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Microinverter Topology based Single-stage Grid-connected Photovoltaic System: A Review

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ABSTRACT

This paper discussed the topology development of a single-stage microinverter in grid-connected PV system. In general, the microinverter topologies can be categorized into four type of topologies: 1) Flyback inverter, 2) Double-boost inverter, 3) Derived zeta-cuk configuration and 4) Buck-boost inverter. Flyback configuration is widely used for single-stage microinverter which offers protection between solar panel and utility grid. However due to the bulkiness of the transformer, new arrangement circuit employ the Half-Bridge topology with film capacitor and microcontroller provide a good room for research and future developments to obtain greater efficiency and compact design of single-stage microinverter grid-connected PV system. Plus, there are several characteristics need to be taken care for future development of the microinverter technology.

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1. INTRODUCTION

Solar Photovoltaic (PV) system has emerged into resourceful platform for converting the sun radiance from the solar module into sinusoidal output waveform to be used at the electrical appliances. There are two basic approaches at the end of the PV system, either to be connected directly to the load and/or storing in batteries (commonly known as isolated-PV system or stand-alone PV system), or injected to the grid (known as grid-connected PV system). This research works towards isolated-PV system were presented in [1]–[5]. However, there will be an excessive amount of energy when applied to the small application (load or battery) with such lots of extraction power. The incentive by government especially with Feed-in Tariff (FIT), cost effective and less maintenance system leads further developing of grid-connected PV system [6]–[17].

In the grid-connected PV system, magnitude, phase and frequency of the AC signal should be properly synchronous with the grid. Thus the inverter is the crucial component in the PV system. There are three common inverter grid-connected configurations which are: 1) Centralized-inverter, 2) String inverter and 3) Microinverter. The common grid-connected type of PV system is shown in Figure 1.

Centralized inverter involves several numbers of solar modules connected in series and parallel configuration which draws a number of drawbacks such as high percentage of losses including high voltage DC cables loss, losses due to centralized maximum power point transfer (MPPT) and power mismatch losses in solar modules due to shading and cloud effects. One failure of the solar module leads to immediate power abruption to the grid, thus reduce the FIT-based income consequently prolong the Return of Investment (ROI) in the future [1], [11], [18]. However the simple structure of centralized inverter make it suitable design for large-scale PV plant producing more than 10 kW up until 1 MW for the three-phase of grid.

Series placement of two or more solar module is known as PV string. Inverter in string configuration can be fed both either from single PV string or numbers of PV string. Overall string inverter system have higher cost compare to centralized inverter. However, string inverter system solves the partial shading and cloud effects, thus offering higher efficiency. This kind of grid-connected PV system suitable for small to medium-scale applications with less than 10kW power rating [11], [19]. This type of string inverter system can be referred to [10], [18], [20].

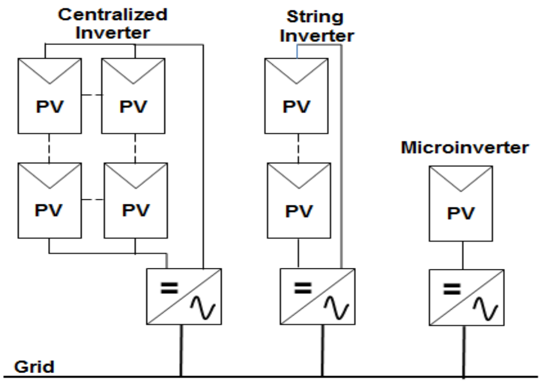


Figure 1. Grid-connected PV system

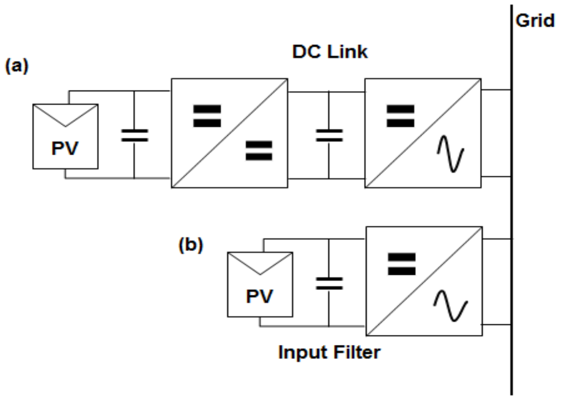


Figure 2. Power conversion stage: (a) Two-stage operation and (b) Single-stage operation

