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Grid-Connected Photovoltaic System without using Boost Converter

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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: *Doubled tuned resonant filter, Fuzzy Logic Controller, Current source inverter (CSI), grid, and photovoltaic array*

I. Introduction

Renewable energy resources are gaining more importance these days owing to the increasing energy demand, rising fuel cost, depletion of fossil fuels, and global warming. Among all the renewable energy resources, solar energy is very popular because sunlight is available throughout the year. Every day, the sun delivers light energy to earth at free of cost. PV plant is used to convert the sun light energy into electricity. PV modules or panels are made of semiconductor material that allows sunlight to be converted directly into electricity and provides electrical power for long time. PV systems are categorized into three types such as standalone, hybrid systems, and grid-connected systems. The type of system is selected based on the needs, location, and budget.

The grid-connected system which generates the power and it is directly connected to local grid, the part of generated power is utilized through local loads which are connected to grid and the remaining excess power is fed to the grid and hence batteries are not required. The grid connected solar PV system requires the power converters. This power converter is used to convert the direct current from the PV plant to the desired values of AC with the highest possible efficiency and provide quality power to the utility grid.

Single-stage 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. High-voltage systems suffer from hotspots during partial shadowing and increased leakage current between the panel and the system ground though parasitic capacitances. Moreover, 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 conventional voltage source inverter (VSI) is the most commonly used interface unit in grid-connected PV system technology due to its simplicity and availability. However, a bulky transformer and an unreliable electrolytic capacitor are still required.

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) CSI provides a smooth dc-side current, which is a desirable feature for PV modules.

2) The energy storage element of a CSI has a longer lifetime than that of a VSI.

3) CSI has an inherent voltage boosting capability, which allows integration of PV panels of lower output voltages and reduces the requirements of the step-up interface transformer.

4) With the evolution of reverse-blocking (RB) IGBT switches, the series diodes will be eliminated, resulting in a considerable reduction in the cost and conduction losses.

Grid-connected PV systems using a CSI have been proposed and successfully delivered PV power to the grid, with a low total harmonic distortion (THD). However, an ac current loop is essential in the grid connected application in order to limit the current and quickly recover the grid current variation during varying weather conditions.

In this paper, 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. To demonstrate the effectiveness and robustness of the proposed system, computer-aided simulation and practical results are used to validate the system

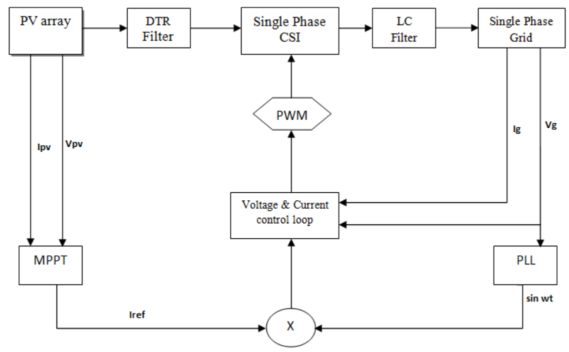


Fig.1 Proposed System

II. SYSTEM DESCRIPTION

A grid-connected PV system using a single-phase CSI is shown in Fig. 1. The inverter has four insulated-gate bipolar transistors (IGBTs) (S1–S4) and four diodes (D1–D4). Each diode is connected in series with an IGBT switch for reverse blocking capability. A doubled-tuned parallel resonant circuit in series with dc-link inductor *Ldc* is employed for smoothing the dc link current. To eliminate the switching harmonics, a *C–L* filter is connected into the inverter ac side

A. Circuit Parameters

Resonant filter inductor,(L1)=5mH
Resonant filter inductor(L2)=10mH
Resonant filter capacitor (C1)=125microfarad
Resonant filter capacitor (C2)=250microfarad
DC link inductor Ldc= 900mH
AC line inductor= 300mH
AC line capacitor= 20microfarad

