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Comparative Study on Solar Powered Interleaved Boost Converter

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Abstract

Solar energy is an important source of renewable energy. But, it is unpleasant that, only partial amount of energy can be extracted from the Solar cells by our conventional DC-DC Boost converters. A comparative study on solar powered Interleaving Boost converters (ILBCs) is initiated. A novel Solar powered, Series-Inductor ILBC with less current ripple than the conventional ILBC is proposed. A comparative study on single- stage, two-stage and three-stage ILBCs are done. The comparison of ripple reduction of output voltage is tried with 'C', 'Pi' and Cascade Filters. The results have been applied to R-Load and motor load. The input of 150V is fed to the ILBC from the solar cell and compared for the ripple. The proposed solar powered series inductor ILBC has reduced ripple than the conventional ILBCs. Comparison table of performance and simulation results of these aforementioned solar powered ILBCs have been exhibited in this paper.

Keywords: Boost Converter, Comparison Study, Interleaving, Solar Power

1. Introduction

To enable the solar cell and to use sunlight efficiently, DC-DC converters are used for the solar power generation[1]. But, the fact is that 100% energy cannot be extracted from the solar cell by the conventional DC-DC converters. Though, many technique have been invented and implemented still, there is a lag and restrictions in the research of boost converters. While commencement of interleaving technique in the converters being an evolving technique, it can be a solution for the aforementioned problem.

2. Design of a Photovoltaic Panel

The efficiency of a solar cell depends mainly on Short circuit current (I_{sc}), open circuit voltage (V_{oc}), Fill factor (FF).FF is nothing but the squareness of the I-V curve Figure 2, which is related to the resistive losses of the solar cell. Best value of a good solar cell should be ≥ 0.80.

$$FF = [V_{oc} - \text{In}\,(V_{oc} - 0.72)] / [V_{oc} + 1];$$

$$V_{oc} = [kT/q] * [\text{In}\,(I_l / I_0) + 1)];$$

Where, I_0 → Recombination current in the material due to the electron-hole pair; I_l → Light generated current; V_{oc} → Maximum voltage obtained when solar cell is left open; I_{sc} → Maximum current when the solar cell terminals are shorted.

The material with large band gap energy will absorb less number of Photon for recombination. I_{sc} will increase with decrease in band gap energy of the material of solar cell. Therefore V_{oc} and $Isc_{increases}$ with decreases in I_o.

Therefore, the model of a solar cell shown Figure 1 is designed with all losses into account. The optical loss of the solar cell is represented by the input current source (I_s). The recombination losses are represented by diode (D) which connected parallel to I_s and the ohmic losses are represented by the shunt resistance (R_{sh}) and series resistance (R_s). R_s should be as low as possible because it is nothing but the sum of all resistance in the current path.

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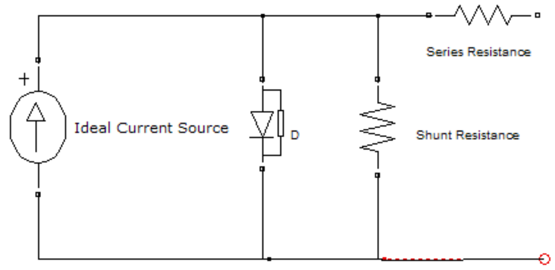


Figure 1. Solar model.

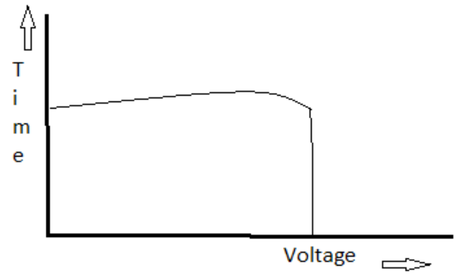


Figure 2. I-V Curve.

R_{sh} should be as high as possible and it is referred as the leakage path of the current in the cell, so it is connected in parallel with current source. Where, k → Boltzmann constant, q → quantity of electronic charge and T → solar cell surface absolute temperature. The ideal I-V equation of a solar cell is given by

$$J = I_s - D\,(\exp\,(qv/kT - 1);$$

This series and shunt resistance have effect on Fill factor (FF), which in turn has effect on efficiency of the solar cell. So, care should be taken to select the value of R_s and R_{sh} in order to maintain the squareness of the curve shown on Figure 2. The relationship between the Rs, R_{sh} and FF is given by the following equations. While, R_{ch} → Characteristic resistance and FF_0 → Ideal FF.

$$FF = FF_0 - (1 - r_s);\ FF = FF_0 - (1 - 1/r_{sh});$$

$$r_s = (Rs/R_{ch});\ \ r_{sh} = (R_{sh}/R_{ch});^2.$$

In this paper we have designed a solar cell for an output voltage of 150V is designed which is shown in the Figure 3 and the pulse generated by the solar cell have been shown in the Figure 4.

3. Comparison of Solar Powered Interleaved Boost Converters

A comparative study of interleaved boost converters has done. The comparison between single phase, two phase

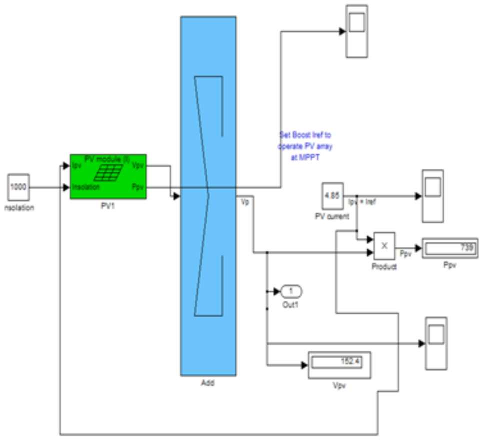


Figure 3. Model for solar cell.

