Direct Control Method Applied For Improved Incremental Conductance MPPT Using SEPIC Converter

Jerin George K

Department of Electrical & Electronics Engineering, M E A Engineering College, Perithalmanna, Malappuram, Kerala, India.

Abstract-**Solar energy forms the major alternative for the generation of power keeping in mind the sustainable development with reduced greenhouse emission. For improved efficiency of the MPPT which uses solar energy in photovoltaic systems(PV), this paper presents a technique utilizing improved incremental conductance(IncCond) MPPT with direct control method using SEPIC converter. Several improvements in the existing technique is proposed which includes converter design aspects, system simulation & DSP programming. For the control part dsPIC30F2010 is programmed accordingly to get the maximum power point for different illuminations.DSP controller also forms the interfacing of PV array with the load. Now the improved IncCond helps to get point to point values accurately to track MPP's under different atmospheric conditions.MATLAB and Simulink were employed for simulation studies validation of the proposed technique. Experiment result proves the improvement from existing method.**

Keywords-Incremental Conductance (IncCond), Maximum power point tracking (MPPT),Digital Signal processor(DSP),Single ended primary inductance converter (SEPIC),photovoltaic (PV) system.

I.INTRODUCTION

Solar power is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP). Photovoltaic's convert light into electric current using the photoelectric effect.Photovoltaics were initially, and still are, used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array. They are an important and relatively inexpensive source of electrical energy where grid power is inconvenient, unreasonably expensive to connect, or simply unavailable. Solar produce direct current (DC) power which fluctuates with the sunlight's intensity. For practical use this usually requires conversion to certain desired voltages or alternating current (AC), through the use of inverters. Multiple solar cells are connected inside modules. Modules are wired together to form arrays, then tied to an inverter, which produces power at the desired voltage, and for AC, the desired frequency/phase. Many residential systems are connected to the grid wherever available, especially in developed countries with large markets. In these grid-connected PV systems[13], use of energy storage is optional. In certain applications such as satellites, lighthouses, or in developing countries, batteries or additional power generators are often added as back-ups. Such stand-alone power systems[14] permit operations at night and at other times of limited sunlight [1].Also solar power systems has less amount of green house gases emission. Now despite the long list of advantages, its efficiency[2] are hindered for power generation because of many factors which include intensity of sunlight, cloudy weather, increase in ambient temperature reduce PV array output power and so on [3].Each PV cell produces energy pertaining to its operational and environmental conditions [4],[5].

Now for tackling with the problems of the poor efficiency of PV systems several concepts and methods were proposed among which the present technique used is Maximum power point tracking technique (MPPT). Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology[15].Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors. This paper focuses on the control scheme of how variable step size incremental conductance and DSP controller tracks the maximum power generated from photovoltaic panel which is used to drive load by SEPIC converter. Also MATLAB Simulink are employed for simulation studies and result verification

II.PROPOSED METHODOLOGY

A new MPPT method have been developed using single ended primary inductance converter (SEPIC) which forms the DC-DC Converter block. The converter act as an interference between PV module and load.MPPT systems are controlled using variable step size Incremental conductance and DSP.The block diagram of the proposed system is shown in Fig 1.The system consists of PV array, SEPIC Converter, DSP Controller along with variable step size incremental conductance algorithm [6] for MPPT.Here the solar radiation is converted into electrical power. The proposed method uses PV array of 50V,5A rating. DSP block has the function of implementing algorithm and conversion of the power from analog form to digital for processing in DSP and enabling proper PWM command for driving the converter. The switching of the SEPIC converter takes place as per the signals generated from DSP according to the algorithm implemented for MPPT.Hence the system tracks MPP and the load is maintained to operate at maximum power.

