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Grid Interfaced 3-phase Solar Inverter with MPPT by using Boost Converter

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ABSTRACT

The paper proposes Grid interfaced 3-phase 750VA solar inverter with MPPT. In general the output of the PV array is unregulated DC supply due to change in weather conditions. The maximum power is tracked with respect to temperature and irradiance levels by using DC-DC converter. The perturbation and observation algorithm is applied for maximum power point tracking (MPPT) purpose. This algorithm is selected due to its ability to withstand against any parameter variation and having high efficiency. The output of Boost (DC-DC) converter is converted to AC voltage by using inverter. The AC output voltage and frequency are regulated. A closed loop voltage control for inverter is done by using sine wave pulse width modulation (SPWM). The regulated AC voltage is fed to AC standalone loads or grid integration. The overall system is designed and developed by using MATLAB/SIMULINK. The simulation results demonstrate the effective working of MPPT algorithm and voltage controller with SPWM technique for inverter in AC load applications.

KEYWORDS: *PV Arra, Maximum Power Point Technique(MPPT), Boost Converter, Sinusoidal Pulse Width Modulation, 3-Phase Inverter, Grid*

I. Introduction

Among various renewable energy systems, photovoltaic power generation systems (PV systems) are expected to play an important role as a clean electricity power source in meeting future electricity demands. However, the power output of PV systems fluctuates depending on weather conditions. In future, when a significant number of PV systems will be connected to the standalone loads or grids of power utilities, combined power output fluctuations may cause problems like voltage fluctuation and large frequency deviation in electric power system operation. In future, with an increasing penetration of PV generation, their impact upon the overall control of the power system will be significant. This will lead a situation where the PV generators will be required to share some of the duties, such as load voltage control. Therefore, for the penetration of multiple or clustered PV system's output power in the utility without reduction of the reliability of utility power systems, suitable measures must be applied to the PV systems side.

Because of the nonlinear relationship between the current and the voltage of the photovoltaic cell, it can be observed that there is a unique maximum power point (MPP) at a particular environment, and this peak power point keeps changing with solar illumination and ambient temperature. An important consideration in achieving high efficiency in PV power generation system is to match the PV source and load impedance properly for any weather conditions, thus obtaining maximum power generation. The technique process of maximum power point is been tracking which is called maximum power point tracking (MPPT). In recent years, a large number of techniques have been proposed for maximum power point tracking (MPPT), such as the constant voltage tracking (CVT), the incremental conductance (INC) method, the perturb-and-observe (P&O or hill-climbing) method, and so on. At last, these algorithms modify the actual voltage in order to increase the power output. The CVT is very simple, but the constant voltage can't track MPP when solar illumination changes so the constant voltage method is not often used in the true MPPT strategy.

The P&O method is based on the principle of perturbation and observation. The majority of these methods are based on the perturbation and observation (P&O), which has the advantage of simple operation. It is an iterative method of obtaining MPP. It measures the PV array characteristics, and then perturbs the operating point of PV generator to encounter the change direction. And incremental conductance method (INC) is also commonly used due to the rapid response.

Power for the Boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and dc generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC-DC Converter with an output voltage greater than the source voltage. It is sometimes called a step-up converter since it "steps up" the source voltage. Since power (P = VI) must be conserved, the output current is lower than the source current. MPP is tracked by using Boost converter. Then it is fed to Standalone load or grid integration through three-phase Inverter. The inverter is built of switching devices, thus the way in which the switching takes place in the inverter gives the required output. Three phase inverters are those inverters which produces three phases of ac output.

II. Proposed System

The block diagram of the proposed solar energy conversion scheme is shown in Fig.1. It consists of PV array driven by BOOST converter interfaced to the stand-alone load through a Three phase Inverter. The output Power of the Boost Converter is varied due to temperature and irradiations. Hence, the Maximum power is tracked and extracted from the PV array and transferred to the stand-alone load through single phase Inverter. The controller generates the gating pulses for the BOOST and Inverter to extract maximum power and to maintain desired ac output voltage and frequency across load terminals.

