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A Modified Incremental Conductance Technique for Maximum Power Point Tracking of a Grid-Connected Photovoltaic System

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***Abstract*—Maximum power point tracking (MPPT) algorithm of a photovoltaic system (PV) connected to the utility grid has been studied in this work. A modified incremental conductance (INC) technique is proposed to achieve MPPT under varying conditions of solar radiation and temperature through the use of a boost converter. The technique aims to improve energy capture while minimizing steady-state oscillations. A digital simulation utilizing the Matlab/Simulink package is conducted to evaluate the performance of the proposed technique. A comparative analysis is performed between the modified and conventional incremental conductance techniques under different operating conditions to highlight the advantages of the proposed method. The results indicate that the modified algorithm is capable of accurately tracking the maximum power point (MPP), even amid fluctuations in weather conditions, in contrast to the conventional INC algorithm.**

Keywords— PV System; MPPT; Modified INC; Boost Converter.

I. INTRODUCTION

Due to the decrease of conventional sources of energy and the increasing problematic of environmental pollution, the research and utilization about the renewable energy sources, such as solar energy, wind energy as so on, have been in favor of more and more attention [1, 2]. The Photovoltaic (PV) systems have some advantages such as environment friendly "pollution free" and low maintenance cost. The main disadvantages of PV systems are they require a high installation cost and they have a low efficiency as their efficiency are not more than 20% [3, 4].

PV grid-integrated systems are the most commonly and extensively used nowadays. They do not need batteries and they use common inverters necessary for connecting to the utility grid. All the generated energy produced from PV system is exported to the electricity grid and we frequently get paid credit for the energy exported by this system. The PV on-grid systems are shut down during power failures for safety motives [5].

The generated power and efficiency of PV array depends on several factors such as solar irradiation, temperature, dirt, shadow and spectral characteristics of sunbeams. A lot of research has been prepared to improve the efficiency of the PV modules. A number of techniques to track the maximum power point (MPP) of a PV modules have been proposed in order to improve the efficiency [6, 7].

Maximum power point tracking (MPPT) is used for achieving maximum power from PV module by accurately adjusting the duty cycle of the DC-DC converter. Several MPPT methods have been employed by the researchers in numerous papers. The most common MPPT algorithms are the perturb and observe (P&O) technique and the incremental conductance (INC) technique [8, 9].P&O can be used for the system which is required simplicity of

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system and for highly complicated system INC can be used [10].

The conventional INC method has two main shortcomings; the first one is the oscillating of the operating point around the MPP in steady state operation, the second is that the technique can lose the tracking of the MPP easily if the solar radiation varies rapidly [11].The fixed step size is considered a problem between faster response and steady-state oscillations. Hence a variable step-size can be used to improve the performance of MPPT technique [12, 13].

This paper presents modeling and control of PV grid connected system based on a modified INC algorithm for achieving MPPT. The performance of PV systems connected to grid for the both conventional and modified algorithm is compared using Matlab/Simulink. The obtained results show that MPPT can be achieved precisely with the modified technique with less oscillation as compared to the conventional one.

II. DESCRIPTION OF SYSTEM UNDER STUDY

Figure 1 shows atypical PV array via DC-DC boost converter connected to grid through three-phase voltage source inverter (VSI) and passive filter. The system contains the following components:

1. PV array to deliver a maximum of 100 kW at different irradiance and temperature levels

2. DC-DC boost converter to increase the voltage output of PV from 273.5 V DC to 500 V DC.

3. Three-level three-phase VSI to convert the DC voltage delivered by the array of (500 V) to an AC voltage of 220 V and also to keep a unity power factor.

4. Passive filter.

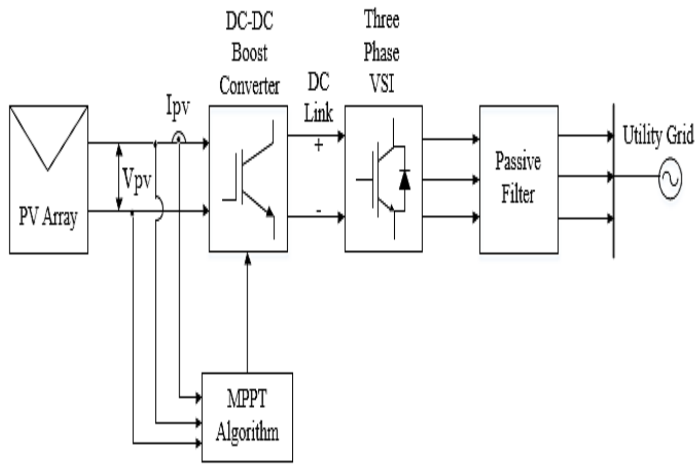

Fig.1 PV array grid-connected system

2.1. PV MODEL

The simplified PV model can be represented as single diode model as shown in Fig.2.

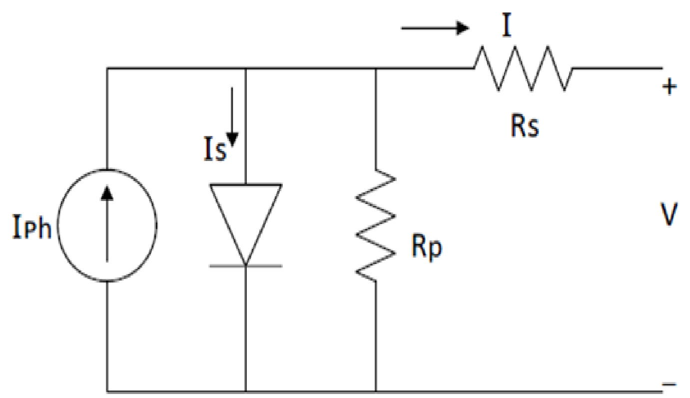

Fig.2 Single diode model

The basic equation that describes the I-V characteristics of the PV model is given by the following one:

$$I = I_{ph} - I_S\left[e^{\frac{q(V+IRs)}{KT}} - 1\right] - \frac{V + IR_S}{R_P} \quad (1)$$

The light generated current, I_{ph} is a function of temperature and solar irradiation is set as follows:

$$I_{ph} = \left(\frac{G}{G_{STC}}\right)\left[I_{ph\ at\ STC} + K_i\,(T - T_{STC})\right] \quad (2)$$

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The single diode saturation current which is a function of working PV temperature is given by the following equation [14]:

$$I_S = I_{S\,at\,STC}\left(\frac{T}{T_{STC}}\right)^3 \exp\left[\left(\frac{q.E_g}{a.k}\right)\left(\frac{1}{T_{STC}}-\frac{1}{T}\right)\right] \quad (3)$$

The most commonly used PV technologies [15] are the mono-crystalline (M-Si),polycrystalline (P-Si) and amorphous silicon (A-Si) ones. The efficiency of the most commonly used M-Si and P-Si modules is normally between 10-18% in the EU. The A-Si PV technology is a kind of thin film PV technology, which currently has an efficiency not exceed than 10.5%. PV cells can be connected in series and parallel to form PV module. The PV modules are connected in series and parallel to form PV system or array. The PV system represented in this paper consists of photovoltaic array. The 100-kW PV array consists of 66 modules connected in series and 5 modules connected in parallel (66x5x305.2 W= 100.7 kW). Manufacturer specifications for the module «SunPower SPR-305 » are listed in table 1.The characteristics I-V and P-V array is shown in Fig.3.

