Closed loop control of multilevel boost converter used in photovoltaic applications

Anil Kumar Vemula

***Abstract* :** This paper presents a novel control scheme based on fractional order PI controller(FO-PI) based maximum power point tracking(MPPT) for a high gain multilevel boost converter used in photovoltaic(PV) applications. The voltage gain obtained using traditional boost converter is very limited. It is not possible to obtain high gain using boost converter without much stress on the switches. Reasonable high gain may be obtained by the use of multiplier circuit with boost converter. Switched capacitor circuit can act as a multiplier circuit and can be combined with boost converters in order to increase the gain. In this paper a combination of FO-PI and perturb and observe (P&O) MPPT technique is used to enhance the performance of PV.The study shows the superiority of FO-PI based MPPT over P&O MPPT and non-MPPT systems. In particular, the simulated response of the FO-PI based MPPT shows that the output reaches to the desired value very quickly and the peak overshoot and ripples in the output is also quite decreased. The simulation was carried out in MATLAB/SIMULINK

Keywords: Photovoltaic cell, MPPT, Multilevel boost converter, Fractional order controller.

1. INTRODUCTION

As the world is facing more environmental problems and depletion of fossil fuels solar energy become very famous and demanding .In recent years photovoltaic sources are getting progressively well due to the advancement in power industry, no pollution and less maintenance[1]. The yield voltage of solar PV cells is significantly less and hence stepping up of the output voltage has to be done to utilize the power more efficiently [2-3]. The conventional boost converters can boost the solar PV voltage but high gain cannot be achieved using this converter without switching stress. A novel high step-up DC–DC multi-level boost converter is used to achieve high voltage gain and efficiency compared to conventional boost converter [4-5]. MLBC has many advantages compared to conventional boost converter such as low switching frequency, low voltage stress, high efficiency etc [6-7].PV power output from solar panel changes due to its intermittent parameters like irradiance, temperature, etc. So to extract maximum power from PV panels under intermittent weather conditions various MPPT techniques are available. Among different MPPT techniques P&O MPPT is most popular due to merits such as good performance, suitable and easy to implement [8-10]

Conventional PID controllers were used traditionally for the control of power electronic converters under varying input/load conditions [11-12]. The PI controllers are not robust and more degree of freedom is not available from the PI controllers. Fractional order controllers are very efficient to achieve good transient and steady state response compared to conventional controllers because it has additional tuning parameters like λ and μ, which provides robustness under closed loop operation[13-15]. In this paper to achieve better output performance with reduced output voltage ripples fractional order-PI based MPPT is used .The performance of the converter in closed loop with fractional order controller based MPPT is compared with the performance of the converter with P&O MPPT and non-MPPT techniques.

The rest of the paper is organized as follows: The description of the solar PV scheme with high gain boost converter and FO-PI MPPT controller is presented in section 2. The modeling of PV is presented in section 3.P&O MPPT is explained in section 4.The high step-up DC–DC converter is presented in Section 5. A brief introduction about the fractional order controller is presented in section 6.The simulation studies of this high gain converter with FO-PI based MPPT controller is presented in Section 7. Conclusions are given in the final section.

2. SYSTEM DESCRIPTION

Figure.1shows a basic schematic block diagram of the proposed scheme of control and regulation of PV fed multilevel boost converter. A Solar panel basically contains photovoltaic (PV) cells which convert the solar energy into electrical energy in dc form directly. To step up the low voltage obtained from PV cell multi-level boost converter is used. To extract maximum power and to get better output performance fractional order –PI based MPPT technique is used for multilevel boost converter. Here the reference voltage is obtained from MPPT which is compared with the reduced value of output voltage and the difference value is sent to the FO-PI controller which will reduce the error and the output of FO-PI is compared with the repeating sequence to generate the pulses.

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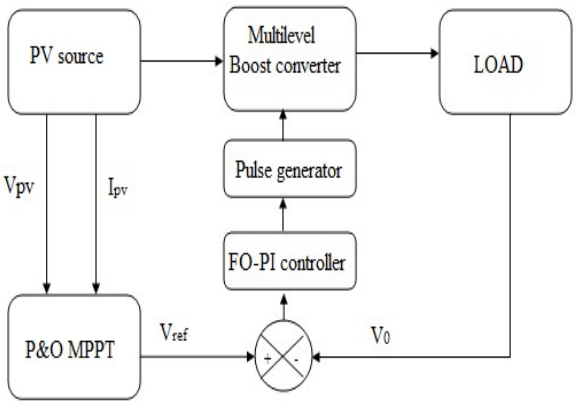

Figure.1.Block Diagram Proposed Scheme.