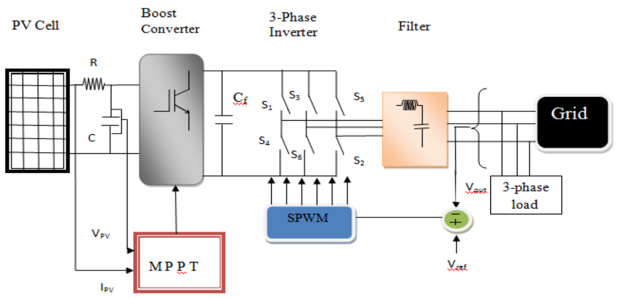

Fig. 1 Block diagram of grid interfaced three phase inverter with PV fed Boost Converter

A. Solar Panel

Fig. 2 shows the equivalent circuit of the ideal photovoltaic cell. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic of the ideal photovoltaic cell is:

$$I = I_{PV.CELL} - I_{o.CELL}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \qquad (1)$$

where $I_{pv,\ cell}$ is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the Shockley diode equation, $I_{0,cell}$ [A] is the reverse saturation or leakage current of the diode, q is the electron charge [1.60217646 * 10^{-19}C], k is the Boltzmann constant [1.3806503* 10^{-23}J/K], T [K] is the temperature of the *p-n* junction, and a is the diode ideality constant.

The basic Eq.1 of the elementary photovoltaic cell does not represent the I-V characteristic of a practical photovoltaic array. Practical arrays are composed of several connected photovoltaic cells and the observation of the characteristics at the terminals of the photovoltaic array requires the inclusion of additional parameters to the basic Eqn. 1.

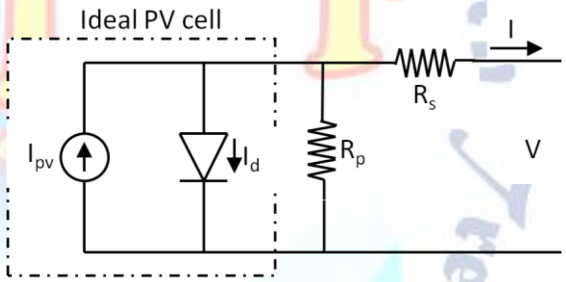

Fig. 2 Single-diode model of the theoretical photovoltaic cell

Eq. 2 describes the single-diode model presented in Fig.2.

$$I = I_{PV} - I_o\left[\exp\left(\frac{V+R_S I}{V_t a}\right) - 1\right] - \frac{V+R_S I}{R_p} \qquad (2)$$

Where I_{pv} and I_0 are the photovoltaic and saturation currents of the array and $V_t = N_s kT/q$ is the thermal voltage of the array with N_s cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. If the array is composed of N_p parallel connections of cells the photovoltaic and saturation currents may be expressed as: $I_{pv}=I_{pv,cell}N_p$, $I_0=I_{0,cell}N_p$. In Eq. 2 R_s is the equivalent series resistance of the array and R_p is the equivalent parallel resistance.

B. Perturbation and Observe ("P&O") Method

The "P&O" method is that which is most commonly used in practice by the majority of authors. It is an iterative method of obtaining MPP. It measures the PV array characteristics, and then perturbs the operating point of PV generator to encounter the change direction. The maximum point is reached when $\frac{dP_{pv}}{dV_{pv}} = 0$.An example algorithm flowchart of the most basic form is shown in Fig. 3.

