A GAUSSIAN AND AN ARC TANGENT FUNCTION BASED MAXIMUM POWER POINT TRACKING METHOD FOR PHOTOVOLTAIC SYSTEMS

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Abstract : ***In this paper a novel complex function based MPPT algorithm used for Photovoltaic system to attain maximum power output. The complex function is formed by 2-dimensional Gaussian and an Arc tangent function. This complex function is used for obtain the duty cycle of the DC-DC converter in Photovoltaic systems to attain the maximum power point (MPP) in any environment and load condition. This proposed function produces correct duty-cycles in case of abrupt irradiance changes. The performance of this method is evaluated through mathematical modeling and by simulating PV system, a complex function based controlled MPPT algorithm and DC-DC converter along with resistive load conditions in MATLAB software. The simulation results exhibits efficient operation of a complex function based MPPT method for PV systems.***

IndexTerms - Gaussian and an Arc tangent function based MPPT technique, Photovoltaic (PV) systems, Perturbation frequency.

I. INTRODUCTION

Maximum power point tracking is a technique used widely with wind turbines and photovoltaic (PV) solar systems to extract maximum power under all conditions. Although solar power is mainly covered, the principle applies generally to sources with variable power: for example, optical power transmission and thermo photovoltaics. A photovoltaic system, is a power system designed to supply usable solar power by means of photovoltaics. PV solar systems with MPPT operation is to transfer efficient power from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the maximum power point(MPP) and MPPT is the process of finding this maximum power point(MPP) and maintaining the load characteristics at maximum power point(MPP). Solar cells[1-2] have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve& P-V curve commonly called as operational curves as shown in Fig.1.

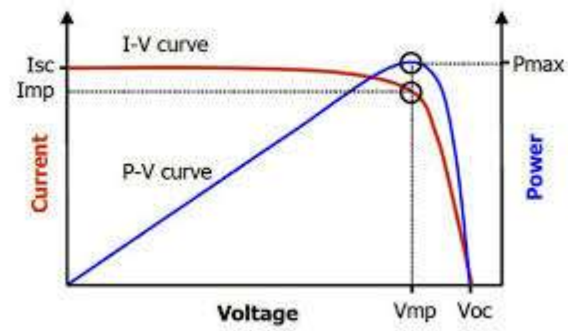


Fig.1. Operational curves

Implementation of MPPT algorithms utilizes that frequently sampled panel voltages and currents, and then adjusts the duty ratio as needed. Microcontrollers are used to implement the algorithms. Based on the operating conditions of the array different MPPT algorithm are implemented and commonly used MPPT algorithm is Perturbation & Observation (P&O)method.[7] In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. It is referred to as a hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Due to its ease of implementation this method is commonly implemented but results in oscillations of output power. The other method commonly used is Incremental conductance method. In this method, the controller measures incremental changes in PV array current and voltage to predict the effect of a voltage change. This method can track changing conditions more rapidly than perturb and observe method (P&O)[11] but requires more computation in the controller and can produce oscillations in power output. There are many recently developed MPPT techniques like Load-current adaptive step size and perturbation frequency (LCASF)[12] using single current sensor which produces oscillations with changes in environmental conditions. In this paper, a novel complex function based MPPT technique is proposed which produces adaptive perturbation step size in abrupt environmental conditions. The proposed function exhibits efficient operation under irrelevant environmental conditions. In order to validate the results, the PV panel, MPPT controller with a boost converter delivering power is simulated in a MATLAB software.

II. PHOTOVOLTAIC SYSTEMS

Photo, means "light" and voltaic, means "from electricity". A Solar PV system uses the sun's light energy or photons to produce electrical current.

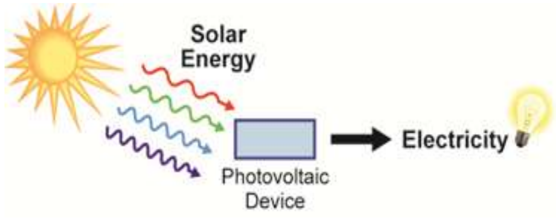


Fig.2.Basic block diagram

PV system consists of interconnected components designed to achieve the specific amount of the desired electricity from a small device to the load. PV system includes four main blocks. One is the energy source, the other are DC-DC converter, load and the MPPT controller. The lead role of the DC converter is to make an impedance matching in such a way the panel delivers its maximum energy.

