MPPT VOLTAGE REGULATING IN THREE-PHASE GRID-CONNECTED PHOTOVOLTAIC SYSTEM

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ABSTRACT: The paper presents the method of harmonic attenuation with better dynamic response in the three-phase grid-connected photovoltaic system by using Maximum Power Point Tracking (MPPT) voltage regulator with varied increment. Since electrical power of PV array depends on the climatic condition. Maximum Power Point Trackers are used to extract maximum energy from photovoltaic generators. In this paper, every time the amount of electrical power generated by solar arrays changes continuously with weather conditions, MPPT voltage is regulated quickly with large increment to decrease dynamic response time, and then with small increment to get lower current THD. The simulation results in Simulink/Matlab show that the proposed MPPT voltage regulator with varied increment is better than with fixed.

Key words: Photovoltaics (PV), maximum power point tracker (MPPT), total harmonic distortion (THD), particle swarm optimization (PSO).

1. INTRODUCTION

The demand of renewable energy sources such as solar energy is becoming more popular for sustainability and environment with enormous potentials [1]. In order to convert solar DC source to three-phase AC power needs to have 3-phase inverters that have been well researched in recent years [2]. Objectives of three-phase grid-connected inverters are low THD to meet grid-connected standard IEEE Std 929-2000 [3] and good dynamic response to get high efficiency [4]. Many MPPT techniques have been proposed in the literature [5], [6], [7], [8] to determine MPPT voltage. In these methods, dynamic power responses are often slow (more than 0.1s) and THD values at the output of inverter haven't been evaluated.

The Perturb and Observe (P&O) method with constant increment in Fig. 1 is an example. If small increment is in large change irradiance condition, dynamic response time is long but output THD is lower. On the contrary, with large increment, dynamic response time is short but THD is higher. In this paper, the proposed diagram of grid-connected photovoltaic system is shown as Fig. 7. In order to generate optimal power with irradiance variety, the MPPT voltage is regulated by using P&O algorithm with varied increment as Fig. 5.
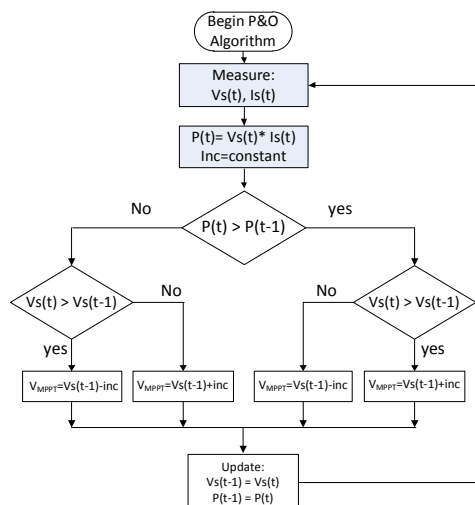
Fig 1. P&O algorithm with constant increment

2. SYSTEM DESCRIPTION

The proposed control scheme of three-phase grid-connected PV system that has been simulated includes 2 parallel rows, each row consists of 34 PV modules (RS-P618-85W) in series connected through a DC bus to a three-phase inverter that is connected to an ideal 380V grid through a LCL filter. In this system, the DC link voltage is controlled accordingly to the necessary output power. The dq control structure is normally associated with PI controllers since they have a satisfactory response when regulating DC variables. Since the controlled current has to be in phase with the grid voltage, the phase angle used by the abc to dq transformation block is extracted from the grid voltage throughout the PLL.