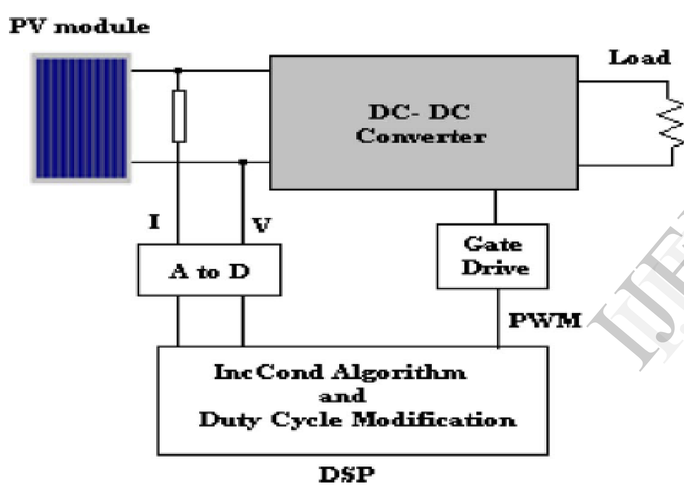

Fig.1.Block Diagram of proposed methodology

III.PHOTOVOLTAIC MODEL FOR MPPT

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept part and create a photocurrent which is directly proportional to solar irradiance.

A solar cell thus can be basically represented by a PN junction. Under dark condition only reverse saturation current of diode is present. Under illumination photo currents are generated. Hence a solar cell can be represented as in Fig.2.Represenatation of a solar cell as below.

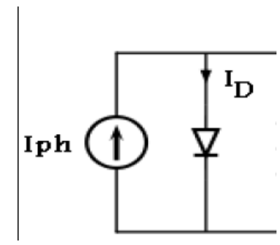

Fig.2.Represenatation of a solar cell

Practically, series and shunt resistances are present as shown in Fig.3.Equivalent circuit PV model.

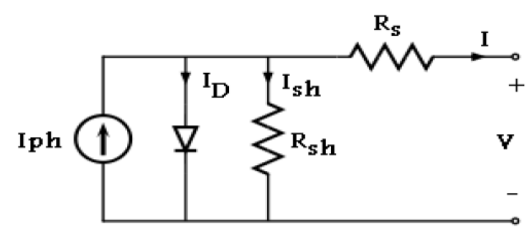

Fig.3.Equivalent circuit PV model.

Under dark condition, reverse saturation current at standard temperature is given by,

$$I_{RS} = \frac{I_{SC}}{e^{\frac{qV_{oc}}{N_s k T_{rk} n}} - 1} \qquad (1)$$

Where, $q = 1.6 \times 10^{-19} C$, $k = 1.38 \times 10^{-23}\, {}^{J}/_{K}$,

V_{oc} = open circuit voltage of cell at 25°C

T_{rk} = 293 K(std temperature) T_k = working temperature

n = diode factor, vary for material(for Silicon, n = 1.6)

I_{sc} = short circuit current of cell at 25°C

E_g = band gap energy

a = temperature coefficient = $0.65 \times 10^{-3}\, {}^{A}/_{C}$

And reverse saturation current at any temperature, T_k is given by,

$$I_S = I_{RS}\left(\frac{T_k}{T_{rk}}\right)^{3/n} e^{\frac{qE_g\left(\frac{1}{T_k}-\frac{1}{T_{rk}}\right)}{nk}} \qquad (2)$$

Photon current is given by

$$I_{ph} = GI_{SC}\left(1 + a(T_k - T_{rk})\right) \qquad (3)$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 1, January - 2014

Where G is irradiance in $^{kW}/_{m^2}$ Then terminal current is given by,

$$I = N_p I_{ph} - N_p I_S (e^{\frac{q\left(\frac{V}{N_s}+IR_s\right)}{kT_k a}} - 1) - \frac{N_p V}{R_{sh}(N_s + IR_s)} \quad (4)$$

Where Np and Ns is the number of solar cells connected in parallel and series to increase current and voltage rating.

