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# Inverter topologies for PV Grid connected Applications: Review

Madhura N. Dehedkar[1], Prof. Subhash Vitthalrao Murkute[2]

PG Student, Department of Electrical Engineering, PESCOE, Aurangabad, Maharashtra, India[1]

Associate professor, Department of Electrical Engineering, PESCOE, Aurangabad, Maharashtra, India[2]

**ABSTRACT**: This paper provides an outline on various multilevel topologies and investigates their appropriateness in single-phase grid linked with photovoltaic systems. Several transformers less photovoltaic systems including multilevel converters are compared regarding issues such as component count and stress, system power rating and the influence of the photovoltaic array earth capacitance. Multilevel voltage source inverters offers some advantages compared to their conventional counterparts. By synthesizing the AC output terminal voltage from several levels of voltages, staircase waveforms can be produced, which approaches the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications.

**KEYWORDS:** Flexible AC transmission system( FACT), photovoltaic (PV), Cascaded (CC)

## I.INTRODUCTION

The function of a power converter is to process and to control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for the user loads.

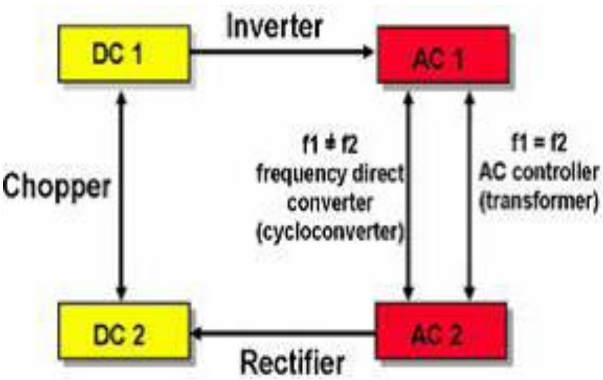


Fig.1. Classification of converter

Fig.1. shows classification of converter. A device which is used to convert DC energy into AC is known as inverter. First commercially available grid connected PV inverters were line commutated inverters are followed by pulse width modulation, self-commutated inverters including both line or high frequency transformers, often incorporating several stages of power conversion. A power rating around 1 kW and transformerless concepts with multilevel converter technology is based on the synthesis of the AC voltage from several different voltage levels on the DC bus side. As the number of voltage levels on the DC side increases, producing a sinusoidal staircase wave with minimum harmonic distortion [2]. Multilevel converters are particularly interesting for high power applications such as FACTS since the need of filters is reduced and the efficiency is high because all devices switch at fundamental frequency [3]. In low power applications where switching frequencies are not as limited as in high power applications various control methods as multicarrier pulse width modulation or multiple hysteresis band control methods are used to further reduce harmonics in the stepped waveforms. Multilevel converter topologies are specifically suitable for PV applications since due to the modular structure of PV arrays different DC voltage levels can easily be provided [2].

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This paper offers an overview on various multilevel topologies which have been suggested or are considered for (transformerless), single phase grid connected PV systems. Each topology is briefly described, listing advantages and dis-SAdvantages related issues such as component count and stress, system power rating and the influence of the photovoltaic array earth capacitance. Due to quick voltage and current transitions most power electronic equipment produces disturbances which propagate either by conduction or radiation. In transformerless systems leakage currents due to the photovoltaic array earth capacitance can also occur and increase electromagnetic emissions (both conducted and radiated). Since the paper focuses on transformer capacitance less systems the issue of leakage currents in transformerless photovoltaic systems will be discussed.

Issues regarding grid connected PV systems such as low cost, reliability, long life time, good environmental conditions are important to requirements for these PV systems. The grid connected PV systems issues related grids are shown in fig.2.