Doing this, the operating voltage of the PV generator is perturbed, by a small increment ΔV_{pv}, and the resulting change, ΔP_{pv}, in power, is measured. If ΔP_{pv} is positive, the perturbation of the operating voltage should be in the same direction of the increment. However, if it is negative, the system operating point obtained moves away from the MPPT and the operating voltage should be in the opposite direction of the increment. The logic of this algorithm is explained in Table 1 and Fig. 3

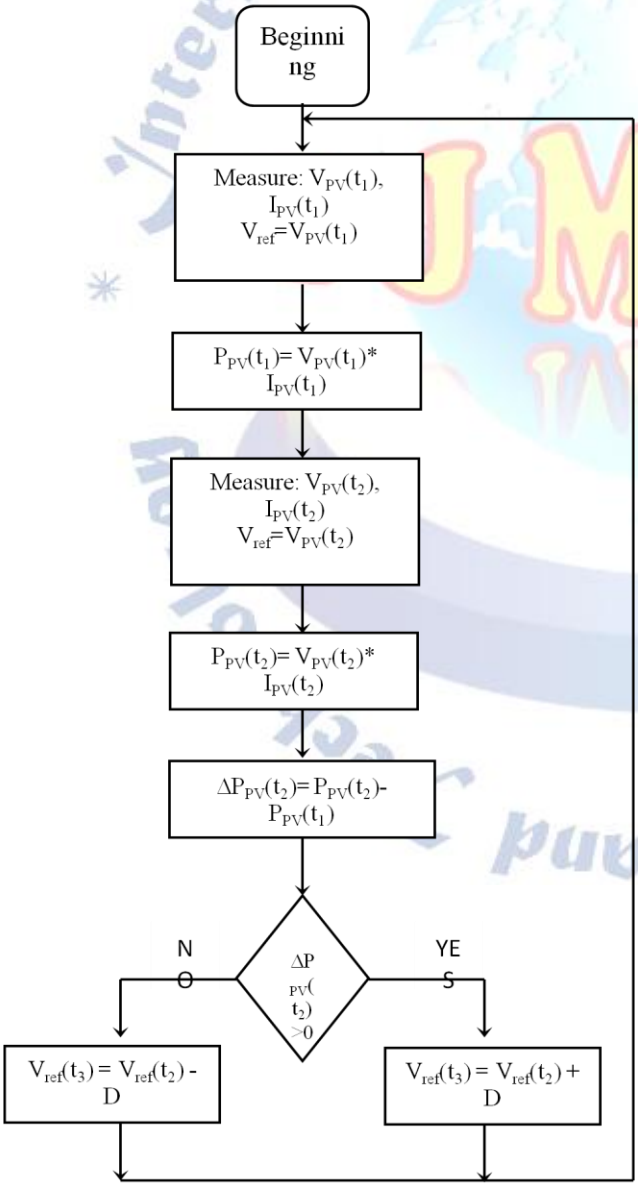

Fig. 3 Conventional P&O algorithm flowchart. D is the step of the perturbation.

True table associated with the operation for the Perturbation and Observe (P&O) method.

Table 1: Operation of P&O algorithm

$\Delta P_{pv}(t_2)$	$V_{pv}(t3)$
>0	+
<0	-

The "+"sign refers to an increment and "-" sign to a decrease.

In accordance with Table 1, if the PV power has increased, the operating point should be increased as well. However, if the PV power has decreased, the voltage should do the same.

Nevertheless, a disadvantage of this method appears in the case of a sudden increase of irradiance, Fig.4, where the algorithm reacts as if the increase occurred as a result of the previous perturbation of the operating voltage. In order to better understand this phenomenon, see Fig. 2.6. Thus, the case is considered in which the irradiance is such that it generates the P–V curve characteristics, curve 1. In this way, the operating voltage initially oscillates around the maximum point, from A to A1. Now, an increase in the power will be measured because the solar irradiation has increased from curve 1 to curve 2. Then, if one assumes that being in point A, that it comes from a diminution of the voltage, and before the following disturbance takes place, the irradiance is increased, with the curve characteristic being now curve 2, and the operation point will occur at B1. Indeed, since there has been a positive increase in power, the disturbance will continue in the same direction, see Table 1.

