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Optimal Design of DC to DC Boost Converter with Closed Loop Control PID Mechanism for High Voltage Photovoltaic Application

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ABSTRACT

This paper proposes a new dc to dc boost converter using closed loop control proportional Integral and Derivative mechanism for photovoltaic (PV) standalone high voltage applications. The boost converter is composed of MOSFETs which are driven by closed loop PWM control. Many advantages including high efficiency, minimum number of switch, high voltage and power, low cost. This converter is attractive for high voltage and high power applications. The analysis and design considerations of the converter are presented. A prototype was implemented for an application requiring a 410W output power, input voltage range from 17.1-V, and a 317-V output voltage. The proposed system efficiency is about 90%.

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1. INTRODUCTION

One of the major concerns in the power sector is day-to-day increasing power demand but the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the primary energy sources which are being utilized in this regard. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming [1-10].

Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever wherever necessary [2].

Solar Photovoltaic (SPV) cells directly convert sunlight into electricity. Many SPV cells are grouped together to form a module. Modules are normally formed by series connection of SPV cells to get the required output voltage. Modules having large output currents are realized by increasing the surface area of each SPV cell or by connecting several of these in parallel. A SPV array may be either a module or group of modules connected in series/parallel configuration. Output of the SPV array may directly feed loads or may use power electronic converter for further processing [3-8]. These converters may be used to serve different purposes like controlling the power flow in grid connected systems, track the maximum power available from the SPV array. Model of SPV system is therefore required to study and optimize the performance of the complete system including these converters and other connected loads [9, 10]. This paper aims at developing a complete mathematical model of a Solar Photovoltaic cell suitable for analysis of a non-uniformly illuminated solar module powered design of dc to dc converter with high voltage gain. MATLAB-M file coding has been used for simulation in the proposed system [11-13].

2. PROPOSED SYSTEM CONFIGURATION

The proposed system consists of a PV module, a new design of DC to DC converter (chopper), DC capacitor, closed loop PID control mechanism and load as shown in Figure1. The measurements are placed at both input and output sides of the converter, load utility. Proposed power control scheme of the PV load connected system is modeled by using MATLAB/Simulink. The subsystem explanation is given detailed.

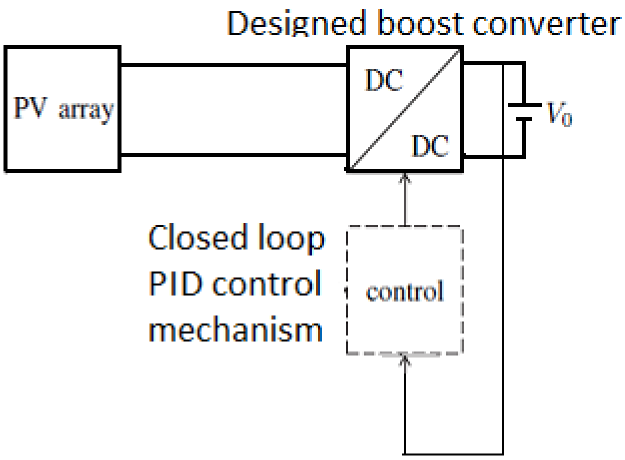

Figure 1. Block diagram of PV grid connected system

2.1 PV System

2.1.1 The P-N Junction

The p-n junction, shown in Figure 2, constitutes of a thick moderately p-doped substrate with extra holes and a heavily n-doped thin layer (around 100 times thinner than the p-doped substrate). [14,15]