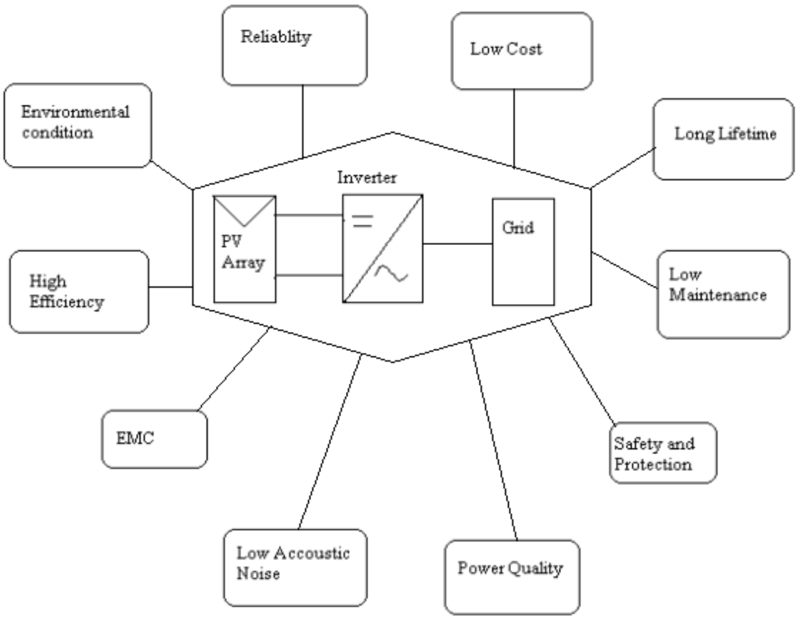


Fig.2. Grid connected PV systems issues

## II. TRANSFORMERLESS PV SYSTEMS

The transformerless photovoltaic (PV) inverters have the advantages of low cost, small size, light weight and high efficiency [5] Multilevel inverters have an advantage over two- and three-level inverters in high power and low power system, which can decrease the total harmonic distortion, voltage stress of dv/dt on switches, electromagnetic interference and increase the output waveform quality. The leakage current in transformerless photovoltaic (PV) inverter systems presents a considerable issue in regard to safety and efficiency PV inverter topology without transformer results in a galvanic connection of the grid and the PV array. Because of capacitance between the PV array and earth, which provides potential differences imposed on the capacitance through switching actions of the inverter inject a capacitive earth current ( Fig. 3).

The PV array earth capacitance ($C_{Earth}$) is the part of resonant circuit consisting of PV array, DC and AC filter elements and the grid impedance. Due to necessary efficiency of PV systems the damping of this resonant circuit can be small so that the earth current can reach amplitudes above the permissible level. Also, the resonant frequency is not fixed due to the varying nature of $C_{Earth}$, which dependent on environmental conditions. Depending on the topology, switch states and environmental conditions the capacitive earth current can cause more or less severe electromagnetic interference, distortion of the grid current and additional losses in the system.[8]

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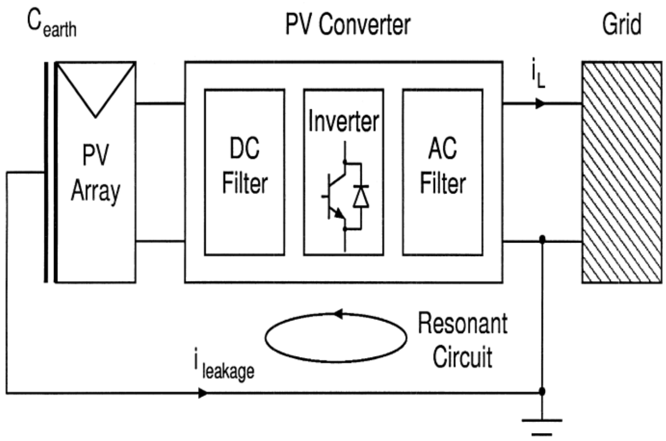


Fig.3. Grid connected PV system without transformer including the PV array earth capacitance

The magnitude of the PV array earth capacitance depends on weather conditions and physical structure of the array. It can be estimated according to the physical dimensions of the PV array and its grounded frame area. One electrode of the capacitance is formed by the photovoltaic cells, the other by the grounded frame.Table 1 summarises estimates and measurement results of PV module earth capacitances for monocrystalline modules with the following specifications and dimensions[8]

