MICROINVERTER TOPOLOGIES FOR SOLAR PV-GRID INTERFACING

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ABSTRACT

The demand for electricity has risen in the recent days, which made us to use more sources of energy like fuel cells, solar, wind, biomass etc. that are renewable. Among these solar is widely available, where energy from sun rays are made into DC power using solar photovoltaic (PV) module. This energy can be utilized by the AC loads by integrating the solar PV to a DC-AC converter at the distribution lines for loads and the grid. Usually, string inverters where employed for connection to the grid, which nowadays is competed by the micro inverters due to its increased efficiency even during shading or failure of the module. Here there is a detailed review on different topologies of micro-inverter for grid tied solar PV, their merits and demerits. This also includes the element or the components involved in a solar PV grid interfacing system. On knowing the different topologies, we can select the most appropriate one as per our desired application based on selection criteria factors.

Keywords: Photovoltaic (PV), Electrical Grid, Microinverters, DC-DC Converters, Inverters.

I. INTRODUCTION

Efficient, compact, and cost-effective grid-connected solar PV systems interconnected using inverters are of great significance in the present scenario, of which microinverter based SPV (solar PV)-grid connected systems are widely analyzed and studied [1]. Since the individual energy control of every single solar module is possible, which improves power generation as the shading effects get reduced, thus microinverters are more effective for Photovoltaic applications than the string inverters. Therefore, microinverters are integrated into a module with low voltage and injects energy to power grid. The merits of microinverters are:

- Perturb and Observe or Incremental Conductance techniques of MPPT helps all energy collected to be utilized.
- Simple installation of microinverters make it a plug in play device.
- PV installations are highly flexible and modular, thus can be further improved capacity as per the need.

Generally, for commercial purposes are satisfied by microinverters with isolated converters which decreases the efficiency, reduces the lifetime and increases the system rate operating at low switching frequency. Recent trend is the transformerless inverters operated at low time period decreases cost, weight and volume of the circuit. Two stage commercial microinverters has a DC-DC based converter accompanied by a DC-AC converter or an inverter feeding a local load or a grid [2]. Grid connection assures increased total system efficiency and reduced losses. PV microinverters are attractive and are focused by researchers for small or large scale household and industrial purposes. Higher switching frequency based microinverters have reduced size. Advanced topologies and proper control schemes helps microinverter to function well at these frequencies [3].

In this paper, a description on the single-phase grid-solar PV micro inverter’s structure is done. Then a detailed study on various solar PV microinverter topologies, analyzing their circuitry and operation. A study on recent trends in microinverters is concluded with each of their advantages and disadvantages. The solar PV microinverters are of great significance in these recent years and grid tied PV requires microinverters with good efficiency and control algorithms.

II. VARIOUS MICROINVERTER TOPOLOGIES FOR SOLAR PV-GRID INTERFACING

a) Interleaved Fly Back Microinverter

Circuit shown in Figure:1 has T1, S1, D1 and T2, S2, D2 forms the two-phase interleaved flyback converter. The operation of this converter is similar to that of a buck-boost converter, but with a galvanic isolation provided by a transformer. The DC output of fly-back converter is inverted into AC using a current source inverter (CSI). The main switches are S1 and S2, D1 and D2 are the rectifier diodes. S3, S4, S5 and S6 is CSI to feed the sinusoidal AC voltage to grid. During the positive-half grid period switches S3 and S6 are ON, while during the negative-half grid period, switches S4 and S5 is turned ON. Ripple cancelation reduces output filter inductance L1 size [4].

[1257]
b) **Multicore Forward Microinverter**

Some eminently coupled transformers that are parallel connected at primary end and are series in the secondary coil constitute the multicore-forward topology. The circuit even though has an increased count of devices, but has reduced thermal drops in circuit due to low current stress and losses per device. Ripple reduction is contributed by the decoupling capacitor split among each phase. The parallel connected primary helps to knock down the current stress in the switches and the transformer primary windings. The secondary series connection results in the current sharing. The synchronous driving of the switches in the former end, also common cathode configuration helps to lessen the stress of current in the latter end diodes to a great extent. Lower turns ratio transformers and the series connected secondary windings yields the grid voltage. The circuit shown in Fig.2. has a reduced leakage inductance and improved primary coil sharing of current flow, due to a better coupling between primary and secondary of each transformer. The unfolding stage is the inversion stage made of a voltage source inverter (VSI) made of two legs of switches controlled as per the positive and negative half cycles of the grid voltage, which produces an AC output from the DC output of a forward converter. The nearly sinusoidal AC is then fed to the grid. The circuit shown in Figure: 2 has a reduced leakage inductance and improved primary side current sharing, due to a better coupling between primary and secondary of each transformer [5].