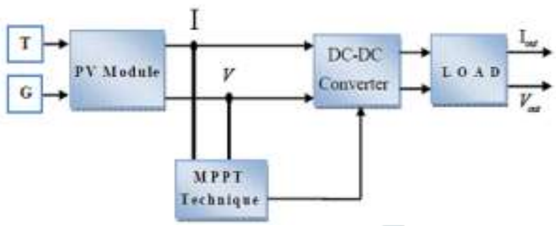


Fig.3.Block diagram of PV system

PV cell is the basic component of PV module. PV cell made of two semi-conductor layers, one is positive and other is negative charged. When light enters the cell, current will flow from positive terminal to negative terminal of the metallic plate connected across the PV cell. When n no. of cells is connected together in series, the voltage gets multiplied and for parallel the current gets multiplied, resulting PV module.

Modeling of a PV cell

To study the photovoltaic cell operation an electrical model is essential.[4] A typical equivalent circuit diagram is shown in Fig.4.

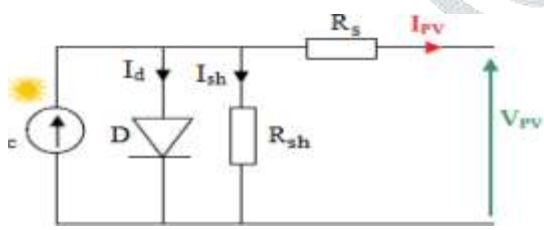


Fig.4.Equivalent circuit diagram of a PV cell

The photovoltaic current delivered from the PV cell is as follows

$$\mathrm{I = Ipv - Id - Ish} \qquad (1)$$

PN junction current Id

$$\mathrm{Id = Io - exp\left(\frac{V+IRs}{a}\right) - 1} \qquad (2)$$

$$\text{where } \mathrm{a = \frac{nKtNs}{q}} \qquad (3)$$

$$\text{and } \mathrm{Ish = \frac{V+IRs}{Rsh}} \qquad (4)$$

Therefore,

$$\mathrm{I = Ipv - Io - exp\left(\frac{V+IRs}{a}\right) - 1 - \left(\frac{V+IRs}{Rsh}\right)} \qquad (5)$$

where I =PV output current.

V=PV output voltage.

Ipv =light current.

Io =diode reverse saturation current.

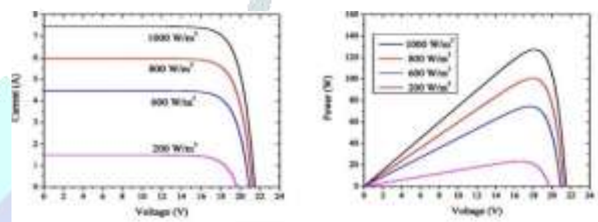
a= modified ideality factor.

Rs=series resistance and a small variation in RS leads to a decrease in the short-circuit current (Isc) but has no effect on the open-circuit voltage (Voc).

Rsh=shunt resistance and variations in RSh has no effect on the PV cell short circuit current (Isc) but it decreases the PV cell open circuit voltage (Voc).

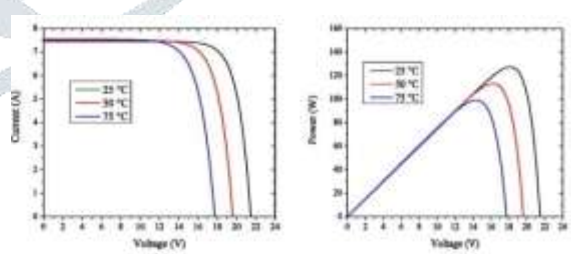
The V-I characteristics and P-V characteristics named as operational curves shows non-linearity with respect to variations in irradiation on I-V curve: as irradiance level increases, output voltage and output current increases, on P-V curve: as irradiance level increases, output power increases with increase in voltage shown in figure 5(a)&5(b).

Fig. 5(a) &5(b) I-V &P-V characteristics of a PV system at



constant temperature(25℃) and at different Irradiance.

Variations in temperature on I-V curve: as temperature increases, Isc increases slightly while Voc decreases more significantly, on P-V curve: as temperature increases, output power decreases due to decrease in Voc shown in figure 5(c)&5(d).



III. PROPOSED FUNCTION BASED MPPT TECHNIQUE

In this technique, a typical solar PV system consists of a PV panel, a DC-DC converter, the MPPT controller and a load. In this analysis, boost converter is used as DC-DC converter, a resistive load (or) battery as load and the MPPT control algorithm adjusts the duty cycle of boost converter to track the MPP of PV panel.

III -1 Description

In this method, the inputs of MPPT controller[10] are tracking error (E) and change in error (ΔE).

$$\mathrm{E(n) = \frac{P(n)-P(n-1)}{V(n)-V(n-1)}} \qquad (6)$$

$$\Delta E(n) = E(n) - E(n-1) \quad (7)$$

where

n=sampling time.

