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Power Electronics for Renewable Energy Systems: Current Approaches and Future Prospects

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***Abstract*—Power Electronics (PE) deals with the conversion and control of electric power in different energy systems. The PE topologies are found as a better option as compared to the mechanical techniques used earlier for Renewable Energy Systems (RES) due to the flexibility, sensitivity, bi-directional power flow control, fast switching capabilities and other important characteristics. This paper mainly reviews the current PE topological approaches used for the generation, transmission and distribution part. Generators used between generation and transmission part are mainly classified into Synchronous, Induction and Doubly-fed Induction Generators (DFIG). For the sustained and continuous output from these generators various control techniques (Scalar, Vector, and Matrix Controller) are used. For the distribution part grid integration techniques which include grid synchronization, control and microgrid are discussed in the paper. Further, the paper reviews the most recently proposed advancements for the development of these techniques. As a result, the study finds the issues and challenges in the modern PE systems and a future pathway is conceptualized**

***Index Terms*—Grid Integration, Power Electronics, Renewable Energy Systems, Synchronization**

I. INTRODUCTION

Power Electronics (PE) is concerned with the efficient conversion and control of electrical power[1]. The recent developments in electronics and communication have taken place majorly due to the advancements achieved in this field. Unlike linear electronics, in power electronics devices are not operated in an active zone but basically in the saturated or cut-off regions[2]. PE has worked exceptionally well in the transformation of energy systems towards automation.

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. This paper mainly gives an overview of the PE topologies used in the RESs. Further studying the latest advances, future possibilities have been analyzed.

Renewable Energy is defined as the type of energy the sources of which can be constantly replenished or the sources are limitless [3], [4]. Though there are various types of renewable energy sources, the paper is mainly focused on the hydroelectric, wind and solar power systems.

II. THE PRESENT APPROACHES TO PE FOR RES

As it is clear that the focus is on electrical power generation, there are major three parts of a electrical system from PE perspective which are: Generation, Transmission, and Distribution[5]. The study which is done in this paper is mainly related with the conversion of mechanical or thermal energy to electrical power.

A. Hydroelectric and Wind Energy Generation

In hydroelectric and wind energy systems, doubly-fed induction machines with Pulse Width Modulator back to back (DFIM-PWMBTB) converters are preferred due to improved power quality [6,7]. There are various control techniques which have been designed to supervise the DFIM-PWMBTB converters which are mainly categorised into scalar, vector, and matrix controller techniques [6]. Vector and Matrix Controller techniques which include decoupled control of active and reactive power [8], stator flux oriented vector control[9] and direct power control [10] are very much popular. Other than this there are various other types of generators [11]-[16] used as per the situations, an overview of which is shown below:

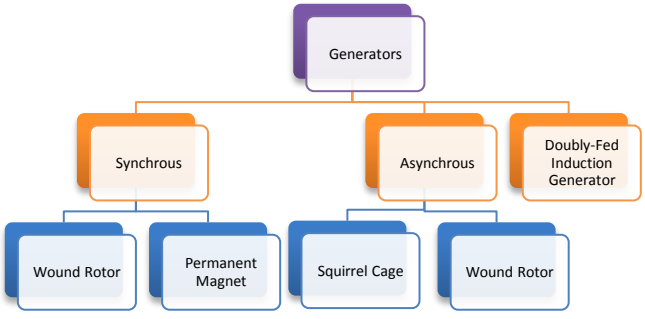

Fig. 1: Types of Generators [11]

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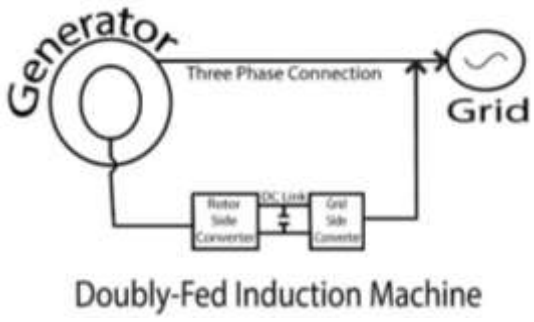

Fig. 2: Basic Design of DFIM [6]

1. Basic Design and Principle of DFIM

The basic operational principle behind the DFIM is electromagnetic induction as mechanical force is produced by the interaction of two rotating magnetic fields applied at different frequencies on the rotor and the stator. Further, the three-phase connection is designed [6] as shown in the Fig. 2.

