Photovoltaic System with Single Stage Conversion and Control

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Abstract: **This paper presents operation and control for improving the efficiency and size of a photovoltaic generation system using a current-source inverter. This system is directly connected utility grid to a solar cell without using a boosting converter. In proposed grid connected PV system the single phase CSI converter used with a double tuned resonant filter circuit. The system uses transformer-less single-stage transformation for tracking the most extreme power point and interfacing the photovoltaic array to the grid. The greatest power point is kept up with a fuzzy logic controller. A proportional-resonant controller is used to control the current injected into the grid. A modified carrier based modulation technique for the current source inverter is proposed to magnetize the dc-link inductor by shorting one of the bridge converter legs after every active switching cycle.**

Keywords: **Current source inverter (CSI), grid, and photovoltaic array, CPWM, MMPT**

I. INTRODUCTION

In distributed generation applications, the PV system operates in two different modes; grid-connected mode and island mode. In the grid-connected mode, maximum power is extracted from the PV system to supply maximum available power into the grid. Single- and two-stage grid-connected systems are commonly used topologies in single- and three-phase PV applications.

In a single-stage grid-connected system, the PV system utilizes a single conversion unit (dc/ac power inverter) to track the maximum power point (MPP) and interface the PV system to the grid. In such a topology, PV maximum power is delivered into the grid with high efficiency, small size, and low cost. However, to fulfill grid requirements, such a topology requires either a step-up transformer, which reduces the system efficiency and increases cost, or a PV array with a high dc voltage. And inverter control is complicated because the control objectives, such as MPP tracking (MPPT), power factor correction, and harmonic reduction, are simultaneously considered.

On the other hand, a two-stage grid-connected PV system utilizes two conversion stages: a dc/dc converter for boosting and conditioning the PV output voltage and tracking the MPP, and a dc/ac inverter for interfacing the PV system to the grid. In such a topology, a high-voltage PV array is not essential, because of the dc voltage boosting stage. However, this two-stage technique suffers from reduced efficiency, higher cost, and larger size. From the aforementioned drawbacks of existing grid connected PV systems, it is apparent that the efficiency and footprint of the two-stage grid-connected system are not attractive.

Therefore, single-stage inverters have gained attention, especially in low voltage applications. The current-source inverter (CSI) has the potential of becoming a preferred topology for interfacing a PV system to the ac power grid for the following reasons.

1. The dc input current is continuous which is important for a PV application;
2. System reliability is increased by replacing the shunt input electrolytic capacitor with a series input inductor;
3. The CSI voltage boosting capability allows a low-voltage PV array to be grid interface without the need of a transformer or an additional boost stage.

II. SYSTEM DESCRIPTION

The Block diagram of grid connected PV system using a CSI is illustrated in fig. 1. Whole solar power conversion system consists of a PV array, a double tuned resonant filter, and a PWM-based single-phase CSI, Grid, low pass filter, PLL, MPPT.

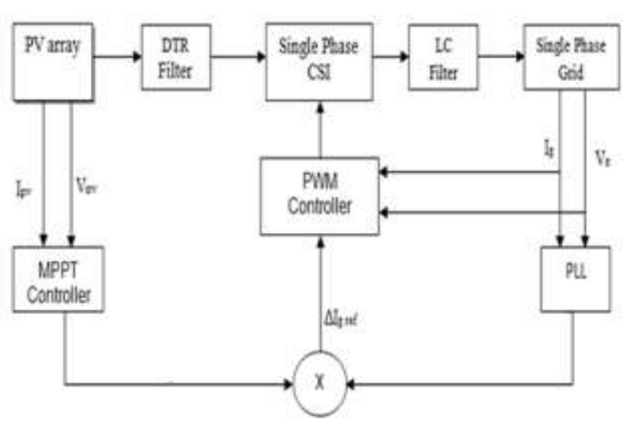


Fig. 1. Block diagram of grid connected PV system using a CSI

The inputs of the MPPT block are measurements from the PV Array (I_{PV} V_{PV}). The output of the MPPT block is then modified the shape of the reference PV AC current magnitude by multiplying PLL output producing the error signal. PLL (phase locked loop) is to provide a reference phase signal synchronized with AC systems. The error signal is the input of the voltage and current control loop in which measured ac current of grid is then compared with the reference signal and error will be sent to the PR controller. The output of the voltage and current control loop is then sent to the PWM block to generate the pulses for PV inverter. The inverter output is filtered by Low pass LC filter and then injected to the utility grid.

III. MODELING OF PHOTOVOLTAIC ARRAYS

A mathematical model of PV array including fundamental components of diode, current source, series resistor and parallel resistor is modeled with Tags in Simulink environment.

