Comparative Study of Maximum Power Point Trackers for PV system

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Abstract- Photovoltaic (PV) generation is gaining increased importance as a renewable source due to its advantages like absence of fuel cost, little maintenance and no noise etc. However photovoltaic cell characteristics are non-linear and largely influenced by solar radiation and temperature. The power output of a PV array changes with varying temperature and irradiation. A maximum power point tracking algorithm is investigated to obtain maximum power from a PV array on varying operating conditions. So far various methods have been proposed to achieve the maximum power from PV module. This work proposed a Golden Section Search MPPT algorithm which has guaranteed convergence under variable atmospheric conditions. The performance of this algorithm is simulated for different irradiation levels. Further, meaningful comparison has been made between proposed method and steepest-descent based MPPT algorithm which is based on the slope of P-V characteristics with respect to the power output at the load side. These systems are modeled and simulated in MATLAB/Simulink environment and results are presented.

Keywords – Photovoltaic cell, maximum power point tracking, Golden section search algorithm, Steepest-descent based MPPT algorithm

I. INTRODUCTION

Due to diminishing deposits of non-renewable energy resources, high oil prices and increasing damages to our environment, the renewable sources of energy have been attained a special importance[1]. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard. A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes[2]. The monocrystalline and polycrystalline silicon cells are the only found at commercial scale at the present time. The solar cell characteristics are non-linear and largely influenced by solar radiation, temperature and load condition[3]. However PV power fluctuates depending on weather conditions, seasons and geographic location. [4].This may cause problems like voltage fluctuation and large frequency deviation in electric power system operation. There exist a peak power corresponding to a particular voltage and current[5].It is desirable to operate the module at peak power point so that the maximum power can be delivered to the load under varying temperature and insolation condition. Maximum power point tracking is used for extracting the maximum power from the PV module and transfer that power to the load. The power output of a PV array changes with varying temperature and irradiation[6] A maximum power point algorithm is investigated to obtain maximum power from a PV array on varying operating conditions. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar array and thus is effective in the field of utilization of renewable sources of energy[7]. A number of MPPT techniques are proposed and implemented. P&O and incremental conductance techniques have almost similar structures and their accuracy and response time are dependent on perturbsize of PV output voltage or current. Another class of MPPT techniques is also considered in which MPPT techniques that use empirical formulae for MPP calculation such as fractional open circuit voltage (FOCV) and fractional short circuit (FSCI) techniques[8]. The empirical formulae are usually dependent on PV system dynamics and hence perform properly when PV system dynamics degraded due to accidental damage, aging etc. Hence, an alternate class of MPPT techniques are used which consists of MPPT techniques such as Newton-Raphson based MPPT and steepest-descent based MPPT techniques that are very fast and accurate[9]. Newton-Raphson technique has to deal with both single and double derivative terms of PV power in its algorithm hence very complex. This complexity is simplified in steepest-descent technique because it has only the single derivative of PV power term. The steepest-descent based MPPT [10] has shown less improvement in MPPT efficiency despite using a variable step-size and a complex of derivative calculation mechanism. This paper proposes a Golden Section Search (GSS) MPPT algorithm which uses voltage as the search variable[11]. This algorithm distinctly has certain advantages like noise and signal fluctuations immunity, fast convergence as compared to many other MPPT algorithms. The MPPT algorithm is developed with the limiting parameters for fast convergence and has been implemented using Matlab/SIMULINK.

II. MATHEMATICAL MODEL OF PV ARRAY

A photovoltaic cell is the building block of a solar panel. The semiconductor device that transforms solar light in electrical energy is termed as 'Photovoltaic cell', and the phenomenon is named as 'Photovoltaic effect'.

To size a solar PV array, cells are assembled in form of series-parallel configuration for requisite energy. The electric power generated by a solar PV array fluctuates depending on the operating conditions and field factors such as the sun's geometric location, irradiation levels and ambient temperature. A solar cell is a non-linear device and can be represented as a current source model as shown in Figure 2.1. The current source Iph represents the cell photo current, Id is reverse saturation current of diode, Rsh and Rs are the intrinsic shunt and series resistance of the cell respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules, which are further interconnected in a parallel-series configuration to form PV arrays or PV generators.

Considering only a single photovoltaic cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of photovoltaic cell.

