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An Advanced MPPT Technique for Photovoltaic Systems

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Abstract— Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. Under fast varying solar irradiation and load resistance, a maximum power point tracking (MPPT) technique is required to ensure the fast response of the PV system with minimum power loss.Our paper introduces a fast MPPT technique whose response is faster than conventional MPPT algorithms. The proposed algorithm is a modified version of conventional incremental conductance and is four times faster than the existing algorithm. Incremental conductance is one of the important techniques in this system and because of its higher steady-state accuracy and environmental adaptability it is widely implemented tracked control strategy. Consequently, the proposed algorithm has higher efficiency.

Index Terms—Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Incremental Conductance, PIC microcontroller, solar irradiation,Algorithm, Solar Energy, Duty cycle

1 INTRODUCTION

Solar energy is one of the most important renewable energy sources. As opposed to conventional unrenewable resources such as gasoline, coal, etc..., solar energy is clean, inexhaustible and free. t is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solardepending on the way they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air. The large magnitude of solar energy available makes it a highly appealing source of electricity. There are many advantages that solar energy has to offer over traditional sources of energy like coal and oil. Not only it is completely renewable but is also protects the environment. Here are some of the advantages of solar energy include long lasting solar cells, eco-friendly, can be used in Remote Locations and abundant availability.

A photovoltaic system, also solar PV power system, or PV system, is a power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current fron DC to AC, as well as mounting, cabling and other electrical accessories to set up a working system.

PV systems have a structure containing solar cells (SCs), connection, protection, and storage components and some additional elements depending on load characteristics. The most important element of these systems, the solar cells, also has distinctive features especially on the initial investment cost and the quality and quantity of other elements. However, the expenditure is acquiring photovoltaic modules has slowed the implementation of solar modules in the generation of electricity. Also, the power produced by photovoltaic modules is unstable because it mainly depends on the level of solar irradiation and the load. The power delivered by a PV system of one or more photovoltaic cells is dependent on the irradiance, temperature, and the current drawn from the cells. Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from these systems. Such applications as putting power on the grid, charging batteries, or powering an electric motor benefit from MPPT. In these applications, the load can demand more power than the PV system can deliver. In this case, a power conversion system is used to maximize the power from the PV system. There are many different approaches to maximizing the power from a PV system, this range from using simple voltage relationships to more complexes multiple sample based analysis. Depending on the end application and the dynamics of the irradiance, the power conversion engineer needs to evaluate the various options.The conversion efficiency of electric power generation for these systems is low about 9-17% without MPPT.

2 CHARACTERISTICS OF A PV CELL

The characteristics of PV cell explain in to two steps. First step is to plot „voltage" Vs „power" graph of the cell. Power iscalculated by multiplying voltage across the cell with correponding current through the cell. From the plot, maximumpower point is located and corresponding voltage is noted. The second step is to go to the V-I characteristics of the cell andlocate the current corresponding to the voltage at maximumpower point. This current is called the current at maximumpower point.

The characteristic curve is observed closely and defines two of the points. First one is the short circuit current Isc and the second one isthe open circuit voltage Voc. Short circuit current is the current where the cell voltage is zero. Open circuit voltage is thevoltage at which the cell current is zero. The point at which Imp and Vmp meet is the maximum power point. This

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is thepoint at which maximum power is available from the PV cell. If the „load line" crosses this point precisely, then themaximum power can be transferred to this load. The value of this load resistant would be given by:

$$Rmp = Vmp/Imp \quad (1)$$

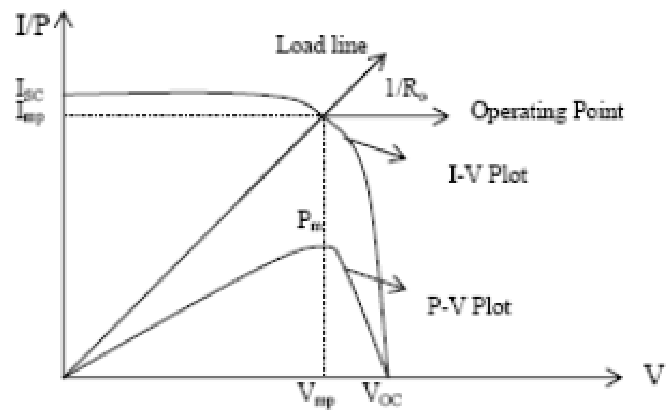

FIG. 1 I-V and P-V characteristic curves of a PV module

3 MAXIMUMPOWER POINT TRACKING

Maximum power point tracking (MPPT) is a technique used with wind turbines and photovoltaic (PV) solar systems to maximize power output. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries. MPPT plays an important role in photovoltaic system because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency.