Block Diagram of Back to Back converters used in the above system has been shown in Fig. 3 [23].

B. Solar Energy Systems

The approach to solar energy systems (SES) is a little different as the transformation of thermal energy is taken into consideration instead that of mechanical energy. SESs are mainly divided into passive and active systems which are further classified into various types [17], [18]. From PE perspective, the main focus will be on the photovoltaic solar cell, a type of active SES. In wind and hydroelectric energy power generation systems studied earlier, the energies are converted to AC by generators but 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: [19]

1. *String Inverter:* In this type of inverter 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.
2. *Module Inverter*: In this type, each PV module is connected to the separate inverters and then these inverters are paralleled which gives AC as the resultant output.
3. *Multi-String Inverter:* This is a modified form of the string inverter in which string inverters are replaced by DC-DC converters and after connecting these in parallel combination, an inverter is connected before the resultant output.

Now, a common topology of PV converters can be figured in the form of the block diagram in the Fig. 4. The major topologies used in PV converters namely are: H5 Bridge topology, Highly Efficient and Reliable Inverter Concept

(HERIC) topology and the single-phase three-level Neutral Point Clamped (3L-NPC) topology etc. [19]. The multilevel converters just like 3L-NPC are more useful as compared to the two-level voltage source converters because they have improved power quality, lower voltage distortion, reduced rate of change of frequency assuring less power loss, lower common-mode voltages, etc. [20]. Control techniques used for PV converters are primarily modulated voltage oriented control [21]. The techniques used for the modulation are phase shift pulse width modulator (PWM), Level-Shifted PWM, Hybrid PWM, Space Vector Modulation algorithms, Selective Harmonic Elimination, Nearest Vector Control, Round Method etc. [20].

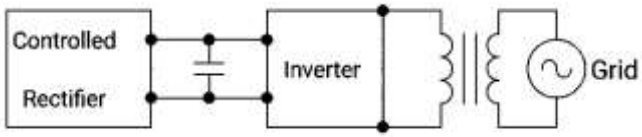

Fig. 3: Block Diagram of Back to Back Converter [23]

To ensure the maximum power extraction, maximum power point tracking (MPPT) techniques are used. For confronting the issue of partial shading which significantly reduces the efficiency these schemes are extremely useful and are also preferred in wind energy systems [22]. These techniques are mainly based on Optimisation Hybrid approaches, Extreme

Seeking Control, Curve fitting, Active Bypassing of Shaded Cells, Distributed MPPT using the programmable logic controller, Optimal Current Control etc. [22]

C. Grid Integration

To achieve the best standards of power quality, it is important that the distribution system (grid) variables are well monitored and controlled. This work is done under the scope of grid integration which is defined as the "interconnection of generating sources in the transmission network" and responsible for the balance in supply and demand for which it includes the concept of synchronization, control and microgrid [6], [24]. Synchronization aims at the minimization of differences in different variables between the generator output and grid supply. The techniques which are being popular for this purpose are: Sliding Discrete Fourier Transform (SDFT) [25], Non-linear least square multi sine fitting algorithm

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[26], Adaptive Notch Filter based algorithms, Artificial Neural Network and Fuzzy Logic, Cascaded delayed signal cancellation phase-locked loop (CDSC-PLL), Synchronous Reference Frame PLL, Enhanced PLL, Radial Function Basis Neural Network (RFBNN) [27], Quadrature based PLL, Frequency Locked Loop etc. all comprehensively cited in [24]. All the mentioned techniques have different implementation methods and are used as per the requirement of modern RESs and their specialised study can be done with the help of mentioned references.

