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HIGH GAIN DC-DC BOOST CONVERTER FOR RENEWABLE ENERGY APPLICATIONS

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***Abstract*—Proposed cascaded dc-dc boost converter driven by single switch is modelled and implemented successfully using MATLAB/ Simulink. The efficiency ofthe converter is 96.65% and step-up voltage gain is 2.25 times as compare to conventional method.Here in the ripples in output voltage is reduced up to 0.25Vin case of close loop converter as compared to open loop which was at .40V. This converter eliminates the need of active snubber, auxiliary resonant circuit, synchronous rectifiers, or switched-capacitor-based resonant circuits and so on, that all are able to achieve soft switching on the main switch for reaching higher efficiency.Converter utilises the single switch there in the circuit, switching losses are reduced and switch will be safer from the stray heating.**

Keywords-Direct Current (DC), Three-Winding Coupled-Inductor (TWCI), High Intensity Discharge (HID),Pulse Width Modulation (PWM), Zero Voltage Switching (ZVS)etc.

I. INTRODUCTION

Generally, cascading is interfacing of two or more units such types of converters for impedance matching; the impedance matching is nothing but the transformation or improvement gain in multiplicative way. In small signal application the cascading is done with the transistor for improving current gain, for example in Darlington pair the gain is given by multiplying each individual transistor gain, but increasing in gain sacrifices its bandwidth. In case of CE-CB configuration the cascading is done for transforming impedance characteristic. Same in this manner in application of high voltage and high-power cascading is introducing by connecting of two or more units for improving gain. But here the increasing in gain sacrifices the efficiency of converter due to increasing in switching loss.

1.1.1. Conventional Cascade boost converter

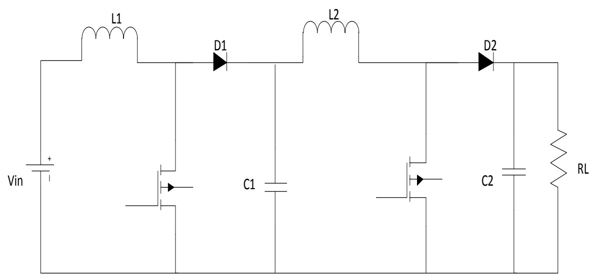

Fig 1.1 Two Stage Conventional Cascaded Boost Converter

1.1.2. Single Switching Concept

High step-up DC-DC converters are necessary in low input-voltage to high output-voltage power conversion applications. By employing the traditional boost converter with extreme duty cycle operation, the voltage gain approximates six times its applied voltage due to the losses of the parasitic components. However, at least ten times voltage gain is needed in many applications such as the frontend stage of the renewable energy systems, the DC bus of the telecom power systems and high intensity discharge (HID) lamp ballast for the automobile headlights.

1.1.3. Proposed Boost Converter

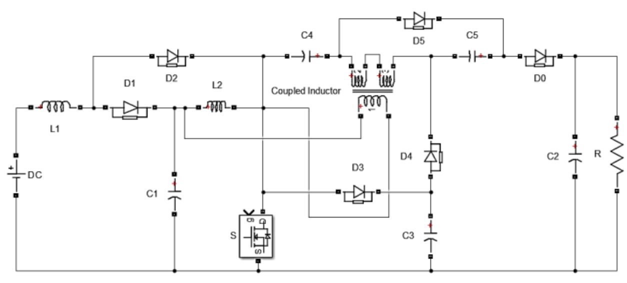

Fig 1.2Two Stage AdvancedQuadratic Boost Converter

Using of single power switching devices overcomes conventional cascaded boost converter low efficiency problem. Use of single switch makes converter with less ripples in waveform, less harmonics content and compact in size.

1.2. Close Loop Operation

There is involvement of the switching devices with energy storing elements i.e., inductor and capacitor; and energy is exchanged in dc-dc converter. Exchange of energy introduces oscillation in system. In another terms we say it acts as second order system with damping. This oscillation is nothing but transients in system or ripple in output voltage waveform. For reduction of this harmful effect close loop operation with PID controller, PWM techniques and lead-lag compensator is necessary.

