A Review on Single Phase single stage transformer less Grid connected PV system

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Abstract – The review focuses on various inverter topologies. The inverters are classified into Different configurations, which are described below. The drawbacks of existing grid connected PV systems, it is apparent that the efficiency and path of the two-stage grid-connected system are not attractive. Therefore, single-stage inverters have gained attention, especially in low voltage applications. Various inverter topologies, & grid connected PV systems are presented here.
Keywords*: current source inverter (CSI), Total harmonic distortion (THD), Photovoltaic (PV), module-integrated converters (MIC).*

I. INTRODUCTION

1.1 Solar Energy: An Alternative Energy Resource

Renewable energy, especially solar photovoltaic (PV), currently play an important role in the global technological scenario with the growing global demand for energy. A photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors.

A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The monocrystalline and polycrystalline silicon cells are the only found at commercial scale at the present time. Silicon PV cells are composed of a thin layer of bulk Si or a thin Si film connected to electric terminals. One of the sides of the Si layer is doped to form the p–n junction. A thin metallic grid is placed on the Sun-facing surface of the semiconductor. Fig. 1 roughly illustrates the physical structure of a PV cell. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short-circuited. Charges are generated when the energy of the incident photon is sufficient to detach the covalent electrons of the semiconductor—this phenomenon depends on the semiconductor material and on the wavelength of the incident light. Basically, the PV phenomenon may be described as the absorption of solar radiation, the generation and transport of free carriers at the p–n junction, and the collection of these electric charges at the terminals of the PV device.

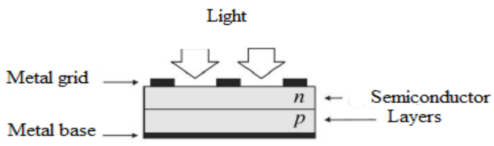

Fig. 1.1 Physical structure of a PV cell.

The rate of generation of electric carriers depends on the flux of incident light and the capacity of absorption of the semiconductor. The capacity of absorption depends mainly on the semiconductor bandgap, on the reflectance of the cell surface (that depends on the shape and treatment of the surface), on the intrinsic concentration of carriers of the semiconductor, on the electronic mobility, on the recombination rate, on the temperature, and on several other factors. The solar radiation is composed of photons of different energies. Photons with energies lower than the bandgap of the PV cell are useless and generate no voltage or electric current. Photons with energy superior to the bandgap generate electricity, but only the energy corresponding to the bandgap is used—the remainder of energy is dissipated as heat in the body of the PV cell. Semiconductors with lower bandgaps may take advantage or a larger radiation spectrum, but the generated voltages are lower. Si is not the only, and probably not the best, semiconductor material for PV cells, but it is the only one whose fabrication process is economically feasible in large scale. Other materials can achieve better conversion efficiency, but at higher and commercially unfeasible costs. Grid connected or grid-tie PV power systems installed near the consumer are used to efficiently generate and distribute electricity without battery storage. Distributed generation brings several benefits such as lower transmission costs, fewer losses and reduction of urgent investments on huge Power plants and transmission lines to supply the increasing electricity peak demand in many countries. Distributed photovoltaic systems are rapidly growing and many studies Show that PV and other renewable sources will highly contribute to the world's needs of electricity in next decades.

II. LITERATURE REVIEW

In [1], a single-stage single-phase grid-connected PV system-based on a CSI is proposed. A doubled-tuned parallel resonant circuit is proposed to eliminate the second- and fourth order harmonics on the dc side. Moreover, a modified carrier based modulation technique is proposed to provide a continuous path for the dc-side current after each active switching cycle.

The control structure consists of MPPT, an ac current loop, and a voltage loop. In a single-phase CSI, the pulsating instantaneous power of twice the system frequency generates even harmonics in the dc-link current. These harmonics reflect onto the ac side as low order odd harmonics in the current and voltage. Undesirably, these even harmonics affect MPPT in PV system applications and reduce the PV lifetime. In order to mitigate the impact of these dc-side harmonics on the ac side and on the PV, the dc link inductance must be large enough to suppress the dc-link current ripple produced by these harmonics. Practically, large dc-link inductance is not acceptable, because of its cost, size, weight, and the fact that it slows MPPT transient response. To reduce the necessary dc-link inductance, a parallel resonant circuit tuned to the second-order harmonic is employed in series with the dc-link inductor. The filter is capable of smoothing the dc-link current by using relatively small inductances. Even though the impact of the second-order harmonic is significant in the dc-link current, the fourth-order harmonic can also affect the dc-link current, especially when the CSI operates at high modulation indices. Therefore, in an attempt to improve the parallel resonant circuit, this paper proposes a double-tuned parallel resonant circuit tuned at the second- and fourth-order harmonics.

