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Study Method of the P&O Algorithm using Pulse Width Modulation and Duty Cycle Modulation: Application to the search for the Maximum Power Point of PV Systems

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Abstract: In this paper, we make a comparative study of the P&O algorithm using pulse width modulation (PWM) and duty cycle modulation (DCM) for the control of DC/DC converters used for the search of the maximum power point of photovoltaic systems. The converter used here is a boost chopper. Details of the two modulation techniques are presented, and the results are obtained using MATLAB/Simulink software. These results show that the power at the output of the PV oscillates around 0.2W for the DCM technique and 0.6W for the PWM. The output power of the boost chopper shows an oscillation of 0.8W for DCM and 2.4W for PWM. The DCM, in terms of speed reaches the PPM 0.012s less than the PWM. We can therefore say that DCM is better than PWM.

Keywords: PV System, MPPT, Partial shading, Duty cycle modulation, P&O algorithm

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1. Introduction

Renewable energy is a topical area and is of particular interest to researchers in the field. Today, with the rapid growth of the population, the demand for energy is also becoming very important. Fossil fuels alone cannot meet the demand, which is why renewable energies are being used. There are several types of renewable energy sources, including wind energy using wind power, hydroelectric power using water power, biomass and photovoltaic energy using the sun as a source. The latter has attracted our attention because of its abundant availability. However, the electricity produced by photovoltaic systems depends on environmental conditions such as temperature and solar radiation. These factors affect the current and voltage characteristics of the system, which is why a maximum power point tracking (MPPT) regulator is required to collect the maximum available power [1]. One of the methods used for this is the perturb and observe (P&O) algorithm [2-4]. The perturb and observe algorithm is one of extensively and preferment scheme of maximum power point

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tracking algorithm. Like all the different methods used for tracking the maximum power point of photovoltaic system [5-7], perturb and observe method use a pulse width modulation (PWM) for control the DC-DC converter. Here, we propose to use DCM instead of PWM, and then make a comparative study. The DCM is a signal conversion class in which an input signal is converted to a pulse width modulation (PWM). x is transformed to a periodic switching wave $x_m(t)$ with $T_m(x)$as a period and $R_m(x)$ as a duty cycle. In the literature [8-10] it is shown that this modulation technic offers more advantages than PWM in the field of signal processing. Here it is a question for us to use it in the field of renewable energies for the research of MPP and to compare it with the classically used technic (PWM) [17-19].

For the rest, we organized the work as follows: In section 2, we will present the configuration of the PV system used for the study. The principles of the PWM and DCM technics will be described in section 3. The simulation results will be presented and the comparison between the two modulation technics will be made in section 4 and concluded in section 5.

2. PV system configuration

Fig. 1 illustrates the conversion chain of a PV system. It consists of the PV array, a DC/DC converter connected to the load, an MPPT controller and an adapter stage located between the controller and the DC/DC converter.

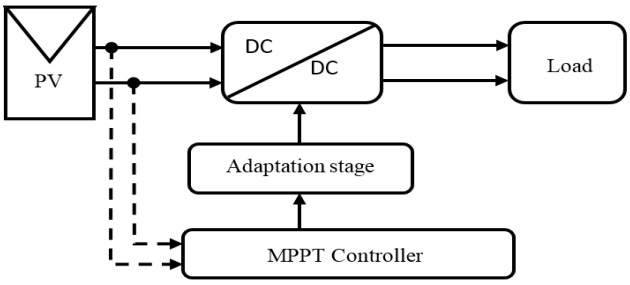

Fig. 1: Configuration of PV power system

2.1 Solar cell and PV module

The operating principle of PV cells is based on the principle of the " photovoltaic effect" [11], which consists of transforming the rays received from the sun or photons into electrical energy. The equivalent circuit of a PV cell is shown in Fig. 2.