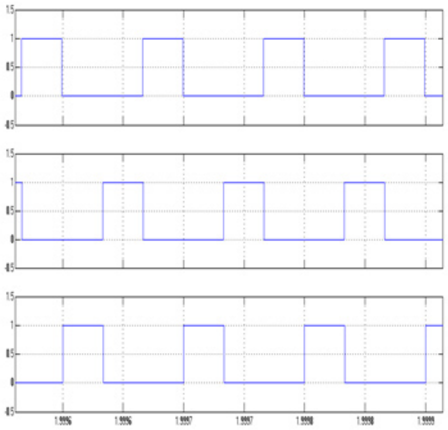


Figure 4. Driving Pulses.

and three phase converters and the results are displayed in the Table 1.

3.1 Conventional Interleaved DC-DC Boost Converter

3.1.1 Working of Single-Phase Converter

A boost converter is one which gives increased output than the given input. The entire converter shown in this paper is a solar cell, which is designed to produce an output voltage of 150V. In Figure 5, a simple boost converter is shown where the input of the converter is a solar cell. The output of the solar cell is given as input to the converter. The converter has an inductance L1 connected in series with the input.

A MOSFET S1 connected in parallel with the input, diode D1, capacitor C is also connected along with R load at the end. The operation is as follows,

Table 1. Comparison of solar powered interleaved DC-DC boost converters

	Single Phase	Two Phase ILBC		Three Phase ILBC	
Parameter	*Conventional*	*Conventional*	*Proposed*	*Conventional*	*Proposed*
Input Voltage (V)	150	150	150	150	150
Output Voltage (V)	300	621	1010	920	1430
Output current (A)	0.6	1.2	1.8	1.84	2.86
Output Power (W)	185	770	1818	1700	4090
Output voltage ripple (V)	2	1.5	1	0.11	0.09
Output Current ripple (A)	0.004	0.0001	0.0002	0.0002	0.00001
Voltage Gain (Vo/Vin)	2	4.14	6.77	6.13	9.53
Inductor ripple current ΔI = L f Vin/Vo(Vo-Vin)	3.33	1.6	0.5	1.05	0.56
Inductor current (A)	IL1 = 6A	IL1 = 13A; IL2 = 20A;	IL1 = 7A; IL2 = 6A;	IL1 = 110A; IL2 = 110A; IL3 = 30A;	IL1 = 20A; IL2 = 20A; IL3 = 10A;
Voltage stress across the Diode (V)	Vd1 = 800V;	Vd1 = 600V; Vd2 = 600V;	Vd1 = 350V; Vd2 = 350V;	Vd1 = 900V; Vd2 = 900V; Vd3 = 900V;	Vd1 = 150V; Vd2 = 400V; Vd3 = 5V;

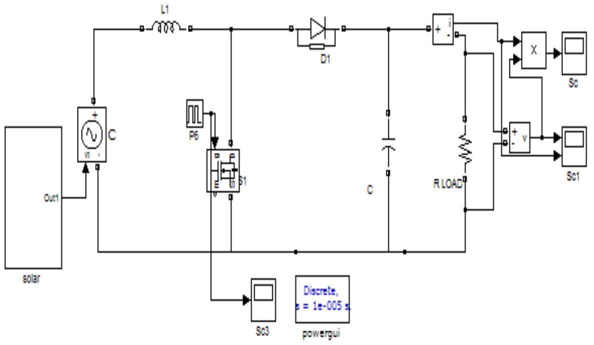


Figure 5. Single-Phase Boost Converter.

Mode (a): ($t_o < T < t_1$)

- S1 in ON, by applying gate pulse; L1 stores energy from input (during T_{ON}); D1 is reverse biased; output stage is isolated from input side.

Mode (b): ($t_1 < T < t_2$)

- S1 is OFF; D1 forward biased; both input and stored L1 energy is supplied to the load side.

Therefore, now the current is supplied through L, D, C and R load[4]. The input voltage of 150V is applied from the solar cell and simulation results of output voltage (300V), output current (0.6A), output current ripple (0.004A) and output power (185W) is shown in Figure 7.

3.1.2 Working of Two Phase Interleaved Converter

In two phase conventional interleaved converter, two single phase converters are connected in parallel shown in Figure 6, the two converters works at same frequency but with a phase difference of 360°/n, where, n → number of phase[3]. In this case, it is 360°/2 = 180° with duty cycle of 0.5. The operation is as follows,

Mode (a): ($t_o < T < t_1$)

- S1 in ON, by applying gate pulse; L1 stores energy from input (during T_{ON}); D1 is reverse biased; output stage is isolated from L1.