2.1. PV array model

The PV array is simulated using a model of moderated complexity based on [9]. In this model, a PV cell is represented by a current source in parallel with a diode, and a series resistance as shown in Fig. 2
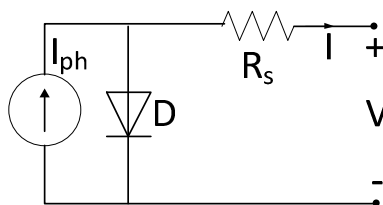

Fig. 2. The equivalent circuit model of a PV cell

The photo current I_{ph} depends on the irradiance G and the cell temperature T_c. The current I_c provided by the cell can be calculated as (1)

$$I_c = I_{ph} - I_s \left(e^{\frac{q(V+IR_s)}{nKTc}} - 1 \right) \qquad (1)$$

where I_s is the cell reverse saturation current, R_s is series resistance, q is electronic charge, K is Boltzmann's constant and T_c is cell temperature in K.
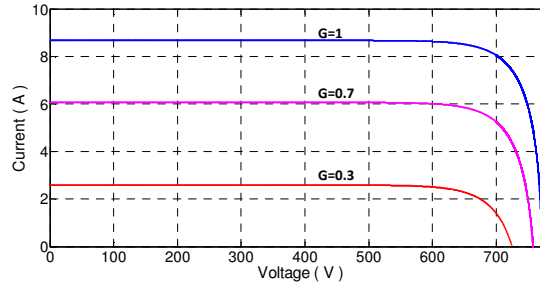

Fig. 3. PV array current vs. voltage for various irradiance and T_c=298K

The PV array model gives a total peak power of around 5.7kW. All modules are considered to be identical, and to work in identical conditions of temperature and irradiance.
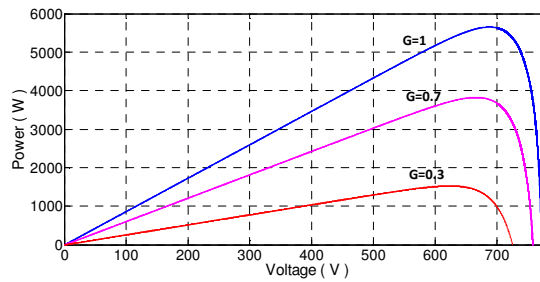

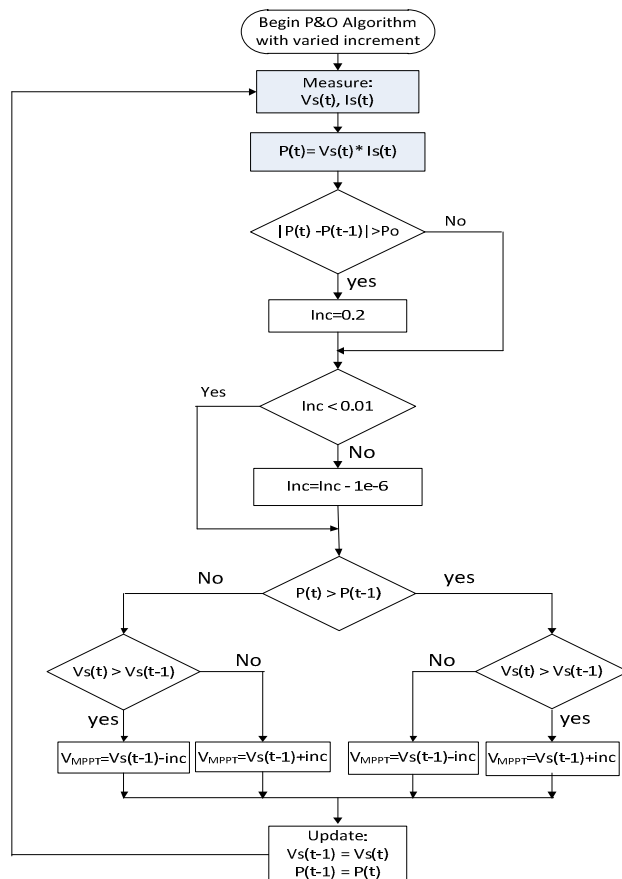**Fig. 4.** PV array power vs. voltage for various irradiance and T_c=298K

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Fig. 5. The proposed MPPT flowchart

2.2. The proposed MPPT scheme

One of the most important objectives of any grid-connected PV converter is to extract as much power as possible from the PV array. There are various methods to perform MPPT [10], (P&O) [11] and fuzzy logic [12] methods.

