International Journal of Scientific Research & Engineering Trends
Volume 8, Issue 5, Sep-Oct-2022, ISSN (Online): 2395-566X

Design and Control Grid-Connected Isolated PV Microinverters: A Review

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Abstract- Galvanic isolation is a very significant feature that should be present in grid-connected photovoltaic (PV) microinverters because it addresses both power quality and safety concerns. However, the efficiency of the isolated varieties of microinverters is reduced due to the presence of high-frequency transformers and significant switching losses. In recent times, a number of different isolated topologies have been suggested as a means of increasing the efficiency as well as the lifetime of PV converters. The purpose of this work is to provide a thorough analysis and assessment of the most recent isolated topologies for PV microinverters. In terms of the number of stages at which they process power, these topologies can be divided into two distinct classes: 1) single-stage microinverter, and 2) multi-stage microinverter. A number of possible topologies are discussed, contrasted, and analyzed in terms of the power losses that occur at various stages, control mechanisms, where the decoupling capacitor should be located, and the overall cost. In order to acquire a comprehensive image of the framework for the future generation of isolated PV microinverters, recommendations are made to improve the existing topologies and select the relevant control mechanisms.

Keywords- Microinverter Photovoltaic system Grid-connected inverter PV.

I. INTRODUCTION

Introduction According to an analysis conducted in 2012 by the International Energy Agency (IEA), approximately 1.3 billion people (or approximately 19% of the world's population) did not have access to electricity in the year 2010, but this number is expected to drop to approximately 1 billion people (or approximately 12% of the world's population) by the year 2030 [1]. In the past five years, renewable energy has reached the point where it can compete economically with conventional fuels. According to the IEA, sixty percent of new connections will need to originate from decentralized micro-grids and off-grid installations, such as solar household systems [2]. The drawbacks of renewable energy sources, such as unpredictability in output, can be alleviated somewhat through the implementation of energy storage strategies [3–5].

To reduce the amount of harmful gases and metals released into the atmosphere by fossil fuel steam electric generators, it is necessary to increase the amount of electricity that can be generated by clean, non-hazardous renewable sources. The United States Annual Energy Outlook 2014 (AEO, 2014) estimated that the total renewable generating capacity will grow by 52% from 2012 to 2040 in the United States alone. Solar power is expected to lead the growth in renewable capacity by increasing from less than 8 GW in 2012 to more than 48 GW in 2040 [6]. [Citation needed] The U.S. Annual Energy Outlook 2014 (AEO, 2014) estimated that the total renewable generating capacity will grow by 52% from 2012 to 2040 in the United States The German Energiewende plans to generate at least 35% of its electricity from green sources by the year 2020, and it is anticipated that this number would surpass 80% (roughly 488 billion kWh per year) by the year 2050. Photovoltaic (PV) energy is widely regarded as one of the most exciting and potentially game-changing new technologies among the various renewable energy sources. According to the road map envisioned by the IEA, the percentage of the world's electricity that comes from PV will increase to 16% by the year 2050.

The price of complete photovoltaic (PV) systems has dropped by one-third in the past six years, while the price of PV modules has dropped by eighty percent as a direct result of mass production [7]. Silicon technology accounts for ninety percent of the world's total photovoltaic cell production. This technology has an average cost of 0.10 USD/kWh and has conversion efficiencies that range from 17–25% [8]. The natural abundance of crystalline silicon semiconductor materials explains why this technology dominates. It is anticipated that the cost of the next-generation of nanostructured solar cells will drop to 0.03 USD/kWh while maintaining a maximum conversion efficiency of 33% [9,10]. In the not too distant future, the proliferation of photovoltaic (PV) technology will be accelerated by the development of low-cost perovskite solar cells [11–13]. PV systems that are connected to the AC grid do not require batteries for storage, which means they are more cost effective and require less maintenance than independent systems. It is standard practice to store energy in lead-acid or lithium-ion batteries in standalone systems. This practice raises the system's overall cost and necessitates additional control for charging and discharging [14–16]. As a result, grid-connected photovoltaic systems make up 99% of the total installed capacity, whereas standalone systems only account for 1% of the total. [17] conducts research and analysis on the performance characteristics of photovoltaic (PV) systems that are connected to the grid. One of the most important components for transferring photovoltaic energy into the alternating current grid is the power inverter. Solar photovoltaic (PV) systems that are connected to the power grid can range in size from a single PV module with a capacity of approximately 100 W to PV plants with more than a million modules totaling 290 MW. On the basis of the various configurations of PV modules, the grid-connected PV inverter can be divided into central inverters, string inverters, multistring inverters, and AC-module inverters or microinverters. Each of these categories has its own set of advantages and disadvantages.