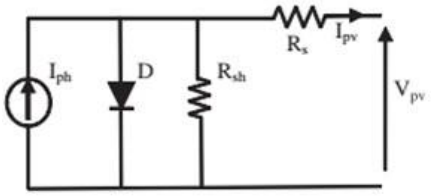

Fig. 2: Equivalent circuit of solar cell

By applying the node law, the output current is calculated as follows I_{pv} given to equation (1)

$$I_{pv} = I_{ph} - I_d - I_{sh} \quad (1)$$

The photo current is proportional to solar irradiation (G in W/m²) and can be expressed by (2)

$$I_{ph} = \left(\frac{G}{G_r}\right)\left(I_{scr} + k_i(T - T_r)\right) \quad (2)$$

Where I_{scr} is short-circuit current of the PV module at standard test condition (STC) of 25°C and $1000W/m^2$, k_i is temperature coefficient of short-circuit, T is cell temperature (K) T_r is reference temperature (K) and G_r is reference solar irradiation (W/m²). The diode current is given by (3)

$$I_d = I_s\left(\exp\left(\frac{q(V_{pv}+R_sI_{pv})}{nK_bT}\right) - 1\right) \quad (3)$$

Where I_s is saturation current and can be expressed by equation (4), q is electron's charge, n is ideality factor and K_b is Boltzmann's constant.

$$I_s = I_{rs}\left(\frac{T}{T_r}\right)^3 \exp\left(\frac{qE_g}{nK_b}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \quad (4)$$

Where I_{rs} is saturation current at T_r and is given by equation (5), E_g is the silicon gap energy of the semiconductor,

$$I_{rs} = \frac{I_{scr}}{\exp\left(\frac{qV_{oc}}{nK_bT}\right)-1} \quad (5)$$

Where V_{oc} is the open-circuit voltage. The shunt current is given by equation (6),

$$I_{sh} = \frac{V_{pv}+R_sI_{pv}}{R_{sh}} \quad (6)$$

For N_s cells in series and N_p cells in parallel, the characteristic equation of a PV module is delivered as below (7)

$$I_{pv} = N_p I_{ph} - N_p I_s \left(\exp\left(\frac{q(V_{pv}+R_s I_{pv})}{N_s n K_b T}\right) - 1\right) - \frac{V_{pv}+R_s I_{pv}}{R_{sh}} \quad (7)$$

2.2 DC/DC power Converter

The converter used here is a boost type chopper. It is used to convert direct current from one voltage level to another. It is one of the most widely used converters in the field of renewable energies because of its advantages [12]. Its circuit is shown in Fig. 3.

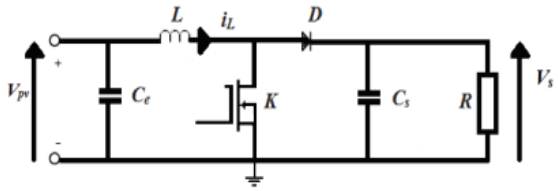

Fig. 3: DC/DC boost converter

The input voltage is V_e which is also the voltage coming out of the PV cell so $V_e = V_{pv}$ and V_s is the output voltage and is expressed as (8)

$$V_s = \frac{V_{pv}}{1-D} \quad (8)$$

The K-switch used in these systems is usually an IGBT or MOSFET [5]. The passive components *R*, *L*, C_e and *Cs* are respectively the resistance which is the load, the inductance, the input and output capacitors.

2.3 P&O MPPT algorithm

It is one of the most widely used algorithms because of its ease of implementation [13]. As its name suggests, it works on the idea of introducing a disturbance at the operating point in order to observe maximum power at the output. Its principle consists of disturbing the voltage of the PV array while acting on the duty cycle x. Following this disturbance, the power is calculated at a time k then compare to the previous one$(n-1)$. If the power increases, it means that we are approaching the PPM, if not, we are moving away from the PPM if the power decreases at the output of the panel. The summary of this algorithm is given as follows and Fig. 4, illustrates the flowchart of this algorithm: First, the voltage $V_{pv}(n)$ and current $I_{pv}(n)$ are measured for calculating the power $P_{pv}(n)$. The variations of power $\Delta P_{pv} = P_{pv}(n) - P_{pv}(n-1)$ and of voltage $\Delta V_{pv} = V_{pv}(n) - V_{pv}(n-1)$ are calculated.If $\Delta P_{pv} \times \Delta V_{pv} > 0$, the duty cycle $\alpha(n+1) = \alpha(n) + \Delta\alpha$, If $\Delta P_{pv} \times \Delta V_{pv} < 0$, the duty cycle $\alpha(n+1) = \alpha(n) - \Delta\alpha$.

