ANALYSIS OF PHOTOVOLTAIC CELLS WITH CLOSED LOOP BOOST CONVERTER

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ABSTRACT

The Conventional sources of energy are rapidly depleting and cost of power has been escalating day by day. Thus an alternative renewable source of energy has become a vital necessity. Photovoltaic system is one of the most promising renewable sources of energy. Its ability to produce power by directly converting solar energy has led to tremendous surge in its demand. The output power generated by it is very less but can be increased by interfacing it with boost converter. Therefore we have proposed a model of Photovoltaic array interfaced with closed loop dc-dc boost converter which considerably steps up the output voltage which could meet the demand of power. In this paper the various characteristics of PV cells and design parameters of boost converter have been discussed in detail. The results and graphs of simulink and hardware model have been compared and discussed.

KEYWORDS: *Renewable source, Photovoltaic cells, solar energy, closed loop dc-dc boost converter, voltage.*

I. INTRODUCTION

Global warming and rise in prices of the conventional energy source (non-renewable source) has become a concerned issue. Conventional energy sources such as coal, natural gases and oil are the major energy sources but these are non-renewable energy sources therefore these sources of energy are decreasing day by day and are not able to meet the increasing demand of energy. These conventional sources of energy have led to serious environmental issues like greenhouse effect, air pollution, water pollution etc. which has led to global warming. Hence there has been a major increase in demand for renewable sources of energy.

Renewable energy sources also called non-conventional energy are sources that are continuously replenished by natural processes. For example, solar energy, wind energy, bio-energy - bio-fuels grown sustainably), hydropower etc., are some of the examples of renewable energy sources. Most of the renewable energy comes either directly or indirectly from sun and wind and can never be exhausted, and therefore they are called renewable [12]. Solar power is the conversion of sunlight into electricity. Photovoltaic (PV) energy appears quite attractive for electricity generation because of its noiseless, pollution-free, scale flexibility, and little maintenance [18]. The major advantage of these systems is that they can be simply adopted in existing buildings and can be installed anywhere [19]. Sunlight can be converted directly into electricity using photovoltaic’s (PV), or indirectly with concentrated solar power (CSP).Earth receives 174 petawatts (PW) of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to space and only 89 pw is absorbed by oceans and land masses. The spectrum of solar light at the Earth's surface is generally spread across the visible and near-infrared reason with a small part in the near-ultraviolet. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 EJ per year [13].

Photovoltaic systems (PV system) use solar panels to convert sunlight into electricity [14]. A solar panel (also solar module, photovoltaic module or photovoltaic panel) is a packaged, connected assembly of photovoltaic cells. Solar panels use light energy (photons) from the sun to generate electricity through the photovoltaic effect [15].The output power produced by the photovoltaic system is very less which is one of its main disadvantages. The boost converter can increase the dc input voltage [20]. Thus in this paper we have proposed a simulink as well as hardware model to step up the output voltage of photovoltaic system so that it can meet the needs of the load and produce high voltage. In the proposed system output of photovoltaic cells is connected to the input of closed loop dc-dc boost converter which steps up the low output dc voltage of PV cells to a considerably high voltage.

This paper is organised as follows, section 1 includes the introduction. In section 2 the designing of photovoltaic cell is discussed. In section 3 designing and working of closed loop boost converter is discussed in detail. In section 4 simulation model of PV array, closed loop boost converter and interfacing of PV array with closed loop boost converter is performed. In section 5 Matlab algorithms for photovoltaic system is proposed. In section 6 hardware implementation of photovoltaic cells with closed loop boost converter is performed and discussed. In section 7 comparisons between practical and theoretical results are discussed. In Section 8 results obtained have been discussed in details followed by Section 9 which includes the conclusion. In section 10 future works are discussed.

II. DESIGN OF PHOTOVOLTAIC CELL

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity:

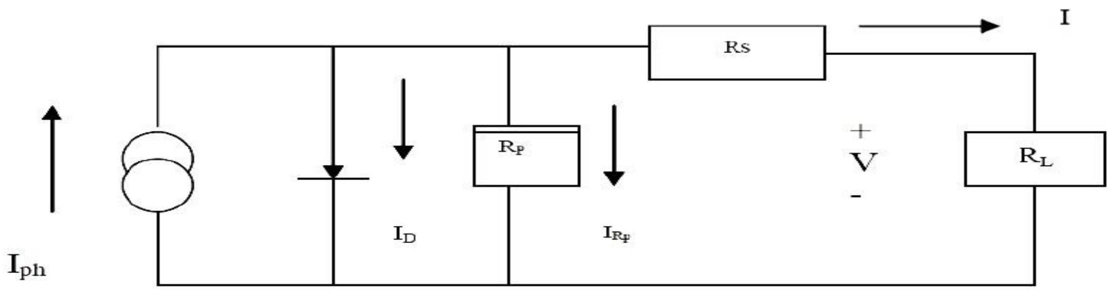

Fig1. Equivalent circuit of a PV cell

An ideal PV cell is modelled by a current source in parallel with a diode. Since no solar cell is ideal therefore shunt and series resistances are added to the model as shown in Fig1. RP is the equivalent shunt resistance which has a very high value [7]. RS is the intrinsic series resistance whose value is very small.

