Journal of Mines, Metals and Fuels, *73(7): 1935-1943; 2025. DOI: 10.18311/jmmf/2025/49149*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Comprehensive Analysis of Solar Photovoltaic System Power Inverter Topologies

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Abstract

The most recent advancements in inverters for solar photovoltaic AC modules are the main topic of this review study. These inverters typically have a power range of 90 to 500 watts, which is sufficient for the majority of commercial solar modules. Grid-commutated inverters have been replaced by self-commutated and multilayer inverters. The transformers with low-frequency and transformers with the high-frequency, can adjust the voltage level, are comparable in this regard. In a range of grid situations, the AC-module offers a flexible behaviour and a modular architecture. The plug-and-play idea makes it feasible to further expand the system and thus, the market for inexpensive photovoltaic power is opened to all.

Major Findings: *This overview, grid performance, and the available photovoltaic modules should all be taken into account when declaring. Simplified for solar grid integration applications, a single phase multilevel inverter has been created.*

Keywords: *Converter Topologies, Multi Level Inverters (MLI), Single-phase Grid Connected Inverter, Solar-photovoltaic System*

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1.0 Introduction

The inverter is useful for two reasons. The module first amplifies the low DC voltage to the grid's greater AC level. Second, depending on the point of operation, the power supplied by the module or modules is extremely sensitive; As a result, the inverter ought to be able to track the maximum power point. Single-crystalline silicon and multi-crystalline silicon modules are currently the most widely used PV technology[1,2]. Such a module has an open circuit voltage that falls between 18 and 26 volts, for an unit consisting of 36 cells, the range is between 46 V to 38 V, or for a module comprising 72 cells[3,4]. Nevertheless, innovative strategies such as thin-layer semiconductor, amorphous silicon, and Photo Electro Chemical (PEC) are currently being developed[5,6]. This implies that single-cell modules could become popular in future generations. These modules have a voltage range of approximately 0.5 V to 2.0 V.[7,8]. A brief history is given at the beginning of this work. Large units several PV modules were once connected to a central inverter; today, decentralized inverters link one or a small number of modules; and in the upcoming era, the inverter will link between a single PV cell and the grid[9,10].

A summary of the current AC-module power converter topologies is then provided, following a discussion of multilayer inverter topology. To evaluate the topologies for future applications, the methodologies are further reviewed before a conclusion is provided[11,12].

2.0 Photovoltaic Inverter Evolution

2.1 The Past: Centralized Inverters

Previous solutions were based on centralized inverters that were interfaced to several modules[13,14]. To attain a high level of power and voltage, the modules were typically connected in parallel as well as series, sometimes known as a string[15,16]. This results in a number of constraints, including power losses from centralized MPP tracking (MPPT), module mismatches, and string diodes[17,18]. Between the modules and the inverter, high voltage DC wires are needed. If one module in a string is under shadow, it will acts as load with less power production form it[19,20]. The shadowing module continues to produce power if the modules are linked in parallel, although the inverter's input voltage will inevitably be reduced because of the parallel connection[21,22]. Present a 3rd system in which a Generation Control Circuit (GCC) interfaces with each module. As a result, each module is guaranteed a distinct MPPT, also reduces the likelihood of hot spots[23,24].

In contrast to the non-shadowed cells, which only reach 22° C above the ambient temperature, complete shadowing of single PV-cell in a string of 160 cells raises the temperature within the cell by more than 70° C. This is crucial because a cell that is overheated quickly shortens the module's lifespan[25,26].

2.2 The Current Situation: AC Units and String Inverter Units

The current gadgets, known as the "string-inverter", are popular area of study in Germany[27,28]. A single string of modules is used by string-inverters to get a high input voltage. The connections between the modules and the inverter must be made by an untrained electrician due to the high DC voltage[29,30]. Alternatively, the string diodes can produce nooses, and each string can have its own MPPT applied. However, there is still a chance of a heat spot developing in the string. Another intriguing option is the AC Module, in which the AC inverter is a built-in component of the PV-module[31,32]. It eliminates the losses brought on by mismatched modules and inverters and facilitates the best possible module-inverter adjustment. Additionally, the risk of hot spots is eliminated. When all of this is combined, greater efficiency could be attained[33,34].

