Analysis of Boost Converter for Improvement of Solar System Performance using Closed Loop System

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Abstract: **Whole world now a days is facing the energy crisis and problems due to depleting energy sources like coal, diesel and nuclear reserves. Day by day all types of consumers have to search for the sources which will be non-pollutants, easily available, and almost less or free of cost. Answer for this is, better to move towards renewables, like solar, wind, tidal, biogas, biomass and small hydro. In tropical countries where abundant sunshine is there, solar source becomes one of the prominent and readily available energy sources. Many other non-conventional and renewable sources are in use but due to numerous advantages of solar source, it is widely used over others. Solar system is used in many high as well as low voltage applications. Between solar module and load, power interface is required to raise or reduce the voltage level. And for this conversion converters are used. Converters are normally used in open loop mode to give the solar yield. If a closed loop system is opted for getting better output then definitely efficiency of the solar system will increase. Also, a proper and suitable converter topology with a solar operated load and MPPT method will again give a better efficiency with accurate and regulated solar yield. This paper focuses on MATLAB SIMULINK based PI controller working with boost converter and its comparative analysis with different values of insolation and heat levels. Also, few important and useful maximum power point methods are explained in brief, which are also known as control algorithms for solar operated structure.**

***Keywords*-PI controller, boost converter, insolation, maximum power point tracking, control algorithms.**

1. INTRODUCTION

Renewable energy is advantageous in many ways over conventional energy sources. It is ecofriendly as well as clean and sustainable [2]. Renewable energy sources are performing a very important role in the contribution of generation of electrical energy. These sources include wind, solar, tidal, bio gas, bio mass and small hydro. Each source is important and advantageous at its place by cost, availability and total energy generation. But the most readily and widely used source is the solar source. It is available far and wide and free to harness. Its advantages are, it is clean, creating no noise, it has no moving parts, easy to install and integrate. In tropical countries like India where an average, sunshine hour is about 6hrs annually and for about 9 months in a year, solar operated loads can be effectively worked [3].

Solar energy production has basic issue related with its conversion capacity which is limited only to 9-20%, this is for low radiation levels. Also, its output potential generated, changes frequently as per environmental circumstances. One more disadvantage of solar system is, the PV module used has nonaligned current and voltage characteristics due to variable insolation and temperature levels [1]. Partial shading in cells is one of the reasons of lowering the output power for any solar system. Partial shading condition (PSC) occurs because of shadow of neighboring building, cloud cover, trees, birds, and other neighboring objects. The observable effect of PSC is that, there is a formation of multiple or pseudo maxima's instead of only 1 global maximum operating point [4]. For this reason, a proper converter topology (DC-DC converter) is needed which will increase the output obtained from a solar system. Which is also called as a power electronic interface. This DC-

DC converter converts PV low potential to a high level, required for the application like solar PV off-grid systems, satellites, solar vehicles, street-lightings, base transceiver stations as well as building integrated PV systems [2]. Along with this power interfacing stage which is an open loop system, an efficient closed loop system is to be interfaced with the system to reduce the errors and regulate the output voltage. For this, proportional integral (PI) controller is used along with the solar system. Apart from the controller, suitable control algorithms (MPPT) can also be implemented to gain more and more accurate output from the solar system.

Following sections gives the details about this paper- section II explains the equivalent circuit of a solar cell. Section III gives the details of Boost converter with fundamental circuit. Section IV gives the analysis of this topology with PI controller as a feedback element and its performance for various atmospheric conditions.

2. EQUIVALENT CIRCUIT OF A SOLAR CELL

Solar cell is made up of silicon material. It is the basic and important component of a solar array/module. It is converted into its equivalent circuit which can be given using a current source, a diode and two resistors. This model is called as a single diode model of solar cell [5].

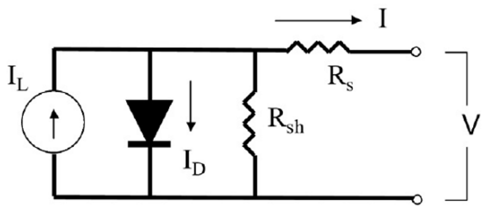

Fig. 1 Equivalent Circuit of a Solar Cell

Mathematical modelling of equivalent PV cell [1]
Diode current,

$Id = I\left[\exp\left(\frac{q(V+Irs)}{KT}\right) - 1\right]$-----------------------------(1)

Gain I,

$I = Il - Id - Ish$------------------------------------(2)

Putting the value of Id and I_{sh}, I will be

$I = Iph - Isat\left[\exp\left(\frac{q(V+IRs)}{AkT}\right) - 1\right] - V + IRs/Rp$ ---------(3)

Where,

I- load side current (A)

I_{ph}-photon current

I_{sat}- diode overload current (A)

q- electron charge -1.6*10-19 C

k- constant (Boltzmann's) -1.38*10-23 J/K

T- Temperature of a solar unit (^{0}K)

R_s- Resistance in series (Ω)

R_p- Resistance in parallel (Ω)

V- Output voltage of a solar Cell

A- Diode ideal factor

A module/panel will form when the cells are connected in series and parallel, further when the modules are connected together in series or parallel, it forms an array. As per load requirement, to have a low or high output voltage, array is connected with a proper interfacing circuit. And that interfacing circuit is nothing but a buck or boost converter (step down or step up converter resp.) used in an open or closed loop form.