Table1 Specifications of PV module

PV model	**SunPower SPR-305-WHT**
No.of cells	96 in series
Maximum power	305 W / One Module
Short circuit current(I_{sc})	5.96 A
Open circuit voltage(V_{oc})	64.2 V
Max.power current(I_{mp})	5.58 A
Max.power voltage(V_{mp})	54.7 V

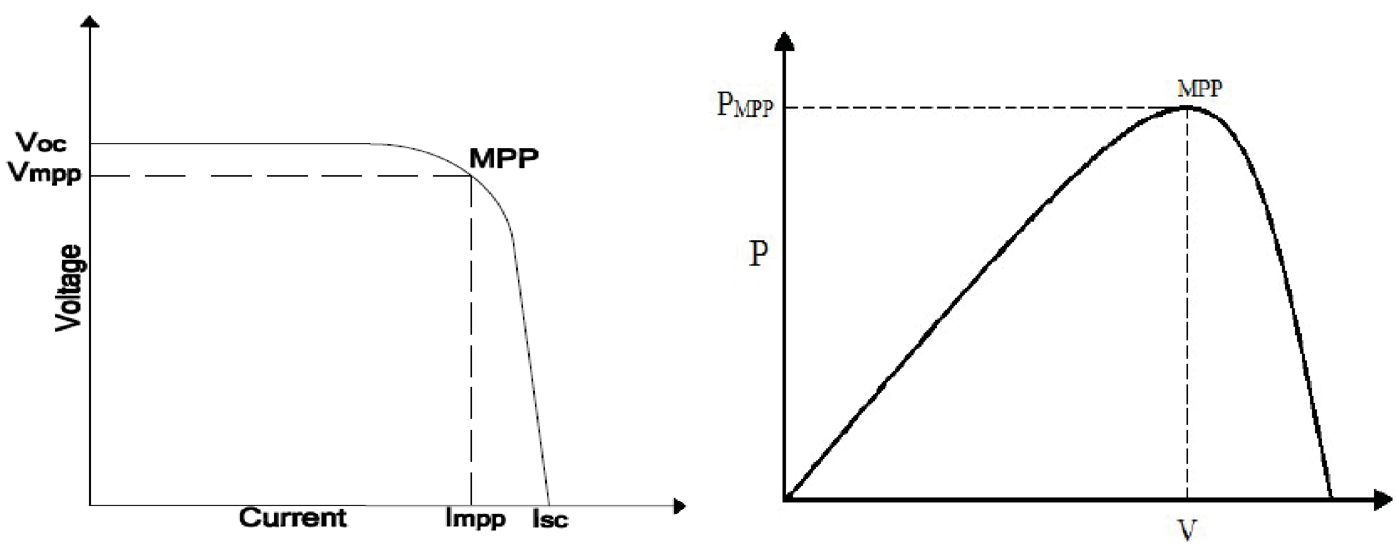

Fig.3 The characteristics I-V and P-V of PV array [16]

2.2. BOOST CONVERTER MODEL

DC-DC converter is used to obtain regulated DC output voltage at a specified voltage level. In the proposed system boost converter topology is used in order to increase the PV array voltage to a level that confirms correct operation of the inverter. The circuit diagram for the boost converter is shown in Fig.4. When the switch "S" is closed, the inductor is charged up across the input source while the diode is reverse biased to make isolation between the input and the output of the converter. When the switch "S" is

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opened, the energy stored in the inductor and the power supply is transferred into the load.

The modeling equations obtained by the Kirchhoff's laws, are given as the following ones [17, 18]:

$$\frac{dI_L}{dt} = \frac{1}{L}[V_{in} - (1-d)V_{out}]$$

$$\frac{dV_{out}}{dt} = \frac{1}{C_{DC}}[(1-d)I_L - I_{inv}] \qquad (4)$$

The relationship between the input and output voltages is given as:

$$V_{in}T_{on} + (V_{in} - V_{out})T_{off} = 0$$

$$\frac{V_{out}}{V_{in}} = \frac{T_{on} + T_{off}}{T_{off}} = \frac{1}{1-D} \qquad (5)$$

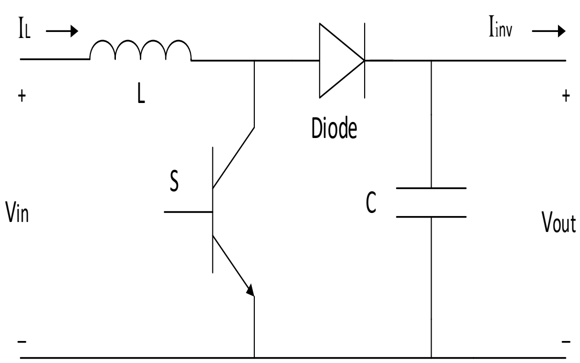

Fig. 4 Schematic diagram of a DC-DC boost converter

III. A MODIFIED INC TECHNIQUE

The conventional INC method can create oscillations around the MPP in the output power of PV system. The oscillations in steady-state are proportional to the step-size which determines the duty cycle necessary for switching the DC-DC converter. If the step-size is high, the oscillations are high. Else, the oscillations would be low; however the variation of the duty cycle would be very low; this may slow down the tracking process. Consequently, by using fixed step-size a problem exists between faster response and steady-state oscillations. Therefore a variable step-size is used to improve the dynamic performance of MPPT and reduce the steady state oscillation [11, 13, 19].