Now, we come to the concept of the microgrid. A microgrid is defined as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid." [28]. A microgrid can be operated either in the grid-connected mode for Island mode. Microgrids can be thought of as a distributed energy resources which provide a specific approach to the power distribution system resulting as improved power quality, enhanced reliability, less greenhouse gas emission, demand reduction, cost control and standby generation etc. These are further helpful in the energy supply to remote rural areas which are connected to the centralized grid. They also provide energy security in the case of weather conditions assuring better cyber and physical security due to the decentralized architecture and also avoiding the dangerous consequences of cascading stages. [29].

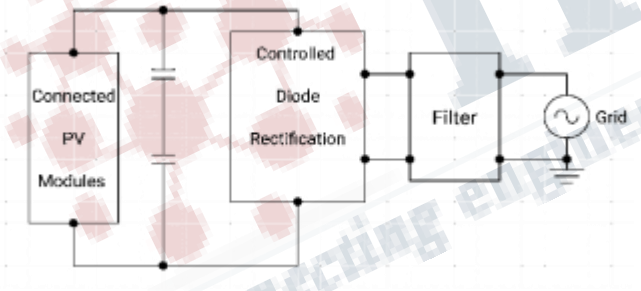

Fig. 4: Block Diagram of PV Converter

III. LATEST CONCEPTS UNDER STUDY

A latest study proposes the use of the liquid cooled pipe conductors in the windings of high frequency and high power inductor PE circuits.

This proposal assures lesser skin effects and smaller winding losses as compared to the other conductors. [30]

- Another study proposes an image processing based Chaotic Baker map array reconfiguration technique which is proven to be very much efficient and has minimised power loss and enhanced energy storage as compared to the techniques are known till now. [31]
- Modern RESs use mathematical modelling for optimal active power dispatch but when real system condition changes and the model becomes inaccurate then there is a huge difference between the desired and that is why a new work proposes AI-based deep reinforcement learning (DRL) based approach to give fruitful results under uncertain conditions on the basis of training given to the DRL agent [32].
- At the trends in inclined towards microgrid for better and easy power quality obtention. In this flow, recently proposed a selective harmonic compensation technique integrated with the hierarchical control framework using current based approach is notable [33]. This work may be further studied and helpful in achieving the optimum power quality even in low voltage microgrid and many other benefits.

IV. CHALLENGES AND FUTURE TRENDS

Power Electronics circuits are the next focus point now due to their inherent characteristics of automation. The researchers being continued on the electric systems are mainly dealing with the smooth operation, increase in dynamism, improving power rating, power quality issues etc. Researches that have been discussed earlier have brought us far but still, there is a huge scope of advancements. Solar energy has yet to achieve its optimum level of usefulness a recent a report published in the TOI [34] reveals that solar energy creates the worst impacts on our environment. Even now due to the lack of efficiency it is taking almost 10 times larger space as compared to the conventional nuclear power source. This issue is a big problem indeed. Commercial application of concentrated power solar cells is yet to be explored. Perovskites solar cells have exceptional potential. [35]. As we notice for solar power generation the trend is going towards using a transformerless inverter for the conversion of DC to AC. Microgrids are being in trend due to the specific approach. AI-based control modelling techniques like the DRL technique discussed in the paper are the subject of further studies

CONCLUSION

This paper analyses the current approaches of PE use for RESs and further possibilities of development due to the potential of automatic operations. Rapid advancements are taking place in PE. The PE technologies are used widely and the advances are taking place, which will soon be in commercial form, are discussed in this paper. An inclination towards microgrid under the scope of transmission distribution part and AI-based control methods have been clearly observed which assimilate a huge scope of research.

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