Improved incremental conductance method for maximum power point tracking using cuk converter

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Abstract: - The Algerian government relies on a strategy focused on the development of inexhaustible resources such as solar and uses to diversify energy sources and prepare the Algeria of tomorrow: about 40% of the production of electricity for domestic consumption will be from renewable sources by 2030, Therefore it is necessary to concentrate our forces in order to reduce the application costs and to increment their performances, Their performance is evaluated and compared through theoretical analysis and digital simulation. This paper presents simulation of improved incremental conductance method for maximum power point tracking (MPPT) using DC-DC cuk converter. This improved algorithm is used to track MPPs because it performs precise control under rapidly changing Atmospheric conditions, Matlab/ Simulink were employed for simulation studies.

Key-Words: - Improved incremental conductance, MPPT, cuk converter, rapidly changing Atmospheric conditions, Matlab

1 Introduction

The renewable energies especially photovoltaic technology (PV) represents an alternative by excellence and it is increasingly used in today[1]. This type of energy is not only free and inexhaustible, but also cleans the environment. Moreover, we often speak of a "green energy", as totally avoids the pollution produced by traditional sources.

Photovoltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect.

The maximum power point (MPP) is the point on the I-V curve at which the PV module operates with maximum output power, The MPP varies with changing conditions such as irradiance levels and temperature. To make best use of PV sources, it is essential to always operate at the MPP.The main job for the MPPT is to control the PV system and run it near its Maximum Power Point. There are a large number of algorithms that are able to track MPPs. Some of them are simple and some are more complicated, In general MPPT methods can be classified as [2]:

The first category is Voltage feedback based methods which compare the PV operating voltage with a reference voltage in order to generate the PWM control signal of the DC-DC converter.

The second category - Current feedback based methods which use the PV module short circuit current as a feedback in order to estimate the optimal current corresponding to the maximum power.

The third category is Power based methods which are based on iterative algorithms to track continuously the MPP through current and voltage measurement of the PV module. In this category, one of the most successful and used method is perturbation and observation [3].

Each PV module can be characterized by its I-V curve. Three points on the I-V curve are important in defining the performance of a PV module; the maximum power point, the short-circuit current and the open-circuit voltage [4].

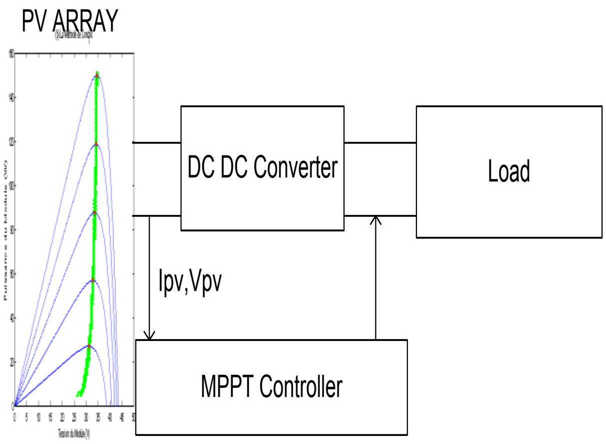

Fig. 1 Photovoltaic system with MPPT

2 MPPT methods

There are a large number of algorithms that are able to track MPPs

1) P&O: The principle of P&O is to send perturbations in the operating voltage of the PV array which makes the output power is approaching to maximum [5]. To be specific, the array terminal voltage is perturbed periodically. The perturbation is incrementing or decrementing. Then the P&O algorithms operate by comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases (dP/dV>0), the MPPT controller moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way. Thus, there are some disadvantages with these methods, where they fail under rapidly changing atmospheric conditions, In other words, P&O algorithm cannot compare array terminal voltage with the actual MPP voltage, since the change in power is only considered to be a result of the array terminal voltage perturbation [6].

2) Hill Escalade (HC): The most common types of algorithms are Hill Climbing algorithms [6]. it is based on the duty cycle control, HC works on the same concept as P & O, but instead of disturbing voltages or current, it updates the operating point of the PV generator disrupting the duty cycle. HC conventional method is interesting that the duty cycle of the power converter can be varied directly; implementation of HC is greatly simplified. Therefore, this method is widely used in PV systems.

3) fuzzy logic and neural network MPPTs: are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects, Fuzzy logic was introduced in 19 65 with the work of L .Zadeh [7] .The fuzzy system is a system based on the concepts of approximate reasoning[8], currently this concept is apply in different domain of technology like design regulator for process control difficulty modeling and improvement of performance of system and regulation[9] .Fuzzy logic control generally consists of three stages: fuzzification, rule base table lookup, and defuzzification [10] (figure 2)The inputs of the fuzzy controller are usually an error, E, and the change in the error, Δ E. The error can be chosen by the designer, but usually it is chosen as ΔP/ΔV because it is zero at the MPP. Then E and ΔE are defined as follows: ,this method have good performance under varying atmospheric conditions and exhibit better performance than the P&O control method[11]; however the main disadvantage of this method is that their effectiveness is greatly dependent on technical knowledge of the engineer in computing the error and coming up with the rule base table [12]. It is greatly dependent on how a designer arranges the system that requires skill and experience.