P(n)= instantaneous output power of PV panel of n^{th} sample.

V(n)=instantaneous output voltage of PV panel of n^{th} sample.

E(n)=tracking error of nth sample.

ΔE(n)=change in error of n^{th} sample.

Sign of tracking error (E) indicates the operating point attained from PV panel is located at left (or) right side of maximum power point (MPP) on operational curve (P-V).Change in error (ΔE) determines the direction operating point movement attained from PV panel. In this technique, MPPT control algorithm initially measures current & voltage of a PV panel and calculate MPPT controller inputs E & ΔE. Afterwards, two variables are determined the perturbation step size for next duty cycle (ΔD) and its time period or delay time (Tdelay)

III-1(i).Selection for Perturbation step size:

Perturbation step size depends mainly on two factors speed and tracking accuracy. A large perturbation step size speeds up convergence of the MPPT controller, and a small perturbation step size limits the loss of power and oscillations around maximum power point on operational curves(P-V) &(I-V). Perturbation step size for next duty cycle (ΔD) depends on E & ΔE for computation of next cycles.

Therefore ΔD=f (E, ΔE) (8)

And duty cycle for next step is calculated as follows

D (n+1) =D (n) + ΔD(n) (9)

III-1(ii) Selection of Perturbation Frequency:

The other MPPT controller variable is perturbation frequency dependent. At a particular perturbation applied to the system, it takes some settling time in the next operating point. So time period or delay time is calculated per iteration using linear formula dependent on frequency.

Tdelay=h|ΔD|=a)01('b + DΔ×'

where h is a variable & a' and b' are constant values.

III-2 Generating Perturbation step size

III-2(i) Proposed function based MPPT technique:

The proposed function is formed by multiplication of a two-dimensional Gaussian function which is an exponential term and Arctangent function which is an inverse tangent term[12].

$$\Delta D = f(E,\Delta E) = -1.4312 \times \Delta D\max \times \tan^{-1}\left(\frac{E-\Delta E}{\gamma}\right) \times e^{\left(-\left(a(E-\alpha)^2+2b(\Delta E-\beta)(E-\alpha)+c(\Delta E-\beta)^2\right)\right)} \quad (11)$$

where ΔDmax= maximum allowable step size of duty cycle, γ=constant

coefficients of a, b and c are calculated by using following formulae and can be determined based on trial and error method, but in general this can be done by using any optimization algorithm considering performance indexes as objectives of optimization.

$\theta = \frac{\pi}{10}$, α = 0 , β =0 , γ = 5 , ΔDmax = 0.05, σE =40, σΔE=σΔE0 + k|E-ΔE|, σΔE0 = 0.5, k= 0.25

$$a = \frac{\cos^2\theta}{2\sigma^2 E} + \frac{\sin^2\theta}{2(\sigma\Delta E0 + k|E-\Delta E|)^2} \quad (12)$$

$$b = -\frac{\sin 2\theta}{4\sigma^2 E} + \frac{\sin 2\theta}{4(\sigma\Delta E0 + k|E-\Delta E|)^2} \quad (13)$$

$$c = \frac{\sin^2\theta}{2\sigma^2 E} + \frac{\cos^2\theta}{2(\sigma\Delta E0 + k|E-\Delta E|)^2} \quad (14)$$

By using Arctangent operator the step size will be always within preset bounds and it is an odd function which generates correct sign in valid-error area. It is also a smooth function and most of the programming languages have the predefined library of this function. So, the function and consequently MPPT algorithm can be easily implemented in low cost digital controllers. The γ value in this function can expand or condense the Arctangent graph in the plane. So, it can speed up/down the variation of perturbation size and consequently the dynamic response of MPPT. Furthermore, proper selection of γ can improve the steady state performance by limiting the oscillations around MPP. Another important feature that must be reflected in behaviour of proposed function is handling the false error situation. The Gaussian function has been used to damp the amplitude of step size in false-error area. When a large change occurs and *E* or *ΔE* varies with large value, the output of Gaussian function will get small in order to avoid large changes in duty cycle. The θ parameter has a significant influence on dynamic performance of algorithm by correct operation in false-error area. In fact, this parameter rotates the False-Error and Valid-Error areas and determines the boundaries between these areas. Consequently, it can affect the correct dynamic performance of the system. The other important parameters are σΔE, σΔE0 and K which determine the spread of Valid-Error area in E–ΔE plane.