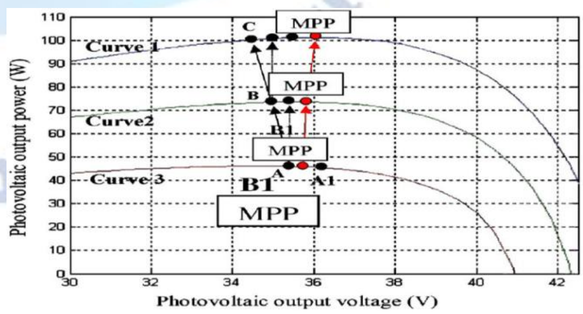

Fig. 4 Deviation from the MPP with the P&O algorithm under rapidly changing

In other words, the voltage will diminish and go to point B. Furthermore, if the irradiance is increased again quickly to curve 3, there will be another increase in positive power, with which the operation point will now be C. That is, due to two increases of irradiance, the operation point has been transferred from A to C, moving away from the maximum point. This process remains until the increase of the irradiance slows or stops.

The advantages of this method can be summarized as follows: a previous knowledge is not required of PV generator characteristics; it a relatively simple method. Nevertheless, in their most simple form, at a steady state, the operating point oscillates around the MPP, giving rise to the wasting of some amount of available energy.

C. Boost Converter

A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. Since power (P = VI) must be conserved, the output current is lower than the source current. The Boost converter has four basic components, namely a power semiconductor switch, a diode, an inductor and a capacitor. The output voltage is controlled by controlling the switch-duty cycle.

The DC to DC converters are widely used in regulated switch mode DC power supplies. The input of these converters is an unregulated DC voltage, which is obtained by PV array and therefore it will be fluctuated due to changes in radiation and temperature. In these converters the average DC output voltage must be controlled to be equated to the desired value although the input voltage is changing. Boost converters are used in battery powered devices, where the electronic circuit requires a higher operating voltage than the battery can supply, e.g. notebooks, mobile phones and camera-flashes. A Boost regulator using a Power MOSFET shown in following fig 5.

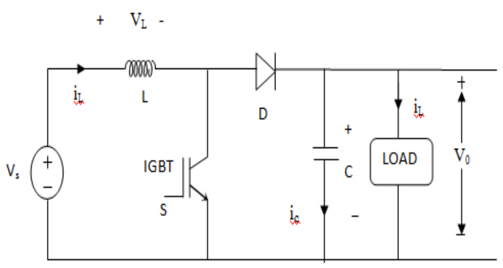

Fig. 5 Basic DC-DC Boost Converter

The circuit operation can be divided into two modes.

(a) Mode1

When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores the energy. Polarity of the left side of the inductor is positive as shown in following Fig 6.

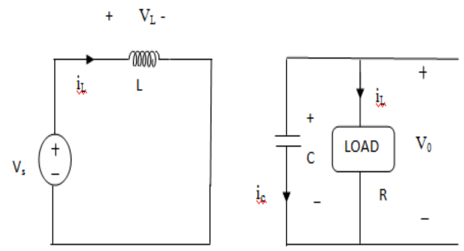

Fig. 6 Mode 1 Operating Circuit

(b) Mode2

When switch is opened, the current that was flowing through the transistor would now flow through L, C, Load and diode D. the inductor current falls until transistor M1 is turned in again in the next cycle. The energy stored in inductor L is transferred to the load. Mode 2 operating circuit is shown following Fig 7.

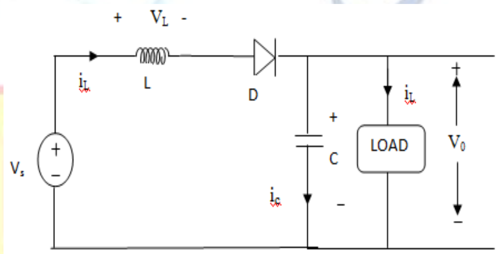

Fig. 7 Mode 2 Operating Circuit

The basic principle of a Boost converter consists of 2 distinct states: The converter can therefore operate in the two different modes depending on its energy storage capacity and the relative length of the switching period. These two operating modes are known as the discontinuous conduction mode, DCM, and continuous conduction mode, CCM. The Current and voltage waveforms of Boost Converter as shown in Fig 8.

