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AN ULTRA STEP-UP DC–DC CONVERTER FOR HIGH VOLTAGE APPLICATION

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ABSTRACT

A non-isolated DC–DC converter with high voltage gain and low voltage stress on switches is proposed in this project. For absorption of energy, n stages of diode– capacitor–inductor (D–C–L) units are used at the input that results in higher voltage gains. Actually, the proposed converter generalizes the voltage lift circuit and combines it with a voltage multiplier cell. Therefore comparing to structures with one stage of D–C–L unit,n stages D-C-L units will be feasible to achieve supposed voltage gain at lower duty cycles. Lower values of duty cycle will result in increasing of converter controllability and increasing of operation region. This paper focuses on the generalized steady state analysis of the proposed converter for three regions of operation named as continuous conduction mode (CCM), boundary conduction mode (BCM) and discontinuous conduction mode (DCM). Theoretical analysis and performance of the proposed converter was carried out and MATLAB simulation results were shown.

Keywords: Step-up-dc-dc converter, CCM, DCM, BCM

I Introduction

The increasing usage of fossil fuels, conventional resources of energy has resulted in depletion of natural resource and causes more pollution in the environment. This has increased the greenhouse effect and global warming effect and there is an urge to shift from conventional energy resource to non-conventional energy resource in present day scenario. Thus use of pure and cheap energy sources has been more paid attention by engineers. Still, it is practically not possible to shift entirely to pure form of energy, because it is not cost efficient and overall system efficient compared to conventional resources. In order to use pure form of energy in large scale, optimization of non-conventional energy resources should be done. This can be achieved by the implementation of DC-DC converters. In recent research trend Fuel cell gained its significant place. A single Fuel can give a minor output voltage .in order to produce 300v, it is necessary to connect 250 cells to 300 cells in series in order to get that output. But only increasing the number of cell decrease the overall system effiency.in order improve the system DC-DC converters are used. Quadratic converters can achieve high voltage gain but the drawback is that the voltage stress on switches is high yet.

Thus no advantage is resulted compared to common boost converters. Some converters based on high frequency transformers or coupled inductors have been pro-posed to achieve high voltage gain without extreme duty cycles. These converters are designed based on soft switching technique or leakage inductor energy recovery to improve efficiency. However, the design of high frequency coupled inductors or resonant components are relatively complex compared to conventional transformer-less boost converters. Combining conventional boost converters and fly back converter, boost-fly back converter is achieved. In this converter the leakage energy of inductors is absorbed without losses and the voltage stress on switches is reduced. But due to series connection of capacitors at the output, their voltage balance should be considered. Converters with active clamps which can recover leakage current and also decrease the voltage stress on main switch.

The main drawback of these converters is that they can’t attain to high voltage gain at duty cycles lower than moderate values. However, cascading several voltage multiplier cells can significantly increase the voltage gain without a high duty cycle operation.

However, this converter needs several switches and the voltage stress on the last switch is equal to output voltage. Combined structures of boost converters and switching capacitors are investigated. But the magnitude of output voltage is limited by the rating of switching component. A new structure is suggested which is expandable for high voltage applications. However negative voltage gain is the main drawback of this converter. Due to the aforementioned drawbacks of the boost converters with high voltage gain, proposition of converters with high volt-age gain, low voltage stress on semiconductors, low losses and therefore high efficiency is a necessary task. In an interleaved boost converter with high voltage gain is suggested which can be an alternative to solve these objectives. This converter has a modular structure and the output voltage and the input current ripple are very low. Also another advantage of this converter is that the rating of currents and voltages of the switches are reduced significantly. Another solution is the utilizing of relift converters. These converters have higher voltage gain and lower current ripple com-pared to the discussed previous ones. High efficiency, increased power density, simple structure and low cost are the other main advantages of these converters. Combining this structure with voltage multiplier cells, high voltage gain and lower voltage stress on switches are attainable. Because of low voltage stress on switches, the use of Schottky rectifier allows lower reverse recovery current which results lower conduction losses. By applying two stages of lift circuit and an additional voltage multiplier cell converter, another high step-up transformerless converter has been achieved. The main advantages of the proposed converter are higher voltage gain and lower voltage stress across the main switch. Extension of the suggested converter in is made by switching inductor cells for high power application.