A microinverter, also known as a module-integrated converter, is a dedicated grid-tied inverter that is utilized for each photovoltaic module that makes up the system. It has a low power rating of between 150 and 400 watts. The ability to realize a true plug-and-play solar AC PV generation is made possible by the small design that is attached to the back of each PV module, which has the highest maximum power point tracking (MPPT) accuracy. Additionally, the provision for further integration of PV modules creates the opportunity to realize this potential. Due to the low voltage rating of PV modules, the AC-module inverters need an additional DC– DC stage in order to enhance the voltage in comparison to the level of the grid (typically o60 V DC). The additional DC–DC stage is typically paired with a high-frequency compact transformer.

This configuration ensures galvanic isolation and satisfies the im proof requirement without the need for a line-frequency bulky transformer on the AC grid side. In the case of a single-stage centralized PV inverter, line frequency transformers are the only option for raising the inverter voltage to grid level.

When compared with isolated topologies, on-isolated boost converters and transformer-less topologies have a higher efficiency, increased compactness, and lower cost than isolated topologies. This allows them to be employed in the DC–DC stage. However, in comparison to isolated topologies, transformerless topologies are inefficient due to the presence of leaky ground currents, the requirement of dual grounding, and the poor voltage gain. Achieving high conversion efficiency, cheap production costs, and a long lifespan are the primary technical hurdles that must be overcome for isolated PV microinverters. Since isolated microinverters typically incorporate high frequency transformers, core losses and switching losses are the primary challenges that need to be addressed in order to achieve increased efficiency. In order to realize a reliable integrated unit with each PV panel, it is desirable to have a microinverter that is both tiny and has a long lifespan. Researchers have investigated a wide variety of approaches to enhance the performance of microinverters. The present investigation starts with the standards that have been stated by the authorities in charge of the utility grid and the performance requirements for PV converters. After that, a concise history of how microinverters came to exist today, beginning with the invention of grid-connected inverters, is presented. After this, a critical analysis of the performance of the topologies and control arrangements of certain existing grid-connected isolated microinverters will be presented as a follow-up to this debate. Single stage and multi-stage topologies are the two primary ways that microinverters can be categorized. The flyback converter is a common method that associates an unfolder circuit with a smaller number of power semiconductor devices. This method is employed in topologies that only have one stage. The DC–DC boost converter is cascaded with the inverter, which provides a DC link to insert the decoupling capacitor. Stage topologies. After then, the performances of these topologies are compared with respect to the norms and demands that were previously established. The following part will provide some recommendations as well as some future directions. In the end, a conclusion is reached in order to provide a clear direction for the construction of a dependable isolated microinverter that is both inexpensive and has a high conversion efficiency.

