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Analysis of Dual Phase Dual Stage Boost Converter for Photovoltaic Applications

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***Abstract*— In the previous two decades, the depletion of fossil fuels has led to applications with renewable energy sources. The approach for renewable energy application is to achieve eminent static boost ratio from with miniaturized ripple content in both current and voltage. The novel converter discussed in this paper is derived by combining the concept of interleaving and cascading of boost converters. The presented design has a dual phase boost converter followed by a stage of boost converter which as a whole acts like dual phase dual stage boost converter. The interleaving concept is utilized in dual phase boost converter to reduce the voltage current stress created in boosting process and its output is boosted by the dual stage boost converter which improves overall efficiency with respect to the existing systems. The converter is designed for a power rating of 200W with output voltage of 192V for an input voltage of 12V obtained from photovoltaic source at a switching frequency of 50KHz this illustrate the advantages over other existing converters . The different parameters of the proposed boost converter are contrasted with that of a conventional boost converter. Furthermore, the simulations results of the proposed converter are presented to validate the system design. The results exhibit that this converter achieves a predominant performance over other dc-dc boost converters by offering improved efficiency and voltage gain, while having lower input current ripple.**

***Keywords*— dual phase; dual stage; voltage ripple; current ripple.**

I. INTRODUCTION

The demand for electricity is getting expanded day by day. Electricity generation by non-renewable energy sources is facing the issue of its limited availability and its heavy expenditure [1]. The way to deal with the demand is by extracting more energy within the available ones and by shifting to renewable sources of energy [2]. The spontaneously restored renewable energy sources such as sunlight, wind, tides can be utilized forever .Solar energy is considered as the ultimate resource as it is a costless never-ending energy source which is enormously accessible across the globe[3].For the sake of attaining large voltage level at output the series arrangement of solar photovoltaic cell or arrays is not viable. DC-DC converters with high boost ratio are crucial to generate large level of output from solar photovoltaic [4], [5].

The conventional DC voltage boost converter is a critical power converter in the electronics domain, and has been utilized broadly in many industrial, automotive, commercial and numerous modern battery powered applications. Now a day there is a huge interest for outstanding efficiency, high stationary gain, minute size and low-cost DC chopper. However, the conventional DC chopper converter is a solution towards a DC voltage step up but needs to manage with issues of high ripple currents, high power dissipation and non-isolation. Another option is to use flyback converter. Though flyback converter gives isolations but uses transformer for achieving high gain which makes the converter bulky [6].

The flaws in isolated converters can be handled by implementing multilevel DC-DC converters [7]. Conjoining non-isolated with voltage multiplier gives high voltage boost ratio in the multilevel DC-DC converters. The step-up ratio of voltage in dc choppers with many levels relies on the count of levels at the output. In this way with a specific end goal to accomplish high voltage pick up, levels in the output must be expanded and it will build its unpredictability [8].

In the last couple of years, research attention has been diverted towards the development of high voltage converters with less percentage of duty cycle ratio by cascading more than one conventional boost converters. The Cascading causes in higher ripple content at the output voltage and current. To overcome the problem of ripple content in voltages and current due to switching a method is to interleave more than one converter [9]. The ripple frequency has surged up by cause of interleaving in multi-phasing following cut down of the filter dimensions. Specifically, the dc-dc converters utilizing interleaved concept [10] has the upper hand because of cutback in ripple content of inductor current and output voltage. Interleaved boost converter using Silicon Carbide (SiC) power switches offers higher switching frequency with reduced losses and restricts the maximum dv/dt ratio [11]. Control over the current sharing between the phases can be achieved by utilizing digital pulse width modulation Techniques [12].

Cascading the input voltages of buck converter in series and paralleling their output was the method proposed by Leong et al. [13]. The analysis and design of a dc step up converter with low current stress by integrating the concepts of multi-phase and multi-stage scheme was presented by Retana et al. [14].

The proposed dual phase dual stage converter will provide rise of step up gain with the help of dual stage boost converter with reduced current and voltage stress benefitted by the interleaving of dual phase boost converter.

II. Materials and Method

A. Dual Phase Boost Converter

1) Circuit Description and Operational Analysis of Dual Phase Boost Converter: The dual-phase boost converter can be built by paralleling one more leg to conventional boost converter as shown in Fig. 1.

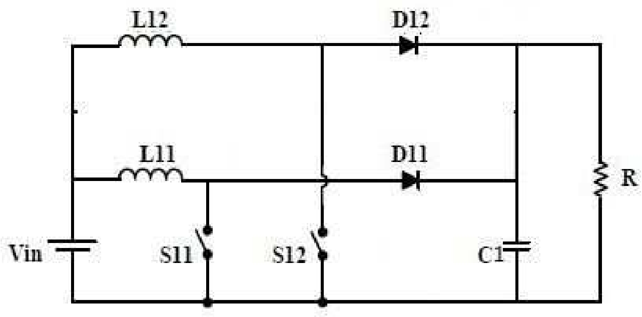


Fig. 1 Dual phase boost converter

Fig. 2 exhibits a 180-degree phase shift between the triggering of switches to provide interleaving in dual phase boost converter. Reduced ripple content and doubling in frequency occurs due to elimination in ripple among the different phases [15]. The output to input ratio of dual-phase boost converter and conventional boost converter are identical.

2) Design Consideration of Dual Phase Boost Converter: The conventional boost converter is designed first. With the same obtained values of inductor and capacitor one more leg is connected parallel to the conventional boost converter to construct the dual phase boost converter. For the following specifications the conventional boost converter equations are presented.