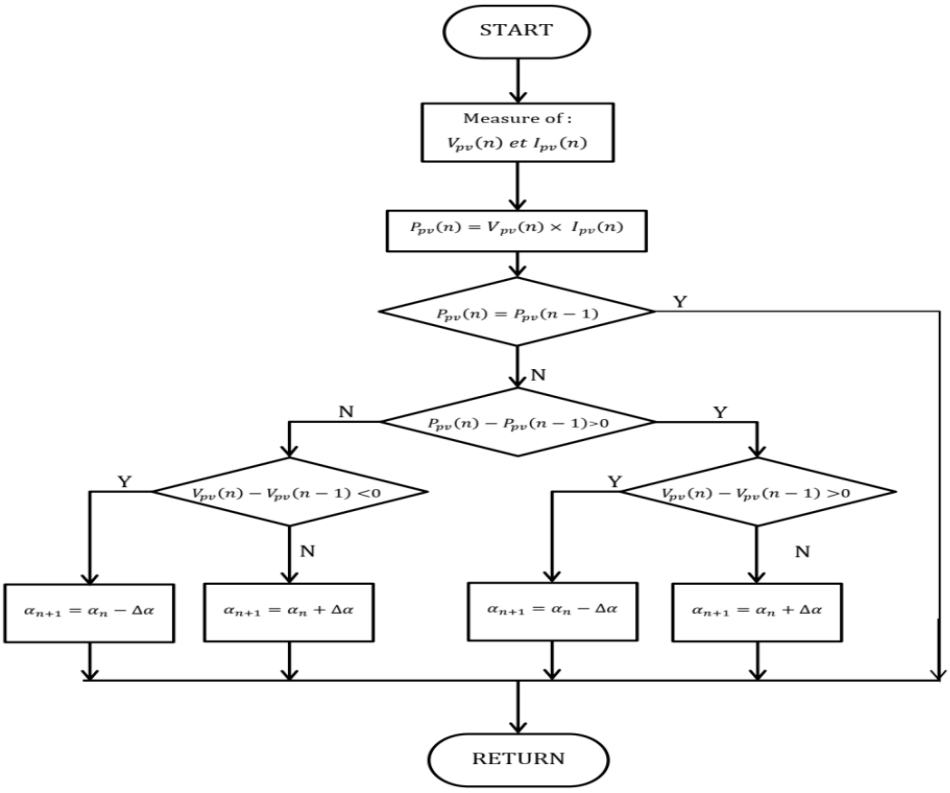

Fig. 4: P&O algorithm [5]

3. Modulations techniques

3.1 PWM technique

Pulse width modulation is one of the oldest techniques and is used in PV systems to convert a DC to DC (in the case of choppers) or a DC to AC (in the case of inverters) [14]. The principle of this control is to synthesize sinusoidal signals from DC signals. This technique is based on the comparison of two signals: one is called the reference signal, and the other is called the reference signal. f_m and the other called a carrier f_p. Two parameters characterize this control strategy: the modulation index $mp$and the modulation rate rp.

3.2 Non Inverting DCM

Duty Cycle Modulation (DCM) is a variable frequency technic. The principle of DCM is that an input signal x is transformed into a periodic switching wave $x_m(t)$ and period $T_m(x)$ and duty cycle $R_m(x)$. The circuit in Fig. 5, illustrates the DCM circuit proposed in [15]. It consists of an operational amplifier (OPA) combined with four passive components (resistors).