Table 1. PV module earth capacitances.

| | $C_{PV\ earth\ min.}$ | $C_{PV\ earth\ max}$ |
|---|---|---|
| Estimated | 17 pF | 6.64 nF |
| Measured | 110 pF | 4.2 nF |

An analysis of different standards addressing the grounding of PV systems shows that US standards require all exposed, non-current-carrying metal parts to be grounded where grounding of the frames is a requires the PV array earth capacitance needs to be considered in transformer less topologies

## III. MULTILEVEL INVERTER TOPOLOGIES

Fig.5. shows a half-bridge diode clamped three-level inverter (HBDC) as part of a single-phase transformerless grid connected PV system as suggested in (Hinz and Mutschler, 1996). With simultaneous switching on the switches *S*1 and *S*2, a positive voltage can be created at the inverter output terminal. A zero output voltage is created by switching on *S*2 and *S*3 and a negative voltage is created by switching on *S*3 and *S*4 respectively. In order to allow power transfer into the grid, the DC bus voltages *V*PVA1 and *V*PVA2 must always be higher than the grid voltage amplitude *Vgrid. Since* currently available PV modules have operating voltages around 17 V a large number of modules is required resulting in a minimum system size of approximately 3 kW. An advantage of this system is that the centre of the PV array is grounded which eliminates capacitive earth currents and their negative influence on the electromagnetic compatibility of the circuit.


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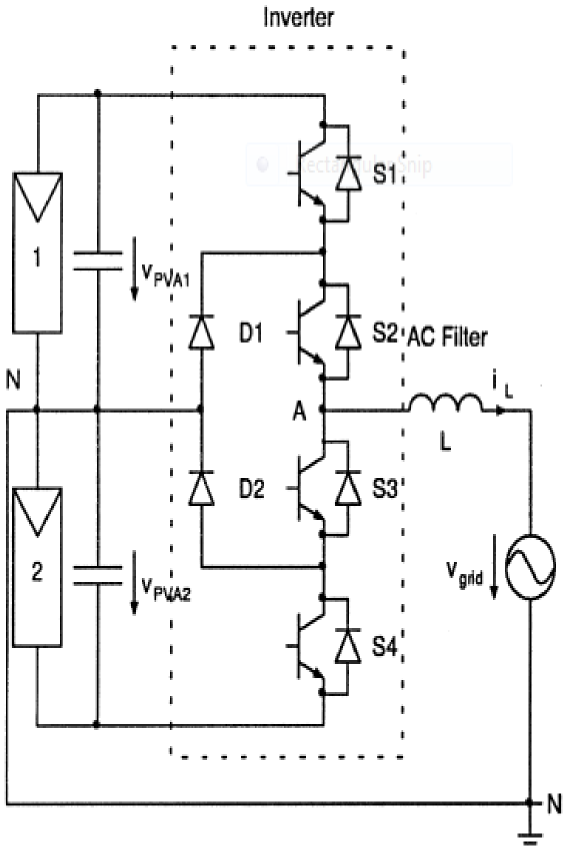


Fig.5. Grid connected PV systems with half-bridge diode clamped three-level inverter (HBDC)

The half-bridge diode clamped inverter can be extended from three-levels to five-levels as shown in Fig. 6 Five switch combinations where four switches are always switched simultaneously, generate five different voltage levels at the AC output of the inverter. By adding more levels on the DC bus, the number of levels of the voltage at the inverter output terminals is also increased. This allows for reduced distortion of the output waveform. To further reduce harmonics an extra degree of freedom is given by choosing the number of cells in series (and thus the voltages) of the outer PV sub arrays (1 and 4) to be different than those of the middle PV sub arrays (2 and 3) Drawback of this topology, are the high number of semiconductor devices required, the DC wiring effort of four PV sub arrays, and since the loading of the outer PV sub arrays (1 and 4) is different to that of the middle PV sub arrays (2 and 3) careful sizing of each PV sub array is necessary to ensure maximum power transfer from each sub array.[9]

