Constant Power Generation Using Modified MPPT P&O to Overcome Overvoltage on Solar Power Plants

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Abstract— **Indonesia is a tropical country that has the privilege of gaining sunshine year-round so that the utilization of solar energy as a solar power plant can be a potential power plant to be developed. One of the problems in the solar power plant system is the power instability generated by the solar panels because it relies heavily on irradiance and relatively low energy conversion efficiency. To solve this problem, the Maximum control of Power Point Tracking (MPPT) is required by the Perturb and Observe (P&O) methods. This P&O MPPT control makes solar PV operate at the MPP point so that the solar PV output power is maximized. However, the MPPT P&O control that works at the MPP point makes the output voltage to the load is also maximum that causes overvoltage. This paper, therefore, discusses the modification of the MPPT Perturb and Observe (P&O) algorithm for Constant Power Generation (CPG) that combines MPPT P&O with the power control settings to the maximum limit of solar PV. This method can set up 2 operating conditions of the solar PV namely MPPT mode and CPG mode. The MPPT mode works when the solar PV output power is smaller than the reference power to maximize solar PV output power. However when the solar PV output power is more than or equal to the reference power then the CPG mode works to limit the solar panel's output power. Based on the simulated results of this MPPT-CPG control shows the load output voltage response can be kept constant 48 V with less than 5% error that has been verified using a variety of irradiance and reference power.**

Keywords— Constant power generation (CPG), maximum power point tracking (MPPT) P&O, solar PV

Nomenclature

Ipv	current of the solar PV terminal (Ampere)
Vpv	voltage of the solar PV terminals (Volt)
Iph	solar PV current (Ampere)
Is	saturation current (Ampere)
Rs	series resistors of solar PV (Ω)
Rsh	parallel resistors of the solar PV (Ω)
Vt	terminal voltage of the solar PV (Volt)
q	diode quality factor
Ns	number of solar cells connected to the solar PV
D	duty cycle
Vs	input voltage of SEPIC converter (Volt)
Vo	output voltage of SEPIC converter (Ampere)

I. Introduction

Based on data from the National Energy Council, the potential of solar energy in Indonesia reaches 4.8kilowatt-hours per square meter per day (kWh / m² / day), 112,000 GWp equivalent compared to the potential land in Indonesia. This is certainly very potential to be used as a solar power plant to meet the needs of electrical energy given the increasingly limited amount of fossil fuels.

In solar energy, the solar power plant system is converted into electrical energy using solar panels. But the use of solar PV as a solar power plant has a disadvantage which is the instability of the power produced by solar PV because it is very dependent on irradiance. Besides, the energy conversion efficiency is also relatively low (approximately 30%) [3], [11]. Therefore solar PV requires the MPPT method to be operated and forced to work at the MPP point [2], [5].

Nowadays it has been widely developed research on the MPPT method using both conventional and artificial intelligence methods. P&O is one of the conventional methods commonly used. This is because P&O is easy to implement [3], [4], [7], [13], low cost [13], has fast rise time [6] and able to produce high power efficiency. The use of the MPPT P&O method that operates at maximum power makes the output voltage to the load also maximum so that it can cause excessive voltage disturbances because the voltage supplied to the load exceeds the load rating voltage itself.

MPPT P&O condition forces solar PV to work on the MPP point. When irradiance fluctuations occur, this condition can cause overvoltage. To avoid this the MPPT is modified with a Constant Power Generation (CPG) [5]. This modification of the MPPT P&O-CPG works to limit the maximum power produced by the MPPT P&O method so that the generated voltage can always be at the rated voltage [8]. To be able to use this MPPT P & O-CPG modification, a DC-DC converter is needed. DC-DC converter used is the SEPIC converter. The duty cycle of the SEPIC converter is always changed according to modified MPPT P & O-CPG with 2 modes, namely MPPT and CPG modes. The MPPT mode works when the PV output power (Ppv) is under than or equals the reference power (Pref) to maximize power re-generated SEPICconverter [9]. Whereas CPG mode works when the PV outputpower (Ppv) is reaching Pref, the PV output power (Ppv) will be kept constant Ppv = Pref [9]. To verify the performance of both MPPT P&O operations and CPG operations in avoiding overvoltage by limiting PV output power then simulated on PSIM software using solar modules with irradiation fluctuations and variations in load value.