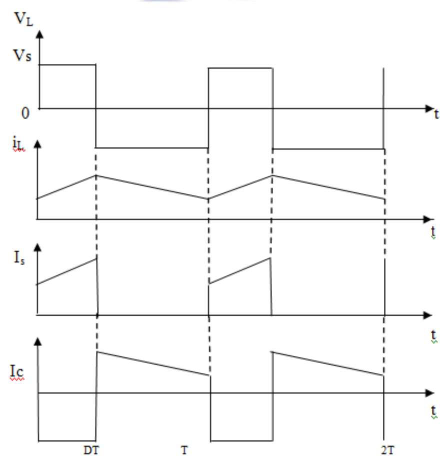

Fig. 8 Waveforms of Current and Voltages

D. Inverter

The block diagram of closed loop operation of single phase inverter is shown in Fig.9. Output voltage of inverter is controlled by using PI controller. Sine wave pulse width modulation (SPWM) is used to control the Six switches of inverter.

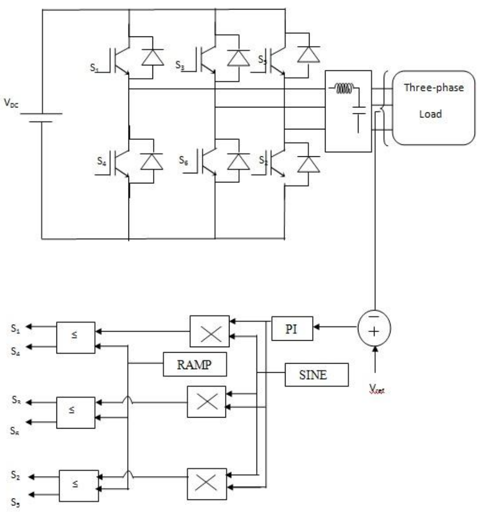

Fig. 9 Closed Loop operation of PWM Inverter

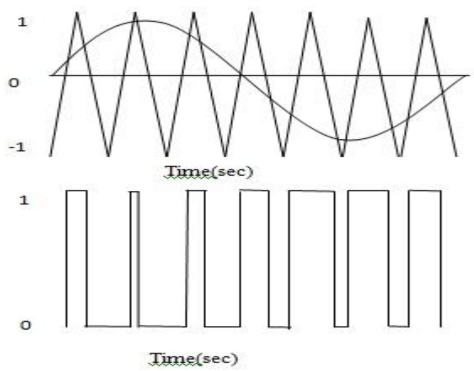

Fig. 10 PWM illustration by the sine-triangle comparison method (a) Sine-triangle comparison (b) switching pulses.

III. Results and Discussion

The simulation results of the proposed scheme such as active power fed to load, load voltage and load current, DC link voltage and current are shown in figures. The Specifications of 750VA PV panel as shown follows.

Temperature	25^{0}C
Solar irradiance	1000W/m^2
Open circuit voltage(V_{oc})	66V
Maximum power voltage(V_{mp})	54.2 V
Short circuit current(I_{sc})	25.44A
Max power current(I_{mp})	23.25A

Due to change in the temperature and irradiance the respective maximum power changes. The following MATLAB simulation shows how MPP is tracked when there is irradiance change. Fig. 14 shows that the output active & reactive power of 3-Ø inverter are 1490W & 820 VAR respectively, by which it is evident that 3-phase inverter is capable of supplying grid with a load of 1KW.