The module model with a given set of various operating conditions of irradiance and temperature shows that the relationships between voltage, current and power are charateristics similar to the ones shown in Fig. 3 and Fig. 4. MPPT voltage that corresponds to the maximum power changes with the variations of irradiance and temperature, so a MPPT system is needed to to get the max power from the module. The proposed MPPT voltage regulator is presented in this paper as shown in Fig. 5. The difference of the strategy is the varied increment that is added to P&O algorithm for better dynamic responds and lower current THD. The varied increment Inc is switched to high level (0.25 volt) when power changing level |P(t) – P(t-1)| is higher than the certain power P_0 to get fast dynamic responds. After that, the Inc decreases low level (0.02 volt) to get smooth MPPT voltage

and to have lower current THD. The d_axis reference current is also calculated in this regulator. The DC voltage of module is regulated by PI_V controller, I_d and I_q currents are also regulated by the PI_d and PI_q

contrllers as shown in Fig. 7. The parameters of these PI controllers are determined by PSO algorithm as table 1.
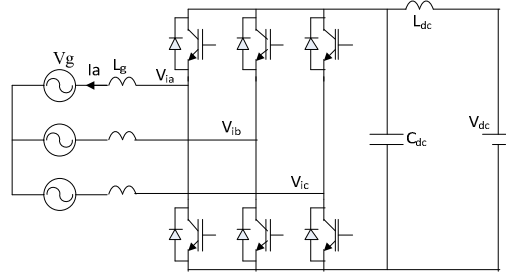
2.3. The inverter

Fig 6. Simplified model of the grid-connected inverter

The system configuration of the three-phase grid-connected voltage source inverter is shown in Fig. 6. And voltage equations in synchronous reference frame are (2) and (3)

$$V_{gd} = L_g \frac{di_d}{dt} - \omega L_g i_q + V_{id} \qquad (2)$$

$$V_{gq} = L_g \frac{di_q}{dt} + \omega L_g i_d + V_{iq} \qquad (3)$$

Where V_{gd} and V_{gq} are grid voltages respectively in dq frame. i_d and i_q, V_{id} and V_{iq} are inverter currents and voltages respectively in dq frame. L_g is inductance between inverter and grid voltage.

The output voltage of inverter is determined by the output of current regulator. In equation (2) and (3), the inverter voltage is the sum of grid voltage components and voltage drop components at the inductor L_g. In order to compensate the voltage deviation caused by approximate parameters and differential

voltage components, PI regulator is usually used in most current regulators. Equation (2) and (3) can be represented by the equation of inverter voltage like equation (4) and (5).

$$V_d^* = V_{gd} + \omega L_g i_q + V_{cd} \qquad (4)$$

$$V_q^* = V_{gq} - \omega L_g i_d + V_{cq} \qquad (5)$$

V_d^* and V_q^* are reference voltages of inverter respectively in dq frame. V_{cd} and V_{cq} are the outputs of PI current regulators which can be represented in equation (6) and (7).

$$V_{cd} = \left(K_p + \frac{K_i}{s} \right) \left(i_{d\_ref} - i_d \right) \qquad (6)$$

$$V_{cq} = \left(K_p + \frac{K_i}{s} \right) \left(i_{q\_ref} - i_q \right) \qquad (7)$$

Where i_{d_ref} and i_{q_ref} are reference currents of inverter respectively in dq frame. For power factor is unity, $i_{q\_ref} = 0$.