II Objective:

To implement ultra step-up DC–DC converter,

- To achieve High Voltage Gain
- To achieve Low Voltage stress on switches
- To achieve high converter controllability by operating the converter at lower values of duty cycles

III Conventional Method:

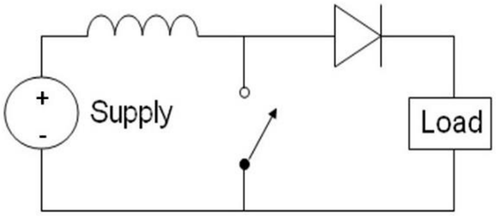


Figure 1: Circuit diagram of conventional converter

A boost converter (step-up converter) is a DC-DC Power Converter with an output voltage greater than its input voltage. It is a class of switched mode power supply (SMPS) containing at least two semiconductors (a diode and a Transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

Drawbacks of Conventional method:

- Step-up gain is limited.
- Extreme duty ratio is required to get high voltage.
- Unsuitable to operate at heavy load given a large input current ripple, which increases conduction losses.
- More switching losses.

IV Block Diagram of Proposed Method:

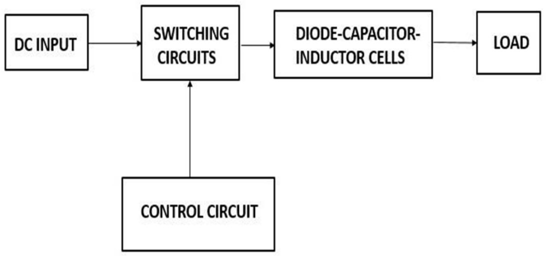


Figure 2: Block Diagram of Proposed Method

The dc source is connected to the voltage lift circuit (D-C-L units) with a semiconductor switch. The control circuit is connected to the switching circuit to apply control signal at the gate terminal. The voltage multiplier circuit is used to add the resultant voltages for every consecutive cycles and supply high output voltage to the load. The control signal is applied to the switch to vary the duty cycle, which energizes the D-C-L circuit to obtain higher output voltages at the load.

Circuit Diagram of Proposed Method:

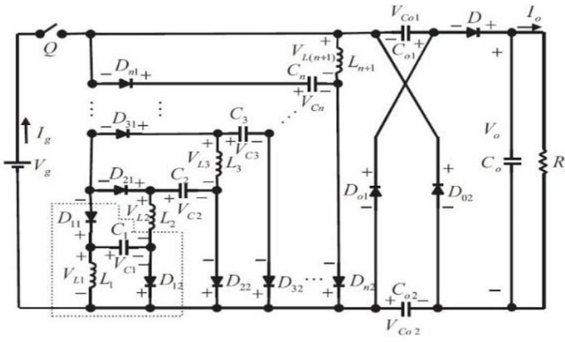


Figure 3: Circuit diagram of proposed converter

The proposed method consist of ‘n’ stages of D–C–L units which are inserted in truncated line are used at the input stage of the proposed converter. Utilizing this structure, attaining of high voltage gains is possible. During interval T_{on} capacitors C_1, C_2, . . .,C_n and inductors L_1, L_2,. . ., L_{n+1} are charged by power supply. With turning off the diodes D_{o1} and D_{o2}, capacitors C_{o1} and C_{o2} are discharged to load. When switch Q is turned off, diodes D_{11}, D_{12}, . . ., D_{n1}, D_{n2} are turned off. Capacitors C_1, C_2, . . .,C_n and inductors L_1,L_2, . . ., L_{n+1} will be in series with each other and charge the capacitors C_{o1} and C_{o2} equally that are connected in parallel with each other. It should be noted that the capacitors and inductors do not resonate and the capacitors are used for voltage step-up capability.

V Mode of Operation: Continuous Conduction Mode:

The current across the inductor does not reaches X-axis (i.e value of current doesn’t reach zero) throughout the operation of converter.