In [2], a single-phase full bridge inverter with high-frequency transformer that can be used as part of two stage converter with transformer less single-stage converter for grid connected PV application is proposed. From the literature review of module-integrated converter (MIC) topologies it is observed that, many converter topologies may be employed & many kind of MIC inverters can be found in the literature using half-bridge, full-bridge, buck-boost, flyback structures. In the proposed system the H-bridge inverter is connected to the grid through the output filter composed of L & C.With a closed-loop current controller, the circuit can behave as controlled current source connected to the grid. The high-frequency square voltage produced by the H-bridge is applied to the transformer, whose secondary applies a stepped-up square wave to the inductor. The voltage is then modulated in order to control the inductor current, which must be sinusoidal and synchronized with the grid voltage.

The filter design is critical issue in the inverter performance. A current controller is used to produce a sinusoidal current synchronized with grid voltage at the output of the RC filter. Many type of current controllers for grid-connected inverters have been proposed in the literature. Controllers PI or PID are most widely used. The author designs the proportional & resonant (P+RES) compensator, which is an alternative to the steady state error of PI & PID compensator. The P+RES compensator does not require coordinate transformation nor require PLL (phase-locked loop) synchronization, hence can be easily implemented in single-phase systems. The resonant controller achieves zero steady-state error, it means a unity power factor at the micro-inverter output.

In [3], the single-stage boost inverter is used as a grid-tied inverter to extract the DC power output from the PV array and inject a high quality AC current into the grid. a modified modulation scheme is proposed to enhance the boosting capability of the boost inverter and to improve the THD of the grid injected current. To overcome the asymmetrical output voltage problem, this paper proposes a modified modulation scheme for the grid connected three phase boost inverters that reduces the DC offset of each converter which in turn reduces the stress on both the capacitors and the switching devices as well as enhances the boosting capability of the boost inverter itself. The most attractive feature of this modified scheme apart the other modulation schemes is that it allows both upper and lower half cycles of the AC output voltage to be generated within the same boosting ratio (gain), which results in symmetrical sine wave with reduced THD of the grid injected current with respect to the other modulation schemes. This modified modulation is inspired from the dead band PWM inverters, where one leg of the inverter is clamped for a certain period of time in each cycle, resulting in a dead band region where switching is inhibited. In a three phase circuit, keeping one leg of the inverter inactive will not result in loss of controllability but will reduce the effective switching frequency. The proposed modulation implies that one of the inverter legs is not switching for 120° over the period giving a constant voltage each sinusoidal one third cycle which results in a 33% reduction in the average switching frequency compared to conventional modulation technique. In this paper, a sliding mode controller is designed and applied to control the output voltages of the proposed three phase boost inverter.

In [4], the proposed system is equipped with PV array, battery storage, and a single-phase VSI, which has a new circuit configuration and PWM method. The VSI output current is controlled by both of the firing angle α and the modulation index MI. The VSI circuit consists of the normal single-phase bridge circuit and an additional arm. The two auxiliary self turns- off devices of the arm avail to adopt a composite PWM control, which contributes to reduce the ripple in the AC output current. The series resonance circuit absorbs the double-frequency AC components included in the DC pulsated current.

In [5], a technique for single phase CSI's oscillating power effect mitigation is proposed. The presented technique utilizes an additional PR controller as a harmonic compensator (HC) on the grid current to minimize its third order harmonic component. This PR controller is tuned at three times the grid frequency and works independent from the fundamental grid current PR controller, hence named 3HC-PR technique. The proposed technique is based on cancellation of the 3^{rd} harmonic component from the inverter's grid current using harmonic cancellator based proportional-resonant controller, hence named (3HC-PR). An additional PR controller, tuned at three times the grid frequency, is introduced to the system's main PR controller which is tuned at the grid fundamental frequency. Also, the proposed system is simple in its implementation utilizing conventional SPWM with constant amplitude symmetrical saw-tooth carrier.

ISSN : 2394-0905

In [6], a single-phase, single-stage [no extra converter for voltage boost or maximum power point tracking (MPPT)], doubly grounded, transformer-less PV interface, based on the buck–boost principle, is presented. The configuration is compact and uses lesser components. Only one (undivided) PV source and one buck–boost inductor are used and shared between the two half cycles, which prevents asymmetrical operation and parameter mismatch problems. Total harmonic distortion and dc component of the current supplied to the grid is low, compared to existing topologies and conform to standards like IEEE 1547. A brief review of the existing, transformer-less, grid-connected inverter topologies is also included. It is demonstrated that, as compared to the split PV source topology, the proposed configuration is more effective in MPPT and array utilization. Design and analysis of the inverter in discontinuous conduction mode is carried out. Single-phase, single-stage, transformer-less grid-connected PV interfaces, capable of resolving the double grounding problem, have been reviewed. Most of the existing transformers-less topologies achieve double grounding by using a split PV source. Such topologies, when operating under nonuniform conditions, face problems such as inefficient array utilization and dc current injection into the grid. Even inverters sourced by a single PV string, but which operate on different principles in the two halves of the ac cycle, inject a significant dc component into the grid current.

