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Comparison of Parallel and Series Connection of Boost Converter Topology for High Voltage Applications

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ABSTRACT: Two-Phase boost converter is making use of current splitting in two branches by using inductor and switch to boost the voltage level. By current splitting stress are removed from the switching device. Higher voltages with good efficiency are found due to parallel cascading of two boost converter. In case of series (cascade) connection of converter the output of one module works as input of the second module, by which the output voltage is boost to a higher value. The advantages of DC-DC boost converters include increased efficiency, reduced size and faster transient response of system. The outputs of two phase boost converter are compared with cascade boost converter. This paper compares the output waveforms of the two-phase boost converter and cascade boost converter, used for high voltage applications. These are used for boosting the level of DC voltages by two topologies working at a time in series and parallel.

KEYWORDS: Boost converter, two-phase, cascade, voltage, current and Efficiency

I. INTRODUCTION

Atmospheric carbon dioxide concentrations have been steadily increasing due to human activity in the form of burning fossil fuels and deforestation. About 8 to 10 billion tons of carbon is added to our atmosphere each year. Even more sobering is that total world energy consumption is projected to increase by 50 percent from 2005 to 2030, according to the Energy Information Administration. As the world population increases from 6.5 billion to 9 billion people over the next 45 years, and countries continue to industrialize, some estimates indicate that we will be adding more than 20 billion tons of carbon per year to the atmosphere [1-2]. There are two categories of DC – DC converters: Isolated and Non-Isolated DC –DC converters. Isolated DC – DC converters as the name implies, electrically isolated the output from the input using a high frequency transformer. The transformer's turns ratio gives the relationship between the input and output voltage. By having multiple secondary windings isolated converters are able to provide multiple levels of outputs. The size of the transformer usually indicates the size of isolated converter; hence they are generally large in size. On the other hand the Non-Isolated topologies can vary the dc output voltage and provide different level of output voltages without the use of transformer and require fewer components to implement.

Boost converter is also known as the step-up converter. It is one of the well-known topology in the field of power electronics, like any other DC – DC converters it aims to achieve high efficiency conversion. The existence of boost converter relies on the discovery of semiconductor switches. These switches are much faster and reliable than others such as vacuum tubes and electromechanical relays. The semiconductor switches are able to operate at very high frequency from about 200 kHz to as high as 2 MH_z. The frequency of Boost converters has an inverse relationship with the size of the magnetic components; therefore having a high switching frequency is beneficial to decrease the size of the converter [3-5]. One of the major concerns in the power sector is day-to-day increasing power demand, but the un-availability of enough resources to meet the power demand by using the conventional energy resources. Renewable

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sources like wind energy and solar energy are the primary energy sources which are being utilized for these works. The continuous uses of fossil fuels have caused the fossil fuel deposit to be reduced and have drastically affected the environment depleting the biosphere and cumulatively adding to global warming [6].

DC/DC converters are widely used for interconnections of two or more networks with different voltage levels. There are such different topologies, which varies in complexity of circuits, stress on used components and quality of input and output power [7]. In these types of boost converter are used to boost the low variable dc voltage from the fuel cell / battery and provide the high quality, regulated dc voltage to the output. From last decades isolated topologies with high frequency step-up transformer have been used commonly in the boost converter topologies. A cleaner energy future depends on the development of alternative energy technologies to meet the world's growing energy needs but that also mitigate carbon dioxide emissions. Some of sustainable energy based power plants, including hydro, geothermal, biofuel-plants, use synchronous generators directly connected to the grid. But some other sources like fuel cells (FC) and photovoltaic (PV) basically produce a dc voltage. Such systems which have a large scope of small scale of implementation produce dc voltage which is much lower for direct implementation. So, an interface between the source and load is a need and the power electronic converter is the interface [8].

Use of several boost converters in parallel expands the output power of the whole system, while the input current is shared between two or more converter modules. The two-phase boost converter operates in the same way like the basic boost converters [9-10] presented in Fig. 1. Sometimes many devices are not capable to withstand such stresses. An extensive amount of research has been carried out on these issues. Many different topological modifications have developed from this. Multilevel converters have had a lot of success, especially on DC-AC applications.