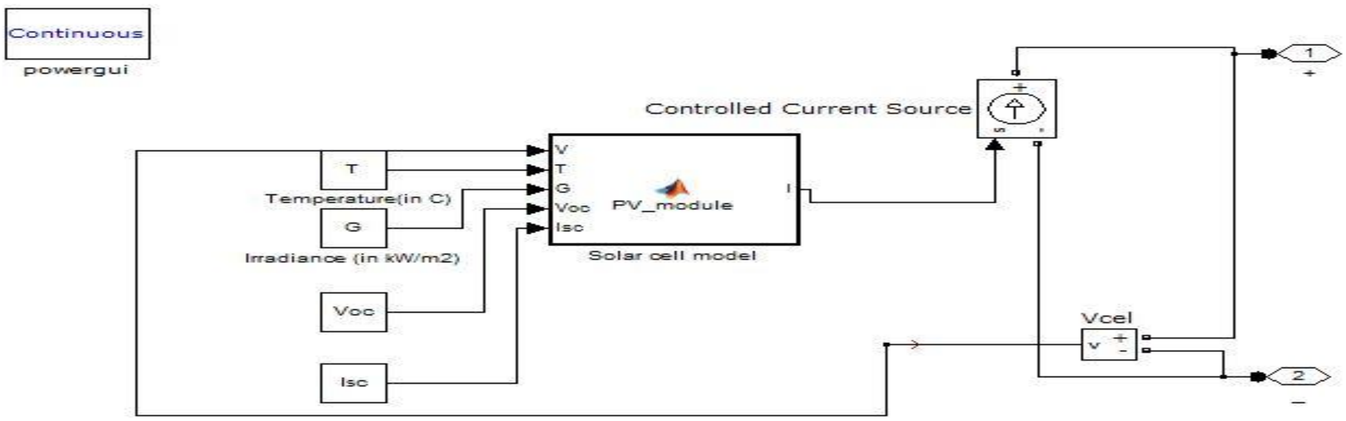

Fig.4.MATLAB Simulink Model of PV array

A.MATLAB SIMULINK MODEL OF PV ARRAY

Solar cell can be realized in MATLAB [7] as shown in figure below using the current controlled source which is controlled by MATLAB embedded function block which solves solar model equation with Newton's Algorithm. A general block diagram of the PVA model for GUI environment of simulink is shown in Fig.4.This block contains the sub models that are connected to build final model. The PVA array consists of 6 PV cells all connected in series to have desired voltage output. Depending upon the load required, the number of parallel branches can be increased to 2 or more. The effects of temperature and solar irradiation levels are represented by two gain blocks.

IV.PROPOSED ALGORITHM & CONTROL METHOD

A.VARIABLE STEP SIZE INC MPPT

The step size for the INC MPPT method is generally fixed. The power drawn from the PV array with a lager step size contributes to faster dynamics but excessive steady state oscillations, resulting in a comparatively low efficiency. This situation is reversed while the MPPT is running with a smaller step size. Thus, the MPPT with fixed step size should make a satisfactory tradeoff between the dynamics and oscillations. Such design dilemma can be solved with variable step size iteration.

The flowchart of the modified variable step size INC MPPT algorithm is shown in Fig. 5, where the converter duty cycle iteration step size is automatically tuned. The PV output power is employed to directly control the converter duty cycle, contributing to a simplified control system. Note that $V(k)$ and $I(k)$ are the PV array output voltage and current at time k. In addition, $D(k)$ and step are the duty cycle and change of duty cycle (step size), respectively. The variable step size adopted to reduce the problem.

$$D(k) = D(k-1) \pm N * |dP|/|dV| \quad (5)$$

where coefficient N is the scaling factor which is tuned at the design time to adjust the step size. Thus, $|dP|/|dV|$ is also employed herein to determine the variable step size for the INC MPPT algorithm.