The modified INC method is based on the fact that the slope of the PV output power curve vs. voltage at the MPP is zero, it is positive (+ve) on the left of it and negative (-ve) on the right. It is similar to the conventional method except for using the variable step-size instead of the fixed one. The PV output voltage (V_{PV}) and current (I_{PV}) are sensed in order to obtain the output power generated from PV system (P_{PV}) as follows:

$$P_{PV} = V_{PV} \text{ x } I_{PV} \qquad (6)$$

Differentiating P_{PV} with respect to V_{PV} and equating to zero gives

$$\frac{dP_{PV}}{dV_{PV}} = I_{PV} + V_{PV}\left(\frac{dI_{PV}}{dV_{PV}}\right) = 0 \qquad (7)$$

The equation (7) can be written as:

$$\frac{dI_{PV}}{dV_{PV}} = -\frac{I_{PV}}{V_{PV}} \qquad (8)$$

This method tracks the MPP by comparing the summation of incremental conductance $\left(\frac{dI_{PV}}{dV_{PV}}\right)$ plus instantaneous conductance $\left(\frac{I_{PV}}{V_{PV}}\right)$ of a PV panel with zero as shown in equations (8) and (9).The modified INC method can be explained based on the conventional one represents by P-V curve as shown in Fig.5. The basic principle of INC method is drawn from P-V curve and tabulated in table 2 [20].

It is impossible to achieve accurate MPP ($\frac{dP_{PV}}{dV_{PV}} = 0$). For that reason, more investigating arrangement is: ($\frac{dP_{PV}}{dV_{PV}} < \varepsilon$) which a small error is allowable. The size of this permissible error (ε) is used to determine the sensitivity of the system [21].

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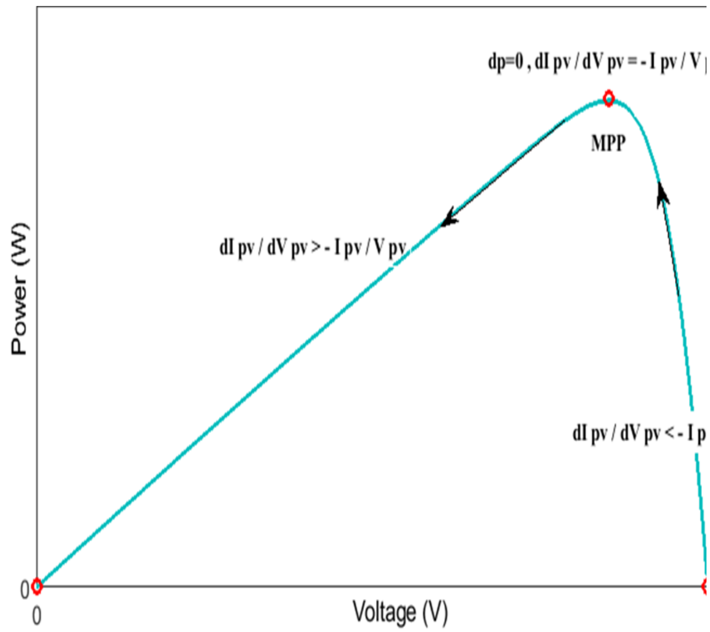

Fig.5 PV curve showing the modified INC MPPT

Table 2 A modified INC method states

S.No.	dP_{PV}/dV_{PV}	dI_{PV}/dV_{PV}	PV curve
1	0	$= -I_{PV}/V_{PV}$	MPP
2	-ve	$< -I_{PV}/V_{PV}$	Right of MPP
3	+ve	$> -I_{PV}/V_{PV}$	Left of MPP

A variable step-size was used to improve the performance of PV system as stated by equations (10 and 11), where SF is the scaling factor for adjusting step size and adopting the performance of MPPT. The variable step-size is a function of the power to voltage derivative of PV system. It is given by the following equation:

$$VSS = \left|\frac{dP_{PV}}{dV_{PV}}\right| x\ SF \qquad (9)$$

The duty cycle of the converter at instant k, D(k)is given by the following equation:

$$D(k) = D(k-1) \pm VSS \qquad (10)$$

The equation (10) can be written as:

$$D(k) = D(k-1) \pm \left|\frac{dP_{PV}}{dV_{PV}}\right| x\ SF \qquad (11)\ [22]$$

However, the use of PV power to voltage derivative $(\frac{dP_{PV}}{dV_{PV}})$ in equation (11) would have several problems which can be mentioned below as follows:

1- If the PV voltage change (dV_{PV}) is low, the derivative $(\frac{dP_{PV}}{dV_{PV}})$ will be large. As a result the power oscillations are increased.

2- If the PV voltage change (dV_{PV}) is large, the derivative $(\frac{dP_{PV}}{dV_{PV}})$ will be low. As a result the power oscillations are decreased but the time response of the tracking process would take more time to reach MPP.

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Therefore, the proposed MPPT technique can overcome these problems. In this method a variable step-size (VSS) is used which depends only on the

PV power change (dP_{PV})instead of the derivative ($\frac{dP_{PV}}{dV_{PV}}$) .In this case the VSS can be calculated as:

$$VSS = |dP_{PV}| x\,SF \quad (12)$$

The duty cycle of the converter at instant k, $D(k)$ is obtained by the following equation:

$$D(k) = D(k-1) \pm |dP_{PV}| x\,SF \quad (13)$$

The procedures of the modified INC technique to evaluate the duty cycle for switching the converter is described by the flowchart given in Fig .7.In this method, The PV output voltage and current are measured at instant k and compared to the previous values at instant k-1 to calculate dV_{PV} , dV_{PV} and $\frac{dP_{PV}}{dV_{PV}}$. The essential steps to estimate the duty cycle of the converter can be explained by the block diagram shown in Fig .6.