The idea of microinverter was introduced in 1990s with aims to improve system efficiency with a simpler design. The compact design of inverter component makes it accessible to be placed at the back side of the single solar module. Single solar module give good features to the system such as; allowing the output of PV system to be unaffected by other solar module, no mismatch power losses between solar module, and easy for failure detection [1], [19]. The microinverter PV system also known as the 'module integrated converter (MIC)' or "plug-and-play" device which suitable for small application with power rating between 150W–600W [11], [13], [22]. D. Petreus *et. al* [22] conclusively shown that microinverter PV system utilized reduced number of components thus contributing lower cost of microinverter. Later in 2015, F. Famoso *et. al* [18] proved that higher energy production was generated by using microinverter PV system compare to the string PV system for the same rooftop area. Global Solar Market forecast the PV market to be growth around 15.3% by 2020 [23]. Based on the report, the residential segments contribute larger percentage to the PV market. Therefore, the literature on grid-connected PV system reveals that the microinverter becomes the trend for the next generation of PV system development [22], [24].

This paper first outlined the overview of the single-stage and two-stage power conversion of microinverter, the definition, advantages and disadvantages of these two types of power conversion. Next the paper presents the bird's-eye view of the single-stage microinverter topology, the comparison in terms of components used, types of filter, overall performance and finally the conclusion.

2. POWER CONVERSION STAGE OF MICROINVERTER

2.1. Two-stage Microinverter

Two-stage power conversion system has been widely used in grid-connected PV system [1], [22-23]. First stage involving the DC-DC converter and MPPT component where PV voltage needs to boost into certain appropriate level and maximum power were tracked. Second, the inverter operation takes place where DC power inverts into AC power. This configuration can be shown in Figure 2a.

A challenge of two-stage microinverter is dealing with power interface when DC power from the solar module is transferred to the AC-grid side. By referring to Figure 2a, there is a capacitor called as DC link, which connected in parallel between first and second-stage in order to balance out the power difference [11] performance [21].

2.2. Single-stage Microinverter

Single-stage microinverter employed only single inverting component from DC input into AC output without encounter with any other converter component. The configuration of single-stage operation can be illustrated in Figure 2b. Single-stage microinverter also needs to manage power difference between input and output of the PV system. Therefore, a huge value of electrolytic capacitance is placed in parallel to the input solar module, which also known as input filter. The electrolytic capacitor is usually large in size, shorter lifetime, large tolerance (±20%), and temperature-dependent device [25]. These obstacles affect the reliability and efficiency of the overall single-stage PV system.

Therefore it would be advantageous to minimize the value of electrolytic capacitance by using film capacitor and adopted minimum stages of operation (single-stage power conversion) in order to achieve compact design with higher efficiency system.

3. SINGLE-STAGE OF MICROINVERTER TOPOLOGY

As stated in previous section, dealing with conventional two-stage grid-connected PV configurations suffer from several drawbacks compared to single-stage grid-connected PV. The obvious drawbacks are significant power losses, complicated controller, higher numbers of component count which all leads to higher cost and lower reliability. Therefore recent researches focus on how to reduce the number of power processing stages by reducing the number of component count and implement the optimization of controlling method. Thus single-stage power configurations represent good solution where MPPT, boosting and inverting component is develop between solar module and grid system [19], [22], [24], [26]. Classifications of different single-stage microinverter topologies in grid-connected PV system implemented by researched are presented in this section.