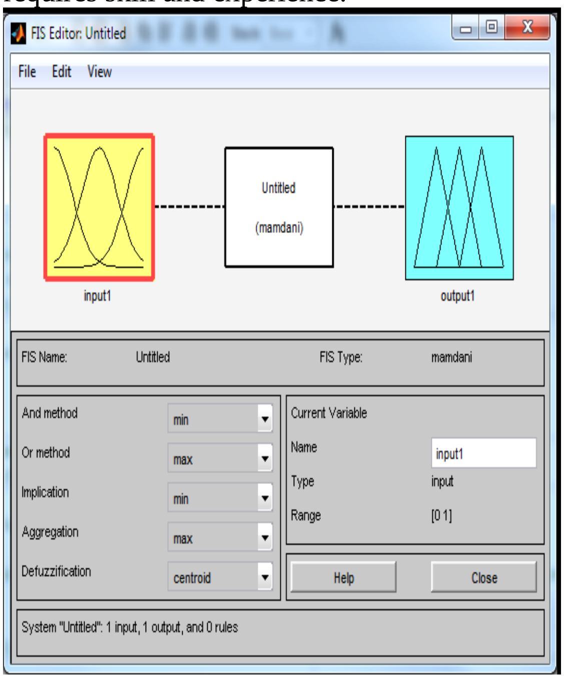

Fig. 2 Fuzzy logic control with Matlab

A neural network is composed of three layers: the input, hidden and output layers. Inputs to a network can be the array terminal voltage and the solar irradiation level or any other measurements needed by the MPPT algorithm. The output is usually one or several reference signal(s) like a duty cycle signal used to drive the power converter to operate at or close to the MPP. The link between nodes i and j is labeled as having a weight of wij. The effectiveness of this MPPT technique is mainly determined by the hidden layer and the amount of training the network received. The weights between the neurons are tuned to generate the required output which could be a command to change a DC converter duty cycle.

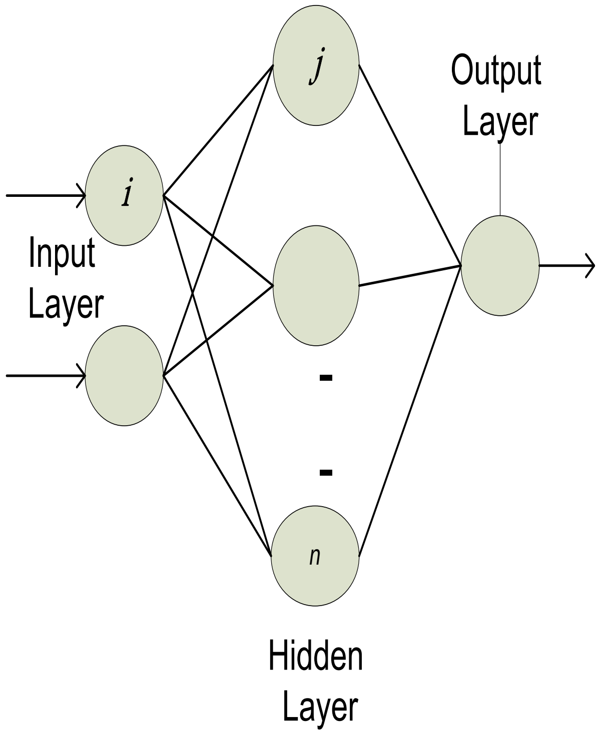

Fig. 3 Neural network MPPT controller

A disadvantage of this technique is the complexity of processing, in addition to its dependency on the characteristics of the PV array to which it is connected.

4) Particle swarm optimization (PSO): Artificial Intelligence techniques such as neural networks, fuzzy logic and genetic algorithms[13] are gaining increased interest nowadays[14]. Among the environmental valuation techniques, particle swarm optimization (PSO) is a high potential due to its simplicity structure, its ability to handle non-linear functions and they are expected to be very effective intreating the problem MPPT [15], easy implementation and fast computation capacity. Particle swarm optimization (PSO) is a technique based on the population stochastic optimization developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of flocking birds or schooling fish. The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike EA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Particle swarm optimization (PSO) is a stochastic, population based search method, modeled after the behavior of bird flocks [15], method yields 99.5% efficiency. Furthermore, the algorithm is tested using a 10 h irradiance and temperature profile of Malaysia by [16].