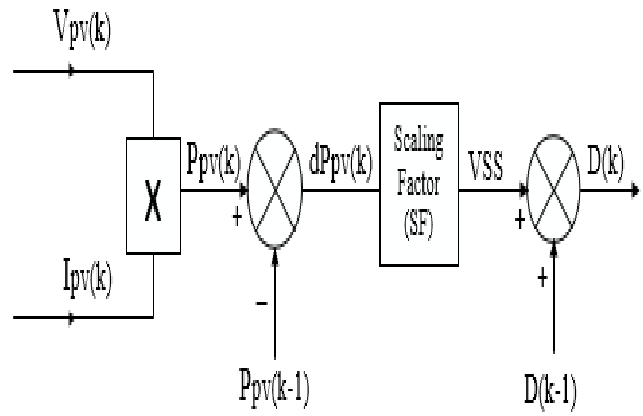

Fig.6 Block diagram of the modified INC algorithm

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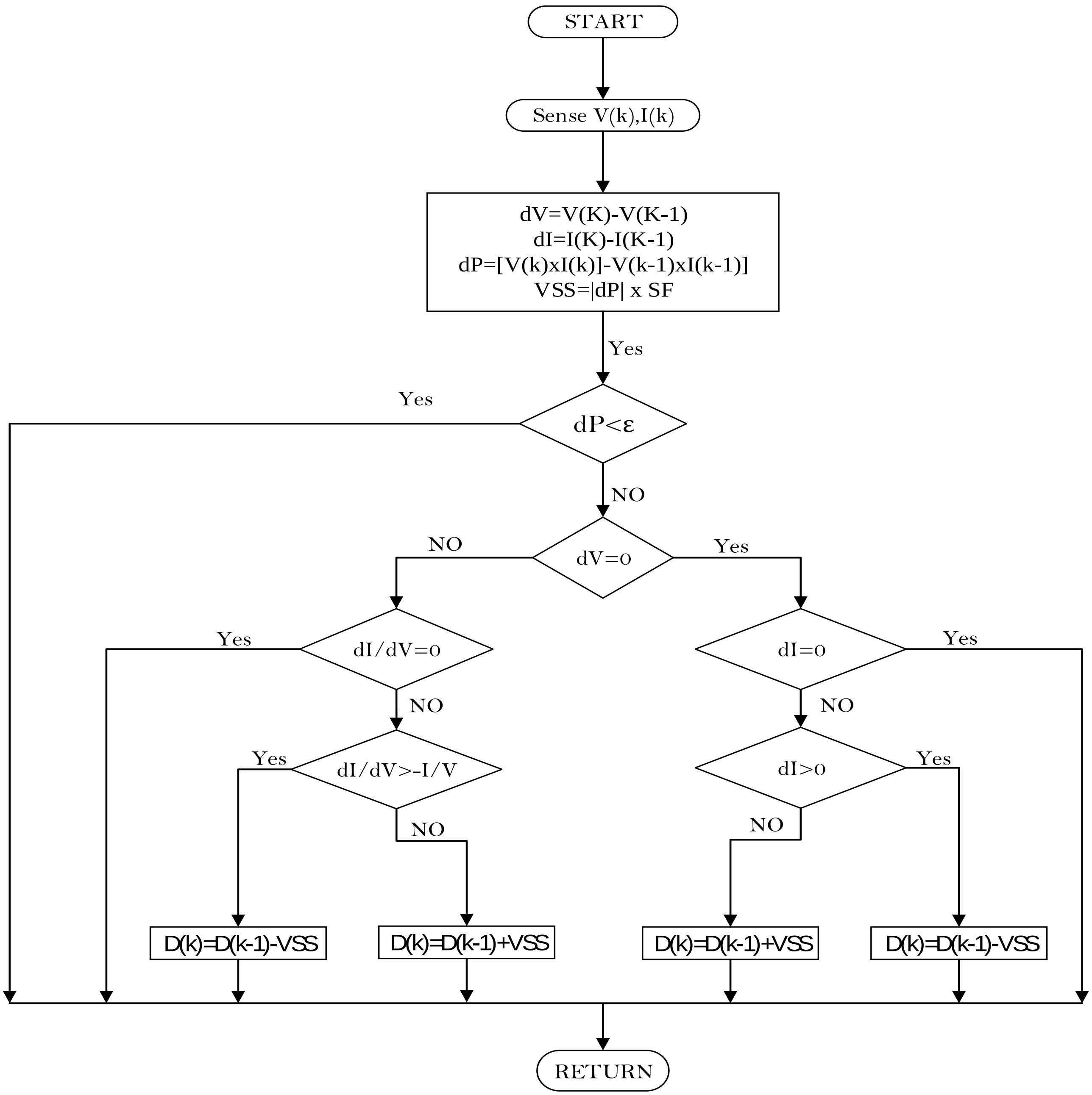

Fig. 7 Flowchart of the modified INC technique

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IV. Simulation Results and Discussion

Digital simulation is carried out based on the proposed system shown in Fig.8 using Matlab/Simulink software package. In the present study, the system is started with standard test condition "STC" (25℃ and 1000 W/m²) and during time period the irradiance (G) and the temperature (T) are changed as shown in Fig .9in order to explain the effect of climate condition change on the performance of PV system.

