Modular Hybrid Multilevel Converter Topologies for Solar PV Farms Connected with Power Grid

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Abstract – This article is oriented to perform a comprehensive study on various modular multilevel converter (MMC) topologies and their properties for solar photovoltaic farms interconnected to power grid. These topologies are advantageous in terms of lower power dissipation on switching, less harmonics at the output, lower electromagnetic interference and are used in medium and high power delivery systems. The selection of particular topology depends upon the power rating and application based demand of converter. The MMC contributes to the improvement in power quality issues such as imbalance and distortions because of interconnection of systems.

Keywords – Modular Multilevel Converters (MMC), Photovoltaic (PV) Farm, Converter Topologies, Chain link converter. Modular hybrid MMC.

I. INTRODUCTION

The utilization of other energy sources such as hydro, fossil fuels feeding the power grids is reduced significantly with the developments in solar photovoltaic power production sector. The growth in solar photovoltaic installations in rural and urban areas revolutionize the evolution of conventional photovoltaic (PV) converters to more complex to topologies to increase power output, efficiency, reliability and stability of the system without impacting the cost. Therefore, the recent research and emerging technological trends of PV converter are discussed and their possible advantages are highlighted.

The considerable advantage associated with connecting the PV farms with the power grid is that the batteries are not required to store the electrical energy which is more cost-effective and also require less maintenance as compare to the standalone PV systems [1-4]. The power delivered by the PV farms to the grid is further transmitted, distributed and consumed helps in generating the revenue to power delivery PV farms. This concept has unleashed the power of the sun with merits such as the cost reduction, technology development, environmental awareness, and the right incentives and regulations.

A typical configuration of PV farm connected to the power grid is shown in figure 1. The PV modules connected in series-parallel combination generate DC current depends on the solar irradiance, module temperature and the DC voltage at the terminals of PV module[5-8]. The generated DC power from the array of PV modules is transformed into AC power and injected to the power grid via PV Converters. The low frequency transformers, filters, converters, measurements and monitoring units are additional elements of grid tied PV farms for the regulation and control. With the advancement in converter technologies the converters have become extremely reliable, compact and tracking the maximum power output from the PV farms.
The power electronic based converters added control degree of freedom that leads to the efficient operation and enhanced controllability of the whole system [9-12]. Whereas the overall performance of the converter can be judged by installation cost efficiency isolation, power density minimization of leakage current galvanic isolation and anti-islanding.

The focus of the paper is on the modular multilevel converter topologies which are targeting high power application with higher efficiency[13].

This paper is organized to present the classification of converter topologies followed by the emerging topologies such as modular/ chain link multi-level converters. The modularity at the converter phase level with different connections is also presented. Finally future trends and challenges are also described and concluded in it.

II. CONVERTER TOPOLOGIES

Based on the PV module arrangements the converters are classified as DC-AC module integrated/ micro converter, string converter, and multi-string/ central converter dedicated to single PV module, string of PV modules and array of modules respectively as shown in figure 2. The micro and single string converters are smaller in size and have low power rating thus require voltage elevation to build the small distribution grid connection [14-18]. Therefore a DC-DC voltage boost stage is associated with these converters usually have a high frequency transformer to provide galvanic isolation and elevated voltage with decrease in power conversion efficiency of converter. Hence these converters are enclosed at the back side of the module and uses low voltage semiconductor devices such as MoSFETs, SiC, GaN in their topologies [19].

The DC-AC string converters have with transformer and transformer-less configurations and sub categorized into single and two stage conversion topologies, where one stage is DC-DC voltage boost. Moreover these converters can be found with or without galvanic isolation that can be introduced at the grid side with low-frequency transformers or within the DC-DC stage with a high-frequency transformer [16-19]. These types of converters are very popular for small and medium scale residential or commercial power production units.

With the number of PV modules connected in series-parallel string combination to make a PV array controlled by single central converter These converters under fault condition makes the whole system shuts down and the maximum power point tracking ability of these converters is poor compared to the string and micro converters [18-22]. These converters are insulated-gate bipolar transistor (IGBT) semiconductor enabled and used for large plants. The dual central converters are applicable for the very large solar PV farms of capacity in several Mega-Watts.
The micro converter of interleaved flyback topology has features such as voltage elevation, maximum power point tracking (MPPT), galvanic isolation and the two H-bridge topology controls the grid synchronization, power flow control and voltage across the DC-link. Further enhancement in the technologies leads to the compactness by removing the high frequency transformers with flyback converters connected in parallel, which further reduces the voltage and current ripples and increases the life of the capacitor. On the other hand the power conversion efficiency of H-bridge is better [22-26].