5) Traditional Incremental Conductance (INC) Method: is also widely applied in the MPPT controllers [17] It is the one which overrides over the aforementioned drawbacks. In this method, the array terminal voltage is always adjusted according to the MPP voltage, the following set of rules is found:

$$\frac{dp}{dv} = \frac{d(IV)}{dv} = I + V\frac{di}{dv} \quad (1)$$

The MPP can be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (dI/dV), because at MPP dp/dv=0, According to [12], [18] and [3] above equations can be rewritten as:

$$\frac{di}{dv} = -\frac{I}{V} \qquad \text{At MPP}$$

$$\frac{di}{dv} \prec -\frac{I}{V} \qquad \text{Right of MPP}$$

$$\frac{di}{dv} = \succ -\frac{I}{V} \qquad \text{Left of MPP (2)}$$

Efficiency of each method MPPT is identified by three parameters:

One is a physical parameter which is quickness or speed, where the response time is the most critical element, the second is a algorithmic factor is complexity which affects on implementation of method in Microprocessor and DSP, the last is economic parameter which is the reliability of system. Table 2 indicates the presence of these parameters on each MPPT method:

Table 1 Comparison of MPPT Methods

MPPT technique	Speed	Complexity	Reliability
Hill climbing	Varies	Low	Low
IncCond	Varies	Medium	Medium
P and O	Medium	Low	Low
Fuzzy Logic	Medium	Digital	Medium
Neural Network	Medium	Digital	Medium
PSO	Medium	Digital	high

3 Choose of DC DC converter

DC/DC converters are used in a wide variety of applications including power supplies, there are four topologies: boost converter, buck converter, buck-boost converter and cuk converter, this last is the most expensive but On the other hand, the Cuk converter has low switching losses and the highest efficiency among no isolated dc–dc converters. It is a two-inductor non-isolated switch mode DC-DC converter in which power transmission is accomplished using an ideal switch.

The relationship between the voltage gain of the converter and the duty cycle is not linear. The voltage increases or decreases if the duty cycle of the converter increase or decrease. Increase or decrease duty cycle of the converter is getting by the displacement of operating point to the right or left of the IV characteristic.

The cuk converter will responsible to inverter the output signal from positive to negative or vise versa [3].

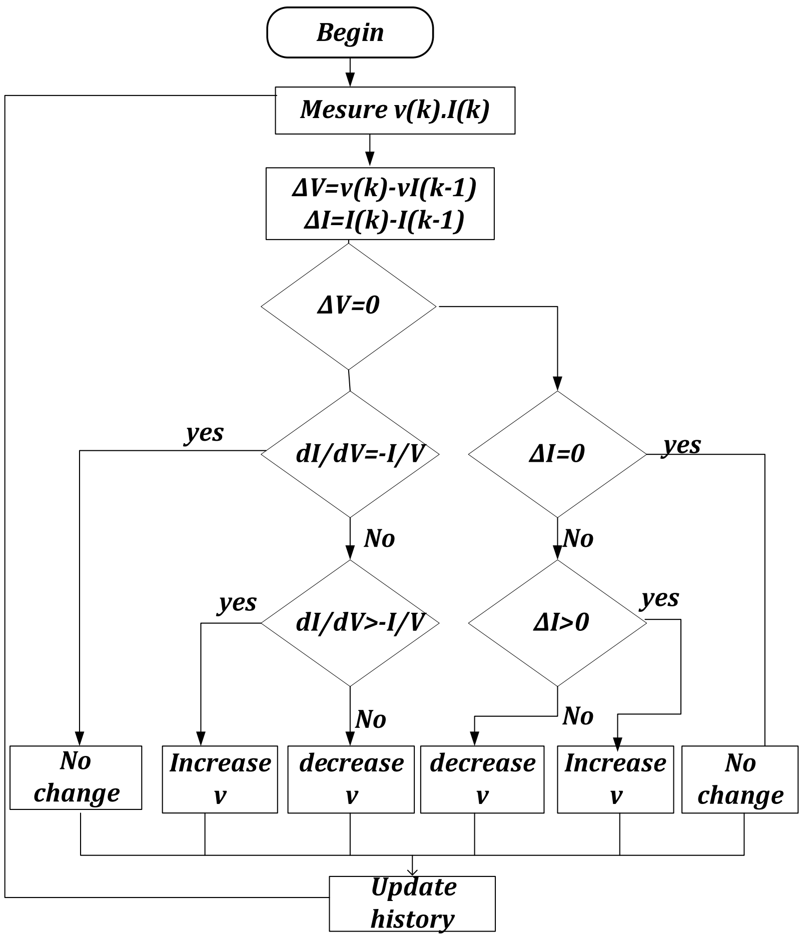

Fig. 4 the flowchart of the InCon method

This converter has two modes of operation. The first mode of operation is when the switch is closed (ON), and it is conducting as a short circuit. In this mode, the capacitor releases energy to the output. The equations for the switch conduction mode are as follows:

$$Ic_1 = I_2 \quad (3)$$

$$VL_1 = Vg \quad (4)$$

$$VL_2 = -V_1 - V_2 \quad (5)$$

$$Ic_2 = I_2 - \frac{V_2}{R} \quad (6)$$

On the second operating mode when the switch is open (OFF), the diode is forward-biased and conducting energy to the output. Capacitor C1 is charging from the input. The equations for this mode of operation are as follows:

$$VL_1 = Vg - V_1 \quad (7)$$

$$VL_2 = -V_2 \quad (8)$$

$$Ic_2 = I_2 - \frac{V_2}{R} \quad (9)$$

$$Ic_1 = I_1 \quad (10)$$

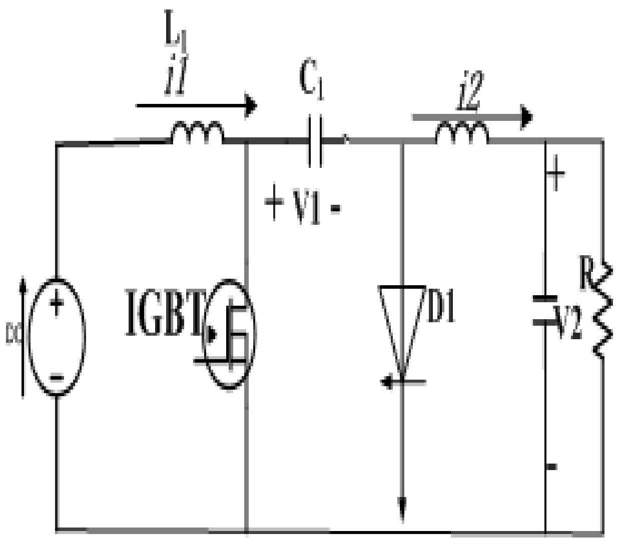

Fig. 5 Electrical circuit of the Cuk converter used as the PV power-stage interface.

The components for the Cuk converter used in simulation were selected as follows:

1) Input inductor L1 = 5 mH;

2) Capacitor C1 (PV side) = 47 μf;

3) Filter inductor L2 = 5 mH;

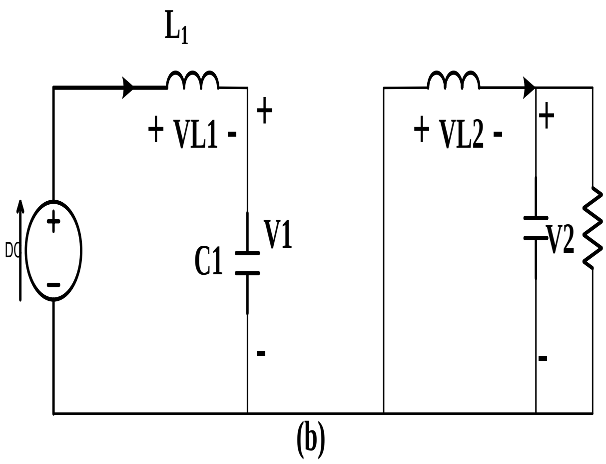

Fig. 6 Cuk converter with switch OFF

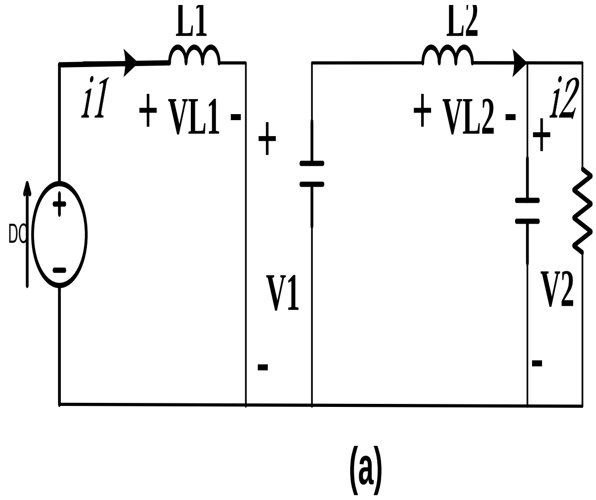

Fig. 7 Cuk converter with switch ON

4) Switch: insulated-gate bipolar transistor [(IGBT)];

5) Freewheeling diode;

6) Capacitor C2 (filter side) = 1 μF;

7) Resistive load = 10 Ω;

8) Switching frequency = 10 kHz;

4 Improved InCon MPPT algorithm

The Incremental Conductance (IncCond) method is based on above algorithm as shown in the flowchart Fig4. The MPP can thus be tracked by comparing

the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV). Vref is the reference voltage at which the PV array is forced to operate. At the MPP, Vref equals to VMPP.
The algorithm decreases or increases Vref only to track the new MPP .this case require two independent control loops to control the MPPT.
The first control loop contains the MPPT algorithm, and the second one is usually a proportional (P) or P–integral (PI) controller.
But in this paper the duty cycle is adjusted directly in the algorithm i.e. a direct control is selected, where the PI control loop is eliminated and the algorithm can be computed very rapidly.