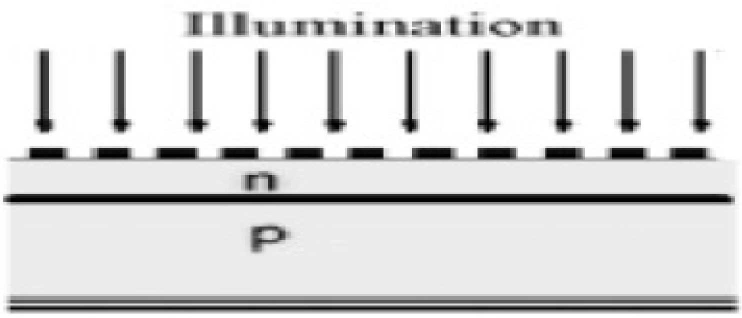

Figure 2. PV cell p-n junction

The basic semiconductor material is usually silicon (Si) which is doped with group III material such as boron (B) to get an n-doped material, or with group V material such as phosphorous (P) to get a p-doped material [3]. When exposed to solar radiation of a specific band gap (around 1.1 eV for Si which is close to the red light energy which is around 1.7 eV), electron-hole pairs are created by photons of energy greater than the band gap. A voltage potential is then created by the electric field which separates the created charge carriers. This potential difference produces a current in a closed circuit when a load is connected to the terminals of the cell.

2.1.2. The PV Cell Circuit Model

The PV cell can be approximated by a current source and a p-n junction similar to that of a diode, thus its equivalent circuit is shown in Figure 3. The model includes also series and shunt resistors where the series resistor $R_s$is usually very small that could be neglected and set to zero, while the shunt resistor $R_{sh}$is very large and could be considered as an open circuit.[14]

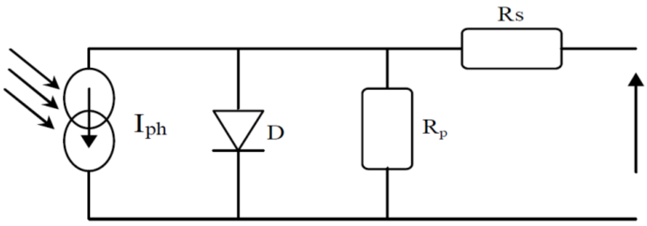

Figure 3. PV Cell Circuit Model

The directions and labels of the circuit currents are shown in Figure 3. When the cell is in the dark, the current source I_{ph}would be zero.

2.1.3. The PV Array Equations

The current and voltage of a PV array are exponentially related which explains the shape of the V-I curve in Figure 1. If one considers that the array consists of $N_p$parallel cells and *Ns* series cells and that $R_{sh}$is infinite, then the equations relating the voltage, current, and power are given in equations (1), (2), and (3) while Table 1 defines the equation variables [4].

Table 1. PV Parameters Definitions

Label	Description
V_{pv}	Array voltage
I_{pv}	Array current
G	Solar irradiance
T	Cell temperature
T_r	Reference temperature
I_{ph}	Light generated current
I_0	PV cell saturation current
A	Ideality factor
B	Ideality factor
K	Boltzman constant
Q	Electron charge
R_s	Series resistance of the cell
I_{scr}	PV cell short-circuit current at 25^{o}C and 100mW/cm^2
K	Short-circuit current temperature co-efficient at I_{scr}
I_{0r}	Saturation current at T_r
E_{g0}	Band gap for silicon

$$V_{pv} = \left(\frac{NsA*T*K}{q}\right) * \ln\left(\frac{Np*Iph-Ipv+Np*Io}{Io}\right) \quad (1)$$

$$I_{pv} = N_p I_{ph} - N_p I_o(\exp\left(\frac{q(Vpv+IpvRs}{NsAKT}\right) - 1 \quad (2)$$

$$P_{pv} = V_{pv} I_{pv} \quad (3)$$

The currents $I_0$and $I_{ph}$are given by equations (4) and (5) and their variables are also shown in Table 1:

$$I_o = I_{or} * \left(\frac{T}{T_r}\right) 3*\exp\left(\frac{q*Ego}{B*K} * \left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \quad (4)$$

$$I_{ph} = \left(I_{scr} + K * (T - 298)\right) * \frac{G}{1000} \quad (5)$$

2.1.4 Photovoltaic Array Characteristics

The main characteristic curves of a PV array are the V-I, P-I, and P-V curves interrelating the voltage (V), the current (I), and the power (P) of the array. Sample V-I and P-I curves are overlaid on the same graph and shown in Figure 4 [5].