2.1 Module Specifications

A solar module used for MATLAB simulations having following specifications and its P-V and I-V characteristics.

Module: - 1 Soltech-1STH-230-P

Table I. PV Module Specifications [7]

Sr. No.	Parameter	Value
1	Number of Modules (in series)	5
2	Number of Cells per module	60
3	Light irradiance (standard) G	$1kw/m^2$
4	Series Resistance Rse	0.3433 Ω
5	Shunt Resistance Rsh	294.1335Ω
6	Diode Ideality Factor	1.0028
7	Diode Saturation Current	3.0478e-10
8	Maximum Power Pmax	228.735W
9	Maximum voltage Vmax	29.9V
10	Maximum Current Imax	7.65A
11	Open Circuit Voltage Voc	37.1V
12	Short Circuit Current Isc	8.18A
13	Temperature Coefficient of Voc	-0.361
14	Temperature Coefficient of Isc	0.102

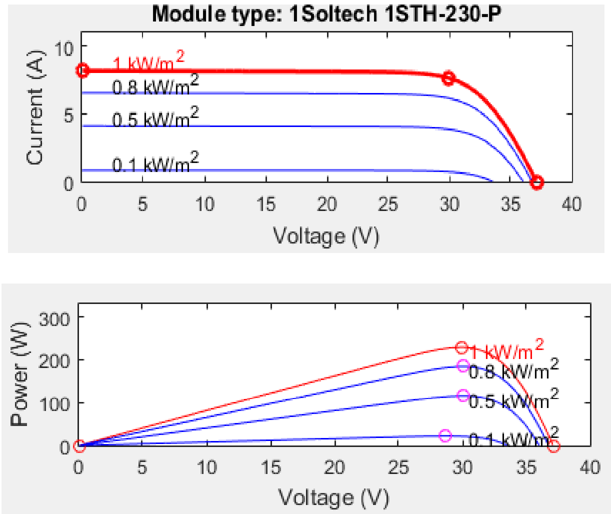

Fig. 2 I-V and P-V Charatristics of a Soltech Module for various Irradiance (G) levels

Fig. 2 shows the current voltage charactristics of a selected module for different irradiance values varying from 100W/m^2 to 1000W/m^2 with specific temperature of 25^{0}C. charactristics shows Voc- open circuit voltage Isc- short citcuit current, Vm- maximum voltage at operating point and Im- maximum current for the module. It also explains the power voltage perfromance curves for radiation levels 100 to 1000W/ m^2. This charactristics gives the value of maximum power Pmax for the STC (standard test conditions)

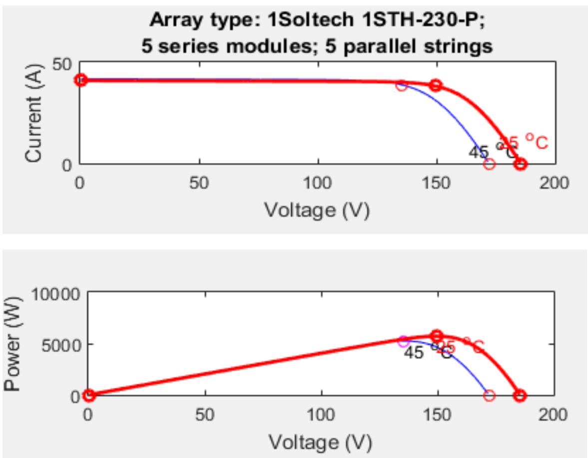

Fig. 3 I-V and P-V Charatristics of a used Module for various Temperture Levels (no load condition)

Fig. 3 explains the performance curves ie. I-V and P-V charactristics for the above mentioned module for different temperature values like 25^{0}C and 45^{0}C.