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3. SIMULATION RESULTS

3.1. Simulation parameters

The system scheme shown as Fig .7 has been simulated on Matlab/Simulink and Table 1 is the summary of the system parameter values.
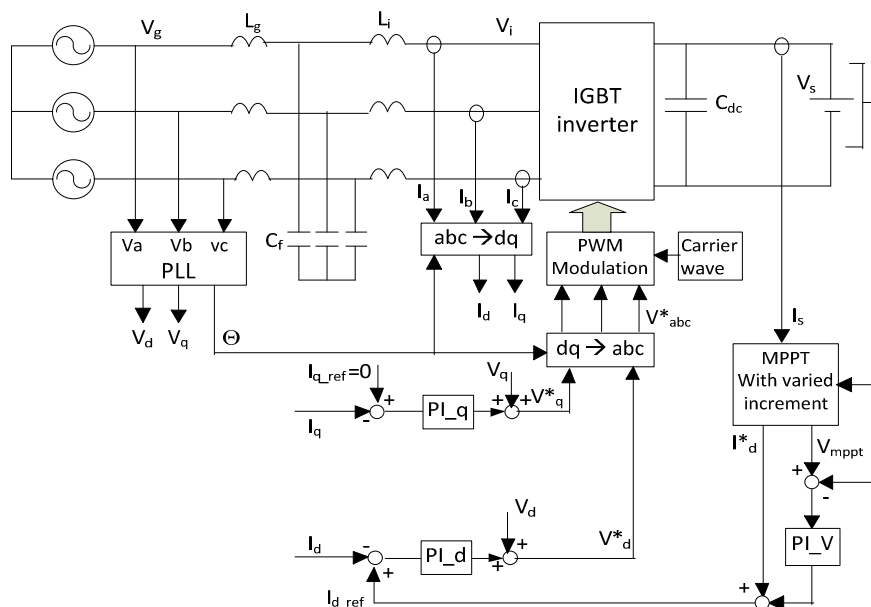

Fig. 7. General diagram of grid-connected photovoltaic system

Table 1. the system parameters

Parameter	Description	Value
L_g	Grid inductance	0.5mH
R_g	Resistance of L_g	0.01Ω
L_i	Inverter inductance	1.8mH
R_i	Resistance of L_i	0.1Ω
C_f	Filter capacitor	10μF
F_{PWM}	PWM frequency	9kHz
F	Grid frequency	50Hz
S_b	Base power	40KVA
V_b	Base voltage	380V
K_{p_dq}	K_p of PI_d and PI_q	393
K_{i_dq}	K_i of PI_d and PI_q	397
K_{p_v}	K_p of PI_V	6
K_{i_v}	K_i of PI_V	0.005
C_{dc}	DC bus capacitor	1500μF

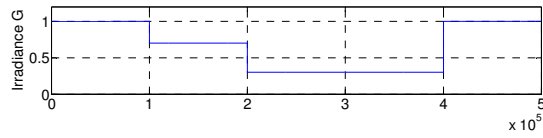**3.2. MPPT with fixed increment = 0.25V**

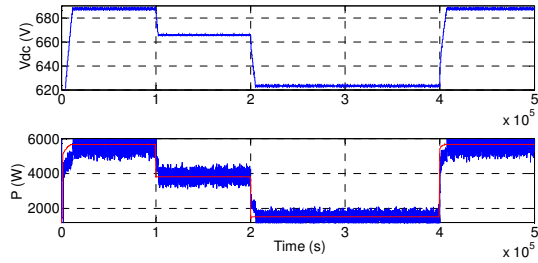**Fig. 8.** Irradiance change and large fixed increment (0.25 volt)

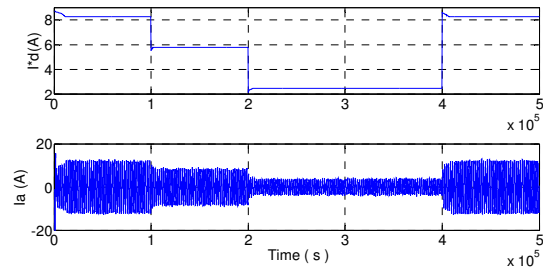**Fig. 9.** PV array V_{dc} and power responses with large fixed increment

