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ANN Based MPPT Controller To An Interleaved Soft Switching Boost Converter For A PV System

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Abstract:

The proposed project uses an Artificial Neural Network(ANN) based Maximum Power Point Tracking (MPPT) Controller to an Interleaved Soft Switching Boost Converter for a stand alone system. This topology used to raise the efficiency of the converter of the PV power conditioning system. It minimizes switching losses by adopting a resonant soft-switching method. The overall efficiency is increased when compared with the conventional hard switching interleaved boost converter. ANN based Maximum power point tracking gives accurate tracking of operating points and improves panel efficiency. Simulation is done using MATLAB Software. The simulation results show the low input current ripple, high overall efficiency and good transient response is achieved.

Keywords:*Maximum Power Point tracking (MPPT), Interleaved Soft Switching Boost Converter (ISSBC), Resonant switching, Artificial Neural Network (ANN) ,Backpropogation feed forward network..*

1.Introduction

Recently photovoltaic (PV) energy has attracted interest as a next generation energy source capable of solving the problems of global warming and energy exhaustion caused by increasing energy consumption. PV energy avoids unnecessary fuel expenses and there is no air pollution or waste. Also, there are no mechanical vibrations or noises because the components of power generation based on PV energy use semiconductors. The life cycle of the solar cell is more than 20 years, and it can minimize maintenance and management expenses.

The output power of the solar cell is easily changed by the surrounding conditions such as irradiation and temperature, and also its efficiency is low. Thus high efficiency is required for the power conditioning system (PCS), which transmits power from the PV array to the load. In general, a single-phase PV PCS consists of two conversion stages (i.e., dc/dc conversion stage and dc/ac conversion stage). The dc/dc converter is the first stage and it performs maximum power-point tracking (MPPT) and guarantees the dc-link voltage under low irradiance conditions.

This paper proposes a high efficiency dc/dc boost converter to increase the overall efficiency of PV power conditioning system [1]. The proposed single-switch type soft-switching boost converter can minimize switching loss by adopting a resonant soft-switching method. And, no additional switches are needed.

The drawback of this converter is that the voltage across the switch is very high during the resonance mode. The voltage across the switch depends on the parameters of the resonant components (i.e., resonant inductance and resonant capacitance) and the resonant inductor current. In this paper, the optimal design of the resonant components and the interleaved method is applied for resonant current reduction. Since the interleaved method distributes the input current according to each phase, it can decrease the current rating of the switching device. Also, it can reduce the input current ripple, output voltage ripple, and size of the passive components. The proposed soft-switching interleaved boost converter cannot only exploit the interleaved converter but also reduce switching losses through the soft-switching technique. Therefore, the output power of the PV array can be boosted with high efficiency, for soft switching [4]

The proposed topology uses the Artificial Neural Network based Maximum power point tracking , which it can gives the accurate tracking and fast transient response for any change in insolation.[2]

This paper presents the operational principle of the converter, a theoretical analysis and design guidelines, and simulation and experimental results are provided to verify the theoretical analysis.

2.Solar Array Mathematic Model

The equivalent circuit model of a solar cell consists of a current generator and a diode plus series and parallel resistance [5]. The mathematical equation expressing the output current of single cell is given as Eq. (1)