3. PHOTOVOLTAIC CELL

A solar cell used to convert the energy of sunlight into dc current by Photovoltaic effect. In order to meet the energy requirements solar cells are connected either in parallel or in series. The performance of PV system gets affected by many parameters like temperature, irradiance etc. The MATLAB/ Simulink model of PV cell is shown in Fig 2.

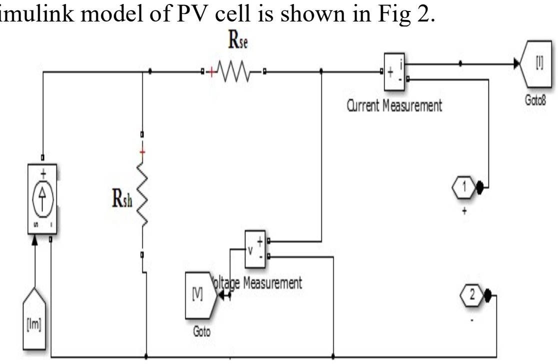

Figure 2. Photo voltaic model

From the basics of semiconductors the mathematical equation which explains the I–V characteristics of the ideal PV cell is

$$I = I_{pvcell} - I_{0,cell}[\exp(\frac{qv}{\alpha kT}) - 1] \quad (1)$$

Where

Where $I_{pv\ cell}$ –generated current by the incident light

$I_{0,cell}$- reverse saturation current.

1) α -diode ideality constant. s the electron charge

q-is the electron charge

k –Boltzmann constant

T-temperature of the p-n junction

Modified form of Eq.(1) including additional parameters which is shown in Eq.(2).

$$I = I_{pv} - I_0[\exp(\frac{V + R_s I}{V_t \alpha} - 1) - \frac{V + R_s I}{R_p}] \quad (2)$$

Where

V_t –thermal voltage of the array= $\frac{N_s kT}{q}$

R_p&R_s-equivalent shunt and series resistance of the array.

The saturation current of a diode is given by

$$I_0 = \frac{I_{sc,n} + K_i \Delta T}{\exp(\frac{V_{oc,n} + K_v \Delta T}{\alpha V_t})} \quad (3)$$

Where

K_v &K_i are the co-efficient of voltage and current.

Where $$I_{pv} = (I_{pv,n} + K_i \Delta T)\frac{G}{G_n} \quad (4)$$

Where $I_{pv,n}$ - generated nominal current by the light

$\Delta T = T - T_n$

G_n &G-nominal and surface irradiation

$$I_m = I_{pv} - I_d \quad (5)$$

4. P&O MPPT TECHNIQUE

Due to non-linear characteristics of PV system by various atmospheric factors like temperature and irradiance its performance significantly affected. MPPT algorithms are used where it always tracks the maximum value of operating in I-V curve. Among different MPPT techniques P&O MPPT is most popular due to merits such as good performance, suitable and easy to implement. So in this proposed system P&O MPPT to track MPP.The flow chart of P&O algorithm demonstrated in Fig 3

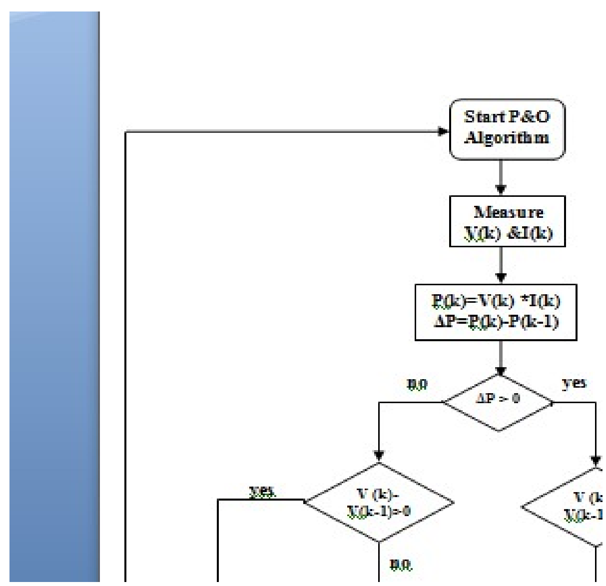

Figure 3. P & O MPPT flow chart

In this method the PV power changes due to slight perturbation. Perturbation is continued in the same direction if the power increases otherwise it would reverse. The algorithm gives reference voltage of the module according to peak voltage. A FO-PI controller then moves the operating point of the module to that particular voltage level.

