Comparison of Basic Control Strategies for Grid Connected Solar Photovoltaic Inverters

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Abstract - *The reserves of coal, oil and natural gas are diminishing day by day and it has become imperative to exploit the non conventional energy sources. The obvious choice amongst the renewable sources is the sun's energy –The Solar Energy, as it is the cleanest of all, in abundance and an everlasting source of energy. The generation of electricity using solar photovoltaic systems is getting popular at a very fast pace. The Sun's energy is incident on earth in the form of photons which is converted into electricity using Solar PV panels. The electrical power produced by the PV panels is dc while majority of electrical loads are running on ac. This makes the role of inverter necessary for conversion from dc to ac. Further the control of the inverter plays a major role in the satisfactory functioning of the grid connected inverters. The main consideration for the inverters for grid connectivity applications is the measurement of phase of the grid voltage and grid current and then the generation of pulses of the inverter such that the inverter voltage and current are in phase with each other. The output power quality is also one of the major considerations which needs to be matched with various international standards along with easy protection and simple system control. The control of inverter may be done by either using PLL, hysteresis current control or using a ZCD circuit. These three methods are discussed here.*

Key Words: Solar PV panels, Grid connected/tied inverters, PLL, ZCD circuit, Hysteresis Band Current Control.

1. INTRODUCTION

Solar power generation has shown a humungous rise in the last decade. The role of inverter in the photovoltaic power generation system as a power conditioning circuit has taken the most important place. The function of inverter is not just of converting dc to ac but also to maintaining output power quality matching the necessary standards, protective functions and control of power. The power conversion equipment is needed to be cost effective, efficient and reliable and should be able to work efficiently over a wide range of input voltage variation, as the intensity solar radiation is never constant. The International Energy Agency has classified the PV applications in four categories [1] viz. Off grid domestic, Off grid non domestic, grid connected distributed and grid connected centralized. The first two categories are standalone systems while the rest two are grid connected systems. The inverters, often known as grid connected PV inverters or grid tied inverters have to produce electrical output which matches always with the voltage, frequency and phase of the grid. This requires an accurate and effective method of control of inverters. Some basic inverter topologies for single stage and multistage inverters have been discussed here and then comparison of three basic methods of control of grid interactive inverters is discussed.

2. DIFFERENT INVERTER TOPOLOGIES

Here we discuss the basic inverter topologies of inverter for single stage and multiple stage inverters. The single stage inverter topology consists of one stage of power conversion for stepping up the low dc voltage available from the PV panel and modulating the sinusoidal load current or voltage. Figure 1(a) shows single stage and Figure 1(b) multi-stage inverters.

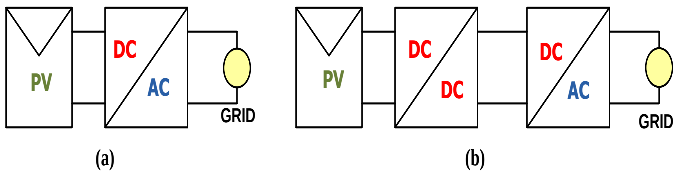

Fig -1: (a) Single stage inverter (b) Multistage inverter

The single stage inverters are classified as buck, boost and buck-boost. Further they are classified as four switch and six switch inverters depending upon the number of switches the inverter uses. The choice of the type depends upon the requirement of particular application. As seen in Figure 1(b), in a multistage inverter, the boost and isolation are carried out in the first stage while inversion is done in the second stage. Each stage can be controlled individually or synchronously [2]. The multi-stage inverters are classified as dc-dc-ac, dc-ac-dc-ac and dc-ac-ac topologies. In the dc-dc-ac topology, the first stage gives elevated dc with tolerable ripples as input to the second stage which is a simple buck inverter. The inverter output is controlled by controlling firing pulses given to the gate of IGBTs of inverter. The dc-ac-dc-ac topology consists of a first stage which converts dc from PV panels to ac by the use of inverter whose ac output is fed to a rectifier through a high frequency transformer. The full wave rectified output from this stage is fed to an inverter converts the half rectified sine waves into full sine waves which can be interfaced with grid. The dc-ac-ac topology is basically useful for standalone systems and usually not adopted for grid connected inverter applications. In this topology both stages of inverter give an ac output with the difference that the second stage is bidirectional. This is to make the provision for power flow from output side to input side. This is useful for grid connected inverters when they are a part of hybrid systems, where sometimes the power flow direction may have to be reversed for battery charging purpose [3].