1.2.1. PWM Technique

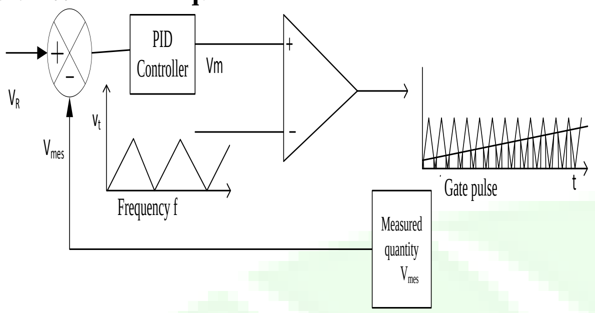

Fig 1.3 Intersection PWM

The most common strategy for controlling the power transmitted to the load is the interceptive Pulse Width Modulation (PWM). A control voltage V_m is compared to a triangular voltageV_t. The triangular voltage V_t determines the switching frequency ft. The switch T is controlled according to the difference $V_m - V_t$ (figure 1.3).

1.2.2. Lead-Lag Compensator

Using of PID controller and PWM techniques reduces ripple in output waveform but not completely. The lead-lag compensator works like a filter that eliminate the output voltage ripple significantly.

II. LITERATURE SURVEY

Hasanpour, Sara, et al. (2021) -In this article, a new non-isolated full soft-switching step-up dc/dc converter is introduced with a continuous input current for renewable energy applications. The use of a three-winding coupled-inductor (TWCI) along with a voltage multiplier, enables the proposed converter to enhance the voltage gain with lower turns ratios and duty cycles. Also, a lossless regenerative passive clamp circuit is employed to limit the voltage stress across the power switch. In addition to zero current switching performance at the turn-on instant of the power switch, the turn-off current value is also alleviated by adopting a quasi-resonance operation between the leakage inductor of the TWCI and middle capacitors. Moreover, the current of all diodes reaches zero with a slow slew rate, which leads to the elimination of the reverse recovery problem in the converter. Soft-switching of the power switch and all the diodes in the proposed converter significantly reduces the switching power dissipations. Therefore, the presented converter can provide a high voltage gain ratio with high efficiency. Steady-state analysis, comprehensive comparisons with other related converters, and design considerations are discussed in detail. Finally, a 160 W prototype with 200 V output voltage is demonstrated to justify the theoretical analysis[1].

Hasanpour, Sara, et al. (2021) - This article proposes a new configuration of quasi-resonant high-gain high-efficiency single-ended primary inductor converter (QRHGHE-SEPIC)-based dc–dc converter with continuous input current. The presented single-switch topology uses a coupled-inductor (CI), a voltage multiplier integrated with a regenerative passive lossless clamp circuit to enhance the voltage conversion ratio. In the proposed converter, the main power switch turns on at zero current switching. Moreover, by adopting a quasi-resonance (QR) operation between the leakage inductor of the CI and the middle capacitors, the current value of the main switch at turn- off moment is alleviated. In addition, the leakage inductanceslows down the turn- off slope of all diodes and hence there is no reverse recovery problem in the proposed converter. Due to soft-switching operation in all switching components, the power dissipations in the converter are significantly alleviated. Thus, the proposed QRHGHE-SEPIC can provide high voltage gain while achieving a high efficiency. Steady-state analysis, comprehensive comparisons with other related converters, and design considerations are discussed in detail. Finally, to verify the validity of the theoretical analysis, a 160 W/200 V sample prototype is demonstrated at the switching frequency of 60 kHz and with voltage gain of 10[2].