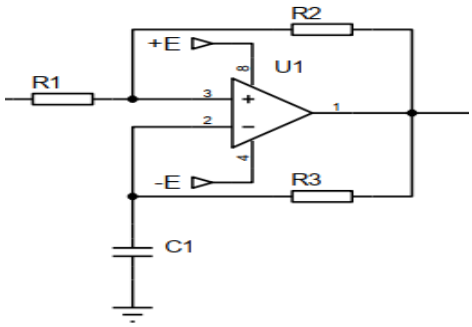

Fig. 5: Non inverting duty cycle modulation [16]

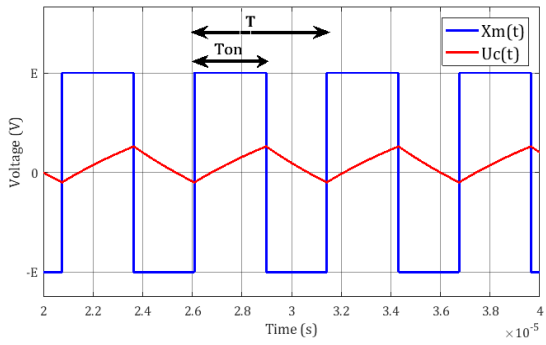

Fig. 6: Steady state of a non-inverting DCM with a constant control

The output signal of non-inverting DCM $x_m(t)$ is a periodic switching wave with period T_m and pulse width T_{on} depend on the control signal x. The signal obtained for a constant control is shown in Fig. 6.

The period T_m and pulse width T_{on} can be computed as follows,

$$T_{on}(x) = \tau \ln\left(\frac{\alpha_2 x - (1-\alpha_1)V_{sat}}{\alpha_2 x + (\alpha_1 - 1)V_{sat}}\right)$$

and

$$T_m(x) = \tau \ln\left(\frac{(\alpha_2 x)^2 - \left((1+\alpha_1)V_{sat}\right)^2}{(\alpha_2 x)^2 - \left((\alpha_1 - 1)V_{sat}\right)^2}\right)$$

where

$$\tau = RC, \alpha_1 = \frac{R_1}{R_1 + R_2} \; and \; \alpha_2 = 1 - \alpha_1$$

Thus, the resulting duty-cycle is given by

$$R_m(x) = \frac{T_{on}(x)}{T_m(x)} = \frac{\ln\left(\frac{\alpha_2 x - (1-\alpha_1)V_{sat}}{\alpha_2 x + (\alpha_1 - 1)V_{sat}}\right)}{\ln\left(\frac{(\alpha_2 x)^2 - \left((1+\alpha_1)V_{sat}\right)^2}{(\alpha_2 x)^2 - \left((\alpha_1 - 1)V_{sat}\right)^2}\right)}$$

The Fig. 7 and Fig. 8 shows the evolution of the Duty Cycle and frequency as a function of the control voltage for different resistance values $R2$.

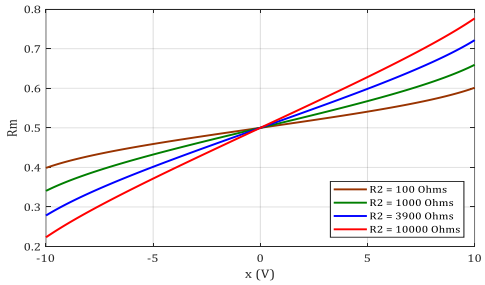

Fig. 7: Duty-cycle of a non inverting DCM

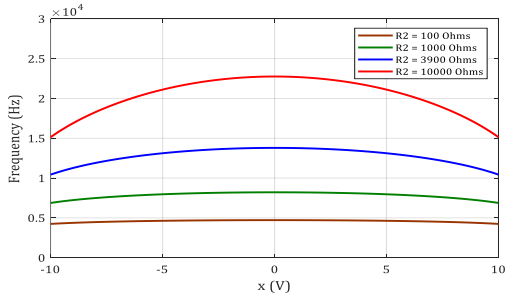

Fig. 8: Frequency of a non-inverting DCM

In addition to its simple and high quality structure, the DCM has a spectral signature that is less rich in harmonics than that of a PWM signal [8-9].

4. Simulation Results

The results of comparison between P&O MPPT algorithm using the PWM technic and the DCM technic for PV system operated under standard environmental conditions ($25°C\ and\ 1000\ W/m^2$) , under variable irradiation and under variable temperatures are presented. In this work, Matlab Simulink tool is used for simulations. The parameters of the boost converter, P&O MPPT algorithm and the Specification of the PV module are listed in [16].