II. Characteristics of Photovoltaic Module

A. PV Equivalent Circuit Model

The photovoltaic module consists of a collection of solar cells that can convert energy from sunlight into electrical energy [11]. PV module can be modeled by an ideal current source, series resistance, and parallel resistances. The direct current generated from the ideal source of current sources is comparable to the light irradiation that the solar cell receives. Resistance series and parallel resistance present drop voltage and leakage current values [4]. The equivalent circuit of the photovoltaic cell is shown in Fig. 1.

Based on a single diode model, characteristic equation for the current and voltage of photovoltaic modules are formulated with [3], [6], [7], [11], [12], [13]:

$$I = I_{ph} - I_s\left(e^{\frac{V_{pv}+I_{pv}R_S}{nN_S V_t}} - 1\right) - \frac{V_{pv}+I_{pv}R_s}{R_{sh}} \tag{1}$$

In this paper used 2 pieces of solar panels that are connected series with the capacity of each solar panel of 100 WP. Table I. shows the electrical parameters of the photovoltaic module that used when ideal conditions (the ambient temperature is set to 25 º C and radiation at 1000 W/m²).

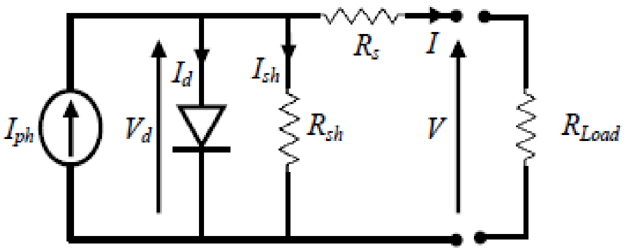

Fig. 1. Equivalent circuit of the photovoltaic cell [3].

TABLE I. Photovoltaic Module Parameter at 25°C and 1000 W/m²

Polycrystalline Photovoltaic Module	
Parameter	**Value**
Maximum Power (Pmp)	200 W
Maximum Power Current (Imp)	5.62 A
Maximum Power Voltage (Vmp)	35.6 V
Short Circuit Voltage (Isc)	6.4 A
Open Circuit Voltage (Voc)	43.8 V

B. PV Characteristic Curve

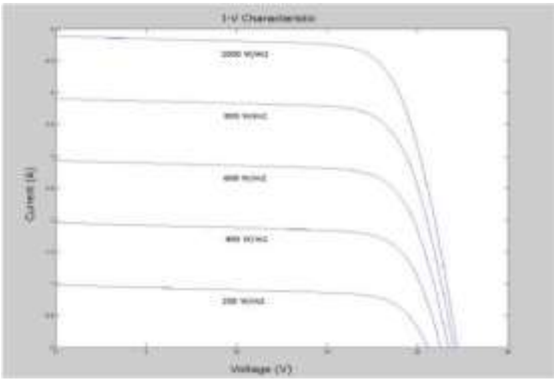

Fig. 2. Current-Voltage (I-V) characteristics with variable irradiation [6].

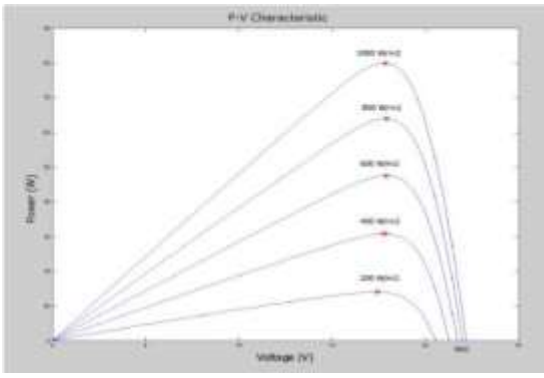

Fig. 3. Power-Voltage characteristics (P-V) with variable irradiation [6].

Solar cells have a characteristic curve indicating the relationship between the current and the output voltage (I-V curve) and the power and the output voltage (P-V curve). The following Fig. 2 and Fig. 3 display the current photovoltaic-voltage (I-V) and power-voltage (P-V) characteristic curves with an irradiated value change of 200-1000 W/m².

In the Fig. 2, shows that irradiance increase with a fixed temperature of 25°C then the output current is also increasing. In Fig. 3, shows that irradiance increase with a fixed temperature of 25°C then the power of PV also increasing.