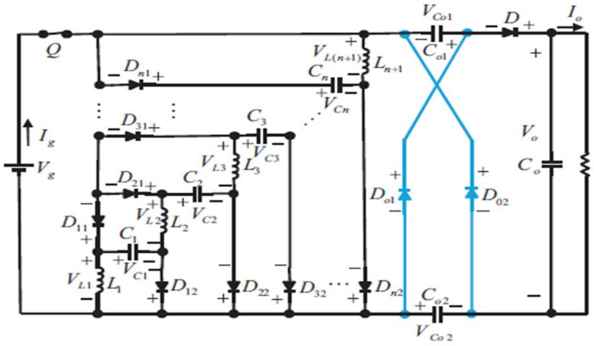


Figure 4: Equivalent circuit of CCM First time interval

1. Current ripple of inductors L_1, L_2, . . ., L_{n+1} is negligible in this mode and the converter performance will be analyzed at both switching intervals in TS.
2. The first time interval is $0 < t < dT_S$ in which switch Q is on and the second one is $dT_S < t < T_S$ in which switch Q is off.
3. First time interval $\{0 < t < dT_S\}$: Switch Q is turned on. Diodes D_{11}, D_{12}, . . ., D_{n1}, D_{n2} are forward biased.
4. Therefore D_{o1},D_{o2} diodes are turned off. Besides, capacitors C_1, C_2,. . ., C_n and inductors L_1, L_2, . . ., L_{n+1} will be in parallel to power supply and being charged.

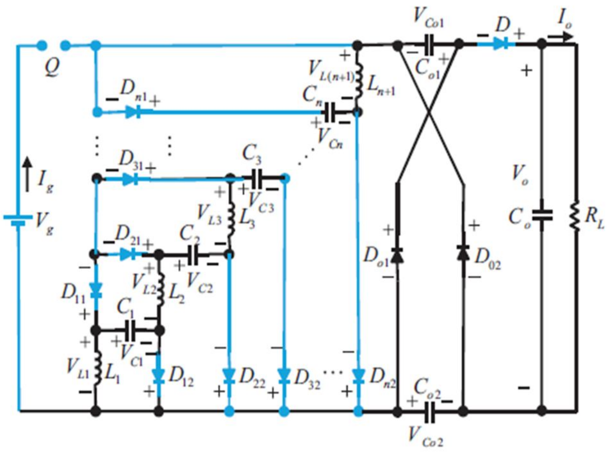


Figure 5: Equivalent circuit of CCM Second time interval

1. Second time interval $\{dT_S < t < T_S\}$:
2. In this time interval switch Q is turned off.
3. Diodes D_{11}, D_{12}, . . ., D_{n1}, D_{n2} are being off.
4. Therefore, capacitors C_1, C_2, . . .,C_n
5. And Inductors L_1, L_2, . . ., L_{n+1} will be in series to each other and charge capacitors C_{o1}& C_{o2} which are connected in parallel.
6. The currents which follow through capacitors C_{o1}& C_{o2} ($i_{Co1,2}$& $i_{Co2,2}$) and diodes D_{o1} & D_{o2}($i_{Do1,2}$& $i_{Do1,2}$).

Discontinuous Conduction Mode:

The current across the inductor reaches X-axis during Toff period and stays in X-axis for some time before it starts charging.

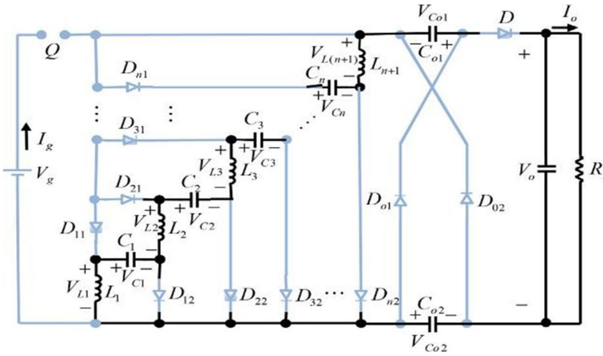


Figure 6: Equivalent circuit of CCM Third time interval

1. Third time interval $[(d + d_2)T_S < t < T_S]$
2. d_2 is the required normalized time that is terminated from the start of time interval $t_1 < t < t_2$ until inductors currents reach to zero.
3. Current of inductorL_1(i_{L1}) in DCM reaches to zero and remains to this value until the switch Q is turned on.

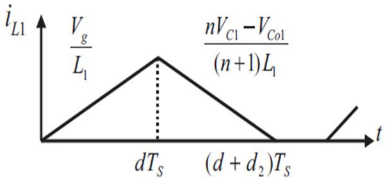


Figure 7: Inductor current of L (DCM mode)

Boundary Conduction Mode:

The current across the inductor reaches X-axis during Toff period and immediately starts charging at the boundary of Toff and Ton period.