Mahmood, Arshad, etal.(2021) - High gain DC- DC converters are increasingly being used in solar PV and other renewable generation systems. Satisfactory steady-state and dynamic performance, along with higher efficiency, is a pre-requirement for selecting the converter for these applications. In this paper, a non-inverting high gain DC-DC boost converter has been proposed. The proposed converter has only one switch with continuous input current and reduced voltage stress across switching devices. The operating range of the duty cycle is wider, and it obtains a higher gain at a lower value of the duty cycle. Moreover, the converter has higher efficiency at a lower duty cycle while drawing a continuous input current. The continuous input current is a desirable feature of the dc-dc converter making it suitable for solar photovoltaic applications. The converter's operation has been discussed in detail and extended to include the real circuit parameters for a practical performance evaluation. The proposed converter has been compared with other similar recently proposed converters on various performance parameters. The loss analysis for the proposed converter has also been carried out. Finally, the simulation has been validated with results from the experimental prototype[3].

Hasanpour, Sara, et al. (2020) - In this article, a new semi-quadratic high step-up coupled-inductor dc/dc converter (SQHSUCI) with continuous input current and low voltage stress on semiconductor components is presented. The proposed structure employs a coupled-inductor (CI) and two power switches with simultaneous operation to achieve an extremely high voltage conversion ratio in a semi-quadratic form. The voltage stress across the main power switch is clamped by two regenerative clamp capacitors. Here, the switching losses of both MOSFETs have been reduced by applying quasi-resonance operation of the circuit created by the leakage inductance of the CI along with the balancing and clamp capacitors. Therefore, by considering the high gain conversion ratio along with low voltage stress on components, the magnetic and semiconductors losses of the SQHSUCI are reduced significantly. Also, the energy stored in the leakage inductance of CI is recycled to the output capacitor. These features make the proposed SQHSUCI more suitable for industrial applications. The operation principle, steady state, and also comparisons with other related converters in continuous conduction mode (CCM) are discussed in detail. Finally, experimental results of a prototype with 20 V input and 200 W-200 V output at 50 kHz switching frequency, verify the theoretical advantages of the proposed strategy[4].

Rahman, Nazia, et al. (2020) - In this paper a non-isolated dc-dc boost converter is described having high voltage gain ability. The proposed high gain boost converter, unlike the conventional boost converter offers high voltage conversion at low duty ratio, thus have high comparative efficiency. The proposed dc-dc boost converter is based on the voltage lift (VL) technique, in which input voltage is boosted in step-by-step manner. A detailed analysis of proposed boost dc-dc converter for non-ideal model is presented. The performance of proposed converter is compared with the conventional boost converter in term of different parameters, viz. number of elements, voltage gain ratio, and switch stress. The proposed dc-dc converter has advantages over conventional one and is suitable for renewable energy resources (RES) applications, especially solar and wind energy. The results obtained both for proposed and conventional converters in MATLAB®/Simulink environment is validated through the lab scaled developed prototype[5].

III. MATHEMATICAL MODELING

3.1 DC-DC Boost Converter

The basic configuration of a boost converter has the diode integrated into the converter.

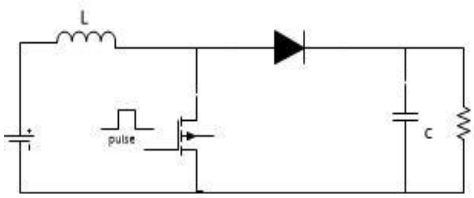

Fig 3.3Boost Converter Power Stage

Here all equations [18], in this document apply besides the power dissipation equation of the diode.

The following four parameters are needed to calculate the power stage:

1. Input Voltage Range: $V_{IN\,(min)}$ and $V_{IN\,(max)}$
2. Nominal Output Voltage: V_{OUT}
3. Maximum Output Current: $I_{OUT\,(max)}$

The first step to calculate the switch current is to determine the duty cycle, δ, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

A. $$\delta = 1 - \frac{V_{IN\,(\min)}\eta}{V_{OUT}} \quad (1)$$

$V_{IN\,(min)}$ = minimum input voltage

V_{OUT} = desired output voltage

η = efficiency of the converter

The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

The next step to calculate the maximum switch current is to determine the inductor ripple current.

$$\Delta I_L = \left(\frac{V_{IN(min)} \times D}{f_s \times L}\right) \quad (2)$$