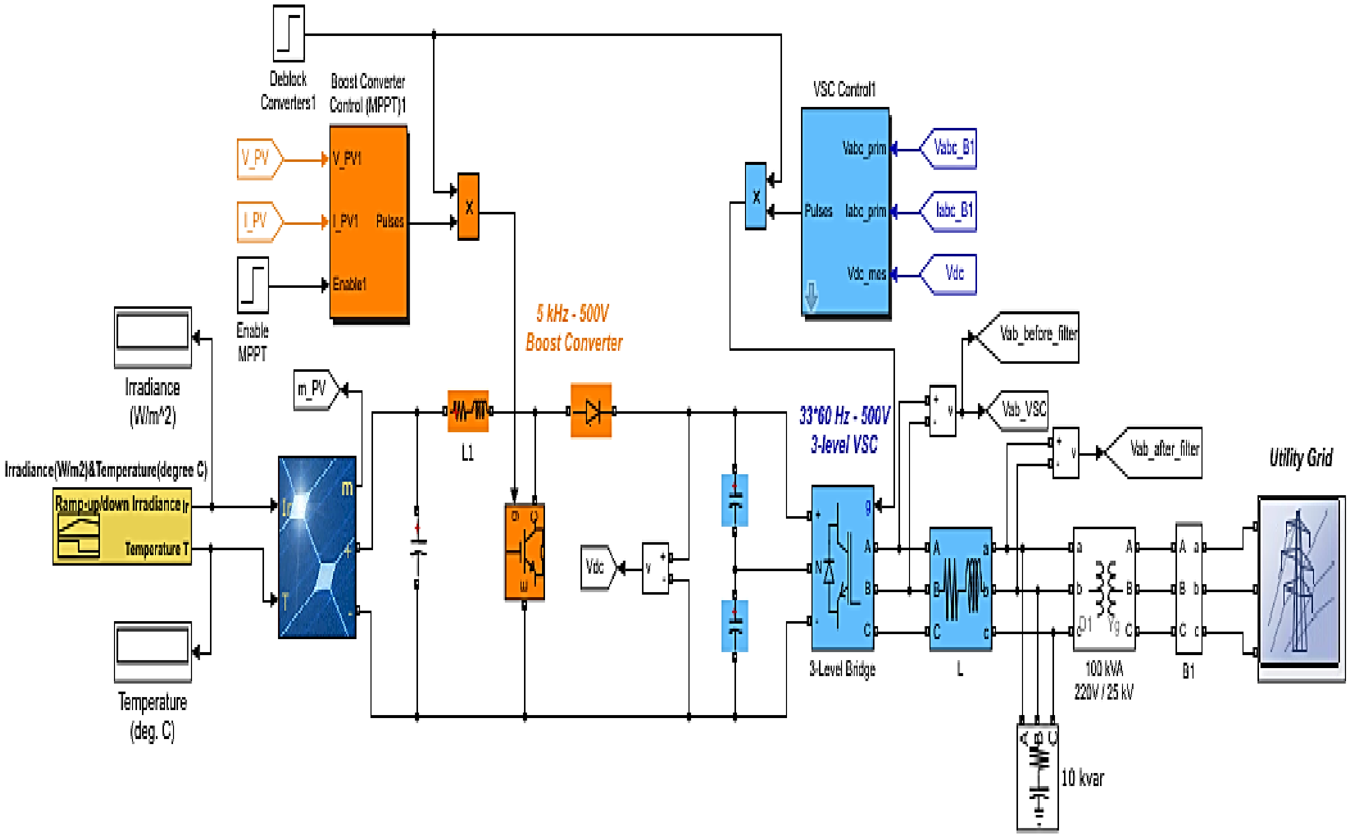
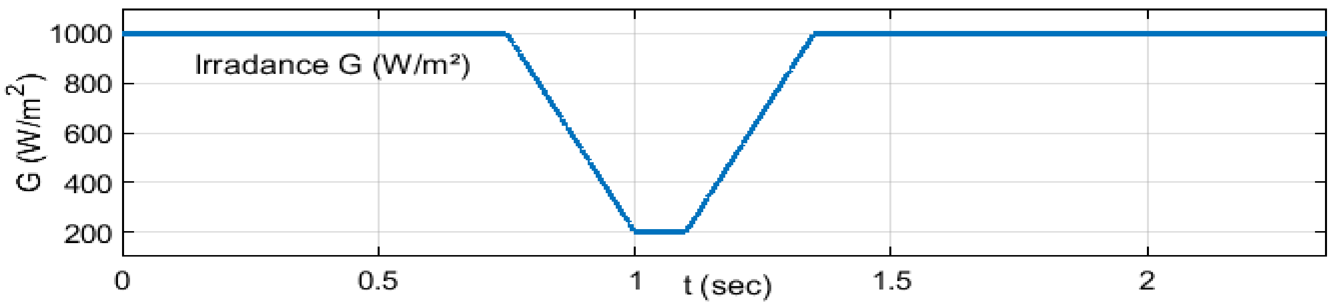
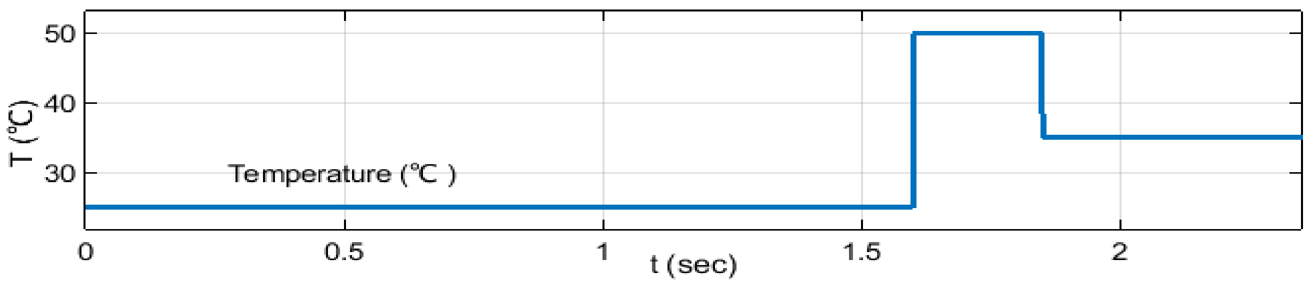


Fig.8 Whole PV grid-connected system in Matlab/Simulink



(a)



(b)

Fig. 9 Climate condition change

(a): Irradiance(G) change, (b) :Temperature(T) change

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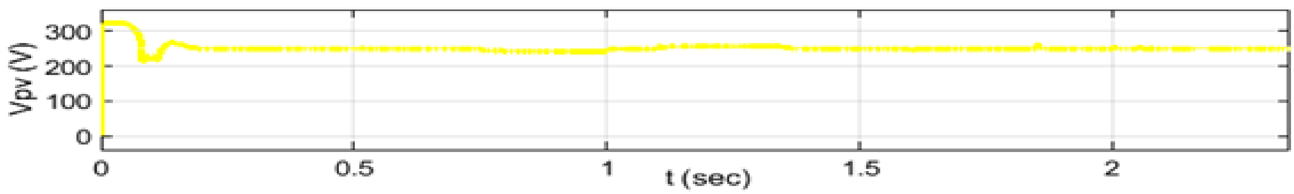
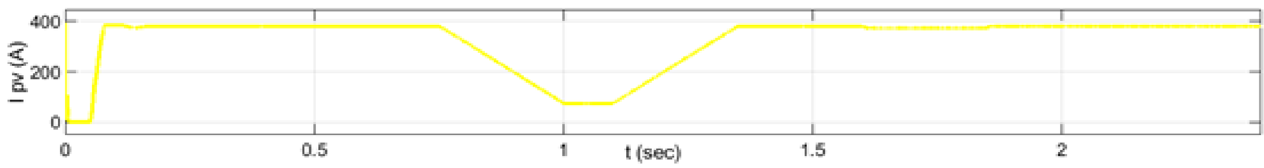
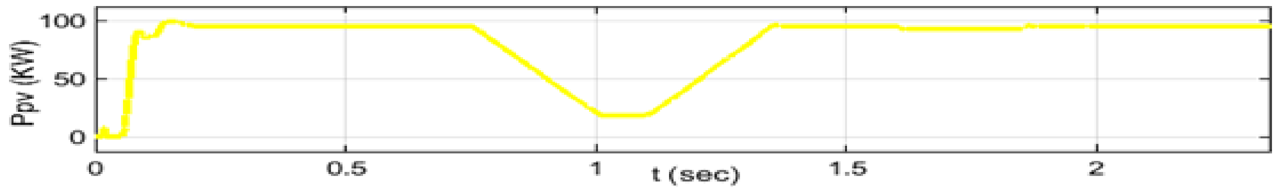
Figure 10 shows the performance of PV array connected to grid during variation of irradiance (G) and temperature (T) without MPPT. The output voltage of PV (V_{PV}) is slightly decreased and increased according to the variation of G in the period (t=0.75 sec to t=1.35 sec), while, this output voltage is reduced slightly according to the variation of T in the period (t=1.6 sec to t=1.85sec) as shown in Fig.10 (a). Figure 10(b) shows the time response of the output current of PV (I_{PV}) during variation of irradiance (G) and temperature (T). From this figure, the output current is decreased and increased according to the variation of irradiance in linear fashion the period (t=0.75 sec to t=1.35 sec). On the other hand, this output current is decreased slightly due to the temperature variation in the period (t=1.6 sec to t=1.85sec). Also, the time response of output power of PV array (P_{PV})is shown in Fig. 10(c). This figure indicates that the variation of $P_{PV}$is depended on the variation of V_{PV} and I_{PV}. The value of the output power generated from the PV array is approximately equal to 94.3 % from its maximum value (95.37 KW).The duty cycle of DC-DC boost converter is almost constant as shown in Fig.10 (d) because the PV system does not operate at MPPT.