Fig. 9 to Fig. 12 represent I-V and P-V characteristics with different solar radiations ($250\ W/m^2$, $500\ W/m^2$, $750\ W/m^2 and\ 1000\ W/m^2$) and a constant ambient temperature fixed at $25°C$. Fig. 9 & Fig. 10 represent I-V and P-V characteristics with different ambient temperatures ($0°C, 25°C, 50°C and\ 75°C$) and a constant solar radiation fixed at $1000\ W/m^2$. The power output characteristic of PV system is nonlinear and crucially influenced by solar radiation and temperature as it is shown.

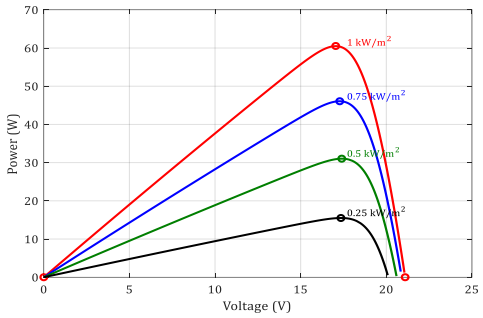

Fig. 9: P-V characteristic at different solar radiations

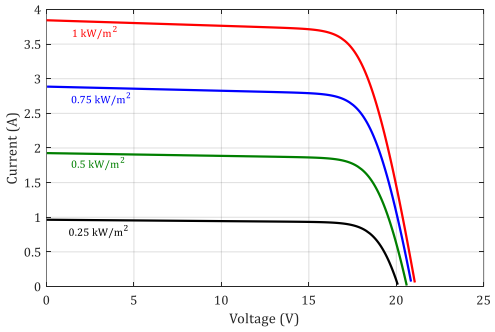

Fig. 10: I-V characteristic at different solar radiations

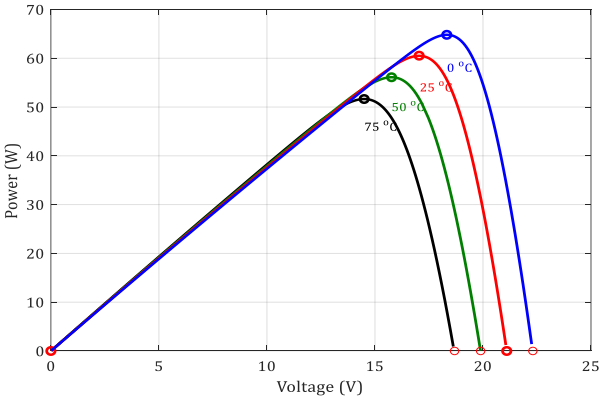

Fig. 11: P-V characteristic at different ambient temperatures

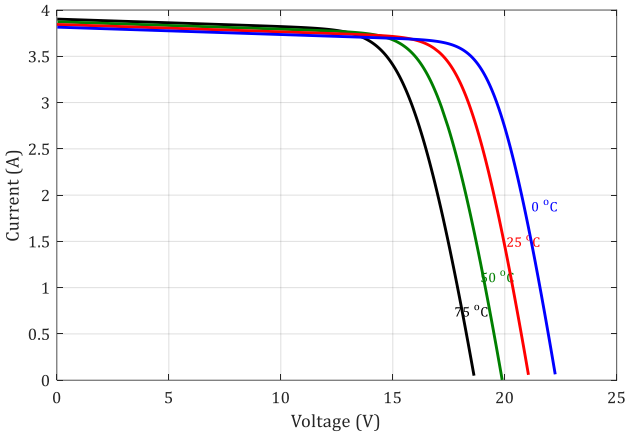

Fig. 12: P-V characteristic at different ambient temperatures

The switching frequency of PWM generator is 10 kHz The Fig. 13 to Fig. 21 shows the power of PV module (Fig. 13, 16 and 19), the output power of boost converter (Fig. 14, 17 and 20) and duty cycle (Fig. 15, 18 and 21) for PWM and DCM.