$V_{IN\,(min)}$ = minimum input voltage

D= duty cycle calculated in Equation 5.1

f_S = minimum switching frequency of the converter

L = selected inductor value

Now it has to be determined if the converter can deliver the maximum output current.

$$I_{OUT\,(max)} = (I_{LIM\,(min)} - \frac{\Delta I_L}{2}) \times (1 - D) \quad (3)$$

$I_{LIM\,(min)}$ = minimum value of the current limit of the integrated switch

ΔI_L = inductor ripple current

D = duty cycle

If the calculated value for the maximum output current of the converter, $I_{OUT\,(max)}$, is below the systems required maximum output current, with a higher switch current limit has to be used. Only if the calculate value for $I_{OUT\,(max)}$ is just a little smaller than the needed one, it is possible to use the converter with an inductor with higher inductance if it is still in the recommended range. A higher inductance reduces the ripple current and therefore increases the maximum output current with the converter.

3.2 DC-DC Quadratic Boost Converter

The proposed converter is transformer less dc-dc converter can be used for microgrid applications. The renewable energy sources such as PV modules, fuel cells or energy storage devices such as super capacitors or batteries deliver output voltage at the range of around 12 to 70 VDC. In order to connect them to the grid the voltage level should be adjusted according to the electrical network standards in the countries.

It's a new modelling technique of a cascade Boost converter. The nonlinear control is applied and gives good performances in grid side and in dc side. PI controller eliminates efficacy the steady state error of the dc bus voltages. The configuration proposed may be used to fast charging electrical vehicle battery by controlling the time charging. The configuration connected to the grid compensates current harmonics, reactive power; the THD of the grid current is less than

5%. The boost converter provides high currents, while the cascade boost converter achieves high voltage. The advantage of the high voltage of the cascade boost converter makes it very suitable for high battery voltage charging current.

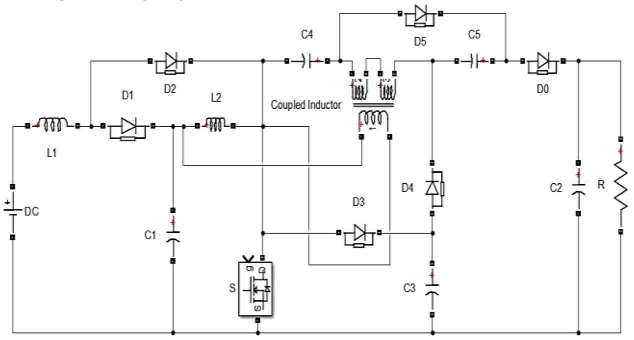

Fig3.4DC-DC Quadratic Boost Converter with Single Switch

Here in the cascade dc-dc boost converter there are two inductors L1 and L2, two capacitors C1 and C2, three diodes D1, D2 and diode2 and single MOSFET are imparted to design and the converter is preceded by the battery.

3.1.1. Modes of operation-

The proposed model operates in two modes: (1) In mode-I some of the inductors and capacitors are energised and charged respectively, (2) In mode-II the voltage across the capacitors aggregates and finally output obtained.

MODE1- The positive pulse is applied to MOSFET or IGBT swich1 and became short circuit ideally it making source current flowing through inductor L1 only as shown in fig 1 during. And charges the inductor L1 sufficiently this is accomplished by taking enough timet1-t2assured CCM (continuous current mode). And inductor voltage polarity is anti-clockwise as shown.

$$V_{L1} = V_i \quad (4)$$

$$V_{LM} = K(V_{C1}) \quad (5)$$

$$V_{C3} = V_{C2} + nV_{LM} \quad (6)$$

$$V_{C4} = nV_{LM} \quad (7)$$

MODE2 -The negative gate pulse of first circle ($T_{on}+T_{off}$) i.e., T2 is applied and switch1 making open circuited (Initially capacitor C1 is uncharged) because property of a conductor to opposing sudden reversal of current it will reverse the polarity i.e., clockwise so source voltage added with inductor voltage and in additive mode both i.e., source and inductor supply power to the capacitor C1 (First unit).

$$v_{L1} = V_i + V_{C1} \quad (8)$$

$$V_{LM} = K(V_{C1} - V_{C2}) \quad (9)$$

Here, K is the coupling coefficient

$$V_o = V_{C2} + V_{C3} + V_{C4} + nV_{LM} \quad (10)$$

3.1.2 Output Voltage Calculation in terms of Duty ratio

The DC source Vin (VDC) and input-inductor L1 are serially and still charged to capacitor C1 with their energies. The energies stored in capacitors C1 and C2 are discharged to the load.

