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Inverter Topologies for Grid Connected Photovoltaic Systems: A Review

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Abstract - *The increase in power demand and rapid depletion of fossil fuels photovoltaic (PV) becoming more prominent source of energy. Inverter is fundamental component in grid connected PV system. The paper focus on advantages and limitations of various inverter topologies for the connection of PV panels with one or three phase grid system. In this paper different converter topologies used for inverter. The inverters are compared and evaluated base on their reliability, cost, rating, shading effect, efficiency and power harvesting on the basis of these parameters most effective topologies suggested.*

***Key Words*: Photovoltaic (PV), centralized inverter, string inverter, multi-string inverter, micro-inverter**

1. INTRODUCTION

The sun energy is considered as the most renewable and freely available source of energy [1]. Photovoltaic (PV) power is clean and unlimited energy source, it is probably the best technology amongst all non-conventional energy sources and therefore a considerable amount of research has been conducted recently in this field. The PV power fed to the utility grid is gaining more and more visibility, while the world's power demand is increasing [2-16]. To better utilize the PV power, interconnection of grid with PV system is needed [3]. Connection of PV system, eliminating battery usage, to the grid has become cost effective with less maintenance [4].

Fig 1 shows the block diagram of a basic grid-connected PV system that involves PV array, converter-inverter combination, Maximum Power Point Tracking (MPPT) control and the entire control unit. The PV array generates the DC power which is converted to suitable or desirable form by using DC-DC converter. Further DC voltage is converted to AC using DC-AC inverter to fed one or three phase utility. In order to satisfy the grid requirements the control unit is used. The efficient power harvesting is monitored by using MPPT control which continuously track down the energy variations and extract maximum available power from the PV module [2].

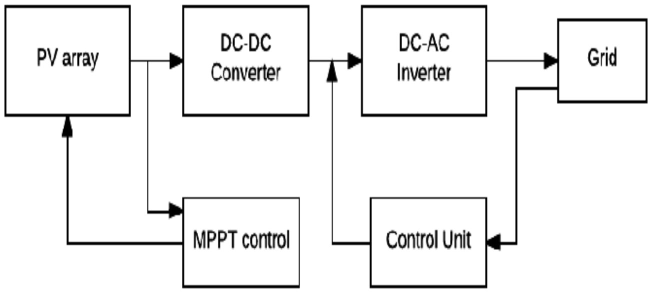

Fig- 1: Block diagram of a basic grid-connected PV system

Inverter constitutes the most significant component of the grid connected photo-voltaic system. The power electronics based device, inverter inverts DC quantity from array in AC quantity as suitable to grid. The three important topologies based on architecture are introduced in the paper, which are centralized inverter, string/multi-string inverter and AC module integrated micro-inverter. For large power generation central inverters are preferred which have common MPPT and centralized inverter for any number of PV modules and their combinations. A multiple PV modules connected in a series is called a string inverter. For each string there is separate inverter and MPPT control, forming a string inverter. Multi-string inverter configuration consists of DC-DC converter connected in every string with own separate MPPT, which further connected to inverter via common DC bus. Integrated inverter technology is used in micro-inverter, in which every module has separate inverter and MPPT, so that power can directly supply to the grid through micro-inverter [8, 9].

2. STANDARDS OF GRID-CONNECTED PV INVERTER

The safe, good quality and reliable electric power is the primary responsibility of power engineers [10]. In consideration of renewable energy sources inverter connecting grid and PV panel satisfying PV system standards, may improve the reliability of system, as the main aim of the inverter is to supply pure alternating current to grid [4].

Several standards are introduced in market, which are dealing with the interconnection of PV system with the grid, like Institute of Electrical and Electronics Engineers (IEEE), *International Electro technical Commission (IEC) and* National Electrical Code (NEC). Out of though the most preferred standards are IEEE 1547 and IEC 61727 [3] are discussed in table 1. Total harmonic distortion, galvanic isolation, DC current injection, anti- islanding protection, voltage range and frequency range are comes in picture when the PV is also connected through inverter to the utility. According to the standards these parameters must be within specified limits [4].