5 SIMULATION RESULTS
5.1 Modeling a PV Module

The PV array used in this paper is a combination of 4 series of KC85T modules. Series combination of modules was chosen to obtain higher output voltage of PV module.
The KC85T module itself is composed of 36 silicon cells connected in series. Each module can generate current up to 5.34A and a voltage of 21.7 volts and give rise to the maximum power of 87W peak at standard testing conditions (25 °C, 1000W/m² and AM=1. 5). In the following simulations a single module is considered and the simulations for the full array are the same.
The characteristics curves shown in figure 10 depict KC85T solar PV module characteristics. The model gives proper results on the MPPT systems and will be used in the following simulations as the PV module.
The solar cell can be represented by the electrical model shown in" Figure 1". Its current voltage characteristic is expressed by the following equation (1):

$$I = Iph - Is\left[\exp\frac{q(v + IRs)}{nKT} - 1\right] - \frac{V + IRs}{Rsh} \quad (11)$$

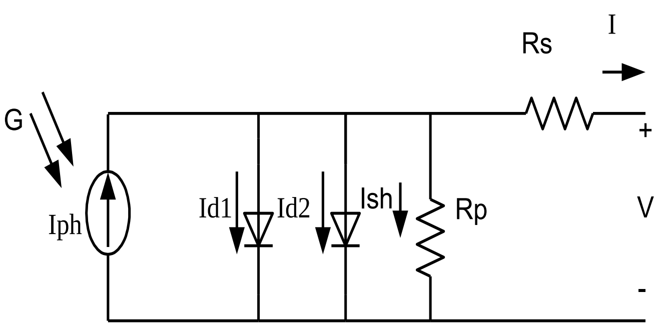

Fig. 8 Equivalent circuit of a solar cell.

where I and V are the solar cell output current and voltage respectively, I_S is the dark saturation current, Iph represents the photovoltaic current , q is the charge of an electron, N is the diode quality (ideality) factor, k is the Boltzmann constant, and Rs and Rsh are the series and shunt resistances of the solar cell.
Where Iph is a light-generated current or photocurrent, Id1, Id2, are the currents of diode 1 and diode 2 ,Ish is the shunt résistance current . When the photocurrent equal:

$$I_{Ph} = (I_{Ph,n} + K_I \Delta T)\frac{G}{G_n} \quad (12)$$

Where Iph,n [A] is the light-generated current at the nominal condition (usually 25 °C and1000W/m^2), ΔT =T−Tn (being T and Tn the actual and nominal temperatures [K]), G , [W/m^2] is the irradiation on the device surface, and Gn is the nominal irradiation. And currents diodes:

$$I_{d1} = I_{01}[\exp(\frac{V + IR_S}{a_1 V_{T1}}) - 1] \quad (13)$$

$$I_{d2} = I_{02}[\exp(\frac{V + IR_S}{a_2 V_{T2}}) - 1] \quad (14)$$

Where I01 and I02 are the reverse saturation currents of diode 1 and diode 2, VT1 and VT2 are the thermal voltages of respective diodes. a1 and a2 represent the diode ideality constants[19].

$$I_{01} = I_{02} = \frac{(I_{sc-n} + K_I \Delta T)}{\exp[(V_{oc,n} + K_V \Delta T)/V_T] - 1} \quad (15)$$

Isc :short circuit current [A].

Ki : cell’s short-circuit current temperature coefficient.

Voc ; open circuit voltage .

A : ideal factor.

Shunt current equal :

$$I_{sh} = \frac{V + R_s I}{R_{sh}} \quad (16)$$

Table 2 describe Electrical parameters of the KC85T module, we note that these values these the same values found by simulation shows in figure 10.

Table. 2 Electrical parameters of the KC85T module.

At standard conditions (T=25 C°, G=1000 w/m^2)	
Open Circuit Voltage	21.7 V
Short Circuit Current	5.34 A
Voltage at max power	17.4 V
Current at max power	5.02 A
Maximum Power	87 W

Each current and voltage point on the I-V curve coordinates to a power point on the P-V curve, but there is only a unique operating point which extracts the maximum power from the PV module (MPP).

5.2 PV MODULE WITH CUK CONVERTER AND MPPT

Cuk converter has been chosen in this study because of the low switching losses and high efficiency, lowest ripple content in output and smallest inductance volume comparing with transformer isolation converters such as fly back or forward.
The aim of employing MPPT is to ensure that at any environ-mental condition (particularly solar insolation and temperature), maximum power is extracted from the PV modules [20], A more efficient method to solve this problem becomes crucially important [21].

