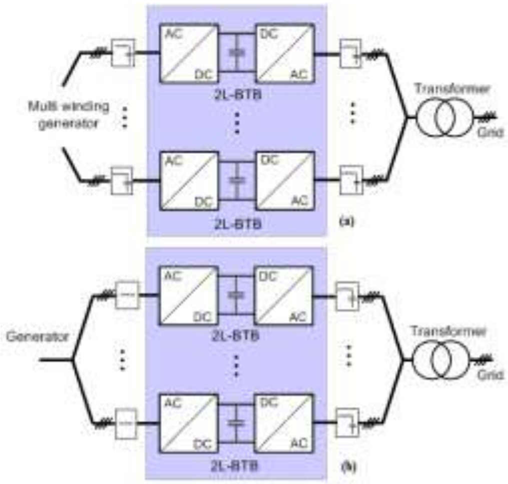

Fig. 13. Multi cell converter with paralleled 2L-BTB converter cells.
(a) With multi-winding generator. (b) With regular winding generator

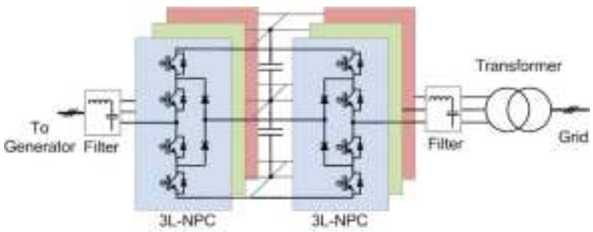

Fig. 14. 3L-NPC BTB converter for wind turbine.

Candidates in the full-scale converter based concept. The three-level neutral point diode clamped (3L-NPC) topology is one of the most commercialized multilevel topologies on the market. Similar to the 2L-BTB, it is usually configured as a BTB structure in the wind power application, as shown in Fig. 14, which is called 3L-NPC BTB for convenience. The 3L-BTB solution achieves one more output voltage level and less d*v*/d*t* stress compared with the counterpart of 2L-BTB, thus it is possible to convert the power at medium voltage with lower current, less paralleled devices, and smaller filter size.

CONCLUSIONS

This paper discusses the basic roles of power electronics and power electronic conversion in different energy systems and their management. After this modern power electronics technologies are discussed. The development of modem power electronics has been briefly reviewed. Finally the contribution of power electronic technologies for both wind turbine and photovoltaic technologies are explained.

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