Centralized configuration: Previously, the primary technology that was used for dc–ac conversion was the 'centralized' inverter for BIPV systems that were interconnected with the grid. This type of inverter required a number of PV modules to be connected in series and parallel arrays in order to obtain the required power and voltage levels (see Figure 1). Because of the requirement for high voltage dc cabling to connect the BIPV system to the centralized inverter, this architecture has a number of significant drawbacks. These drawbacks include problems with safety, cable losses, dc arcs, and potential fire hazards. Centralized maximum power point tracking (MPPT) performed on the solar array as an aggregate leads to less than optimal power harvest due to inefficient tracking of the maximum power point resulting from shadowing circumstances of individual panels in the system, consequent module mismatch, and the resultant complex current–voltage curves. Centralized MPPT is performed on the solar array as an aggregate. As there is no option for voltage boost in this system, the minimum number of BIPV panels that must be installed in order to set up the system is considerable. This is necessary in order to achieve the needed voltage levels. Increasing the power rating of a centralized inverter results in an increase in the space requirement for the device, which necessitates the supply of expensive cooling systems. Once the system has been designed and set up, the expandability of the system as well as the freedom in adjusting the voltage, current, and power levels is restricted.

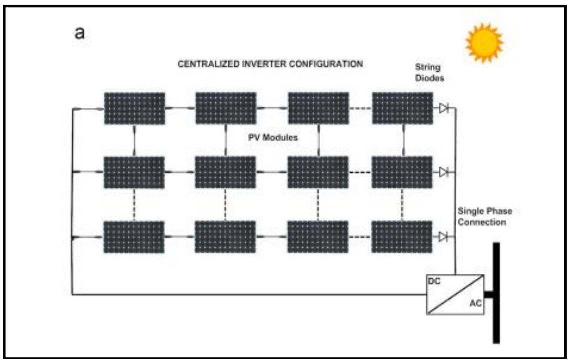

Fig. 1 Centralized Inverter Configuration

b. String configuration: to overcome some of the disadvantages of centralized inverters, string inverters, as shown in Fig.2 have been developed. In this configuration, a group of series-connected BIPV modules called ‘strings’ have their own inverters; the voltage generated by individual strings is high enough to attain the grid voltage level. The losses connected with poor MPPT are less in this configuration while the reliability and modularity is improved in comparison to centralized inverters. However, problems like complex dc cabling and associated issues remain even in this configuration. In addition, like their centralized counterparts, string inverters require auxiliary cooling and protection devices. The necessity of deploying semiconductor circuit elements of higher ratings and the resultant system bulkness are issues that do not act in favor of string inverters.

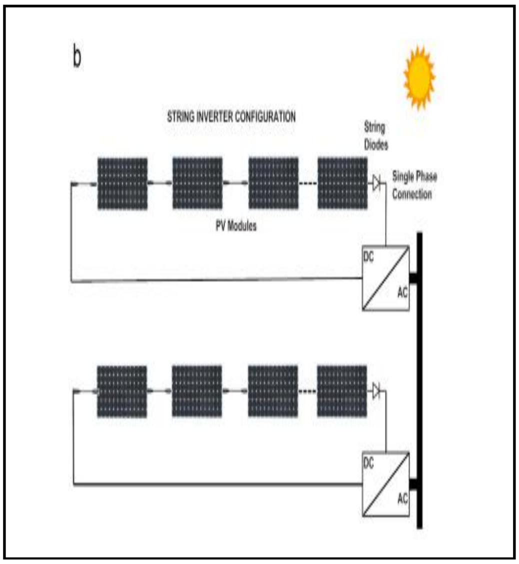

Fig.2 String Inverter Configuration

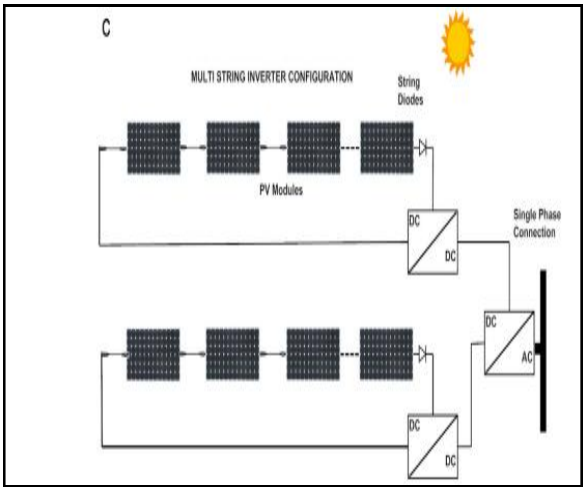

Fig 3 Multi-String Inverter Configuration.