III. SEPIC Type DC-DC Converter

Single-Ended Primary Inductance Converter (SEPIC) converter is a kind of derivative converter of Buck-Boost converter. SEPIC converter can produce output voltage greater or smaller than the input voltage without changing its polarity [10].

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The characteristics of a SEPIC converter are as follows:

1. Both inductor values are very large and the current is generated more constant.
2. Both capacitor values are very large and the resulting voltage is more constant/stable.
3. Network in steady-state, meaning that the voltage and current waveforms are periodic.
4. The ratio of duty cycle D, when the switch closes DT, and when the switch opens (1-D) T.
5. Switches and diodes in ideal conditions.

In Fig. 4 shows the power series of SEPIC converter consisting of power switches K (MOSFET transistor), SEPIC inductor (L1 and L2), filter capacitors (C1 and C2), diode D outputs, and load resistor RLoad.

The large output value of the SEPIC converter is determined by setting the duty cycle value as seen in the equation 2 and 3. Duty cycle (D) is a time comparison when the switch is on compared to the switching period.

$$D = \frac{Vo}{Vo+Vs} \quad (2)$$

$$Vo = Vs \frac{D}{(1-D)} \quad (3)$$

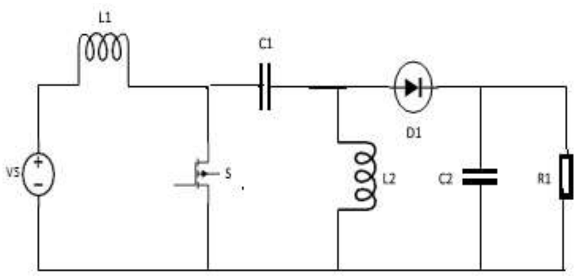

Fig. 4. The power series of SEPIC converter.

IV. Proposed Method

A. Design Configuration System

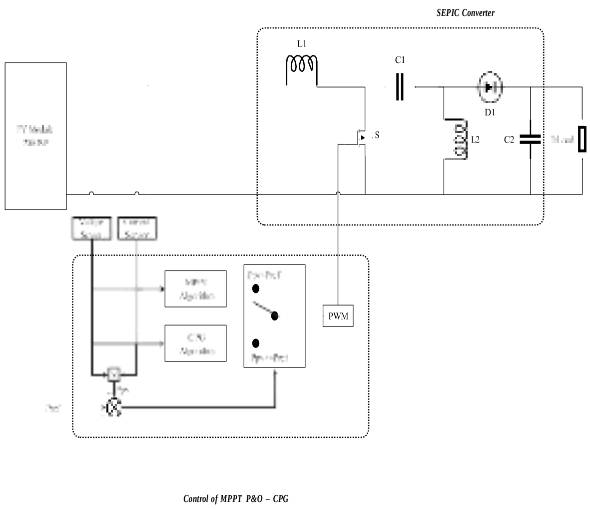

Fig. 5. Block diagram operational principles MPPT P&O-CPG.

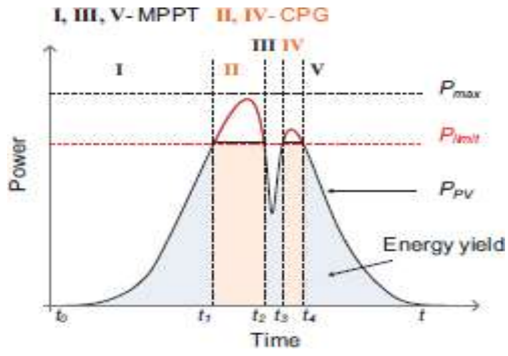

Fig. 6. Areas of operation for MPPT and CPG modes in the PV system for a day [8].

The block diagram system is depicted in Fig. 5. shows that on this system using a solar PV 200 WP related SEPIC converter with a variable resistive load of 48 Volts (0-200 Watts). There are two voltage sensors and two sensors, both sensors are installed on the input SEPIC converter and the output side. The current and voltage sensor on the input side of the SEPIC converter is to provide the voltage and return the current information to the control algorithm system MPPT P&O-CPG. While the current and voltage sensors on theoutput side of the SEPIC converter are to monitor the voltage and load output power whether according to the currently active MPPT P&O or CPG control modes.