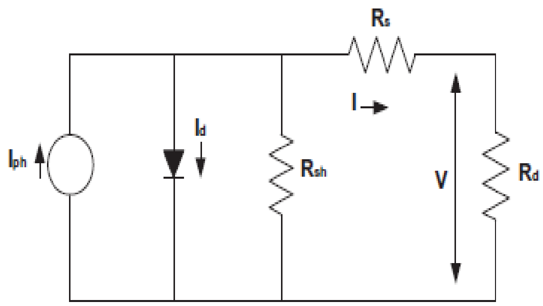

Fig 2.1: Equivalent circuit of a photovoltaic cell

Based on the equivalent circuit of cell, cell output current can be written as,

$$I = I_{ph} - I_D - I_{sh} \qquad (2.1)$$

The photo current Iph depends on the solar radiation and the cell temperature as given by:

$$I_{ph} = [I_{sc} + K_1(T - 298)]\frac{\beta}{1000} \qquad (2.2)$$

Current through diode is given by

$$I_D = I_o\left(e^{q\frac{V+IR_s}{KTA}} - 1\right) \qquad (2.3)$$

Current through shunt resistance,

$$I_{sh} = \frac{V + IR_s}{R_{sh}} \qquad (2.4)$$

Cell saturation current I_o varies with cell current which can be relate by the equation given below:

$$I_o = I_{rs}\left(\frac{T}{296}\right)^3 e^{\frac{qE_g\left(\frac{1}{298} - \frac{1}{T}\right)}{KA}} \qquad (2.5)$$

Reverse saturation current at the reference temperature can be approximately obtain as

$$I_{rs} = \frac{I_{sc}}{\left(\frac{T}{298}\right)^3 e^{\frac{qE_G\left(\frac{1}{298} - \frac{1}{T}\right)}{KA}}} \qquad (2.6)$$

Since a typical PV cell produces less than 2W at 0.6 V approximately, the cells must be connected in series-parallel configuration on a module to produce enough high power. In fact, the PV efficiency is sensitive to small change in

Rs but insensitive to variation in Rsh. For a PV module, the series resistance becomes apparently important and the shunt down resistance approaches infinity which is assumed to be open. In most commercial PV products. PV modules are then arranged in series-parallel structure to achieve desired power output. PV modules are then arranged in series-parallel structure to achieve desired power output.The mathematical model of generalized model can be obtained as :

$$I = N_p I_{ph} - N_P I_0 \left(e^{\frac{q\left(\frac{V}{N_s}+\frac{IR_s}{N_P}\right)}{KTA}} - 1\right) \quad (2.7)$$

Where ,
Iph : Photogenerated current
q :Charge of electron
K : Boltzmann’s constant(j/K)
A : Ideal factor depend on PV technology
Eg : Band gap energy of semiconductor
Isc : Short circuit current
Ki : Cell’s short circuit current temperature coefficient

III. PROPOSED MPPT ALGORITHM

The Golden Section Search is a technique for finding extremum (minimum or maximum) by sequential narrowing the range of values inside which extremum exists. The Golden Section Search (GSS) technique is used for finding maximum value of a function by successive narrowing the range of values inside which function existsThe main aim is to find maximum functional value of f(x) within the input interval [a b].Two points x1 and x2 are selected in the interval [a, b] and function f(x) is evaluated at these points. The points x1 and x2 are such selected each point subdivides interval into two parts such that :
Length of whole line / Length of larger fraction = Length of larger fraction / Length of smaller fraction.
Assume a line segment [0, 1] as shown in Fig 3.1 then 1/r = r/1-r
i.e. r2+r-1=0, hence, r=0.618
x1 = b- r (b-a) i.e. x1 is 0.618 of interval away from ‘b‘ (1)
x2= a+ r (b-a) i.e. x2 is 0.618 of interval away from ‘a‘ (2)

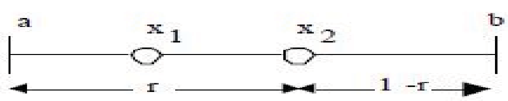

Fig 3.1: Division of interval

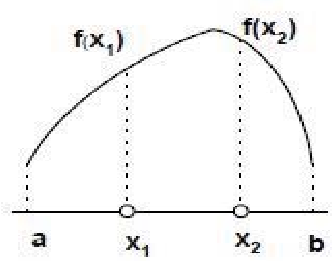

Fig 3.2: Interval markings on characteristics

When GSS is applied to photovoltaic system for maximum power point tracking, the P-V characteristics is the operating characteristics wherein f(x) correspond to power whose maximum value has to be tracked is to be and x1 and x2 corresponds to array voltage. The range of operation is from zero to open circuit voltage (Voc), i.e. a=0 and b=Voc. The flowchart for finding the maxima of a function using GSS is shown in Fig.3.3. When GSS is applied to photovoltaic system for maximum extraction of power, the P-V characteristics is the operating characteristics wherein f(x) corresponds to the power that is to be maximized and x1 and x2 corresponds to array voltage, the voltage is used as the search variable.. The GSS computes the voltage (Vref) that corresponds to the maximum power point for the corresponding operating condition i.e. irradiation and temperature level.