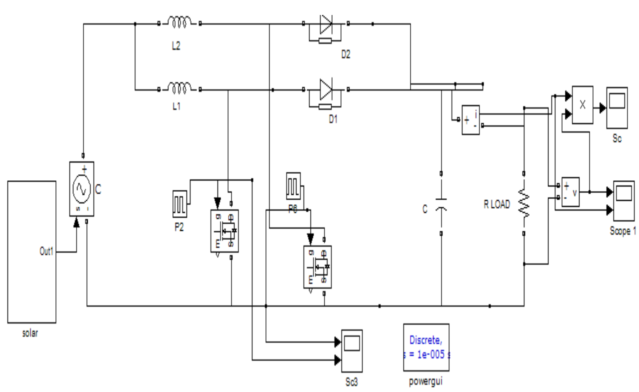


Figure 6. Two-Phase interleaved Boost Converter.

Mode (b): ($t_1 < T < t_2$)

- S1 is OFF; S2 in ON, by applying gate pulse; L2 stores energy from input (during T_{ON}); D1 is forward biased, D2 is reverse biased, output stage is isolated from L2; L1 releases the stored emery which is stored during mode (a).

Mode (c): ($t_2 < T < t_3$)

- S2 is OFF; S1 in ON, by applying gate pulse; L2 releases the energy which is stored during mode (b); L1 stores energy from input, same as mode (a); D1 is reverse biased; D2 is forward biased.

Thus, both the converters feed the output continuously which results in continuous current. The input voltage of 150V is applied from the solar cell and simulation results of output voltage (621V), output current (1.2A), output current ripple (0.001A) and output power (770W) is shown in Figure 8.

3.1.3 Working of Three Phase Interleaved Converter

Three phase interleaved conventional boost converter is shown in Figure 9. The operation is similar to that of the two phase conventional converter (explained in

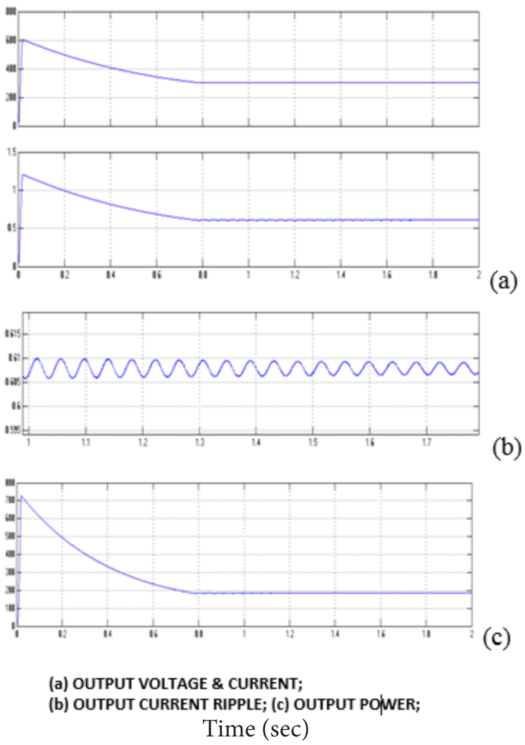


Figure 7. Results of Single Phase Boost converter.

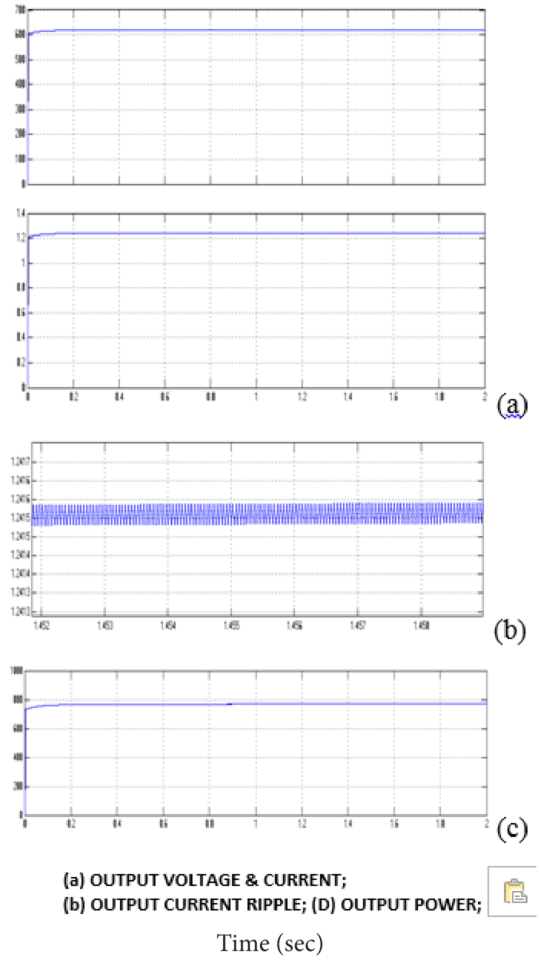


Figure 8. Results of Two-Phase Boost Converter.

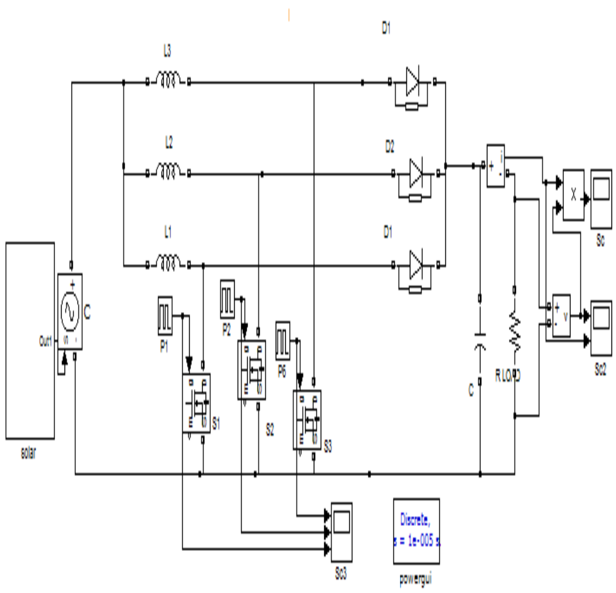


Figure 9. Three Phase conventional boost converter.