Applying Kirchhoff's law to the node where Iph, diode, Rp and Rs meet, we get

$$I_{ph}=I_D+I_{Rp}+I \quad (1)$$

Following equation is obtained for the photovoltaic current:

$$I= I_{ph}-I_{Rp}-I_D \quad (2)$$

$$I = I_{ph} - I_o\left[exp\left(\frac{V+IR_S}{V_T}\right)-1\right]-\left[\frac{V+IR_S}{R_P}\right] \quad (3)$$

Where, I_{ph} is the Insolation current, I is the Cell current, I0 is the Reverse saturation current, V is the Cell voltage, Rs is the Series resistance, Rp is the Parallel resistance, V_T is the Thermal voltage. K is the Boltzmann constant, T is the Temperature in Kelvin, q is the Charge of an electron.

Equivalent circuit of PV cell is shown in Figure 2[1].

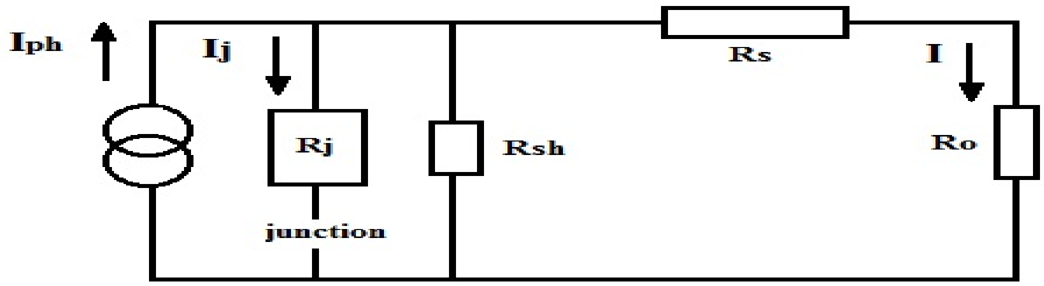

Fig2. Equivalent circuit of a PV cell.

An ideal solar cell is modelled by a current source in parallel with a diode. However no solar cells are ideal and therefore shunt and series resistances are added to the model. The current source Iph represents the cell photocurrent; Rj represents the nonlinear impedance of the p-n junction; Rsh and Rs are the intrinsic shunt and series resistances 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.

To simulate our PV array, a PV mathematical model was used according to the following set of equations:

$$I = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{q}{kTA}\frac{V}{n_S}\right) - 1\right] \tag{4}$$

where I is the PV array output current (A); V is the PV array output voltage (V); ns is the number of cells connected in series; np is the number of modules connected in parallel; q is the charge of an electron; k is Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); and Irs is the cell reverse saturation current. The factor A in eqn. 1.1 determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1 and 5, 1 being the ideal value [6]. In our case, A = 2.46.

The cell reverse saturation current Irs varies with temperature according to the following equation:

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \tag{5}$$

Where T, is the cell reference temperature, Irr is the reverse saturation current at Tr and EG is the band-gap energy of the semiconductor used in the cell.

The temperature dependence of the energy gap of the semiconductor is given by [16]:

$$E_G = E_G(0) - \frac{\alpha T^2}{T+\beta} \tag{6}$$

The photocurrent Iph depends on the solar radiation and the cell temperature as follows [7]:

$$I_{Ph} = [I_{scr} + k_i\,(T - T_r)]\,\frac{S}{100} \tag{7}$$

where Iscr is the cell short-circuit current at reference temperature and radiation, ki is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm2. The PV array power P can be calculated using equ.1.1 as follows:

$$P = IV = n_p I_{ph} V - n_p I_{rs} V\left[exp\left(\frac{q}{kTA}\frac{V}{n_s}\right) - 1\right] \tag{8}$$

III. DESIGN OF BOOST CONVERTER

The boost converter also known as the step-up converter is the basic dc–dc converter configuration with an output voltage higher than its input voltage [17]. A boost converter is designed to step up a supply of 6V to 22V.The design parameter include Inductor of 3.3mH and load R of 10kΩ. The diode carries about 0.5A average current and blocks about maximum voltage of 50V and suitable for fast switching. The reverse recovery time has to be more than 50ns. IN4007 is selected for this design, as it needs to block only about 22V.Electrolytic capacitor of 100 µF, having a high capability to withstand voltage up to 160 V is used. Mosfet IRF 640N has been used as a switch. Pulse with duty cycle of 72% with switching frequency of 300 kHz is supplied to the switch.

Block diagram of hardware model of closed loop boost converter is shown in fig3.As in figure 3 the key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores the energy. When the switch is opened, current will be reduced as the impedance is higher. Therefore, change or reduction in current will be opposed by the inductor. As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D. If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much. The output of boost converter is fed to the common of power transistor and pulse is given to the base. The output pulse of power transistor is obtained from emitter which is of the amplitude with respect to the output dc voltage of boost converter fed to the common of transistor. The output pulse of the power transistor is fed to the integrator circuit where the pulse is integrated to give a ramp signal. This output ramp signal is fed to a comparator circuit where it is compared with DC voltage to get the pulse of required duty ratio. This pulse is given to the switch of the boost converter and thus it completes a closed loop. Duty ratio of the pulse that is fed to the switch of boost converter is varied by the varying the DC voltage that is being compared in the comparator circuit with the output ramp signal of the integrator circuit.