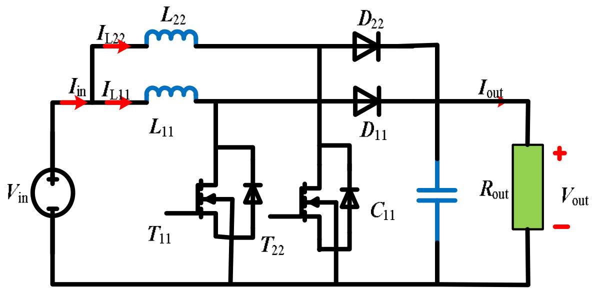

Fig.1. Two-phase boost converter circuit

If a very high voltage gain is required it may be more beneficial to use of two or more series connected (cascaded) boost converters, like presented on Fig. 2. This approach gives some advantages, but it creates new challenges in the same time. Main advantages include a high voltage gain, a good power decoupling between the output and the input, better utilization of semiconductors, presence of an intermediate DC bus. Major drawbacks are more complex circuit, more complex controls and a potential stability problem.

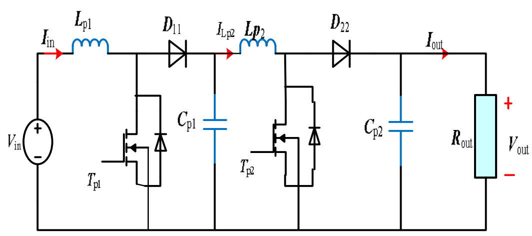

Fig. 2. Cascaded boost converter circuit

When a DC voltage has to be stepped up, the boost converter has long been the preferred scheme. This is because of its adjustable step-up voltage conversion ratio, continuous input current, simple topology and high efficiency. Nevertheless, when the power level increases, the inductor becomes large, bulky, costly and heavy. Also, as the required output voltage rises, conduction and switching losses increases as they are proportional to voltage. Sometimes, there aren't devices capable to withstand such stresses. An extensive amount of research has been carried out on these issues. Many different topological modifications have developed from this, for example: serializing switching components, cascading converters, high frequency transformer based converters and even multilevel

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converters either diode clamped or of the flying capacitor type. Multilevel converters have had a lot of success, especially on DC-AC applications. Some research has been made on their application on DC-DC circuits mostly of the diode clamped and the flying capacitor types.

Nevertheless, a two level version of the boost converter will be very simple efficient and will have a low part count [11- 17]. Gating signals for both transistors have the same duty cycle and phase shifted by 180º (interleaving). One may observe that the input current ripple is smaller than ripples observed in particular inductor current. Main challenges in case of paralleled boost converters are to provide exactly the same duty cycle for all transistors. Even a small mismatch in duty cycles may lead to a significant current sharing unbalance and reduce reliability of the system. Different active and passive current sharing methods are discussed in [18].

II. WORKING OF BOOST CONVERTER

In case of paralleled converters the voltage gain *k* does not change and it is given by (1). Also transistors blocking voltage and diode reverse voltage don't change and about to output voltage V_{out}, and the transistor rms current is given by (2). A significant inductor current ripple can't be neglected this time and it has an influence on the transistor power rating according to (3). The term *n* means number of paralleled modules, sharing the input current, required power rating of the diode D_{11} is given by (4). The required inductance L_1 is given by (5).