MPPT P&O-CPG operational principles depicted in Fig. 5. It can be divided into two modes:

a) MPPT P&O mode (Ppv <= Pref), where the MPPT P&O algorithm should track maximum power and oscillate around the MPP.
b) CPG mode (Ppv > Pref), where PV output power is limited to Pref. In this CPG mode, PV voltage continuously interrupted a point called Constant Power Point (CPP) (Ppv = Pref). Areas of operation for MPPT and CPG modes in PV system for a day depicted in Fig. 6.

B. Design of MPPT P&O-CPG

On the MPPT method P&O-CPG consists of 2 modes, namely MPPT mode and CPG mode. In determining which mode is activated based on 2 variables: solar panel output power (PPV) and reference power (Pref). Solar panel output power is obtained from the readings of the current sensor and the voltage on the solar panel output. While the reference power is the boundary power that is inputted. When PPV is < = Pref then the MPPT mode is enabled and when PPV > Pref then CPG mode is enabled. This active mode will determine the duty cycle of the SEPIC converter. So from this control system generated loads are saved from the failure of excess voltage. The flowchart of the MPPT P&O-CPG system is shown in Fig. 7.

In this paper observed technique MPPT P&O method for MPPT mode. The MPPT P&O method compares the output power while being measured and previously to be converted into a duty cycle by taking the current-voltage and data on the solar panels through the current sensor and voltage on the input SEPIC converter. If the PV output power changes to increased voltage changes (dP/dV > 0), then perturbation in the same direction is done to move the working voltage of the solar panels forward towards the MPP. Whereas if the power change output to a change in voltage is reduced (dP/dV < 0), then the direction of the perturbation reversed. This process is repeated periodically until the MPP is reached [3]. The system then oscillated around the MPP. The MPPT P&O Flowchart method is shown in Fig. 8.

Then in Fig. 9 shows the modified flowchart of the P&O algorithm MPPT. Both modified methods are almost identical to the original MPPT P&O method, but in the modified MPPT P&O method, the Vref value is in the reverse direction. By doing this technique it is possible to force the solar PV operation to the left of the MPP and allow it to control the feed-in power on variable resistive loads.

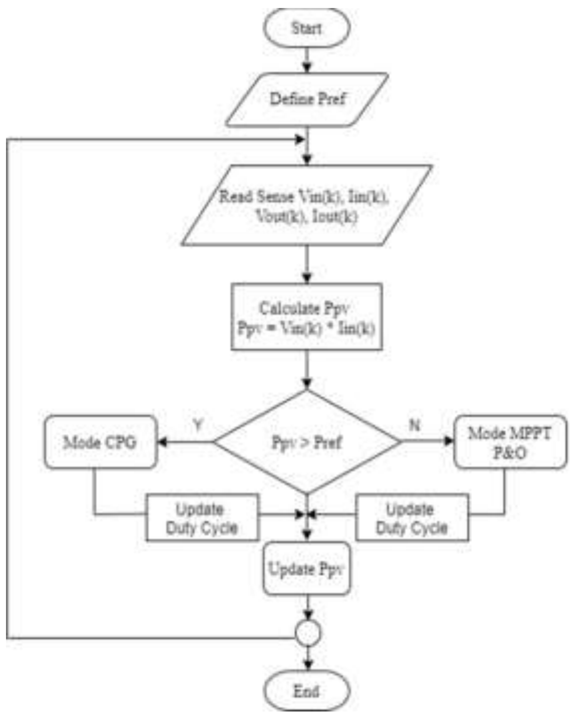

Fig. 7. Flowchart of MPPT P&O-CPG system.

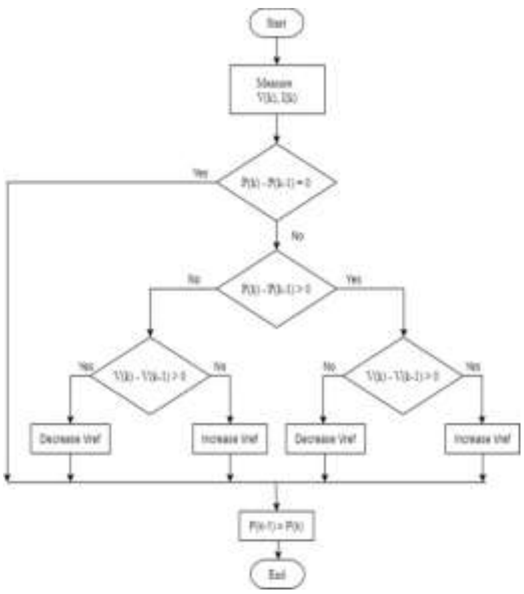

Fig. 8. Flowchart of MPPT P&O method.