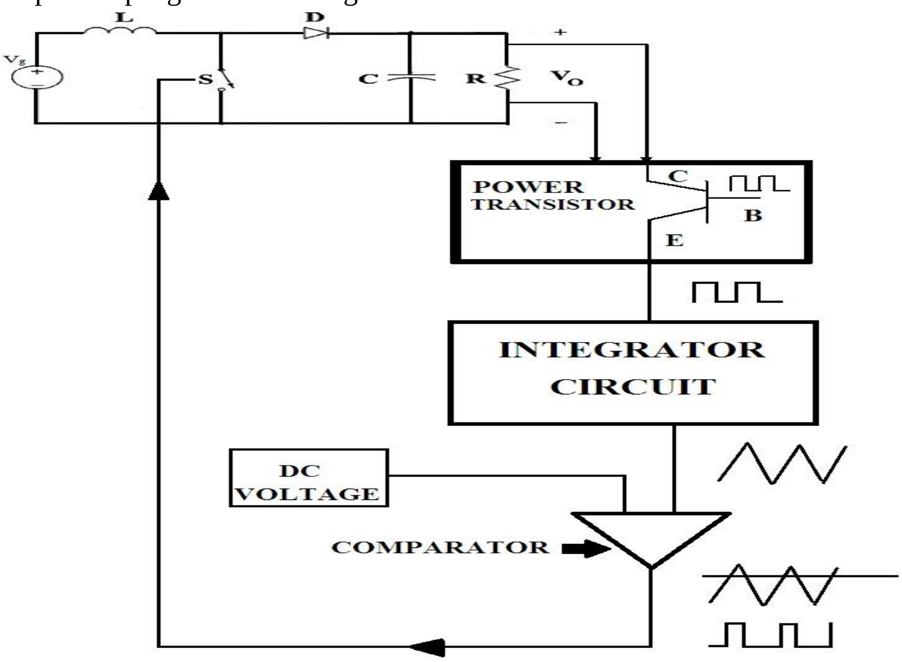

Fig3. Block diagram of the hardware model of closed loop boost converter

IV. Simulation of Photovoltaic Cells with Closed Loop Boost Converter

Simulink model of PV array has been shown in figure 4. PV array has been designed considering five parameters. Temperature(T), irradiance(S), number of PV cells connected in series(Ns), number of PV cells connected in parallel(Np), and the inductor current of closed loop boost converter which is same as the load current (Ipv) of the PV system is used as feedback for designing the PV array. Here Vout is the output voltage of pv array, Iout is the output current of pv array and Pout is the output power of pv array. PV panel in the simulink model is the subsystem whose internal model is shown in figure 5.

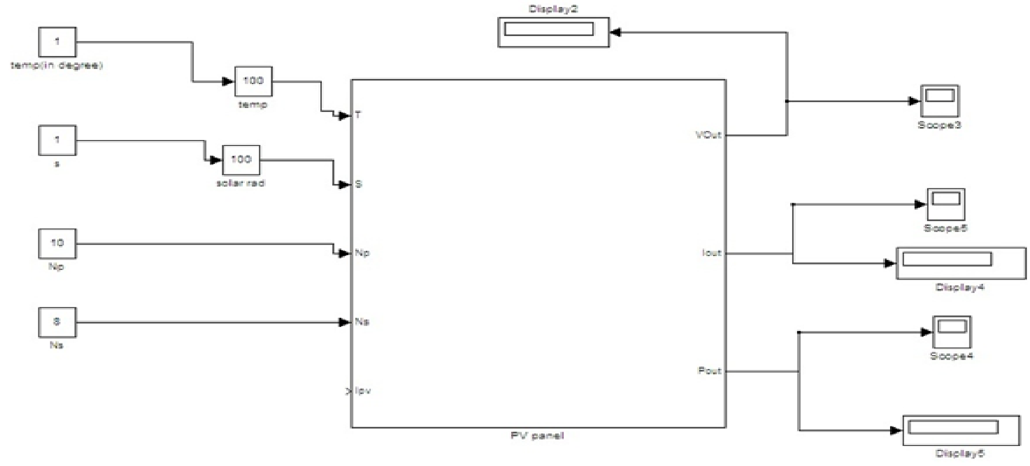

Fig4. Simulink model of PV array.

Internal model of PV subsystem is shown in figure 5. The PV array has been modelled using equations (1) to (8). The M-file for Irs function has been developed using equation (5) and that of Iph function using equation (7).Thus the output of PV array is with respect to the equations provided from (1) to (8).