Because of its modular design, it also offers the potential for simple system expansion. Another intrinsic characteristic is the potential to develop into a "plug and play" gadget that can be used by those who have no prior knowledge of electrical systems[35, 36].

2.3 The Future: AC-modules and AC-cells with MLI

The AC-cell, which combines a single excellent PV cell with an inverter, may be a future option[37,38]. These cells are intended to be a seamless component of the building's climate barrier. The main function of the inverter is to achieve high efficiency while raising the naturally low voltage of the cell to a level appropriate for the inverter which is grid connected. The request is for completely new converter technologies for the same purpose[39,40].

Induction motor and filters, machine drives, active rectifiers, renewable energy source interfaces, flexible AC transmission systems, and static compensators are just a few of the current uses for MLIs. This study examines the topology of multilevel inverters[41,42].

3.0 AC-Module Topologies

A few key characteristics are required of inverters for PV applications. Across a broad range of PV power, the low voltage produced at the MPP typically about 17 V for a 36 cell module and 34 V for a 72 cell module must be converted as efficiently as possible for comparable sinusoidal current supplied in the grid[43,44]. The sun's irradiance distribution, depicted in Figure 1 for a Danish Reference Year, is the reason for this requirement. The majority of power is produced between 1000 to 200 W/m^2 of radiation, as seen in Figure 1.

The grid-connected step in almost all systems that have been examined use of a bridge inverter that is either commutated at twice of the grid-frequency or connected to the grid. Figure 2a, or a high switching frequency self-commutation, regulating the current that is supplied to the grid connected rectified sinusoidal current with PWM operation is one way to accomplish grid commutated functioning[45,46]. Use of the grid-commutated approach include the elimination of all stage switching losses, leaving only conduction losses[47,48]. In other words, the grid current needs to be sine-modulated, like by the converter which is DC-to-DC. On the other hand, the module-connected converter is used to replace the switching losses[49,50].

Eliminating disturbances in power at the module is more difficult because of the dual step inverter's decreased power isolation from the grid[51,52]. The sudden low frequency power flow into the grid is the cause of the oscillation Figure 1. A further limitation is that the grid inverter and the module which is connected for conversion have to be built for peak power instead of mean power, which results in larger and more costly equipment[53,54]. In Figure 2, the maximum power is equal to double the mean power[56-57].

Either a low-frequency or a high-frequency transformer may be used by the transformer-included inverters[5,8-11]. One of the low-frequency transformer's shortcomings is its weight, which must be secured to the module in some way without making it mechanically brittle. The

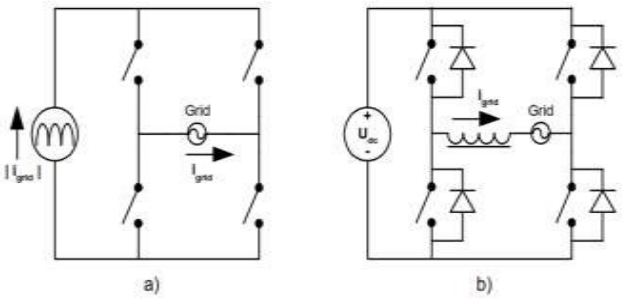


Figure 1. Grid inverters: **(a)** Current source, grid commutated inverters that operate at double the frequency of grid. **(b)** A voltage source, commutated inverter that switches at higher frequencies[5].

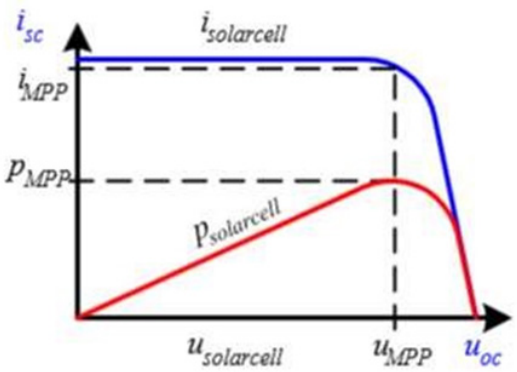


Figure 2. Normal power and current characteristics for a photovoltaic cell or module[7].