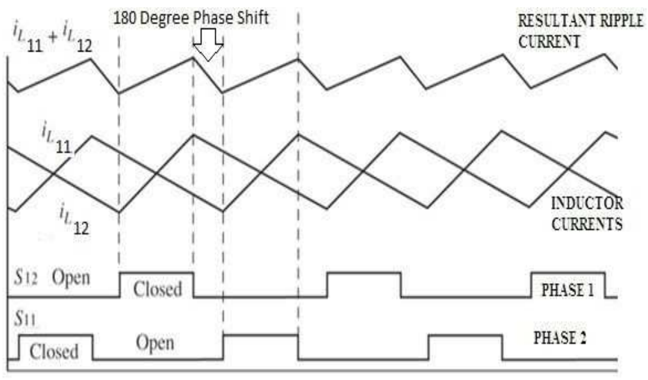


Fig. 2 Dual phase inductor and resultant current

Input Voltage(V_{in}) =12V
Output Voltage (V_0) =48V
Switching Frequency(F_{SW}) =50KHz
Output Power(P_0) =200W
The static gain of the conventional boost converter is expressed as:

$$V_0 = \frac{V_{in}}{1-D} \tag{1}$$

where D is the switching duty cycle. Therefore, for above given parameters switching duty cycle [16] D is calculated as

$$D = \frac{(V_0 - V_{in})}{V_0} = 0.75 \tag{2}$$

The Equivalent load is calculated as:

$$\mathrm{R_0} = \frac{\mathrm{V_0}^2}{\mathrm{P_0}} = 11.52\Omega \tag{3}$$

The inductor current is given by,

$$I_{L\_phase} = \frac{V_0}{R_0(1-D)} = 16.67A \tag{4}$$

Considering 40% peak to peak ripple, ripple current

$$\Delta I_{L\_phase} = 6.67A$$

The inductor value is given by

$$L_{phase} = \frac{V_{in}DT}{\Delta I_{L\_phase}} = 26.99\mu H \tag{5}$$

where T is the switching period. Considering 4% ripple in output voltage, the capacitance value is given by

$$C = \frac{V_0 DT}{\Delta V_0 R_0} = 32.55\mu F \tag{6}$$

B. Dual Stage Boost Converter

With a specific end goal to accomplish a larger step up in ordinary chopper circuit the enforced duty ratio required is more. The duration for which the semiconductor control switch is kept closed is more as the inductor keeps accumulating the charge. In such case, the OFF time will be of short parts, contrasted with ON interval of the switch. The discharge of the inductor needs to be within the OFF interval. Duty ratio near to 1 will continuously be a danger to the framework, making the semiconductor devices get harmed as the dissipated power surpasses the rated.

The Dual Stage boost converter is a series of two boost converters with an outcome of voltage at the output expanding in a geometric progression. The Fig. 3 demonstrates the architecture of boost converter with two stages to accomplish a huge boost ratio. The outcome of each stage will move as the input of the accompanying stage and in this manner the step up occurs.

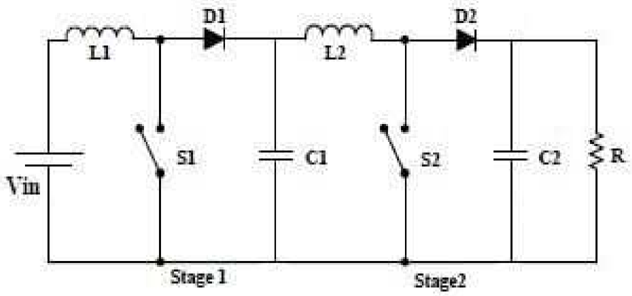


Fig. 3 Dual stage boost converter

1) Circuit Description and Operational Analysis of Dual Stage Boost Converter: The architecture of boost converter with double stages is achieved by connecting two individual boost converters in series manner. Higher static gain can be obtained by appending a greater number of stages. Since same duty cycle is given for the switches of all the stages in the converter, circuit operations in a switching cycle can be concluded for two states, ON and OFF cycles. The Table 1 interprets the status of the two step-up converters in series connection for different states of the two switches. The equivalent circuit diagram of the two state operations are shown in Fig. 4 and Fig. 5.

TABLE I
SWITCHING STATUS OF DUAL STAGE BOOST CONVERTER

States	Switch S1	Switch S2	Status
First	ON	ON	Vin supplies energy to inductor L1, capacitor C1 transfers its stored energy to L2, the stored energy in the output capacitor C2 is delivered to the load.
Second	OFF	OFF	Inductor L1 discharges its energy through charging of capacitor C1, inductor L2 discharges by charging capacitor C2 and supplying to load

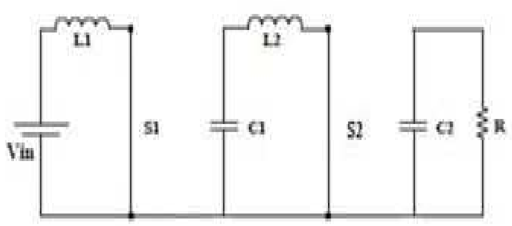


Fig. 4 Both switches ON

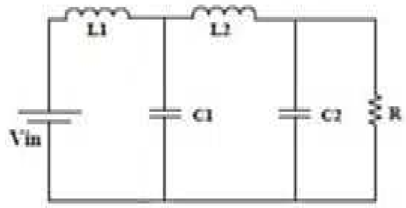


Fig. 5 Both switches OFF

The voltage transformation for two-stage booster is given as,

$$V_0 = V_2 = \left(\frac{1}{1-D}\right) V_1 = \left(\frac{1}{1-D}\right)^2 V_{in} \quad (7)$$

where V_1, V_2 are the output voltages of first and second stages respectively for the rated input voltage V_{in} .Similarly, the current relation is given by,

$$I_0 = (1-D) I_{L2} = (1-D)^2 I_{L1} \quad (8)$$

where I_{L1}, I_{L2} are the inductor currents of first and second stages respectively for the rated output current I_0

2) Design Consideration of Dual Stage Boost Converter: The dual stage boost converter is designed for the following specifications