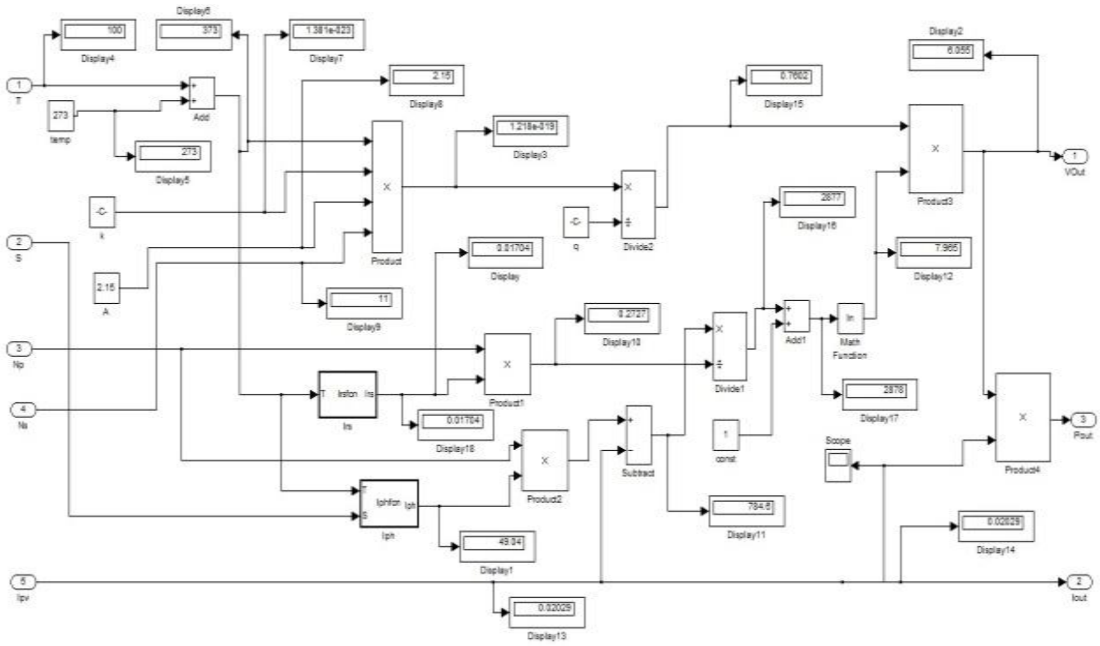

Fig5. Internal model of PV subsystem.

Simulink Model of closed loop Boost Converter is shown in figure 6. Here DC voltage of 6volts is given as an input voltage. Inductor of 3.3mH, capacitor of 100µF, load R of 10kΩ, and a diode has been used. The output voltage of boost converter is fed to the gain block where it is multiplied with the gain. Output of the gain is subtracted with the reference voltage of 22 volts which gives the error voltage. This error voltage is fed to the PID block for reduction of error. The output of the PID is given to the saturation block which limits the input signal. This saturated signal is given to the PWM block with switching frequency of 300 kHz which gives the required output pulse having duty cycle of 72%. And finally this pulse is fed to the switch of the boost converter.

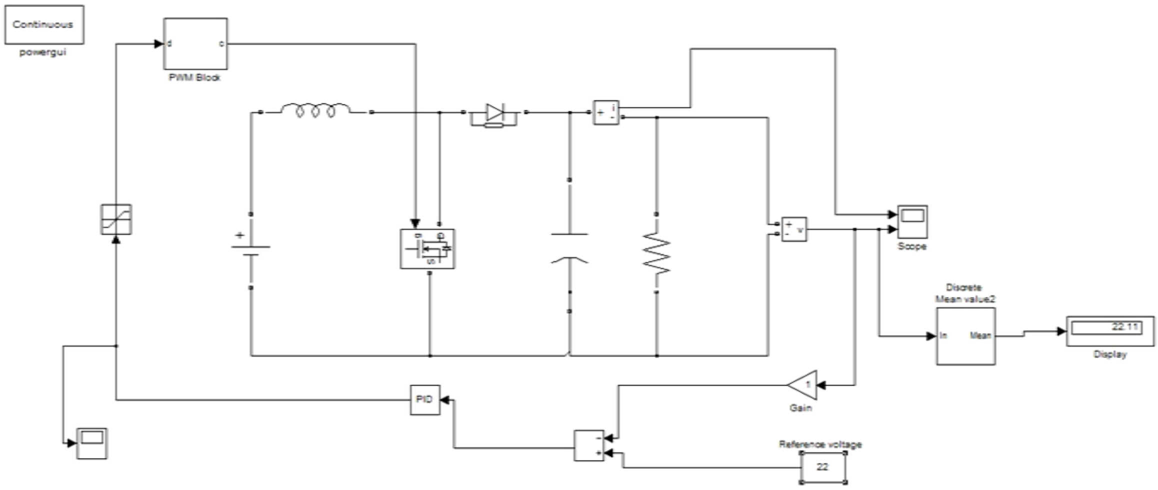

Fig6. Simulink Model of closed loop Boost Converter

As shown in figure 7 five parameters have been taken into consideration for simulink model of PV array. These parameters are temperature, solar irradiation, number of PV cells in series, number of PV cells in parallel and inductor current of closed loop boost converter. Thus varying values of these parameters the output voltage of PV array can be varied. The PV array is interfaced with closed loop boost converter using a controlled voltage source. Thus output voltage of PV array is fed as input voltage to closed loop boost converter. Therefore output voltage of 6volts is stepped up to 22 volts using closed loop boost converter.