1. In this mode of operation, the switch Q is turned on at the instant of zero transition of inductor current.
2. BCM is the boundary between CCM and DCM of Inductor L_1 current

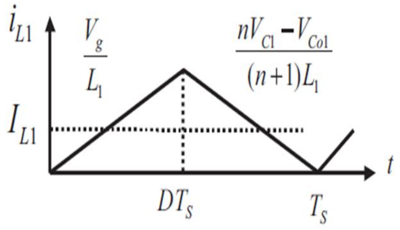


Figure 8: Inductor current of L (BCM mode)

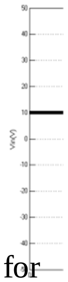
Design of Inductor:

Design of the inductors the values of inductors should be designed in such a way that their current ripple (ΔiL) don't exceed from allowed values. In the first time interval following expression can be written:

$L_1\ \Delta i_{L1}/\ dT_S = V_g$

If $\Delta i_{L1} < \Delta i_{L1,max}$, and then

we have: $L_{min} = dV_g/ f_s \Delta i_{L1,max}$



Also minimum values of inductors for operation in CCM can be calculated. According to aforementioned discussions, in order to operate in CCM, K should be greater than Kcrit. Thus considering= Vo/RL, lower limit for inductors will be calculated as

$L_{min,BC} = V_o d d'^2 / (4 f_s I_o (2n + 1 + d))$

$d=T_{on}/T$

$d'=1-d$

$F_S=20$ kHz, $d=0.6$, $d'=0.4$, $V_o=119$v, $I_o=0.41$A

n=number of lift circuit

$L_{min}=63\mu H$

VI Simulation Diagram:

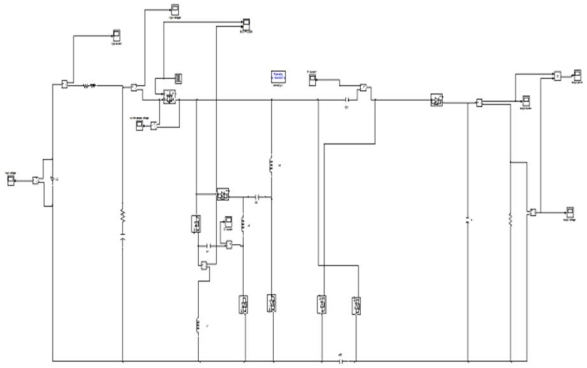


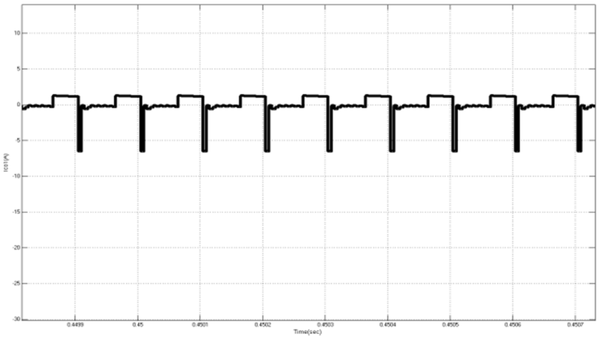
Figure 9: Simulation Diagram of Proposed Ultra step-up DC–DC converter when N=2

VII Simulation Results:

Figure 10: Input Voltage of Ultra Step-up DC-DC Converter

CCM Operation:

igure 11: Comparison between Gate pulse and inductor current for CCM of Proposed Ultra step-up DC–DC converter when, L=2.6e-3H, Pulse Width=60%