$$D(k) = D(k-1) \pm N * \frac{|P(k) - P(k-1)|}{|V(k) - V(k-1)|} \quad (6)$$

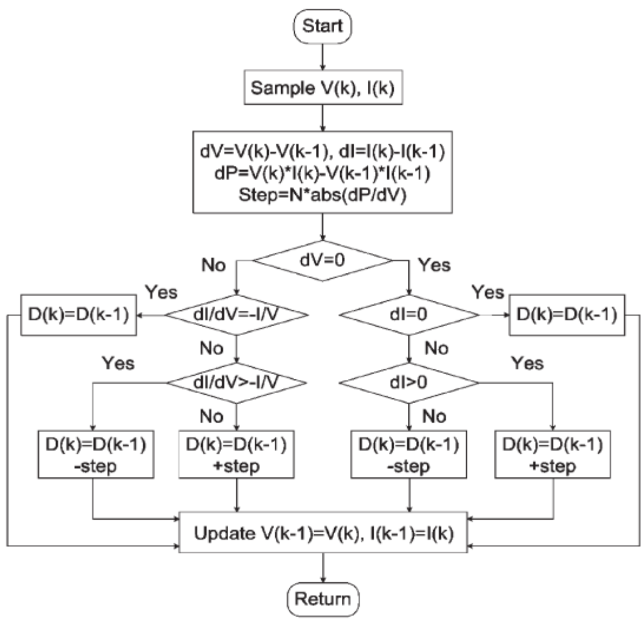

Fig.5.Flowchart of variable step size INC algorithm

Scaling factor N essentially determines the performance of the MPPT system. Manual tuning of this parameter is tedious and the obtained optimal results may be valid only for a given system and operating condition. A simple method to determine the scaling factor is proposed here. Comparatively large step size ΔD_{max} for fixed step size MPPT operation is initially chosen. With such value, the dynamic performance is good enough, while the steady-state performance may not be satisfactory. The steady-state value instead of dynamic value in the startup process of the derivative of PV array output power to voltage can be evaluated under the fixed step size operation with ΔD_{max}, which will be chosen as the upper limiter as the variable step size INC MPPT method. It is known that $|dP|/|dV|$ is almost at its lowest value around the PV MPP. To ensure the convergence of the MPPT update rule, the variable step rule must obey the following:

$$N * \frac{|dP|}{|dV|} < \Delta Dmax \qquad (7)$$

where $|(dP/dV)|$fixed step$=\Delta D_{max}$ is the $|dP|/|dV|$ at fixed step size operation of ΔD_{max}. The scaling factor can therefore be obtained as

$$N < \frac{\Delta Dmax}{\frac{|dP|}{|dV|}} \qquad (8)$$

If above equation cannot be satisfied, the variable step size INC MPPT will be working with a fixed step size of the previously set upper limiter ΔD_{max}. Equation provides a simple guidance to determine the scaling factor N of the variable step size INC MPPT algorithm. With the satisfaction of above equation, larger N exhibits a comparatively faster response than a smaller N. The step size will become tiny as dP/dV becomes very small around the MPP.

B. DIRECT CONTROL METHOD

Conventional MPPT systems have two independent control loops to control the MPPT. The first control loop contains the MPPT algorithm[9], and the second one is usually a proportional (P) or P–integral (PI) controller. The main purpose of the second control loop is to make the error from MPPs near to zero. Simplicity of operation, ease of design, inexpensive maintenance, and low cost made PI controllers very popular in most linear systems. However, the MPPT system of standalone PV is a nonlinear control problem due to the nonlinearity nature of PV and unpredictable environmental conditions, and hence, PI controllers do not generally work well . In this paper, the variable step size IncCond method with direct control is selected. The PI control loop is eliminated, and the duty cycle is adjusted directly in the algorithm. The control loop is simplified, and the computational time for tuning controller gains is eliminated. To compensate the lack of PI controller in the proposed system, a small marginal error of 0.002 was allowed. The objective of this paper is to eliminate the second control loop and to show that sophisticated MPPT methods do not necessarily obtain the best results, but employing them in a simple manner for complicated electronic subjects is considered necessary. DSP[8],[10],[12] generates pulse width modulation[11] (PWM) waveform to control the duty cycle of the converter switch according to the variable step size IncCond algorithm.

V.SEPIC CONVERTER

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. The efficiency of switch-mode dc–dc converters is widely used. Most switching-mode power supplies are well designed to function with high efficiency.

Among all topologies available, the single-ended primary inductance converter (SEPIC)[17] is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. It operates in continuous, discontinuous, or boundary conduction mode. SEPIC is controlled by the duty cycle of the control transistor. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. As with other switched mode power supplies specifically DC-to-DC converters, the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. A simple circuit diagram of a SEPIC converter is shown in Fig. 6, consisting of a coupling capacitor, C1 and output capacitor, C2; coupled inductors L1 and L2 and diode.

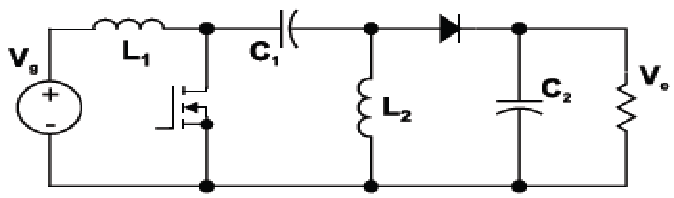

Fig.6.SEPIC Converter

Fig. 7 shows the circuit when the power switch is turned on. The first inductor, L1, is charged from the input voltage source during this time. The second inductor takes energy from the first capacitor, and the output capacitor is left to provide the load current. No energy is supplied to the load capacitor during this time. Inductor current and capacitor voltage polarities are also marked.