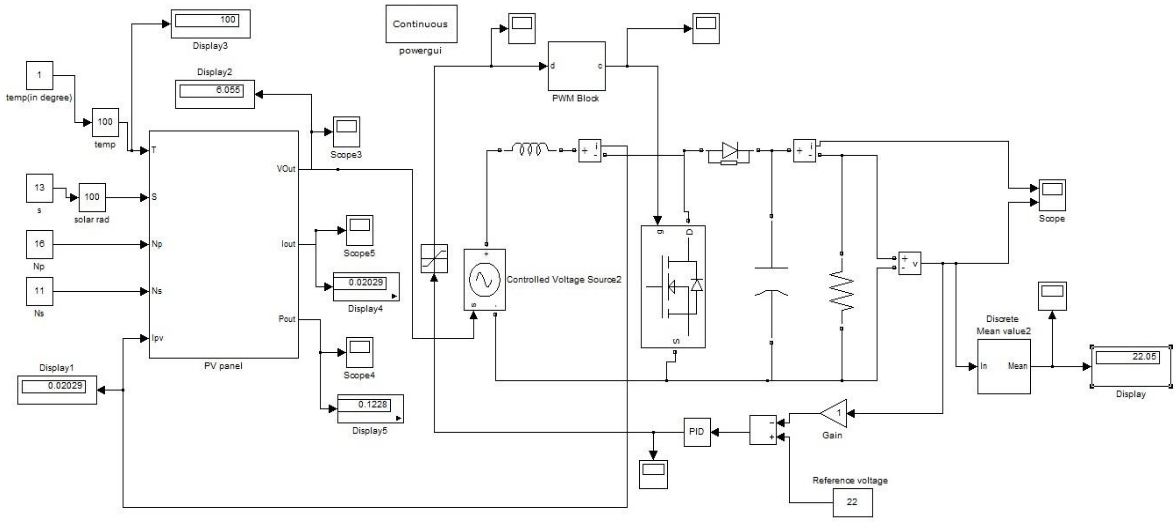

Fig7. Complete simulink circuit model showing interfacing of PV array with the closed loop boost converter.

V. MATLAB ALGORITHM FOR PHOTOVOLTAIC SYSTEM

In step1 T is taken as sum of 28 degree which is the fixed temperature and 273.
In step2 Tr1=40 which is the Reference temperature in degree Fahrenheit.
In step3 Reference temperature in Kelvin has been derived which is Tr=((Tr1-32)*(5/9))+273.
In step4 Solar radiation in mW/sq.cm has been taken as S=[100 80 60 40 20].
In step5 ki=0.00023 in A/K, Iscr=3.75 which is SC Current at ref. temp. in A, Irr=0.000021 in A, k=1.38065*10^(-23) which is Boltzmann constant, q=1.6022*10^(-19) which is charge of electron, A=2.15, Eg1=1.166,alpha=0.473,beta=636 has been implied.
In step6 band gap energy of semiconductor in joules has been derived from the formula Eg=Eg1-(alpha*T*T)/(T+beta)*q.

In step7, step8, step9 the value of Iph, Irs, and I0 are found out respectively applying equations Iph=(Iscr+ki*(T-Tr))*((S(i))/100), Irs=Irr*((T/Tr)^3)*exp(q*Eg/(k*A)*((1/Tr)-(1/T))), and current in ampere is given by I0=Np*Iph-Np*Irs*(exp(q/(k*T*A)*V0./Ns)-1). Where Np=4, Ns=60, V0=[0:1:300] and i=1:5.
And in step10 output power has been derived using the equation P0 = V0*I0.

VI. Practical Implementation of Photovoltaic Cell with Closed Loop Boost Converter

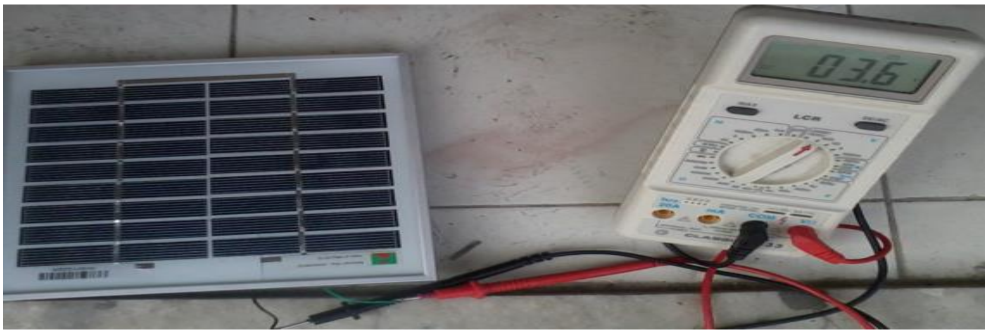

Fig8. Output voltage of PV cell.

Fig9. Hardware of closed loop boost converter.

Hardware model of closed loop boost converter is shown in figure9.This hardware model of boost converter is designed to step up a supply of 6V to 22V.The design parameter include Inductor of 3.3mH and load R of 10kΩ. The diode carries about 0.5A average current and blocks about maximum voltage of 50V and suitable for fast switching. The reverse recovery time has to be better than 50ns. IN4007 is selected for this design, as we need to block only about 22V.Electrolytic capacitor of 100 µF, having a high capability to withstand voltage up to 160 V is used. Mosfet IRF 640N has been used as a switch. Pulse with duty cycle of 72% with switching frequency of 300 kHz is supplied to the switch. Here output of boost converter is fed to the common of power transistor and pulse is given to the base. The output pulse of power transistor is obtained from emitter which is of the amplitude with respect to the output dc voltage of boost converter fed to the common of transistor. The output pulse of the power transistor is fed to the integrator circuit where the pulse is integrated to give a ramp signal. This output ramp signal is fed to a comparator circuit where it is compared with DC voltage to get the pulse of required duty ratio. This pulse is given to the switch of the boost converter and thus it completes a closed loop. Duty ratio of the pulse that is fed to the switch of boost converter is varied by the varying the DC voltage that is being compared in the comparator circuit with the output ramp signal of the integrator circuit.