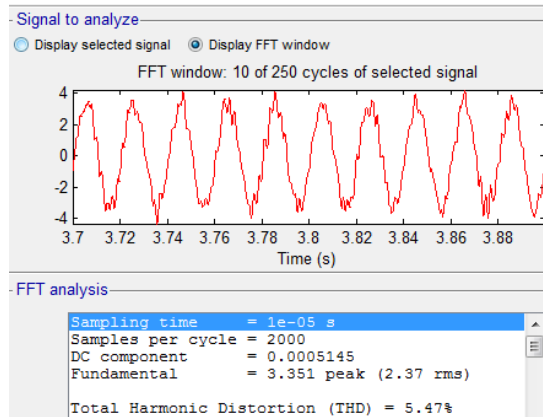**Fig .10.** Grid current and I^*_d with large fixed increment

Fig. 11. The phase current THD

The simulation results in Fig. 8 to Fig. 11 show that dynamic responses of PV array power are very fast but current THD is higher than 5%.

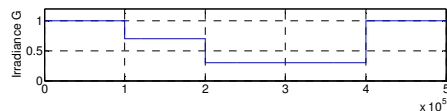### 3.3. MPPT with fixed increment = 0.02V

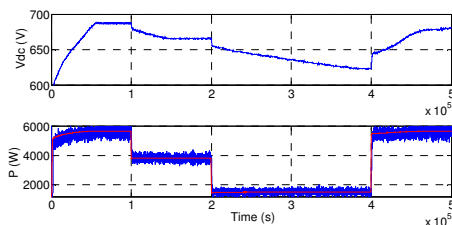**Fig. 12**. Irradiance change and small fixed increment (0.02 volt)

Fig .13. PV array V_{dc} and power responses with small fixed increment

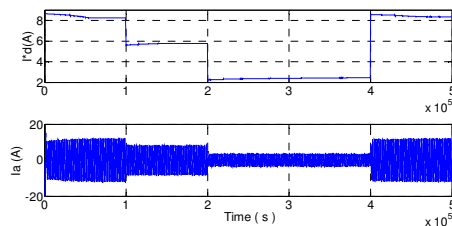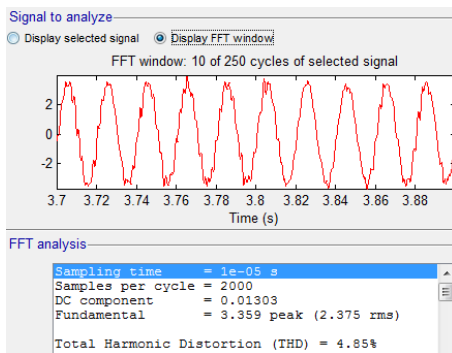**Fig. 14.** Grid current and I^*_d with small fixed increment

Fig. 15. The phase current THD

The simulation results in Fig. 12 to Fig. 15 show that dynamic responses of PV array power are very slowly but current THD is lower than 5%.
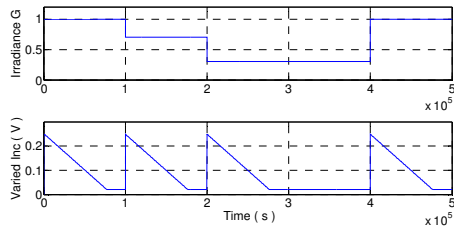
3.4. MPPT with varied increment

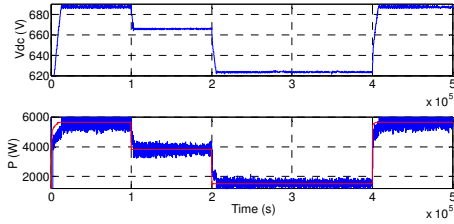**Fig. 16.** Irradiance change and varied increment (0.02 to 0.25 volt)