5. MULTILEVEL BOOST CONVERTER

The combination of boost converter and switched capacitor is called dc-dc Multi level boost converter. For a MLBC to generate N levels in the yield voltage it should has on switch, 2N-1 capacitors and 2N-1 diodes, one Inductor. Circuit of 2 level boost converter is given in Fig 4.

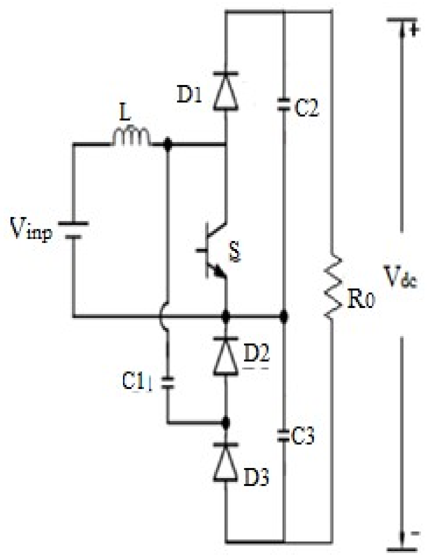

Figure 4. Multilevel boost converter

5.1. Design of MBC

The yield voltage of the normal boost converter is

$$V_{dc}=\frac{V_{inp}}{1-d} \tag{6}$$

The output voltage (V_{dc}) of N level MLBC with duty ratio d and input voltage (V_{inp}) is given by

$$V_{dc}=\frac{n\times V_{inp}}{1-d} \tag{7}$$

The value of Capacitor and Inductor to reduce ripples at output of MLBC is given by the following equations

$$C_1=C_2=C_3=d\times\frac{Vo}{\Delta Vin\times Fs\times Rout} \tag{8}$$

(8)

$$L_{min}=\frac{5\times(R_{out}(1-d)^2)dT_s}{n^2} \tag{9}$$

Where R_{out} is load resistance, T_s is switching period=$1/F_s$.

6. FRACTIONAL ORDER CONTROLLER

Proportional–integral–derivative (PID) controllers are extensively used in process control applications because of their low percentage of overshoot, design simplicity and low settling time. By using suitable settings for the fractional-I and fractional-D actions, PID controllers can be additionally enhanced. A PID controller comprising an integrator of order λ and a differentiator of order μ is known as an FO controller ($PI^{\lambda}D^{\mu}$) .

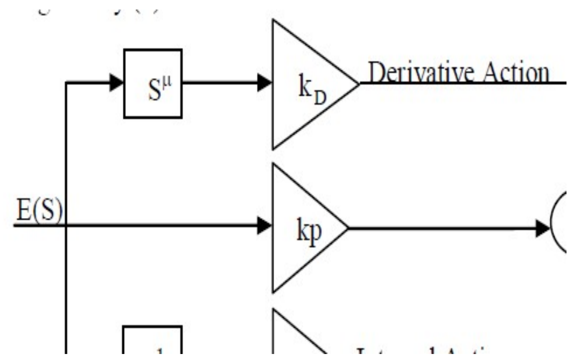

Figure.5 Block Diagram of FO-PID Controller.

The transfer function of the FO-PID controller can be written as follows:

$$G_C(s)=K_P+\frac{K_I}{s^{\lambda}}+K_D s^{\mu} \tag{18}$$

Where λ and μ > 0.

A fractional PID controller, which has additional tuning parameters like λ and μ including K_p,K_i,K_d to tune, which provides robustness under closed loop operation. To realize the FO-PI controller the values of K_d and μ can be considered as zero.

The transfer function of the FO-PI controller (PI^{λ}) is given as follows:

$$G_c(s)=K_P+K_I/s^{\lambda} \tag{19}$$

7. RESULTS & ANALYSIS

The parameters of photovoltaic system and two level boost converter used in the present study are given in Table 1 and Table 2 respectively..The simulation of the circuit is carried out in MATLAB/SIMULINK. The performance of fractional order PI controller (FO-PI) based maximum power point tracking (MPPT) for a high gain multilevel boost converter is compared with P&O MPPT and non-MPPT systems.