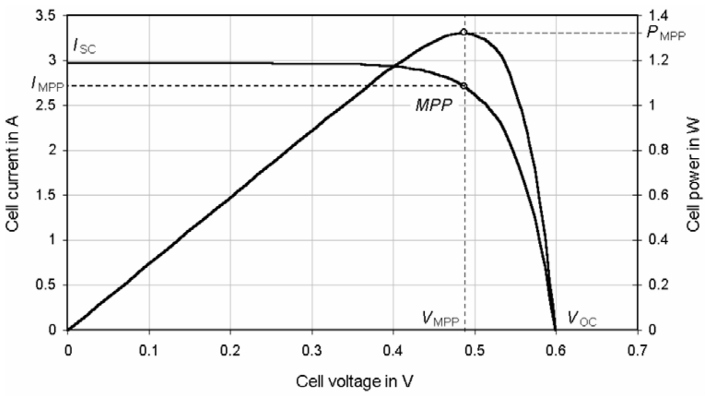

Figure 4. Photovoltaic V-I and P-I characteristic curve

Figure 4. Typical V-I and P-I characteristic curves of a PV array The formulas standing behind these curves are discussed where a detailed literature survey of PV arrays and their operation is included.

The main purpose behind introducing Figure 4 is getting an idea about the notion of the maximum power point of a PV array. The bending point of the V-I,P-I curves is the MPP of the array under a certain temperature and irradiance shown in Figure 4. Thus when operating a PV array at its MPP, maximum power is extracted and the array is operating at its maximum efficiency (for the available irradiance and temperature) because the input power of the solar irradiance is fully utilized.

2.2 Analysis of Boost Converter

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinated manner supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change [6] and [7].

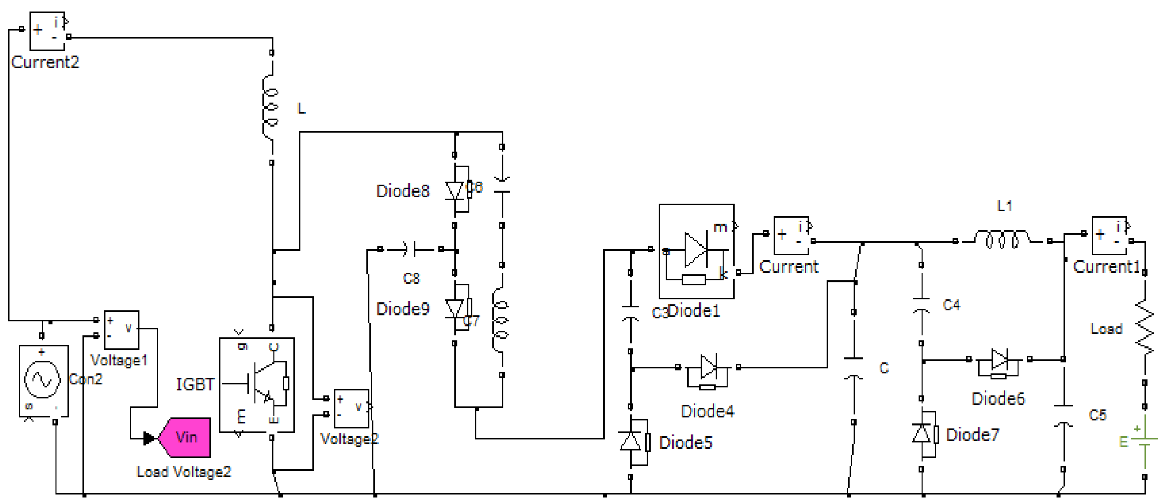

Figure 5. Design of a new boost converter

There are two modes of operation of a boost converter. They are based on the closing and opening of the switch. The first mode is when the switch is closed; this is known as the charging mode of operation. The second mode is when the switch is open; this is known as the discharging mode of operation [8]. During charging mode of operation; the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for simplicity is assumed to be linearly varying [8]. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor.