VII. COMPARISON BETWEEN THEORETICAL AND PRACTICAL RESULTS

Theoretically when input voltage of 6 volts was given to the closed loop boost converter the output voltage received was 22 volts. In the matlab simulink model the same was obtained but in practical model output voltage received was 18.3volts. The decrease in the output voltage is due to many factors like harmonics, noise, wirings. Thus the difference of 3.7volts was observed between theoretical and practical output voltage of closed loop boost converter. Therefore the actual output value can be received practically if harmonics and noise is eliminated.

VIII. RESULTS AND DISCUSSION

Output pulse of PWM block which is supplied to the switch of closed loop boost converter interfaced with PV array in the simulink model is shown in figure 10.This pulse has the duty cycle of 72%.

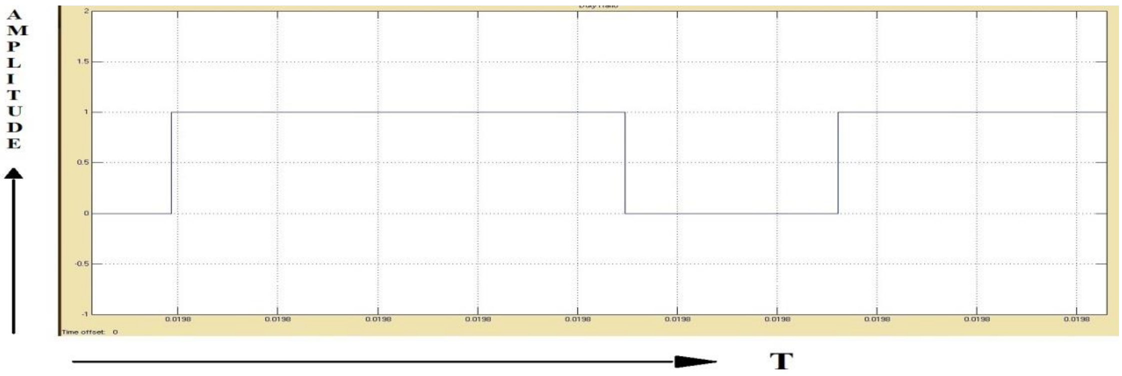

Fig10. Driving pulse of switch of simulink model

The output voltage of PV array of simulink model is shown in figure 11. Output voltage of 6 volts is observed where Vpv is the output voltage of PV array.

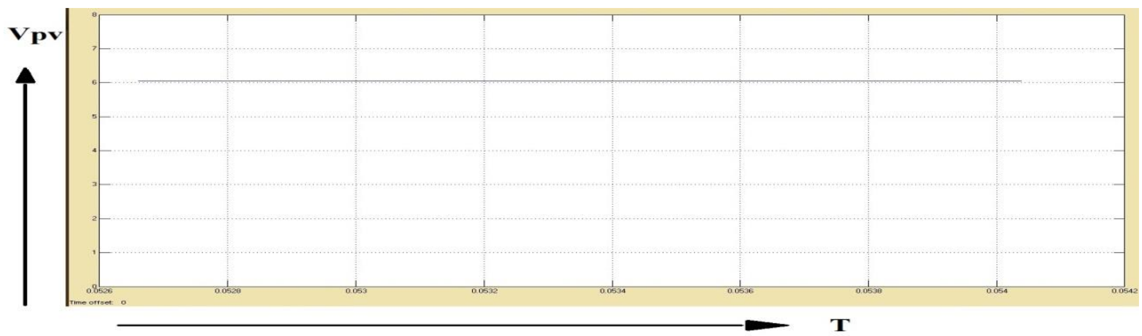

Fig11. Output voltage of PV array of simulink model.

The output voltage of closed loop boost converter interfaced with PV array is shown in figure 12. It is observed that output voltage of closed loop boost converter interfaced with PV array is initially 0 and then rises. It is initially 0 due to the fact that no input voltage is supplied from the PV array to the boost converter as at this initial period the parameters are being calculated in the PV array and initially for a very small period of time the output voltage of PV array is 0.Then as the voltage is supplied from PV array to the boost converter the output voltage of the boost converter rises. Transient state is observed and then steady state is observed.

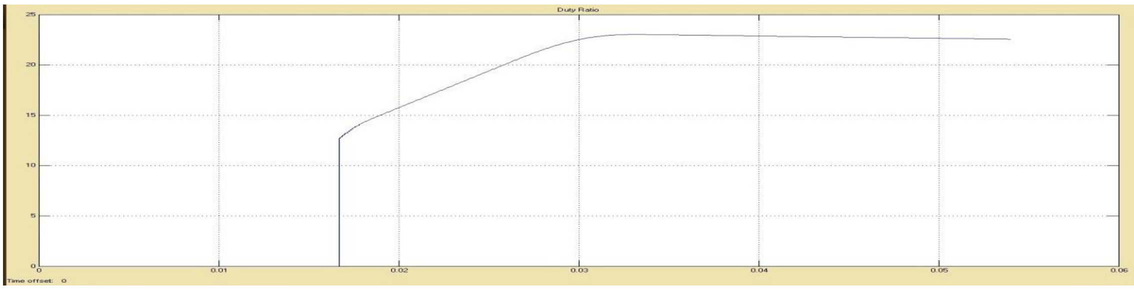

Fig12. Output of closed loop boost converter interfaced with PV array.

The output pulse of the hardware comparator circuit of closed loop boost converter is shown in figure13.This output pulse is given to the switch of the hardware model of boost converter.