sec: 3.1.2). Since, three phase are employed, each phase works at 360°/3 = 120°, (i.e.) at 120° phase difference with duty cycle of 0.3. The gate pulse applied to the switches S1, S2, S3 accordingly. The input voltage of 150V is applied from the solar cell and simulation results of output voltage (920V), output current (1.84A), output current ripple (0.0002A) and output power (1700W) is shown in Figure 11.

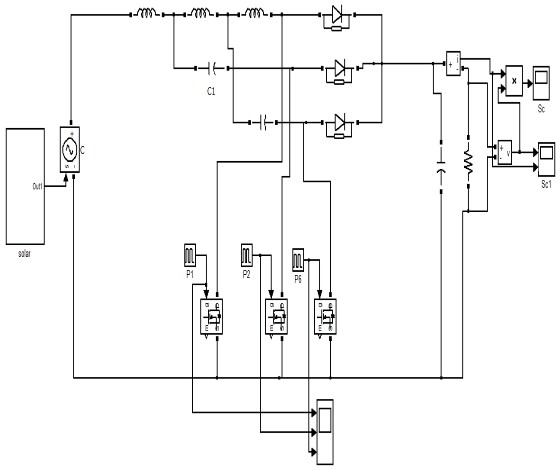
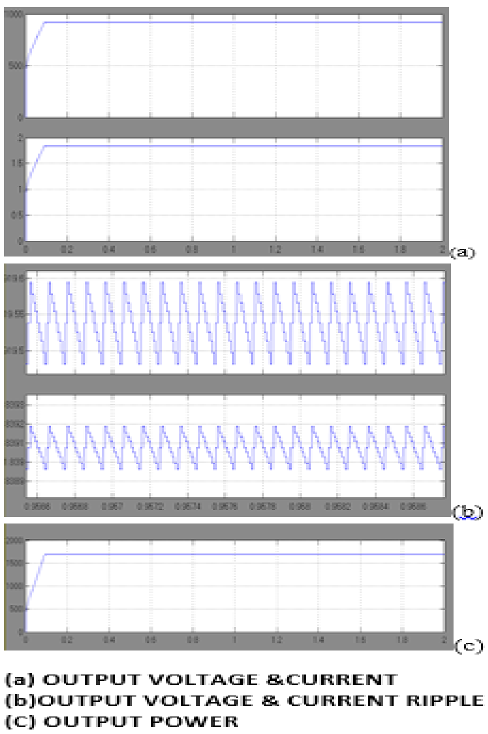


Figure 10. Proposed Series inductance converter.



Time (sec)

Figure 11. Conventional ILBC.

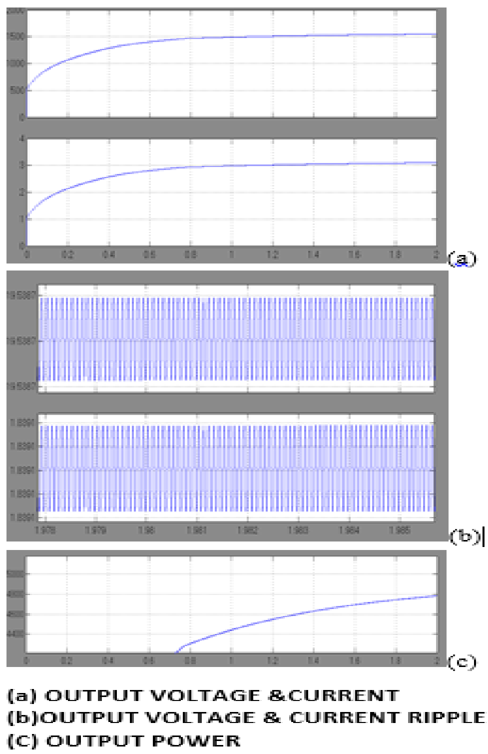
Therefore, each converter has a switch, diode and an inductor. It is assumed that the parallel converters are symmetrical and operate in continuous conduction mode[4].

The above literature dose not compare various solar powered interleaved converters .This work proposes comparison of various converters in order to find the best converter.

3.2 Proposed Interleaved DC-DC Boost Converter

3.2.1 *Working of Proposed Interleaved DC-DC Converter*

The series-inductance, single switch boost converter is shown in the Figure 10; the input voltage of 150V is given from a solar cell. Three inductors are connected in series with the input and diodes D1, D2, D3 are placed in between them, capacitors C1 and C2 are connected in parallel to the R load[5]. The operation of the converter is as follows. Modes of operation[6–11] of the converter are shown in Figure 13 to Figure 17 respectively. The simulation results are displayed in Figure 12.



Time (sec)

Figure 12. Proposed Boost Converter.