### A. When Full-bridge single leg is clamped

A full-bridge single leg switch clamped inverter (SLSC) is suggested for residential PV systems. The topology (see Fig.7 is comprised of a conventional full-bridge (switches $S_{a1}$, $S_{a2}$ , $S_{b1}$ and $S_{b2}$ ) where a bidirectional switch (realised with $S_{a3}$, $S_{a4}$ , $D_{a1}$ and $D_{a2}$ ) is added controlling current flow to and from the midpoint of the DC bus. When applied in a transformerless PV system, the minimum system size with this topology is approximately 1.5 kW.

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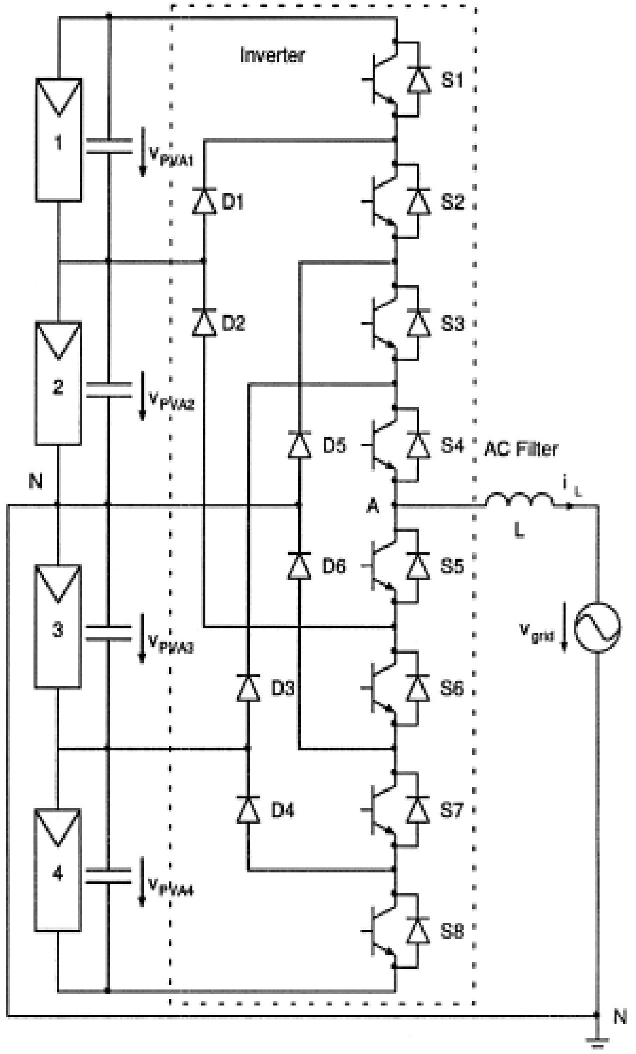


Fig.6. Grid connected PV systems with half-bridge diode clamped five-level inverter.

A transformerless PV system with similar characteristics can be realised with a full-bridge single leg diode clamped inverter (SLDC) as shown in Fig.8. With the single leg diode clamped configuration the devices $D_{a1}$ , $D_{a2}$ , $S_{a1}$ , $S_{a2}$ , $S_{a3}$ and $S_{a4}$ all can be rated for half the blocking voltage of switches $S$b1 and $S$ . However, with the single leg switch clamped configuration, this only applies to the devices $D_{a1}$ , $D_{a2}$ , $S_{a3}$ and $S_{a4}$ , and not to $S_{a1}$and $S_{a2}$ . In both systems both PV sub arrays are symmetrically loaded.[14]