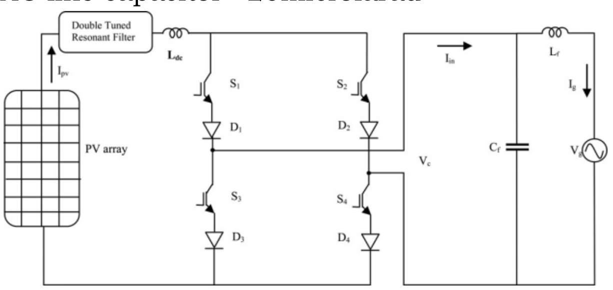


Fig.2 Interfacing the Photovoltaic Array to the Grid

III. DOUBLE-TUNED RESONANT FILTER

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 dclink 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, as shown in Fig. 3

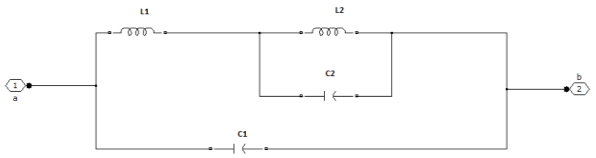


Fig. 3. Proposed double-tuned resonant filter

IV. PROPOSED SYSTEM CONTROL TECHNIQUE

To design a grid-connected PV system using a CSI, the relationship between the PV output voltage and the grid voltage is derived as follows

By neglecting inverter losses, the PV output power is equal to the grid power

$$V_{PV}I_{PV} = 1/2 I_{g,peak} V_{g,peak} \cos\theta \qquad (3.1)$$

where θ is the phase angle, V_{pv} and I_{pv} are the PV output voltage and current, respectively, while $V_{g,peak}$ and $I_{g,peak}$ are the grid peak voltage and current, respectively. The grid current is equal to the PV output current multiplied by the inverter modulation index M

$$I_{g,peak} = M I_{PV} \qquad (3.2)$$

Substituting (3.2) into (3.1), assuming unity power factor, the equation describing the relationship between the PVoutput voltage and the grid voltage is

$$V_{PV} = 1/2 M V_{g,peak}. \qquad (3.3)$$

Therefore, in order to interface the PV system to the grid using a CSI, the PV voltage should not exceed half the grid peak voltage. 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.

To operate the PV at the MPP, MPPT is used to identify the optimum grid current peak value. Any conventional MPPT technique can be used. However, to prevent significant losses in power, the tracking technique should be fast enough to handle any variation in load or weather conditions. Therefore, a fuzzy logic controller (FLC) is used to quickly locate the MPP.

The inputs of the FLC are

$$\Delta P = P(k) - P(k-1) \qquad (3.4)$$

$$\Delta I_{PV} = I_{PV}(k) - I_{PV}(k-1) \qquad (3.5)$$

and the output equation is

$$\Delta I_{g,ref} = I_{g,ref}(k) - I_{g,ref}(k-1) \qquad (3.6)$$

where ΔP and ΔI_{PV} are the PV array output power and current change, $\Delta I_{g,ref}$ is the grid current amplitude change reference, $I_{g,ref}$ is the grid current reference, and k is the sample instant. The variable inputs and output are divided into four fuzzy subsets: PB (Positive Big), PS (Positive Small), NB (Negative Big), and NS (Negative Small). Therefore, the fuzzy algorithm requires 16 fuzzy control rules; these rules are based on the regulation of the hill climbing algorithm, where the fuzzy rules are shown in Table I.

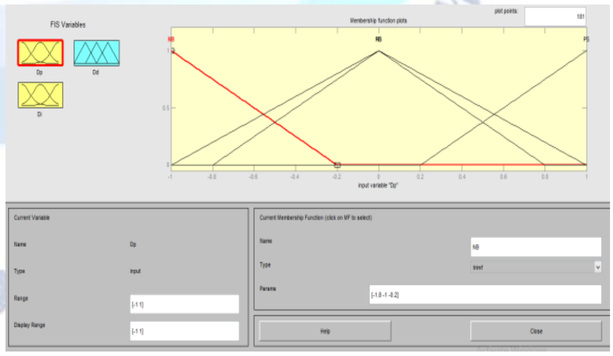


Fig 4. FLC Membership Functions for ΔP, ΔI and ΔD.