Power conversion topological configurations of microinverters

Panel voltage for the popular mono crystalline and multicrystalline silicon PV modules is around 25–40 V dc at maximum power point operation.Main challenge of a microinverter is to step up this PV panel voltage to the range of utility supply voltage (which is 120–230 V ac). One option is to use a line-frequency transformer that affords a high step-up gain through the selection of a proper turns-ratio. However, bulk and high leakage inductance restricts this option for practical applications .Next best option reported in the literature suggests the use of dc–dc boost converter to obtain the required amplification of the voltage which can be achieved by using transformer or transformerless topologies. High frequency transformer based topologies have simple structure and are easy to control as the amplification is achieved by selecting appropriate turns ratio .Also high frequency transformers allow for dual grounding on both input and output terminals thereby avoiding resonance between stray capacitances of the PV panel and the inductances in the current main paths.

However high frequency transformers can reduce the efficiency of system and increases the input current ripple from the PV panel. Reduction of current ripple warrants the use of electrolytic capacitors resulting in decrease of life time and an increase in overall system size and cost .To eliminate this problem some topologies with current fed schemes are proposed .Transformer less conventional boost converters are to be operated at extremely low duty cycles to achieve high amplifications required in a microinverter. However as the switch turn off period becomes short ripple in the currents increase thereby increasing the conduction loss and voltage stresses of the power semiconductor switches. Several options like power device paralleling, multilevel boost converters, cascaded boost converters, interleaved boost converters, coupled inductor and switched capacitor circuits are proposed in the literature to obtain the required boost.

Increased reliability and life High reliability is a major operational requirement for microinverters; their average life time should also match the standard warranty of 20–25 years that accompany most of the PV modules. This is particularly important as the microinverters are often mounted on roof tops and in locations that are difficult to access, thereby increasing the costs associated with frequent maintenance. The life time of a microinverter is also an issue of importance in calculating the life cycle cost of electricity. Electronic components in a microinverter system experience higher thermal stresses because of the following reasons.

1. Ambient temperatures can vary from 80 1C at noon under maximum irradiation to 0 1C during the night, especially in desert regions leading to huge thermal stresses.
2. Internal temperatures of microinverters can be 25–30 1C higher than the ambient temperatures as they are mounted on the roof top at the back of panels.
3. Self heating of microinverter due to internal losses further enhances this temperature.

A major challenge for the next generation microinverters therefore is the capacity to withstand these cyclic thermal stresses and achieve a life time of 25 years or more. Some of the switching devices used in inverters, relays and electrolytic capacitors are also the potential weak points for inverter reliability. Electrolytic capacitors are very sensitive to temperature where an increase in 1C can halve the lifetime of the electrolytic capacitor due to loss of electrolyte .The next generation microinverters should therefore explore the use of film capacitors which are rugged, can withstand higher voltage surges and have self-healing properties inherent in their construction .Reliability can further be enhanced by limiting the electrical and thermal stress on components through the proper thermal management design.

