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A comprehensive review on inverter topologies and control strategies for grid connected photovoltaic system

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ABSTRACT

The application of Photovoltaic (PV) in the distributed generation system is acquiring more consideration with the developments in power electronics technology and global environmental concerns. Solar PV is playing a key role in consuming the solar energy for the generation of electric power. The use of solar PV is growing exponentially due to its clean, pollution-free, abundant, and inexhaustible nature. In grid-connected PV systems, significant attention is required in the design and operation of the inverter to achieve high efficiency for diverse power structures. The requirements for the grid-connected inverter include; low total harmonic distortion of the currents injected into the grid, maximum power point tracking, high efficiency, and controlled power injected into the grid. The performance of the inverters connected to the grid depends mainly on the control scheme applied. In this review, the global status of the PV market, classification of the PV system, configurations of the grid-connected PV inverter, classification of various inverter types, and topologies are discussed, described and presented in a schematic manner. A concise summary of the control methods for single- and three-phase inverters has also been presented. In addition, various controllers applied to grid-tied inverter are thoroughly reviewed and compared. Finally, the criteria for the selection of inverters and the future trends are comprehensively presented.

1. Introduction

Research towards improving photovoltaic efficiency and increasing installation of residential rooftops PV systems is a clear indication that the distribution generation (DG) in upcoming years will be dominated by PVs. The desire to limit conventional energy sources and their use due to environmental concerns has also played an important role towards increased DG utilization. Furthermore, the electricity bills for the consumers having PV rooftop systems are drastically decreased (for example, in countries with net-metering system installed), realized as benefit by the consumers. Renewable Energy (RE) sources are the best solution to provide green energy to overcome the global energy issues. Furthermore, the use of RE sources is increased during the last decade through the advancement in the grid integration technologies [1]. Solar PV energy is one of the extensively emerging RE source. PV has the proficiency of generating the electricity in a reliable, clean, and noiseless way. Worldwide, around 75 GW of solar capacity was installed until 2016 and its capacity increased drastically to 303 GW at the end of the year [2]. Now PV is the third most important RE after hydro, and wind in terms of globally installed capacity.

PV systems can be categorized into two main groups, that are, the standalone (off-grid) PV systems and the grid-connected (on-grid) PV systems [3]. The standalone system operates independent of the utility grid. On the other hand, the grid-connected applications employ PV system in conjunction with the grid. Currently, in comparison to the standalone PV systems, the use of grid-connected PV is widely adopted in my practical applications [4–7]. A typical configuration of the grid-connected system is presented in Fig. 1, consisting of a PV system and number of peripheral modules, such as the filters, transformers and the conversion technologies. The conversion technologies includes the DC/DC and DC/AC power electronics based converters. As opposed to the off-grid PV systems, the grid-connected PV does not require storage system as they operate in parallel with the electric utility grid. In addition, they supply power back to the utility grid when the generated power is greater than the load demand.

A DC/DC converter together with a Voltage Source Inverter (VSI) or

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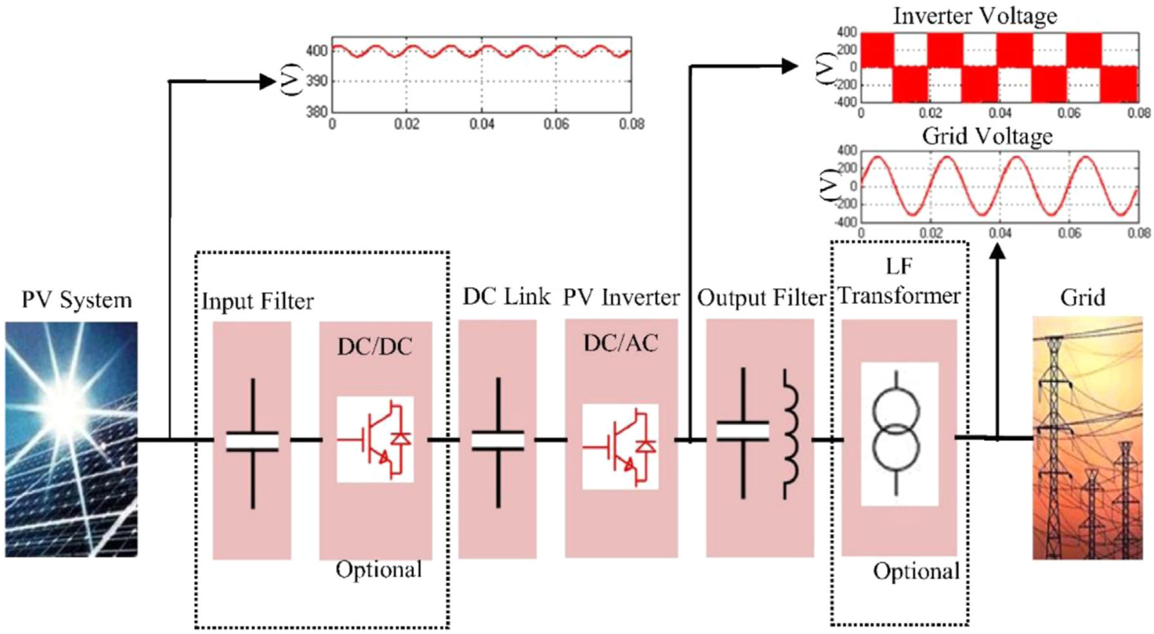