TABLE I; - Fuzzification of modified hillclimbing rules

If ΔP>0 If ΔI>0 D(t)=D(t-1)+ΔD	If ΔP is PB and ΔI is PB then ΔD is PB
	If ΔP is PB and ΔI is PS then ΔD is PB

Else D(t)=D(t-1)+ ΔD End	If ΔP is PB and ΔI is NB then ΔD is NB
	If ΔP is PB and ΔI is NS then ΔD is NB
	If ΔP is PS and ΔI is PB then ΔD is PS
	If ΔP is PS and ΔI is PS then ΔD is PS
	If ΔP is PS and ΔI is NB then ΔD is NS
	If ΔP is PS and ΔI is PB then ΔD is NS
elseIf ΔP<0 If ΔI>0 D(t)=D(t-1)- ΔD Else D(t)=D(t-1)+ ΔD End	If ΔP is NB and ΔI is PB then ΔD is NB
	If ΔP is NB and ΔI is PS then ΔD is NB
	If ΔP is NB and ΔI is NB then ΔD is PB
	If ΔP is NB and ΔI is NS then ΔD is PB
	If ΔP is PS and ΔI is PB then ΔD is NS
	If ΔP is PS and ΔI is PS then ΔD is NS
	If ΔP is PS and ΔI is NB then ΔD is PS
	If ΔP is PS and ΔI is PB then ΔD is PS

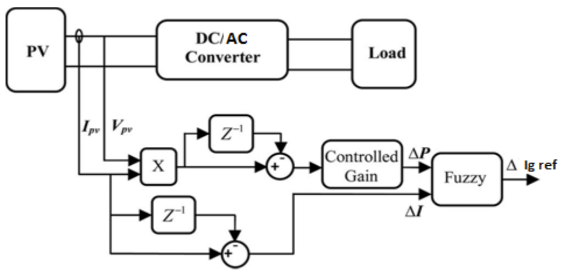


Fig. 5. Block diagram of the FLC-based MPPT.

To operate the fuzzy combination, Mamdani's method with Max–Min is used. A center of area algorithm (COA) is used in the defuzzification stage to convert the fuzzy subset duty cycle changes into real numbers.

$$\Delta ig.ref = \sum_i^n \mu\,(Ig.ref.i)Ig.ref.i \div \sum_i^n \mu\,(Ig.ref.i) \quad (3.7)$$

To ensure synchronization between the grid current and voltage, a sinusoidal signal generated by a phase-locked-loop (PLL) is multiplied by the MPPT output. Fig. 5 shows a block diagram of the MPPT structure. For precise control of the single-phase inverter, proportional resonant (PR) control is employed in the voltage and current loop controllers. The basic principle of the PR controller is to introduce an infinite gain at a selected resonant frequency in order to eliminate steady-state error at that frequency. The PR controller transfer function is expressed as

$$y = \text{Kpe} + \text{Ki}\,\frac{\text{es}}{\text{s2}+\omega 2} \quad (3.8)$$

Where Kp is the proportional gain, Ki is the integral gain, *e* is the signal error, and ω is the fundamental angular frequency.

V. SIMULATIONS AND RESULT

In order to validate the theoretical analysis, closed loop operation of grid connected photovoltaic system using single phase current source inverter is simulated on MATLAB/Simulink. The simulated closed loop system has taken the circuit parameter values are shown in (a).

The simulated PV array is connected to the Double tuned resonant filter which mitigates the DC side harmonics.