Using the volt-second balance principle on the input and magnetizing inductors (L1 and LM), the voltage of the capacitors C1 and C2 are obtained as follows:

$$V_{C1} = \frac{V_i}{1-D} \quad (11)$$

$$V_{C2} = \frac{V_{C1}}{1-D} = \frac{V_i}{(1-D)^2} \quad (12)$$

$$V_{C3} = \frac{1+nK\ (1-D)}{(1-D)^2} V_i \quad (13)$$

$$V_{C4} = \frac{nKV_i}{(1-D)} \quad (14)$$

Finally, the output voltage can be written in terms of duty ration as,

$$V_o = \frac{2+n(1+K-KD)+n(1-D)(1-K)}{(1-D)^2} V_i \quad (15)$$

IV. METHODOLOGY

4.1 Project Design

The proposed general block diagram for this project is shown in **Error! Reference source not found.** shows the overview of the proposed flow chart of this projectController [20], design for any system needs knowledge about system behaviour in time domain and frequency domain. Usually this involves a mathematical description of the relation among state variables, input to the process and output. This description in the form of mathematical equations which describe behaviour of the process (system) is called model [21], of the system. This thesis describes an efficient method to learn, analyse and simulation of power electronic converters, using non-linear system solution method, and switched state-space models.

4.2 Simulink Model Construction of DC-DC Switching Converter

System modelling is mainly the most important phase in any form of system control design work. The choice of a circuit model and its parameters depends upon the objectives of the simulation. If the performance is to predict the behaviour of a circuit before it is built. A good system model provides a designer with valuable information about the system dynamics. Due to the difficulty involved in solving general nonlinear differential equations, all the governing equations will be put together in block diagram form and then simulated using MATLAB's Simulink program. Simulink will solve these nonlinear equations numerically methods like newton Raphson, and provide a simulated response of the system dynamics.

The proposed converter is transformer less dc-dc converter can be used for micro-grid applications. The renewable energy sources such as PV modules, fuel cells or energy storage devices such as super capacitors or batteries deliver output voltage at the range of around 12 to 70 V dc. In order to connect them to the grid the voltage level

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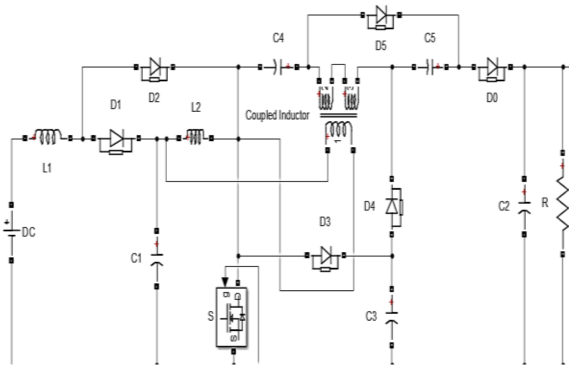

Fig 4.3DC-DC Quadratic Boost Converter with Single Switch

It's a new modelling technique of a cascade Boost converter. The adaptive control is applied and gives good performances in grid side and in dc side. PID controller eliminates efficacy the steady state error of the dc bus voltages. The configuration proposed may be used to fast charging electrical vehicle battery by controlling the time charging. The configuration connected to the grid compensates current harmonics, reactive power; the THD of the grid current is less than 5%. The boost converter provides high currents, while the cascade boost converter achieves high voltage. The advantage of the high voltage of the cascade boost converter makes it very suitable for high battery voltage charging current.