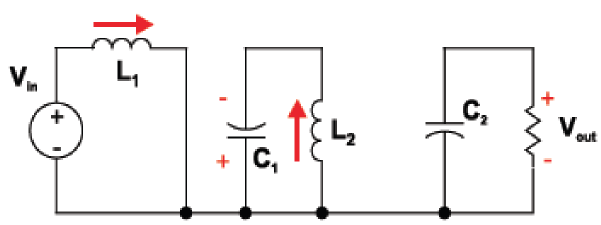

Fig.7.SEPIC converter ON state

When the power switch is turned off, the first inductor charges the capacitor C1 and also provides current to the load, as shown in Fig. 8. The second inductor is also connected to the load during this time. The output capacitor sees a pulse of current during the off time, making it inherently noisier than a buck converter.

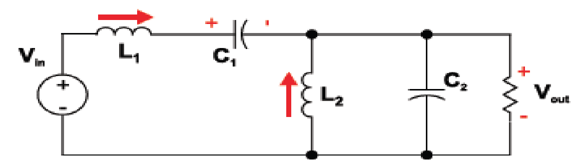

Fig.8.SEPIC converter OFF state

The formulae for calculation of duty cycle considering the design parameters of the SEPIC[16] converter are given below:

$$Dmin = \frac{Vout + Vd}{Vin(\max) + \mathrm{Vout}+\mathrm{Vd}} \qquad (9)$$

$$Dmax = \frac{Vout + Vd}{Vin(\min) + \mathrm{Vout}+\mathrm{Vd}} \qquad (10)$$

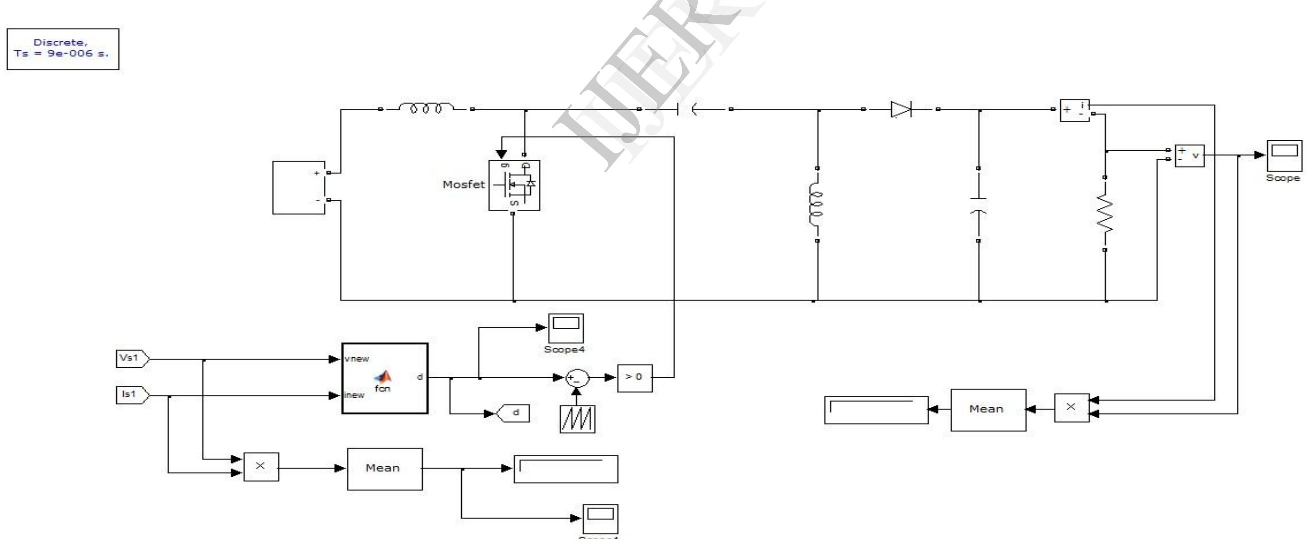

Fig.9.Simulink model of proposed system

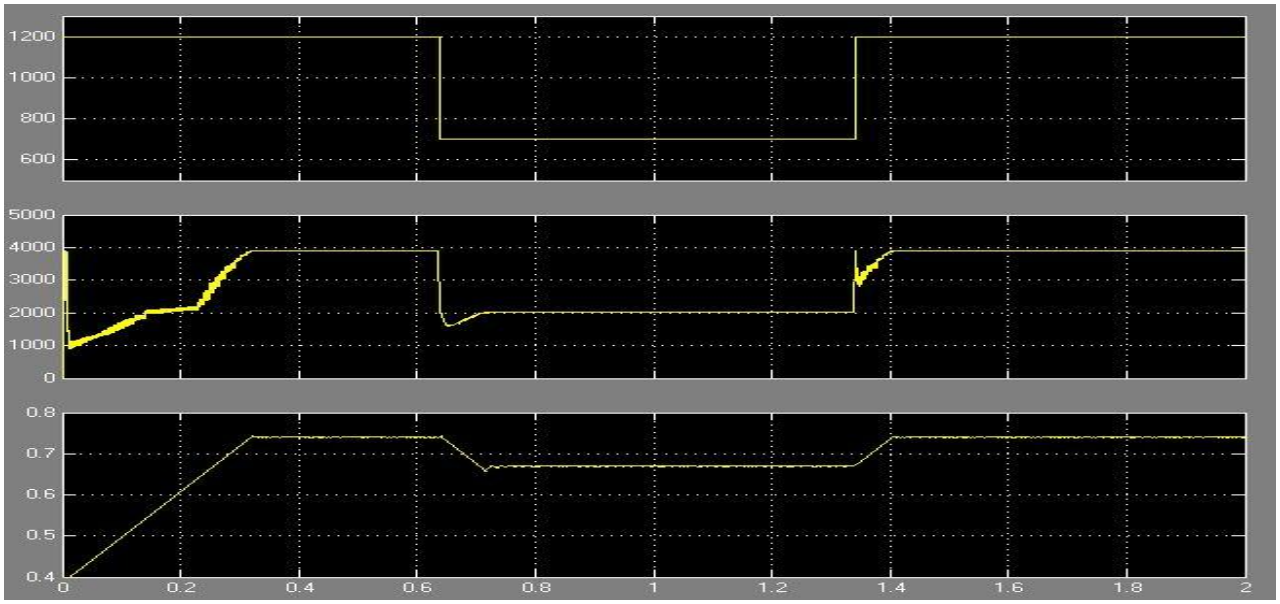

Fig.10.MATLAB Simulation of IncCond MPPT with change in illumination level, variation of power and duty cycle