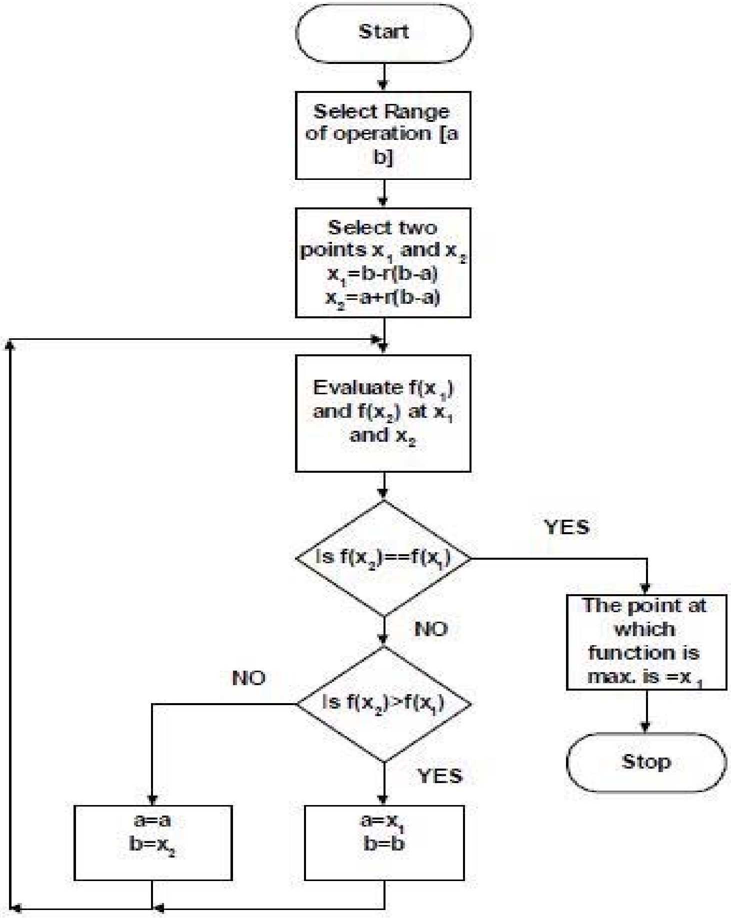

Fig 3.3: Flowchart of GSS algorithm

A. STEEPEST-DESCENT BASED MPPT

The proposed SDMPPT algorithm is a steepest-descent algorithm and described as follows. The MPPT tracking problem considers the maximization of power, *p*, which can be achieved by

$dp/dv = 0$

Let, F(X) denotes dp/dv where *X* represents the control variable *v*. The necessary condition for achieving Pmpp is that F(X) should be differentiable. *X* is initialized by taking the value of Vmpp that is provided in the manufacturer's datasheet. dp/dv is calculated as follows.

dp/dv= dp/dt/dv/dt

where dp/dt is change in PV power (dp) for a very small timespan (dt) and dv/dt is change in PV voltage (dv) for same small time-span dt. Flowchart of steepest-descent based MPPT algorithm is shown below:

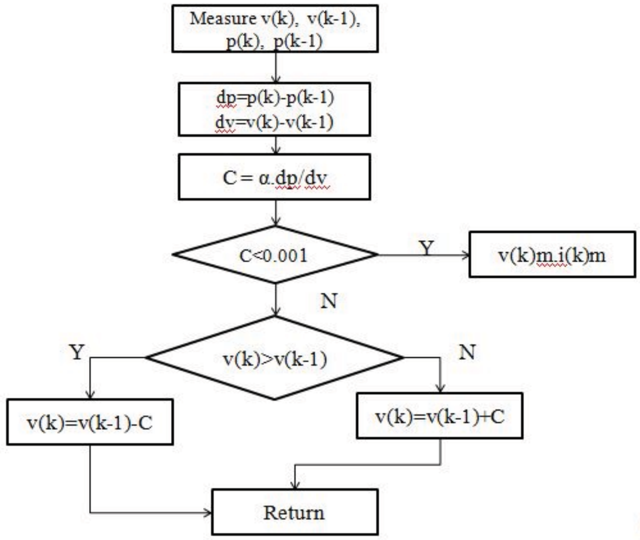

Fig 3.4 :Flowchart of SDMPPT

IV.SIMULATION AND RESULTS

Fig: 4.1 and Fig 4.2 are the characteristics of photovoltaic array which is obtained when the mathematical equations that are representing the photovoltaic array is simulated in MATLAB. From the simulation, the maximum power point is obtained as 79W.