III-2(iii). Proposed function based MPPT algorithm:

The proposed function MPPT digital controller algorithm flowchart is shown in Fig. 7. The control strategy of this algorithm is to continuously adjust the duty cycle perturbation values and adjust the perturbation frequency while observing the power. The proposed function MPPT algorithm mainly consists of two schemes: the adaptive determination of the perturbation values ΔD and the adaptive determination of perturbation periods Tdelay. After ΔD and Tdelay values are obtained, the duty cycle of the power stage is perturbed by ΔD and after waiting Tdelay period of time, the MPPT controller starts the next perturbation.

In the digital controller algorithm of Fig. 7, during the power algorithm perturbation cycle/iteration, duty cycle of DC-DC converter and power are denoted by $D(n)$ and $P(n)$, respectively. The duty cycle and power from the previous perturbation cycle/iteration are denoted by $D(n-1)$ and $P(n-1)$, respectively. The changes in the power and duty cycle from one cycle to the next are defined as

$$P\text{diff} = P(n) - P(n-1) \quad (15)$$

$$D\text{diff} = D(n) - D(n-1). \quad (16)$$

If the signs of *P*diff and *D*diff are the same, the duty cycle is incremented by ΔD and remains the algorithm in last perturbation direction of the duty cycle for Tdelay time If the signs of *P*diff and *D*diff are opposite, the duty cycle is decremented by ΔD and remains in last perturbation direction of the duty cycles for Tdelay time. The duty cycle value is always compared and limited to a minimum value *D*min and a maximum value *D*max.

The duty cycle for the next algorithm cycle is given by

$$D(n + 1) = D(n) \bullet + \Delta D(n) \quad (17)$$

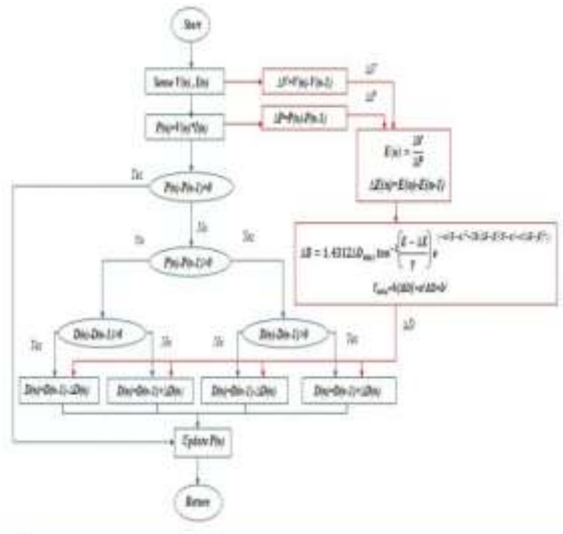


Fig.7.Flow chart of a complex function based MPPT technique

IV. SIMULATION

In the PV systems, the maximum power point tracker uses DC-DC converter to attain the maximum output voltage value of the PV panel. The proposed function based MPPT unit receives the output voltage and output current values of the PV panel, the computes the power using the relation (P=V*I). This is used for calculation of tracking error and change in the error, which determines the duty-cycle of the pulse width modulation to switch DC-DC converter.

The proposed function algorithm computes duty cycle as multiplication of Gaussian and arc tangent function operator at each sampling time.

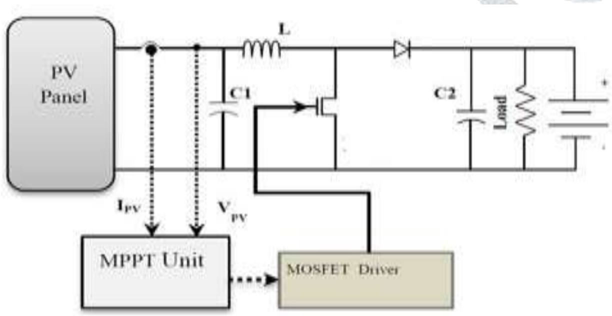


Fig.8.Typical PV system

The Gaussian function operator is exponential term of E, ΔE and other variables. Arc tangent function operator is inverse tangent function of E, ΔE and γ. Finally, a concrete value of duty cycle is generated for DC-DC converter with proper delay time.