In the discharge mode of operation; the switch is open and the diode is forward biased. The inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

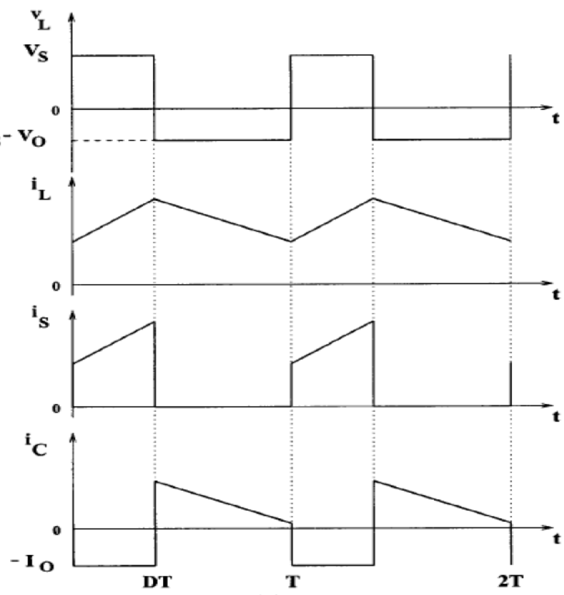

Figure 6. Waveforms of boost converter

3. RESULT AND DISCUSSION

This project was done by using MATLAB/Simulink in order to observe the performance of PV load connected system. Figure 7 illustrates the overall model of PV system in MATLAB/Simulink.

The parameters were obtained for a generalized solar cell. The plot is similar to the theoretically known plot of the solar cell voltage and current. The peak power is denoted by a circle in the plot. Since only one solar cell in series is considered, hence the solar output voltage is less (0.61 V) in this case.

This plot gives the solar output power against the solar output voltage shown in Figure 9. This clearly abides by the theoretical plot that was shown previously. The maximum power point is marked with a small circle. The initial part of the plot from 0 V to the maximum power point voltage is a steady slope curve but after the maximum power point the curve is a steeply falling curve. A solar panel that has the key specifications listed in Table 2.

Figure 11 and 12 are different P-V characteristics of a certain panel as different irradiances and temperature respectively. The circles represent a single MPP in each characteristic. As the P-V characteristic is constantly varying by changing the irradiance and temperature, the MPP must be tracked at the changed moment to maximize the output power from the panel. Therefore, both a tracking speed and accuracy are required to the PV system. The MPPT performance may be considered as an important factor to increase generation revenue.

