Single-Phase Single-Stage PV-Grid System Using VSI Based on Simple Control Circuit

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ABSTRACT

Integrating electric energy generated by PV with utilities has been developed. Some of these using two-stage converters and the others using single stage converters. For systems with two-stage converters, the first stage converter acts as a MPPT to maximize power generated by PV and the second stage is used as an interface to the utilities. In the single-stage system, an inverter is used for both function. In this paper, PV-Grid System using a single-stage Voltage Source Inverter is proposed. The simple control circuit to make PV generate maximum power and keeping power equilibrium between PV and inverter output power is used. To verify the analysis, simulations are done.

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1. INTRODUCTION

Solar energy can be used as an alternative resource due to the global crisis on fossil fuel and increasing concern about global environment problems. Photovoltaic (PV) converts solar energy into electricity directly and recently is widely used. With nonlinear characteristics, connecting loads to PV will cause the power generated by PV is not maximum. This is an important problem due to cost of PV arrays. To reduce this cost, implementation of PV must concern about the effectivity so PV must be operated to generate it's maximum power. A device called MPPT (Maximum Power Point Tracker) is a device that is able to force PV operates at it's maximum operating point and must be used in application.

Applications of PV can be classified into stand-alone and grid-connected systems. The first one is applications where PV systems are separated from utilities and the second one is applications where PV and grid are integrated. Owing to the rapid progress of power conditioning, PV-grid connected systems are more interested to be a focus in many researches. It also offers some advantages in applications. Integrating PV and utilities must keep PV operates at it's maximum power point. In application with two converters, PV-grid system contains a DC-DC converter as an MPPT and a DC-AC converter as an interface to the grid [1]-[4].

In single-stage converter PV-grid systems, the DC-AC converter must also acts as a MPPT. By using modified incremental conductance based control for three-phase inverter, the system is capable to improve stability in PV-grid application [5] with DSP to implement the hardware. The other control can also be based on sliding mode [6]. To increase the response, paper [7] uses fuzzy logic to control the three-phase inverter. Using DSP or other digital hardwares are commonly rather complicated in algorithm and required advanced chips.

Different from the above, this paper proposes a single-stage PV-grid system implemented by a single-phase Voltage Source Inverter. A control based on combination of modified hill-climbing and hysteresis concept is used. This control scheme is aimed to achieve power equilibrium, this means that the average power of inverter output will be forced to have the same value as the maximum power generated by PV. Finally, simulations are done to verify the analysis.

2. RESEARCH METHOD

To understand the proposed single-stage PV-Grid System, it will be described theoretical analysis about PV, power equilibrium concept and the proposed system as shown in Figure 1. Referring to the I-V characteristic of PV which is nonlinear, it can be seen that maximum power (P_{MPP}) will be generated by PV under certain values of voltage (V_{MPP}) and current (I_{MPP}). These values will vary under different condition of irradiance and temperature. When a PV module is directly connected to a load, its operating point will be a point at the intersection of the I-V characteristic curve and the load line.

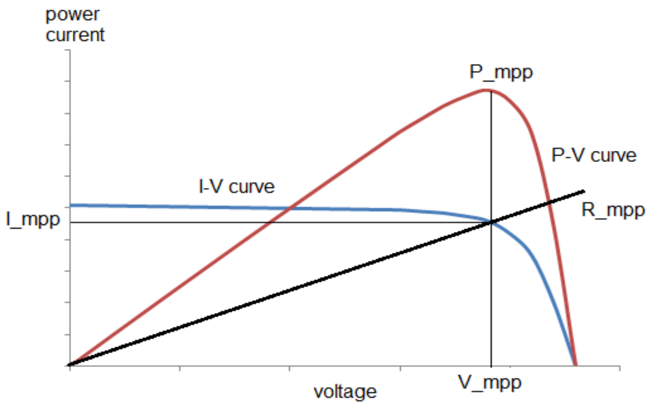

Figure 1. Characteristic curve of a PV (a) I-V curve (b) P-V curve

For the output of PV module is DC voltage, it is needed inverter to convert PV output into AC voltage. Parallel connecting this inverter to grid voltage, it is required some restriction, one of these is the output voltage of inverter must be synchronized to the grid voltage. If this inverter is operated as a controlled current source, the inverter output voltage will be automatically locked to the grid voltage. If it is assumed under ideal condition, to deliver all power generated by PV module to the grid at maximum point operation, the average power output of this inverter must equal to the PV modules' output power. Figure 2 shows the block system contains PV modules, inverter and grid.