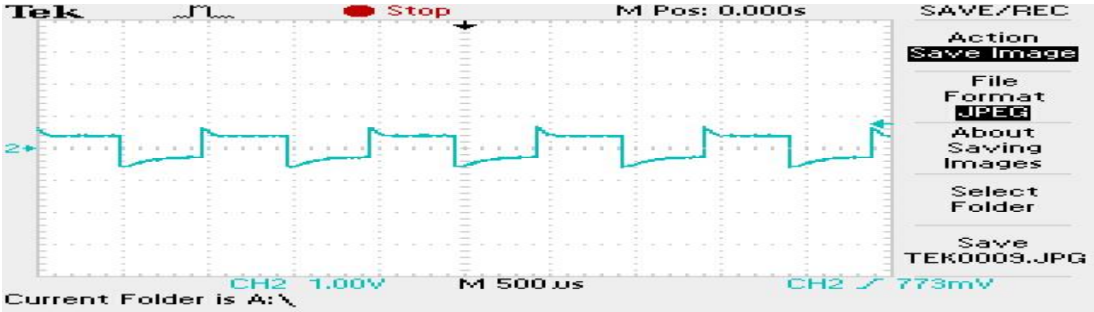

Fig13. Driving pulse of switch of hardware model.

Voltage across inductor of hardware model of closed loop boost converter is shown in figure 14. Here VL is the voltage across inductor. During switch on period voltage across inductor (VL) is equal to input voltage which is 6Volts. During switch off period voltage across inductor (VL) = Input voltage – output voltage, i.e. 6 – 22 = **-** 16. Since it is a hardware model distortion and disturbance was observed in the graph which is due to noise and disturbance produced by the wirings and probes.

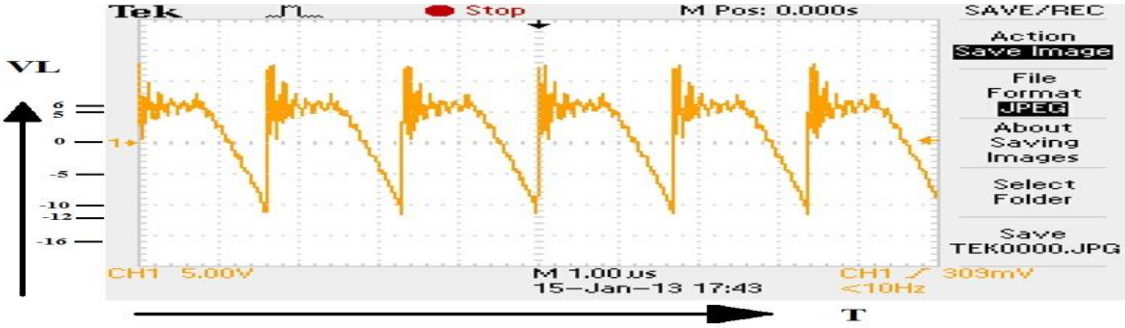

Fig14. Voltage across inductor of hardware model of closed loop boost converter.

Voltage across drain and source (VDS) of hardware model of closed loop boost converter is shown in figure 15.During ON period voltage across switch is zero because the circuit becomes short circuit and the current becomes maximum. During off period the voltage becomes maximum because the circuit becomes open circuit and current becomes zero. Distortion and disturbance was observed in the graph which is due to noise and disturbance produced by the wirings and probes.

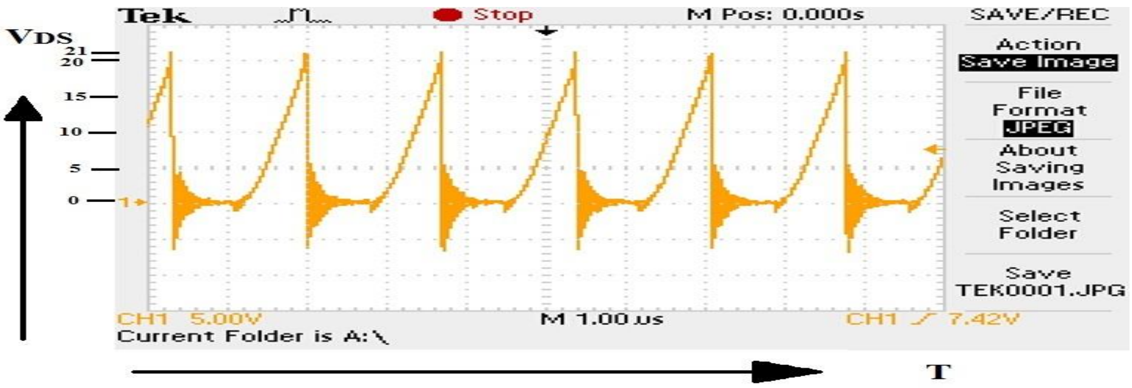

Fig15. Voltage across drain and source of hardware model of closed loop boost converter

P-I curves obtained at 28 degree C for various irradiance levels is shown in figure16. Matlab codes have been written for photovoltaic system to observe the effect of various irradiance levels applying the algorithm shown in section 5. From figure.15 it is observed that at a fixed temperature of 28 degree C with increase in the irradiance level there is increase in power and current.

