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Design and Control of Solar Powered Boost Converter

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Abstract: **This paper presents closed loop voltage controlled solar powered boost converter. The major issue in the solar powered boost converter is to deliver a constant voltage to the load irrespective of the changing climatic conditions namely irradiance and temperature. The need of the hour is to deliver a constant voltage to the grid irrespective of the variation in solar insolation. The boost converter with the input voltage of 24 V and output voltage of 48 V is designed. A simple PI controller is used to maintain the output voltage of boost converter constant. The performance of the proposed system is compared with solar powered boost converter without voltage controller. All the investigations are carried using MATLAB. The results obtained are presented.**

Keywords: **Boost converter, PV arrays, Voltage Control, PI controller, Solar insolation.**

I. INTRODUCTION

The majority of the world's energy demand is met from conventional sources-fossil fuels such as coal, natural gases and oil. The availability of these fuels are falling day by day, after a few years it will end. Hence renewable energy source demand increases as it is environmental friendly and pollution free, which reduces the greenhouse effect. Earth receives 174 pet watts (PW) of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to space. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 EJ per year [1]. Solar powered electricity generation relies on photovoltaic system. A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. PV cells are made of semiconductor materials, when light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. The received solar energy is not a constant value but varies with temperature (˚C) and irradiance (mW/sqcm). The sophisticated applications require electronic converters to process the electricity from the array. These converters may be used to regulate the voltage and current at the load [2].

A DC converter is equivalent to an AC transformer with a continuously variable turn’s ratio. Boost converters are used to obtain higher output voltage in comparison with the input DC voltage and it is increasingly employed in battery sources, photovoltaic solar systems and fuel cells. Application of Boost Converter important in case of batteries, large or small, their output voltage varies as the available charge is used up, and at some point the battery voltage becomes too low to power the circuit being supplied. However, if this low output level can be boosted back up to a useful level again, by using a boost converter, the life of the battery can be extended. These converters, when operated under open loop condition, it exhibits poor voltage regulation and unsatisfactory dynamic response and hence, this converter is generally provided with closed loop control for output voltage regulation [3]. The operation of the boost converter is fairly simple, with an inductor and two switches that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load. In closed loop operation, a PI controller is employed to control the output voltage so as to obtain a constant output voltage with varying operating condition of solar array. PI controllers are the most widely-used type of controller for industrial applications. They are structurally simple and exhibit robust performance over a wide range of operating conditions [8]. Analysis of PI controller operation is carried out under various operating conditions.

II. PROPOSED SYSTEM

The design of a voltage controlled Boost converter to deliver a high constant voltage from PV system to the load connected. Fig 1 shows the block diagram of proposed system. Solar cell acts as input to the designed voltage controlled DC-DC converter, where the output voltage is regulated to the desired value of 48V and supplied to the load. The converter operation is analyzed under open loop condition coupled with solar cell, it exhibits poor voltage regulation and hence, this converter is provided with closed loop control for output voltage regulation. The results obtained from the analysis in Matlab Simulink is tabulated.

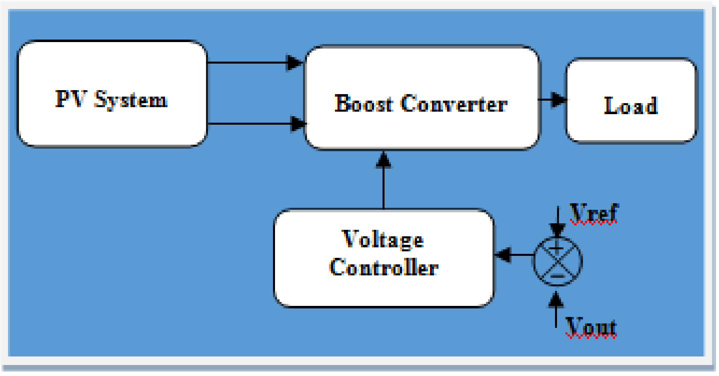

Fig.1: Solar powered voltage controlled boost converter.

A. PV Array:

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (Ns, for high voltage) and in parallel (Np, for high current) to form a PV module for desired output. When connected together the cells properties add together to create an I-V curve that has the same appearance as that of an individual cell but is larger in magnitude.

Marcello Gradella [4] uses the basic equation from the theory of semiconductor to describe mathematically the I-V characteristic of the ideal photovoltaic cell. It is a semiconductors diode with p-n junction. The material used is monocrystalline and polycrystalline silicon cells. The ideal model consists of a current source parallel with a diode. In real photovoltaic device must include the effects of series and parallel resistance of the PV. The model is obtained with the parameters of the I-V equation given by manufacturer datasheet such as open circuit voltage, short-circuit current, maximum output power and diode constant 'a' is to be guessed. The model gives a good correlation of PV characteristics and I-V curve.

