In this paper, a grid connection of single-phase PV inverter system is presented, which can deal with solar energy and performs power conditioning. To draw maximum power from the solar system we use maximum power point tracking technology for PV arrays. This MPPT technology based on the maximum power point varies with irradiation and temperature linearly. The control of a grid-connected inverter is investigated. There are two key control issues that need to be examined. The first is the control of the AC side of the converter to ensure that sinusoidal output waveforms are produced. And the output from the PV panel is controlled by the boost converter. The second key issue that needs to be examined is the current that is fed from the PV panels to the inverter. The ripple on this current must be minimized as much as possible so that the inverter can be implemented with maximum power point tracking techniques (MPPT) that will enable it to extract the maximum power that is available from the PV panels at any given time.

Keywords: Grid-Connected Inverter, PV, Current Control, voltage source inverter, MPPT.

1. INTRODUCTION

Due to the rapid development of industry, the Grid-connected solar inverter is one the most demanding power electronic converter nowadays. It is due to the fact that solar energy is considered as an alternation for the fossil fuels like coal and oil. Adopting renewable and clean energy resources to replace fossil fuel is imperative. Among all kinds of renewable-energy resources, solar energy is obtainable readily so that the demand for photovoltaic (PV) panel has been increasing more and more. The output voltage and current of a PV panel vary with irradiation, panel temperature, and power loading nonlinearly. Under the certain atmospheric condition, there exists a maximum power point. To draw maximum power from PV panel, a large number of researchers have proposed maximum power point tracking (MPPT) algorithms. There are many methods of power point tracking like voltage feedback method, power feedback method, and linear approximate method. Each MPPT algorithm has its advantages, disadvantages, and limitations.

To deal with PV power. PV inverter system is in charge of the conversion transferring dc power into ac power and then injecting PV power in utility. PV inverter system can be briefly in two Stages. One is a multistage system, the other is a single stage. The multi-stage system has the demerits of low efficiency, high cost, large size and poor reliability.

2. SYSTEM CONFIGURATION

Solar energy is clean, pollution-free and inexhaustible so that developing solar energy power system can solve the
the energy crisis of exhausting in fossil fuel. Recently, photovoltaic arrays are widely used for power supply. PV systems can be briefly classified into stand-alone and grid-connection types. Owing to more flexibility in power conditioning, the study on the grid-connection type stimulates many interests. Fig. 1 shows the configuration of a conventional grid-connection PV system, which consists of multiple stages, leading to low efficiency, large volume, and high cost. To improve part of the disadvantages, some researchers have designed two-stage configurations, as shown in Fig. 3. For further efficiency improvement and cost reduction, single-stage PV system has been developed. Even though the structure of a single-stage PV system is simpler than that of a two-stage one, a couple of active switches, current sensors, and corresponding drivers are still needed in the power stage.

Configuration of the presented PV inverter system with DLA circuit in this paper is shown in Fig. 4. The input filter including an LC series-resonant circuit (Lf and Cf) and a dc-bus capacitor Cdc. The LC series-resonant circuit can filter out the double line frequency of ac components on the dc side and switching frequency noise can be reduced by the dc-bus capacitor. In addition, the output filter prevents inrush current and absorbs switching harmonics to lower EMI. In the system, as the full-bridge converter is adopted, power flow can be processed bi-directionally and unipolar switching scheme can be performed.

In the unipolar switching scheme, only one pair of switches operates at carrier frequency while the other pair operates at the reference frequency, thus having two high-frequency switches and two low-frequency switches.

In inverter control system, the primary DC to DC boost converter can regulate the variable input DC voltage (output from PV cells) by controlling the on-off control of switch which set the charging and discharging time of voltage boosting Inductor coil. And the inverter has four switches like IGBT, MOSFET etc. by controlling a pair of 1,3 and 2,4th no. switch we control the inverter output and convert DC input into AC output.
3. OPERATION PRINCIPLE OF THE PV SYSTEM