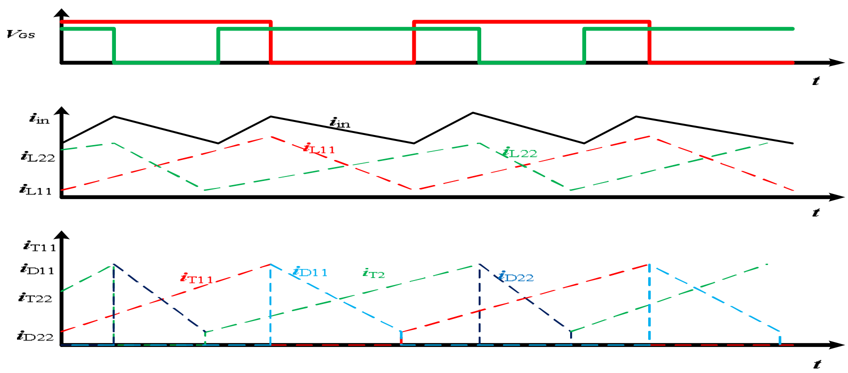

Fig. 3. Waveforms of a two-phase boost converter

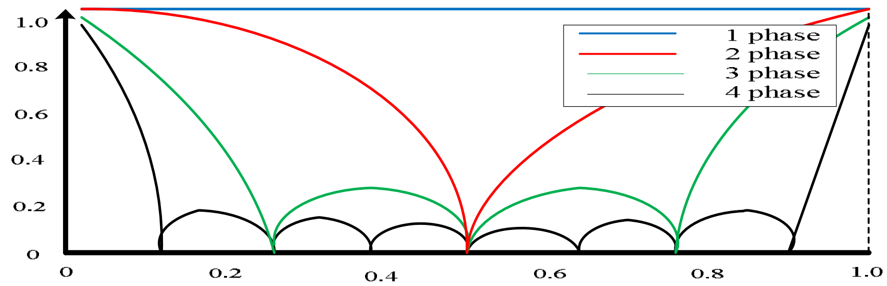

Fig. 4. Reduction of current ripple in a multi-phase converter

$$k = \frac{1}{1-D} \tag{1}$$

$$I_{T11(rms)} = \frac{I_{in}}{n}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{L11}}{I_{L11}}\right)^2}\,.\sqrt{D} \approx \frac{k}{n}.I_{in}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{L11}}{I_{L11}}\right)^2} \tag{2}$$

$$\text{volt X amp}_{T11} = V_{T11(off)}.I_{T11(rms)} \approx V_{out}.\frac{k}{n}.I_{in}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{L11}}{I_{L11}}\right)^2} = \frac{k}{n}.P_{out}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{L11}}{I_{L11}}\right)^2} \tag{3}$$

$$\text{volt X amp}_{D11} = V_{out}.\frac{I_{out}}{n} \approx \frac{P_{out}}{n} \tag{4}$$

$$L_{11} = \frac{V_{in}.D}{2.\Delta i_{L1}.f_s} \tag{5}$$

$$C_{11} = \frac{I_{out}.D}{2.\Delta v_{out}.f_s.n} \tag{6}$$

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It is important to note that allowed inductor current ripple may become significantly larger than allowed input current ripple ($\Delta i_{L11} > \Delta i_{in}$), thus required inductance L_{11} can be reduced. The current ripple reduction depends on number of interleaved phases and duty cycle. However one should be aware that increased inductor current ripple may lead to increased ac copper losses in the inductor winding and increased conduction losses in the transistor.

The voltage gain of the cascaded boost converter operating in CCM is the product of the voltage gain of each stage in (7). The transistor T_{p1} and the diode D_{11} have to handle the intermediate voltage V_{C11}, while the transistor T_{p2} and the diode D_{22} have to handle the output voltage V_{out}. Transistors rms currents are given by (8) and (9), under assumption of a small input current ripple and a large intermediate ripple current. Required power rating of both transistors is the sum of respective power ratings and is given by (12). Similarly requires power rating of both diodes is given by (15). For a large voltage gain k cascading of two or more boost converters lead to a significant reduction of the required transistors power rating, but in the same time it increases required diodes power rating by number of cascaded converter stages.