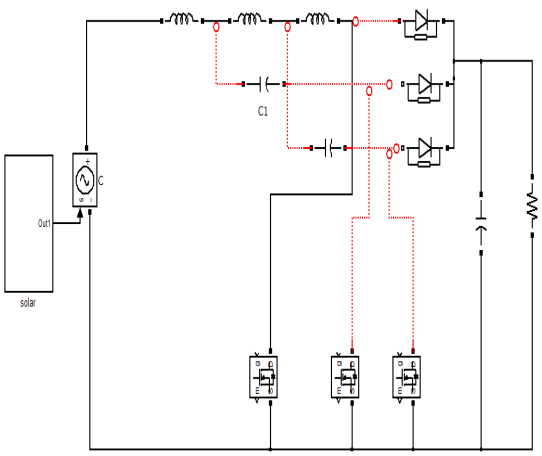


Figure 13. Mode (a): (to < T < t1).

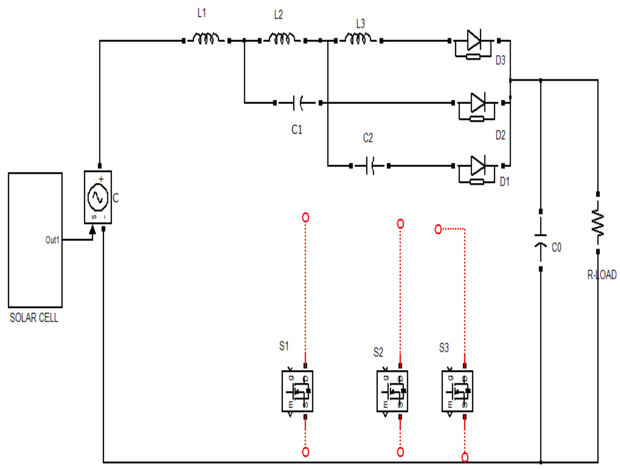


Figure 15. Mode (d): ($t_3 < T < t_4$).

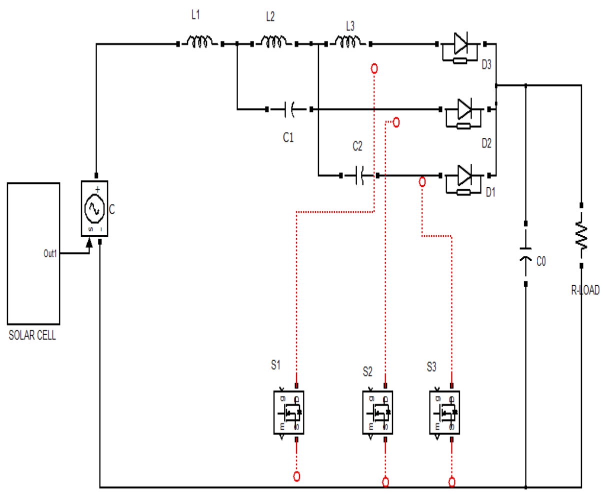


Figure 14(a). Mode (b): ($t_1 < T < t_2$).

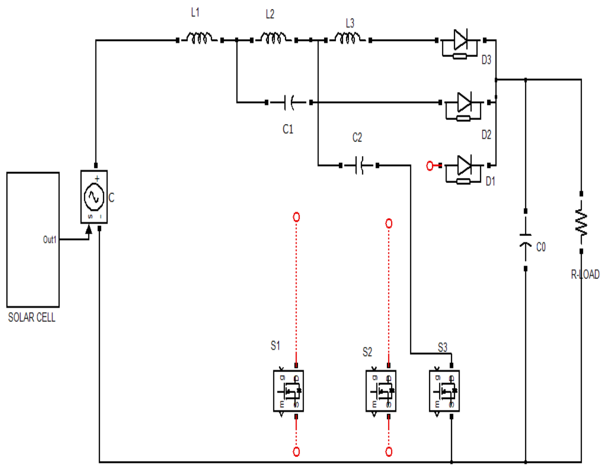


Figure 16. Mode (e): ($t_4 < T < t_5$).

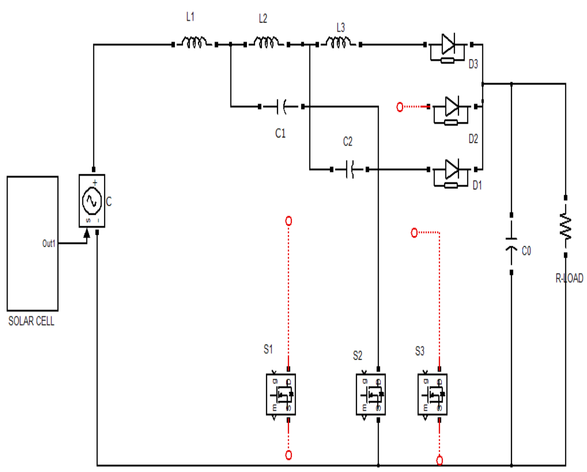


Figure 14(b). Mode (c): ($t_2 < T < t_3$).

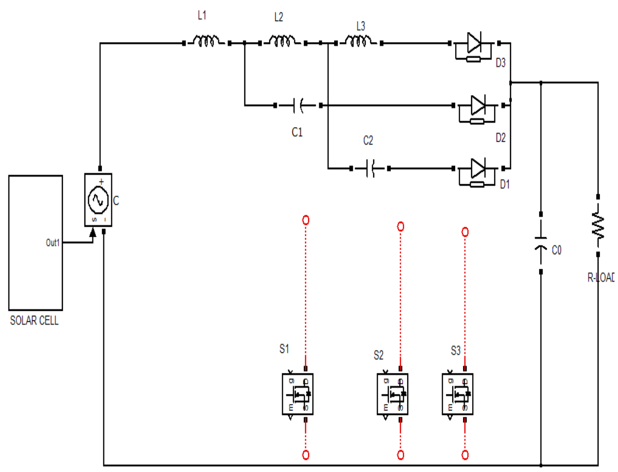


Figure 17. Mode (f): ($t_5 < T < t_6$).