Input Voltage(V_{in}) =12V
Output Voltage (V_0) =192V
Switching Frequency(F_{SW}) =50KHz
Output Power(P_0) =200W
The rated load for given output power (R_{out}) =184.32Ω
The static gain of dual stage boost converter is given by

$$V_0 = \left(\frac{1}{1-D}\right)^2 V_{in} \quad (9)$$

where D is the switching duty cycle. Therefore, for above given parameters switching duty cycle D is 0.75.
First stage output capacitance voltage is given by

$$V_1 = \frac{V_{in}}{1-D} = 48V \quad (10)$$

Second stage output capacitance voltage or the output voltage is given by

$$V_0 = \left(\frac{1}{1-D}\right)^2 V_{in} = 192V \quad (11)$$

First stage inductor current or the input current, for the load current of $I_0 = 1.04A$for above specifications is given by

$$I_{L1} = \left(\frac{1}{1-D}\right)^2 I_0 = 16.64A \quad (12)$$

Second stage inductor current is given by

$$I_{L2} = \left(\frac{1}{1-D}\right) I_0 = 4.16A \quad (13)$$

Considering 40% peak to peak ripple, for switching time period T the inductance values are given by

$$L_1 = \frac{V_{in}DT}{\Delta I_{L1}} = 26.99\mu H \quad (14)$$

$$L_2 = \frac{V_{in}DT}{\Delta I_{L2}} = 431.65\mu H \quad (15)$$

Considering 4% peak to peak ripple, for switching time period T the capacitance values are given by

$$C_1 = \frac{V_1 DT}{\Delta V_1 R_0} = 32.55\mu F \quad (16)$$

$$C_2 = \frac{V_0 DT}{\Delta V_0 R_{out}} = 2.03\mu F \quad (17)$$

Where R_0 , R_{out} is the equivalent load of first stage and second stage.

C. Dual Phase Dual Stage Boost Converter

Generally, as per the power equality law the dc-dc chopper with high boost ratio must deal with its very high current at the input compared to that of its output. Thus, the semiconductor control switches at the input undergoes stress. In boost converters with more than one stages, compared to other control switches the switches in first stage must deal with higher stress.

To accomplish the benefits of the two modalities, dual phase booster is incorporated in dual stage step-up. To interleave the stress due to larger input current dual phase is employed at the primary level of the double stage boost converter. A Dual phase Dual-stage boost converter which provides a high boost ration and has significantly less stress is demonstrated in Fig. 6. Though, the dual phase dual stage boost converter has more components it is remunerated by better efficiency.

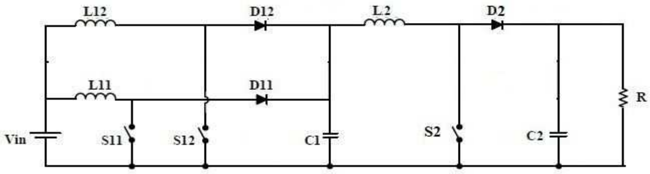


Fig. 6 Dual phase dual stage boost converter

III. Results and Discussions

The stage by stage simulation results of Dual Phase Dual Stage Boost Converter simulated using MATLAB –Simulink is explained below. All the simulations were carried out for a switching duty ratio of 0.75 for the time interval of 10ms.

A. Simulation Results of Dual Phase Boost Converter

The Dual Phase Boost Converter was simulated with the parameters mentioned in Table 2 and the MATLAB Simulink model of the same is shown in Fig. 7.