2.1 Voltage Source Inverter (VSI) and Current Source Inverter (CSI).

The inverters used for grid interfacing are classified as voltage source inverter (VSI) and current source inverter (CSI). Each type is further subdivided based on the control schemes; which are voltage-control inverter (VCI) and current-control inverter (CCI).In the VSI, the dc side is made to appear to the inverter as a dc source. The voltage source inverters have a capacitor in parallel with the dc input. The CSI, on the contrary, have an inductor in series with the dc input. Photovoltaic arrays are fairly good approximation to a current source. However, most of the PV inverters are voltage source inverters (VSI). Usually VSI are preferred when they are to be connected to solar source and fuel cells. Figure 2 shows a single phase full bridge bidirectional voltage source inverter with a voltage control and phase shift control (δ) control.(VSI as VCI). The active power transfer from the PV panels is accomplished by controlling the phase angle between the inverter voltage and the grid voltage. Thus the inverter voltage follows the grid voltage.

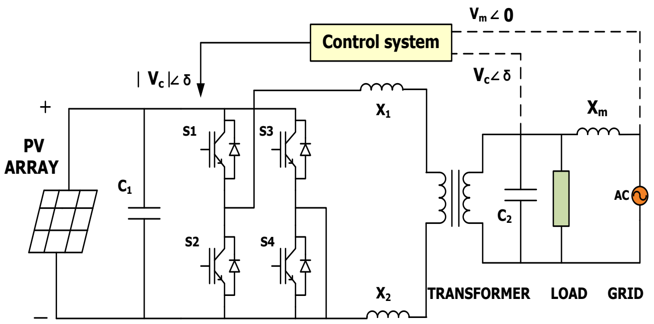

Fig -2: Grid interactive VCI

Figure 3 shows the VSI operated as current control inverter (CCI). The objective of this control is to control the active and reactive components of the current fed to the grid. In this project, solar arrays are implemented as a voltage source and the inverter is designed as current controlled voltage source inverter. The output current of the inverter is controlled to follow the phase angle and frequency of the grid. As a consequence the inverter appears as a current source in parallel with the grid. One important point to note about VSI is that the power semiconductor devices in VSI always remain forward biased due to the dc supply voltage

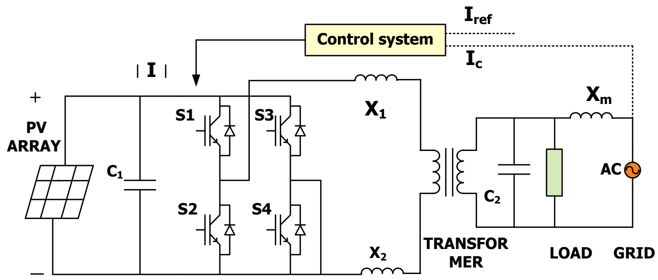

Fig -3: Grid interactive CCI

And therefore self controlled forward or asymmetric blocking devices such as GTOs, BJTs, IGBTs and power MOSFETs are suitable. Also, in the VSI, the fabricated voltage wave is not affected by the load parameters [4].

3. CONTROL OF SINGLE PHASE INVERTER USING PLL

The control structure of a single phase single stage inverter using PLL is shown in Figure 4[5].