The PV mathematical model used to simplify our PV array is represented by the equations (1) to (4):

$$I = Np*Iph-Np*Irs[\exp(\frac{q}{KTA}*\frac{V}{Ns})-1] \quad (1)$$

$$Irs = Irr[\frac{T}{Tr}]^3\exp([\frac{qEg}{KA}[\frac{1}{Tr}-\frac{1}{T}]) \quad (2)$$

$$Iph = [Iscr + Ki(T-Tr)]\frac{S}{100} \quad (3)$$

$$P = VI \quad (4)$$

Where, Iph is the Insolation current, I is the Cell current, V is the Cell voltage, Irs is the cell reverse saturation current, VT is the Thermal voltage, K is the Boltzman constant, T is the Temperature in Kelvin, Tr is the cell reference temperature, Irr is the cell reverse saturation temperature at Tr, Eg is the band gap of the semiconductor, q is the Charge of an electron, 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 has been designed taken into consideration its dependence upon the irradiance, temperature, number of PV cells connected in series and parallel [5, 6].

TABLE.I: PV SYSTEM FOR AN OUTPUT VOLTAGE OF 24V

Parameters (Solar array)	Specifications
Np	1
Ns	34
I scr	3.75 A
Tr	40 C
Ki	0.00023 A/K
Irr	0.000021 A
K	1.38065 * 10-23 J/0K
q	1.6022* 10-19 C
A	2.15
Eg0	1.66 eV
S	100 mW/sqcm

B. Boost Converter:

The components of the converter include DC supply, inductor, MOSFET which acts as a switch, shunt capacitor and diode. It is explained in [7] that the boost converter can operate in continuous conduction mode along with discontinuous conduction mode. The mode of conduction depends of the capacity for storage of energy along with the relative timeframe of the switching. The output voltage is dependent of the duty cycle; it is adjusted by the maximum power controller. During the ON time, the power switch SW is in ON state, inductor current flows through the inductor L and the power switch SW. During the OFF time, the power switch SW is in OFF state, the energy in the inductor is transferred to the output capacitor C and to the load through the diode [9-11].

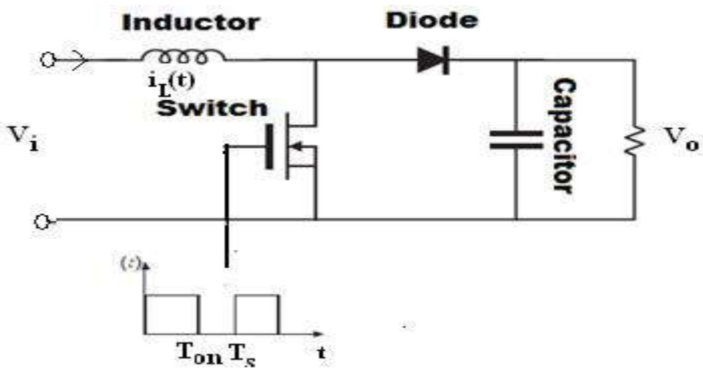

Fig.2: Boost converter

The selection of various components of the boost converter to get an output voltage of 48V and load current of 1A with an input supply of 24V is given below:

[1] Inductor selection:

Switching converters use an inductor's magnetic field to alternately store energy and release it to the load at a different voltage. Higher the inductor value, higher is the maximum output current because of the reduced ripple current. The lower the inductor value, the smaller is the value of current. The inductor must always have a higher current rating than the maximum current because the current increases with decreasing inductance.

$L = \frac{Vin*(Vo-Vin)}{\Delta IL * fs * Vo}$ where, Vin = typical input voltage, Vo = desired output voltage, fs = minimum switching frequency of the converter, ΔIL = estimated inductor ripple current. A good estimation for the inductor ripple current is 20% to 40% of the output current.

[2] Capacitor selection**:**

Capacitors reduce the output voltage ripple and allows a continuous conduction. Min output capacitance required, Cout $>= \frac{Iout * D}{fs * \Delta Vo}$ where, D = duty cycle, IOUT= maximum output current of the application, fs = minimum switching frequency of the converter, ΔVo = desired output voltage ripple.

[3] Diode selection :

To reduce losses, Schottky diodes should be used. The forward current rating needed is equal to the maximum output current. $I_f = I_{out\ (max)}$, where I_f = average forward current of the rectifier diode and $I_{out\ (max)}$ = maximum output current necessary in the application. Schottky diodes have a much higher peak current rating than average. Therefore the higher peak current in the system is satisfied.