Fig. 17. PV array V_{dc} and power responses with varied increment
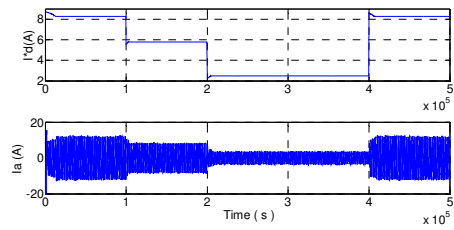
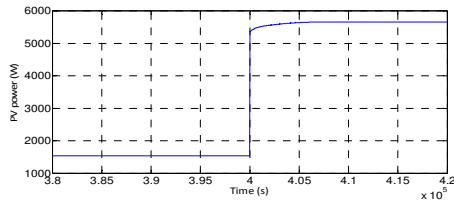

Fig. 18. Grid current and I^*_d with varied increment

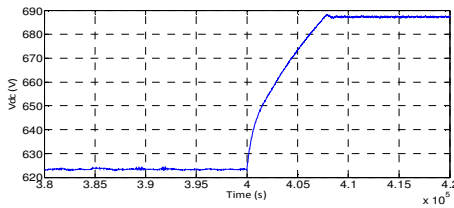**Fig. 19.** System PV power response to an irradiance step at t=4s

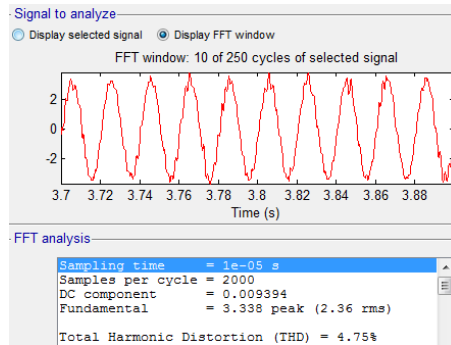**Fig. 20**. System V_{dc} response to an irradiance step at t=4s

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Fig. 21. Phase current THD

The system responses to an irradiance step is shown in Fig. 16 to Fig. 20 at t=4s when the irradiance is changed from 300W/m^2 to 1000W/m^2. They show that the system tracks the maximum operating point faster than most MPPT strategies. Irradiation change level is very extremely rapid that shows the good performance of the proposed MPPT voltage regulator.

4. CONCLUSIONS

A three-phase grid-connected photovoltaic inverter system has been presented. In this paper, the inverter does not require an intermediate stage of DC/DC control to get optimal power. In order to extract the maximum power from the PV module, a MPPT voltage regulator is applied by using P&O algorithm with varied increment to get better dynamic responds and lower current THD. The simulation results in Simulink/Matlab show that the proposed MPPT voltage regulator with varied increment is better than with fixed.

ĐIỀU CHỈNH ĐIỆN ÁP MPPT TRONG HỆ THỐNG ĐIỆN MẶT TRỜI
NỐI LƯỚI 3 PHA

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TÓM TẮT: *Bài báo này trình bày phương pháp giảm thiểu sóng hài trong hệ thống pin mặt trời nối lưới 3 pha với đáp ứng động nhanh bằng cách sử dụng bộ điều chỉnh điện áp MPPT có gia số biến thiên. Do công suất điện của dàn pin mặt trời thay đổi theo điều kiện thời tiết. Bộ dò điểm công suất cực đại MPPT được sử dụng để chiết xuất năng lượng điện cực đại của dàn pin. Trong bài báo này, mỗi khi công suất điện của dàn pin thay đổi theo điều kiện thời tiết, điện áp MPPT sẽ được chỉnh rất nhanh đến điểm có công suất cực đại với gia số lớn, sau đó gia số sẽ giảm nhỏ xuống để nhằm đạt được độ méo dạng sóng hài THD dòng điện thấp hơn. Kết quả mô phỏng trên Simulink/Matlab cho thấy bộ điều chỉnh điện áp MPPT đề xuất có gia số biến thiên tốt hơn bộ điều chỉnh có gia số cố định.*

Từ khóa: *Pin mặt trời (PV), bộ dò điểm công suất cực đại (MPPT), độ méo dạng sóng hài toàn phần (THD), tối ưu bầy đàn (PSO).*

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