![Interleaved flyback microinverter](image1)

**Figure: 1** Interleaved flyback microinverter

![Forward microinverter with primary parallel and secondary series transformer](image2)

**Figure: 2** Forward microinverter with primary parallel and secondary series transformer

c) **Doubly Grounded Microinverter**

This operates on a buck-boost principle and circuit is given in Figure: 3. It has one individual PV source, an inductor which is shared between two half cycles. Operates in discontinuous mode. The negative conductor of PV source is always grounded (thus double grounding). Circuit has 5 switches and 3 diodes. Inductor L and capacitor C forms the lowpass filter that lets 50Hz alone to pass through grid. S1, S2, S5, D1 forms the buck-boost DC-DC converter for the grid voltage’s negative half cycle. S3, S4 are always off and S2, S5 are on at all times. When S1 is on, the inductor L1 is energized. As switch S1 is off, energy gets passed to electrical grid. S1, S3-S5, D2, D3 forms buck-boost circuitry for the grid voltage’s positive half cycle. S2 is always off and S3, S4 are always on. When S1 and S5 turned on, L1 stores energy. When S1 and switch S5 made off, energy is send to the grid [6].

![Doubly grounded microinverter](image3)
d) Two-Stage Microinverter

A two-stage topology for interfacing the Photo Voltaic system with distribution network is presented here. The first stage consists of non-isolated dc-dc step-up converter. The maximum power point for individual panel is tracked continuously using MPPT controller, thus the circuit shown in Figure: 4 is highly efficient. The boost converter operates in continuous conduction mode (CCM). Single phase full bridge two-level VSI is the second stage that transfers power from PV system to the power grid. DC-link capacitor $C_{dc}$ keeps voltage input to inverter constant. The dc-link voltage is regulated with a level higher than the grid peak voltage to ensure the adequate direction of flow of energy. $L_2$ is an interlinking inductance, LC filter of inductance $L_1$ and capacitance $C$ smoothen the high switching frequency distortions. The controller consists of three cascaded loops. An outer voltage control loop to regulate the dc-link voltage $V_{dc}$. The grid current loop to control $i_g$ so that it exactly in phase with the grid voltage. An inner current control loop to sense the inverter side inductor current $i_1$. The outer dc voltage control loop is used for generating the reference for the grid current control loop through the PLL [7].

The controller consists of three cascaded loops. An outer voltage control loop to regulate the dc-link voltage $V_{dc}$. The grid current loop to control $i_g$ so that it exactly in phase with the grid voltage. An inner current control loop to sense the inverter side inductor current $i_1$. Here the voltage ($V_{PV}$) and the power ($P_{PV}$) are continuously sensed to calculate the instantaneous power. The dc-link voltage can be controlled by controlling the current injected into the grid. If the irradiation is increasing, the dc link voltage increases, as the dc-dc converter stage is operating with MPPT. When $V^*_{dc}$ is greater than $V_{dc}$, the dc-link voltage controller output, $i_d$ increases, so that more current will be injected to the grid. If the irradiation is decreasing, then the current injected to the grid decreases. The outer dc voltage control loop is used for generating the reference for the grid current control loop through the PLL. A PLL is generally used to synchronize the inverter with the grid, which collects the grid voltage phase information and produce the reference current $i_{ref}$ for the grid current loop [7].

![Figure 3: Doubly Grounded Microinverter](image)

![Figure 4: Typical two-stage microinverter](image)
Active NPC Microinverter

Active Neutral Point Clamped topology inverter obtained from conventional NPC topology is presented in Figure 5. Active switches and anti-parallel diodes helps in clamping. The typical NPC uses diodes to clamp voltage, while ANPC can do it in many ways. When switches S2, S5 ON results in upper clamping and switching on S3, S6 results in lower clamping. The current conducts in two directions through both upper and lower clamping paths. Various NPC paths can be selected to distribute conduction losses in zero states. On selecting different commutation states, in turn controls the switching losses. Various PWM strategies that uses zero states and conducting paths already exists, while a new control is Adjustable Losses Distribution (ALD) is used in [8].

![Figure 5 Active NPC Microinverter](image)

Microinverter with Series Compensation

A series compensator is provided in series to supply between the DC-DC converter and DC-AC inverter gets the energy from power assist circuit without isolation problems. As the compensator produces positive voltage and negative voltage which evaluates the up, down mode of operation. Power assist circuit is a DC-DC fly-back converter which controls voltage. A compensator joining dc link and load helps in balancing the voltages. The circuit is given in Figure 6. only needs the relating to specific change between supply voltage and load voltage. The series converter produces both positive and negative voltage which is evaluate individually the boost and buck [9].

![Figure 6 Microinverter with series compensator](image)
An SPV system comprises an SPV array as the DC source, VSI, ripple filter, non-linear load and interfacing inductor is given in Figure:7. The filter inductance of the VSI is $L_f$, interfaced with grid. A ripple filter is a series combination of resistance $R_f$ and capacitance $C_f$ suppress high-frequency switching noise in the PCC voltage in parallel. The bridge rectifier considered as the non-linearly connected load. ALCF-based control algorithm scheme with MPPT has been used for controlling power quality issues of grid-interfaced system while transferring active power $P$ to load and the grid. The ALCF-based control algorithm is quite robust in nature. Furthermore, the control helps in mitigating the harmonics content of grid entering current in accordance with an IEEE-519 standard [10]. The active filtering is required whenever the load connected to the system is non-linear in nature and injects harmonics to the system, which need to be filtered out efficiently using these active filters in order to prevent harmonic injection into the grid. The circuit operates as: the DC power extracted from solar using MPPT whose ripple is reduced using a decoupling capacitor placed across PV, this is then inverted into AC using a Voltage Source Inverter made of four switches $S_1$, $S_2$, $S_3$ and $S_4$. And then fed into the grid.