$$k = k_1.k_2 = \left(\frac{1}{1-D_{11}}\right).\left(\frac{1}{1-D_{22}}\right) \tag{7}$$

$$I_{Tp1(rms)} = I_{in}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{in}}{I_{in}}\right)^2}.\sqrt{D_{11}} \approx k_1.k_2.\sqrt{D_{11}}.I_{out} \tag{8}$$

$$I_{Tp2(rms)} = I_{Lp2}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{Lp2}}{I_{Lp2}}\right)^2}.\sqrt{D_{22}} \approx k_2.\sqrt{D_{22}}.\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{Lp2}}{I_{Lp2}}\right)^2}.I_{out} \tag{9}$$

$$volt\ X\ amp_{Tp1} = V_{Tp1(off)}.I_{Tp1(rms)} \approx \frac{V_{out}}{k_2}.k_1.k_2.\sqrt{D_{11}}.I_{out} = k_1.\sqrt{D_{11}}.P_{out} \tag{10}$$

$$volt\ X\ amp_{Tp2} = V_{Tp2(off)}.I_{Tp2(rms)} \approx V_{out}.k_2.\sqrt{D_{22}}\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{Lp2}}{I_{Lp2}}\right)^2}.I_{out} = k_2.\sqrt{D_{22}}\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{Lp2}}{I_{Lp2}}\right)^2}.P_{out} \tag{11}$$

$$volt\ X\ amp_{TT} = volt\ X\ amp_{Tp1} + volt\ X\ amp_{Tp2} = \left(k_1.\sqrt{D_{11}} + k_2.\sqrt{D_{22}}\sqrt{1+\frac{1}{3}.\left(\frac{\Delta i_{Lp2}}{I_{Lp2}}\right)^2}\right).P_{out} \tag{12}$$

$$volt\ X\ amp_{D11} = \frac{V_{out}}{k_2}.I_{out} \approx P_{out} \tag{13}$$

$$volt\ X\ amp_{D22} = V_{out}.I_{out} \approx P_{out} \tag{14}$$

$$volt\ X\ amp_{DT} = volt\ X\ amp_{D11} + volt\ X\ amp_{D22} = 2.P_{out} \tag{15}$$