V. SIMULATION RESULTS

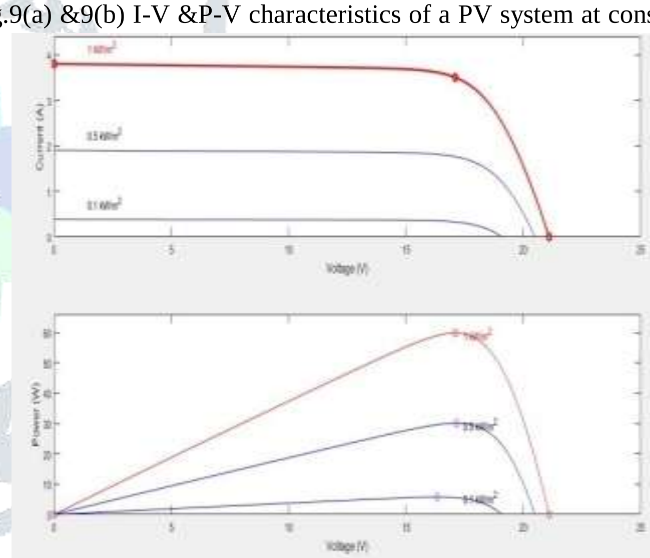
To evaluate the performance of proposed MPPT algorithm, a PV panel of 60 watts with proposed MPPT algorithm, DC-DC converter and resistance load has been simulated in MATLAB software. PV system electrical specifications have been provided in Table 1. DC-DC converter used in this technique is conventional boost regulator with a single MOSFET.

Table 1

PV system electrical specifications	
Parameters of PV system	
Maximum power (Pmax)	60 watts
MPP voltage(Vmpp)	23.1 V
MPP current (Impp)	2.5 A
Voc	30 V
Isc	2.66 A
Temperature coefficient of Isc	0.024%/℃
Temperature coefficient of Voc	-0.0356%/℃
Parameters of Boost converter	
Input Capacitance	100uF
Output Capacitance	1000uF
Inductance	1000uF

Modeling of PV system in MATLAB/Simulink are simulated and it's simulation results i.e; Operational curves at different irradiances is shown in Fig.9(a) & 9(b) and Operational curves at different temperatures is shown in Fig.9(c) &9 (d).

Fig.9(a) &9(b) I-V &P-V characteristics of a PV system at constant



temperature(25℃) and at different Irradiance

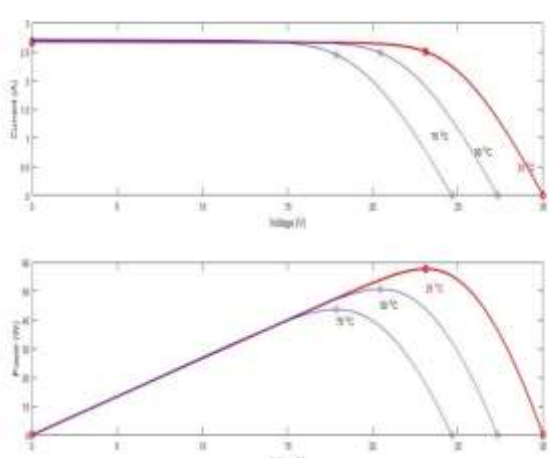


Fig.9(c) & 9(d) I-V &P-V characteristics of a PV system at constant Irradiance(1000w/m^2) and at different Temperature.

Output power of PV system with MPPT control algorithm at sudden irradiance changes is shown in Fig.10 which is almost 57.95 watts with very fewer oscillations.

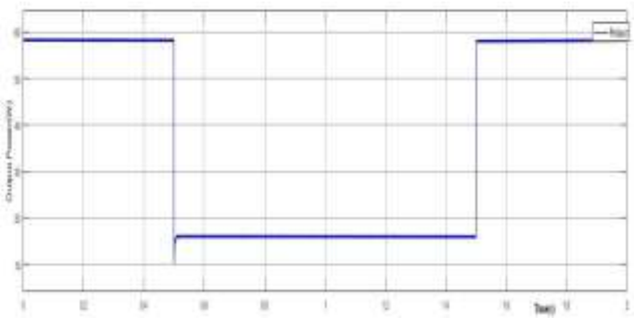


Fig.10 Output PV power with MPPT control algorithm

PV system	Output Power
PV system without MPPT technique	55 watts
PV system with proposed function based MPPT technique	57.95 watts

Table 2

VI. CONCLUSION

In this paper, designing and modeling of PV system are analyzed. Designing and implementation of a complex function based MPPT technique is analyzed in order to control photovoltaic system. Since an efficient MPPT technique is crucial to increase the PV output power, a novel MPPT algorithm is chosen to control the photovoltaic system. This MPPT algorithm improves the PV output power from 55watts to 57.95watts with very fewer oscillations and behaves robustly in case of load variations and the other major advantage is its simplicity of design. Even though computational costs are high, it can be easily implemented in low cost micro-controllers. This feature makes it suitable for tracking fast irradiance changes like mobile solar applications.

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