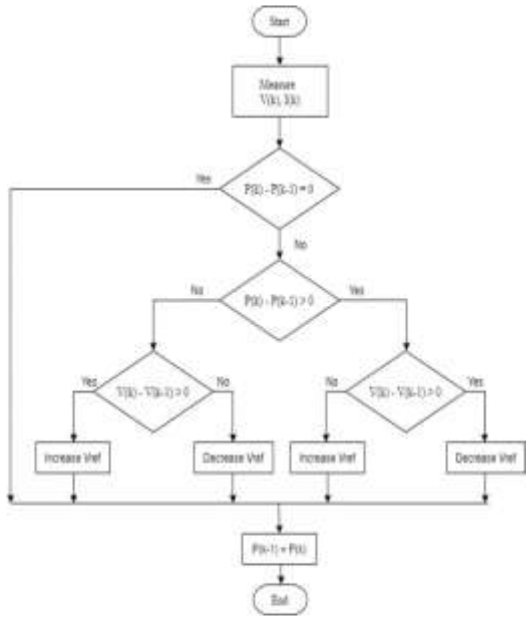

Fig. 9. Flowchart of Modified MPPT P&O method for CPG.

V. Simulation Result

A. Simulation Circuit

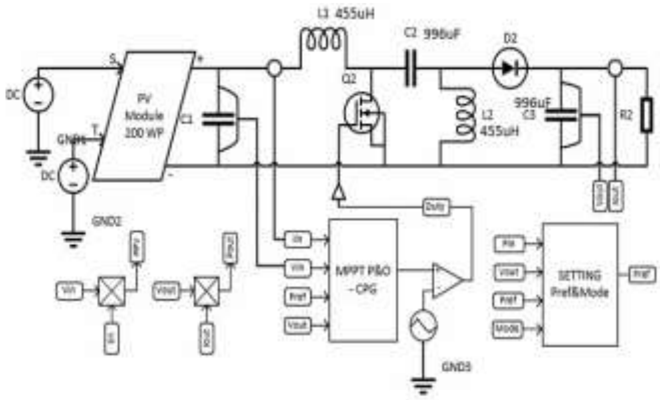

Fig. 10. Simulation circuit for MPPT P&O-CPG.

TABLE II. Design of SEPIC Converter

Terms	Values
Input voltage	35.6 Volt
Input current	5.62 Ampere
Output voltage	48 Volt
Output current	3.3 Ampere
Frequency switching	40 kHz
Size capacitors (C1 and C2)	996 uF
Size inductors (L1 and L2)	455 uH

In Fig. 10, shows the overall simulation circuit of the system with the MPPT P&O-CPG method modeled on the PSIM software, in which the DC-DC SEPIC converter is used to connect the solar PV module 200WP to a variable resistive load. The parameter of the solar PV module is tabulation in Table I. Then the capacitor design size and inductor of the SEPIC converter are tabulation of Table II.

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B. Result Simulation

To know the performance of the proposed MPPT P&O-CPG method is conducted simulated testing using 3 variations of the reference power (Pref) value (75W, 150W, 200W) with 3 variations of irradiance value of 300 W/m^2, 650 W/m^2, 1000 W/m^2) and the same temperature of 25°C. Then the results of the response MPPT P&O-CPG method is compared with the method response MPPT P&O. The calculation of the load resistor for the above-tabulated reference power (Pref) in Table III.