2.1. Anti- Islanding protection

Anti-islanding protection required the interruption of inverter from grid when the fault takes place on grid. The islanding condition can severely affect the equipment connected to the system, so anti-islanding identification is very essential. According to the IEC 61727 and IEEE 1547 standards anti-islanding protection is required. PV system cannot be able to sustain islanding condition that can be attended in 2 seconds [7].

2.2. Galvanic isolation

Galvanic isolation constitutes the most important issue while considering safety in the PV system. The non-existence of galvanic isolation results in ground leakage current occurs because of the capacitance present in between the PV cells and ground plate. Galvanic isolation helps to decrease leakage current of PV and grid system. As per National Electrical Code (NEC) galvanic isolation should be used for PV system more than 50V. In PV system the main advantage of this isolation is that when fault takes place on any side the other side remains unaffected [4, 6].

Table -1: Standards of Inverters for Grid Connected PV System [5, 6]

Parameters	IEC 61727	IEEE 1547
Total Harmonic Distortion (THD)	5.0%	< 5%
Power factor (p.f)	0.90	0.85
DC current injection	Less than 1.0% of output current	Less than 0.5% of output current
Nominal Power	10 kW or smaller PV systems connected to low voltage utility grid	This standard covers distributed resources as large 10 MVA.
Voltage range	85 - 110%	88 - 110%
Frequency range	49 to 51Hz	59.3 to 60.5Hz

3. INVERTER TOPOLOGIES

For three and one phase grid connected PV systems various inverter topologies are used such as central, string, multi-string inverter, and micro-inverter base on their arrangement or construction of PV modules interface with grid and inverter as shown in fig 2.

3.1. Grid Connected Centralized Inverter

The central inverter transforms high DC power which is greater than 10kW to grid through three phase interconnection [comp 3]. It contain multiple panels connected in series which form strings and the string diode is applied to form parallel combination of these individual string to satisfy the need of larger system fig. 3(a) shows the series-parallel combination of PV panels. This centralized inverter technique has certain conditions such as mismatch between the PV modules, high voltage DC cable and high rating bulky electrolyte capacitor which decreases the life period of inverter. The centralized inverter system has some drawbacks like problematic installation, bulky, poor power factor (pf), high harmonic present in output current, inflexible design and complication in incorporating the system in future. Absence of MPPT for every PV module is the main limitation of this system. If the clouding or partial shading effect appears on some of the PV modules then overall operation of PV system get affected, that reduces the

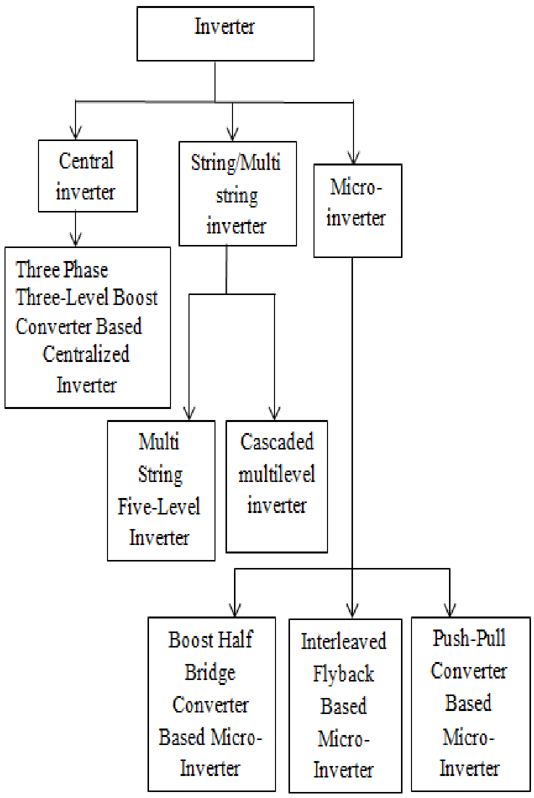

Fig-2: Inverter topology classification tree power generation and overall system efficiency decreases. These disadvantages encourage evolution of further inverter topologies [8, 9].