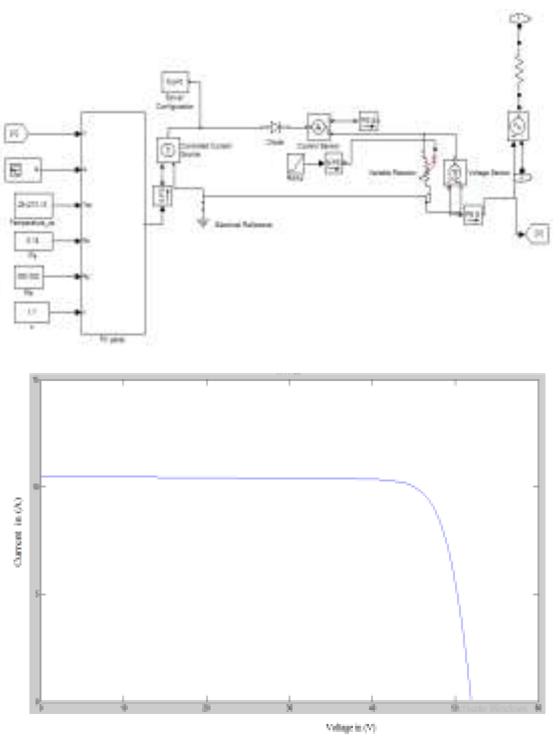


Fig. 2Solar subsystem simulation model along with its I-V Characteristics

IV. INTERNAL CONTROL OF INVERTER

Modified carrier-based pulse width modulation (CPWM) is proposed to control the switching pattern for the single-phase grid-connected CSI. In order to provide a continuous path for the dc-side current, at least one top switch in either arm and one bottom switch must be turned ON during every switching period. In conventional sinusoidal pulse width modulation (SPWM), the existence of overlap time as the power devices change states allows a continuous path for the dc current. However, the overlap time is insufficient to energize the dc-link inductor, which results in increased THD. Therefore, CPWM is proposed to provide sufficient short-circuit current after every active switching action. CPWM consists of two carriers and one reference. Fig. 3(a) shows the reference and carrier waveforms, along with the switching patterns.

Table 1 Switching Combination Sequence

Region	combination sequence
t_1	(S_1-S_3) (S_1-S_4) (S_2-S_4) (S_1-S_4)
t_2	(S_1-S_3) (S_1-S_4) (S_2-S_4) (S_1-S_4)
t_3	(S_1-S_3) (S_1-S_4) (S_2-S_4) (S_1-S_4)
t_4	(S_1-S_3) (S_1-S_4) (S_2-S_4) (S_1-S_4)
t_5	(S_1-S_3) (S_1-S_4) (S_2-S_4)
t_6	(S_1-S_3) (S_2-S_3) (S_2-S_4) (S_2-S_3)
t_7	(S_1-S_3) (S_2-S_3) (S_2-S_4) (S_2-S_3)
t_8	(S_1-S_3) (S_2-S_3) (S_2-S_4) (S_2-S_3)
t_9	(S_1-S_3) (S_2-S_3) (S_2-S_4) (S_2-S_3)
t_{10}	(S_1-S_3) (S_2-S_3) (S_2-S_4)

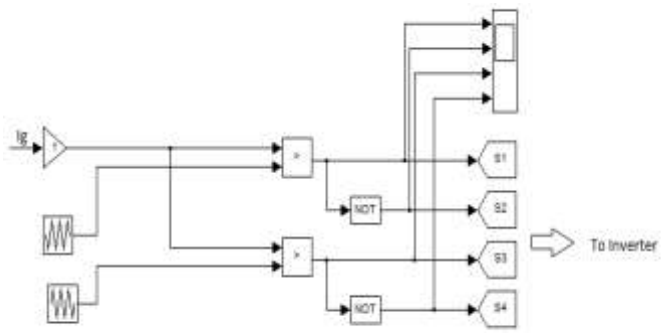


Fig. 3(a)

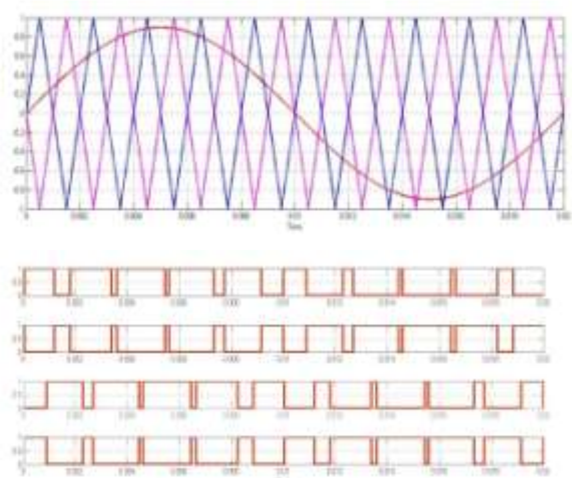


Fig. 3 (b)

Fig 3(a) Simulation diagram of CPWM (b)Generation of Modified carrier base pulse width modulation

The carrier with the blue line shown in Fig.3(b) is responsible for the upper switches, while the pink line carrier is responsible for the lower switches and is shifted by 180◦. To understand the switching patterns of the proposed CPWM, Fig. 3 is divided into ten regions ($t_1 - t_{10}$), and each region represents one carrier frequency period. Table1 shows the switch combination for each of the ten regions. As shown in Fig. 3(b) and Table 1, CPWM operates in two modes, a conductive mode and a null mode, and the switching action of each IGBT is equally distributed during every fundamental period.