![Figure:7 Microinverter with Active Filtering](image1)

The inverter shown in Figure:8 consist of four H-bridge fed through single DC supply. The outputs of cascaded h-bridge (CHB) inverter is connected in shunt with transformer. The secondary of transformer is series connected to get the desired voltage. Each module of CHB inverter has four MOSFETs such that it can produce $+E$, $0$, $-E$ at its output terminal, where ‘E’ is voltage from solar PV module available across the DC-DC converter. $Q_1$, $Q_2$, $Q_3$…$Q_8$, $Q$, $Q_b$…$Q_h$ are the MOSFET switches. $T_1$, $T_2$, $T_3$, $T_4$ are the transformers for cascading output of CHB and delivers the desired output voltage.

![Figure:8 Cascaded MLI](image2)
implemented due to the decreased cost, size and weight of the system as galvanization transformer is avoided in it. When transformer is removed, there arises issues like flow of ground leakage current as these acts as grounding purposes, DC injection to grid system is other problem thus contents of DC may exist in AC, the other thing is the isolation requirement as it’s also an isolation transformer. These need to be overcome by the circuitry proper design and appropriate control. A comparative study on the various topologies discussed yet is given in Table 1.

Table 1. Summary of Various microinverter topologies.

<table>
<thead>
<tr>
<th>Topology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interleaved flyback microinverter</td>
<td>High voltage gain is obtained for the circuit.</td>
<td>Reliability of the circuit is less.</td>
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<tr>
<td></td>
<td>Galvanic isolation is provided by the transformer.</td>
<td>Ripple is formed within the circuit.</td>
</tr>
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<td></td>
<td>Single stage conversion of power from DC-AC.</td>
<td>The circuit exhibits a low performance.</td>
</tr>
<tr>
<td>Multicore forward microinverter</td>
<td>The circuit has a reduced THD at the output.</td>
<td>Circuit is somewhat complex to design as the number of phases increases.</td>
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<tr>
<td></td>
<td>The output voltage has an increased quality due to low distortions.</td>
<td>Thus difficulty to implement also.</td>
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<tr>
<td>Doubly grounded microinverter</td>
<td>The circuit can achieve a high bandwidth.</td>
<td>Switching losses occur across the five switches used.</td>
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<td></td>
<td>Highly stable circuit.</td>
<td></td>
</tr>
<tr>
<td>Two-stage microinverter</td>
<td>Reduced harmonics and voltage unbalances in the circuit.</td>
<td>DC link voltage need to be regulated always using a controller.</td>
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<td>Two-stage power conversion decreases the efficiency.</td>
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<tr>
<td>Active NPC microinverter</td>
<td>Have low leakage current as the circuit is properly grounded.</td>
<td>If unequal distribution of losses in switches occurs, it may lead to an unequal temperature in the devices.</td>
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<td>It has high efficiency due to the distribution of losses among switches by proper control scheme.</td>
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<tr>
<td>Microinverter with series compensators</td>
<td>Reduced power loss.</td>
<td>The proper output waveform may be difficult to obtain due to operational complexity.</td>
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<td></td>
<td>Efficiency is increased as losses are reduced.</td>
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<tr>
<td>Microinverter with active filtering</td>
<td>Less stress on electronic components is observed.</td>
<td>Ground leakage currents is more due to improper grounding without isolation transformer.</td>
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<td>Better THD at the voltage.</td>
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<td></td>
<td>Switching losses of the circuitry is reduced.</td>
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<tr>
<td>Cascaded H-bridge microinverter</td>
<td>Increase in voltage levels at the output AC reduced THD.</td>
<td>More switching losses produced during operation as count of switching devices may increase as per the voltage level.</td>
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<td></td>
<td>The quality of the output voltages and currents can be increased by increasing levels and reduced THD.</td>
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III. CONCLUSION

Solar micro-inverter topology examined over here proves that it is different among the others as it offers high quality output and reports safety related issues. Many researchers’ latest publications aim at better reliability, compactness, efficiency, implementation cost. At present scenario, PV inverter is to be disconnected from electrical power grid for any abnormal/fault condition occurs. Thus, many control schemes to be advanced and considered between grid tied and islanding modes. Presently, the grid connected transformerless topologies are configured as high frequency transformerless topologies and low frequency transformerless topologies. This comparison shows that transformerless inverter topology is the best choice for grid-PV microinverters based on long lifespan, high efficiency, and lowest cost SPV converters.

IV. REFERENCES