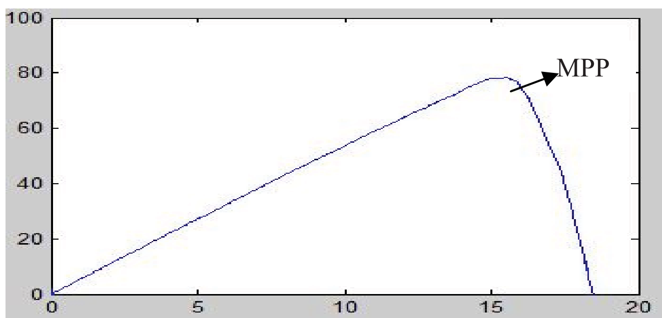

Fig 4.1: P-V characteristics for 1000w/m^2

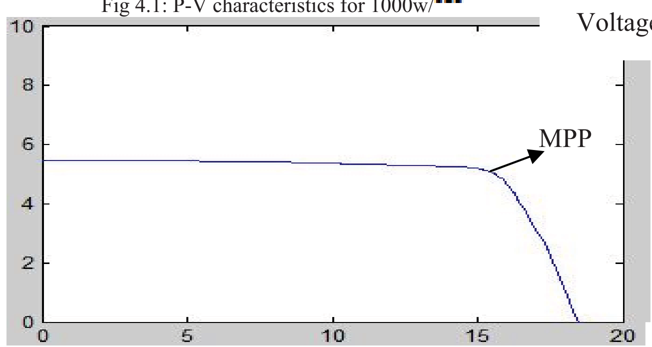

Fig: I-V characteristics for 1000w/m^2

SIMULINK MODEL OF PROPOSED PHOTOVOLTAIC SYSTEM

According to the maximum power transfer theory, the power delivered to the load is a maximum when the source internal impedance matches the load impedance. A DC-DC converter (step up) can be used to serve the purpose of transferring maximum power from the solar PV module to the load. The converter is able to draw maximum power from the PV panel for a given solar insolation and temperature by adjusting the duty cycle of the switching device**.** So the system model consists of a DC-DC boost converter along with a resistive load. Here MOSFET is used as the switching device and a pulse generator is used to trigger gate pulses to it. Both the MPPT algorithms are programmed in Embedded Matlab functions. The output from the MPPT unit is a reference voltage which is used to generate a PWM signal that controls the output of system. Voltage is measured by a voltage measurement unit across the photovoltaic array. This voltage along with the current from array is used to get the power output of PV array. The below shown waveforms corresponds to an insolation level of 1000w/m^2 and 323 k temperature for both the MPPT algorithms .