V. RESULTS AND DISCUSSION

5.1 Simulation Result

On the basis of methodology and mathematical modelling proposed in earlier discussions, the values of various circuit parameters were calculated and are tabulated as below-

Design Parameters

Table 1 Open Loop & Close Loop Boost converter design parameters

Type of Boost Converter	V_{in} (v)	L_1 (µH)	L_2 (µH)	C_1 (µF)	C_2 (µF)	F (KHz)	R (Ω)	L_M (µH)
Open Loop Converter	30	10	8	12	200	50	25	250
Close Loop Converter	30	200	20	10	50	1	10	250

Open Loop Converter

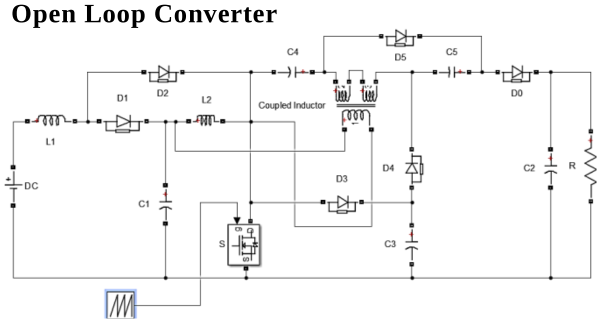

Fig5.5 Circuit Diagram of Open Loop Converter

When the open loop cascade converter is operated, the diode voltage, current exist which is shown in scope 1 of Figure 5.1, Diode current flows as the preceding circuit response.

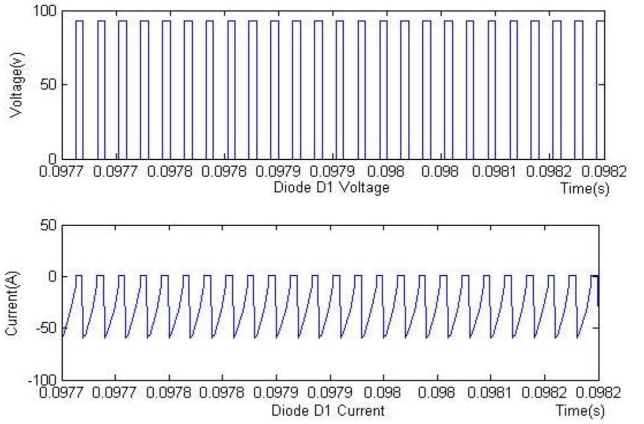

Fig5.6Diode D1 current and voltage

Scope 1 of Figure 5.2 shows the output current which is of minimum limit 6.45 ampere and maximum limit 6.485 ampere i.e. average current is 6.475 ampere.

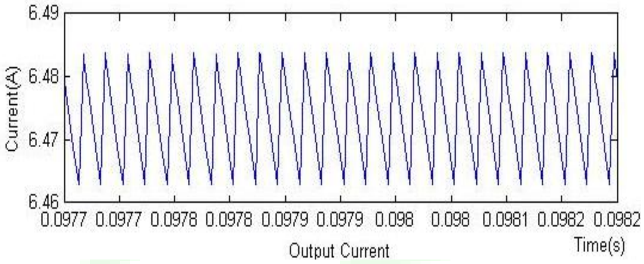

Fig 5.7Output current

Close Loop Converter-

The closed loop lead-lag filter based, PID control of cascade converter is shown in Fig 5.4.

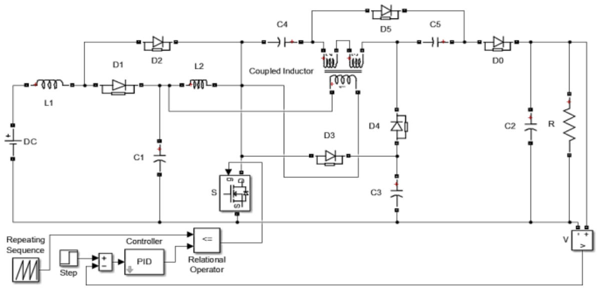

Fig5.4 8DC-DC Quadratic Boost Converter with PID Controller

The output current of proposed cascaded dc-dc boost converter is shown in scope 2 of Fig 5.5. Maximum current is about 25 amperes while minimum current is 2 amperes. The average current is nearly 10 amperes.