Mode (a): ($t_o < T < t_1$)

- S1 is ON; S2, S3 are OFF; D1,D2,D3 are reverse biased; Inductor L1, L2, L3 store energy from input during (T_{ON}); output stage is isolated from L1, L2, and L3. C1, C2 gets charged.

Mode (b): ($t_1 < T < t_2$)

- S1, S2, S3 is OFF; D1, D2, D3 is forward biased output stage is connected to L1, L2, L3; Inductor L1, L2, L3, C1, C2 releases the energy which is stored during mode (a) to the C0 and Load;

Mode (c): ($t_2 < T < t_3$)

- S2 is ON; S1, S3 are OFF; D1, D3 are forward biased; D2 is reverse biased; Inductor L1, store energy from input during this mode; output stage is isolated from L1 and C1 gets charged.

Mode (d): ($t_3 < T < t_4$)

- S1,S2, S3 are OFF; D1, D2, D3 is forward biased output stage is connected to L1, L2, L3; Inductor L1, L2, L3, C1, C2 releases the energy which is stored during the previous mode to the C0 and Load;

Mode (e): ($t_4 < T < t_5$)

- S3 is ON; S1, S2 are OFF; D2, D3 are forward biased; D1 is reverse biased; Inductor L1, L2 store energy from input during this mode; output stage is isolated from L1, L2 and C2 gets charged.

Mode (f): ($t_6 < T < t_7$)

- S1, S2, S3 are OFF; D1, D2, D3 is forward biased output stage is connected to L1, L2, L3; Inductor L1, L2, L3, C1, C2 releases the energy which is stored during the previous mode to the C0 and Load;

The input voltage of 150V is applied from the solar cell and simulation results of output voltage (1430V), output current (2.86A), output current ripple (0.0001A) and output power (4090W) is shown in Figure 12.

Table 1 shows the comparison table of solar powered interleaved DC-DC boost converter. The comparison shows that the ripple I minimum in the case of proposed three phase ILBC system.

4. Comparison of Solar Powered Interleaved Boost Converters with Motor Load

4.1 Single Phase Boost Converter with Motor Load

The operation of single phase boost converter has been already explained in the section 3.1.1.

The same converter has been tried with motor load as shown in Figure 18. The simulation results are shown in Figure 19 and the results are presented in the Table 2. The speed and torque are shown in the Figure 19.

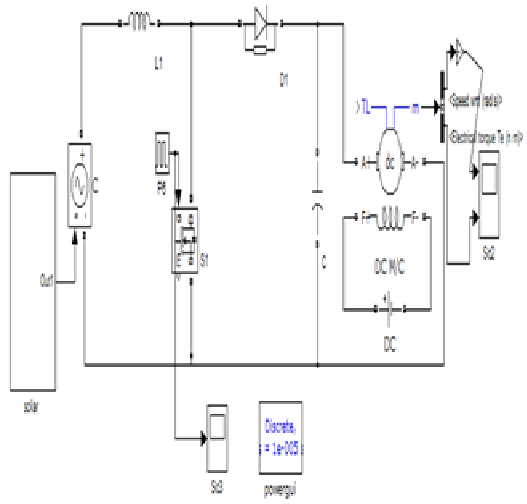


Figure 18. Single Phase ILBC with Motor.

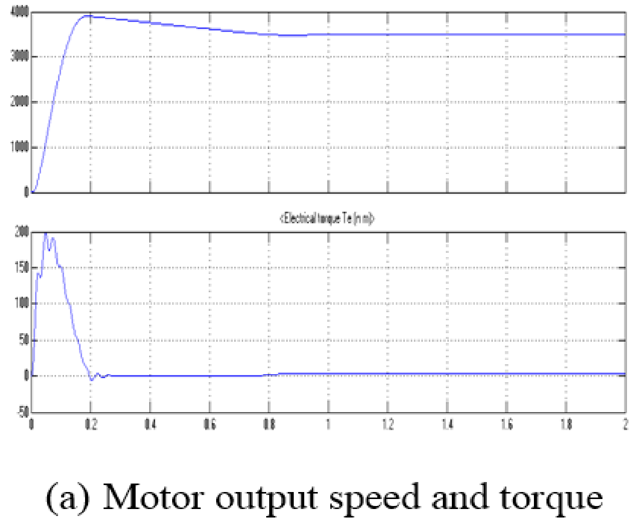


Figure 19. Simulation result of Single Phase ILBC with Motor Load.

Table 2. Comparison of solar powered ILBC's with motor load

Parameter	*Single Phase ILBC*	*Two Phase ILBC*	*Three Phase ILBC*
Input voltage (V)	150	150	150
Speed of the Motor (rpm)	300	621	1180
Torque (NM)	0.6	1.2	2.3

4.2 Two Stage Interleaved Boost Converter with Motor Load

The operation of two stage boost converter has been already explained in the section 3.1.2. The same converter has been tried with motor load is shown in Figure 20. The simulation results for speed and torque are shown in Figure 21 and the results are displayed in the Table 2.