**B. Cascaded (CC)**

Fig.9 shows a transformerless grid connected PV system where a cascaded inverter is used for DC to AC power conversion. The topology comprises of two full- bridges with their AC outputs connected in series. Each bridge can generate three different voltage levels at its AC output allowing for an overall five-level AC output voltage. The advantage of this topology is the modular character. The concept is suggested for transformerless PV systems using more than two full bridges connected in series on the AC side with small DC bus voltages of e.g. 40 V each.[12]

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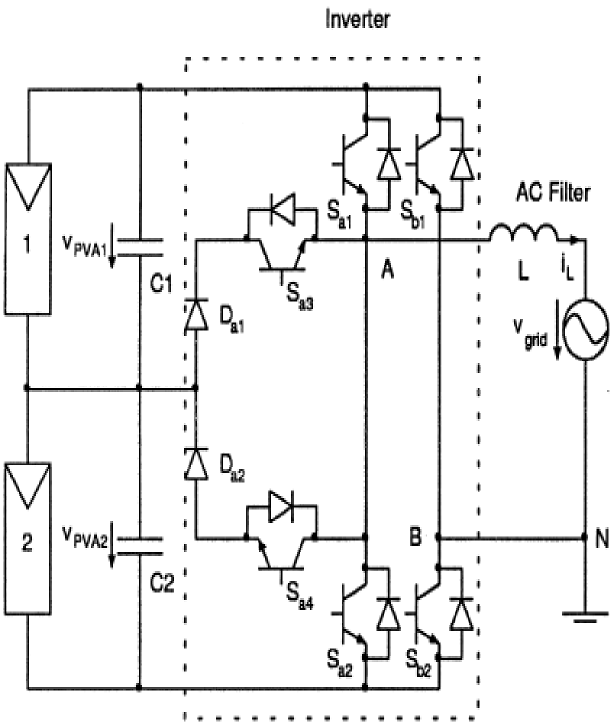


Fig.7. Grid connected PV systems with full-bridge single leg switch clamped inverter (SLSC)

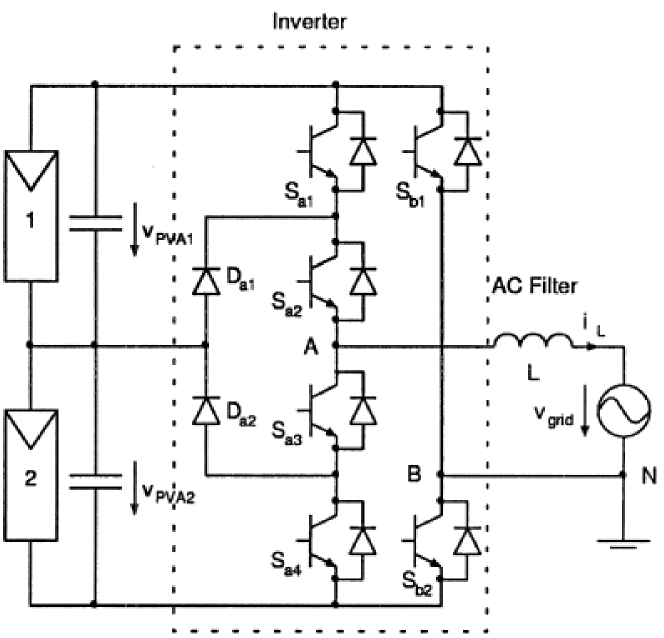


Fig.8. Grid connected PV systems with full-bridge single leg

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**C. Step converter**

The step converter switches PV sub arrays of different voltages to the AC output. In a topology using five arrays with nominal voltages of 11 V 22 V, 44 V, 88 V and 176 V is suggested for a grid connected PV system as shown in Fig. 10. A first conversion stage generates a rectified AC voltage waveform with 32 different voltage levels, a second conversion stage changes the polarity of every second half-wave generating an AC voltage with 63 different voltage levels. The energy delivered from each of the PV sub arrays increases with increasing voltage. Each PV sub array has different sizing requirements in order to ensure maximum power extraction of each individual PV array during operation.[11]