Maximum power point is the voltage and current at which the PV module can produce maximum available power.The IPV- VPV characteristics is non linear and varies with solar irradiation. Now, consider the power-voltage characteristics of the PV panel in Fig 1.There is a unique point on the IPV- VPV or PV curve called the maximum power point (MPP) at which the entire PV system operates with maximum efficiency and produces its maximum output power. The location of MPP is not known, but can be located either through calculation models or by search algorithms.There are many algorithms for implementing MPPT, among those Perturb and Observe method (P&O) & Incremental Conductance method (IC) are the most popular algorithms.The algorithm we use here is a modified version of incremental conductance method. In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module.

3.1 Perturb and Observe Algorithm

MPPT is nothing but a DC to DC converter connected in between the PV module and the load, by varying the dutycycle of the converter we can fixeoperating point of the system at the maximum power point.

In P&O algorithm, if increasing the voltage increases the output power, the system continues increasing the operating voltage until the power output attains a maximum value (MPP) and starts to decrease.Once the power output decreases, the voltage is decreased to get back towards the MPP. This Perturbation continues indefinitely, the power output value oscillates around the MPP and never stabilizes, and is considered as the major drawback of P&O algorithm.

3.2 Incremental Conductance Algorithm

In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module. Fig2.1 shows that the slope of the P-V array power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.

$$dI/dV = -I/V \text{ at MPP} \quad (2)$$
$$dI/dV > -I/V \text{ at Left of MPP} \quad (3)$$
$$dI/dV < -I/V \text{ at Right of MPP} \quad (4)$$

Where I and V are PV array output current and voltage respectively.The left hand side of equations represents incremental conductance of P-V module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the maximum power point.

Equation (2) is held true when the PV module is operating at the MPP; Eq. (3) is held truewhen the PV module is operating in the left region of the MPP in the P-V curve; and Eq. (4) is held true when the PV module is operating in the right region of the MPP in the P-V curve.This algorithm is based on the fact that the gradient of the P-V curve is equal to zero at MPP.ie, dP/dV=0 at MPP.

4 CHARACTERISTICSOF A PV SYSTEM WITH DC-DC CONVERTER

MPPT system is simply a DC-DC converter, which acts as a power interface between the PVmodule and the load. The key characteristic in designing a MPPT is to control the switching activityof the converter and deliver the maximum power to the load at each operating condition. Whena PV module is connected to a load, its operation point will be determined by the intersection pointof its I-V curve and the load line. At a single point, when two curves intersect each other exactlyat the MPP, the PV module is operating at the MPP.14 There are several non-isolating DC-DC converters,including buck, boost, buck-boost converters. Among all these converters,the buck-boost converter has a simple structure and a lower cost compared to the other converters.

During the operation time, the switching activity of buck-boost converter is controlledby the Pulse-Width Modulation (PWM) in order to control the operation mode of the converter.The relationship between the input and the output voltage of the buck-boost converter and inup and output currents of the converter isshown below in equations (6) & (7)

$$V_{\text{in}} = \frac{1-D}{D} V_{\text{out}}$$
$$I_{\text{in}} = \frac{D}{1-D} I_{\text{out}}.$$
(6) & (7)

Where D is the duty cycle ,Vin is the input voltage of the converter which is equal to the voltage of PV module,Vout is the output voltage of the converter ,Iin is the input current of the converter which is equal t6 Ipv,Rin is the input resistance of the converter ,Rout ist the output resistance of the convereter which is equal to load resistance Rload.

Knowing Vin&Iin, we can calculate Rin as in equation (8)
Rin = Vin/Iin
=
$$\frac{(1-D)^2}{D^2} R_{\text{out}}$$

5 MODIFIED MPPT ALGORITHM

The proposed algorithm adopts the relationship between the load line and the *I–V* curve to introduce a fast-converging algorithm.In the proposed system, only the voltage and current ofPV module are sensed by the MPPT controller.