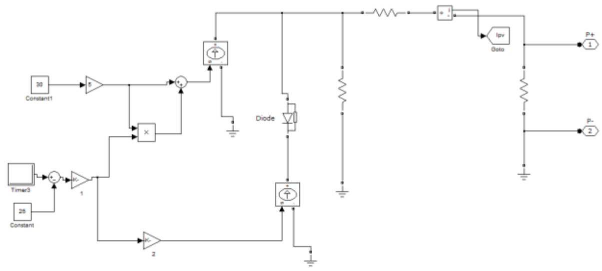


Fig.6. PV Array Structure in Matlab-Simulink

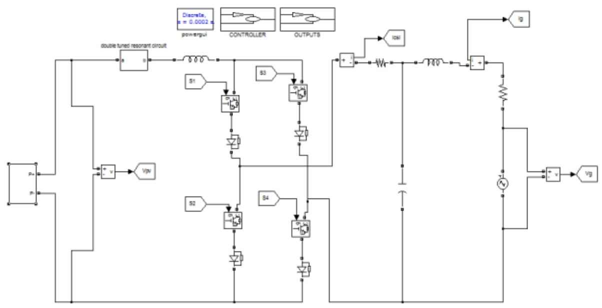
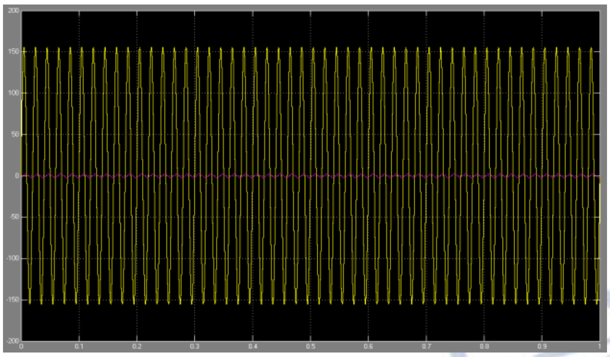


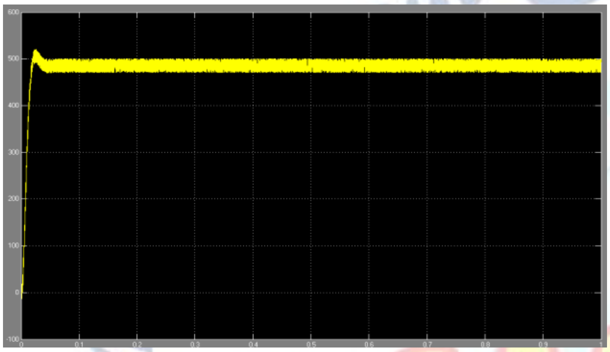
Fig.7. Simulation of grid connected PV system using CSI

The regulated dc power from PV side is fed into CSI to convert it from dc power to ac power. The MPPT of this PV plant is controlled by using FLC and The PV array is simulated by using matlab/simulink is shown in Fig.6.

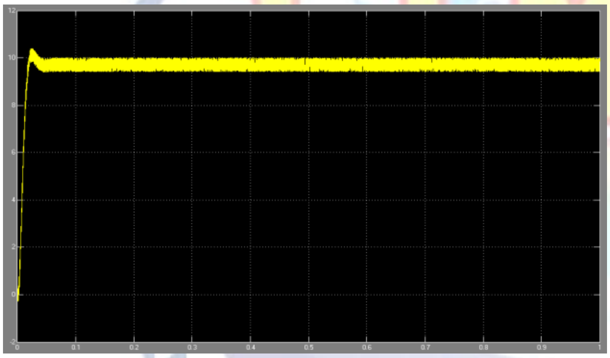
To ensure synchronization between the grid current and voltage, a sinusoidal signal generated by a phase-locked-loop (PLL) is multiplied by the MPPT output and produce reference signal will be sent to the PR controller. The output of the PR controller is then sent to the PWM block to generate the pulses for PV inverter. The CSI output current waveform and the Grid voltage Vg and Grid current Ig are verified through simulation results.



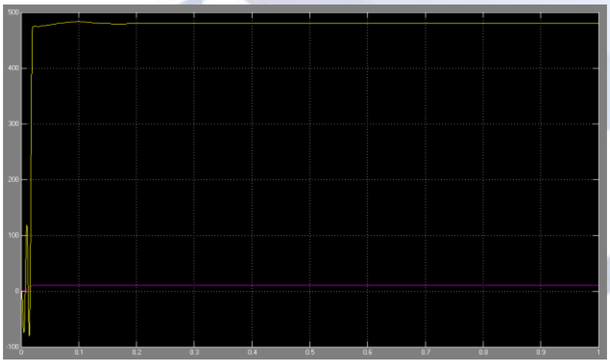
(a)



(b)



(c)



(d)

Fig.8.output waveforms (a) grid voltage and current ,(b) PV output power(c) PV current (d)Grid active and reactive power.

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 95.95%, 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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