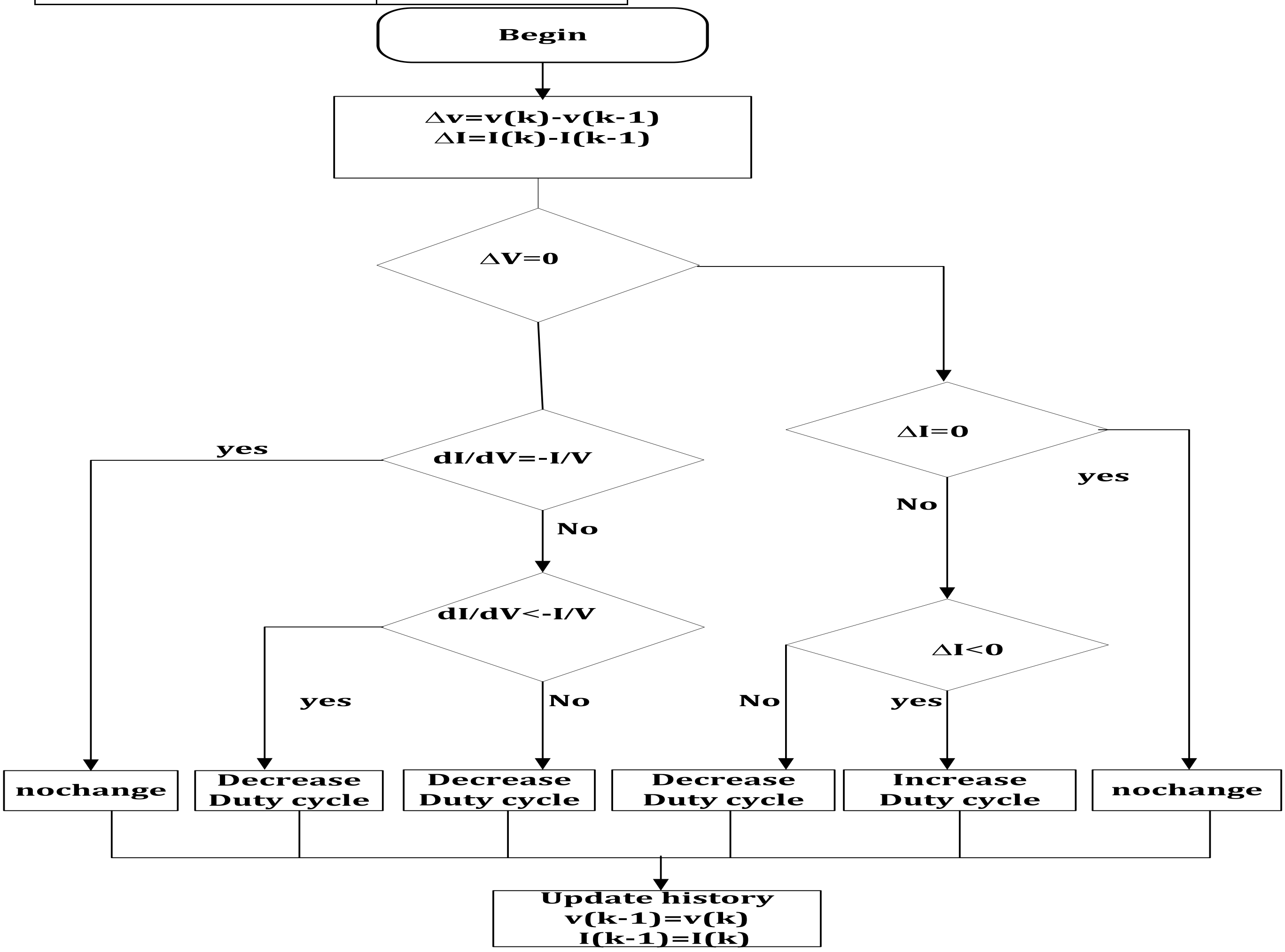

Fig. 9 Flowchart of the IncCond method with direct control

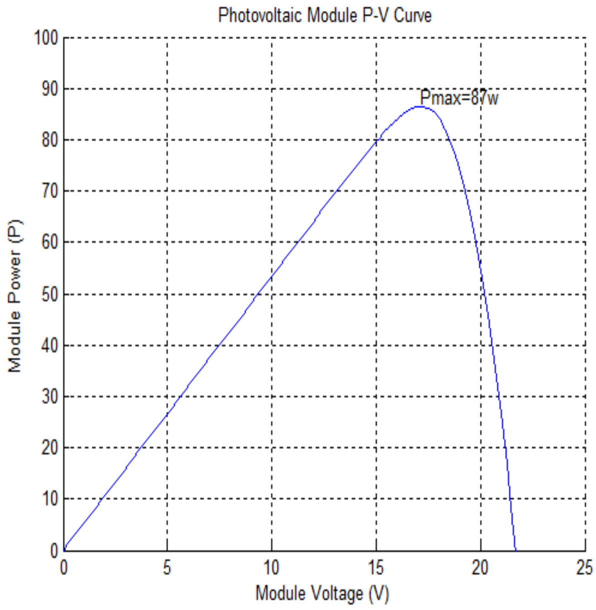

Fig. 10 KC85T P-V curve

The figure 10 shows that MPP of the KC85T module is 87w under uniform conditions (insolation=1000w/m^2 and temperature=25^{0}C).