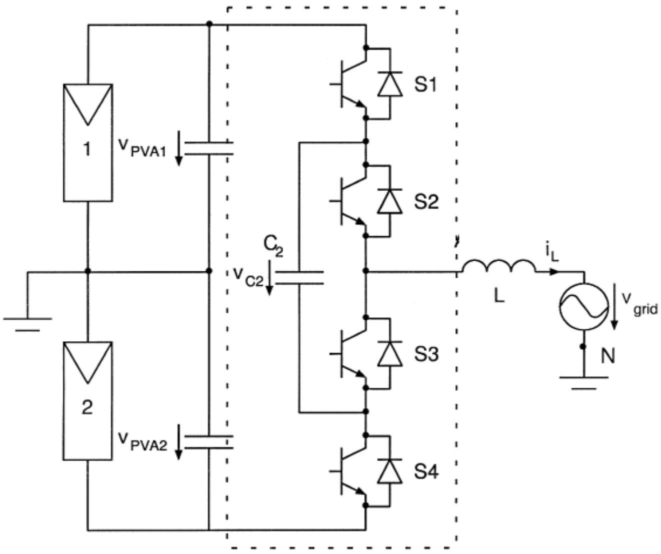


Fig.9. Grid connected PV system with a cascaded inverter.

A major drawback of this topology is the high and complicated DC wiring work due to the five differently sized PV sub arrays.

**D. Magnetic coupled**

Fig.11 shows a single-phase PV system with a magnetic coupled inverter as described in Thomas (1994). The inverter involves of three full-bridges each with their midpoints linked to a primary winding of a transformer. The secondary windings of the transformers are connected in series. Due to altered turn ratios of each of the transformers and the ability of each full-bridge to generate three different voltages across the primary winding the voltage at the AC terminals can be contained of 27 levels.[12]

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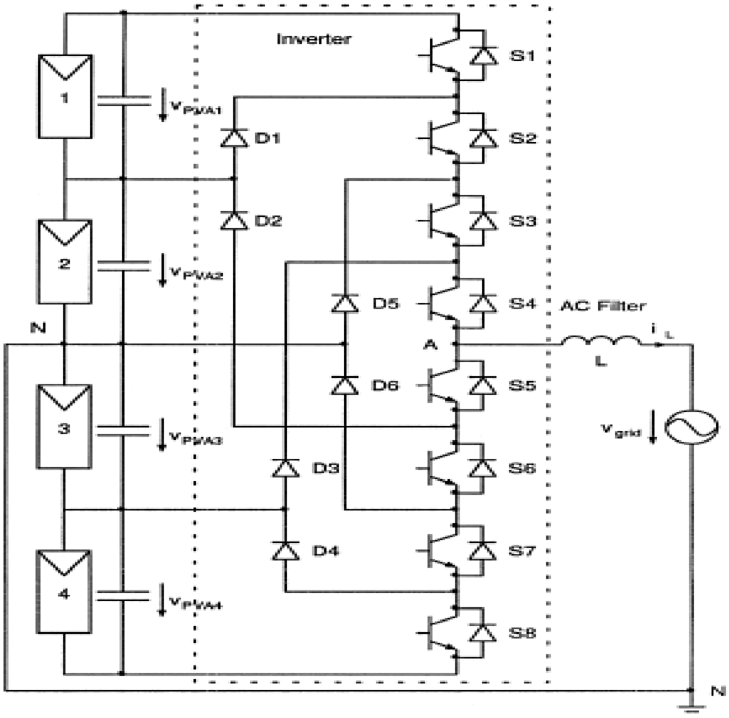


Fig.10. Grid connected PV system with a step inverter.

The advantage of this circuit is the relatively accurate imitation of a sine wave accomplished with low switching frequencies. A major disadvantage of the circuit, however, is the requirement of three transformers.