Table.1 PV system simulation parameters

Parameter	Value
Open circuit voltage	24V
Short circuit current	3.87A
Temperature	298K
Irradiance	1000 W/m^2

Table 2.MLBC simulation specifications

Parameter	Value
Switching frequency	25KHz
Inductor	25mH

Capacitors	1500µF
Load resistance	100Ω

The performance PV system using multilevel boost converter without MPPT are given in Figures 6&7. The output responses of the two-level converter with perturb & observe MPPT are given in Figures 8&9. The performance PV system using multilevel boost converter FO-PI based P&O MPPT are given in Figures 10&11.

The results prove that the open loop response without MPPT got much disturbed and has much higher overshoot and the regulation is achieved after some time only. The response of the multilevel converter with P&O MPPT has less overshoot but still it takes more time to reach steady state .But with FO-PI based MPPT controller the response is much better. The overshoot is much reduced and the response settles much faster.

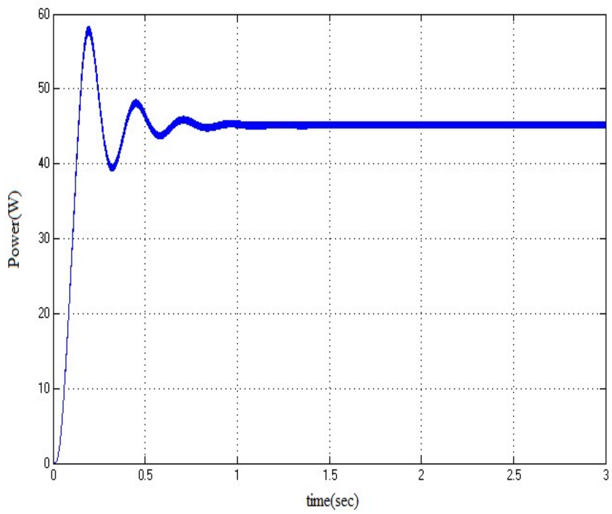

Figure 6.Output power of MLBC with out MPPT

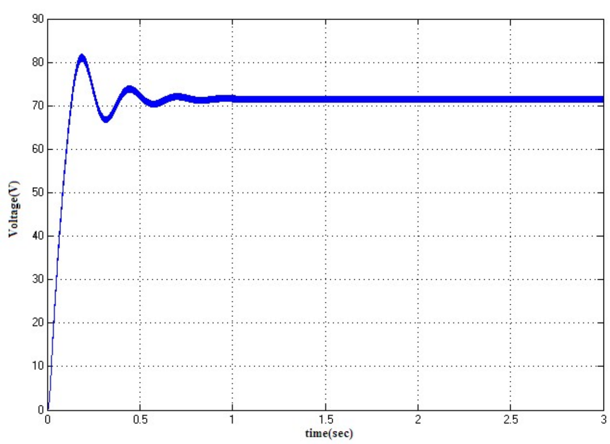

Figure 7.Output voltage of MLBC with out MPPT

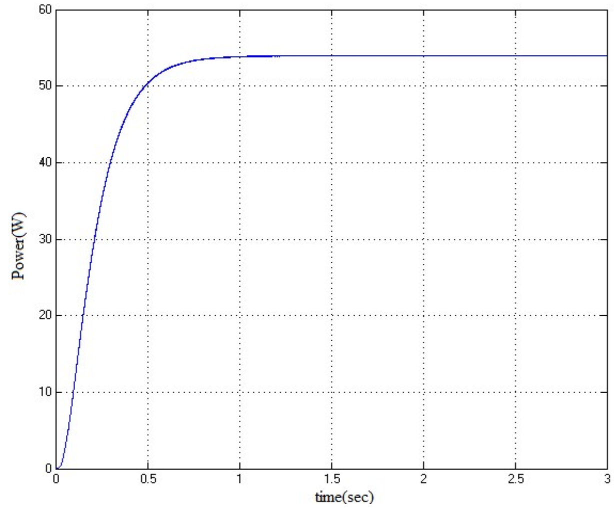

Figure 8.Output power of MLBC with P&O MPPT

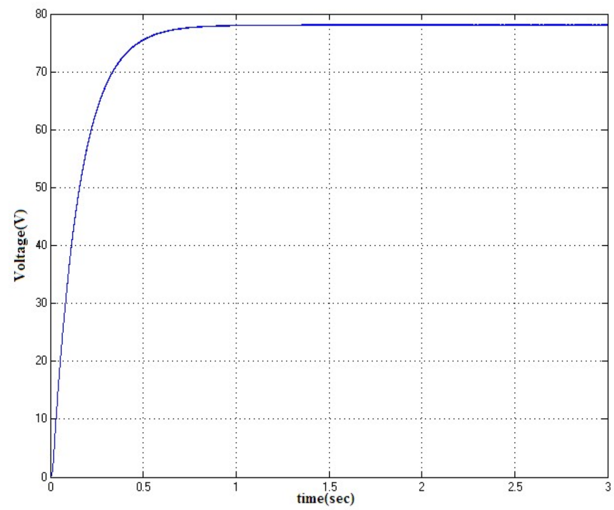

Figure 9.Output voltage of MLBC with P&O MPPT

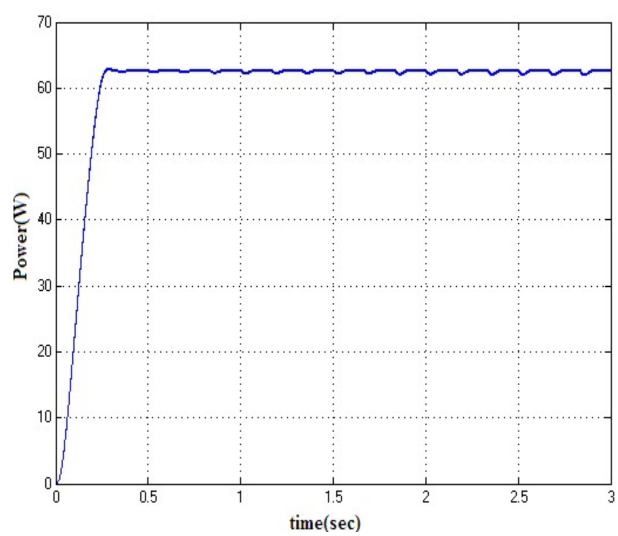

Figure 10.Output power of MLBC with FO-PI based MPPT