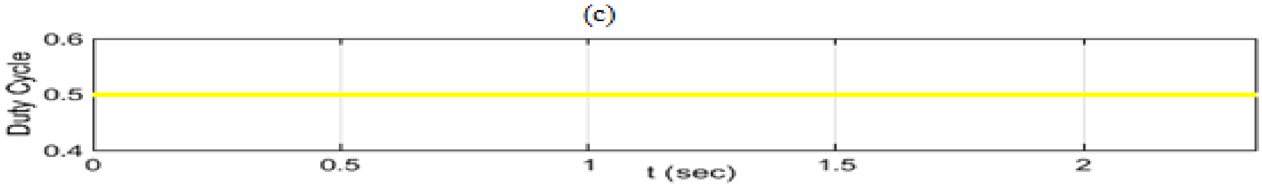
(a)



(b)



(c)



(d)

Fig.10 The performance of PV array during variation of irradiance (G) and temperature (T) without MPPT (a): The PV array output voltage (V_{PV}), (b): The PV array output current (I_{PV})

(c): The PV array output power (P_{PV}), (d): The duty cycle of the converter

Figure 11 shows the performance of PV array connected to grid during variation of irradiance (G) and temperature (T) with the conventional INC algorithm. The output voltage of PV (V_{PV}) is slightly decreased and increased according to the variation of G in the period (t=0.75 sec to t=1.35 sec), while, this output voltage is reduced according to the variation of T in the period (t=1.6 sec to t=1.85sec) as shown in Fig.11 (a).Figure 11(b) shows the time response of the output current of PV (I_{PV}) during variation of irradiance (G) and temperature (T). From this figure, the output current is decreased and increased according to the variation of irradiance in linear fashion the period (t=0.75 sec to t=1.35 sec). On the other hand, this output current is decreased slightly due to the temperature variation in the period (t=1.6 sec to t=1.85sec). Also, the time response of output

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power of PV array (P_{PV})is shown in Fig.11(c). This figure illustrates that the variation of P_{PV} is depended on the variation of V_{PV} and I_{PV}. The value of the output power generated from the PV array is approximately equal to 99.64 % from its maximum value (100.37 KW).The duty cycle of DC-DC boost converter is adjusted to improve the power generated from the PV array as shown in Fig.11 (d). The output power of PV array is improved with using the conventional MPPT. However, the output power response suffers from some oscillations.