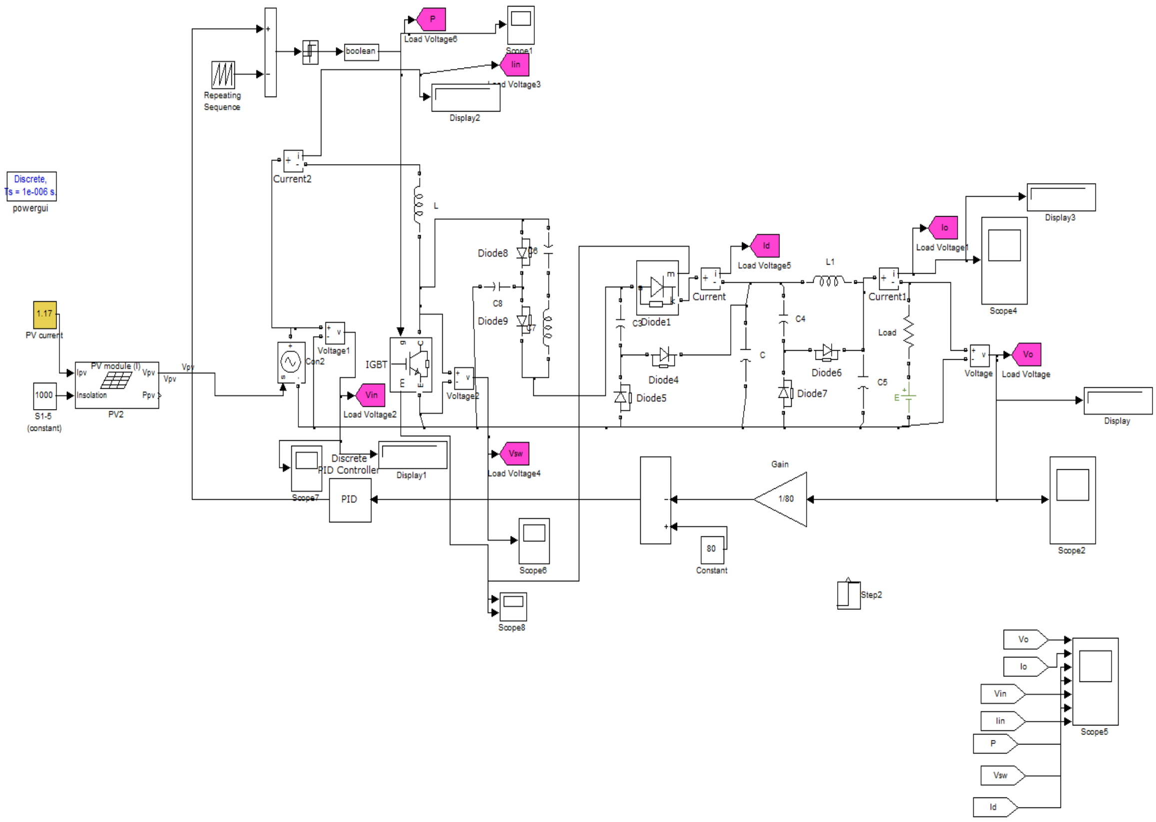

Figure 7. overall model of proposed system

The P-V and I-V curves from the simulation are as shown.