A compact PV–grid interface, which operates with a single PV source and has the capability of double grounding has been proposed, analyzed, designed, and developed. It is observed that the maximum voltage that can develop on the ungrounded conductor is limited to the PV array output voltage, and hence, the topology exhibits a good safety feature. The topology uses only one PV source, a single buck–boost inductor, and a decoupling capacitor that are shared in both the half cycles. This eliminates the problems arising out of asymmetrical operation and mismatch in the components. The THD and dc component of the injected grid current are much lower as compared to other topologies. In addition, due to its inherent nature, it can work over a wide input voltage range.

In [7], analysis of the development of a method for the mathematical modeling of PV arrays is presented. The objective of the method is to fit the mathematical I–V equation to the experimental remarkable points of the I–V curve of the practical array. The method obtains the parameters of the I–V equation by using the following nominal information from the array datasheet: open circuit voltage, short-circuit current, maximum output power, voltage and current at the MPP, and current/temperature and voltage/temperature coefficients. This paper has proposed an effective and straightforward method to fit the mathematical I–V curve to the three (V, I) remarkable points without the need to guess or to estimate any other parameters except the diode constant a. This paper has proposed a closed solution for the problem of finding the parameters of the single-diode model equation of a practical PV array. This paper has presented in detail the equations that constitute the single-diode PV I–V model and the algorithm necessary to obtain the parameters of the equation. In order to show the practical use of the proposed modeling method, this paper has presented two circuit models that can be used to simulate PV arrays with circuit simulators. This paper provides all necessary information to easily develop a single-diode PV array model for analyzing and simulating a PV array.

In [8], the work focuses on inverter technologies for connecting photovoltaic (PV) modules to a single-phase grid. The inverters are categorized into four classifications: 1) the number of power processing stages in cascade; 2) the type of power decoupling between the PV module(s) and the single-phase grid; 3) whether they utilizes a transformer (either line or high frequency) or not; and 4) the type of grid-connected power stage. Various inverter topologies are presented, compared, and evaluated against demands, lifetime, component ratings, and cost. Finally, some of the topologies are pointed out as the best candidates for either single PV module or multiple PV module applications. This review has covered some of the standards that inverters for PV and grid applications must fulfill, which focus on power quality, injection of dc current sin to the grid, detection of islanding operation, and system grounding. The demands stated by the PV modules have also been reviewed; in particular, the role of power decoupling between the modules and the grid has been investigated. The next part of the review was a historical summary of the solutions used in the past, where large areas of PV modules were connected to the grid by means of centralized inverters. This included many shortcomings for which reason the string inverters emerged. A natural development was to add more strings, each with an individual dc–dc converter and MPPT, to the common dc–ac inverter, thus, the multi-string inverters were brought to light. This is believed to be one of the solutions for the future. Another trend seen in this field is the development of the ac module, where each PV module is interfaced to the grid with its own dc–ac inverter.

III. Methodology

3.1Classification of Inverter Structures:

One classification for grid-connected inverters is based on their internal topology. As can be seen in Fig. 3.1, grid-connected inverters for PV panel application are divided into the following categories:

- Current Source Inverter (CSI), or
- Voltage Source Inverter (VSI).

The standard voltage source inverter or current source inverter are the trivial choices to provide single stage DC-AC conversion. Figure 3.1 (a) illustrates the standard voltage source inverter topology. The VSI is fed from a DC-link capacitor which is connected in parallel with PV panels. Figure 3.1 (b) presents the topology of a standard current source inverter. The inverter is fed from a large DC-link inductor.

ISSN : 2394-0905

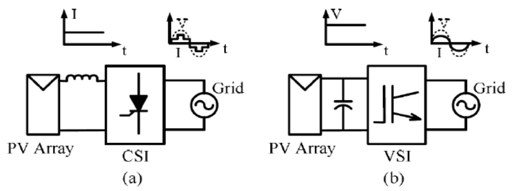

Fig. 3.1 Different topologies of grid-connected PV systems: (a) current source inverter, and (b) voltage source inverter.

3.2 Classification of Inverter Configurations:

Generally, there are several classifications for inverter configurations with respect to the number of power stages. According to this classification, all the configurations can be divided into three classes.