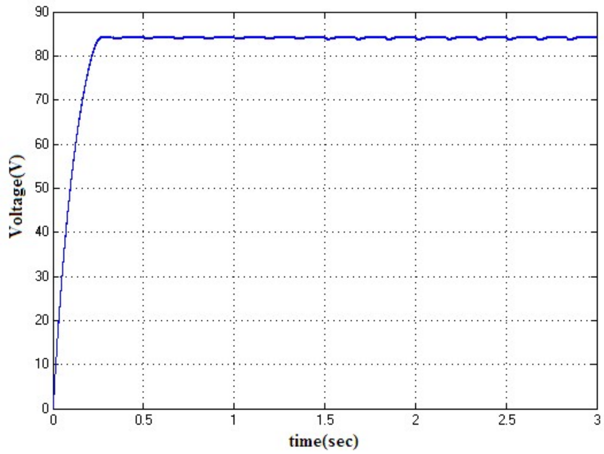

Figure 10.Output voltage of MLBC with FO-PI based MPPT

Table 3 gives the output values of converter with different MPPT techniques. From this fractional order –PI based MPPT gives more output voltage and power. Table 4 gives the time domain specifications of output of the converter with different MPPT techniques.

Table.3 Output of MLBC with different techniques

	INPUT VOLTAGE	OUTPUT VOLTAGE	OUTPUT POWER
Without MPPT	24V	70.85V	44.74W
P&O MPPT	24V	78.04V	53.94W
FO-PI based MPPT	24V	84.2V	62.22W

Table.4 Performance parameters with different techniques

	Without MPPT	P&O MPPT	FO-PI based MPPT
Maximum over shoot	29.63 %	0	0
Settling time	1 sec	0.85sec	0.25 sec
Rise time	0.2 sec	0.85 sec	0.25 sec
oscillation	1.4 V	0.5V	0.3V

8. CONCLUSION

In this study, a novel control scheme for multilevel boost converter with fractional order PI controller (FO-PI) based maximum power point tracking (MPPT) is developed for photovoltaic (PV) applications. Higher voltage can be obtained by using MLBC without the use extreme duty ratio.The performance of the proposed system is compared with P&O MPPT and non MPPT systems. Fractional order –PI based MPPT gives more output voltage and power with reduced distortions .Also it gives better results such as less overshoot,less settling time .Hence the proposed system is useful for solar PV application .

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