C

Figure 12: Capacitor Current of Ultra Step-up DC-D Converter in CCM mode

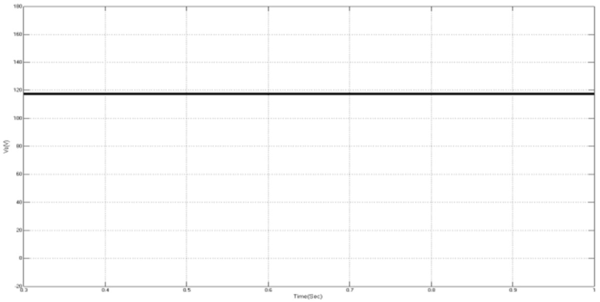
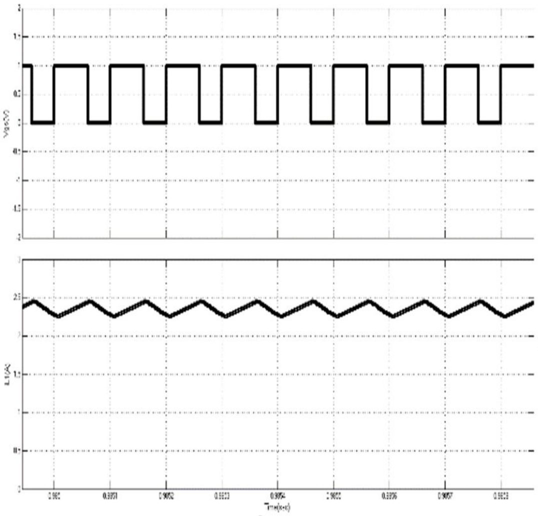
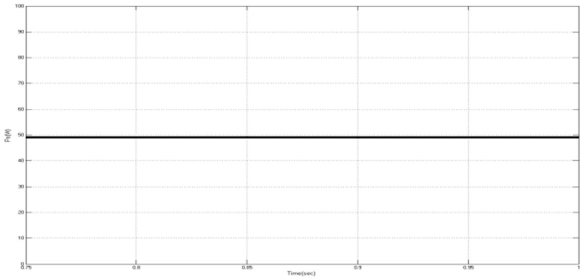


Figure 13: Output Voltage of Ultra Step-up DC-DC Converter in CCM mode




100
90
80
70
60
Po(W)
50
40
30
20
10
0
0.75
0.8
0.85
0.9
0.95
1
Time(sec)

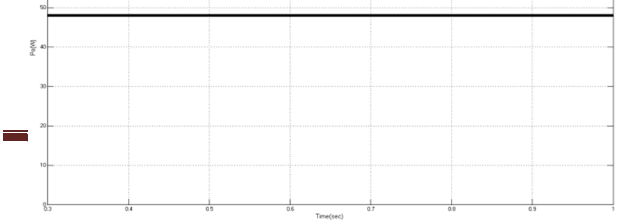


Figure 14: Output power of Ultra Step-up DC-DC Converter in CCM mode

BCM Operation:

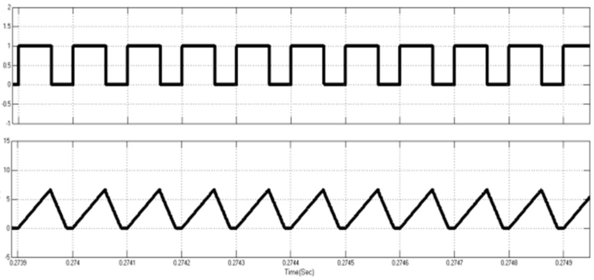


Figure 15: Comparison between Gate pulse and inductor current for BCM of Proposed Ultra step-up DC–DC converter When L=66e-6H, Pulse Width=60%

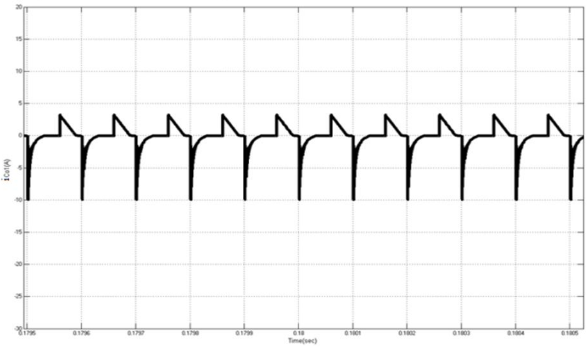


Figure 16: Capacitor Current of Ultra Step-up DC-DC Converter in BCM mode

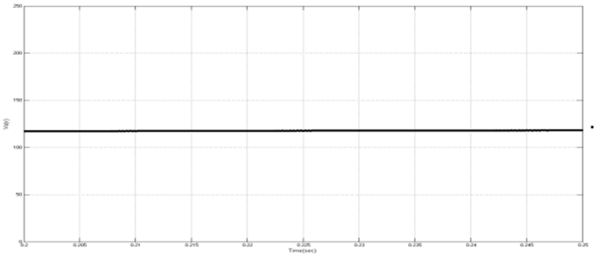


Figure 17: Output Voltage of Ultra Step-up DC-DC Converter in BCM mode

Figure 18: Output Power of Ultra Step-up DC-DC Converter in BCM mode

DCM Operation:

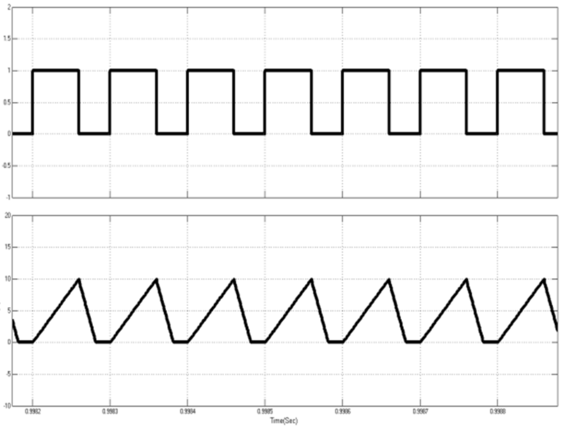


Figure 19: comparison between Gate pulse and inductor current for DCM of Proposed Ultra step-up DC–DC converter when, L=40e-6H, Pulse Width=6

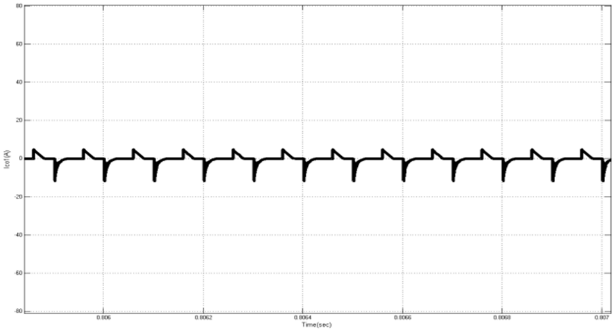


Figure 20: Capacitor Current of Ultra Step-up DC-DC Converter in DCM mode

Figure 21: Output voltage of Ultra Step-up DC-DC Converter in DCM mode

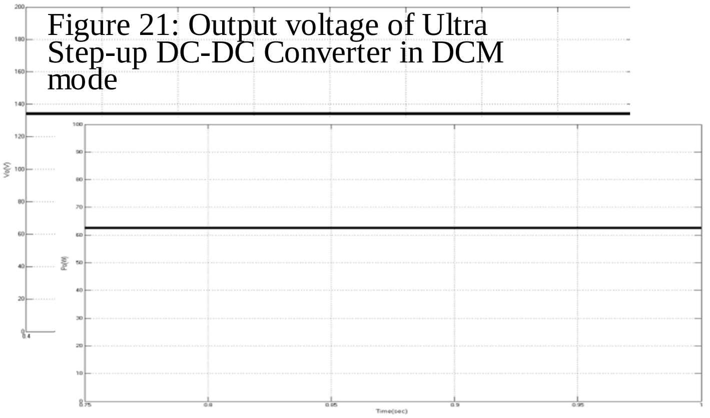


Figure 22: Output Power of Ultra Step-up DC-DC Converter in DCM mode

VIII Simulation Diagram:

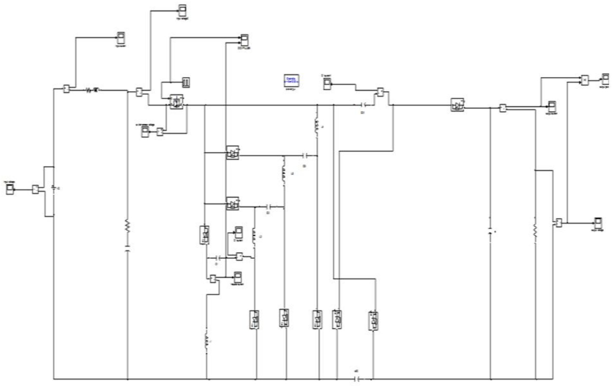


Figure 23: Simulation Diagram of Proposed Ultra step-up DC–DC converter When N=3 for CCM mode

IX Simulation Results:

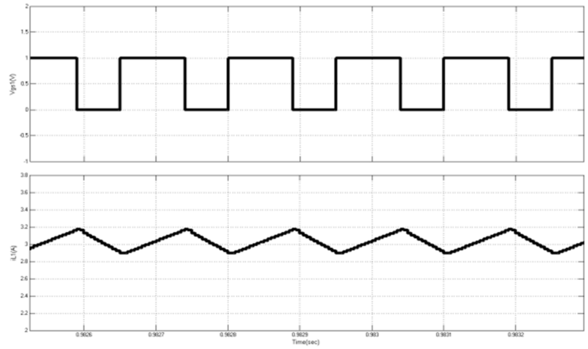


Figure 24: Comparison between Gate pulse and inductor current for CCM of Proposed Ultra step-up DC–DC converter when, L=2.6e-3H, Pulse Width=60%