3.1.1. Three Phase and Three-Level Boost Converter Based Centralized Inverter

In this centralized inverter topology grid connected 3 phase PV system contains PV array, 3 level boost dc-dc converter and 3 phase inverter. Boost converter supports the MPPT performance and step up DC output voltage of PV array, further the 3 phase inverter regulates the voltage and inverts it in AC to supply the grid. 3 level boost converter have some superiority like it decreases switching losses, reverse recovery losses of diode and also reduction in rating of switches. All these factor result in reduction of cost and increase in the speed of operation as compare to traditional boost converter [10].

3.2. Grid Connected String and Multi-String Inverter

In order to get over the drawback of centralized inverter, string inverters are introduced. String is known as a group of series connected PV modules. The string inverter include number of series connected PV panels, forming a string and AC power get fed to the utility grid via inverter which is coupled to that string as the fig. 4(b) represent. Its power rating is less than 10kW due to single string is coupled with inverter. Presence of MPPT in every string results in more efficient MPPT operation as compare to centralized inverter. Therefore the clouding or partial shading effect is reduces by some amount.

In this system the power harvesting to the utility grid is more, minimized the losses take place in string diode and reduction in capacitor size hence the life period of this inverter is increases and the efficiency is better than the central inverter. But still there are some issues such as shading effect or effect of clouding. In this topology if the effect of shading arises on any of the PV modules from string, then the allover performance of that string get decrease so the power harvesting is minimal in grid connected string topology. For larger power rating further evolution in string inverter is carried out which is known as multi-string inverter [2,3].

The multi-string inverter topology has improve the power level because of which high rating power can be generated and also harvested in utility grid. As the fig. 3(c) shows this system comprises of lower power DC-DC converters with their individual MPPT in every string which are connected by common DC bus to supply the grid. This inverter has higher energy harvesting level than central inverter. The merits and drawbacks of this inverter are similar to string although it is high scale system [3, 9].