In Fig. 11 is a simulated result of the MPPT P&O method and the MPPT P&O-CPG method using PSIM on a 2x100 WP solar panel with an irradiance variation of 300W/m^2, 650 W/m^2, 1000W/m^2 and a load of 75W. Response Pout, Vout and Iout of the method MPPT P&O showed an overvoltage occurred where the converter's output voltage exceeded the rating load voltage of 48V when the irradiance point of 650W/m^2 and 1000W/m^2 with the converter output voltage reached 75.48V and 64.32V. As for response Pout, Vout and Iout of the method MPPT P&O-CPG with Pref of 75W indicates active MPPT mode when irradiance point 300W/m^2 due to output voltage and Pref has not been reached. However, when the output voltage is 48.21V and output power is 75.61W at the irradiance point 1000W/m^2 and the output voltage is 48.18V and output power is 75.52W at irradiance point 650W/m^2 then the MPPT mode switches CPG mode to keep the PV output power constant so that the output voltage does not exceed the 48V. The output voltage will go up and down by the control fault limit of ± 5% of 48V (load voltage rating), the load can be said to be overvoltage when tension > 5% of the rating voltage load. When MPPT mode switches to CPG mode or the reverse overshoot occurs due to irradiance fluctuations.

In Fig. 12 is a simulated result of the MPPT P&O method and the MPPT P&O-CPG method by using PSIM on a 2x100 WP solar panel with an irradiance variation of 300W/m^2, 650 W/m^2, 1000W/m^2 and a load of 150W. Response Pout, Vout and Iout of the method MPPT P&O showed an overvoltage occurred where the converter's output voltage exceeded the rating load voltage of 48V only when the irradiance point 1000W/m^2 with the output voltage of the converter reached 53.76V. As for response Pout, Vout, and Iout of the method MPPT P&O-CPG with Pref of 150W indicates active MPPT mode when irradiance point 300W/m^2 and 650W/m^2 because the output voltage and Pref have not been reached. However when the 48.12V output voltage and output power of 150.69W at the irradiance point of 1000W/m^2 then the MPPT mode when the irradiance point 300W/m^2 previously switched to CPG mode to keep the PV output power constant so that the output voltage does not exceed the 48V rating. The output voltage will go up and down by the control fault limit of ± 5% of 48V (load voltage rating), the load can be said to be overvoltage when tension > 5% of the rating voltage load. Then when the irradiance point drops to 650W/m^2, the MPPT mode is re-activated. When MPPT mode switches to CPG mode or instead overshoot occurs due to irradiance fluctuations.

In Fig. 13 is a simulated result of the MPPT P&O method and the MPPT P&O-CPG method by using PSIM on a 2x100 WP solar panel with an irradiance variation of 300W/m^2, 650 W/m^2, 1000W/m^2 and a load of 200W. In this case MPPT P&O method does not produce overvoltage in all three irradiance variations. Besides, the same Pout, Vout, and Iout response is obtained on both methods as the active MPPT mode works on all three irradiance variations when using the MPPT P&O-CPG method. This MPPT mode is activated because the output voltage and Pref have not been reached at all three irradiance points. The maximum output voltage and maximum output power achieved when the irradiance point of 1000/m^2 only reaches 47V and 191.86W so that CPG mode isnever activated in this condition.

TABLE III. THE CALCULATION OF THE LOAD RESISTOR

Power (W)	Voltage (V)	Current (A)	Resistor (Ohm)
75	48.8	1.042	30.72
150	48.8	2.083	15.36
200	48.8	3.472	11.52

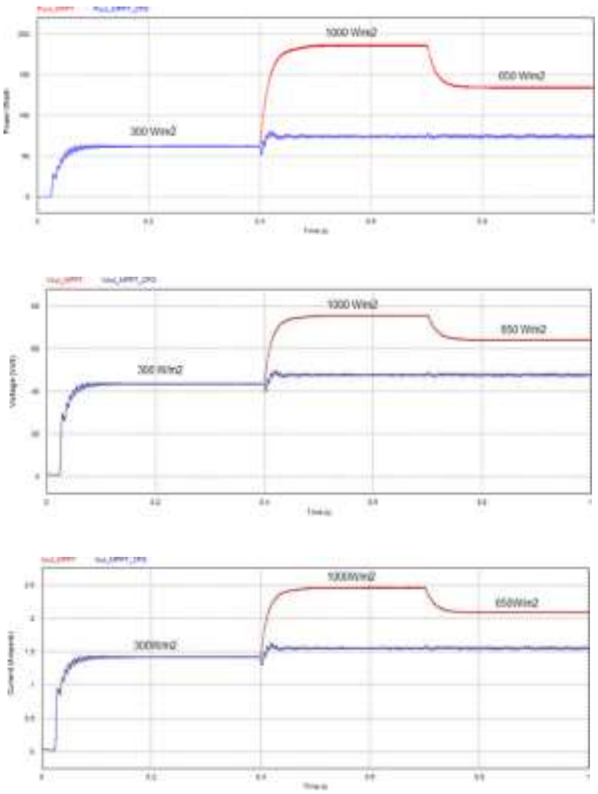

Fig. 11. Comparison of Pout (W), Vout (V) and Iout (A) response with 75W load when using MPPT P&O method and MPPT P&O-CPG method.