$$I = I_{ph} - I_o[\exp\{q(V+I R_s)/AkT\}-1] - (V+I R_s)/R_{sh} \quad (1)$$

where I_{ph} = photo current

I_o = leakage or reverse saturation current,

q = electron charge,

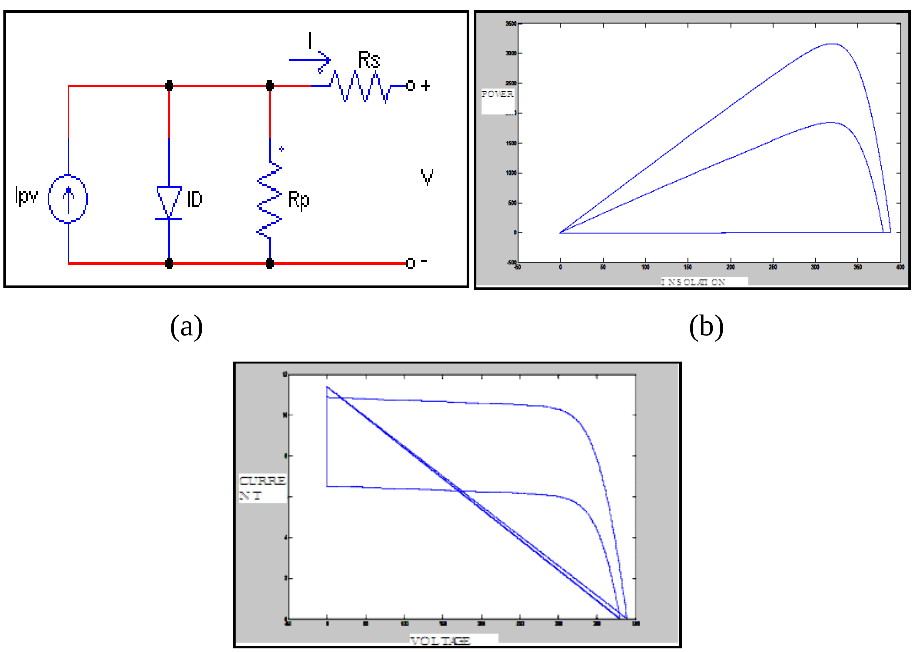
V = solar cell voltage,

A = Ideality factor,

k = Boltzman constant,

R_s = series cell resistance,

R_p = shunt cell resistance



(a) (b)

(c)

Figure 1: a) Solar cell Model b) P-V Characteristics of a Solar Cell c) I-V Characteristics of a Solar Cell (For a change in Insolation from (1000 W/m^2 to 600 W/m^2)

3.Proposed Topology

3.1.Proposed Soft-Switching Boost Converter

The block diagram is shown in fig1. In this the insolation is sensed and it is given to the neural network. And the neural network will deliver the corresponding duty cycle to that particular insolation. In such a manner the neural network is trained in off- line. The interleaved boost converter consists of two single-phase boost converters connected in parallel. The two PWM signal difference is 180◦ when each switch is controlled with the interleaving method. Because each inductor current magnitude is decreased according to one per phase, we can reduce the inductor size and inductance when the input current flows through two boost inductors. The input current ripple is decreased because the input current is the sum of each current of inductor *L*1 and *L*2.

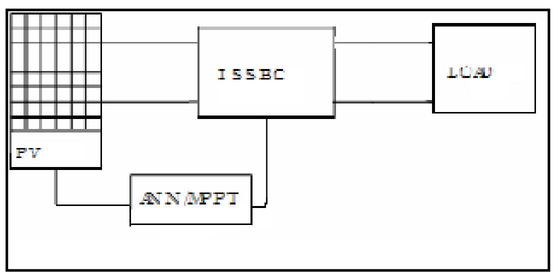


Figure 1: Proposed Block diagram

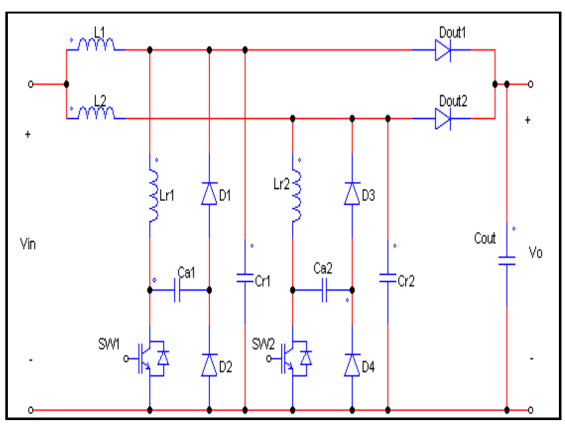


Figure 2: Proposed Interleaved soft-switched Boost Converter (ISSBC)

Fig. 2 shows the interleaved soft-switching boost converter (ISSBC) proposed in this paper. Two single-phase soft-switching boost converters are connected in parallel and then to a single output capacitor.