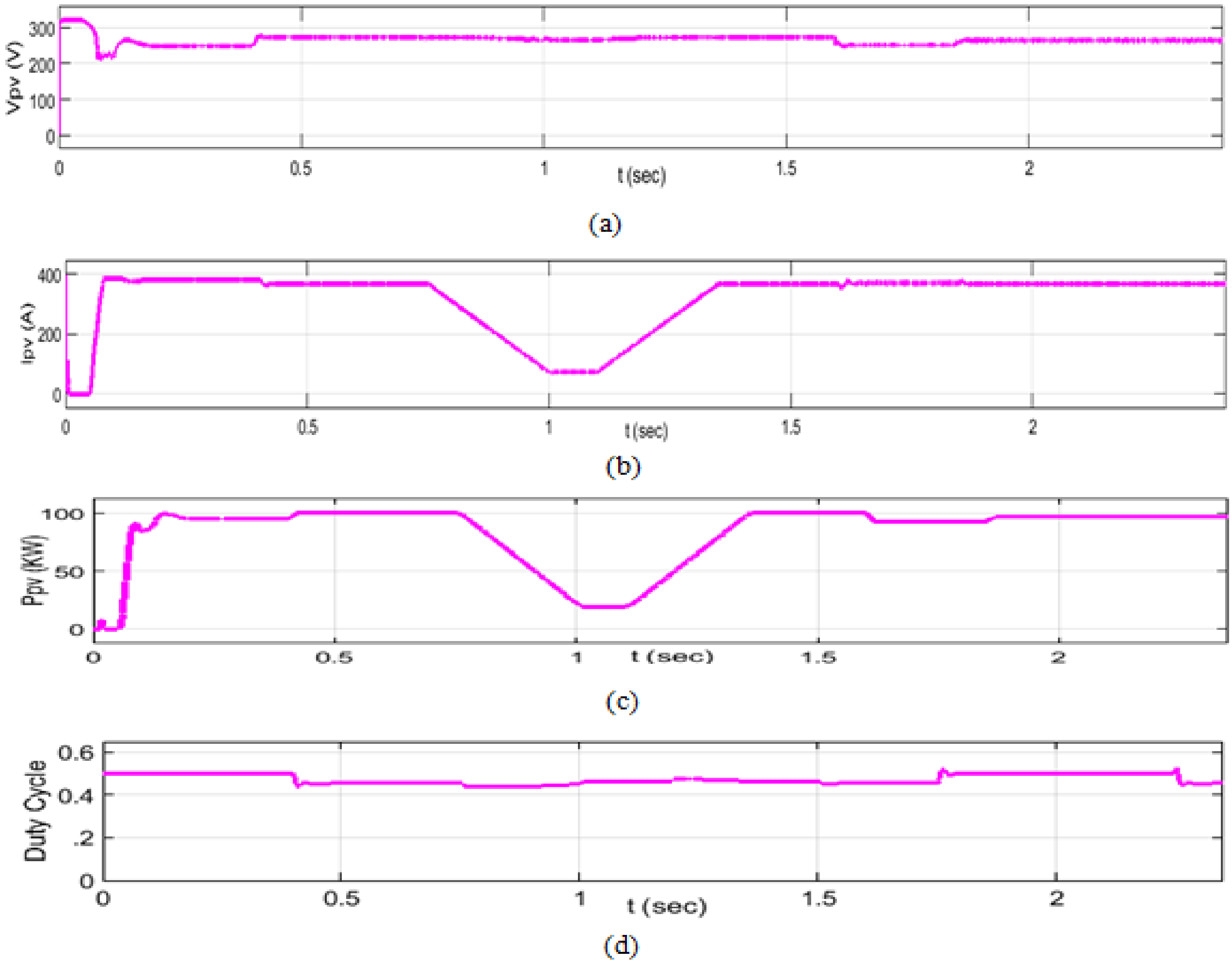

Fig.11 The performance of PV array during variation of irradiance (G) and temperature (T) with the conventional INC algorithm

(a): The PV array output voltage (V_{PV}), (b): The PV array output current (I_{PV})

(c): The PV array output power (P_{PV}), (d): The duty cycle of the converter

Figure 12 shows the performance of PV array connected to grid during variation of irradiance (G) and temperature (T) with the modified INC algorithm. The output voltage of PV (V_{PV}) is slightly decreased and increased according to the variation of G in the period (t=0.75 sec to t=1.35 sec), while, this output voltage is reduced according to the variation of T in the period (t=1.6 sec to t=1.85sec) as shown in Fig.12 (a). Figure 12(b) shows the time response of the output current of PV (I_{PV}) during variation of irradiance (G) and temperature (T). From this figure, the output current is decreased and increased according to the variation of irradiance in linear fashion the period (t=0.75 sec to t=1.35 sec). On the other hand, this output current is changed slightly due to the temperature variation in the period (t=1.6 sec to t=1.85sec). Also, the time response of output power of PV array (P_{PV}) is shown in Fig.12(c). This figure illustrates that the variation of $P_{PV}$is depended on the variation of V_{PV} and I_{PV}. The value of the output power generated from the PV array is approximately equal to 99.63 % from its maximum value (100.36 KW). The duty cycle of DC-DC boost converter is adjusted using variable step-size as

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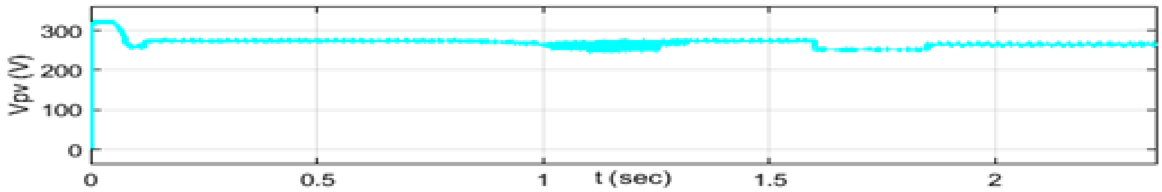
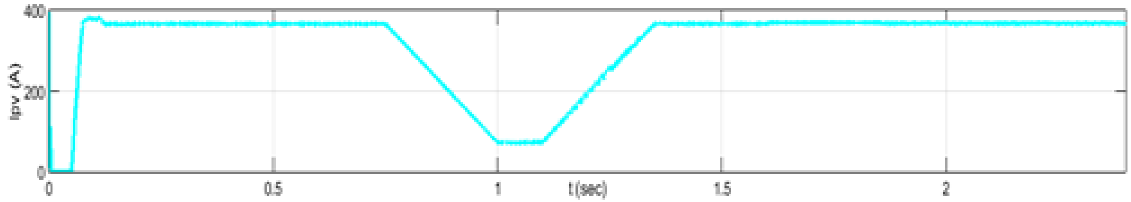
shown in Fig.12 (d) in order to extract MPP from the PV array and reduce oscillations in the output power. The output power of PV array is improved with using the modified algorithm and has less oscillation as compared to the conventional one.



(a)



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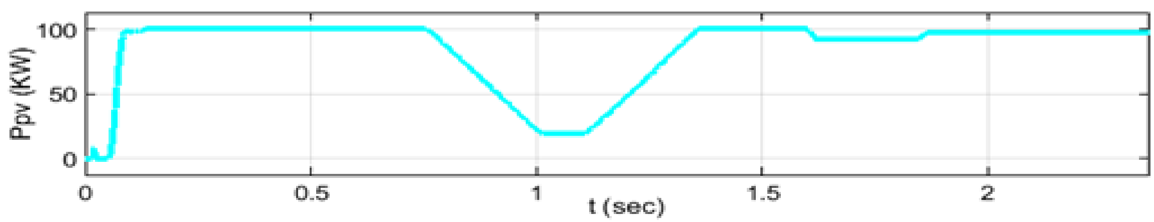

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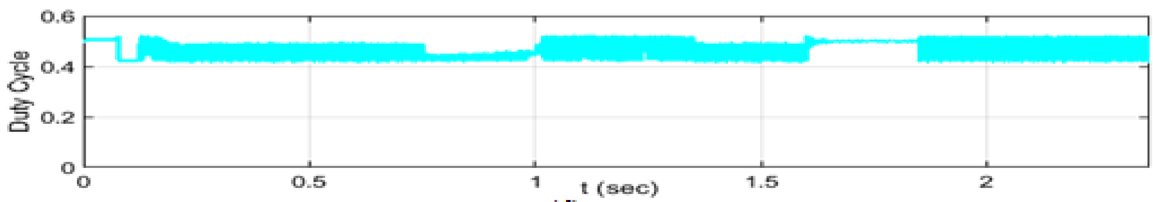

(d)

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Fig.12 The performance of PV array during variation of irradiance (G) and temperature (T) with the modified INC algorithm

(a): The PV array output voltage (V_{PV}), (b): The PV array output current (I_{PV})

(c): The PV array output power (P_{PV}), (d): The duty cycle of the converter

Figure 13 shows the comparison between the output power of PV array without MPPT, with the conventional INC and with the proposed INC algorithm during the variation of irradiance and temperature. The waveforms of the output power display that the modified INC technique can achieve MPPT accurately under varying irradiance and temperature levels with less oscillation as compared to the conventional one.