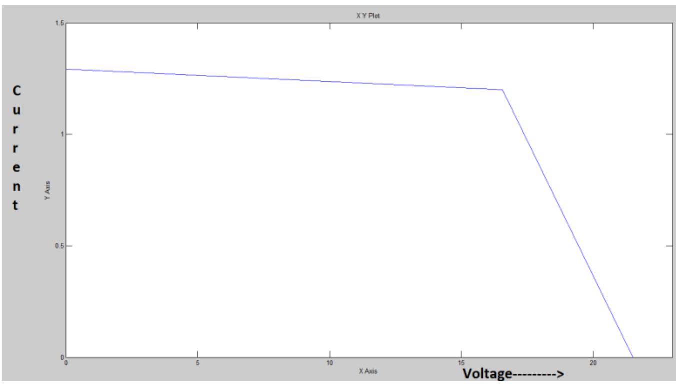

Figure 8. I-V characteristics of a solar cell

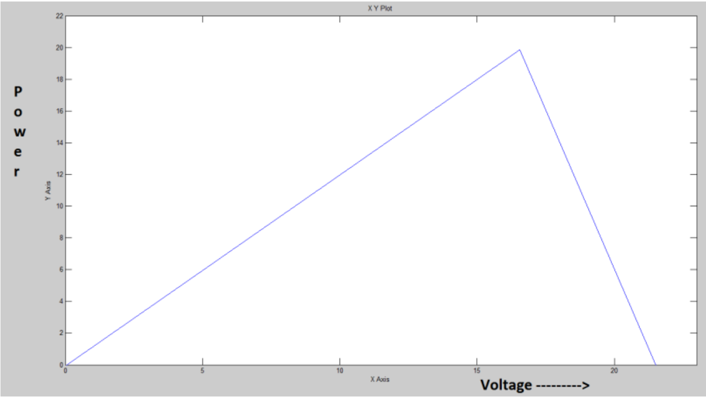

Figure 9. P-V characteristics of a solar cell

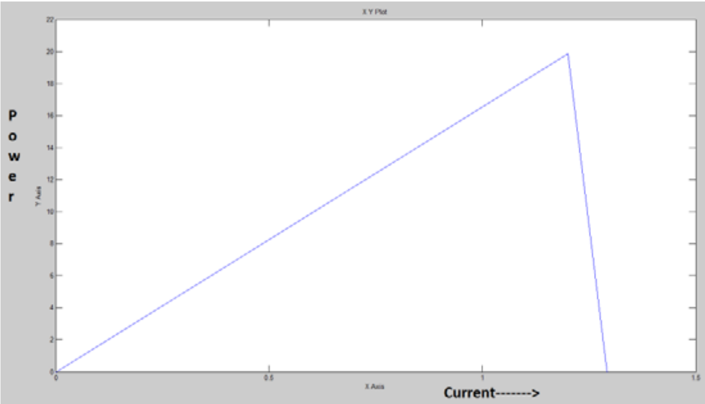

Figure 10. P-I characteristics of a solar cell

Table 2 Datasheet of KL020

Electrical characteristics	Value
Peak power	20 W
Peak voltage	17.1 V
Peak current	1.17 A
Open circuit voltage	21.5 V
Short circuit current	1.30 A
No. of cells	36

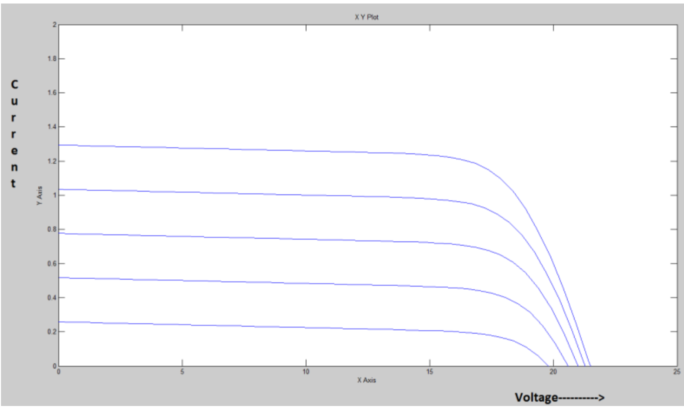

Figure 11. I-V different irradiance of a solar cell

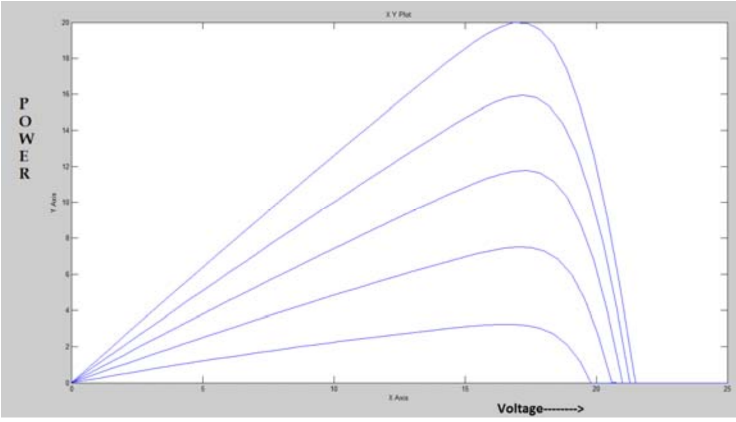

Fig.ure 12. P-I different temperature of a solar cell

The simulations were carried out for dc to dc converter in Simulink and the various waveforms such as output and input voltages, output and input currents, voltage across switch, control pulse, measurement port across switch and diodes plots were obtained shown in Figure 13, 14, 15, 16, 17, 18 respectively.