Table II. Insolation Vs. Approximate values of Voc,Isc, and Power (no load condition)

Sr.No.	G (Kw/m^2)	Voc(v)	Isc(A)	P(W)
1	1000	37.1	8.18	303.47
2	800	36.68	6.54	239.88
3	500	35.94	4.02	144.47
4	400	35.68	3.27	116.67
5	100	33.52	0.81	27.15

Table III. Insolation Vs. Approximate values of Vm,Im, and Fill Factor (no load condition)

Sr. No.	G (Kw/m^2)	Vm(v)	Im(A)	Pm(W)	FF= Pmax/Voc*Isc
1	1000	29.9	7.65	228.73	0.75
2	800	29.44	6.23	183.41	0.76
3	500	29.28	3.91	114.48	0.79
4	400	29.26	3.13	91.58	0.78
5	100	29.12	0.75	21.84	0.80

2.2 Boost Converter/Step Up Topology

DC-DC converter/choppers are working as a switching mode regulator. The unregulated voltage or power is getting converted into a regulated one with the help of converters. Also, a configuration of proper and suitable semiconducting switching device is used in a converter circuit for turn ON and turn OFF purpose. The main topologies are buck, boost, buck-boost, cuk, Single Ended Primary Inductor Converter (SEPIC) and fly back–boost converter. Switches used are MOSFETs, IGBTs, BJTs and thyristors. As per the design requirement and load connected at the output side, switches are used in converter circuits [2]. Converters used, can be classified according to the separation of power and control circuit. There are 3 types of converters namely- isolated, non-isolated and hybrid converters. Out of above-mentioned types of converters, boost topology has a continuous input current and a discontinuous output current. It gives high output voltage for low source voltage. These characteristics of boost topology makes it suitable for different PV applications [6]. The following sections explains boost topology, its open and closed loop circuitry and simulation results.

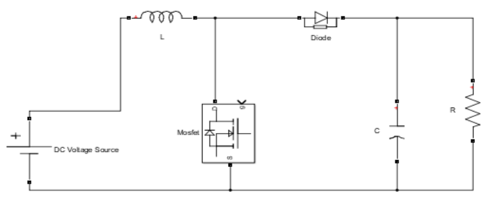

Fig. 4 Boost/Step up chopper (MOSFET used as a switching device)

Step up converters/boost converter increases the source voltage to a higher value at load side ie. output voltage is always greater than input voltage. Components used in the boost topology are -inductor(L), switch (MOSFET), diode(D), capacitor(C) and Resistive load(R). When the switch is turned ON, inductor starts storing energy, as no current flows through the load, the output voltage is zero. When switch is turned OFF, input gets applied to the load. In the OFF period whatever energy stored in inductor, gets discharged through the load during ON period. Hence the output voltage becomes more than the input voltage. Output voltage is given by equation [9]

$$V_0 = V_{in}/1-\alpha$$

Where, V_0 is output voltage, V_{in} is input voltage and α is the duty ratio.

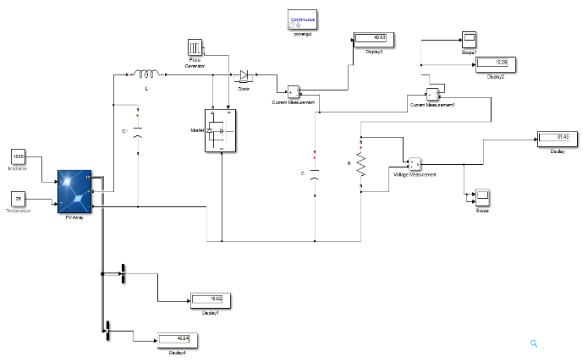

Fig. 5 Computer Simulation circuit of Step-up Converter without PI controller (at STC G=1000W/m^2 and T=25^{0}C)

Table IV. Boost Converter Parameters

Sr. No.	Parameter/Component	Value
1	**MOSFET**	
	FET resistance Internal diode resistance (Rd)	0.0001 Ω 0.01 Ω
2	Inductor (L)	100 mH
3	**Diode (D)**	
	Resistance Forward voltage (V_f) Snubber resistance Snubber capacitance	0.001 Ω 0.8V 500 Ω 250e $^{-9}$ F
4	Capacitor (C)	300µF
5	Frequency	25khz
6	Pulse width	70
7	Load Resistance	5 Ω

Table V. Boost Topology Performance for Different values of G and T = 25^{0}C and 45^{0}C without feedback loop for a step-up chopper (no PI controller)

S/w	G W/m^2	T ^{0}C	Vin (V)	V out (V)	I_{in}	I_{out}	η=Pout/ Pin (%)
MOSFET	1000	25	18.52	61.45	40.84	12.29	99.85
	800	25	14.87	49.19	32.69	9.83	99.47
	500	25	9.39	30.77	20.45	6.15	98.54
	1000	45	18.97	62.96	41.67	12.59	99.72
	800	45	15.23	50.39	33.35	10.08	99.99
	500	45	9.57	31.39	20.86	6.27	98.59

Average value of η for 25^{0}C= 99.28 and for 45^{0}C=99.43

The above simulations results show the values of efficiency obtained from the solar system with a boost topology at different values of temperatures (T) and irradiances (G).