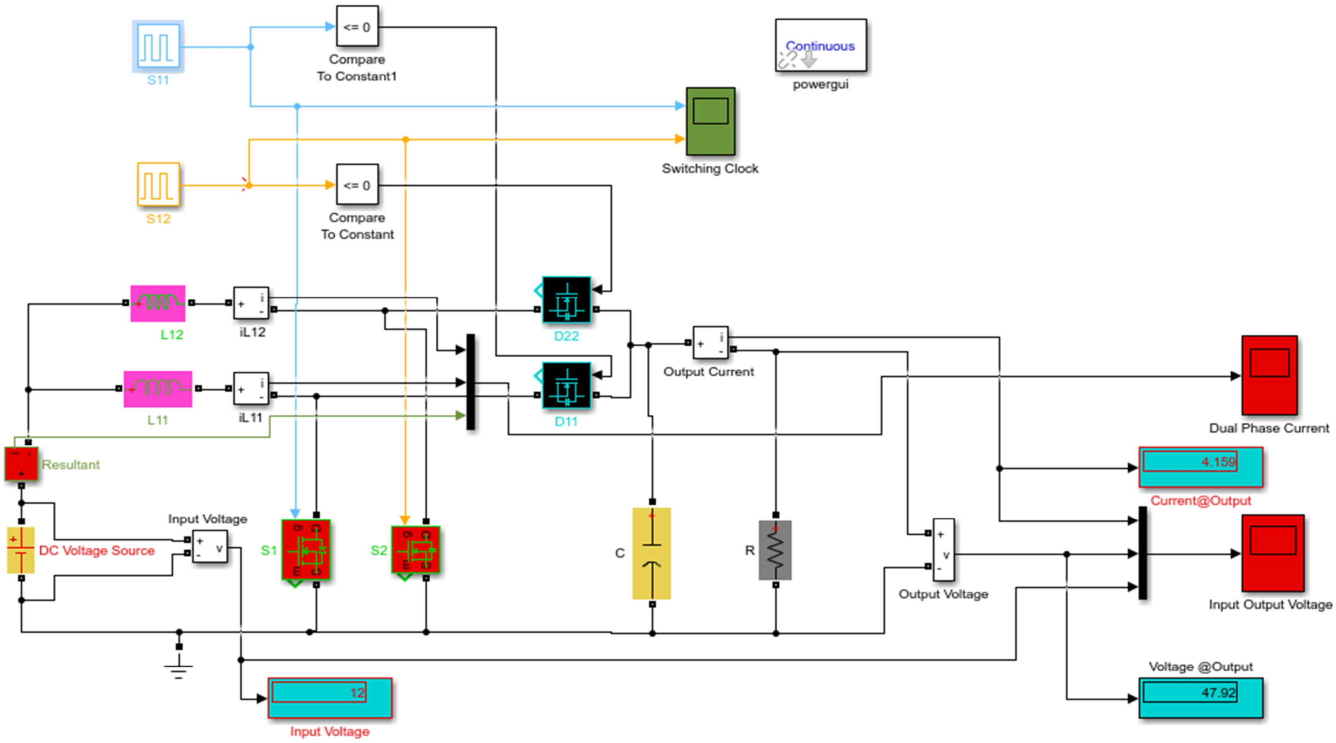


Fig. 7 Simulink Model of Dual Phase Boost Converter

The waveforms of voltages at input, output and output current of Dual Phase Boost Converter are shown in Fig. 8. For the input voltage of 12V DC the output reaches steady state value of 47.92V after 2ms.

TABLE II
SIMULATION PARAMETERS OF DUAL PHASE BOOST CONVERTER

Parameter	Value
Input Voltage	12V
Output Voltage	48V
Output Current	4.17A
Switching Frequency	50KHz
Inductor	27µH
Capacitor	33µF
Resistor	11.52Ω

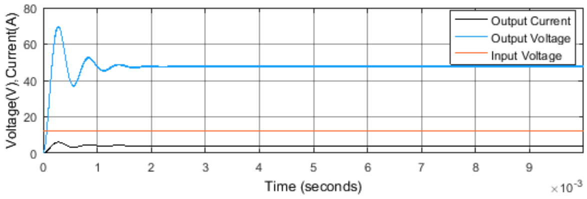


Fig. 8 Input voltage, output voltage and current

The input voltage, output voltage and current waveforms of Fig. 8 has been enlarged for a time interval of 7.1ms to 7.6ms which demonstrates the ripples in the output voltage is shown in Fig. 9. The equation for ripple percentage is given by

$$ripple = \frac{(peak \rightleftarrows \rightleftarrows to\ peak)}{mean} * 100 \qquad (18)$$

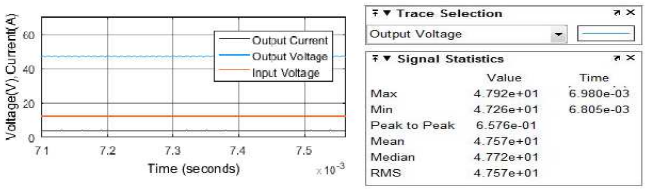


Fig. 9 Enlarged and signal statistics of output voltages

The individual phase inductor currents iL11, iL12 and their resultant current are shown in Fig. 10. The magnitude of individual phase inductor currents is same. The inductor currents start the charging discharging cycle from the time of 2ms.

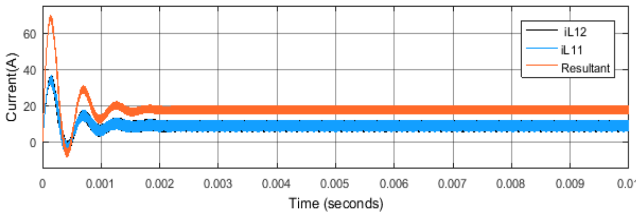


Fig. 10 Individual Phase Inductor current and Resultant

The Fig. 11 depicts the magnified individual phase and resultant inductor currents of Fig. 10 for a time interval of 6.65ms to 7.0ms which demonstrates the ripples in the inductor current. Theoretical ripple reduction and doubling of ripple frequency in inductor current of dual phase boost converter due to parallel modality which is depicted in Fig. 2 and is strongly validated by the simulation result shown in Fig. 11.

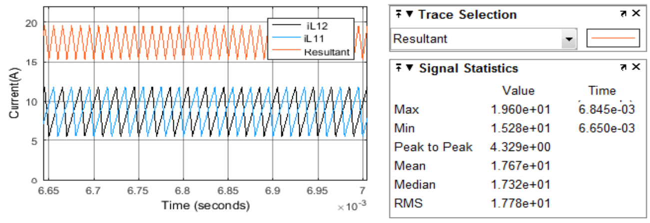


Fig. 11 Enlarged and signal statistics of resultant current

The switching pulses for the two switches S11, S12 respectively of Dual Phase Boost Converter are shown in Fig. 12 Each switching pulse has a 180-degree phase shift among them for the same duty ratio of 0.75.

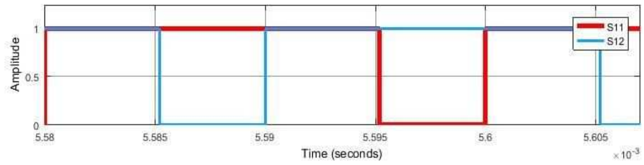


Fig. 12 Phase shifted switching pulses in dual phase boost converter

The ripple percentage in the output voltage and resultant inductor current can be calculated using equation (18) with the statistics of peak to peak and mean shown in Fig. 9 and Fig. 11 respectively.

TABLE III
DUAL PHASE BOOST CONVERTER RESULTS

Parameter	Value
Output Voltage	47.92V
Output Current	4.159A
Resultant Inductor Current Ripple	24.58%
Output Voltage Ripple	1.38%

The Output voltage, Output current, inductor current ripple and output voltage ripple percentage of Dual Phase Boost Converter obtained in simulation for a input of 12V DC are shown in Table 3. The conventional boost converter was designed for inductor current ripple of 40% and output voltage ripple of 4%. With the help of dual phasing in the boost converter the ripple in inductor and output currents has dropped to 24.58% and 1.38% respectively.