Fig. 1. A typical structure of off-grid system.

a Current Source Inverter (CSI) are typically used to connect the PV system to the grid. For DC to AC inversion purposes, the use of VSI in the grid-connected PV system is gaining wide acceptance day by day. Thus, the high efficiency of these inverters is the main constraint and critical parameter for their effective utilization in such applications [8]. The proper operation of the grid-connected PV mainly depends on the fast and accurate design of the VSI control system. A proper VSI controller is, therefore needed for the effective tracking of the desired reference command and achieving a good performance of the PV system. In a grid-connected PV system, the injected currents are controlled by the inverter, and thus, maintains the DC-link voltage to its reference value and regulates the active and the reactive power delivered to the grid [9].

The design of the appropriate control system for enabling the injection of controlled PV power into the grid is very critical for the effectiveness of the system. The active power from the PV is controlled with the temperature and incident solar irradiance of the PN junction diode. Considering the voltage regulation scheme and the system rating, the output reactive power reference is designed based on the method discussed in [10]. It is worth mentioning that the generated output power from the PV array is inherently unstable. With the modern developments and advancements in the power electronics, the parameters of the PV system, i.e. active (P) and reactive (Q) power can be effectively controlled to enhance the overall performance of the grid-connected system.

The generation of active power in order to fulfill the load demand is the main purpose of the PV system. However, it can also be used to perform the advance functionalities of supporting the grid such as the voltage and reactive power support, fault ride through, power quality improvement, reduction in power losses and the active power filtering. The advanced functionalities can be accomplished by using diversified and multifunctional inverters in the PV system. Inverters can either be connected in shunt or series to the utility grid. The series connected inverters are employed for compensating the asymmetries of the nonlinear loads or the grid by injecting the negative sequence voltage. On the other hand, the shunt inverters are used for enabling the active power filtering function of PV by injecting the asymmetric and nonlinear current locally through the PV systems at the Point of Common Coupling (PCC) [11,12]. In some case, the series-parallel combination is carried out for providing both voltage (through series inverter) and current (through parallel inverter) support, such as in unified power quality conditioner (UPQC). Various power inverter topologies and their control structures for grid-connected PV systems are comprehensively reviewed in this paper.

In recent years, the development in the solar PV is progressing day by day due to the continuous government support for RE based electricity production, cost reduction in materials, and technological improvements. In this review, the global status of PV market and classifications of power electronic based converters are focused in detail. Furthermore, various inverter topologies based on their design, classification of PV system, and the configuration of grid-connected PV inverters are discussed, described and presented in a schematic manner. A concise review of the control techniques for single- and three-phase inverters has also been demonstrated. After that, various controllers applied to grid-tied inverter are thoroughly reviewed and compared. Finally, selection of inverters and future trends are comprehensively presented. The contribution of the proposed review study is comprehensively summarized in Table 1 by an extensive critical and analytical comparison with the various surveys already published in the literature.

The rest of the paper is organized as following: an overview of the global status of PV market is demonstrated in Section 2. Section 3 categorizes the several classifications of power electronic based converters. The various topologies of inverter based on their design are elaborated in Section 4. Section 5 and Section 6 respectively investigate the classification of the PV systems and various configurations of the grid-connected PV inverters. The generic control of the grid-connected PV system is described in Section 7. Section 8 scrutinizes various control methods for the grid-connected PV systems. The selection of appropriate inverter and control method is elaborated in Section 9. Section 10 presents the future scope of the research in the grid-connected PV systems. Section 11 concludes this review with a concise summary and proposition for the future work.

2. Global status of the PV market

The installed capacity of solar energy in 2016 is equivalent to the installation of more than 31000 solar panels every hour [34]. Considering the cumulative comparison status of the last five years, more solar PV capacity is installed in 2016. The percentage increase of the installed PV capacity in 2016 is 48% compared to that of 2015. The