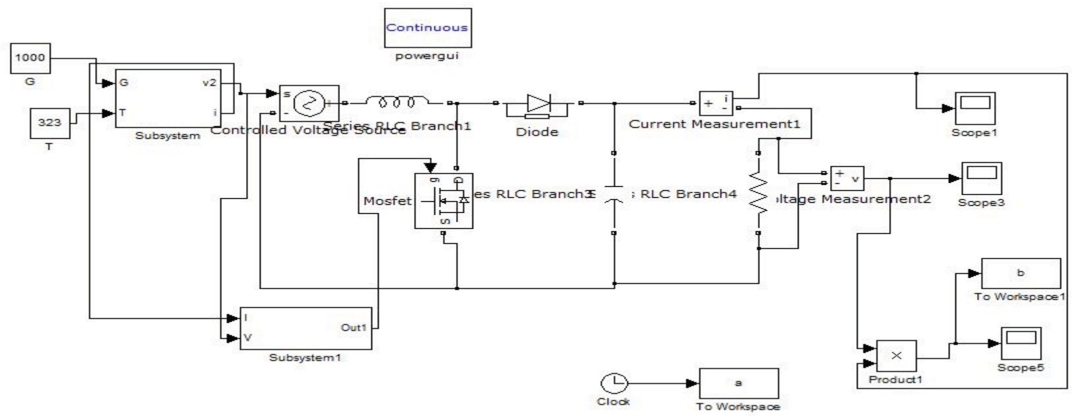

Fig 4.3: Simulink model of complete system

A. GOLDEN SECTION SEARCH MAXIMUM POWER POINT TRACKING METHOD

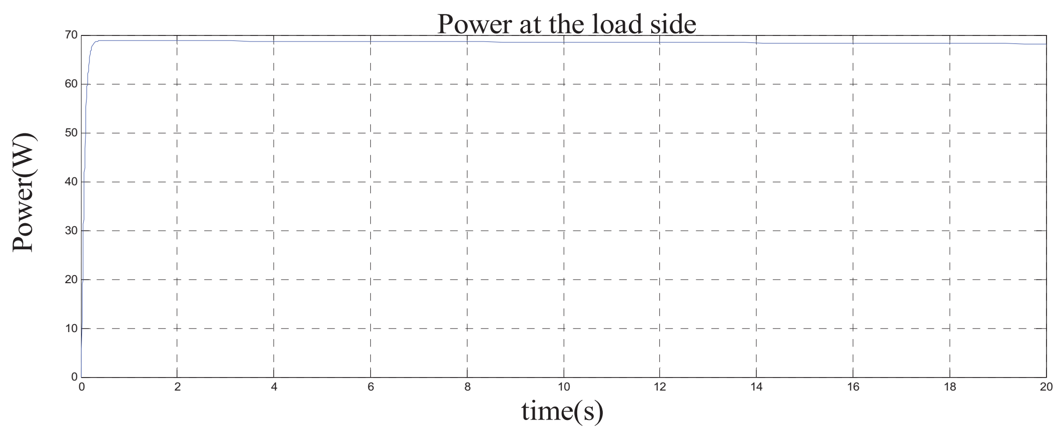

Fig 4.4 Power output for 1000w/m^2

B. STEEPEST-DESCENT BASED MAXIMUM POWER POINT TRACKING METHOD

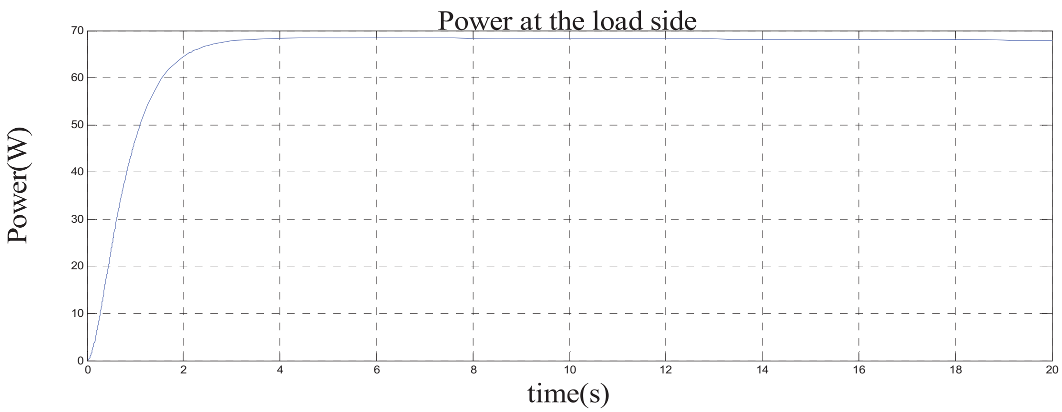

Fig 4:5: Power output for 1000w/m^2

Table 4.1: Performance characteristics of MPPT techniques

MPPT TECHNIQUE	Settling Time	Convergence Speed	Implementation complexity	Sensed Parameters
SDMPPT	3 sec	Slow	Low	Voltage, Current
GSS MPPT	0.4 sec	Fast	Low	Voltage, Current

V. CONCLUSION

This work is used to highlight the difference between the maximum power point tracking algorithms, steepest-descent based MPPT algorithm and golden section search MPPT algorithm. The power output using both the MPPT algorithms are same under same operating conditions. Golden section search algorithm has faster convergence than steepest-descent based MPPT algorithm. Also golden section search algorithm has less peak amplitude when compared to steepest-descent based MPPT algorithm. Therefore it was seen that using the golden section search MPPT technique, the output performance can be improved in minimum time when compared to steepest-descent based MPPT algorithm.

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