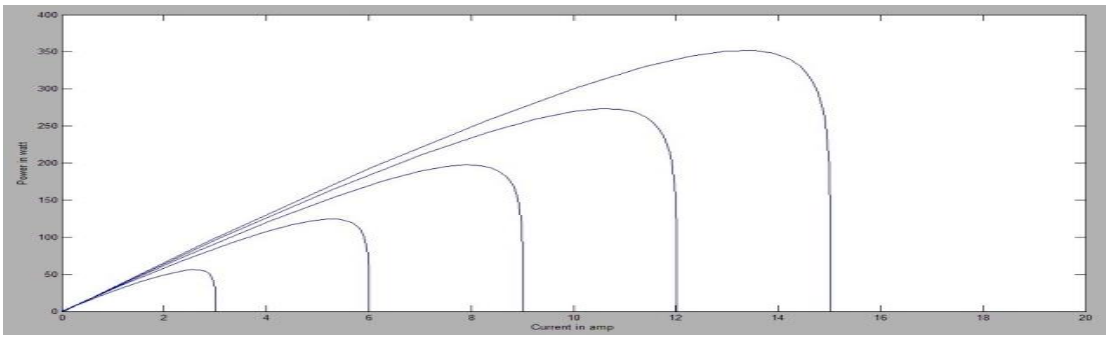

Fig16. P-I curves obtained at 28 degree C for various irradiance levels

From figure.17 it is observed that at a fixed temperature of 28 degree C with increase in the irradiance level there is increase in power and voltage.

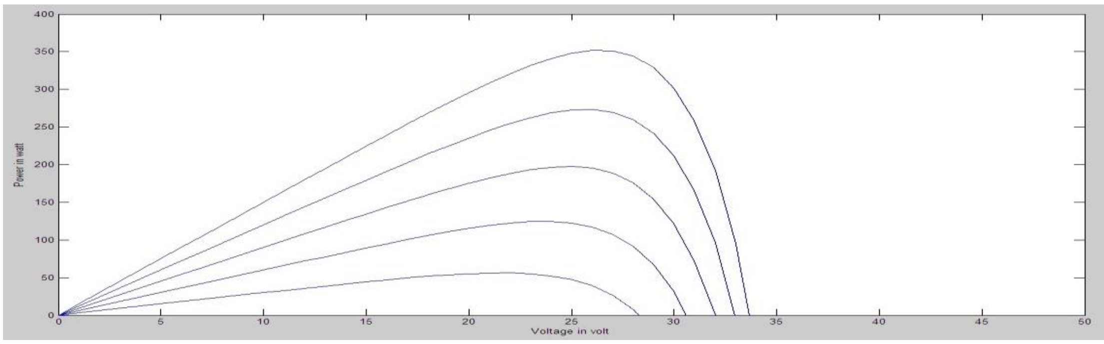

Fig17. P-V curves obtained at 28 degree C for various irradiance levels

From figure.18 it is observed that at a fixed temperature of 28 degree C with increase in the irradiance level there is increase in current and voltage.

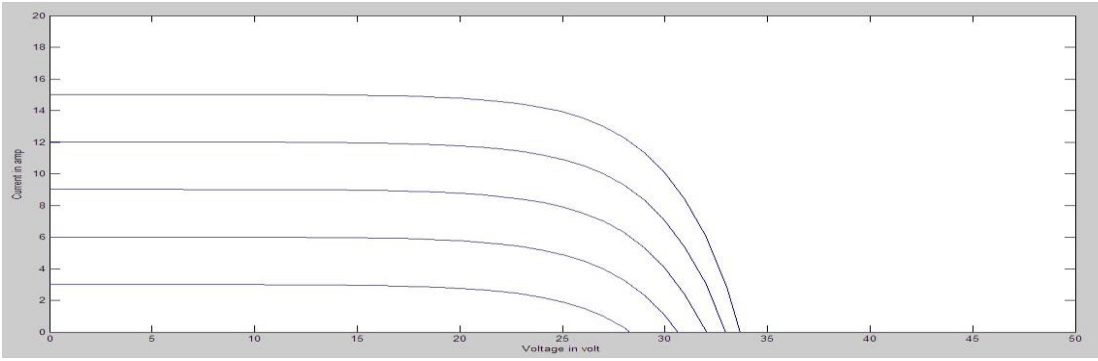

Fig18. I-V curves obtained at 28 degree C for various irradiance levels.

IX. CONCLUSION

In this paper we have proposed a system which overcomes the disadvantage of PV cells of low voltage production. In the proposed system we have interfaced PV cell with closed loop boost converter such that the output voltage produced by PV cell is fed as input voltage to closed loop boost converter which steps up the given input voltage to a considerably high output voltage to meet the voltage requirement of load. Theoretically values match with the output values of the simulink model. The distortions observed in the graphs obtained from practical model is caused due to harmonics and noise which could be overcome by use of various filtering techniques. Thus the proposed system can help PV system to produce high voltage to meet the needs of load overcoming its disadvantage of low voltage production. The PI, PV, VI curves obtained from the execution of matlab codes based on photovoltaic array and simulation of PV array in simulink platform explains its dependence on the irradiation levels and temperatures and other parameters.

X. FUTURE WORKS

The proposed work can be improved by applying the concept of Maximum power point tracking to receive maximum power by obtaining maximum irradiation levels during the daylight such that the output voltage of the PV cells can be increased. Harmonics from the output can be removed by applying various techniques including different types of filters or by usage of software's based on artificial intelligence.

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