fact that these transformers need to be constructed and installed by hand is another disadvantage. High-frequency transformers are frequently used in modern inverters. This leads to completely new designs, such the integrated magnetic components in Printed Circuit Boards (PCBs), even in a core-less version. However, according to task V of the International Energy Agency-Photovoltaic Power Systems, a general demand for small amounts of DC current injected into the grid have no effect on local distribution transformers, transformer-included topologies are not justifiable[7]. To optimize the module operation, when it produces UMPP and IMPP, the inverter must likewise include an MPPT (Figure 2). Last but not least, the inverter needs to be inexpensive while also having a lifespan of about 25 years[2], the typical lifespan for a PV module. It necessitates using fewer capacitors and magnetic devices in favor of more silicon devices, such as MOSFETs and IGBTs, which are still getting cheaper.

4.0 Single-Step Topologies for AC Modules

Voltage increase, MPPT, DC to AC inversion, and power separation must all be incorporated into the single step topology. An all-in-one inverter, without a transformer, acceptable efficiency cannot be achieved, even though the necessary voltage amplification for European grids may exceed 16 times. Here, the innovative Bi-directional Fly-back inverter topology is showcased (Figure 3). As the name suggests, it is made up of two bi-directional fly-back converters. When the duty cycle of the first converter is D, the duty cycle of the second converter is (1-D), the currents flowing from the transformers are continuous, the voltage-gain A, is determined.

Where the numbers for the secondary and primary turns are Nsec and Npri, respectively. The voltage between the grid-connected inductor and the grid is depicts by Uout, while Uin represents the module voltage. The current flow in bi-directional is to allow the converter to be configured to always run in Continuous Conduction Mode (CCM).

As assessed to the multiple-stage inverters, the insertion of the 100 Hz power fluctuation might be rather significant. Using an input capacitor is one way to eliminate the ripple. To get power ratio, which is defined as PPV, AVG / PMPP equal to k, where UMPP is the maximum power point voltage, ω grid is the grid frequency, PMPP is the power at the MPP, AVG is the average power given by the module, C is necessary capacitor in front of the module.

The transformer's specs include a magnetizing inductance of 100 μH and Npri = Nsec. A piezo-ceramic activator with a frequency that operates between zero and 500 Hz is driven by the converter, while maintaining a switching frequency of 100 kHz.

Another strategy is to combine a large 50 Hz transformer with a typical full-bridge inverter[3]. However, because the low-frequency transformer is large and there is no power decoupling between the module and the grid, this is considered a bad solution.

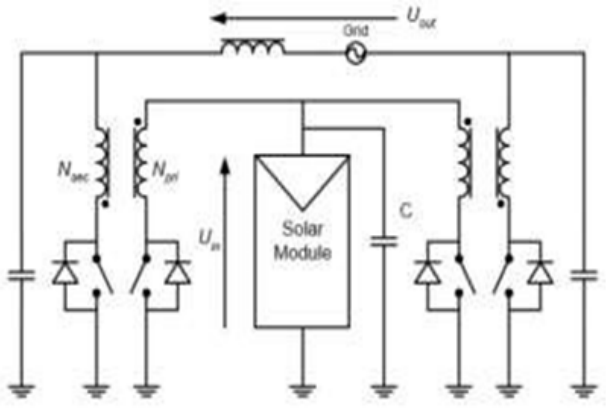


Figure 3. An innovative one-step AC module solution is bidirectional fly-back inverter[11].

5.0 Multi-step Topologies for AC-module

Since the multi stage topology requires three or more stages, it is believed to be more complex and expensive than the one and two-step systems previously discussed. Alternatively, a rectified-sine modulated DC-DC converter can be used with a 100 Hz inverter to achieve a power separation between the grid and module. Hence the grid-connected stage has minimal switching losses and good MPPT characteristics.