The overall control structure can be distinctly divided to perform

i) Synchronization based on phase locked loop (PLL)
ii) Input power control
iii) MPPT control and
iv) Grid side control

The PLL provides the phase angle information derived from the utility which ensures a unity power factor operation and implies synchronization of inverter output current with the grid voltage, thus to provide a sinusoidal current reference. The overall PLL structure assesses the amplitude and frequency of grid voltage and keeps track of it.

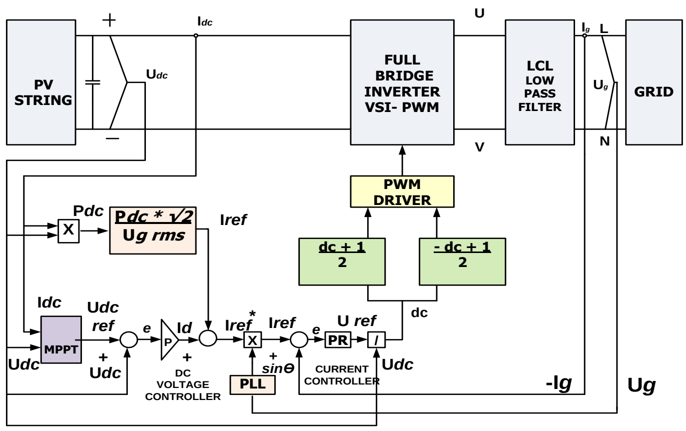

Fig -4: Control of single phase inverter using PLL

The power feed-forward is used for input power control. This requires information of PV power on DC side and amplitude of grid voltage on AC side. The phase angle information is provided by the PLL according to which the input power control updates the reference value of current amplitude. The dynamic response of the PV system using feed forward method is better than the one with MPPT control. In single stage PV inverters the instantaneous values of current and voltage both on PV side are tracked and a dc voltage reference U_{dcref} is generated. The PI (Proportional Integral) controller gives zero steady state error with dc reference, but in the application where sinusoidal is to be tracked, a PR control has better performance. A harmonic controller with PR control action is used to compensate for selected third, fifth and seventh harmonics as they are the most predominant harmonics [5].

4. GRID CONNECTED INVERTER USING ZCD CIRCUIT

Figure 5 shows an inverter circuit for grid interfacing which uses a ZCD for collecting the phase angle and frequency information from the grid voltage. The idea here is to tap the grid voltage using a step down transformer and obtain a phase shift to make the sensed voltage signal lead the grid voltage. Then this signal is fed to the ZCD to identify the zero crossing instant of the grid voltage. The pulses from the ZCD are fed to the timer in capture mode of a microcontroller which generates the SPWM pulses to be given to the inverter which gets dc from a boost converter. This method still requires some modifications for taking care of the load power factor.

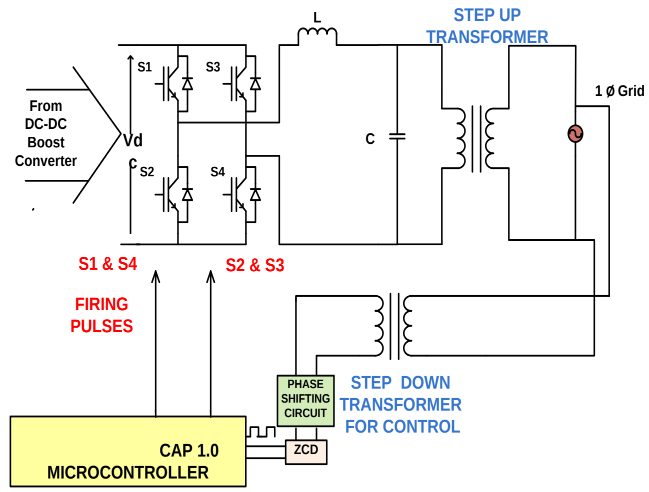

Fig -5: Grid connected inverter using ZCD circuit

5. HYSTERESIS CURRENT CONTROL FOR GRID CONNECTED INVERTER

In the hysteresis current control method, a voltage source inverter is controlled by comparing the measured current to a reference current on instantaneous basis. The current error is then compared against a predefined band called the hysteresis band to produce switching pulses for the VSI. The proposed controller is shown in Figure 6[6].