**E. Flying capacitor (FC)**

In Fig.12 a half-bridge three-level flying capacitor inverter is suggested for a transformerless grid linked PV system. Flying capacitor converters (which are also mentioned to as floating capacitor or imbricated cell multilevel converters) are described in (Lai and Peng, 1996; Meynard *etal.*, 1997). The features of this topology are related to the diode clamped topology. Important for the operation of this converter is a stable voltage ratio of $V$PVA1 /$V$C2 =$V$PVA2 /$V$C2=1. There-fore control methods are required which ensure that the average current flowing in the capacitor$C$2 is zero. This complicates the control of the inverter and excludes solutions with varying duty cycles (e.g. hysteresis control).[12]

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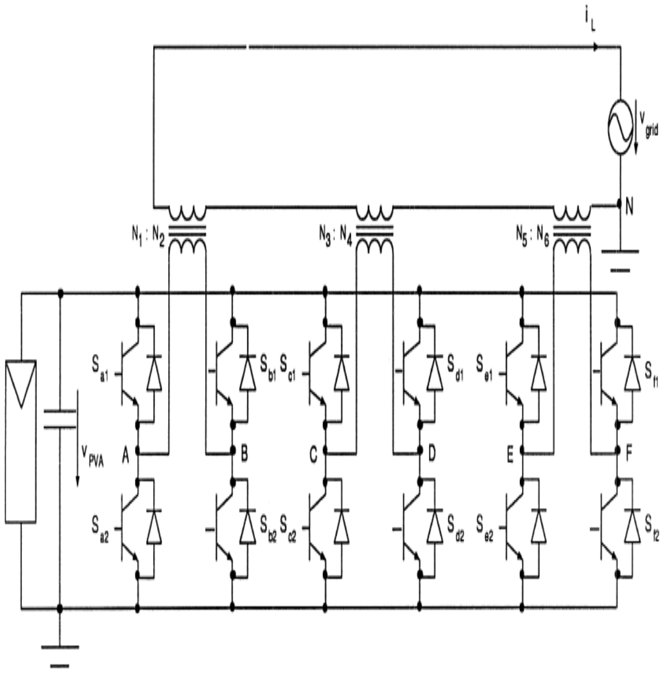


Fig.11. Grid connected PV systems with magnetic coupled inverter.

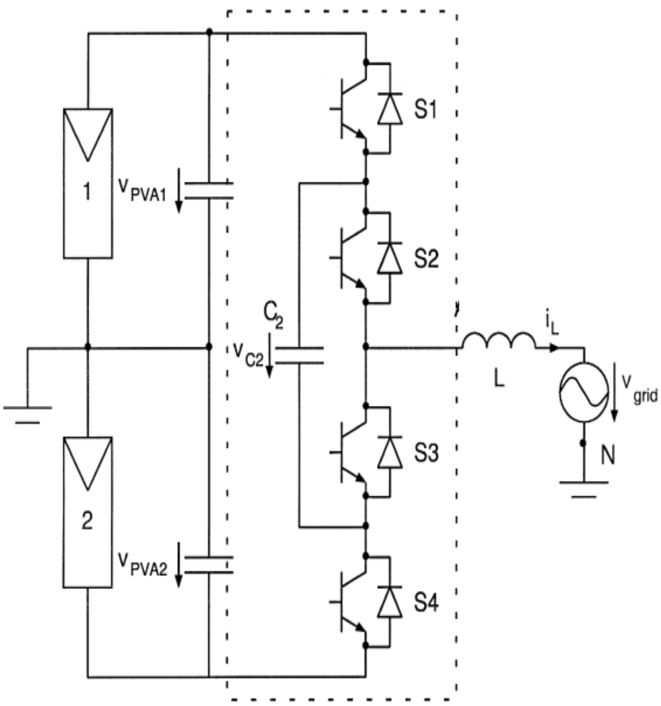


Fig.12. Grid connected PV system with a half-bridge three-level flying capacitor inverter (FC).