If the grid voltage and the output current of inverter are v_s and i_c so the instantaneous power injected to the grid is the multiplication of those voltage and current values (Figure 3), expressed as

$$p_c = v_s(t).i_c(t) \quad (1)$$

and the average power can be found as

$$P_c = \int_0^T p_c dt \quad (2)$$

For sinusoidal current and voltage which is in phase, the average power can calculated by using it's RMS value of current I_c and voltage V_s, therefore

$$P_c = V_s.I_c \quad (3)$$

Under ideal condition the average value of injected power has the same value of the power generated by PV modules installed.

$$P_{PV} = P_c$$
$$(V_{PV}).(I_{PV}) = V_s.I_c \qquad (4)$$

Under maximum operation, PV modules will generate P_{MPP}. This amount of power must be delivered to the grid by inverter. So equation (4) will be

$$P_{MPP} = P_c$$
$$(V_{MPP}).(I_{MPP}) = V_s.I_c \qquad (5)$$

Under this condition, inverter output current can be stated as

$$I_c = \frac{(V_{MPP}).(I_{MPP})}{V_s} \qquad (6)$$

or can also be found it's amplitude as

$$I_{c\_peak} = \frac{(V_{MPP}).(I_{MPP})}{\sqrt{2}V_s} = \frac{(V_{MPP}).(I_{MPP})}{V_{s\_peak}} \qquad (7)$$

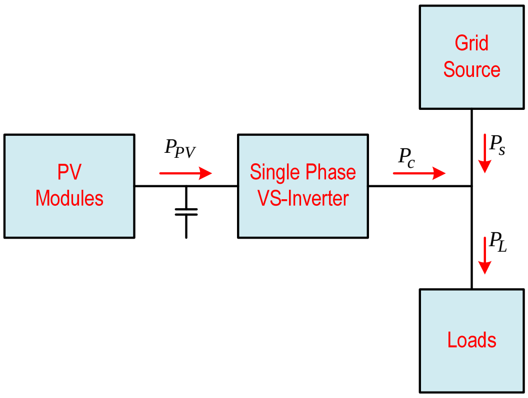

Figure 2. Block system of PV-Grid with single-stage inverter

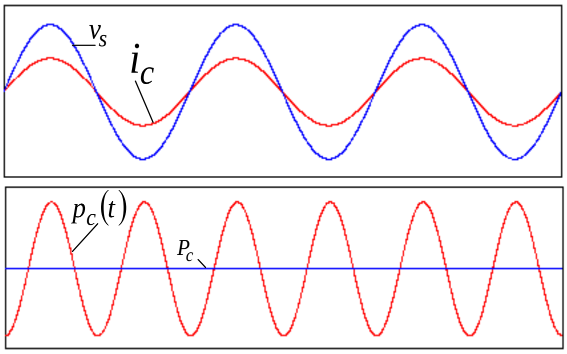

Figure 3. Instantaneous values of voltage, current and power

Based on equation (7), it can be concluded that under a common condition of irradiance and temperature, there is only a value of inverter output current which makes PV modules operate in maximum power point. The change of this value of current will move the operating point of PV away from this maximum power point. To keep the operating point of PV modules near the MPP, there must be a controller that can be tracked the location of instantaneous power point and then moves this closer to the MPP.

The important one that must be considered in comparing two different values of power is that the first value of power is instantaneous and the other is average value. For the controller operates under instantaneous condition, it is required a capacitor as an energy stored element, which is installed between PV modules and inverter side. When the instantaneous power of inverter output is greater than power generated by PV, the energy stored in capacitor will be released. The opposite condition happens when the instantaneous power of inverter output is less than power generated by PV, this will make capacitor absorbs power from PV.