The Sunmaster 130S, which is also shown in Figure 4, is the final commercial inverter for the AC-Module inverter that has been studied here[9]. This inverter differs greatly from the ones that were just shown. An auxiliary MPPT circuit is used for the first, and three stages are used for the second. Once more, the stages are not separated because the inverter that connects to the grid operates at 100 Hz. A transformer which is operating on high frequency and rectifier are utilised in the subsequent phase, which is a series resonant converter. The resonant is composed of the transformer, a resonant capacitor with inductor, which is a component of the transformer's leaking inductance. This stage operates as a "DC-transformer", meaning that it has no control and operates at a constant frequency with a fixed duty cycle that is just under 50%. The output current of the

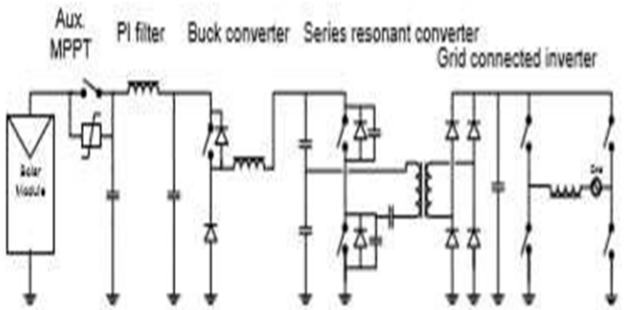


Figure 4. Schematic for multistep topology[13].

module-connected converter is regulated to adhere to the buck converter's popular rectified sinusoidal current. The rectified current's amplitude is controlled by the MPPT.

A pi-filter is placed between the MPPT circuit and the buck converter as a result of the supplemental MPPT circuit. Every two seconds, the PV module is detached in 200 µs. After the input capacitor feeds the step-down converter, the MPP voltage is calculated using the module's voltage when open circuit, Uoc, as follows: UMPP = 0.8 Uoc. As long as the module characteristics are known, this is a quick and easy method to complete the MPPT. It will be impossible to precisely track the MPP if they are altered as a result of a change in, say, the temperature, which will result in lower power.

The following inverter is shown in Figure 8[10]. In order to track the MPP and increase the module voltage in the DC-link to about 200 V, a boost converter is utilized. Additionally, the auxiliary circuits are supplied by it. A corresponding rectifier and an output winding on the boost converter are used to accomplish this. Galvanic separation of the module and the grid is provided by a push-pull converter. In addition, it regulates the grid ampere; the buck- boost converter's rectified sine current is unfolded by the 100 Hz Bridge inverter.

This inverter's prototype, which has the following specs: Pin = 500 W, Uin = 170 V to 30 V. Input of Uin = 45 V and power more than 0.09 KW, efficiency is said to be better than 70%[10]. The boost converter is primarily to blame for the low efficiency. This is expected given that the PV-module voltage must be amplified 4.44 times, from 200 to 45 V, into the DC link.

The multistep topology schematic is shown in Figure 4. The sinusoidal current is modulated by the buck converter. The resonant converter in series creates the "DC-transformer", while the grid-connected inverter distributes the current which is rectified into the grid. The topology that is described and shown in Figure 8, unfolding the rectified AC current produced by the buck boost converter is the grid-connected inverter[10]. MPPT makes use of the boost converter. The current and, thus, the voltage are ensured to be same by positioning of a PV module boost converter, which acts as a rated load. This creates a power separation between the module and grid. The Auxiliary power supply unit uses the boost inductor's auxiliary winding.

For 90 W of power, the boost converters efficiency is estimated to be around 80%. Although an inverter with a

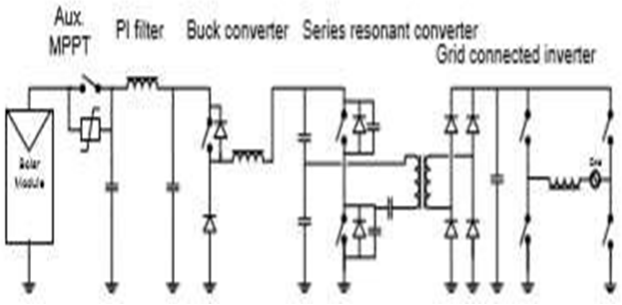


Figure 5. The AC current produced by the converter is unfolded by the suggested architecture for a grid-connected inverter[15].

Thyristor only has twice the diode forward-voltage drop and the losses are due to the absolute average grid-current, a grid-connected inverter's efficiency is consistently more than 99 %.