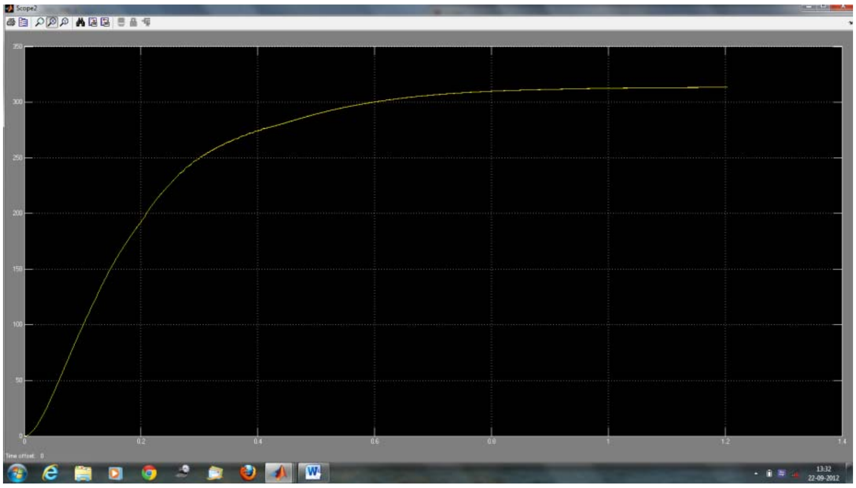

Figure 13. Output voltage of the converter

Figure 14. Output current of the converter

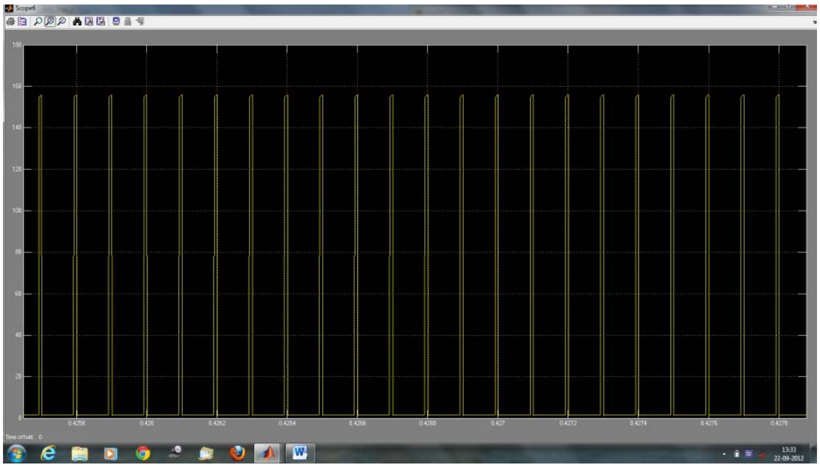

Figure 15. Voltage across switching device

Figure 16. Photovoltaic output voltage

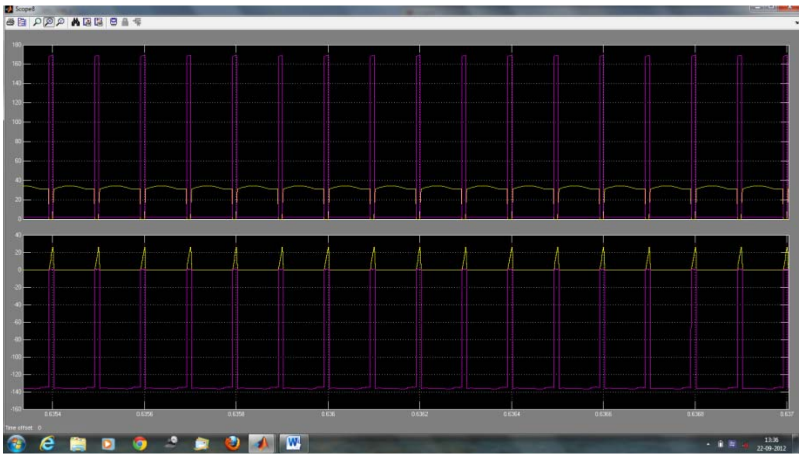

Figure 17. Measurement port across switch and diode

Figure 18. Combined Vo, Io, Vin, Iin, Pulse, Vsw, Id

4. CONCLUSION

Analysis and design consideration of dc to dc boost converter using closed loop PID control mechanism for photovoltaic high voltage applications is proposed. Simulation results were obtained as 317-V dc to dc converter from a 17.1-V standalone photovoltaic system. Efficiency attained under load condition was over 90%. The converter may be adequate for high voltage and high power application. Since the converter has many advantages such as minimum number of device, soft switching of the switch, high voltage and power output and so on.