$$L_{p1} = \frac{V_{in}.\delta}{2.\Delta i_{in}.f_{S1}} \tag{16}$$

$$L_{p2} = \frac{V_{C1}.D_{22}}{2.\Delta i_{Lp2}.f_{S2}} \tag{17}$$

$$C_{p1} = \frac{I_{L2}.D_{11}}{2.\Delta v_{Cp1}.f_{S1}} \tag{18}$$

$$C_{p2} = \frac{I_{out}.D_{22}}{2.\Delta v_{out}.f_{S2}} \tag{19}$$

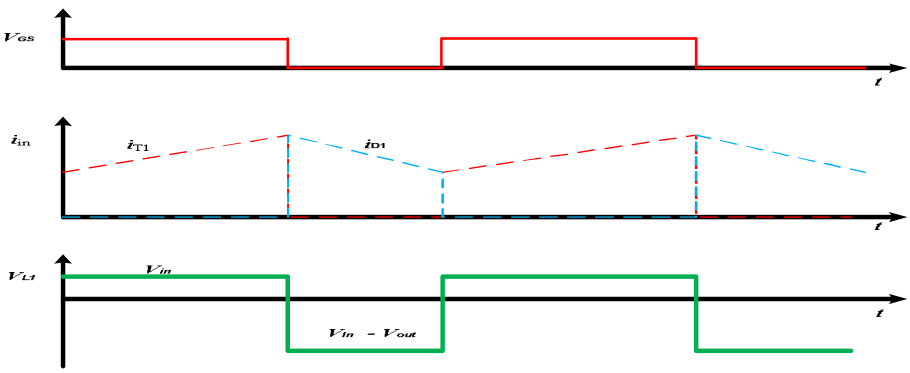

Fig. 5. Waveforms of cascade (one module) boost converter

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III. SIMULATION RESULTS

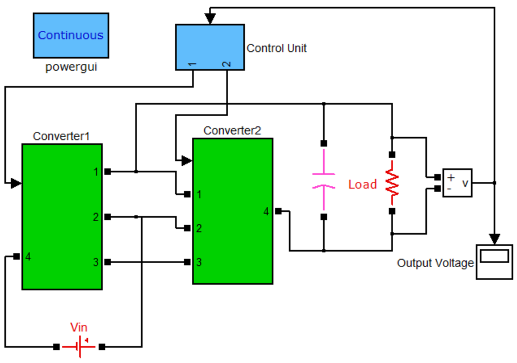

Fig. 6.Simulink diagram of two-phase boost converter

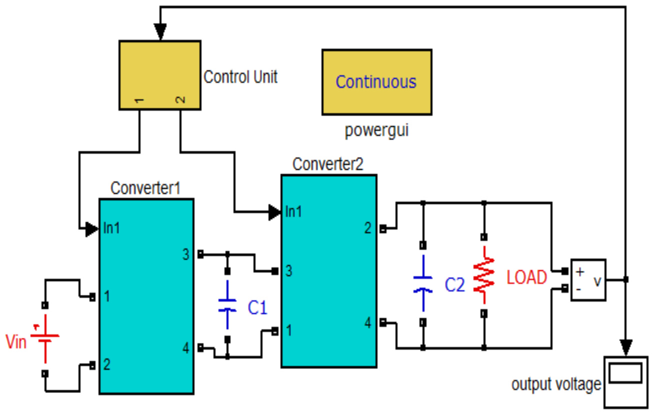

Fig. 7.Simulink diagram of cascade boost converter

The performance of the boost converter is verified via computer simulation. The simulation is conducted using MATLAB/SIMULINK software package.

A. ANALYSIS OF THE CONVERTERS:

By making use of MATLAB/SIMULINK software package the analysis of both converters are performed and results are observed.