The proposed scheme of a single-phase single-stage PV-Grid system is shown in Figure 4. The PV modules is connected to input side of a Voltage Source Inverter via capacitor. To maximize the power generated by PV modules, it is required to understand MPPT concepts. In this paper, the concept based on modified hill-climbing is choosen. Detections of current and voltage of PV modules are needed. Interfacing to grid can be realised by using Voltage Source Inverter operated as a controlled current source as shown in Figure 5. This kind of inverter can be made by detecting inverter output current. Power delivery can be done by injecting sinusoidal current that in phase with respect to the grid voltage, so the sinusoidal waveform as a template is required. This template must be multiplied by k factor to produce reference current for inverter. Based on the I-V characteristic curve (Figure 1), it is seen when the k factor tends smaller, it means that the operating point moves to the left. It represents that the power generated by PV will increase.

Due to the PV characteristic curve where its operating point can be at any location in P-V curve as depicted in Figure 6, the value of k factor must vary to force the operating point of PV near its MPP. If the operating point is moved from the right to the left side, the power generated will increase at its MPP then decreases when it is away from the MPP. The moving operating point to the left side has its voltage decrease, it means that the value of Δv is negative. If the power generated by PV decreases, the k factor will be smaller. The opposite condition of power will make k factor greater. To make value of Δv positive, the operating point must be moved to the right side. It will make power generated by PV increases at its MPP then decreases.

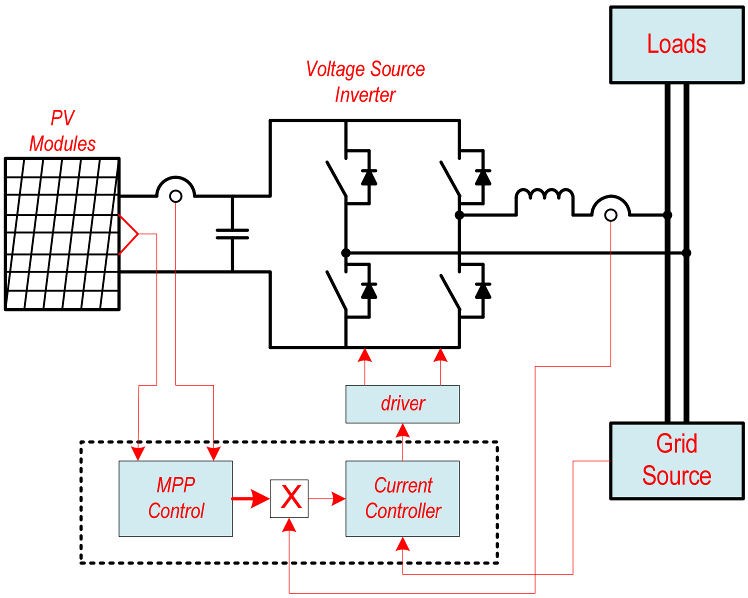

Figure 4. The proposed scheme

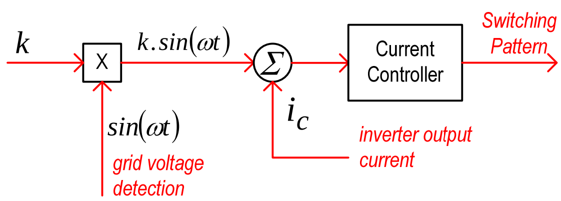

Figure 5. Current controller scheme

Referring to these two conditions, there are some possibilities to determine the decision of the control instructions: when Δv and Δp are positive, it means that the operating point moves to the right at left side of MPP. The control instruction must keep the direction of the point movement. If the voltage of PV increases, its current will decrease. Under this condition the k factor will also be smaller. The negative value of Δv and Δp indicates that the operating point moves to the left at left side of MPP. The control instruction must reverse the direction of the point movement by forcing k factor decrease. At the right side of the MPP, the operating point movement to the right results in the positive value of Δv and the negative value of Δp. To have greater value of power generated, the PV current must be increased by making the k factor greater, the same variation of k factor happens when the operating point shift to the left at the right side of the MPP. Based on the above description, the flowchart of the control can be derived (Figure 7).