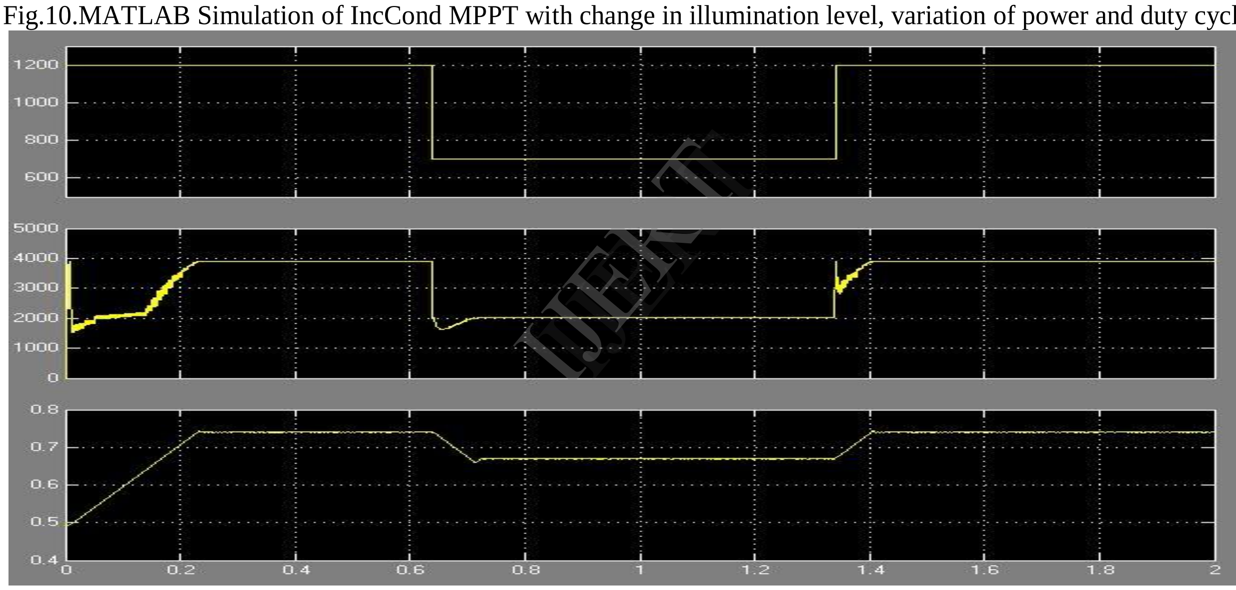

Fig.11.MATLAB Simulation of proposed variable step size IncCond MPPT for change in illumination level, variation of power & duty cycle

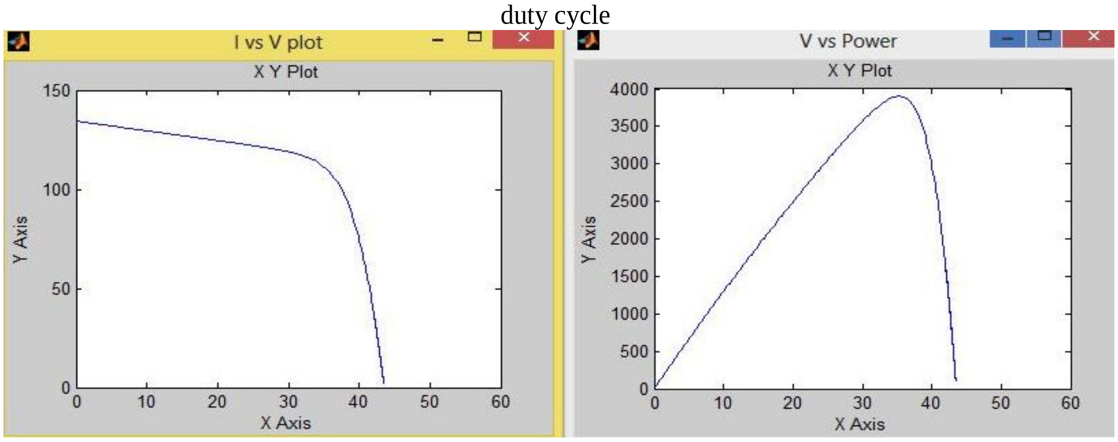

Fig.12.I-V Characteristics and P-V Characteristics of PVA Simulimk Model

VI.SIMULATION RESULTS

The diagram of the closed-loop system designed in MATLAB and Simulink is shown in Fig.9, which includes the PV array electrical circuit, SEPIC converter, and the MPPT Algorithm implemented for the proposed system. The PV array is modeled according to the design consideration discussed ins section III, Fig.12. shows the simulink output for I-V and P-V Characteristics of PV array.PV array current is fed to the converter and the DSP controller simultaneously.

Here PI control loop is eliminated and the duty cycle is adjusted directly in algorithm. To compensate the lack of PI controller in the proposed system, a small marginal error is allowed. To test the system operation the condition of changing irradiation was modeled. The temperature is constant at 25ºC,and the illumination level is varying between two levels wherein first illumination level is 1200W/m^2 at t=0s and for second illumination level it is 700W/m^2 at t=0.65s.Now the corresponding graphs in Fig 11,shows the improved efficiency of the variable step size IncCond algorithm from IncCond algorithm for change in illumination level and corresponding duty cycle and power variation.Fig10.,shows the variation of corresponding duty cycle and power with change in illumination with IncCond algorithm. The MPP tracking time is improved in variable step size INC algorithm.