[4] Load Resistance:

$Ro = \frac{Vo}{Io}$ $\{\frac{48}{1} = 48\ \Omega\}$

[5] Duty Cycle:

$D = 1 - \frac{Vin}{Vo+Vloss}$ = 0.507

Table 2 shows the parameter specification of boost converter designed for an output voltage of 48V from 24V input.

TABLE.2: BOOST CONVERTER (DUTY CYCLE = 0.5)

Parameters	Specifications
Input voltage	24V
Output voltage	48V
Switching frequency	100 KHz
Inductance	470μH
Capacitance	5.6μF

The voltage mode control is to make the dc-link voltage constant. The voltage at feedback is compared to the reference voltage to generate the voltage error signal and fed to the PI controller. After going through the controller, the control signal was connected to the Pulse Width Modulator (PWM) that drives the MOSFET [12, 13]. In voltage mode control, this control voltage is compared with a sawtooth ramp. When the converter output voltage changes, the control voltage Vc also changes and thus causes the duty cycle of the power switch to change. The higher the error voltage, the longer is the duty cycle. This change of duty cycle adjusts the output voltage to reduce to error signal to zero. A PI controller with Kp=0.001 and Ki=5 is used.

III. SIMULATION RESULTS AND DISCUSSION

The performance of proposed system is investigated under varying irradiance condition at the temperature of 28^o c. The irradiance is gradually varied from 30 to 100mW/sqcm. Table 3, Fig. 3 and Fig. 4 shows the step change in irradiance and corresponding changes in uncontrolled converter output and its load current and controlled boost converter output and its load current respectively.

TABLE.3: IRRADIANCE VARIED KEEPING TEMPERATURE CONSTANT

Irradiance, (mW/sqcm)	**Solar Output voltage(V)**	**Output voltage (V) (Controlled)**	**Output voltage (V) (Uncontrolled)**
30	17.22	48.60	34.44
40	20.01	48.55	40.02
50	21.28	48.52	42.56
60	22.12	48.50	44.24
70	22.74	48.45	45.48
80	23.33	48.34	46.66
90	23.64	48.26	47.28
100	24	48.10	48.00