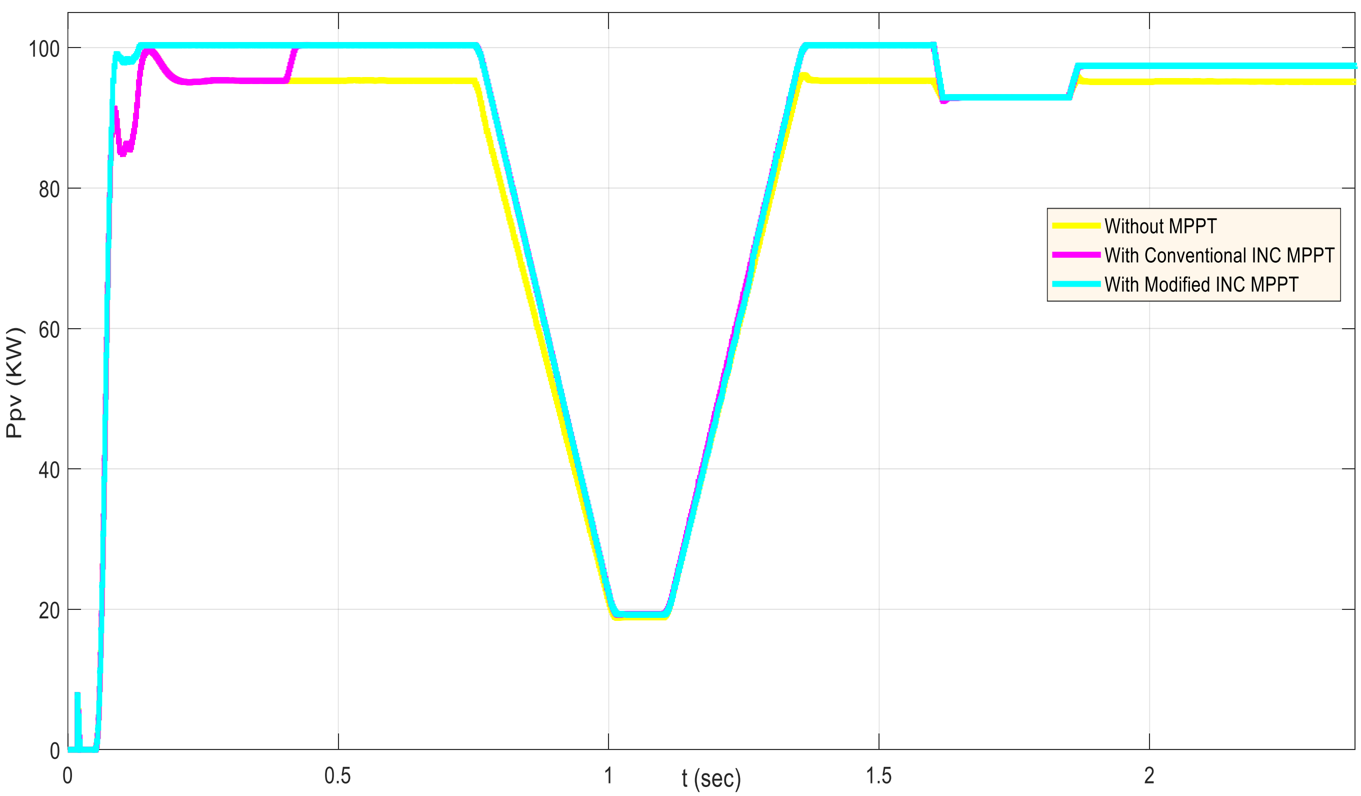

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Fig.13 Comparison between power generted by PV without MPPT, with the conventional INC and with the modified INCalgoirthm

Table 3 demonstrates the different cases of system under study at different weather conditions. The comparison between the PV array outputs for the different cases are presented and tabulated in table 4.

Table 3. The different cases of system under study at different weather conditions

Case. No	G (W/m²)	T (°C)
1	1000	25
2	900	25
3	600	25
4	500	25
5	350	25
6	200	25
7	1000	50
8	1000	35

Table 4. Comparison between PV system without and with MPPT at different weather conditions

Case. No	PV array output without using MPPT			Conventional INC algorithm			Modified INC algorithm		
	Voltage (Volts)	Current (Amps)	Power (kW)	Voltage (Volts)	Current (Amps)	Power (kW)	Voltage (Volts)	Current (Amps)	Power (kW)
1	249.6	381.77	95.37	274.68	365.37	100.37	273.60	367.65	100.36
2	242.33	346.35	86.51	273.55	330.38	93.41	274.12	329.65	93.42
3	241.58	229.95	58.40	272.46	219.74	62.94	272.82	219.41	62.94

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4	241.39	191.92	48.86	271.60	183.29	52.53	271.36	183.47	53.58
5	241.24	135.44	35.18	269.01	128.31	37.58	268.60	128.51	37.58
6	248.06	76.00	18.83	267.74	71.99	19.22	266.85	72.34	21.45
7	249.63	372.2	92.89	253.02	366.84	92.86	251.53	369.36	92.90
8	249.62	381.13	95.14	265.38	367.07	97.42	263.66	369.51	97.40

V. CONCLUSION

Simulation results of PV system connected to the grid with the modified incremental conductance (INC) technique are carried out for achieving MPPT using Matlab/Simulink software package. The modified perturb and observe technique based on variable step-size is proposed in this paper to achieve MPPT and improve the system performance. The performance of PV array connected to grid is obtained at different weather conditions. Also, the performance of PV system is obtained using conventional and modified incremental conductance methods at different weather conditions to achieve MPPT for comprising purposes. From the present analysis, One can draw the following conclusion:-

1- The response of the generated output voltage of PV array is greatly reduced due to the variation of temperature and slightly changed with irradiance variation.

2- The response of the generated output current of PV array is linearly decreased and increased due to the variation of irradiance and slightly changed with temperature variation.

3- The response of the generated output power of PV array is changed depending on the variation of the PV output voltage and current.

4- The value of the generated output power from PV system using MPPT algorithms is a good tracking with its maximum value of PV system and its time response is improved using the proposed algorithm as compared to the conventional one.

5- Better performance of PV system has been achieved with minimum oscillation with using the modified incremental conductance algorithm as compared to the conventional one.

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