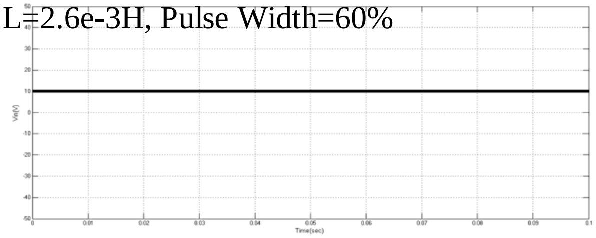


Figure 25: Input Voltage of Ultra Step-up DC-DC Converter in CCM mode N=3

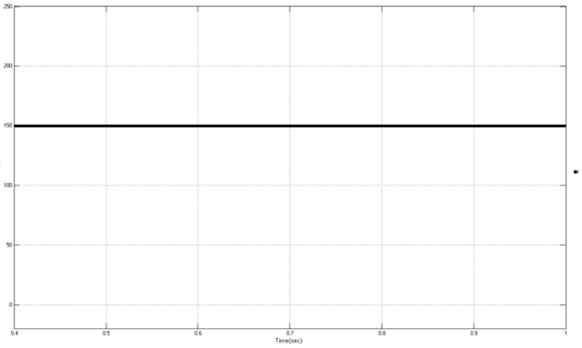


Figure 26: Output Voltage of Ultra Step-up DC-DC Converter in CCM mode N=3

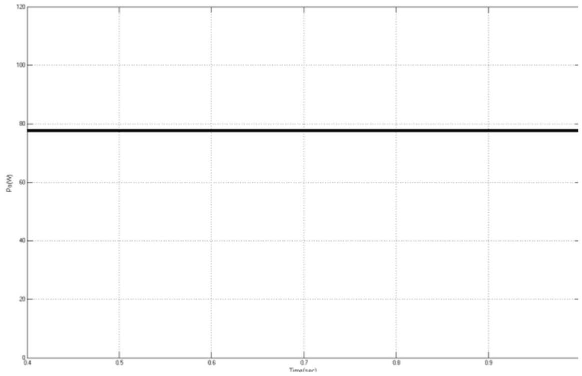
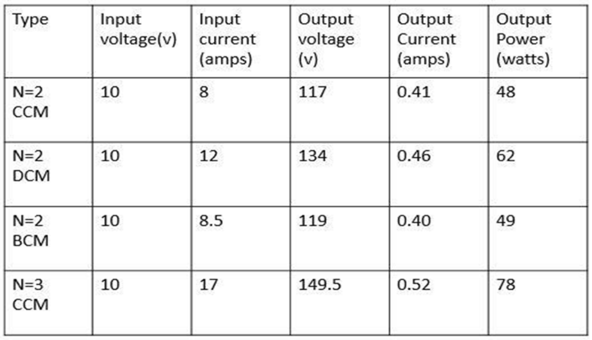


Figure 27: Output Power of Ultra Step-up DC-DC Converter in CCM mode N=3



Type	Input voltage(v)	Input current (amps)	Output voltage (v)	Output Current (amps)	Output Power (watts)
N=2 CCM	10	8	117	0.41	48
N=2 DCM	10	12	134	0.46	62
N=2 BCM	10	8.5	119	0.40	49
N=3 CCM	10	17	149.5	0.52	78

Figure 28: Comparison of Simulation Results of Ultra Step-up DC-DC

Converter

X Conclusion:

This paper proposed DC–DC converters which used n stages of D–C–L units at the input stage. With increasing of the n, it was possible to achieve higher voltage gains. In the other words, it was possible to obtain the proposed voltage gain with lower values of duty cycles compared to the custom DC–DC converters. Three regions of operation named as CCM, BCM and DCM have been investigated in detail for the proposed converter. The added advantage of proposed converter is Simple and generalization of the converter will be achieved easily.The main disadvantage of the proposed converter is that with higher stages number, the switch Q current stress would be increased that deteriorate the converter efficiency at high- power levels. Another disadvantage of the proposed converter is that for higher voltage gain, more passive components should be used. Finally simulation and experimental results confirmed the correctness of carried analysis. The applications of the ultra step-up DC-DC converter is high voltage application like electric tractions, battery charging, UPS, industrial DC drives.

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