V. PROPOSED SYSTEM CONTROL TECHNIQUE

Due to the very large variety of transformer-less PV inverter topologies, the control structures are also very different. The modulation algorithm has to be specific for each topology. In the following a generic, topology invariant control structure will be presented for a typical transformer-less topology, as shown in Figure 4

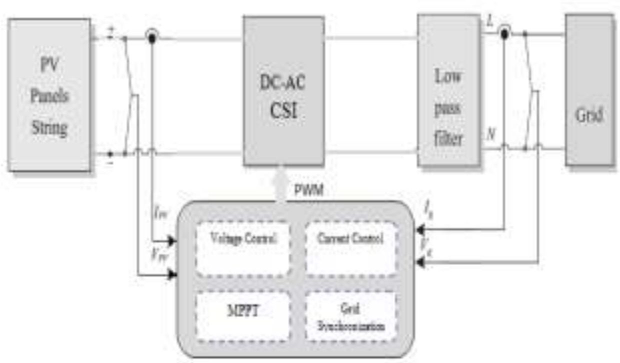


Fig.4: block diagram of single phase grid connected PV system using CSI control technique

The CSI is utilized to track the PV MPP and to interface the PV system to the grid. In order to achieve these requirements, three control loops are employed, namely MPPT, an ac current loop, and a voltage loop. As can be seen, four different control functions are:

1. MPPT
2. Voltage control
3. Current control
4. Grid synchronization

VI. SIMULATIONS AND RESULT

To validate the performance of the proposed system, simulations are performed using MATLAB/Simulink. The results of the proposed system under normal weather conditions are shown in Fig.5

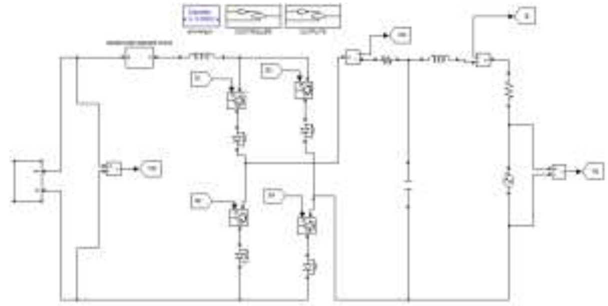
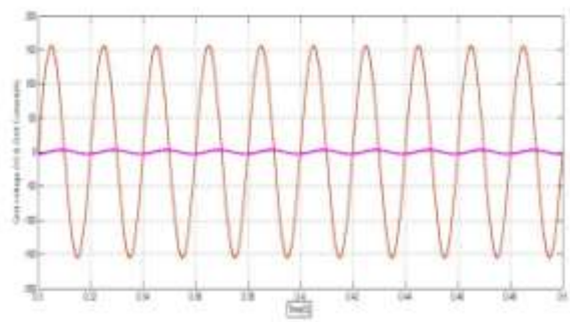
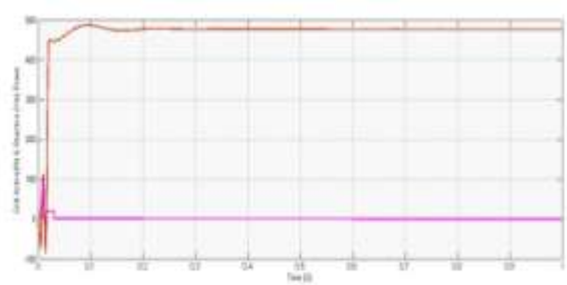


Fig.5. Simulation of grid connected PV system using CSI

The PV maximum power is extracted in a relatively short time with small oscillation in steady state, as shown in Fig. 6(a).



(a)



(b)

Fig.6: output waveforms (a) grid voltage and current (b) Grid active and reactive power

Moreover, MPPT successfully locks the dc current to the optimum value. On the ac side, the PV maximum power is successfully injected into the grid with low THD, high efficiency, and unity power factor. The total system efficiency is 95.27%, and the power factor is almost unity.

VII. CONCLUSION

A single-stage single-phase grid-connected PV system using a CSI has been proposed that can meet the grid requirements without using a high dc voltage or a bulky transformer. The control structure of the proposed system consists of MPPT, a current loop, and a voltage loop to improve system performance during normal and varying weather conditions. Since the system consists of a single-stage, the PV power is delivered to the grid with high efficiency around 95.27%, low cost, and small footprint. A modified carrier-based modulation technique has been proposed to provide a short circuit current path on the dc side to magnetize the inductor after every conduction mode. Moreover, a double-tuned resonant filter has been proposed to suppress the second- and fourth-order harmonics on the dc side with relatively small inductance. The feasibility and effectiveness of the proposed system has been successfully evaluated with various simulation studies.

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