VII.CONCLUSION

In this paper, a variable step size IncCond MPPT with direct control method was employed and the necessity of another control loop was eliminated. The proposed system was simulated, constructed and functionality of suggested control concept was proven advanced than the prevailing IncCond MPPT.Proper design of the PV array and the converter has made to it improve the efficiency of the existing system to track MPP.The proposed system is simple and easily constructed to achieve expected efficiency level of the PV module. So the proposed system reduce the steady state oscillations, power loss and system cost.

REFERENCES

[1] R.-J. Wai, W.-H. Wang, and C.-Y. Lin, “High-performance stand-alone photovoltaic generation system,” *IEEE Trans. Ind. Electron.*, vol. 55,no. 1, pp. 240–250, Jan. 2008.

[2] R. Faranda, S. Leva, and V. Maugeri, *MPPT Techniques for PV Systems: Energetic and Cost Comparison*. Milano, Italy: Elect. Eng. Dept. Politecnico di Milano, 2008, pp. 1–6.

[3] G. Petrone, G. Spagnuolo, R. Teodorescu, M. Veerachary, and M. Vitelli*: Reliability issues in photovoltaic power processing systems*. In IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2569–2580, Jul. 2008.

[4] N. Mutoh, M. Ohno, and T. Inoue, “A method for MPPT control while searching for parameters corresponding to weather conditions for PV generation systems,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1055–1065, Jun. 2006.

[5] K. H. Hussein, I. Muta, T. Hoshino, and M. Osakada, “Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions,” *Proc. Inst. Elect. Eng.—Gener., Transmiss. Distrib.*, vol. 142,no. 1, pp. 59–64, Jan. 1995.

[6] F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, “A variable step size INC MPPT method for PV systems,” *IEEE Trans. Ind. Electron.*, vol. 55, no. 7,pp. 2622–2628, Jul. 2008.

[7] F. M. González-Longatt, “Model of photovoltaic module in Matlab,” in *2do congreso iberoamericano de estudiantes de ingenierıacute;a eléctrica,electrónica y computación, ii cibelec*, 2005, pp. 1–5.

[8] C. Hua, J. Lin, and C. Shen, “Implementation of a DSP-controlled photovoltaic system with peak power tracking,” *IEEE Trans. Ind. Electron.*,vol. 45, no. 1, pp. 99–107, Feb. 1998.

[9] A. Pandey, N. Dasgupta, and A. K. Mukerjee, “Design issues in implementing MPPT for improved tracking and dynamic performance,” in *Proc. 32nd IECON*, Nov. 2006, pp. 4387–4391.

[10] E. Koutroulis, K. Kalaitzakis, and N. C. Voulgaris, “Development of a microcontroller-based, photovoltaic maximum power point tracking control system,” *IEEE Trans. Power Electron.*, vol. 16, no. 1, pp. 46–54, Jan. 2001.

[11] K. K. Tse, B. M. T. Ho, H. S.-H. Chung, and S. Y. R. Hui, “A comparative study of maximum-power-point trackers for photovoltaic panels using switching-frequency modulation scheme,” *IEEE Trans. Ind. Electron.*,vol. 51, no. 2, pp. 410–418, Apr. 2004.

[12] W. Wu, N. Pongratananukul, W. Qiu, K. Rustom, T. Kasparis, and I. Batarseh, “DSP-based multiple peak power tracking for expandable power system,” in *Proc. 18th Annu. IEEE Appl. Power Electron. Conf.Expo.*, Feb. 2003, vol. 1, pp. 525–530.

[13] E. Roman, R. Alonso, P. Ibanez, S. Elorduiza Patarietxe, and D. Goitia, “Intelligent PV module for grid-connected PV systems,” *IEEE Trans. Ind.Electron.*, vol. 53, no. 4, pp. 1066–1073, Jun. 2006.

[14] V. Salas, E. Olias, A. Barrado, and A. Lazaro, “Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems,”*Sol. Energy Mater. Sol. Cells*, vol. 90, no. 11, pp. 1555–1578, Jul. 2006.

[15] W. Xiao, W. G. Dunford, P. R. Palmer, and A. Capel, “Regulation of photovoltaic voltage,” *IEEE Trans. Ind. Electron.*, vol. 54, no. 3, pp. 1365–1374, Jun. 2007.

[16] “Designing DC-DC Converter based on Sepic topology”Texas Instruments incorporated by Jeff Falin.