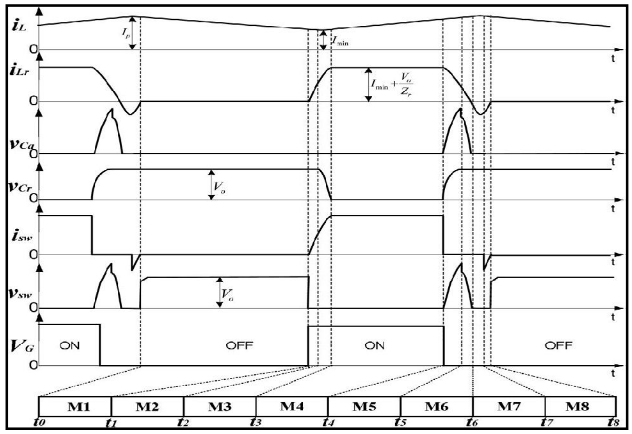


Figure 3: Key waveforms for the proposed converter

3.2.Mode Analysis Of The Proposed Converter

Each mode is presented during one switching cycle of steady-state operation of the proposed converter. For illustrating the soft-switching operation using resonance, we describe the operation modes of a single-phase soft switching boost converter [see Fig. 2], which consists of the proposed ISSBC. The key waveforms associated with the operation stages are shown in Fig. 3. The operation modes shown in Fig. 4, and the duty ratio is assumed to be 0.5 in order to simplify the analysis. The operation can be analyzed in terms of eight modes according to the operating conditions defined in the following paragraphs.

- All switching devices and passive elements are ideal.
- The parasitic components of all switching devices and elements are ignored.
- It is assumed that the initial value of each operation mode is equal to zero.

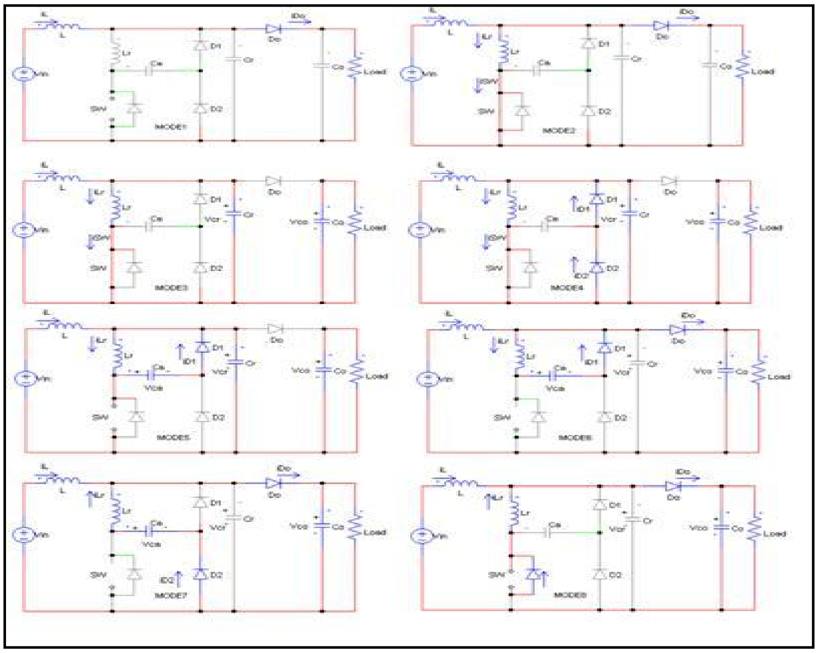


Figure 4: Mode analysis for the proposed converter

- Mode 1 (t0 ≤ t < t1): The switch is in the off state and the dc output of the solar cell array is transmitted directly to the load through L and D_{out}. In this mode, the main inductor voltage becomes – (Vo – Vin). Thus, the main inductor current decreases linearly.
- Mode 2 (t1 .t<t2): In mode 2, the switch is turned on under zero-current switching (ZCS) because of the resonant inductor L_r . In this case, as the output voltage is supplied to the resonant inductor L_r , the current increases linearly. When the resonant current iL_r becomes equal to the main inductor current iL, the current of the output side diode D_{out} becomes zero .
- Mode 3 (t2 ≤ t <t 3): When the output current iD_{out} becomes zero, the mode starts. In this mode, the resonant inductor L_r and the resonant capacitor C_r resonate and the voltage of C_r decreases from the output voltage V_o to zero. In this case, the main inductor current iL flows through L_r and the switch.
- Mode 4 (t3 ≤t<t4): When the resonant capacitor voltage VC_r becomes zero, the two auxiliary diodes D1 and D2 are turned on and the mode starts. In this mode, the resonant inductor current is separated into two parts. One is the main inductor current iL and the other is the current turning through the two auxiliary diodes. The main inductor current iL increases linearly.

