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Overview of micro-inverters as a challenging technology in photovoltaic applications

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ABSTRACT

One of the key components of the photovoltaic (PV) system is inverters due to their function as being an operative interface between PV and the utility grid or residential application. In addition, they can be employed as power quality conditioners at the point of common coupling (PCC). It should be noted that in inverter technologies, there has been an increasing interest to achieve robust output power injection capabilities with lesser design complexity in terms of controller part and power circuit topology. Micro-inverters (MIs) are module based type of inverters that have aroused much interest in recent years. Owing to their distributed architecture mounted with individual PV modules, system reliability can be improved remarkably by using MIs. Furthermore, a module based nature of the MI architecture provides a number of advantages, such as low converter power rating, low power losses, accurate maximum power point tracking (MPPT) ability against partially shading conditions and elimination of PV panel mismatches. However, there is still known weighted conversion efficiency of MIs ranges between 90% and 95%. Therefore, novel designs focus on the known weak aspects of traditional MIs and their failure mechanisms. In this paper, state-of-the-art technologies for MIs with a detailed survey on the technical features consisting of power circuit configuration, control structures, grid compatibility abilities, decoupling capacitor placement, energy harvesting capabilities, and safety mechanisms are presented. Additionally, elaborated comparison on MIs topologies is realized and some future research fields on MIs are summarized.

1. Introduction

Energy sources including coal and natural gas consumption for electricity generation grow over the world in 2016, on the other hand the use of petroleum and other liquid fuels continues to decline steadily in recent years. However, consumption of these sources is leading to energy crisis and environmental issues such as global warming and impact of carbon emissions [1]. Therefore, renewable energy sources attract great interest because of being sustainable, abundant, inexhaustible and environmentally friendly. The sources of the renewable energy are inherently renewed on its own nature such as biomass, wind, hydropower, geothermal and solar. Among these, solar energy has the advantage of being applicable in almost every place with the appropriate placement of PV arrays compared to other renewable sources [2]. Over the last decades, PV technology has been demonstrated a remarkable growth and the global power generating capacity of installed solar PV systems reach to 231 GW as shown in Fig. 1 [3].

The capacities of PV power plants continue to increase with decreased installation costs and financial supports provided by governments. However, solar systems are suffering from low efficiency and they are employed with the power electronics based devices for efficient energy yielding [4]. In order to use solar energy effectively, a comprehensive research has been performed on the grid-connected PV generation systems. The 98.7% of total PV power installed in the Europe corresponds to grid-connected and only 1.3% of it for off-grid [5]. In both grid connected and residential PV systems, the inverter that converts the direct current (DC) to alternating current (AC), attracts great attention, due to having a crucial effect on enhancement of power efficiency and reliability. The researches in PV interface are focused on reducing cost and improving performance by modifying power circuit topologies and controller structures. The configuration of the PV panels and proper selection of inverter associated with the placement of PV panels will directly have an influence on cost and efficiency of the entire system. Depending upon the solar PV panel arranging, the system can be designed in different four general ways. There are centralized inverters, string inverters, multistring inverters and module based inverter configurations available as demonstrated in Fig. 2 [6]. The centralized inverters, which demonstrated in Fig. 2(a), are defined as an

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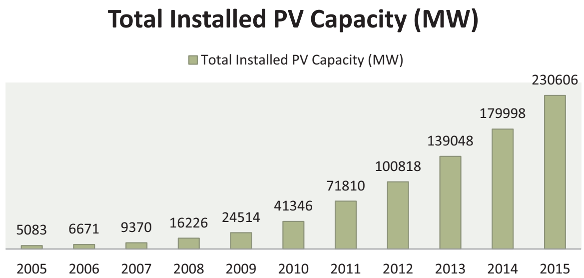

Fig. 1. Global cumulative installed solar PV capacity.

old technology. These inverters are based on the connection of a large number of PV modules to an inverter. The most crucial drawback of these inverters is mismatching losses. They suffer from missing individual MPPT for strings, different orientation of modules and when a part of an array exposed to different shading conditions during the day, entire of the system is affected by this condition. Centralized inverters are not capable of dealing with these states. Further, the losses in the string diodes and the utilization of high-voltage DC-cables between the PV modules and the converter make these inverters inconvenient. Besides these disadvantages, having high inverter efficiency, simplicity and low cost make it popular. Centralized inverters have been still enormously used in medium and high power PV system applications [5,7]. String inverters, which provided in Fig. 2(b), can be considered as a reduced version of centralized inverters. When we consider a medium power application (1–10 kW) of PV systems, which is installed on a roof and may be positioned on an irregular area, PV panels cannot be installed with the same orientation and be exposed to different shading conditions during the day [7–9]. So this type of inverter is usable for such applications because only one string is attached to one inverter and thus the orientation problems are reduced. Also allowing individual MPPT of each string is another advantage of the string inverter. Consequently, this configuration increases the overall system efficiency when compared to the central inverter. However, a disadvantage compared to the centralized inverters is higher price per kW because of the rather low power level per unit [10,11].