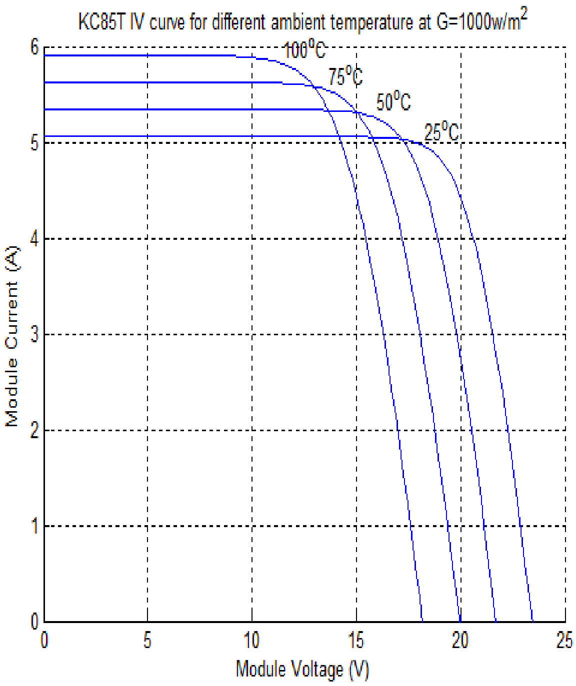

Fig.11 KC85T module I-V curve at various temperatures.

The solar irradiation and temperature change according to the operating condition, the effect of the irradiance on the voltage-current (V-I) characteristics is shows in Figure 12 and the effect of temperature on the voltage-current (V-I) characteristics is depicted in Figure 11.

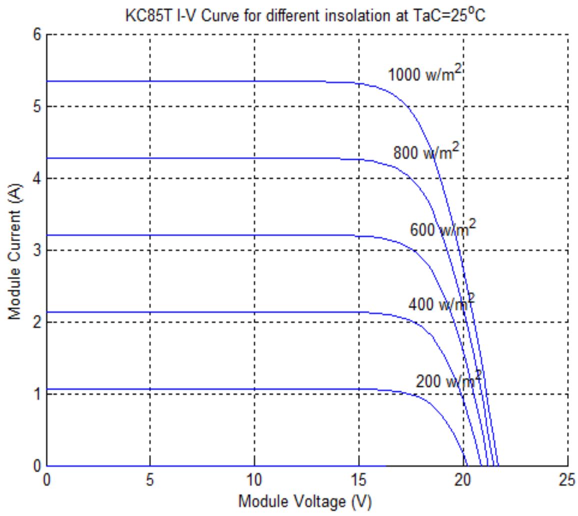

Fig.12 KC85T module I-V curve at various insolations.

The PV module electrical model designed is used to generate voltage and current of the module at each sampling time. MATLAB embedded function contains the IncCond algorithm with direct control method, so it will directly calculate the new duty cycle. The algorithm determines the new duty cycle where the system should move next and also replaces old values with the new(Figure. 9),the simulation of proposed control of MPP with Matlab/Simulink is showed in Figure 15.

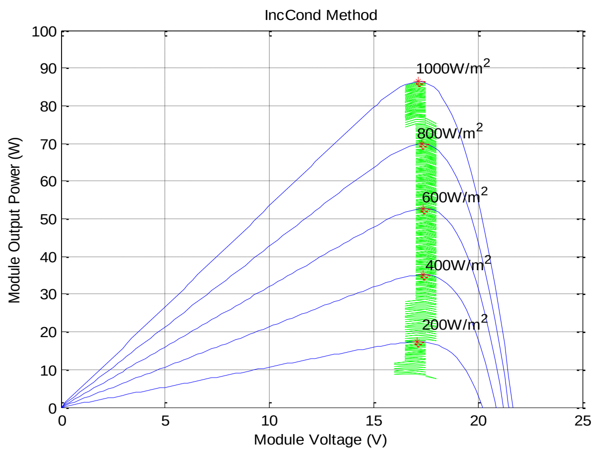

Fig. 13 IncCond MPPT algorithm with various irradiations.

The provided current and voltage are fed to the converter and the controller simultaneously, the PI control loop is eliminated, and the algorithm proposed follows MPP quickly and with high precision (Fig.13). On the other hand the algorithm tracks the MPP In all case if we make a disturbance on insolation between 200 w/m^2 at 1000 w/m^2.

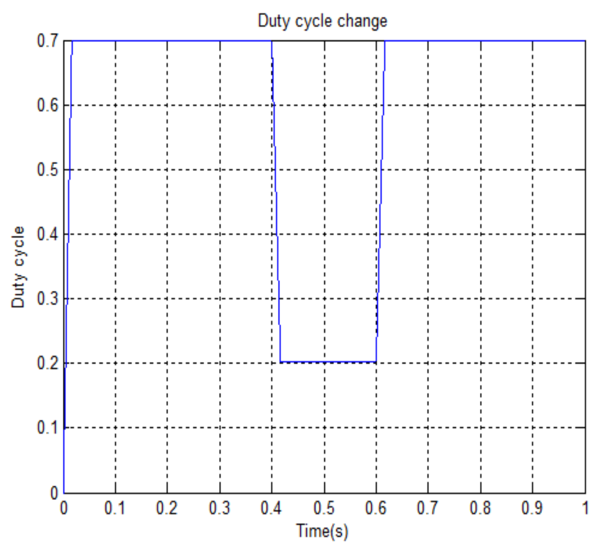

Fig. 14 Duty cycle response curve with the proposed method.