3.1. Flyback Topology

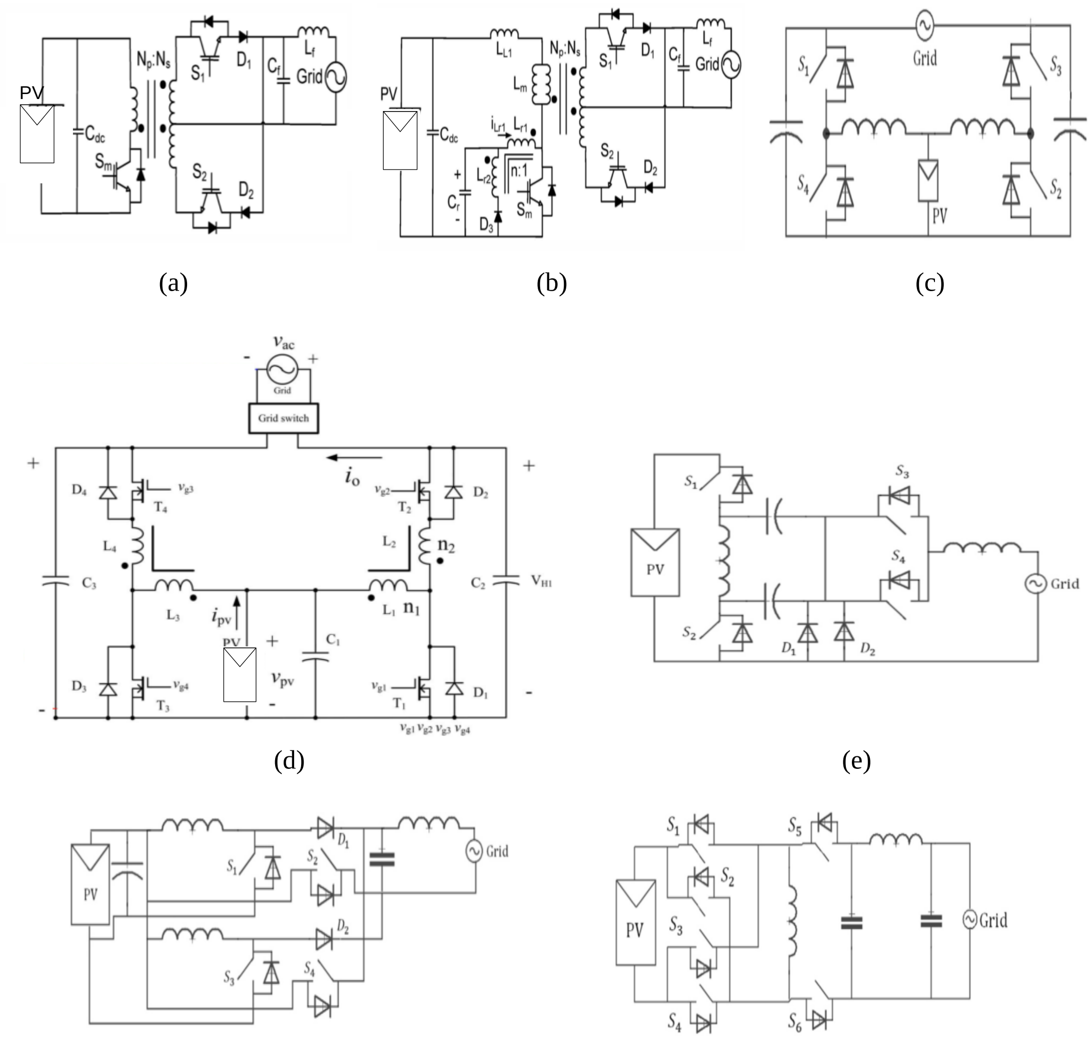
A conventional flyback topology [11] with three power switches is constructed for PV system as shown in Figure 3a. This transformer-based microinverter topology adopted the idea of circuit isolation by integrating the line frequency transformer between solar module and grid. The LC-filter was connected before the grid to obtain smoother AC output. The leakage inductance of the transformer in the conventional flyback topology caused high switch stress thus reducing the output power performance.

M. Kalilian *et. al* [26] in 2015 proposed the same topology with additional auxiliary circuit at the primary side of the transformer. The proposed topology as shown in Figure 3b has additional components: diode, capacitor and inductor. The 100W flyback-auxiliary circuit topology does not have auxiliary switch, thus somehow allowing the switch and diode at the primary side could be turn on using soft switching operation. However, topology design without transformer is more desirable and offer greats benefit in terms of cost, greater performance and compact design [11], [22].

3.2. Double-boost Topology

A conventional double-boost topology applied in microinverter PV system is shown in Figure 3c. This transformer-less based topology provide mirror circuit at the right and left of the circuit, allowing for both operation waveform. Each mirror circuit consists of two boost converters with total of 4 power switches, 2 inductor and 2 capacitors. The conventional boost topology circuit suffers with additional switching losses due to the simultaneously high-frequency switched of the device [11]. Apart from that, the duty cycle of the conventional double-boost microinverter limits the voltage gain consequently producing lower instantaneous output AC compared to input DC.

Y. Fang and X. Ma [27] in 2010 successfully solved this problem by adopted coupled-inductor to the conventional double-boost topology circuit. The proposed topology as shown in Figure 3d make the limitation of voltage gain is no longer a controlling factors. When duty cycle is around 0.5, the duty cycle is proportional to the voltage gain, thus generated larger AC output voltage than DC input voltage. The output power reaches 217.8W with efficiency more than 97.5%. However, the proposed system used DSP controller which is complicated control circuitry when a simpler digital controller can be used for microinverter under 300W small-application [28].