In the PV system, (8) can be rewritten to obtain (9) and (10) as follows:

$$\frac{Vpv}{Ipv} = \frac{(1-D^2)}{D^2} R_{load} \quad (9)$$

$$R_{\text{load}} = \frac{D^2}{(1-D)^2} \frac{V_{\text{pv}}}{I_{\text{pv}}}. \quad (10)$$

Under any operating point, the load resistance can be calculatedby substituting the duty cycle, voltage, and current of PV moduleinto (10). After the value of load resistance is obtained, (10) Can be rewritten into (12). Then, the duty cycle can be calculatedby substituting the desired voltage (*V*mpp) and current (*I*mpp) of PV module into (7) as follows:

$$\frac{D^2}{(1-D)^2} = \frac{I_{\text{pv}}}{V_{\text{pv}}} R_{\text{load}}$$
$$D = \frac{\sqrt{a}}{1+\sqrt{a}}$$
eqns (10) & (12)

Where

$$a = \frac{I_{\text{pv}}}{V_{\text{pv}}} R_{\text{load}}.$$

In the proposed algorithm, the load of the PV system is calculated by using (10). Then, (12) is used to ensure that the system responds rapidly and operates near to the new MPP wheneverthere is variation in solar irradiation. For the case of load variation, (10) is used to calculate the new load resistance, then *V*mpp and *I*mppare substituted into (12) to obtain the new duty cycle.

5.1 Decrease in Solar Irradiation Level

If the PV module operates at load line 1 and the solar irradiationis 1.0kW/m2, the current and voltage of PV module are *V*mpp and *I*mpp as shown in Fig. 3(a). Then, if the solar irradiationdecreases to 0.4kW/m2, while the duty cycle of the dc–dcconverter remains unchanged, the operating point of PV moduleis at point A (*V*1, *I*1) of load line 1 which is far away from theMPP of 0.4kW/m2, point C in Fig. 3(a). In order to perturb theoperating point of the PV module to the new MPP by using (12),the voltage and current of the new MPP is required. However,these two values are unknown. Therefore, approximated values are substituted into (12) to ensure the PV module operates nearto the new MPP. As shown in Fig. 3(a), the current of point A,*I*1 is close to the short circuit current of 0.4kW/m2 and thecurrent of MPP is always approximately 0.8 ∗*I*sc. Thus, *I*1 isapproximated as the current of newMPP. Then, Fig. 2 shows thevoltages of MPP for each level of solar irradiations are closed toone another. Hence, the previous MPP voltage, *V*mpp is approximatedas the voltage of new MPP. Subsequently, *V*mpp and *I*1 are substituted into (12) to perturb the operating point of PVmodule to load line 3, point B (*V*2, *I*2) which is near to the newMPP. With only single perturbation, the operating point of thePV module converged from point A to point B rapidly. Finally, afew more steps of conventional incremental conductance algorithmare used to track the new MPP, point C. Therefore, theconvergence time from point A to point C is greatly reduced.

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5.2 Increase in Solar Irradiation Level

If the PV module operates at load line 2 and the solar irradiationis 0.4 kW/m2, the current and voltage of the PV module are*V*mpp0.4 and *I*mpp0.4 as shown in Fig. 3(b). Then, if the solarirradiation increases to 1.0 kW/m2, while the duty cycle

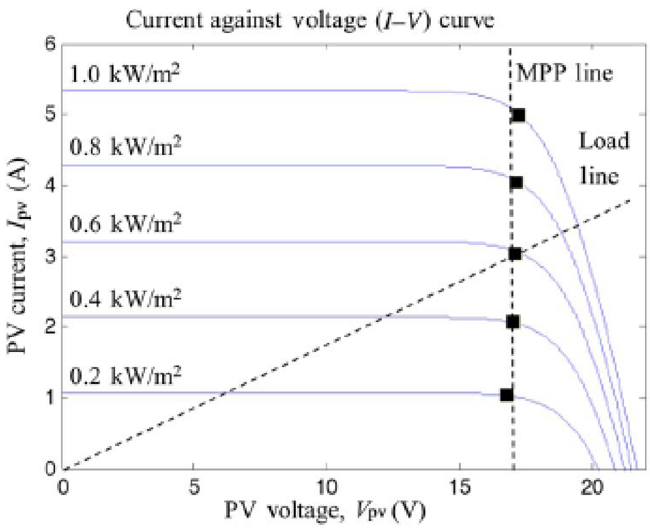


Fig. 2. MPP line and load line on the *I*–*V* curves for different levels of solar irradiation