B. Simulation Results of Dual Stage Boost Converter

The Dual Stage Boost Converter with the parameters as shown in Table 4 was simulated using MATLAB Simulink and is shown in Fig.13

TABLE IV
SIMULATION PARAMETERS OF DUAL STAGE BOOST CONVERTER

Parameter	Value
Input Voltage	12V
Output Voltage	192V
Output Current	1.042A
Switching Frequency	50KHz
First Stage Inductor	27µH
Second Stage Inductor	432µH
First Stage Capacitor	33µF
Second Stage Capacitor	2.03µF
Resistor	184.6Ω

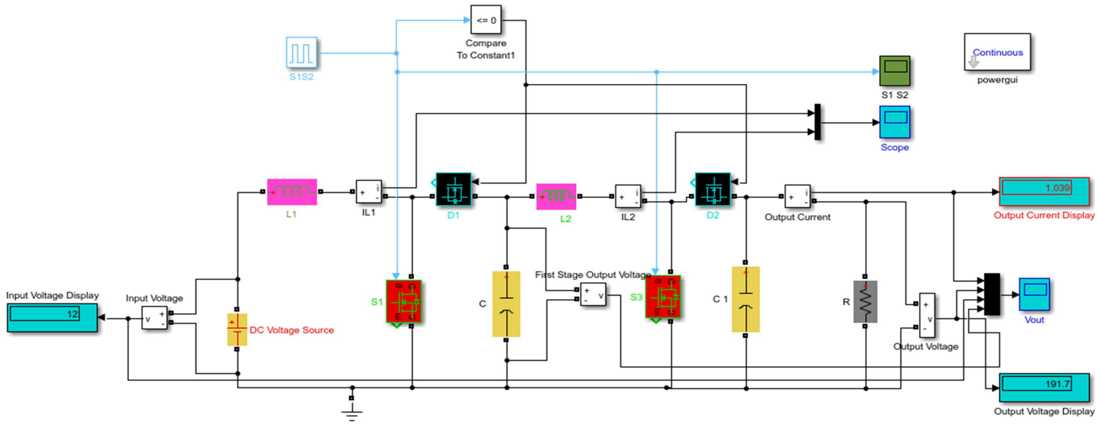


Fig. 13 Simulink model of dual stage boost converter

The Fig. 14 shows the input voltage, first stage output voltage, second stage output voltage and output current waveforms of Dual Stage Boost Converter. Time interval of 4ms is elapsed before the First stage output and second stage output voltages reaches steady state value of 47.7V and 191.7V respectively for the applied input voltage of 12V DC.

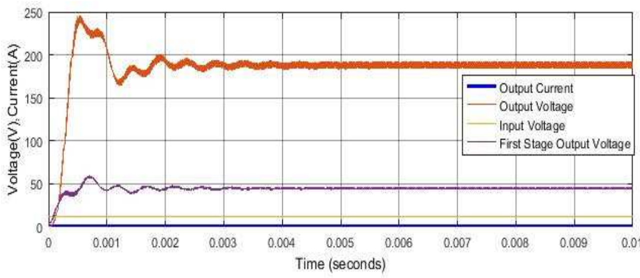


Fig. 14 Voltages at each stage of dual stage boost converter

The Fig. 14 is stretched between the time interval 8.3ms and 9.3ms to demonstrates the ripples present in output voltages of first and second stages and is shown in Fig. 15.

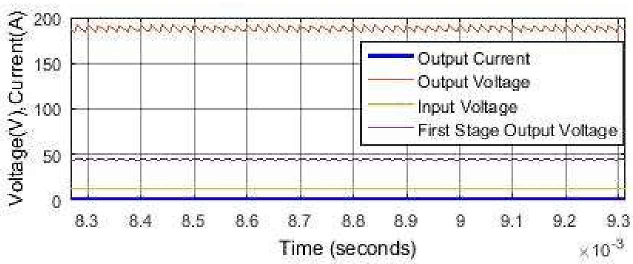
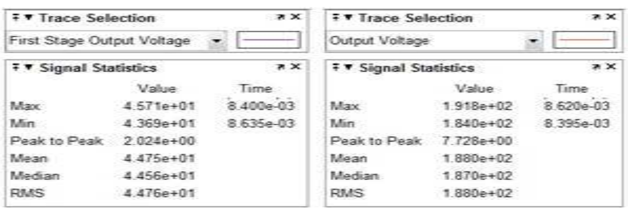


Fig. 15 Enlarged waveforms of voltages at each stage

The Fig.16 shows the statistics of first stage output voltage and second stage output voltage for the Fig.15.



Trace Selection: First Stage Output Voltage

Signal Statistics	Value	Time
Max	4.571e+01	8.400e-03
Min	4.369e+01	8.635e-03
Peak to Peak	2.024e+00	
Mean	4.475e+01	
Median	4.456e+01	
RMS	4.476e+01	

Trace Selection: Output Voltage

Signal Statistics	Value	Time
Max	1.918e+02	8.620e-03
Min	1.840e+02	8.395e-03
Peak to Peak	7.728e+00	
Mean	1.880e+02	
Median	1.870e+02	
RMS	1.880e+02	

Fig. 16 Signal statistics of voltages at output of each stage

In Fig. 17 inductor current IL1 is the current flowing through the inductor at first stage and inductor current IL2 is the inductor current of second stage. IL2 is the output current of first stage boost converter. The Magnitude of IL2 will be less than that of IL1 as the converter is of boost type.

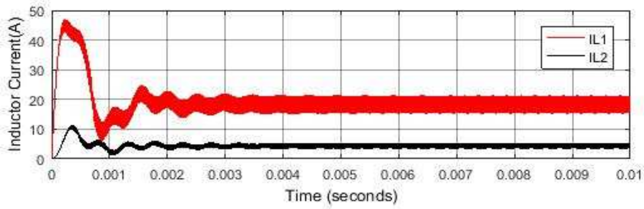


Fig. 17 Inductor currents at each stage

The time interval between 7.8ms and 8.035ms of the Fig. 17 is taken to demonstrate the ripple content of each stage inductor currents and is shown in Fig.18.