Figure 14 shows the change in duty cycle adjusted by algorithm to extract maximum power from the module KC85T.

At t=0.4 s rapid change in insolation (from 1000 w/m^2 to 400 w/m^2) is applied to test the performance of our algorithm under rapidly changing atmospheric conditions, where we observe that a new duty cycle is calculate quickly and at t=0.6 s another value of insolation is applied from 400 w/m^2 to 1000 w/m^2), that is to say two abrupt changes are made in a short period and duty cycle adjusted to go well with MPP.

So we can see that the proposed algorithm follow MPP high precision and it is capable to give the response in short time.

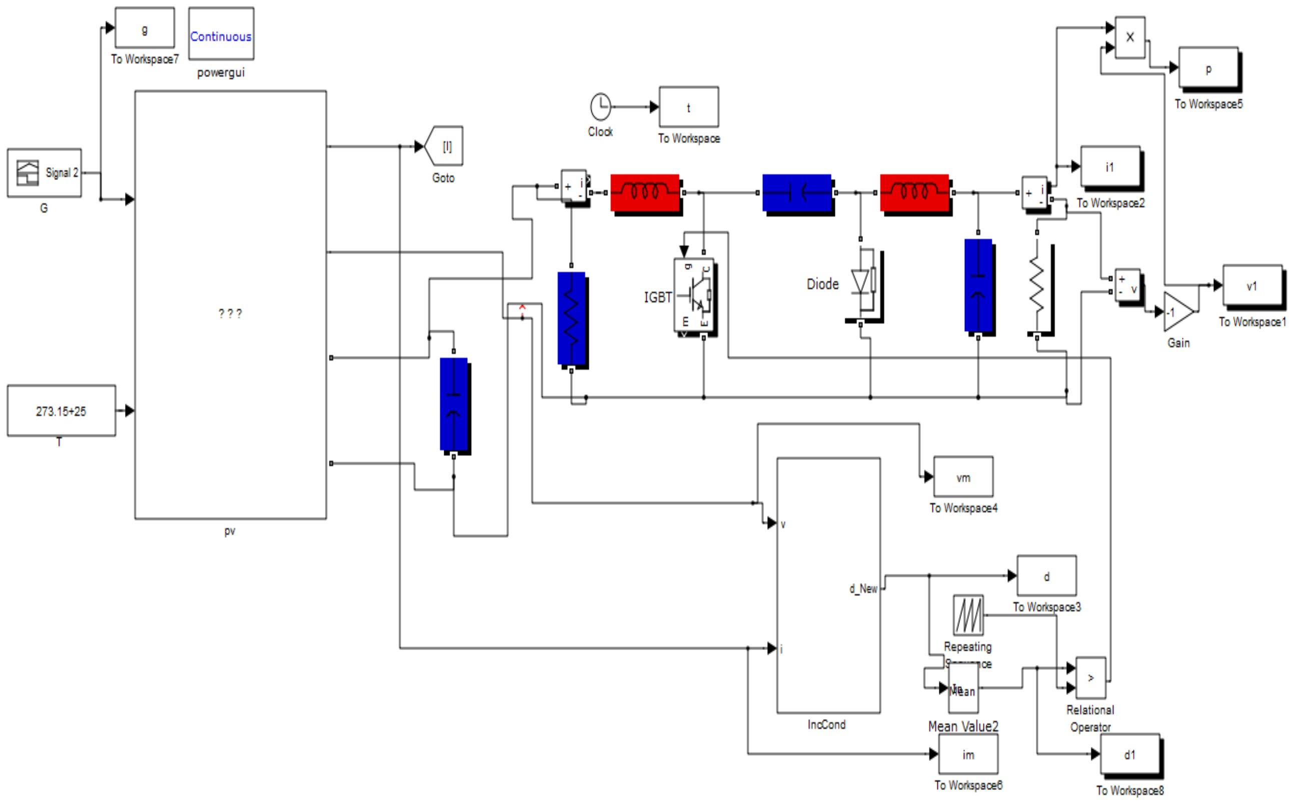

Fig. 15 MPPT system with Cuk converter designed in Matlab/Simulink.

6 Conclusion

In this paper an improved incremental conductance algorithm under rapidly changing Atmospheric conditions is proposed for PV array applications. It automatically adjusts the duty cycle according to the operating point of the PV array.

The proposed algorithm has been simulated in Matlab. The results acquired during the simulations it indicate that the proposed control system is capable to track MPP with performance, simplicity and fast response.

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