The H-bridge low frequency transformer and H-bridge high frequency transformer string converter topologies have features like voltage elevation, galvanic isolation and simple circuitry. These topologies are less popular because the transformers are bulky and have low power density making the transformerless H-bridge topology overshadow its usage with H4, H5 converter configurations with a DC-DC boost stage [25-28]. The H5 string converter helps in dealing with the leakage current and maintains the DC-link voltage. Another converter topologies are H6D1 and H6D2 having six switches with freewheeling diodes blocks the reverse flow of current and provides unipolarity unlike H5. The neutral point clamped topology with two levels (2L-NPC), three levels (3L-NPC) are further modified to five level (5L-NPC) provides output without a switched common-mode voltage since the neutral of the grid is grounded to the same potential as the midpoint of the dc link[26-28]. The cascaded H-bridge (CHB) configuration available in single, two and four H-bridge are substantially used in solar PV application due to stability. The highly efficient and reliable integrated converter (HERIC) separate the grid filter from the converter during freewheeling are also favored for PV applications. However the modular converter topologies become popular because of their advantages such as high efficiency, high reliability, durability, easy switching and control [27-30].
III. MODULAR CONVERTER TOPOLOGIES

In the modular topologies the need of external source is eliminated and a capacitor or inductor is used as voltage and current source floating with respect to ground potential to power the converters [31-32]. These sources are actively balanced by the switching process of power converters.

The power converters used for the transmission and distribution purpose are voltage source converters (VSC) and current source converters (CSC) respectively are further classified based on the switching actions i.e. multilevel, multi-pulse and mixed level converters. The modular multilevel VSC have shown a breakthrough in the converter technology where the modularity refers to the development of a large system using small subsystems with compactness and results are comparable to large system [33].

The power electronic building blocks or cells integrate the passive elements in series or parallel to the functional blocks of modular multilevel converters (MMC), which are highly efficient in delivering high voltage without power quality problem such as harmonics and inter-harmonics. In addition the simple design and ease in controllability have increased their popularity over monolithic converters [32-35].

The cells provide forced commutation are categorized as half-bridge cells having two switching devices and the current flow in it is unidirectional, full bridge commutation cells the output obtained is different voltage levels, mixed commutation cells provides different voltage levels at output, double commutation cells, flying capacitor commutation cells etc. The multilevel VSC are broadly classified as monolithic multilevel converters and chain multilevel converters as shown in figure 3.

The monolithic converters need large number of switches connected in series for high voltage applications. This is expensive and the system is complex. The different types of monolithic converters based on the various structures of DC-link voltage or current to generate leveled voltage or current. The commonly used monolithic converter topologies are neutral point clamped (NPC), flying capacitor (FC) and reinjection voltage controlled sources etc [28-33]. The current and voltage are controlled by pulse width modulation (PWM) technique in these topologies.

On the other hand the modular/chain multilevel converters have chain link structures with number of cells having low switching frequency and high conduction losses. Thus the modular hybrid VSC comes in to picture which inherits the features of monolithic and chain multilevel converters [33-34]. The major advantage of this topology is that the power electronics devices used in it are lesser than the monolithic and chain link whereas the modularity rate is higher.
The merits such as defined pure sine wave output, defined voltage level output, power quality controllability and the challenges such as large energy storage in capacitors, limited current scaling and DC short circuit faults are associated with the other converters are handled by the modular hybrid converter topologies as shown in figure 4.

In the modular hybrid converters the number of active and passive switched used are lower, reduced switching losses, compact structure and the need of filters is nil. These modular hybrid converters are connected either in series or in parallel connection of phases. Figure 5 represents the output, DC-link and chain link and parallel link respectively[35].
CONCLUSION

This paper is dedicated to review the state of art in the converter topologies for the grid connected solar PV farms. The modular multilevel converters voltage source converters are categorized, analyzed and synthesized. In addition the concept of multilevel hybrid converters has been discussed to get insight of high power application areas. The general trends and challenges are also highlighted to clarify the choice of converter topology based on the application area and to derive and shape the future of modular multilevel converter technology.

REFERENCES