I. Two-Phase boost Converter waveforms:

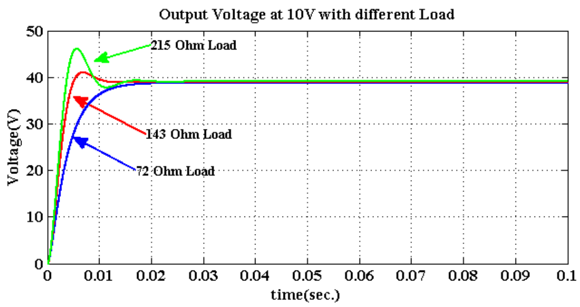

Fig. 8.Output voltage for different load at 10V

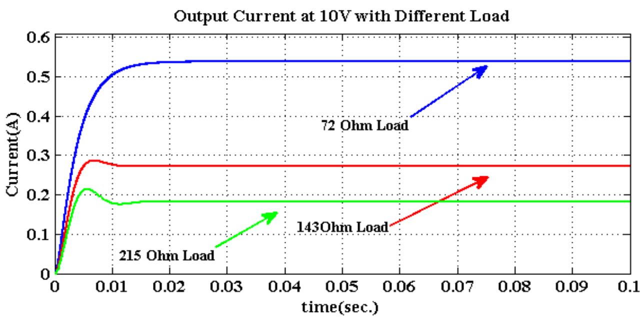

Fig. 9. Output current for different load at 10V

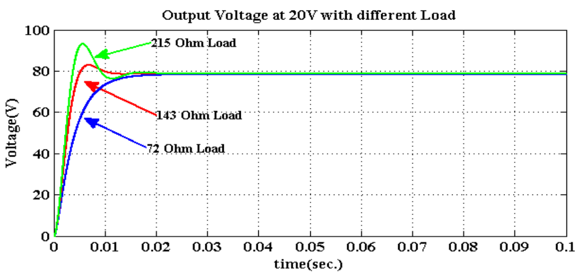

Fig. 10.Output voltage for different load at 20V

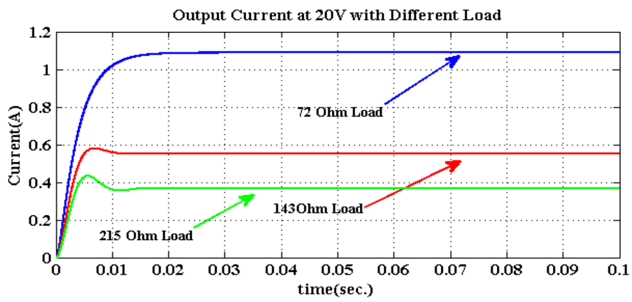

Fig. 11. Output current for different load at 20V

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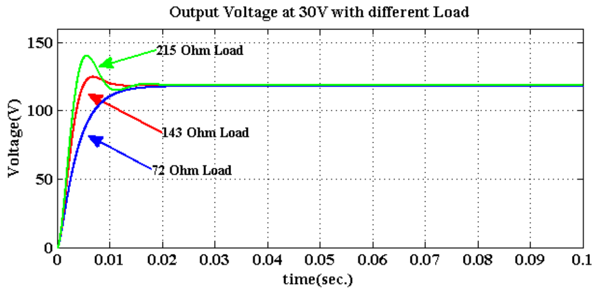

Fig. 12.Output voltage for different load at 30V

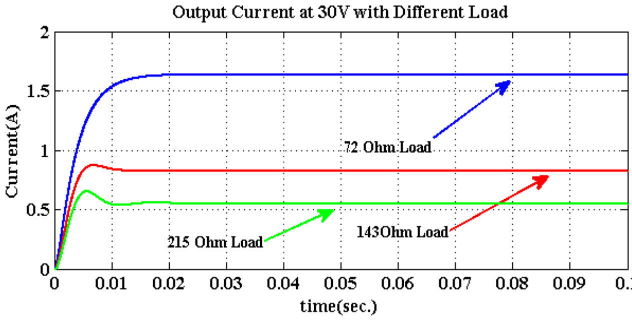

Fig. 13. Output current for different load at 30V

II. Cascade-boost Converter waveforms: In this section all the comparison are done at same parameters as in case of two inductor boost converter.