REFERENCES

[1] Mummadiveerachary, “Fourth-order buck converter for maximum power point tracking applications”, *IEEE transactions on aerospace and electronic system*, vol. 47, No. 2. pp. 896-911, April 2011
[2] Zhong Yi He, Hong Chen, “Integrated solar controller for solar powered off-grid lighting system”, *Elsevier, Energy Procedia* 12, pp. 570-577, September 2011.
[3] Patel H, Agarwal V. “MATLAB-based modeling to study the effects of partial shading on PV array characteristics Energy Convers”, *IEEE Trans* vol. 23, pp. 302–10, 2008
[4] Ishaque K, Salam Z, Taheri H. “Accurate MATLAB simulink PV system simulator based on a two-diode model”, *J Power Electron* vol. 11, no. 9, 2011.
[5] Enslin JHR, Wolf MS, Snyman DB, Sweigers W. “Integrated photovoltaic maximum power point tracking converter”. *IEEE Trans. Ind. Electron*, vol. 44, no. 6, pp. 769-773, 1997.
[6] Martins, D., Weber, C. and Demonti, R. (2002). Photovoltaic power processing with high efficiency using maximum power ratio technique, *Proc. 28th IEEE IECON*, v. 2, pp. 1079–1082.
[7] Rajib Baran Roy, “Design and performance analysis of the solar PV DC water pumping system”, *Canadian Journal on Electrical and Electronics Engineering*, Vol. 3, No. 7, September 2012
[8] Renewable Energy Technologies: “Cost Analysis Series”, *International Renewable Energy Agency*, Volume 1: Power Sector, Issue 4/5, pp. 1-45, June 2012.
[9] Veerachary, M, “Two-loop voltage-mode control of coupled inductor step down buck converter”, *IEE Proceedings on Electric Power Applications*, vol. 152, no. 6, pp. 1516—1524, 2005.
[10] Eung-Ho Kim and Bong-Hwan Kwon, “Zero voltage and zero current switching full bridge converter with secondary resonance”, IEEE transactions on industrial electronics, 2009
[11] Patel H, Agarwal V. “MATLAB-based modeling to study the effects of partial shading on PV array characteristics. Energy Convers”, *IEEE Trans*, vol 23, pp. 302–10, 2008.
[12] Ishaque K, Salam Z, Taheri H. “Accurate MATLAB simulink PV system simulator based on a two-diode model”, *J Power Electron*, vol. 11, pp. 9, 2011.
[13] Ishaque K, Salam Z, Syafaruddin, “A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model.”, *Solar Energy*, vol. 85, pp. 2217–27, 2011.
[14] Ahmed M. Kassem, “MPPT control design and performance improvements of a PV generator powered DC motor-pump system based on artificial neural networks”, *Elsevier Ltd, Electrical Power and Energy Systems* 43, pp. 90–98, 2012.
[15] A.B.G. Bahgat, N.H. Helwa, G.E. Ahmad, E.T. El Shenawy, “Maximum power point traking controller for PV systems using neural networks”, *Renewable Energy* 30 pp. 1257–1268, 2005.
[16] Masafumi Miyatake, Mummadi Veerachary, Fuhito Toriumi, Nobuhiko Fujii, Hideyoshi Ko, “Maximum Power Point Tracking of Multiple Photovoltaic Arrays: A PSO Approach”, *IEEE Transactions on Aerospace and Electronic Systems*, vol. 47, no. 1 january 2011.

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