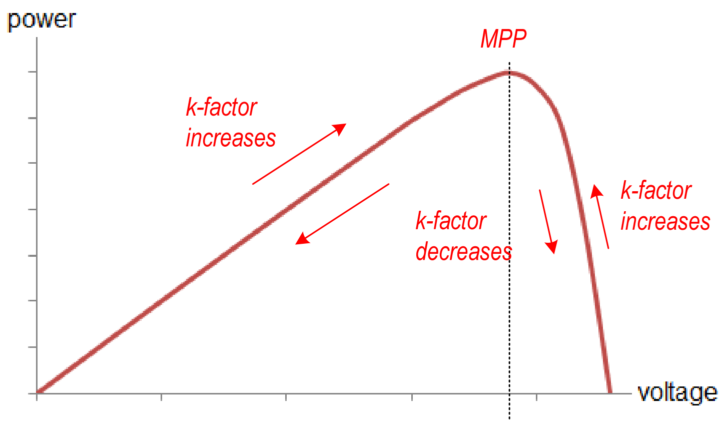

Figure 6. k-factor variation

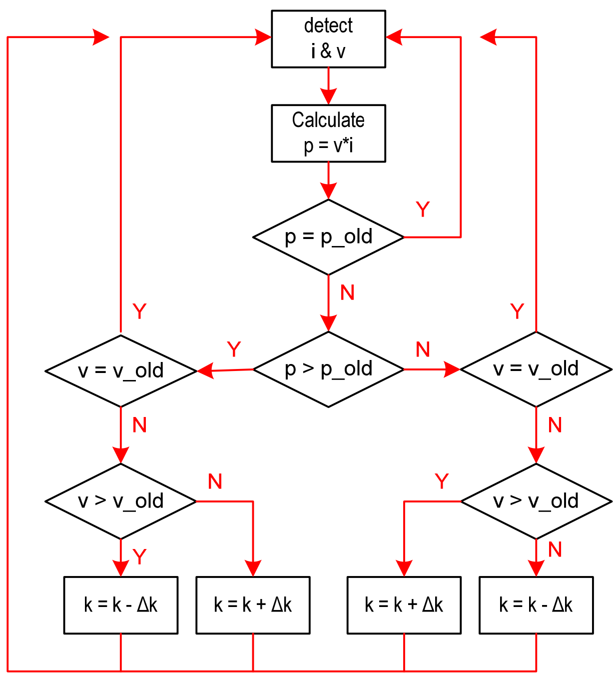

Figure 7. Flowchart of the control scheme in k factor variation

3. RESULTS AND ANALYSIS

To verify the above analysis then simulations are done. Simulating works are based on PSIM by using the scheme depicted in Figure 4. The parameters used in the simulation are expressed in the Table 1. The AC system contains resistive loads is used as grid where the PV-inverter is connected to. Three 60 Wp PV modules are series connected to achieve output voltage greater than grid voltage. Two conditions for simulation is taken under 1000 W/m^2 and 500 W/m^2. Under 1000 W/m^2 irradiance, it is considered that the power absorbed by the loads is less than the power generated by PV therefore amount of power will be sent to the grid and the grid current's phase angle is 180 degree with respect to the grid voltage (Figure 7). Because of the inverter output current and voltage are sinusoidal and in phase, it's instantaneous power will fluctuates from zero to maximum value whose average power equals to the power generated by PV. Capacitor at input side of inverter takes significant role to keep power equilibrium power between delivered PV and inverter. When the instantaneous power of inverter is greater than the PV's power, amount of power will be taken from capacitor to achieve power equilibrium. This results in capacitor voltage decreases. The opposite condition happens when inverter output power is less than PV's power. This makes capacitor voltage increases (Figure 8).

Table 1. Parameters for simulating works

PV module max. power	60.53 Watt
PV module voltage at max. power	17.04 Voltage
PV module current at max. power	3.55 Ampere
Numbers of modules in array	3
Modules connection	Series
Grid voltage	40 Volt (peak)