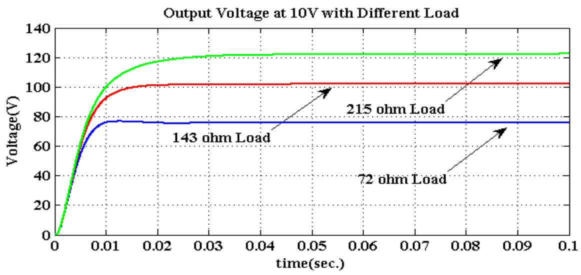

Fig.14. Output voltage for different load at 10 V

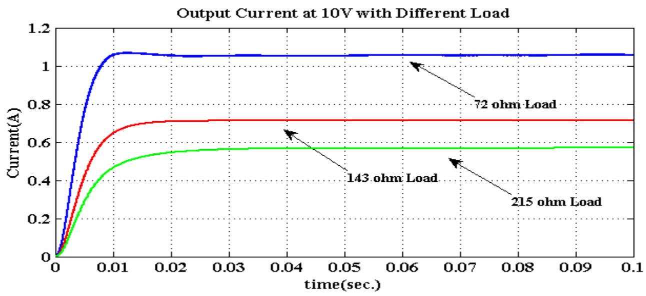

Fig.15. Output current for different load at 10 V

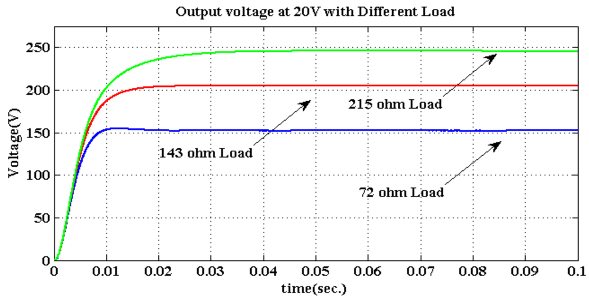

Fig.16. Output voltage for different load at 20 V

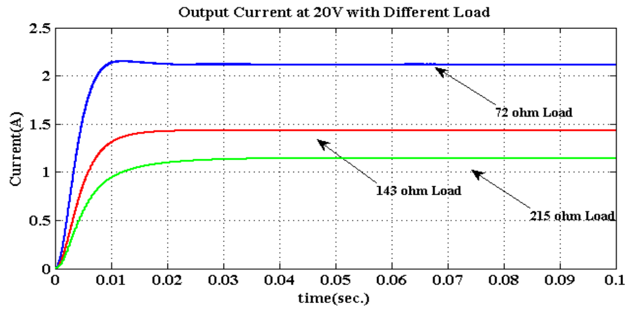

Fig.17. Output current for different load at 20 V

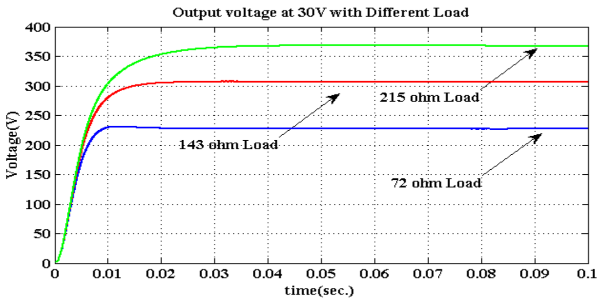

Fig. 18.Output voltage for different load at 30 V

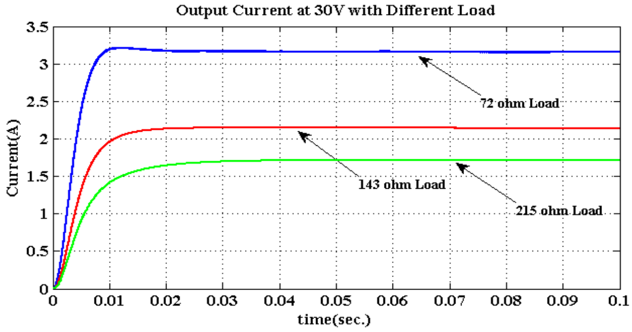

Fig.19. Output current for different load at 30 V

The performance of the two-inductor and two-phase boost converter system with resistive load in tabular form is shown in Table-1. Where three input voltages (10V, 20V and 30V) and three resistive loads (72Ω, 143Ω and 215Ω) are used for analysis of the converters. Performances of the converters are made according to the output voltage, current and efficiency and study takes place.

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Table-1*Comparison chart of the converters*

S. N.	V_{in} (V)	Load (Ω)	Output Current (A)		Output Voltage (V)		Efficiency	
			Cascade	Two Phase	Cascade	Two Phase	Cascade	Two Phase
1	10	72	1.06	0.541	76.02	38.95	85.23	92.54
2	10	143	0.72	0.273	102.2	39.07	85.33	88.17
3	10	215	0.57	0.182	122.4	39.10	84.94	84.05
4	20	72	2.12	1.093	152.3	78.70	87.47	93.54
5	20	143	1.43	0.552	205	78.93	87.10	89.16
6	20	215	1.14	0.368	245.8	79.01	86.50	85.03
7	30	72	3.15	1.645	226.9	118.4	88.12	93.47
8	30	143	2.14	0.831	305.9	118.8	87.62	89.49
9	30	215	1.71	0.553	367.3	118.9	86.86	85.35

The comparison of the converters is shown in form of the graph below, which includes waveforms of voltage, current and efficiency of the systems. By this the comparisons of the converters takes place and analysis is done by these waveforms.