- Single-stage inverters,
- Dual-stage inverters,
- Multi-stage inverters.

For single-stage inverters, the maximum power point tracking and control loops (current and voltage control loops) are handled all in one stage (Fig. 3.2(a)). For dual-stage inverters, the maximum power point tracking is handled by additional DC-DC converter in between the PV panels and inverter, and control loops are applied to the inverter (Fig. 3.2 (b)) .For multi-stage inverters, a DC-DC converter takes care of the maximum power point tracking control of each string and one control inverter handles the control loops (Fig. 3.2 (c)). Despite these classifications for grid connected PV systems, for commercial applications there are four acceptable configurations.

- Central plant inverter,
- Multiple string DC-DC converter,

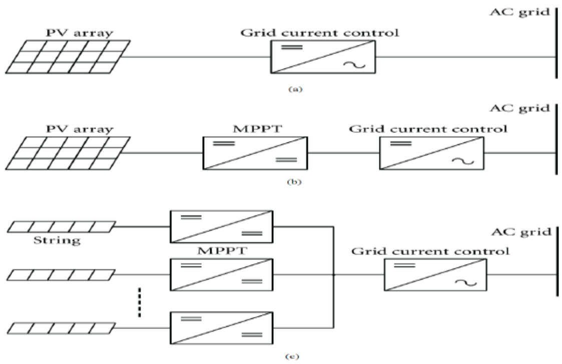

Fig. 3.2 Different configurations of inverters: (a) single-stage inverter, (b) dual-stage inverter, and (c) multi-stage inverter.

- Multiple string inverter, or
- Module integrated inverter.

The central plant inverter configuration as shown in Fig. 3.3 (a) consists of a large capacity inverter which is interfaced between the PV modules and utility grid to convert the output DC to AC power. The PV modules are divided into series connections (called strings) and the series strings are connected in parallel. The strings produce sufficiently high voltage, and the parallel connections increase the output power level. As can be seen in Fig. 3.3 (b), the multiple string DC-DC converter employs an additional DC-DC converter between each string and the common DC link which feeds the inverter. Figure 3.3 (c) illustrates the multiple string inverter configurations which includes one inverter for each string of PV modules. The outputs of these inverters are fed directly into the utility grid. In module integrated inverters, as shown in Fig. 3.3 (d), each PV module has its own inverter which is synchronized with the utility grid. There are some advantages and disadvantages in using each of these configurations. As mentioned earlier, since the efficiency of commercial PV modules is not high (< 20%), extracting and delivering the most achievable power to the utility grid is one of the most important factors in grid-connected PV systems. To reach this goal, the inverter (converter) is designed to achieve high power conversion efficiency. Additionally, the inverter (converter) cost per watt is as important as efficiency of the inverter (converter) because these two factors (efficiency and manufacturing cost) directly influence final price of the generated power. Typically, a single-stage (central plant) inverter has higher efficiency, lower cost, and higher reliability, since the chance of component failure is lower (with respect to other configurations with higher number of components). However, this configuration requires higher DC voltage in order to provide voltage/var control. Also, it has been indicated that eliminating a DC-DC converter stage reduces the total cost of grid-connected PV Systems and makes this option more attractive on the market.

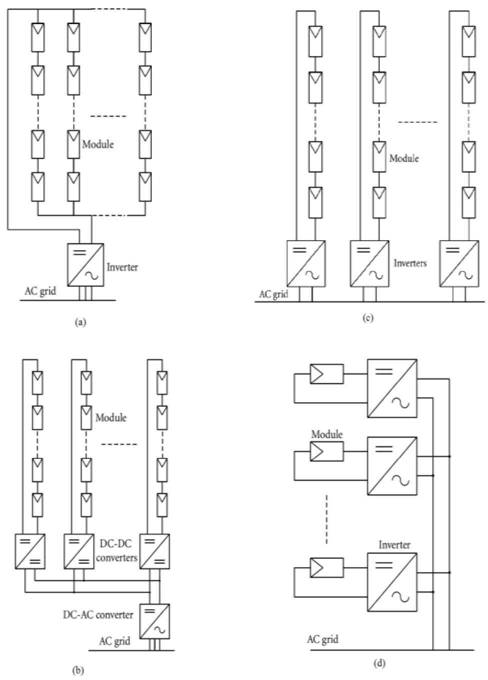

Fig. 3.3 Different commercial configurations of grid-connected PV systems: (a) central plant inverter, (b) multiple string DC-DC converter, (c) multiple string inverter, and (d) module integrated inverter.

CONCLUSION

From the literature review it can be observe that there are various concepts regarding to connect the PV cell to the conventional grid. It may possible to interface PV cell with conventional grid with transformer less inverter.

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