of thedc–dc converter remains unchanged, the operating point of PVmodule is at point D (*V*1, *I*1) of load line 2 which is far awayfrom the MPP of 1.0 kW/m2. Similar to the algorithm used inthe case of decrease in solar irradiation level, the approximatedvalues are substituted into (7) to ensure the PV module operatesnear to the new MPP. However, the operating current, *I*1 isfar away from the short circuit current of 1.0 kW/m2 as shownin Fig. 3(b). Thus, an additional step is required to ensure theoperating current of PV module is near to the *I*sc of new MPP.As shown in Fig. 3(b), point E, *V*oc1.0, and *V*mpp0.4 form aright-angled rectangle.By applying the trigonometry rule in (8), the operating current*Ix*, which is near to the *I*sc of 1.0kW/m2 is obtained. Theopen circuit voltage *V*oc of the PV module in (9) is the approximatedopen circuit voltage obtained from *V*mpp/0.8. Then,*V*mpp is the voltage of the MPP before the variation in solarirradiation. *V*1 is the voltage of PV module after the variation insolar irradiation

$$\frac{V_1 - V_{\mathrm{mpp}}}{I_x - I_1} = \frac{V_{\mathrm{oc}} - V_{\mathrm{mpp}}}{I_x}. \qquad (13)$$

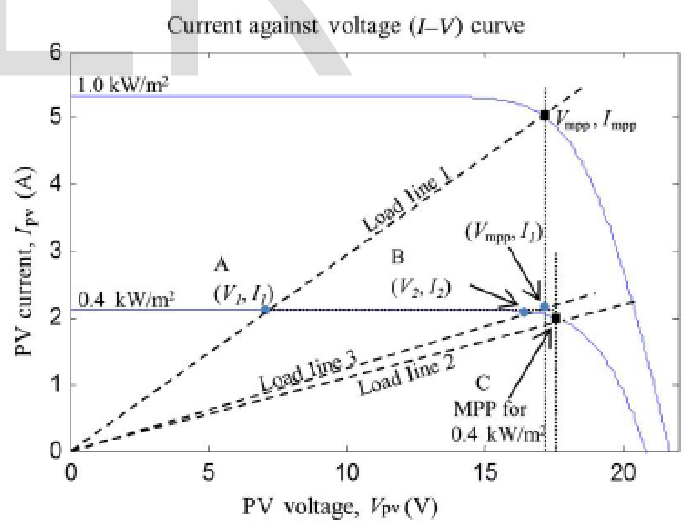
Equation (13) is rearranged to obtain (14)

$$I_x = \frac{V_{\mathrm{oc}} - V_{\mathrm{mpp}}}{V_{\mathrm{oc}} - V_1} I_1. \qquad (14)$$

In the second step, *Ix* and the voltage of the previous MPP*V*mpp0.4 are substituted into (12) to obtain the new duty cycle.With the new duty cycle, the PV module operates at point F(*V*2, *I*2) of load line 4, which is close to the new MPP at1.0kW/m2. Then, the conventional incremental conductance algorithm is used to track the MPP.

5.3 Load Variation

Table I is used to identify the existence of load variation.After the load variation, the operating point of the PV modulediverts from the MPP (load line no longer cut through MPP). A new duty cycle is required to ensure the PV module operates atthe MPP again (load line cut through MPP). As variation onlyexists in the load, the voltage and current at the MPP should bethe same (*I*–*V* curve unchanged). Thus, (5) is used to obtainthe new resistance of the load. Then, by substituting the voltageand current at the MPP into (7), the new duty cycle can becalculated. With the new duty cycle, the PV module operates atthe point close to the MPP and then, the conventional algorithmis used to track the MPP.