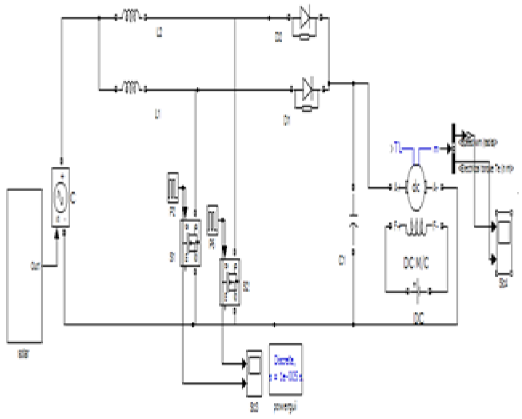


Figure 20. Two Phase ILBC with Motor.

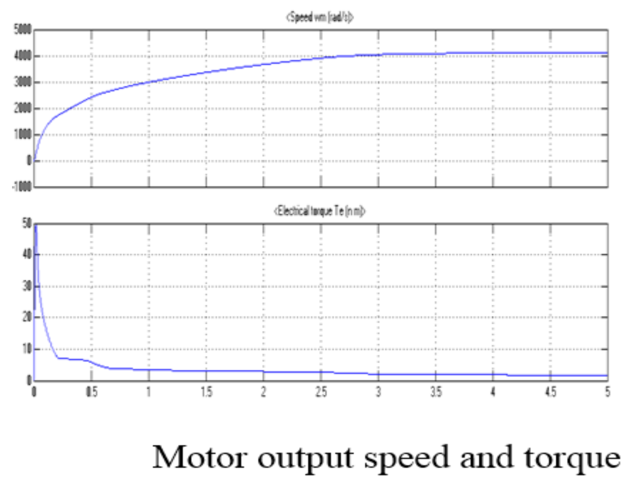


Figure 21. Simulation result of Two Phase ILBC with Motor Load.

4.3 Three Stage Interleaved Boost Converter with Motor Load

The operation of single phase boost converter has already explained in the section 3.1.3. The same converter has been tried with motor load Figure 22. Simulation results are shown in Figure 23 and the results are displayed in the Table 2. The comparison shows that the torque and speed are higher in the case of three phase ILBC system.

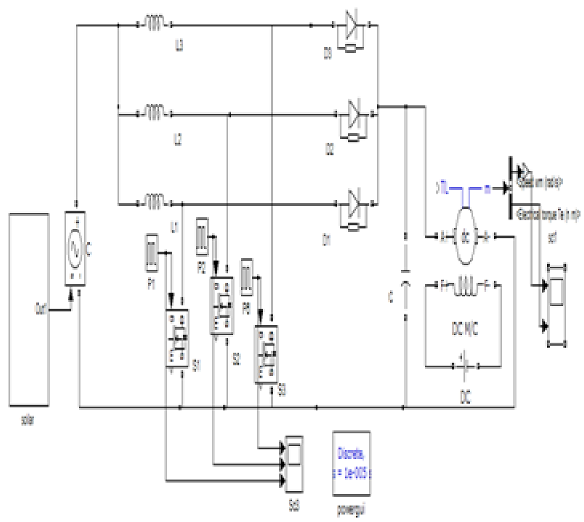


Figure 22. Three Phase ILBC with Motor.

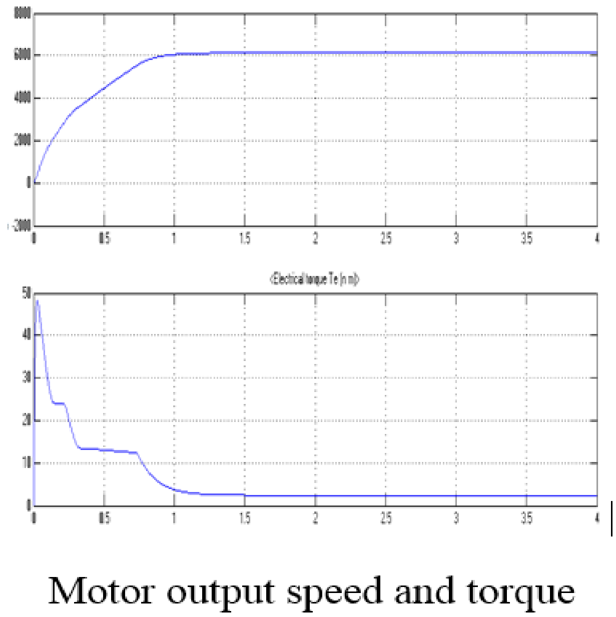


Figure 23. Simulation result of Three Phase ILBC with Motor Load.

5. Comparison of Solar Powered Interleaved Boost Converters with different Filters

5.1 Three Phase ILBC with 'C' Filter at the Output side

The Solar Powered Three Phase Interleaved DC-DC Boost Converter with 'C' Filter shown in the Figure 3 and the simulation results are shown in the Figure 5.

5.2 Three Phase ILBC with Cascade Filter at the Output side

Three Phase ILBC with Cascade filter are shown in Figure 24 and the simulation results are shown in Figure 26.

5.3 Three Phase ILBC with Cascade Filter at the Output side

Three Phase ILBC with Cascade filter are shown in Figure 25 and the simulation results are shown in Figure 27.

The Comparison table of the entire Filter in Three Phase ILBC is shown in Table 3.