3. PI CONTROLLER and PERFORMANCE OF BOOST CONVERTERS

Proportional and Integral (PI) controller, increases the speed of reaction of a system and removes offset. This combination has lot of advantages [11]. PI controller calculates an error value as the difference between a measured process variable and a desired set point. The controller tries to reduce the error by adjusting the process through the use of a manipulated variable.

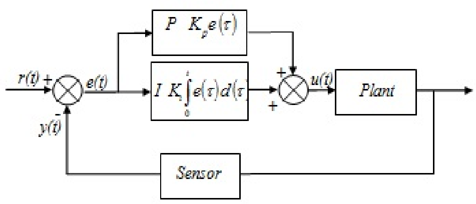

Fig. 6 Block diagram of PI controller system

PI controller is used to control the buck/boost converter (topology used as per requirement) input voltage to set it at the reference voltage that gives the maximum power [12]. The PI controller is adjusted manually by setting the value of Ki equal to zero. The value of Kp is manually tuned in order to eliminate any error between the set-point and process variable. By increasing the value of Ki for the system until the offset, it will decrease the rise time of the system. However, the system will become unstable and the overshoot will be increased. The value of Ki must be adjusted in certain amount to make sure the system endures the overshoot while decreasing the settling time and keeping the stability. The derivation of the PI controller is obtained as follows [10]

$$u(t) = Kp(t) + Ki \int_0^t e\,(\tau) d\,\tau$$

Thus, by using PI controller in a buck or boost circuit efficiency of a solar system can be increased to the better extent.

3.1 Analysis OF Boost Converter with PI Controller

Fig. 7 shows the computer simulation of a dc-dc boost converter with a MOSFET as a switch and PI controller in a feedback path. This simulation shows the increase in efficiency due to PI controller.

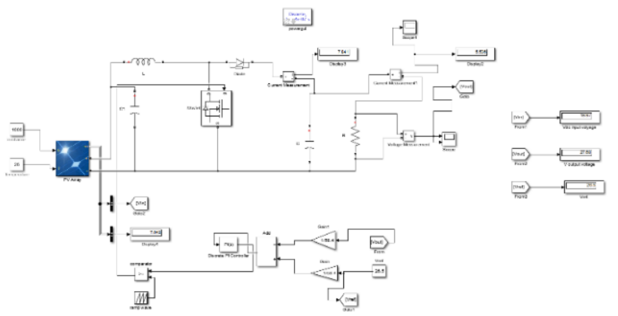

Fig.7 Computer Simulation circuit of Step-up Converter with PI controller (at STC G=1000W/m^2 and T=25^{0}C)

Table VI. MOSFET as a switch for step up converter for different Values of G and T with PI controller

S/w	G W/m^2	T ^{0}C	Vin (V)	V out	I_{in}	I_{out}	η=Pout/Pin (%)
MOSFET	1000	25	50.39	101.6	40.73	20.32	100
	800	25	40.43	81.36	32.62	16.27	100
	500	25	25.46	50.93	20.42	10.19	99.90
	1000	45	51.41	103.7	41.56	20.73	100
	800	45	41.25	83.02	32.28	16.06	100
	500	45	25.97	51.97	20.83	10.39	99.81

Average of efficiency with PI controller for 25^{0}C= 99.96 and for 45^{0}C= 99.93

Table VII. Efficiency values for Boost Topology with and without PI controller

G(W/m^2)	Without PI	With PI	Error
(1000,800,500)	99.28 (25^{0}C)	99.96(25^{0}C)	0.68
(1000,800,500)	99.43(45^{0}C)	99.93(45^{0}C)	0.5

Any circuit with a closed loop forming a subsystem gives the results more accurate and less offset in an output value. Table 7 shows the comparative results for the Boost topology for efficiency values related to various radiation levels and temperatures. From the results it is clear that efficiency of boost topology can be increased using closed loop system using PI controller which gives a very small amount of error between the outputs obtained with PI and without PI controller.

4. CONCLUSION

From MATLAB simulations, analysis of boost converter will be done which shows that the efficiency of a solar system using PI controller can be increased. A closed loop system is always better to use instead of open loop system using a PI controller. This will surely give high efficiency as the yield from the solar syatem is always varies as per the environmental changes which will in turn changes the maximum operating point and maximum power obtained from it. Hence a suitable closed loop system can be used which keeps the MPP always at its peak.

5. FUTURE SCOPE

Further this simulation can be done using different Maximum power point techniques like perturb and observe (P and O), incremental conductance

(INC), bat algorithm, open circuit voltage control, short circuit current control, neural network, fuzzy logic control, back stepping control etc. These all control algorithms tracks and measures the maximum power point of the respective system at each instant of time and try to reduce the error formed by using open loop for any irradiance (G) and temperature (T). So always a maximum power can be extracted from the solar arrangement using these control algorithms. Thus, by using above said methods efficiency can be raised to a required application level with various loads.

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