(a)

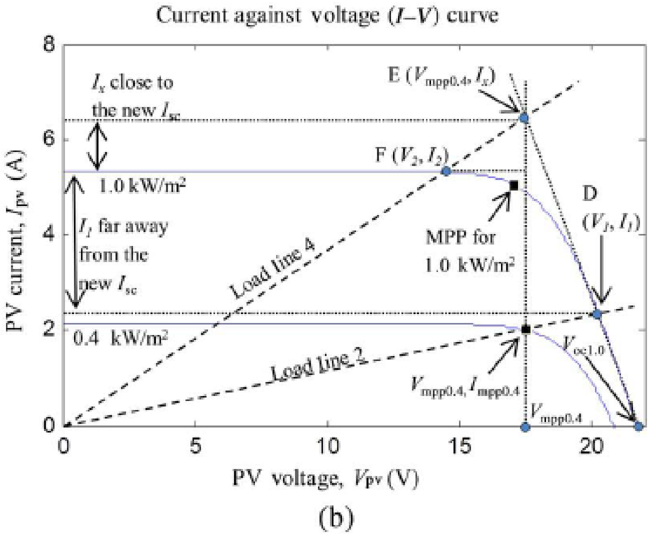


Fig. 3. Load lines on I–V curves for solar irradiation level of 0.4 and 1.0 kW/m2 during (a) decrease of solar irradiation and (b) increase of solar irradiation.

TABLE I
Variation In The Voltage And Current Of The Pv ModuleDuring The Variation In Solar Irradiation AndLoad Resistance.

		Variation of Voltage (dV)	Variation of Current (dI)
Solar irradiation	Increase	Positive	
	Decrease	Negative	
Load resistance	Increase	Positive	Negative
	Decrease	Negative	Positive

Fig. 4 shows the flowchart for the proposed algorithm. A flag Value issused to indicate that the PV system is operating at theMPP if it is set to 1. Therefore, the flag is set to 0 initially. Then,the conventional incremental conductance algorithm is used totrack the MPP. A permitted error of 0.06 is used in the proposed algorithm to eliminate the steady-stateoscillation in the system after the MPP is reached. The permittederror is chosen based on the duty cycle step size (0.005), andthe accuracy in the power of the PV module at MPP is ±0.7%.

$$\left|\frac{dI}{dV} + \frac{I}{V}\right| < 0.06. \quad (15)$$

After the algorithm tracked the MPP, the flag is set to 1, and the program is loaded into the proposed algorithm. Then, (15) is checked, and the duty cycle does not regulated if (15) is satisfied.When the solar irradiation or load is varied, (15) no longerholds and the flag is set to 0. Then, the resistance of the load is calculated by using (10) and the direction of variation in the solarirradiation or load is determined. If both the current and voltageof the PV module are decreased, (12) is used to calculate the newduty cycle. If both the current and voltage of the PV moduleare increased, Ix is calculated by using (14), and then, the newduty cycle is calculated by using (12). In the case of a nonlinearload, the response of the system is slower (the PV system isunable to operate near to the new MPP in single perturbation.Thus, changes in the power of the PV module are monitored.If the power of the PV module increases after the perturbation in duty cycle, (12) is used to calculate the new duty cycle again.Until the difference in power (dP) is smaller than 0.06, onlythen the conventional algorithm is applied. Meanwhile, for loadvariation, the new duty cycle is calculated by using (12) after theresistance of the load is obtained by (10).

6 HARDWARE IMPLEMENTATION

The proposed system consists of the PV module, DC-DC converter, PIC controller, PWM,and the load. By controlling the duty cycle of the DC-DC converter, the operating point of the PV module is moved to the MPP. PIC controller is programmed with proposed algorithm to generate the suitable PWM which is used to control the duty cycle. The current ofthe PV module is sensed by the current sensing resistor. A voltage divider isdesigned to sense the input and output voltage of the converter. The output terminal of the converteris connected to a constant load.

In order to always exploit the maximum power from the PV module, the proposed algorithm is coded into a PIC controller. The controller uses the input current andvoltage of the converter to calculate the suitable PWM for the switching device. The PWM signal fromthe controller is amplified from 5V to 15V by using a gate drive circuit. In this paper, the PIC16F877A from Microchip is used.

Employing PIC controller has many advantages including cost efficiency of less than $50,easy to programming and debugging, and large range of interfaces. They have also built-in oscillatorwith selectable speeds. They use 10-bit analog to digital converter (ADC) and processingspeed of 40MHz which is appropriate for MPPT system. They can also provide therequired frequency to generate the PWM signal. In summary, PIC is capable of taking controlof the MPPT system with less cost and complexity.