Here the actual current is compared with two reference currents. The two reference currents form the hysteresis band within which the actual current keeps on switching and accordingly the switches S1, S4 and S2, S3 keep turning ON and OFF respectively. The actual current I_{actual} through the inductor L is sensed and compared with two reference currents, forming the upper current reference and the lower current reference viz. $I_{ref\,upper}$ which is $I_{ref} + e_{max}$ and $I_{ref\,lower}$ which is $I_{ref} - e_{min}$. The current references are tapped directly from the grid, the grid voltage being converted into current of suitable value that matches the I_{actual}. This arrangement ensures that the current produced by the PV inverter is in phase with the grid voltage and also achieves unity power factor. This thesis presents Hysteresis current control of single phase inverter which can be used for grid connectivity. The simulation of a half bridge inverter circuit was carried out using PSIM software and then the hardware of the same has been implemented using C8051F120 microcontroller, inverter card and the required circuitry.

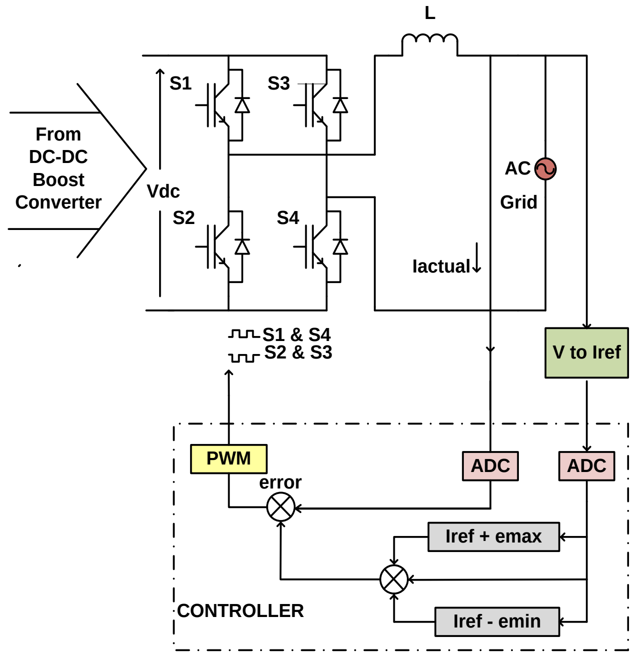

Fig – 6: Hysteresis current control for grid connected inverter

6. CONCLUSION

The Grid connected PV inverters need accurate determination of phase angle information of grid voltage and current. Three methods discussed here were PLL based control, control using ZCD and Hysteresis band current control technique. The PLL method gives good results but the component count increases as compared to Hysteresis band current control, while the method using ZCD for phase angle determination needs modifications for accurate load power factor control. The hysteresis current control technique is advantageous over the technique using PLL as it uses fewer components and thus it reduces circuit complexities. The hysteresis control technique is better and effective as the reference signal is sensed directly from the grid. First the grid voltage is sensed and adjusted to desired value before converting it into a current signal which becomes the reference current signal. This ensures that the current produced by the PV inverter is in phase with the grid voltage and thus helps achieve unity power factor. The question of synchronizing the single phase PV inverter with the grid is comparatively simple than synchronizing of three phase alternator with grid as here equal capacity single phase inverters in each phase can be interfaced with grid However the current and the voltage waveforms of the inverter are of much importance. The load sharing of the PV inverter with the grid is also an important issue but it has been found that when the inverter current exceeds the grid current it starts sharing the load automatically and it is expected that for higher insolation levels, greater load can be shared by the PV inverter, of-course not more than the rated capacity of the PV panels.

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