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## IV. OBSERVATIONS AND DISCUSSION

By studying and observing number systems we can compared all these number of topology. Where the amounts of energy extracted from each PV subarray are equal are considered. By observing the different topologies regarding minimum rated power, *P* , number of PV modules and PV sub arrays, number of DC bus capacitors, number of semiconductor devices and their ratings, the inverter output at possible levels of the AC voltage at terminals and the negative influence of the PV array earth capacitance are discussed with their advantages and drawbacks.
SLSC, SLDC, and CC can create five-level inverter output voltage waveforms and therefore demand less filter effort on the AC side. In all three topologies, however, PV array earth leakage currents can have a negative impact and measures to decrease these are required. For the three topologies the essential numbers of semiconductor switching devices and their ratings are specified in Considering costs, the Cascaded topology promises to be cheaper to produce than the SLSC and SLDC due to its modular nature.

We have studied Grid connected PV System different topology as follows:
-Grid connected PV system without transformer including the PV array earth capacitance
-Grid connected PV systems with half-bridge diode clamped three-level inverter (HBDC)
-Grid connected PV systems with half-bridge diode clamped five-level inverter.
-Grid connected PV systems with full-bridge single leg switch clamped inverter (SLSC)
-Grid connected PV system with a cascaded inverter.
-Grid connected PV systems with magnetic coupled inverter.
-Grid connected PV system with a step inverter.
-Grid connected PV system with DCMLI (diode Clamped multilevel inverter)

Table 2. Specification of inverter characteristics of the Multiple topologies and table 3 Summary of the characteristics of the Multiple topologies

Table 2.

| Id. | Inverter characteristic | Priority |
|---|---|---|
| M1 | **Single source input**<br>Justification: *Required by standard designs.* | Mandatory |
| M2 | **Mainly based on low-frequency switching**<br>Justification: *Maximum robustness and efficiency can be achieved by using low-frequency switching.* | Mandatory |
| M3 | **Capable to feed loads with DC level component**<br>Justification: *Like the grid, it is desired that SARES must be capable to support loads of diverse nature.* | Mandatory |
| M4 | **Suitable to implement high-resolution waveform**<br>Justification: *The use of filters for low-frequency waveforms is not practical for these applications.* | Mandatory |
| A1 | **Bi-directional (4-quadrant operation)**<br>Justification: *Improve robustness. (It is optional because a battery charger can be added).* | Optional |
| A2 | **Input-output isolation**<br>Justification: *Assures more flexibility.* | Optional |

Table 3.

| Topology | M1 | M2 | M3 | M4 | A1 | A2 |
|---|---|---|---|---|---|---|
| Diode clamped | Y | Y | N | N | Y | N |
| Flying capacitor | Y | Y | Y | N | Y | N |
| H-bridge (isolated DC sources) | N | Y | Y | Y | Y | N |
| **H-bridge ( multi-winding transf.)** | Y | Y | Y | Y | N | Y |
| H-bridge (+ isolated DC/DC conv.) | Y | N | Y | Y | Y | Y |
| **Multiple transformer** | Y | Y | Y | Y | Y | Y |
| Multiple source | N | Y | Y | Y | Y | Y |
| **Multi-winding transformer** | Y | Y | Y | Y | Y | Y |
| Modular | Y | Y | N | Y | Y | N |

Y: Characteristic is available ; N: not available

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## V. CONCLUSION

In this paper many single-phase, multilevel topologies for PV grid connected systems have been reviewed and studied. Amongst the topologies for transformerless systems, the HBDC and CC have been identified as the most promising topologies. However, by means of the CC topology (when applied in a transformerless system) measures are necessary to decrease the capacitive earth currents which are produced by potential differences imposed on the PV array earth capacitance. Also further research is required in order to evaluate whether the advantages of multilevel conversion shows the higher cost due to the more number of components. The step-down nature of all topologies requires system sizes of 1.5 kW upwards in transformerless applications due to the relatively low operating voltages of most presently available PV modules. Availability of PV modules with higher operating voltages is desirable since this would reduce system costs. An additional step-up conversion stage between inverter and PV array can increase the flexibility regarding the system size, but will reduce the systems overall efficiency.

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