Another approach in this paper is that by applying boost converter, the PV moduleoperates in a larger operational region. The structure of this converter is also simpler and easierto build than that of other types of DC-DC converters. Boost converter also provides anoutput voltage polarity reversal without a transformer. It has high efficiency, current limitingand the output short circuit protection is easy to implement.

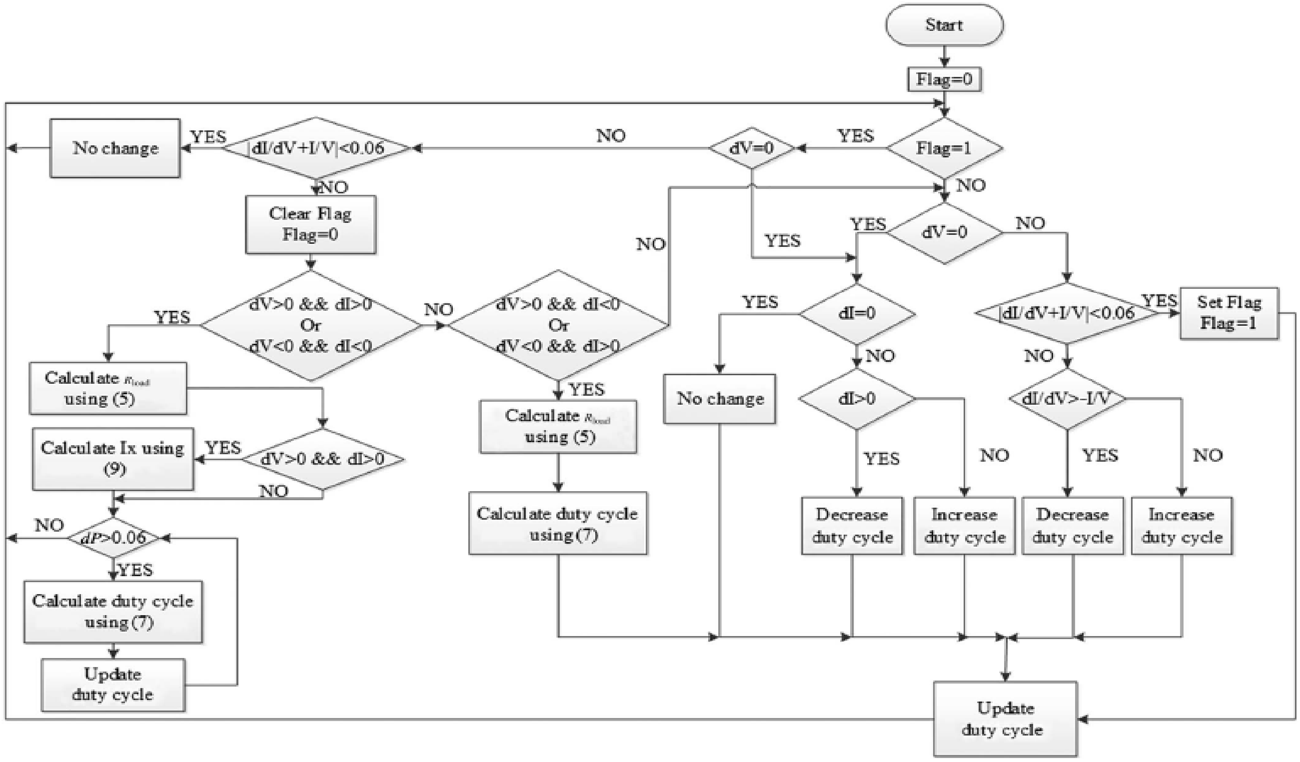


Fig. 4. Flowchart of the proposed MPPT algorithm

7 CONCLUSION

The proposed system only requires a dc–dc converter and aPIC microcontroller which is simpler than those which requiresextra control loop and intermittent disconnection. Furthermore,the proposed algorithm responds to the variation in solar irradiationand load faster than the conventional algorithm. In addition, thereis no steady-state oscillation in the proposed algorithm andthus reduce the power losses. As a conclusion, a fast convergingand low losses MPPT algorithm is proposed in this paper.

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