3.1 Derivation of Current Commands

In the PV system, once a current command is determined, the output current of the full-bridge inverter will trace the waveform of the reference current to perform power flow controlling and power quality improvement. In the followings, an optimal current command is derived. According to the current and voltage definitions shown in Fig. 4, the line voltage $v_s(t)$ and non-linear load current $i_L(t)$ are expressed as:

$$v_s(t) = \sqrt{2}V_{\text{rms}} \sin(\omega t - \phi), \quad (1)$$

$$i_L(t) = \sum_{n=1}^{\infty} \sqrt{2} I_n \sin(n \omega t - \theta_n), \quad (2)$$

respectively. Then, the load instantaneous real power $p_L(t)$ and instantaneous reactive power $(q_L(t))$ can be calculated as follows:

$$p_L(t) = v_s(t)i_L(t)$$

$$= V_{\text{rms}} I_1 \cos(\phi - \theta_1) - V_{\text{rms}} I_1 \cos(2 \omega t + \phi + \theta_1)$$

$$+ \sum 2V_{\text{rms}} \ln \sin(n \omega t + \theta_n) \sin(\omega t + \phi) \quad (3)$$

$$= p_L(\text{con.}) + p_L(\text{vari.}),$$

where

$$p_L(\text{con.}) = V_{\text{rms}} I_1 \cos(\phi - \theta_1), \quad (4)$$

and

$$p_L = -V_{\text{rms}} I_1 \cos(2 \omega t + \phi + \theta_1)$$

$$+ \sum 2V_{\text{rms}} \ln \sin(n \omega t + \theta_n) \sin(\omega t + \phi), \quad (5)$$

Notation $\bar{p}_L$ represents the constant part and $\tilde{p}_L$ denotes the variant component. The instantaneous reactive power can be obtained by multiplying the nonlinear load current with a $90^\circ$-shifted voltage as follows:

$$q_L(t) = v'_s(t)i_L(t)$$

$$= V_{\text{rms}} I_1 \sin(\phi - \theta_1) - V_{\text{rms}} I_1 \sin(2 \omega t + \phi + \theta_1)$$

$$- \sum 2V_{\text{rms}} \ln \sin(n \omega t + \theta_n) \cos(\omega t + \phi) \quad (6)$$

$$= \bar{q}_L + \tilde{q}_L,$$

where $v'_s(t)$ is the line voltage shifted by $90^\circ$, $\bar{q}_L$ is the constant part and $\tilde{q}_L$ is the variant component of Instantaneous reactive power. Apparent power is determined by

$$S = V_{\text{rms}} \sqrt{\sum \frac{P_n^2}{n}}$$

$$= \sqrt{[V_{\text{rms}} I_1 \cos(\phi - \theta_1)]^2 + [V_{\text{rms}} I_1 \sin(\phi - \theta_1)]^2 + \sum_{n=2}^{m} V_{\text{rms}} I_n^2}, \quad (7)$$

in which the first, second and third terms are the square of real, reactive and distortion power, respectively. The reactive and distortion power of a nonlinear load will be supplied by the PV system. As a result, a compensated line current, of which amplitude depends on PV power is purely sinusoidal and in phase with line voltage. It can be determined by

$$i_s^* = \sqrt{2} \left(\frac{P_{\text{MPPT}} - \bar{p}_L(t)}{V_{\text{rms}}} \right) \sin(\omega t - \phi), \quad (8)$$

3.2 The MPPT Algorithm

From characteristics of a p-n junction and the equivalent circuit, output current of PV arrays, $I_pV$, can be decribed as

$$I_{PV} = n_p I_{ph} - n_p I_{sat} \left[ \exp \left( \frac{q V_{PV}}{kT A n_s} \right) - 1 \right], \quad (9)$$
where \( VPV \) is output voltage of PV arrays, \( n_s \) is the total number of cells in series, \( n_p \) stands for the total number of cells in parallel, \( q \) denotes the charges of an electron \((1.6 \times 10^{-19} \text{ coulomb})\), \( k \) is the Boltzmanns constant \((1.38 \times 10^{-23} \text{J/}^°\text{K})\), \( T \) is temperature of PV arrays \((^°\text{K})\), and \( A \) represents ideality factor of the p–n junction \((1 \text{ to } 5)\). In addition, \( I_{\text{sat}} \) is the reversed saturation current of the PV cell, which depends on the temperature of PV arrays and it can be expressed by the following equation:

\[
I_{\text{sat}} = I_r \left( \frac{T}{T_r} \right)^3 \exp \left[ \frac{q E_{\text{gap}}}{kA} \left( \frac{1}{I_r} - \frac{1}{T} \right) \right],
\]

where \( T_r \) is cell reference temperature, \( I_r \) is the corresponding reversed saturation current at \( T_r \), and \( E_{\text{gap}} \) stands for the band-gap energy of the semiconductor in the PV cell. The \( I_p \) varies with irradiation \( S_i \) and PV array temperature \( T \), which can be represented as

\[
I_{\text{ph}} = [I_{\text{so}} + k_i (T - T_r)]S_i/100,
\]