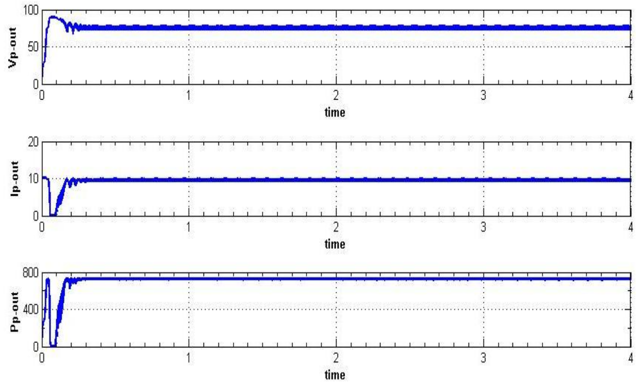

Fig. 11 Voltage, current and Power outputs of PV panel

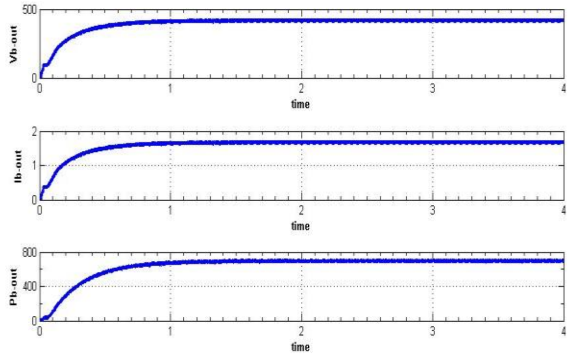

Fig. 12 Voltage, current and power outputs of Boost converter

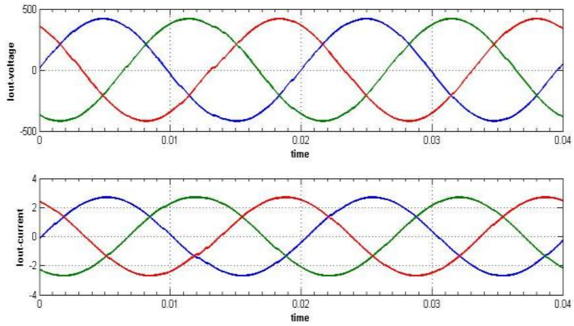

Fig. 13 Output waveforms of 3-phase Inverter

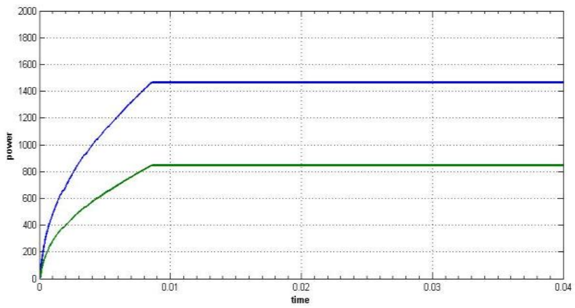

Fig. 14 Active and Reactive powers of Inverter

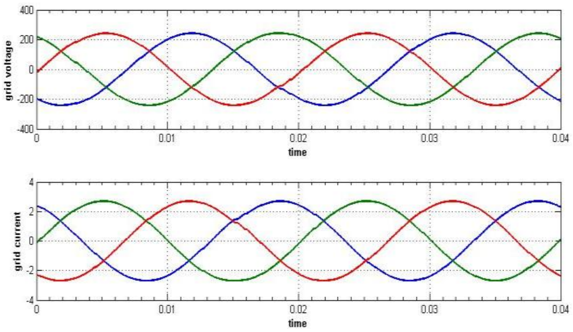

Fig. 15 Output Voltage and Current of grid integration

IV. Conclusion

The mathematical modeling of photovoltaic cell has been analyzed. When the PV cell is used as a source of power supply to grid integration, it is necessary to use the MPPT to get the maximum power point from the PV cell, which is obtained using boost converter. The MPP is tracking by using a Boost-Converter, which is designed to operate under continuous conduction mode. The perturbation and observe algorithm is used as the control algorithm for the MPPT.

The output of the boost converter is fed to 3-phase inverter in order to obtain the required for grid integration. SPWM control algorithm is used to obtain the required output voltage for standalone loads or grid integration. The entire system is simulated with MATLAB/SIMULINK. From simulation results it is evident that MPPT using P & O algorithm is obtained with dynamic and steady state stability. At the same time, output results of inverter with SPWM control strategy have better voltage control and simulation results of system demonstrate that the PV system has the fast and effective response under changing irradiance and temperature. So the PV generation system based P&O MPPT method and SPWM control for three-phase inverter is feasible and effective and efficient for grid integration.

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