Figure 5 shows another three-stage inverter[11]. The module voltage is increased to a suitable level for the DC-link about 400 V using a Current Fed Push-Pull converter. Some intrinsic benefits of using the CFPP converter include its constant input current characteristic, which eliminates the need for a capacitor or only a very tiny one to stabilize the voltage of the module around the UMPP. The grid current is again produced using the next step, by buck converter. The next step is the 100 Hz inverter, which expands the modulated rectified AC wave current and is constructed around Thyristors. The following details are reported for a prototype: Pin = 300 W, Uin = 14 V. At full load, an overall system efficiency of 80% is achieved. The low voltage of only 14 V is the cause of the comparatively low efficiency; a greater module voltage would be preferable.

6.0 Multi Level Inverter Topology

Static compensators, active rectifiers, filters, induction machine and motor drives, Flexible AC Transmission Systems (FACTS), and interfaces of renewable energy sources are only a few of the latest uses of MLIs. Other multilevel inverter topologies are not as prevalent in motor drive applications as diode clamped inverters, especially the structure of three-level. Among MLIs are induction machine and motor drives, filters, active rectifiers, Flexible AC Transmission Systems (FACTS), interfaces for renewable energy sources, and static compensators.

In the medium voltage and high power application areas, multi-level inverters have garnered a lot of attention because of their numerous advantages, which include a lower common mode voltage, less voltage stress on power switches, and a lower dv/dt ratio to deliver fewer harmonic contents in output voltage and current[12]. Aside from other multilevel inverter topologies, diode clamped inverters especially the three-level structure-are widely used in motor drive applications.

The most common MLI topologies classified into 3 types[12]:

1. Diode Clamped MLI (DCMLI),
2. Flying Capacitor MLI (FC-MLI)
3. Cascaded H-Bridge MLI (CHB-MLI)
4. Hybrid MLI.

Using various DC bus levels or combining pre-existing multilevel inverter topologies, the hybrid and asymmetric hybrid inverter topologies were created, respectively. However, if the level goes above 3, the DC-MLIs would be limited in terms of complexity and clamping diode count.

Based on balancing capacitors on phase buses, the FC-MLIs provide a multilayer output voltage waveform that is capacitor-restrained rather than diode-restrained. An m-level inverter using the FC-MLI architecture additionally has to have balancing capacitors per phase at a number of (m -1)*(m -2)/2. As a result, high level inverter topologies will need more capacitors and have a harder time accounting for DC-link balance. The cascade inverter is the least complex of the 3 types of multilevel inverters for a given number of levels.

In addition to these MLI types, the Cascade Multilevel Inverter is a great choice for applications involving solar grid integration. For multilevel inverters, a number of modulation and control strategies have been developed, such as Space Vector PWM (SVM), Sinusoidal PWM (SPWM), Selective Harmonic Elimination PWM (SHE-PWM), and comparable variants of the 3 primary methods. The ability of the SPWM control approach to decrease harmonics through the use of several carrier signal phase shifting options makes it particularly popular in industrial applications. In order to create a desired voltage from several independent DC sources (SDCSs), which can be derived from fuel cells or batteries, cascade multilevel inverters use a sequence of H-bridge cells. Because of these characteristics, cascade inverters can be precisely controlled using a variety of Pulse Width Modulation (PWM) techniques. Therefore, the cascading H bridge multi-level inverter is ideal for applications involving renewable energy.

7.0 Conclusion

This review has covered a number of inverter designs for solar-powered devices as well as particular inverters related to the AC module. Bi-Directional Fly-Back (BDFB) and resonant inverters appear to be the most practical topologies for single and multistage systems. However, when utilizing the BDFB architecture, measures must be taken to decrease the power connection between the module and the grid. Furthermore, further research is required to ascertain whether the BDFB justifies the use of two high-frequency transformers. This study looks at the AC-module as a possible future remedy. Therefore, in order to develop exact inverter specs, the next step in the construction process will be developing an inverter with an AC unit. Its simulated voltage waveform is then compared to that of an H-bridge inverter with a single-phase cascade. Consequently, the SPWM topology-based control strategy is a simple grid mixing technique.

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