- Mode 5 ($t4 \leq t < t5$): In mode 5, the switch turns off under the zero-voltage condition because of the auxiliary resonant capacitor C_a . There are two current loops. One is the L-C_r - V_{in} loop for which the voltage of the resonant capacitor Cr increases linearly from zero to the output voltage V_o . The other is the Lr–C_a–D1 loop for which the second resonance occurs. The energy stored in L_r is transferred to C_a . The resonant current iL_r decreases linearly and the voltage across C_a becomes maximal.
- Mode 6 ($t5 \leq t < t6$): When the resonant capacitor voltage vCr is equal to the output voltage V_o , the mode starts. In this mode, the energy flow from L_r to C_a is completed and the resonant current iL_r becomes zero .
- Mode 7 ($t6 \leq t < t7$): In mode 7, the voltage of C_a decreases, continuously resonates on the D2–C_a–L_r –D_{out}–C_o loop and the energy is transferred from C_a to L_r . When the C_a voltage becomes zero, the resonant current iL_r is the reverse of the current direction of mode 6. When the voltage of C_a becomes zero, the anti parallel diode of the switch turns on and it transitions to the next mode.
- Mode 8 ($t7 \leq t < t8$): There are two current loops. The main inductor current iL transmits energy to the output through D_{out} and decreases linearly. The resonant inductor current iL_r also transmits energy to the load through D_{out} and flows through the anti parallel diode of the switch. When the resonant inductor current iL_r becomes zero, mode 8 ends.

4.ANN

ANNs are widely accepted as a technology offering an alternative way to solve complex problems. Particularly, in recent years the application of ANN models in various fields is increasing because these ANN's operate like a black box model, requiring no detailed information about the system. They learn the relationship between the input and output variables by studying the previously recorded data. These trained ANN's can be used to approximate an arbitrary input–output mapping of the system.

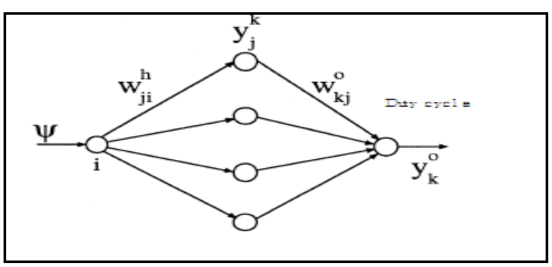


Figure 5: Feed forward neural network

Among the available training algorithms, the back propagation algorithm [2] is one of the most widely used, because it is stable, robust, and easy to implement. We now begin by considering the feed forward neural network consisting of a single hidden layer with sigmoid activation function. An

input vector x= (Ψ1, Ψ2, Ψ3, …… Ψn),^{T} is applied to the input layer of the network which is nothing but the insolation as shown in Fig. 3. The net input of jth the hidden unit is

$$net_j^h = \sum_{i=1}^{n} w_{ji}x_i + \theta_j^h \qquad (2)$$

where w_{jj} is the weight on the connection from the *i* th input $\theta^h{}_j$ for j-1,2…..unit, for represents the bias for hidden layer neurons. Now, the output of the neurons in the hidden layer is written as

$$y_j^h = f(\sum_{i=1}^{n} w_{ji}x_i + \theta_j^h) \qquad (3)$$

and the net input to the neurons in the output layer becomes

$$net_k^o = \sum_{j=1}^{N_h} w_{kj}y_j^h + \theta_k^o \qquad (4)$$

Finally, the output of the neurons (Duty cycle for the feedforward loop) in the output layer is

$$y_k^o = f(\sum_{j=1}^{N_h} w_{kj}y_j^h + \theta_k^o) \qquad (5)$$

The learning stage of the network is performed by updating the weights and biases using the backpropagation algorithm with the gradient-descent method in order to minimize a mean-squared-error performance index E_p given as