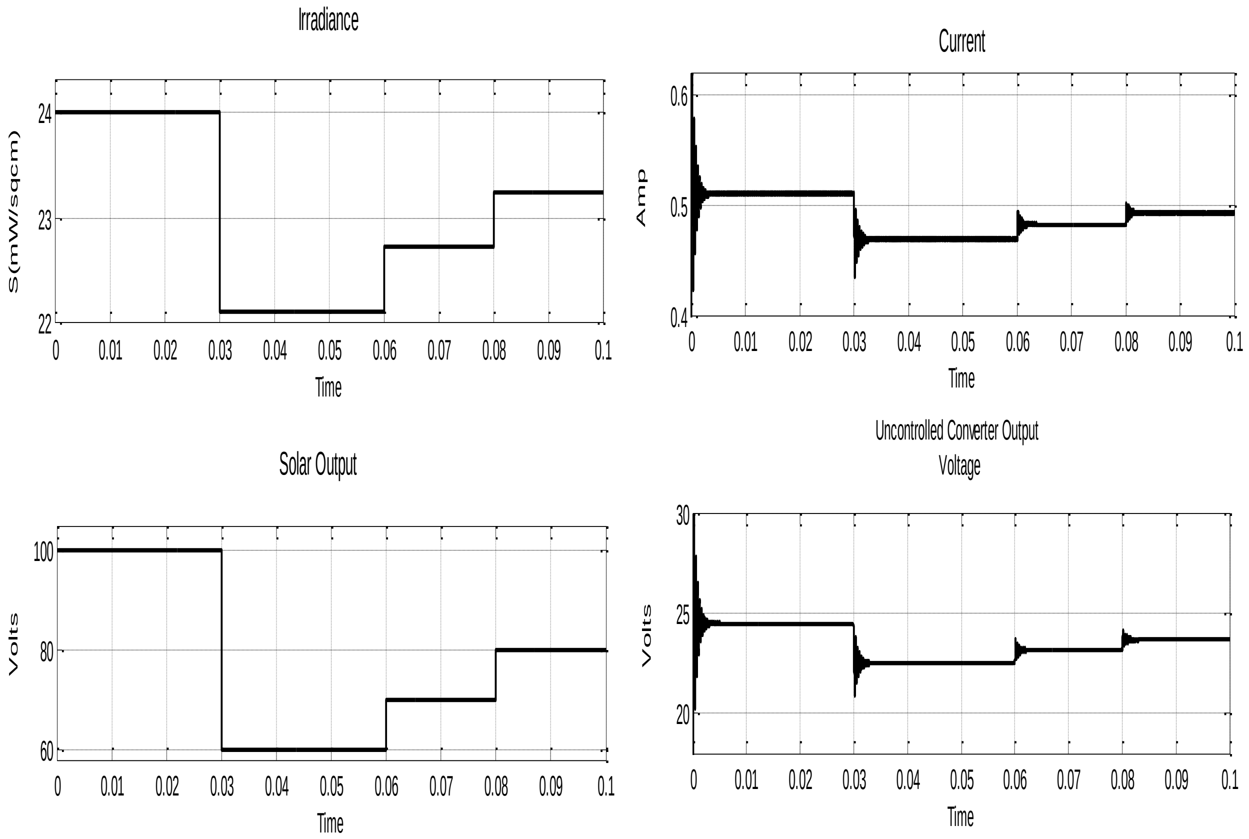

Fig.3: Uncontrolled output for Irradiance variation

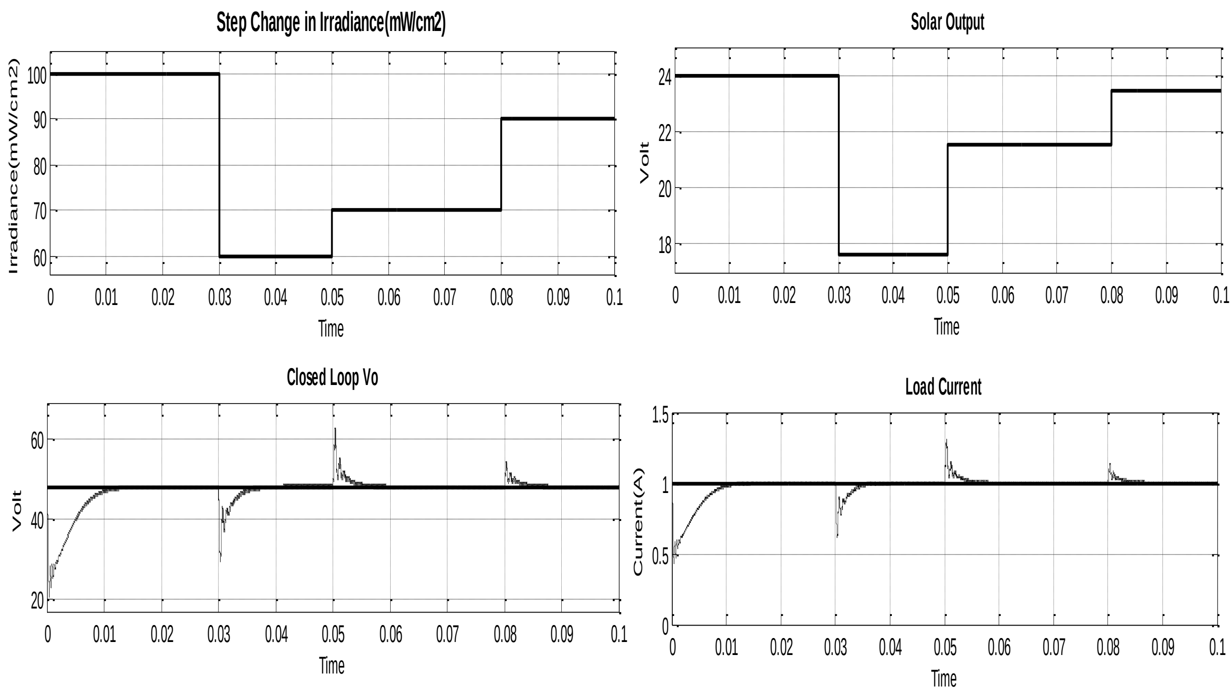

Fig.4: Controlled output for Irradiance variation

The closed loop Boost Converter shows better results when compared to the open loop Boost Converter in terms of voltage regulation and response. It is observed that with change in irradiance of solar array, the output of uncontrolled Boost converter varies and the output of controlled converter is maintained constant at 48V. Hence, the desired output is obtained under varying irradiance condition.

IV. CONCLUSION

In this paper, a solar array is designed for the generation of 24V, which acts as an input to the Boost converter designed for an output voltage of 48V and load current of 1A. The analysis of solar powered boost converter without a controller and with a PI controller under various solar irradiance /insolation are carried out. From the results obtained it is observed that, in case of open loop boost converter, converter output is the double of solar input as per the design and in case of closed loop boost converter, converter output tracks the designed 48V after a minimum settling time.

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