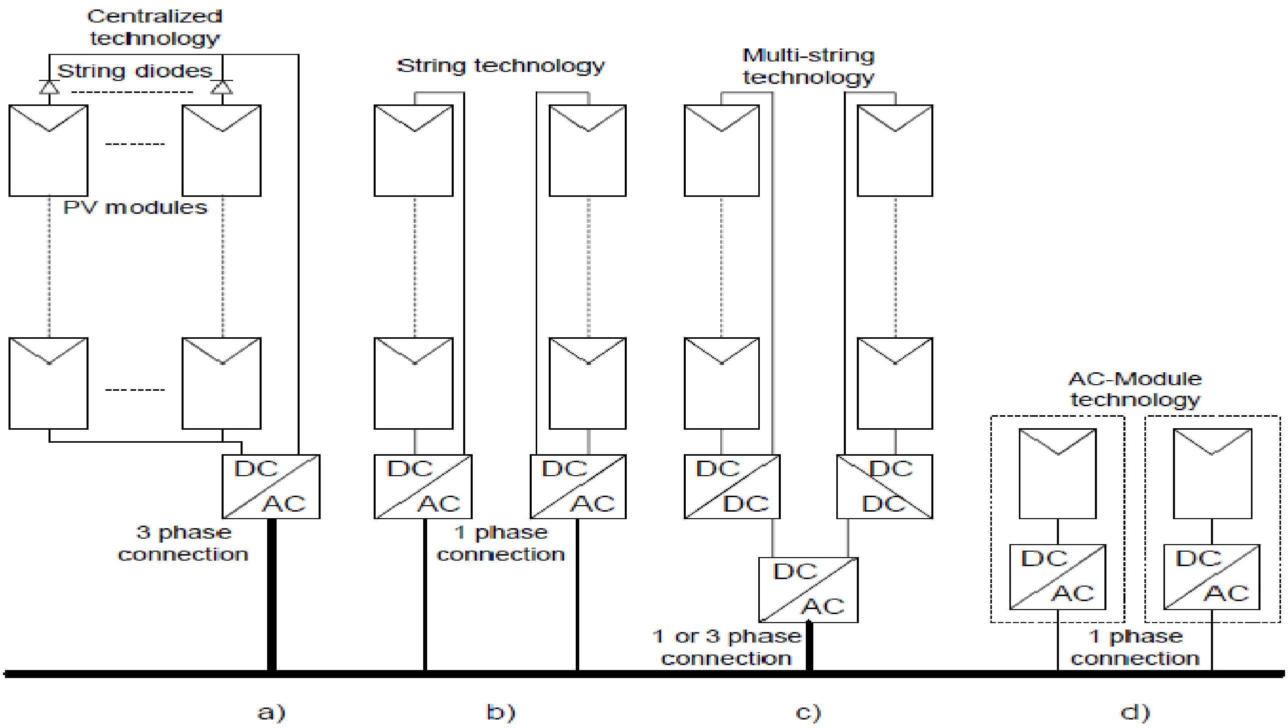

Fig-3: Photovoltaic inverter technologies a) Centralized technology, b) String technology, c) Multi-string technology, d) AC-Module micro-inverter technology [16]

3.2.1. Multi-String Five Level Inverter Topology

Multi-string 5 level inverter consisting of 3 strings of PV panels in that every string has its personal DC-DC boost converter and these converters are connected to common DC bus. These three strings are alliance with full bridge inverter via converter and bus. Due to this converter each string extracts maximal power separately and step- up the output voltage of inverter so that it can adjust with utility grid voltage to assure the power flow from panel to utility grid. In this inverter topology Pulse Width Modulation (PWM) control technique is used because of which the THD of this inverter is very much lesser as compare to conventional converter [11].

3.2.2. Cascaded Multi-level Inverter for String Topology

In comparison with any other multi-level inverter, cascaded multi-level inverter is more reliable. It consists of series combination of multiple numbers (n) of H-bridge inverters. String of photovoltaic panels delivers DC voltage to DC link and DC to AC inverter produces output voltage along with n number of levels. This topology generates the voltage waveform of high quality and the harmonics contained in output current get reduced, resulting in cutting down the need of filter. The main benefit of this inverter is that the semiconductor devices used in it having low rating as compare to conventional multilevel inverter and hence it come to be cost efficient and effective [12].

3.3. *Grid Connected Micro-Inverters*

The AC-module technology is the advancement in the inverter technologies to solve the drawbacks and losses of the central and string inverter system [16]. Module integrated inverter is used for small application with power range less than 300W [5]. Fig. 3(d) represent the micro-inverter topology involve the module integrated inverter means every module has its small size, low rated inverter with individual MPPT for every module, due to this micro-inverter the power is directly supplied to utility grid. The main advantage of this inverter system is that it can diminish or terminate the clouding and shading effect in PV system. If partial shading takes place on any one module, then it affects the performance of only that module and the other modules are unaffected. This micro-inverter topology also provides more accuracy in maximum power point tracking operation (MPPT) because every PV module has separate MPPT and no mismatch losses between PV modules. Therefore power harvesting to utility grid increases as compare to other inverter system due to its increasing efficiency and it also increases the life-span of the micro-inverter. It is compact and flexile in design and it is plug and play device that can be used easily by a person without any knowledge of PV installation [3]. There are few drawbacks like cost of installation is high, complex circuit model still there are some merits like reliability, compact design, supply maximum energy, low maintenance and also probability of expansion of PV system in future made this micro-inverter technology more trusted [2, 9].