Increased efficiency The efficiency of microinverters has to be high enough to compete with classical string or central inverters. Achieving efficiencies of about 95% may be a difficult task because of the lower power levels involved and also because of the fact that each micro inverter will have its own signal processing circuitry, protection circuitry with relays, etc. that contribute to increase in losses in comparison to centralized inverters. The high frequency transformers provided for the galvanic isolation between the panels and grid for compliance with the leakage current standard add to the losses of microinverters .Choice of the power converter topology plays a vital role in the success of the product and may affect the key parameters, cost, overall size, EMC performance and efficiency. Cascaded topologies have lower efficiencies because of the losses involved in two stages of the converter. When hardswitching techniques are used, the switching loss tends to be high as the semiconductors in both conversion stages switch under high frequencies. Soft-switching technique can be utilized in both conversion stages to minimize the drawback of this arrangement, but that may result in a higher component count and therefore a higher cost and a lower reliability. The use of single stage topologies with pseudo-dc link can, however, reduce the losses to some extent as the second stage needs to be switched only at power frequencies. Semiconductor switches have a major influence on the converter efficiency. Inspite of unique characteristics like higher break down voltage, reduced recovery voltage applicability of SiC (Silicon Carbide) [70] its applicability in microinverters may be limited as the module voltages and currents are very low. However they do find applications on the grid connection side because of relatively high voltages involved. GaN-on-Si (Gallium Nitride on Silicon) technology developed by International Rectifier Corporation (IR).

II. RELATED WORK

Aydin BOYAR (2020): Solar energy has become an easy way to get electricity because it doesn't pollute, doesn't release as much carbon, and needs less maintenance because it has fewer needs. An inverter is one of the most important parts of a photovoltaic (PV) power conversion system. It can be set up in a central, string, or micro topology. The micro inverter is one of the gadgets that have gotten the most attention and research in the past few years. It has both pros and cons. In this research project, the flyback converter and H-bridge parts that make up the micro inverter are designed and studied in terms of how well they work and how reliable they are. Sinusoidal pulse width modulation is used to make the switching pulses of an H-bridge. A technique called Incremental Conductance based Maximum Power Point Tracking (IC MPPT) is used to control the switching of a flyback converter (SPWM).

During this research, the micro inverter that was designed was made both in a simulation and in the real world. In a flyback micro inverter, the input voltage comes from a single PV module at 50 volts direct current. For single-phase lines, the output voltage is 220 volts alternating current at a frequency of 50 hertz. The first simulation of the proposed flyback micro inverter, which has an LC filter, is done with MATLAB Simulink. The simulated micro inverter was found to have an efficiency of 0.35 and a THD ratio of 94%. LC and LCL filters are used to study how well a flyback micro inverter works after it has been built. The focus of this study is the quality of the output voltage. Using LC and LCL filters, the THD ratios of the output voltage can be found to be 4.41 and 2.57%, respectively. The efficiency of the developed flyback micro inverter can be found to be about 82.3%.

M. Seyyed Hosseini (2020) Not only does the term "Internet of Things" (IoT) refer to the connectivity of systems and devices, but also to the associated applications and services that offer monitoring and control of more complex systems and services. The advantages that micro inverters have over central inverters have led to more attention being paid to these devices. In solar applications, conventional micro inverters are only capable of transferring electricity from solar cells to the grid or to loads. Solar smart inverters, in addition to being able to transfer electricity, can monitor the system's condition to identify malfunctions and can also function as multi-agent systems. The connecting of IOT devices is capable of conferring a great deal of new properties on micro inverters. This type of Internet of Things solar energy system can gather and analyze data from inverters, operate solar farms, monitor the condition, identify errors, and enhance efficiency under a variety of different operational settings.

The system that is being proposed in this study has the capability to continually monitor the parameters of the micro inverter as well as the solar module. These parameters include voltage, current, temperature, and power. In addition, the system under consideration has the capability of modifying control parameters such as the present controller parameters and operating points such as the delivered power. If, when an aberrant state is present, any of the parameters, such as voltage and current, fall below their ideal values, this will be monitored, and the values will be shown on a web-based website. In this article, we examine the uses of this tiny inverter, as well as the opportunities that may be realized through the utilization of an IOT solar system. Additionally, we implement a prototype to demonstrate the concept.

Ersan KABALCI (2020): Photovoltaic (PV) power conversion is one of the areas of research that has been looked into the most when it comes to renewable energy sources. The inverters, which are an important part of the process of converting power, have also been changed so that they can work with applications that use alternating current and integrate PV systems into grids that use alternating current. Micro inverters are one type of modern inverter topology that has been used to connect solar PV plants to utility grids and ac loads. Maximum power point tracking (MPPT) management can be done with these inverters for each solar module that is connected to a PV plant.