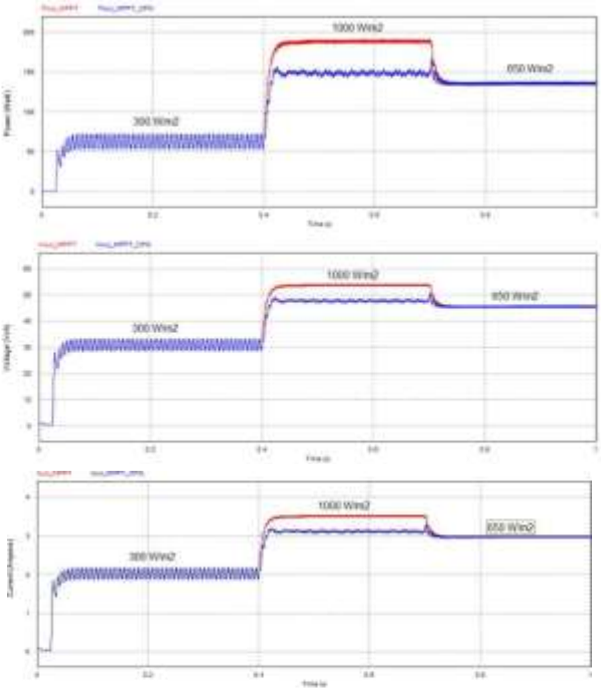

Fig. 12. Comparison of Pout (W), Vout (V) and Iout (A) response with 150W load when using MPPT P&O method and MPPT P&O-CPG method.

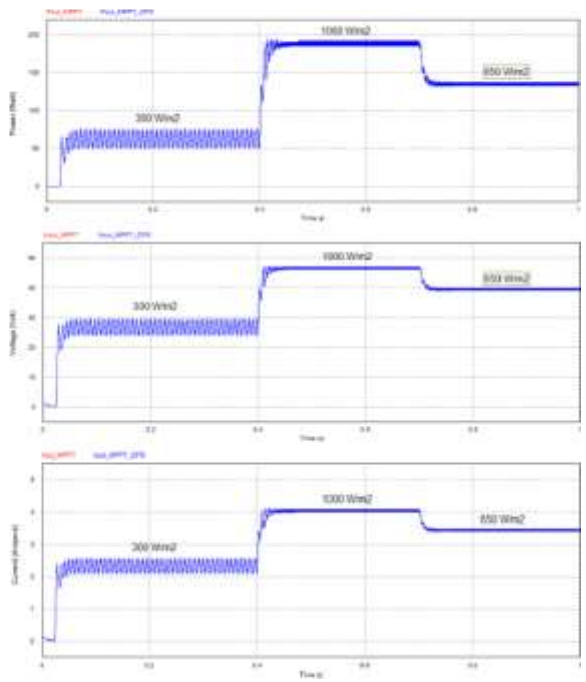

Fig. 13. Comparison of Pout (W), Vout (V) and Iout (A) response with 200W load when using MPPT P&O method and MPPT P&O-CPG method.

VI. Conclusion

In this paper, we propose the MPPT P&O-CPG method to be able to control solar panels that work on 2 conditions i.e. in MPPT operations and CPG operations to avoid overvoltage on the load. This MPPT P&O-CPG method has been evaluated through a PSIM simulation. Simulated results indicate that the MPPT mode is identified when the load requirements are greater or equal to the solar power panel (PPV < = Pref) and the voltage on the output side of the < 48V. While CPG mode is identified when the power requirements of the solar panel are greater than the load power (PPV > Pref) and the voltage at > 48V output. The performance of the MPPT P&O-CPG method is proven to avoid excess voltage with a control error limit of ± 5% of the rating voltage on the load although it is still overshot during mode switching due to irradiance fluctuations.

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