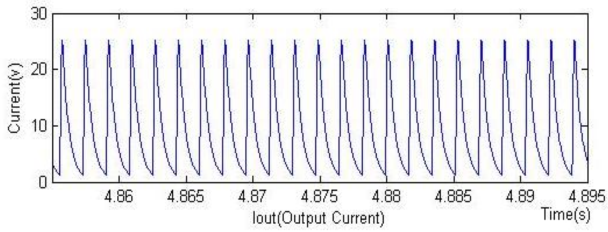

Fig5.5Output Current waveform of Close Loop converter

Scope 3 of Fig 5.5the output voltage is shown, the compensated output is about 89.25 volt with very minimal ripples. The dc voltage is boost and stepped up to 3.57 times.

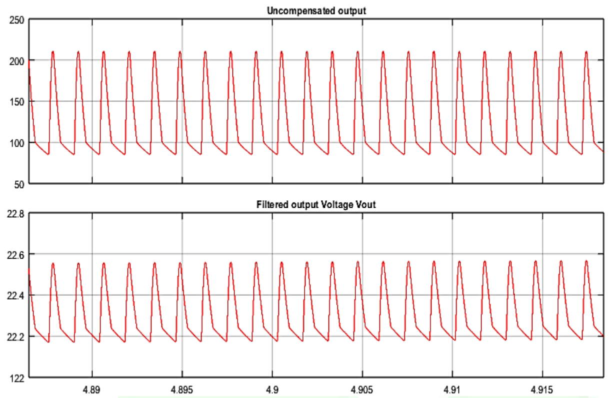

Fig5.6Output voltage waveform of Close Loop converter

5.1.1 Results in tabled form

Table 2 open loop and close loop with and without compensator

Type	Vi (V)	Io(min) (A)	Io(max) (A)	Iavg (A)	Vout(max) (V)	Vout(Min) (V)	Vout(avg) (V)	Freq. (Khz)	Duty ratio
Open Loop	30	6.450	6.485A	6.475	162.00v	161.60	161.8v	50	0.65
Closed loop Without Comp.	30	2	25A	10	50V	220	200.25	50	0.8

Performance of Proposed Boost Converter System

Table 3 Performance of Open Loop and Close Loop

s.no.	Performance parameter	Open Loop Parameters	Close Loop Parameters
1	Ripple voltage	0.4volt	0.25 volt
2	Ripple in current	0.035A or .54%	23 volt or 250%
3	Boosting	6.472times	7.33 times
4	Operating frequency	50KH	50 kHz (average)
5	Efficiency	89.98%	96.65%

From the tabulated results above, it is clear that the boost provided by open loop converter is 6.472 times while the boost provided by close loop is 7.33 times. The ripple in voltage is found to be 0.4 volt in case of open loop and 0.25 volt in case of close loop system.The output voltage of open loop system is high because of working with duty ratio of 0.65. So the voltage ripple is high and losses is more that causes efficiency is low i.e. 89.98% at .01 ohm active switch resistance.The output voltage of close loop system is high because of working with duty ratio of 0.8 only. The efficiency of system working in close loop system is high i.e., 96.65%.

VI. CONCLUSION

Proposed cascaded dc-dc boost converter driven by single switch is modelled and implemented successfully using MATLAB/ Simulink. The efficiency ofthe converter is 96.65% and step-up voltage gain is 2.25 times as compare to conventional method.Here in the ripples in output voltage is reduced up to 0.25Vin case of close loop converter as compared to open loop which was at .40V. This converter eliminates the need of active snubbed, auxiliary resonant circuit, synchronous rectifiers, or switched-capacitor-based resonant circuits and so on, that all are able to achieve soft switching on the main switch for reaching higher efficiency.Converter utilises the single switch there in the circuit, switching losses are reduced and switch will be safer from the stray heating.

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