where \( I_{\text{so}} \) is the short-circuit current while reference irradiation is 100mW/cm\(^2\) and reference temperature is set at \( T_r \), and \( k_i \) is the temperature coefficient. Based on output power (PPV) of PV arrays then can be determined as follows:

\[
PPV = I_{\text{PV}} V_{\text{PV}} = n_p I_{\text{ph}} V_{\text{PV}} - n_p I_{\text{sat}} V_{\text{PV}} \left[ \exp \left( \frac{q}{kT} \frac{V_{\text{PV}}}{n_i} \right) - 1 \right],
\]

which reveals that the amount of generated power PPV varies with irradiation \( S_i \) and PV-array temperature \( T \). So it can be found that a maximum power point occurs when the derivative of PV output power with respect to terminal voltage equals zero. Therefore, the optimal PV terminal voltage \( V_{\text{ref}, \text{MPPT}} \) in order to draw maximum power from PV arrays can be obtained:

\[
V_{\text{ref}, \text{MPPT}} = \frac{kTA}{q} \ln \left( \frac{kTA [I_{\text{so}} + k_i (T - T_r)]S_i - 100I_{\text{sat}}]}{100I_{\text{sat}} [qV_{\text{ref}, \text{MPPT}} + kTA]} \right),
\]

In the derivation, both \( n_s \) and \( n_p \) have been assumed to be one. Then, by substituting (13) into (12), the maximum power \( P_{\text{MPPT}} \) is expressed as

\[
P_{\text{MPPT}} = I_{\text{ph}}V_{\text{ref}, \text{MPPT}} - I_{\text{sat}}V_{\text{ref}, \text{MPPT}} \left[ \exp \left( \frac{q}{kT} V_{\text{ref}, \text{MPPT}} \right) - 1 \right].
\]

For analog circuit implementing, we choose the element of photo-diode (PD) to sense irradiation for the first linear equation realizing and we also adopt the element of negative temperature coefficient of thermal resistor (NTC) for sensing temperature to realize the second part of the linear equation. As shown in Fig. 9, the front part of the proposed circuit is in charge of the determination of the affection from irradiation. Under various sunlight irradiation, the photo-diode will produce a corresponding potential and this potential goes through a follower circuit along with a differential operation amplifier to find \( E_i \). It is given as:

\[
y = mx + b = - \left( \frac{R_f}{R_2} \right) \cdot (E_i) - \left( \frac{R_f}{R_3} \right) \cdot (E_{dc}),
\]

Accordingly, the use of equation (15) can trace the maximum power point instantaneously under different irradiation. When the temperature is changing, the rear part of Fig. 9 is capable to determining the temperature affection. Under a certain irradiation, a voltage by way of the PD can be obtained. While temperature increasing, the resistance of the NTC is decreasing. Since the temperature and the resistance is in linear relationship. The output voltage determined by the front part of the MPPT circuit can be modified by the rear part and thus a correct MPPT voltage is readily obtained. The modification is represented as follows:

\[
V_{\text{ref}, \text{MPPT}} = y \cdot (-R_5/R_4),
\]
4. SIMULATED & EXPERIMENTAL RESULTS

To demonstrate the effectiveness of the MPPT System and the feasibility of the PV inverter system, a prototype is built and then, is simulated and measured. If the inverter system draws PV power with perturb-and-observe method, Fig. 10 shows the simulated
MPPT trajectory. With the same atmospheric conditions, once the DLA is adopted instead of the perturb-and-observe method, Fig. 11 is the simulation result of MPPT trajectory. In practical measurements, Fig. 12 and Fig. 13 show the corresponding traces of MPPT of perturb-and-observe method and DLA, respectively. From Figs. 10-13, it is obvious that the DLA can improve the vibration caused from perturb-and-observe method significantly. Fig. 14 is the experimental waveforms of line voltage and injection current in the case of step-up irradiation, while in the case of shading is shown in Fig. 15.

Fig. 10: MPPT trajectory by the perturb-and-observe method while irradiation and temperature increase

Fig. 11: MPPT trajectory by the DALL while irradiation and temperature increase

Fig. 12: Practical measurement of the PV power system with the perturb-and-observe method

Fig. 13: Practical measurement of the PV power system with the MPPT
5. CONCLUSIONS

In this paper, a grid-connection single-stage PV inverter with MPPT is proposed. The PV inverter system not only can determine maximum power point instantaneously but inject PV power into as mains effectively. The configuration of the system is single-stage instead of multi-stage architecture such that it improves efficiency and is cost-effective. The simulations and hardware measurements have verified the MPPT and demonstrated the feasibility of the PV inverter system.

6. REFERENCE