$$E_p = 0.5 \left(V_{ref}(n) - V_A(n)\right)^2 \qquad (6)$$

The synaptic weights updating expressions are

$$w_{ji}(n+1) = w_{ji}(n) - \eta \left(\frac{\partial Ep}{\partial w_{ji}(n)}\right) + \alpha \Delta w_{ji}(n) \qquad (7)$$

$$\Delta w_{ji}(n) = w_{ji}(n) - w_{ji}(n-1) \qquad (8)$$

where and are learning and momentum factors, respectively. With the above equations in the forward direction, the ANN training is performed with the help of the Neural Tool box in the Matlab Software. The Training samples are taken in the trail and error for different insolation level and corresponding duty cycle is mapped. The function fit obtained is shown in Fig 6.

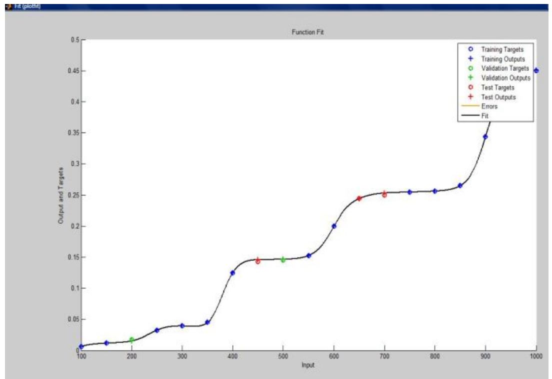


Figure 6: Insolation versus duty cycle

5.Simulation

5.1.*Solar Panel Model And Converter Specifications*

The simulation is done with the help of MATLAB / SIMULINK. The maximum power point tracking is done for the voltage based peak power tracking using a PI Controller and transient response for these method and the proposed method is checked. The panel specifications and the converter parameters are listed in the Table I and Table II respectively.

The input and output patterns for the Neural Network (i.e., Insolation and Duty cycle) is either determined by experimental means or by trail and error methods,

Sl No	Description	Rating
1	Short circuit current (Isc)	10A
2	Open circuit voltage(Voc)	388.89V
3	Rated current at MPP(Imp)	9.9A)
4	Rated voltage at MPP(Vmp)	319.5V

Table 1:Solar Panel Specifications

The more samples we take the more the accuracy could be yielded. In this paper by taking the maximum power obtained trough the voltage based peak power tracking was taken as a reference. and by keeping that values as reference, the output patterns are determined for the proposed topology. for particular insolation the maximum power is obtained that can be done by changing the Duty cycle of the converter. Likewise, the other samples or taken and these values to be used for training once the network is trained that can be implemented for the proposed circuit.