3.3.1. Boost Half Bridge Converter Based Micro-Inverter

The boost half bridge micro-inverter topology contains two power conversion stages. At front stage the output capacitor is break into two individual capacitors C_1 and C_2 in DC-DC converter, also C_{in} and L_{in} are input capacitor and boost inductor respectively. The turns ratio of boost transformer which are having 2 output capacitor and 2 power MOSFET switches is 1: n and leakage inductance of primary winding is L_S. In DC– AC conversion stage, two capacitors C_3 and C_4 with voltage doubler circuit formed by 2 diodes (D_1, D_2) which are connected secondary winding of transformer and give DC voltage to this conversion stage.

Operation of both conventional and half bridge converter is same but the high step up ratio and galvanic isolation are an added attributes of the boost half bridge, which gives high voltage boosting capacity and fault protection. This topology has simpler circuitry consist of lesser number of semiconductor devices which contributes in reduction of cost, making the system reliable [13].

3.3.2. Interleaved Flyback Based Micro-Inverter

In front stage of interleaved flyback based microinverter carries MPPT, voltage boost, output voltage and shaping of converter. Interleaved flyback inverter is basically design to get maximum from the PV module. The two flyback converters interleaving each other to form a DC-DC converter which is used to prevent high frequency noise get back to the source. In this topology S1 and S_2 are primary switches having PWM function and diodes D_1 and D_2 are used for reducing the reverse recovery losses. So output of interleaved flyback inverter is unfolded to AC by using full bridge inverter which has four power MOSFET known as S_{H1}, S_{H2}, S_{L1}, S_{L2}.This topology has simple circuitry, closed loop system, reduced conduction losses, low cost making it reliable for the application of micro-inverter and system life is improved [14].

3.3.3. Push-Pull Converter Based Micro-Inverter

The push-pull converter based single stage micro-inverter topology is constructed with the help of back to back connected IGBTs by replacing the output rectifier of conventional push-pull converter, due to which the set of bidirectional switches connected to push-pull transformer. The output of the transformer is high frequency square wave, which further can be unfolded by using these switches and converted AC is supplied to grid.

This topology fulfill the requirements of micro-inverter like single stage power conversion, discard of high rating electrolyte capacitor and used of reactive components is less. This push-pull converter also reduces the electromagnetic noise and has low semiconductor stress [15].

4. COMPARISON BETWEEN THE PV INVERTER TOPOLOGIES

Comparison between different grid connected inverter topology are described in Table 2 on the basis of reliability, cost, shading effect, rating, efficiency, power harvesting and some other aspects.

Table- 2: Comparison between Different Inverter Topologies [1, 3]

Parameters	Central inverter	String / multi string inverter	Micro-inverter
Reliability	Low	Medium	High
Installation cost	Low	More than central inverter	Higher than both the inverter
Maintenance cost	High	Less than central	Very low
Shading effect	Overall perform ance get affected due to shading on any one module	Performanc e of modules connected to that string get affected due to shading on any one module	Performanc e of only that module get affected due to shading on any one module
Efficiency	Average	More than central	Greater than both inverter
Rating	High (greater than 2kW)	Medium (upto 2kW)	Low (upto 400W)
Phases	3 phase	1 phase /3 phase	1 phase
Power harvesting	Less	More than central inverter	Greater than both inverter
Design	Non - flexible design	Flexible in the design	Flexible & expandable in design

5. CONCLUSION

This paper presents the inverter standards of photovoltaic (PV) systems which must be satisfy by the inverter used in grid connected PV systems focusing on DC current injection, Total Harmonic Distortion (THD) which is less than 5% and also the anti-islanding protection standards. In grid connected PV system different inverter and their converter topologies are discussed. The small scale string topologies are developed to overcome the limitations of conventional topology in which multiple PV module are connected to grid via centralized inverter.

The further development is carried in string inverter topology which results in multistring inverter topology. The new AC module integrated micro-inverter topology is more suitable for grid connected PV system because of its advantages such as reducing partial shading effect, reduce mismatch between the PV modules, compact design with plug and play operation, long life-span, more power harvesting and low maintenance which makes the inverter more efficient and reliable.

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