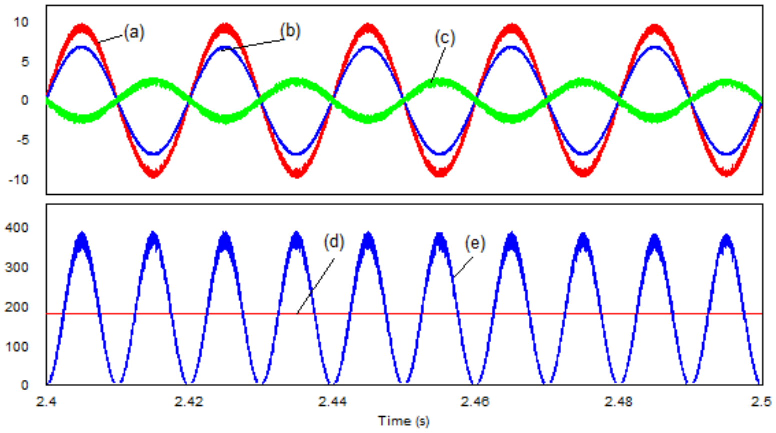

Figure 7. Simulated waveforms under irradiance 1000W/m2 (a) inverter output current (b) load current (c) grid current (d) PV maximum power (e) inverter output power

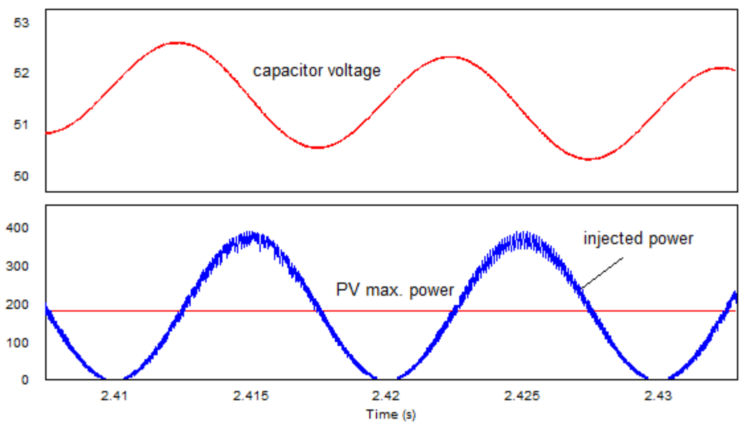

Figure 8. Capacitor voltage variation with respect to comparation between the values of P_{PV} and p_c

When the solar irradiance drops, the power is generated by PV will also decreases. This condition will influence the power delivered by the inverter. For the loads' power is greater than the power produced, amount of power will be supplied by the utility. Its current will be in phase with respect to the grid voltage (Figure 9).

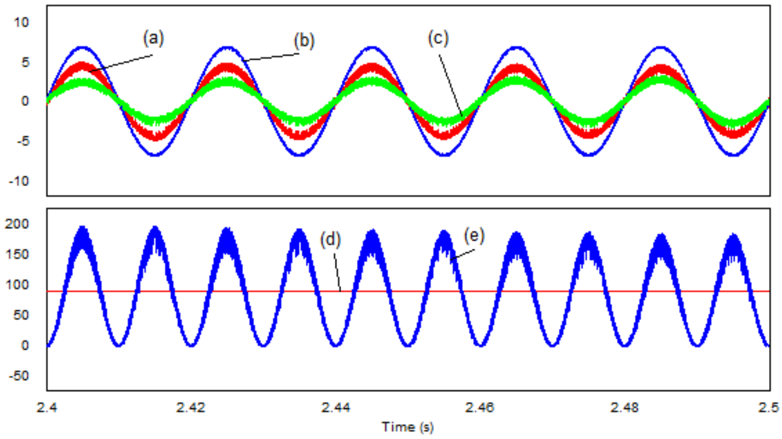

Figure 9. Simulated waveforms under irradiance 1000W/m2 (a) inverter output current (b) load current (c) grid current (d) PV maximum power (e) inverter output power

4. CONCLUSION

The analysis about single stage PV-Grid system using single phase VSI has been done and described. Based on the analysis, a simple control scheme for the inverter to maximize the power generated by PV and to transfer power to the grid is derived. The proposed control is capable to achieve the required functions. The simulated results show that under maximum irradiance, maximum power can be produced. By using the Voltage Source Inverter, this maximum power can be delivered to the grid. When the solar irradiance drops, its maximum power will also decrease but the inverter is still capable to deliver all the power generated by PV to the grid.

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