5.2.Simulation Model For The Proposed Topology

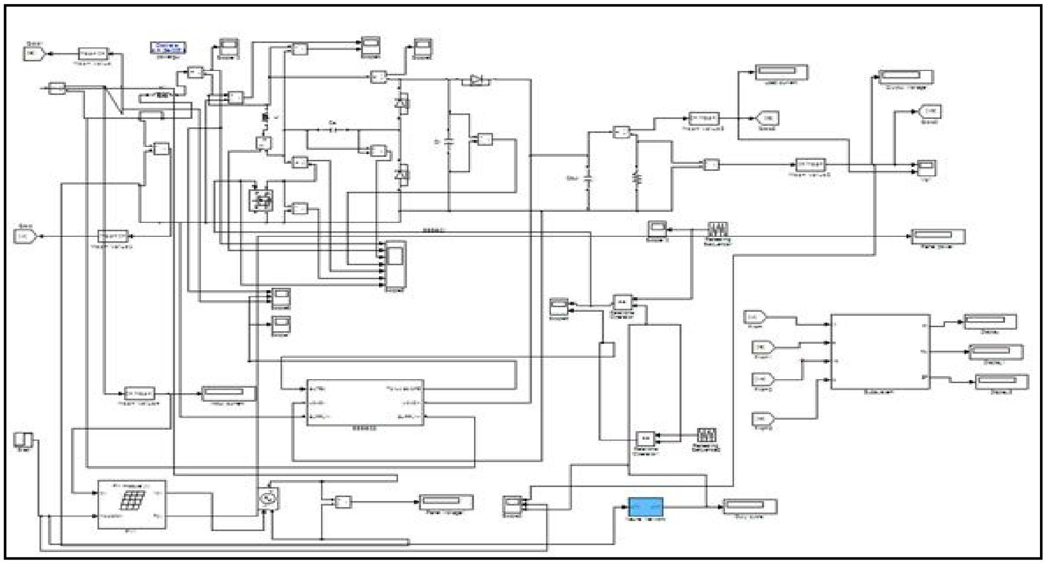


Figure 7(a):Simulation model for the ISSBC

Parameter	Symbol	Value	Unit
Input Voltage	V_{in}	90-330	V
Output voltage	V_o	500	V
Main inductor	L1,L2	1	mH
Resonant Inductor	L_{r1},L_{r2}	50.6	µH
Resonant Capacitor	C_{r1},C_{r2}	100	nF
Auxillary capacitor	C_{a1},C_{a2}	10	nF
Output capacitor	C_{out}	10	nF
Switching frequency	F_{sw}	30	kHz

Table 2: Converter Specifications

The key waveforms for the proposed converter is simulated is shown in the fig.7(b). and these characteristics matches with the fig 3. and also the main advantage for the Interleaved soft switched boost converter(ISSBC) is the reduction of the switch current rating due to that the average current of the converter is divided into half and hence the device stress is minimised.

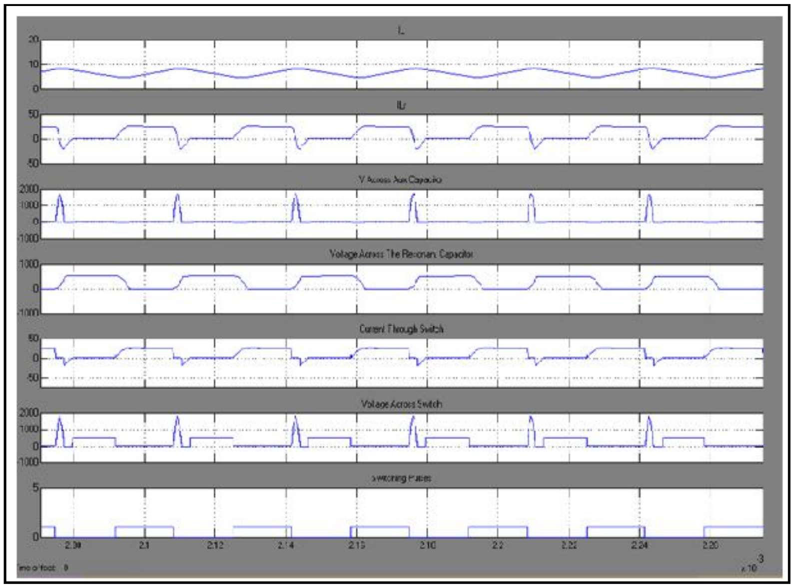


Figure 7(b): Simulated waveforms for the ISSBC

The above waveforms is for the single converter alone and similar kind of waveforms can be obtained in the other converter also but the firing pulses are 180^o degree out of phase between the first converter.

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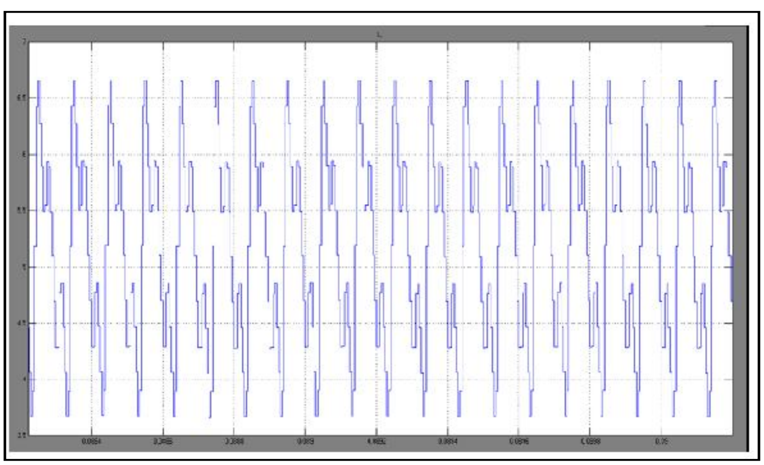