Multi-string inverters can be assumed as a variation of the string inverter. Fundamentally, it is a string inverter, but it has one more input. Extra input ports of inverter ensure efficient control of the entire system by controlling of MPP in small strings of PV systems. Actually, the multi-string inverter configuration formed on more than one distinct and independent PV panel strings with their own MPPT connected to a unique inverter [11]. Moreover, it can reach a higher power level than a string inverter and removes the higher price per kW handicap of string inverters against to centralized inverters. Also, a plant can be constructed with fewer components when compared to string converter, and this supplies financial gain in terms of cost and workmanship. Because of having two-stage designs, input voltage range varies in a wide range. Hence, it may benefit from the daylight more than other types of inverters and this increases power generation capability. Last but not least, multi-string inverters, which is exhibited in Fig. 2(c), allow design facility in different orientations to designers [7,12]. In MI configuration (also named as module integrated converters or AC module), which is demonstrated in Fig. 2(d), one inverter is attached to per PV panel. MIs are mostly designed for power rating between 50 and 400 W with power conversion efficiencies above 90%. Due to being proper to the low power applications, these inverters are small and can be integrated to the frame of the PV panel. In addition, these panels can be connected to the grid through the module integrated inverters. Advantages of this configuration can be expressed as eliminating of the mismatch losses between the PV modules, removing the bulk of DC cabling, providing the facility of optimizing the converter to the PV module, and also allowing individual MPPT of each module [6,7,10–14]. Moreover, minimizing of DC wiring prevents the risk of electric arc and firing. On the other hand, the low power level per unit

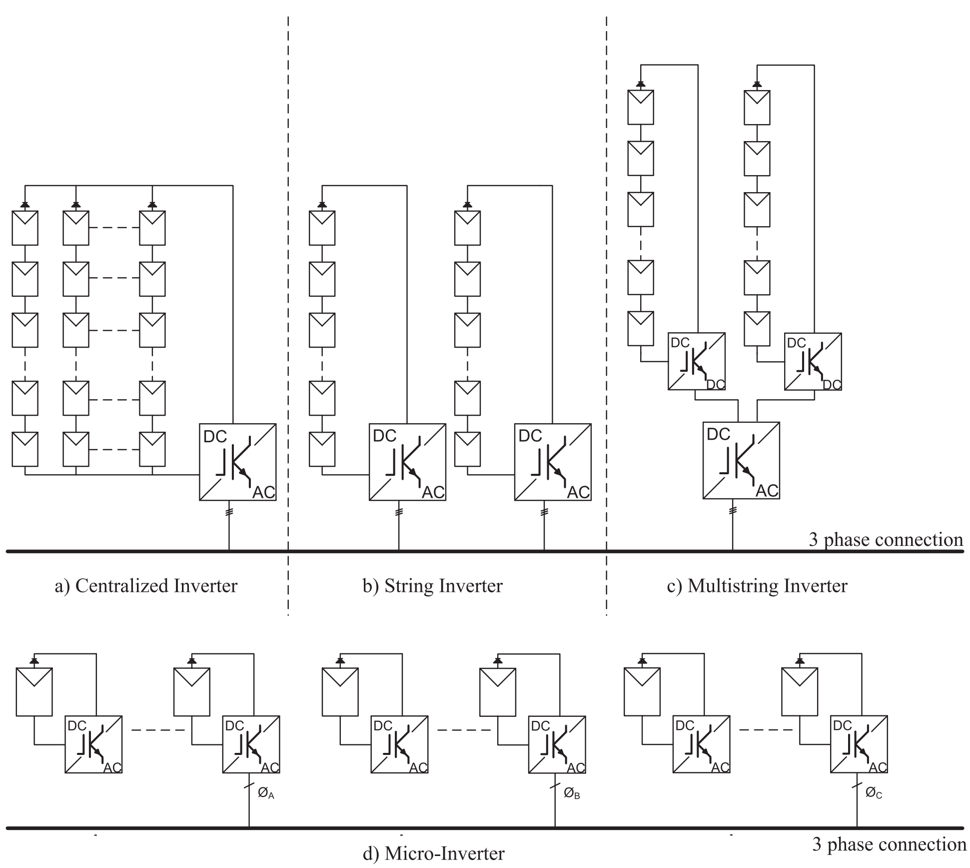

Fig. 2. Inverter design configurations.