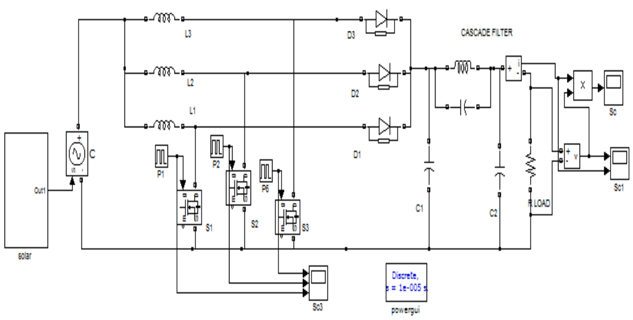


Figure 24. Three Phase ILBC with Cascade Filter.

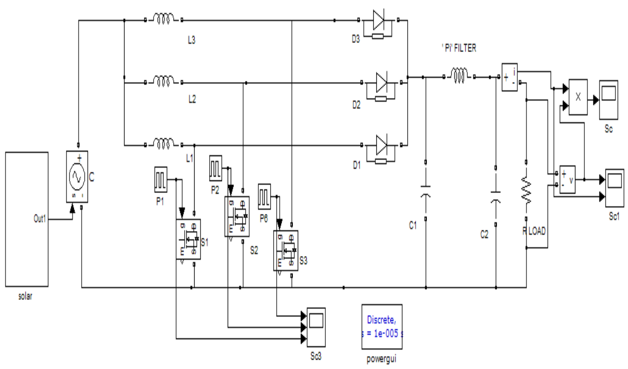


Figure 25. Three Phase ILBC with 'Pi' Filter.

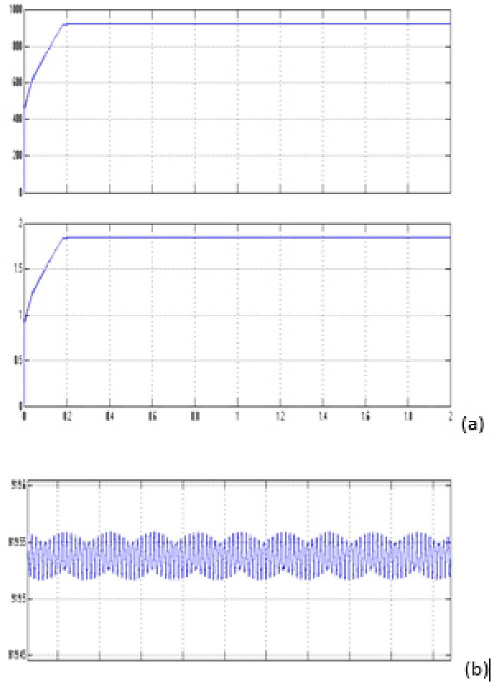


Figure 26. Simulation results Three Phase ILBC with Cascade Filter. Time (sec)

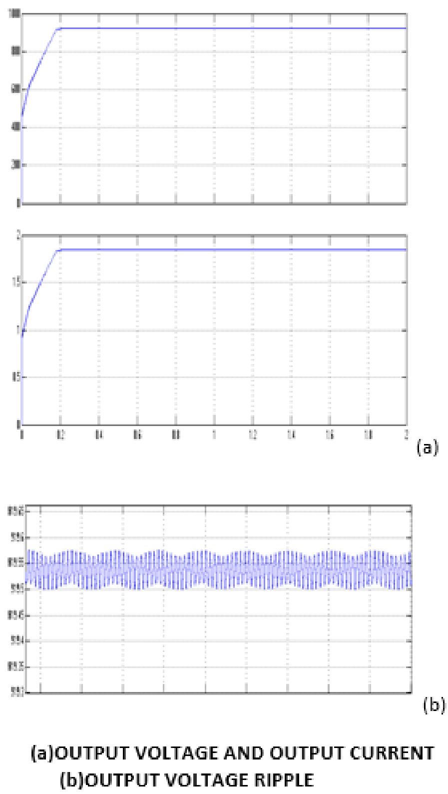


Figure 27. Simulation results Three Phase ILBC with 'Pi' Filter. Time (sec)

Table 3. Comparison of solar powered ILBC with different types of filters

Parameter	*'C' Filter*	*Cascade Filter*	*'Pi' filter*
Input Voltage (V)	150	150	150
Output Voltage (V)	920	920	920
Output current (A)	1.8	1.8	1.8
Output Power (W)	1690	1690	1690
Output voltage ripple (V)	0.13	0.04	0.07
Output Current ripple (A)	0.002	0.0002	0

The comparison indicates that the output voltage ripple is minimum in the case of 'Pi' filter system.

6. Conclusion

An investigation on solar powered Interleaving Boost converters (ILBC) is done. A Solar powered, Series-Inductor ILBC with less number switches than the conventional ILBC is simulated. A comparative study on single-stage, two-stage and three-stage ILBCs are done. The Proposed converter gives reduced ripple. The comparison ILBCs with different types of filters like 'C', 'Pi' and Cascade Filters is done. Where, the 'Pi' filter performs best in ripple reduction. The results have been applied to R-Load and motor load. Comparison table of performance and simulation results of these aforementioned solar powered ILBCs have been exhibited in this paper. The circuit are simulated using MATLAB/Simulink.

Collectively, the results are provided, we propose further study of multiphase interleaved boost converters in future.

7. References

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