Figure 8(a): input current waveforms for the SSSBC

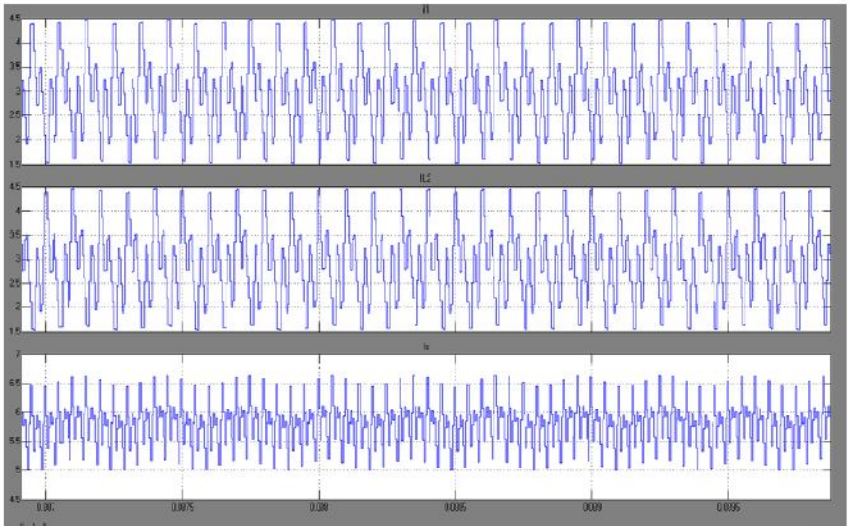

Figure 8(b): input current waveforms for the ISSBC

The Fig 8. and Fig 9 shows the input current waveforms for the Single switch soft switching Boost converter and the proposed ISSBC and it has been observed that in SSSBC the ripple was about 3A, and it has been reduced to 50% i.e.,1.5A by implementing the interleaved boost converter. The above waveform is obtained for the Insolation 600W/m^2.

5.3.Simulation Model For Voltage Based Peak Power Tracking

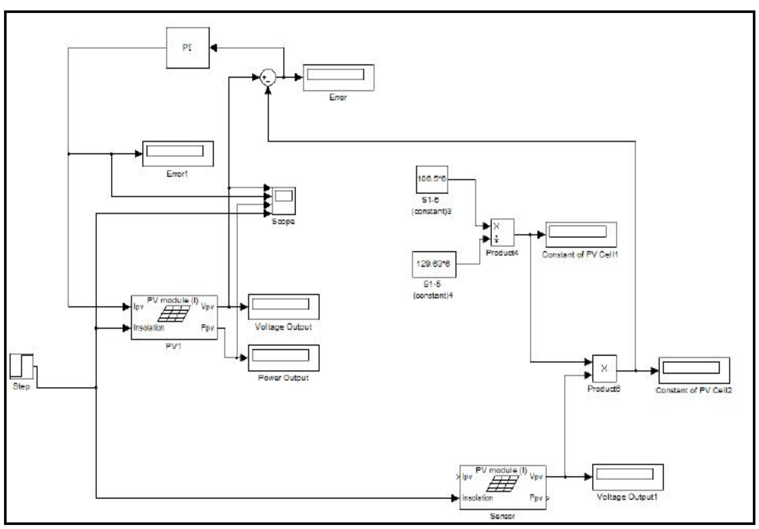

Figure 10 (a): Simulation model for MPPT using PI Controller.

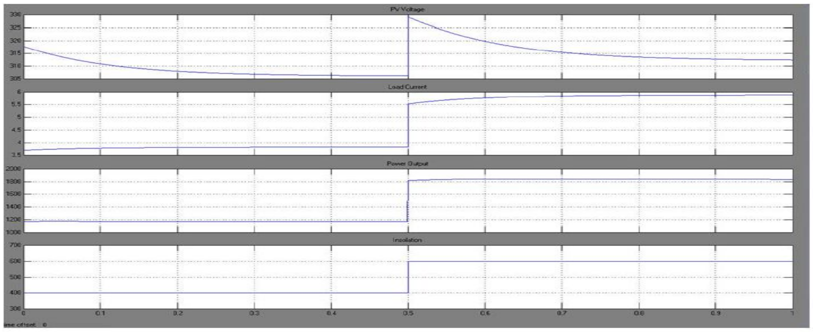

Figure 10 (b): Simulated waveforms for the MPPT using PI controller (for a step change 400 to 600W/m^2)