(a) (b) (c)

(d) (e)

(f) (g)

Figure 3. Single-stage Grid-connected Microinverter Topology: (a) Conventional flyback [10], (b) Flyback with auxiliary circuit [24], (c) Conventional double-boost [10], (d) Coupled-inductor double-boost [25], (e) Derived zeta-cuk topology [10], (f) Derived buck-boost configuration [10] and (g) Buck-boost with 6 switching devices [10]

3.3. Derived Zeta-Cuk Topology

A derived microinverter topology obtained from zeta and cuk converter employ 4 power switches, 2 diodes, capacitor, inductor and LC filter before the grid. Figure 3e illustrates the proposed circuit topology. This topology also classified under transformer-less based topology for microinverter PV system. However, this derived zeta-cuk topology face a challenge with an asymmetrical operation; where the output current is injected to the grid during half cycle of the grid voltage [11].

3.4. Buck-boost Topology

A buck-boost topology microinverter circuit is another example of transformer-less based topology. This microinverter topology employs the LC-filter to reduce the current harmonics generated by semiconductor switching. In 2001, a derived buck-boost [11] topology circuit have been introduced consists of 4 power switches, 2 diodes, capacitor and 2 inductors as shown in Figure 3f. The proposed topology utilized optimum number of switches where all switches in the upper circuit was turn on and all switches in the bottom circuit was turn off, and vice versa. This gives an advantage of lower switching losses to this kind of topology.

In the same year, buck-boost with 6 switching devices [11] was proposed with reducing the number of inductor. That single inductor is stored energy from two directions thus producing output AC current. The additional two semiconductor devices were used for solar module and grid grounding. Figure 3g shows the buck-boost topology with 6 switches.

4. FUTURE DEVELOPMENT

Microinverter is a niche area, however it provides an upcoming trends and a lot of research can be carried out for this field. This review has covered several single-stage grid-connected microinverter topologies; however each topology has their own benefits and circuit limitations. Based on the literature, there are several characteristics need to be accounted for before designing the single-stage microinverter PV system.

4.1. Compact design

Only a single PV panel is required to be attached with the microinverter circuit and controlling strategy of the PV system. A compact design with higher efficiency of the microinverter technology is vital since the microinverter circuit should be light enough to be placed at the back of the PV panel. One of the smart ways is by reducing the power conversion stage and optimizes the component count. The arrangement of microinverter topology is important to determine the lower component count. Besides, microinverter based- transformer should be excluded from the designing process because of the area and weight issue.

4.2. Proposed Algorithm

Elimination of the converter stage can be substitutes by developing microcontroller algorithm. The proposed microcontroller should be running several tasks: 1) MPPT, 2) switching of inverter's switches, 3) anti-islanding and 4) synchronous unit. There are various methods for MPPT algorithm to extract maximum power; however, Perturb and Observe (P&O) becomes the most familiar algorithm in the PV system [29]. The controlling strategy is also being applied to power up the switches. Besides, anti-islanding algorithm should be programmed to turn off the inverting process, when the sun irradiance and temperature is not enough to produce an AC-output. The synchronous unit functioned to avoid the generated current to flow from the grid to the microinverter, thus degrade the circuit topology. The main purpose of the algorithm should be able to maintain the unity power factor (pf $\sim$ 1); where the generated AC-current is in-phase with the AC-grid voltage. Beside, other algorithm could be programmed by adjusting the magnitude and phase angle of the generated AC-inverter voltage, aims for higher efficiency of the microinverter PV system.

4.3. Realibility Issue

Realibility factor also play an important role in the microinverter PV system. Lifespan of the microinverter is limited due to the inverter component which needed regular maintainance compare to the other elements in the PV system. Therefore, reducing the power conversion stage is a wise action toward higher realibillity design. The inverter need to be arranged carefully and neatly so that only requires minimum power switches, capacitor or inductor in the circuit topology. The film capacitor also could be used to replace the conventional electrolytic capacitor which also not a space-efficient. Low-pass filter that were located before injecting to the utility grid also impact on the realibility issue. Thus a minimum filter component could be employed such as L-filter, not LC or LCL-filter.

5. CONCLUSION

This review has covered basic configurations and challenges of the commercialize microinverter (utilized of two-stage operation, DC-DC and DC-AC) and single-stage power conversion (DC-AC) for the grid-connected microinverter PV system respectively. Single-stage microinverter PV system still a new field and relevant for future study, which include on the topology arrangement, less-complex of control strategy, efficient and compact design of PV system. Therefore, these characteristics discussed above should not be taken lightly as it can be executed for future development of low-cost and high realibility single-stage microinverter grid-connected PV system.

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