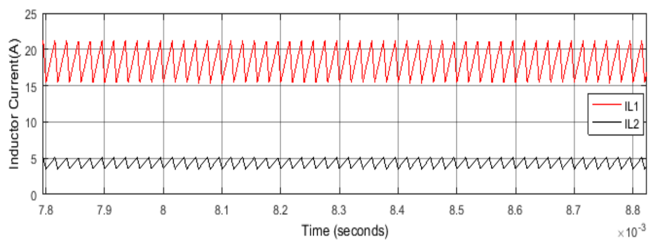
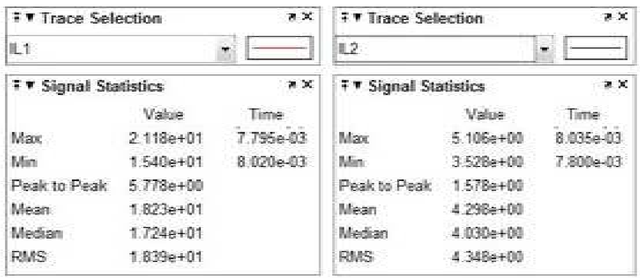


Fig. 18 Enlarged waveforms of inductor current IL1, IL2

The Fig.19 gives the statistics of inductor currents IL1, IL2 flowing through the two stages from the Fig.18.



Trace Selection: IL1

Signal Statistics	Value	Time
Max	2.118e+01	7.795e-03
Min	1.540e+01	8.020e-03
Peak to Peak	5.778e+00	
Mean	1.823e+01	
Median	1.724e+01	
RMS	1.839e+01	

Trace Selection: IL2

Signal Statistics	Value	Time
Max	5.106e+00	8.035e-03
Min	3.528e+00	7.800e-03
Peak to Peak	1.578e+00	
Mean	4.298e+00	
Median	4.030e+00	
RMS	4.348e+00	

Fig. 19 Signal statistics of inductor current IL1, IL2

The switching pulses for the two switches S1, S2 of dual Stage Boost Converter with duty cycle of 75 percentage is shown in Fig. 19. Both switching pulses are identical with no phase shift between them.

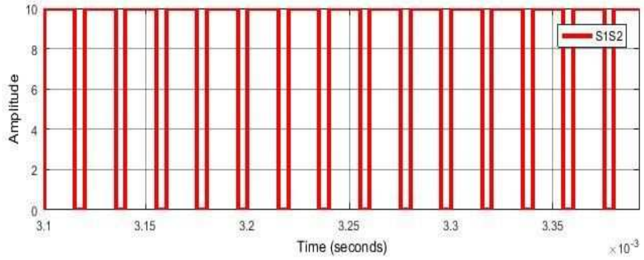


Fig.19 Switching pulses of switches S1, S2

The ripple percentage in the output voltages at first stage and second stage and inductor currents of first stage and second stage can be calculated by equation (18) with the statistics depicted in Fig. 16 and Fig.19 respectively. The first stage output voltage, second stage output voltage, output current of Dual Stage Boost Converter obtained in simulation for an input of 12V DC are shown in Table 6.

C. Simulation of Dual Phase Dual Stage Boost Converters

The MATLAB Simulink model of Dual Phase Dual Stage Boost Converter simulated with the parameters depicted in Table 5 is shown in Fig.23. The Fig. 20 demonstrates the waveforms of voltages at input, output and output current of Dual phase dual Stage Boost Converter. Since the input voltage of 12V is applied, time interim of 4ms is taken for the output at first stage and second stage to settle at steady state values of 47.9V and 191.8V respectively.

TABLE V
SIMULATION PARAMETERS OF DUAL PHASE DUAL STAGE BOOST CONVERTER

Parameter	Value
Input Voltage	12V
Output Voltage	192V
Output Current	1.042A
Switching Frequency	50KHz
First Stage Phase1 Inductor	27μH
First Stage Phase2 Inductor	27μH
Second Stage Inductor	432μH
First Stage Capacitor	33μF
Second Stage Capacitor	2.03μF
Resistor	184.6Ω

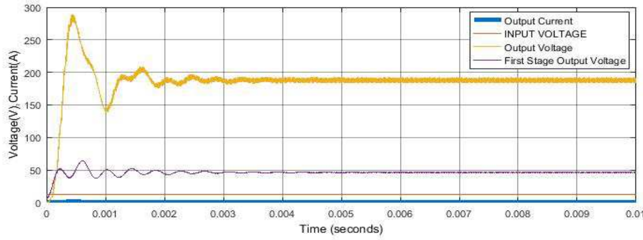


Fig. 20 Voltages at each stage of dual phase dual stage boost converter

The Fig. 20 is stretched from 7.3ms to 8.9 ms to demonstrate the ripples in output voltages of first sage and second stage boost converter and is shown in Fig. 21. First Stage output is nothing other than output of dual phase stage.

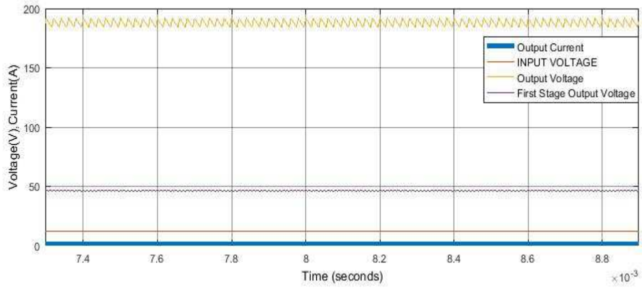


Fig. 21 Enlarged waveform of each stage voltages

The Fig.22 shows the statistics of output voltages of first stage and second stage for the Fig.21.