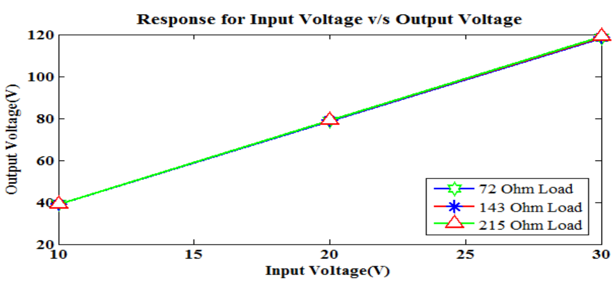

Fig. 20.Response of two-phaseat different load

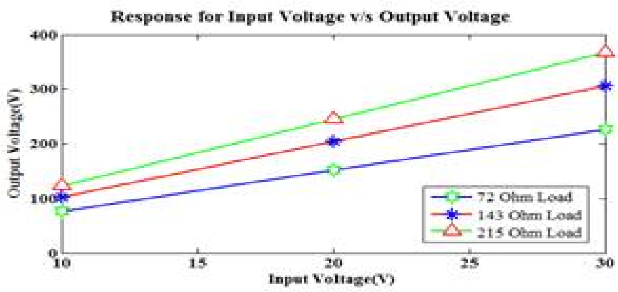

Fig.21. Response of cascade boost converter with input

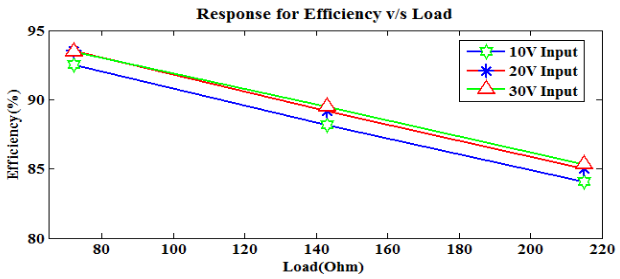

Fig. 22.Efficiency response of two phase boost converter

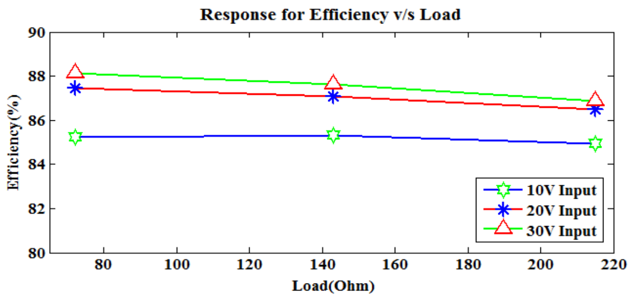

Fig. 23. Efficiency response of cascade boost converter

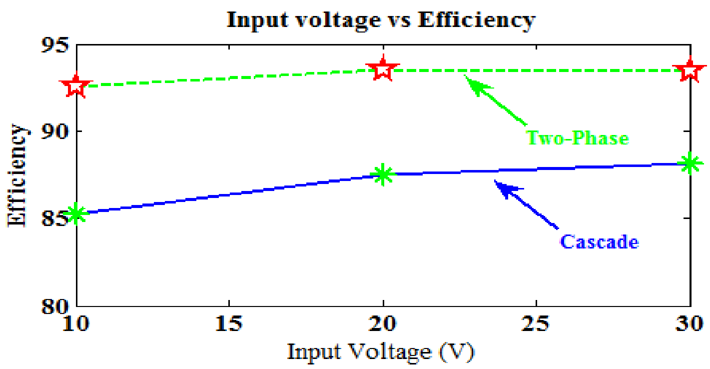

Fig. 24. Efficiency response of the both converters

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From this table it is to be discussed, that how the system output voltage and efficiency varied according to the input voltage and load. The variation in output voltage and efficiency is shown in Fig. 20 to Fig. 24.

IV. CONCLUSIONS

For all values of input voltage two phase boost converter gives nearly same output voltage at all load. In-case of cascade output voltage comes nearly 2 to 3 times the output voltage of the two-phase boost converter at any input voltage and load. The output voltage is more in case of cascade boost converter in comparison to two-phase boost converter and gives nearly double output voltage at low load. At low load two-phase boost converter has good efficiency, but at high load it comes near to the cascade boost converter efficiency. By increasing the input voltage efficiency is increased in cascade and near to constant in case of two-phase boost converter. As cascade is giving very high voltage at nearly same efficiency to that of two-phase, so it can be said that cascade is good one for boosting the voltage.

In future it can be used to provide power for the electrical vehicles. Cascade boost converter gives good performance at every level of the load. It reduces the space of storage and number of the battery to save the economy. So it can be good option for future.

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