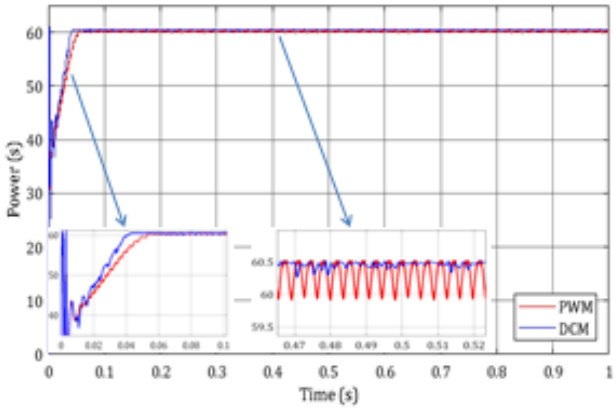

Fig. 13: Power of PV module for standard environmental conditions

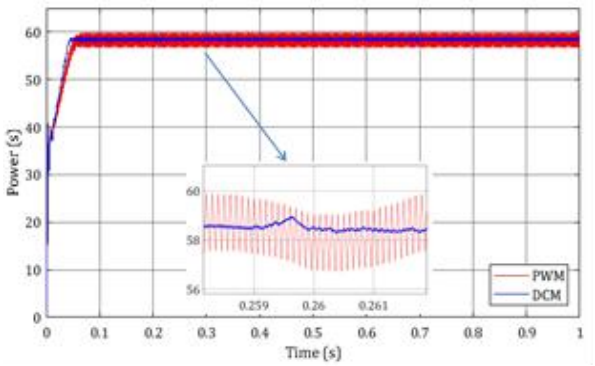

Fig. 14: Output power of Boost converter for standard environmental conditions

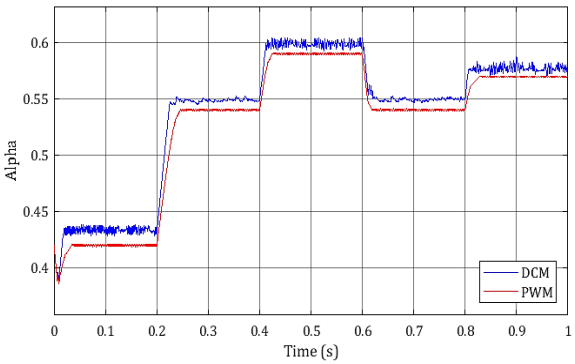

Fig. 18: Duty cycle for constant temperature and varying irradiation

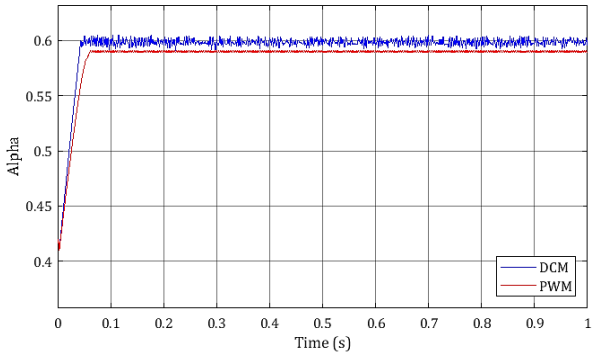

Fig. 15 : Duty cycle for standard environnemental conditions

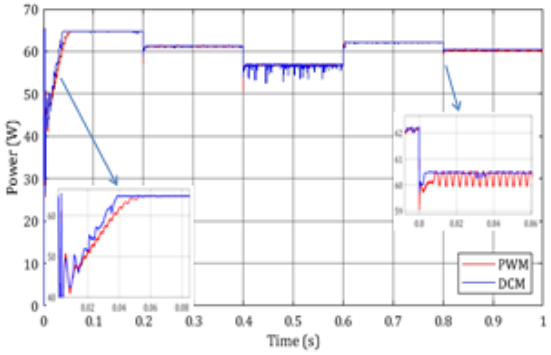

Fig. 19: Power of PV module for constant irradiation and varying temperature

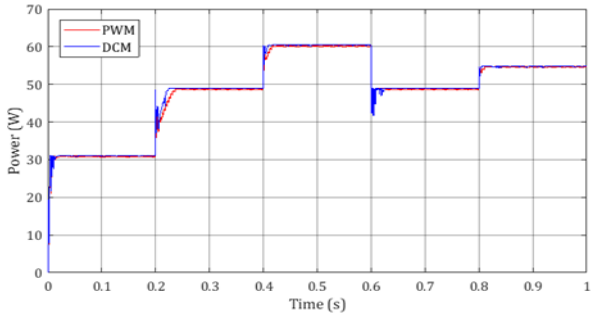

Fig. 16: Power of PV module for constant temperature and varying irradiation

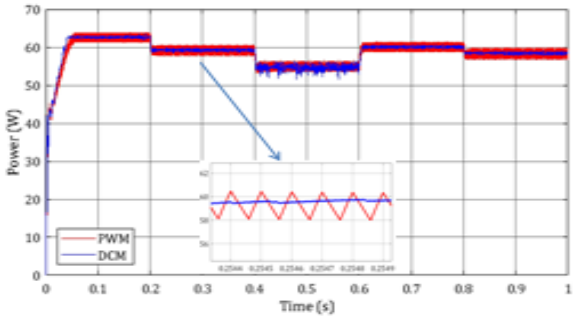

Fig. 20: Output power of Boost converter for constant irradiation

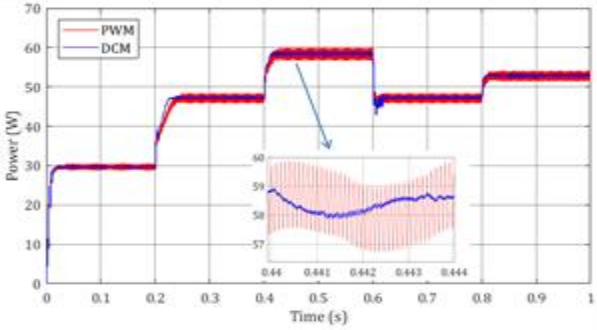

Fig. 17: Output power of Boost converter for constant temperature and varying irradiation

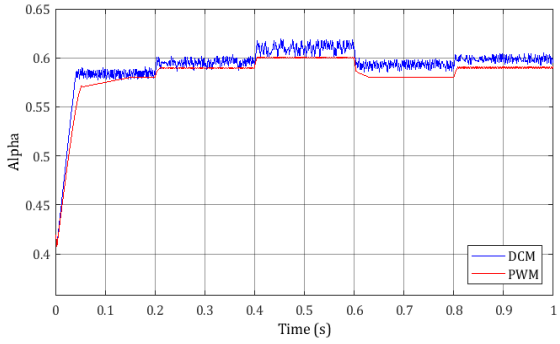

Fig. 21: Duty cycle for constant irradiation and varying temperature

Table 1: Comparison between DCM and PWM

	Modulation techniques	Oscillations	Rise time to reach PPM
Power at the output PV system	DCM	0.2W	0.04s
	PWM	0.6W	0.052s
Power at the output of the Boost chopper	DCM	0.8W	0.04s
	PWM	2.4W	0.052s

The comparison between the P&O algorithm using DCM and the one using PWM to track de MPP is giving in the Table. 1. The results obtained for different climatic variations show that: The power at the output of the PV has an oscillation of 0.2W, at the output of the chopper 0.8W for the DCM. On the other hand, with PWM, the power at the output of the PV at an oscillation of 0.6W at the output of the chopper is evaluated at 2.4W. The MPP is reached from 0.04s for the DCM and 0.052s for the PWM. From these results, we can say that the DCM has less oscillation and reaches the MPP faster than the PWM.

5. Conclusion

Two approaches of P&O MPPT technic are presented in this paper to track MPP of PV system under different temperatures and different irradiations. The first approach uses pulse width modulation while the second approach uses duty-cycle modulation to control the DC-DC converter. Based on the simulation results obtained with Matlab/Simulink, the dynamic and steady state performance of the P&O MPPT algorithm using duty-cycle modulation is better than that using pulse width modulation.

Conflict of Interest

Authors declared "No conflict of interest".

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