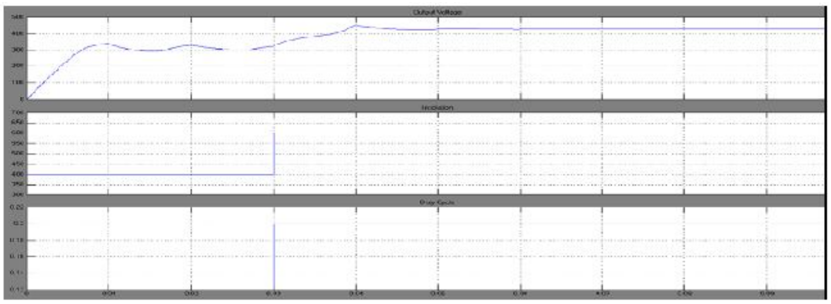

Figure 10 (c): Simulated waveforms for the ISSBC for a step change 400 to 600W/m^2

In Fig 10(b) ,The response for the PI based control MPPT which is sluggish, it will take approximately 0.3seconds for the change in insolation. Which is quite large but in the proposed method ANN based MPPT which it take 0.01 seconds for the new insolation which is much faster transient response compare to the conventional method. The response for the proposed method is shown in fig 10 (c).

5.4.Result Analysis

Sl No	Parameter	Boost Converter	SSSBC	ISSBC
1	Input ripple	>50%	33%	15%
2	Output voltage(V)	520	545	554
3	Output voltage ripple	>10%	2%	1%
4	Source current (A)	8.7	9	9.645
5	Output current ripple	12%	2.05%	1%

Table 3: Performance Comparison(in converter side)

The Simulation was done for 1000W/m^2 for the three different converters and the performances are tabulated in Table III.The Simulation results for the two different MPPT techniques has been listed in Table IV, In PI control the steady state error will be lesser compare to all other conventional and soft computing techniques. Panel output voltage will be better at higher Insolation in ANN based MPPT and also duty cycle manipulation is also very faster in the case of ANN and the error rate also within the acceptable limits.For a change in insolation In PI based it takes much time to attain the new voltage value either from higher to lower or vice versa but in ANN it is much faster than the conventional techniques, In Table V the values show for change in insolation from 400 to 600W/m^2.

Insolation (W/m^2)	Voltage based PI control MPPT		ANN Based MPPT		Duty cycle		Error in %
	Panel o/p power (W)	Panel o/p voltage (V)	Panel o/p power (W)	Panel o/p voltage (V)	Trained	Actual	
1000	3163	319.5	3251	325.8	0.4500	0.4507	-0.1500
900	2835	318.0	2814	324.8	0.3435	0.3432	0.0800
800	2503	316.3	2489	321.3	0.2561	0.2561	0
700	2170	314.3	2174	319.4	0.2500	0.2530	-1.2
600	1835	312.1	1840	316.7	0.2000	0.2000	0
500	1500	309.4	1454	304.3	0.1450	0.1465	-1.034
400	1166	306.0	1135	291.3	0.1250	0.1250	0
300	833.8	301.5	801.4	282.1	0.0393	0.0392	0.254
200	506.6	294.7	355.9	139.8	0.0175	0.0171	2.2
100	190.5	280.9	93.77	89.61	0.0060	0.0061	-1.66

Table 4: Performance Comparison(Based On MPPT Techniques)

PI Control	ANN
0.3	0.01

Table 5: Response Comparison(in secs)

6.Conclusion

The proposed Interleaved soft switched Boost converter having less ripple at both input as well as the output side as a result the filter requirements will be less. Without any additional filters by using these topologies the performance of the converter can be improved. For tracking the maximum power, it has been compared with the simulation results between voltage based peak power tracking and ANN based MPPT, The transient response is much higher than all other algorithms. This will enable the system to settle at new operating point very sooner.

7.**Acknowledgement**

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8.Reference

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