This study will suggest a new micro inverter topology called IFMI because it will be made up of interleaved flyback micro inverters (IFMI). The micro inverter is made with a two-stage design. In the first stage, a two-phase interleaved flyback converter converts dc power to dc power. In the second stage, an H5 inverter topology changes the DC power to AC power. For controlling the dc-dc converter stage, the typical incremental conductance MPPT method was used. A sinusoidal pulse width modulator and a PI controller have been added to the H5 inverter's controller to make it better. Both simulations and real-world tests have shown that the proposed converter's power conversion and tracking of a reference are stable. A thorough study has been given and discussed about the pros and cons of the suggested device architecture, as well as what could be done in the future.

Widamuri Anistia (2020): This article shows a new way to use a Fuzzy Interference System (FIS) controller to manage reactive power in an AC grid network for solar PV that is connected to the grid. The flyback type of inverter is chosen because it is easy to control, gives stable current injection, is reliable, and is cheap. This fuzzy controller takes into account two kinds of inputs: the solar PV voltage and an MPPT reference voltage. Next, this controller will send the phase signal to the comparator circuit, which will use it to make PWM signals for the switches. We also talk about a traditional PID controller method so that we can compare the two. The testing software used to get the job done is MATLAB/SIMULINK. The simulation tests show that the FIS controller works well enough for the user to be happy with it. This controller can control the solar PV's ability to send reactive power into the AC grid in an effective way. In addition, it has fewer harmonic than the standard PID controller.

Anthony Bier (2020) this paper describes the design and implementation of a control system for a single-phase, grid-connected GaN micro-inverter that is best for use with solar panels. First, the wide-band-gap parts of the power circuitry are shown. Then, the switches, pulse controls, and control loops that are unique to this grid-tied inverter are talked about.

Arup Ratan Paul (2020) this paper describes the design and implementation of a control system for a single-phase, grid-connected GaN micro-inverter that is best for use with solar panels. First, the wide-band-gap parts of the power circuitry are shown. Then, the switches, pulse controls, and control loops that are unique to this grid-tied inverter are talked about. Requirements of next generation microinverters though promising tremendous growth potential, there are certain technical and commercial issues that the next generation microinverters should properly address. Technical requisites like efficiency and reliability and commercial issues like cost, market visibility play a vital role in deciding the future of penetration of microinverters in the PV market. In this section, we deal with some such salient issues.

III. CONCLUSION

During the past two decades, photovoltaic (PV) energy has undergone significant expansion, becoming one of the most advantageous forms of distributed power generation that is based on renewable energy resources. It has been demonstrated that the grid-connected isolated microinverter topology is a suitable choice among the various types of PV converter topologies since it provides good power quality and handles safety concerns. Recent publications have presented a number of research concepts that have been developed with the intention of enhancing efficiency, dependability, cost, and compactness. When it comes to microinverter topologies, the single-stage flyback with soft switching is the most advantageous design in terms of both cost and efficiency. However, the lifetime of the converter will be diminished as a result of this. The interleaved flyback inverter with active clamp switching has one and only one drawback, and that is its relatively limited lifespan. It is possible to perform additional research in order to lengthen the lifetime of the single-stage microinverter while preserving its high level of efficiency. A multi-stage microinverter that combines an active clamp DC–DC converter with a single switch modulated inverter may be an effective solution for the construction of a power converter with a longer lifespan, higher efficiency, and a lower cost. This solution utilizes an active clamp DC–DC converter. Additional research efforts are constantly being undertaken in the direction of improving the performance of micro inverters and addressing difficulties with grid dependability. For those conducting research on solar power converters with high efficiency, long lifespans, and low costs, a comprehensive analysis of the many isolated microinverter topologies will serve as a useful reference.

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