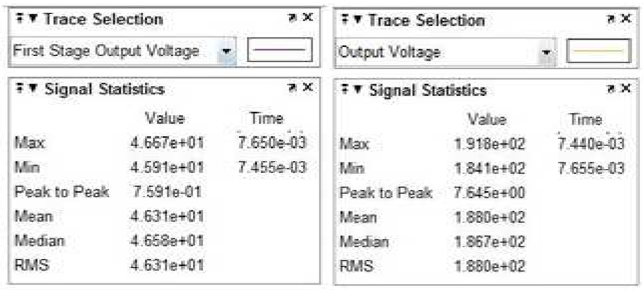


Fig. 22 Signal statistics of first and second stage output voltages

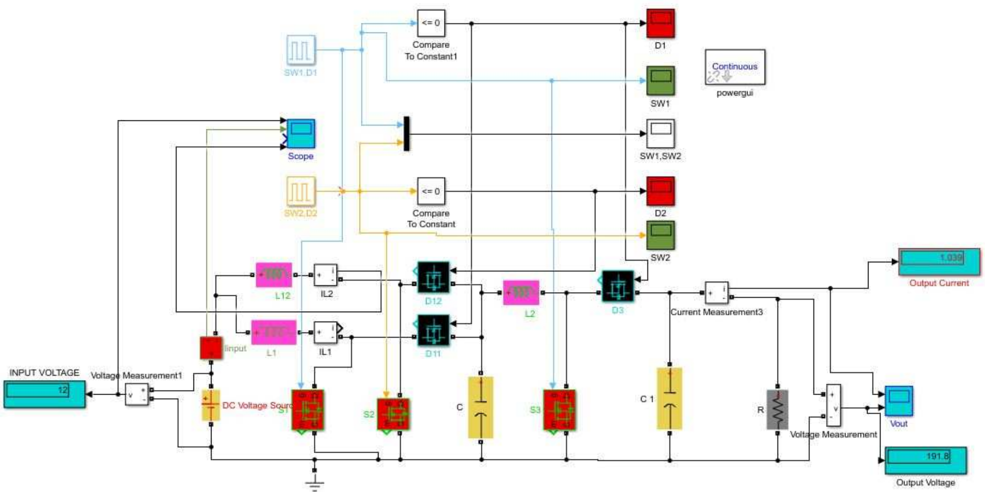


Fig. 23 Simulink model of dual phase dual stage boost converter

In Fig. 24 inductor current IL11 is the inductor current through the first phase of first stage, IL12 is the inductor current of second phase in first stage. Magnitude of IL11 and IL12 are same but with a phase shift of 180̊ in charging and discharging cycle. Resultant is the resultant inductor current at first stage. IL2 is the current flowing through second stage inductor.

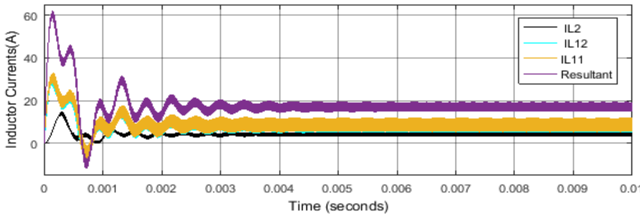


Fig. 24 Inductor currents at each phase and each stage

The Fig.24 is intensified for a time interval of 8.55ms to 8.68ms to observe the ripple content in inductor currents of each stage and is shown in Fig. 25.

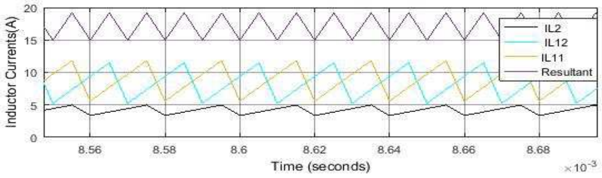


Fig. 25 Enlarged waveforms of Inductor current

The Fig.26 gives the statistics of inductor current at two phases IL11, IL12 and their resultant of first stage and inductor current at second stage IL2 for the Fig. 25.

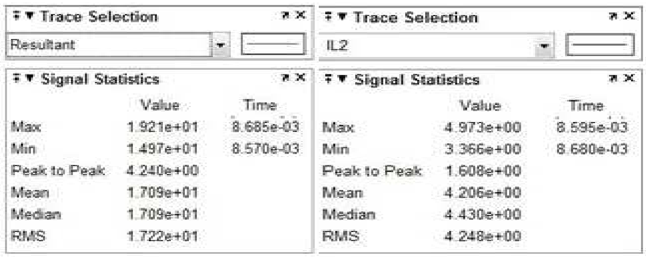


Fig. 26 Signal statistics of Resultant Inductor Current and IL2

The control pulses for the two switches S11, S12 shown in Fig. 27 are of dual Boost Converter which overall makes i the first stage of the proposed converter.S11 and S12 are 180̊ phase shifted .The switching pulse the switch S2 in second stage of the converter is identical to that of switch S11 in dual phase boost converter.

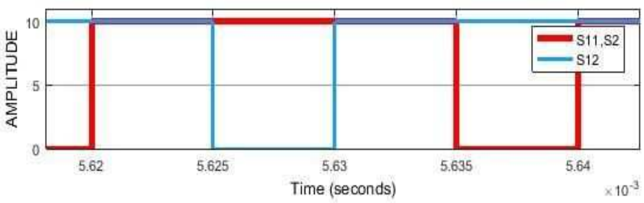


Fig. 27 Switching pulses of three switches S11, S12, S2

The equation (18) can be used with the statistics portrayed in Fig. 23 and Fig. 26 can be utilized to calculate the ripple percentage in the output voltages at first stage and second stage and inductor currents of first stage and second stage. The Table 6 depicts the comparison of dual stage boost converter and dual phase dual stage boost converter.

TABLE VI
COMPARISON OF DUAL STAGE BOOST CONVERTER AND DUAL PHASE BOOST CONVERTER

Parameter	Dual Stage Boost Converter	Dual Phase Dual Stage Boost Converter
First Stage Output Voltage	47.7V	47.8V
Output Voltage	191.7V	191.8V
Output Current	1.03A	1.04A
First Stage Inductor Current Ripple	33.51%	24.80%
Second Stage Inductor Current Ripple	39.1%	38.23%
First Stage Output Voltage Ripple	4%	1.6%
Second Stage Output Voltage Ripple	4.13%	4%

From the table it has been observed that the proposed converter provides drop in inductor current and output voltage ripple at first and second stages which makes the dual phase dual stage boost converter more efficient. Resultant inductor is considered as the first stage inductor current.

IV. CONCLUSIONS

The dual phase dual stage Boost Converter effortlessly overwhelms the flaws in conventional single stage boost converter. By indistinguishable parallel methodology, current at input gets partitioned. In dual phase boost converter reduced ripple content and doubling in frequency occurs due to elimination in ripple of inductor current among the different phases. This gives the best approach to cut down the size of the filter, prompting to a compressed converter. The dual phase dual stage booster topology will be best appropriate proficient framework for the applications which desire reduced ripple. The simulation results confirm the theoretical assumes.

V. REFERENCES

[1] S.M.Ameli, M.Shamlo Clerk Maxwell,"Economical load distribution in power networks that include hybrid solar power plants," *Elect. Power Syst. Res.*, Vol. 78, No. 7, pp. 1147–1152, 2008.

[2] P. Bhatnagar, R.K. Nema, "Maximum power point tracking control techniques: State-of-the-art in photovoltaic applications," *Renew Sustain Energy Rev*, 23, pp. 224–241,2013.

[3] M. Almaktar, H. Abdul Rahman, M. Y. Hassan, and I. Saeh,"Artificial neural network-based photovoltaic module temperature estimation for tropical climate of Malaysia and its impact on photovoltaic system energy yield," *Prog. Photovoltaics Res. Appl.*, Vol. 23, No. 3, pp. 302- 318, 2015.

[4] R.J Wai, W.H Wang and C.Y Lin, "High-Performance Stand-Alone Photovoltaic Generation System," *IEEE Transactions on Industrial Electronics*, Vol.55, No.1, pp.240-250, Jan.2008.

[5] M. E. Ahmed, M. Mousa and M. Orabi," Development of high gain and efficiency photovoltaic system using multilevel boost converter topology," *in Proc. IEEE International Symposium on Power electronics for Distributed Generation Systems*, pp. 898-903,2010.

[6] A.E.L. Costa, R.L. Andersen, "High-gain Boost-Boost-Flyback converter for renewable energy sources applications", *2015 IEEE 13th Brazilian Power Electronics Conference and 1st Southern Power Electronics Conference (COBEP/SPEC)*, 2015.

[7] M. Prudente, L. Luciano, P. Fitscher, E. Gustavo, E. F. Romaneli and R. Gules," Voltage Multiplier Cells Applied to Non-Isolated DC–DC

Converters”, *IEEE Transactions on Power Electronics*, Vol.23, No.2, pp.871-887, March 2008.

[8] J.C Rosas-Caro, J.M Ramirez, F.Z Peng and A. Valderrabano, "A DC-DC multilevel boost converter," *IET Power Electronics*, Vol.3, No.1, pp.129-137, 2010.

[9] R.Giral, L.M Salamero, S. Singer, “Interleaved Converters Operation Based on CMC,”*IEEE Trans. on Power Electronics*, Vol. 14, No.4, pp. 643-652, 1999.

[10] W. h. Li, Y. Zhao, Y. Deng, X. He, “Interleaved Converter with Voltage Multiplier Cell for High Step-Up and High-Efficiency Conversion,” *IEEE Transactions on Power Electronics*, Vol. 25, No. 9, pp. 2397 - 2408, Sep. 2010.

[11] M. R. Ahmed, G. Calderon-Lopez, F. Bryan et al., "Soft-Switching SiC Interleaved Boost Converter", *IEEE Applied Power Electronics Conference and Exposition (APEC)*, pp. 941-947, 15-19 March 2015.

[12] G. Calderon-Lopez, A. Villarruel-Parra, P. Kakosimos, S. K. Ki, R. Todd, A. J. Forsyth, "A comparison of digital PWM control strategies for high power interleaved DC-DC converters", *8th IET International Conference on Power Electronics Machines and Drives (PEMD 2016)*, pp. 1-6, 2016.

[13] K. Leong, G. Deboy, K. Krischan and A. Muetze, "A single stage 54V to 1.8V multi-phase cascaded buck voltage regulator module," *IEEE Applied Power Electronics Conference and Exposition (APEC*), Vol. 2015, pp. 1966–1973, Charlotte, March 2015.

[14] M.C Retana, L.H Gonzalez and J.C Cabrera,”Design of Multi-phase Multi-Stage Boost Converter 100W,” *14th IEEE International Conference on Electrical Engineering, Computer Science and Automatic Control*, Mexico ,November 2017.

[15] S. Suraj, S. Sarun, J.J Jijesh, “Implementation of interleaved dual boost converter utilizing FPGA for PWM”, Proceedings of 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), ISBN: 978-1-5090-0774-5, DOI: 10.1109/RTEICT.2016.7807787, pp. 79 – 83, May 20-21, 2016.

[16] S.Vishwanatha.V.H Yogesh, “Systematic Circuit and Analysis of a Non Ideal DC-DC Pulse Width Modulation Boost Converter”,*IET Circuits,Devices and Systems* , Vol.1 2, No. 2, pp.144–156, 2018.