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Advanced Cascade DC-DC Boost Converter for Microgrid Applications

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***Abstract* – The proposed work is an advanced step-up dc-dc converter designed for microgrid applications. The configuration of the proposed converter is a PID controlled cascaded boost converter for improved output with low ripples. Among renewable energy resources the cascade converter is more effective as it provides proper output first-boost stage also benefited the input current ripple reduction and less stress in the switching devices. The second stage works as another boost converter, first-boost stage also benefited the input current ripple reduction andthe conversion efficiency is significantly improved. A 25V input voltage, 90V output voltage, and 1100W output power circuit of the proposed converter has been implemented. MATLAB is used for the study.**

***Keywords* – Microgrid, High Step-Up Voltage Gain, Single Switch, PID Converter, Coupled-Inductor, ESR (Effective Series Resistance), Continuous Conduction Mode (CCM).**

I. Introduction

The renewable energy is an increasingly important and going to be thebest green energy source in distribution systems, as the technology is advancing and improving day by day harnessing of energy from renewable energy resource is efficient. The power is utilised by the consumers from main electricity source or in forming a micro-source not only to fulfil their own demand but also alternatively to be a power producer supplying to microgrid so that the generation and demand be stabilised locally.A microgrid usually consists of various micro-sources and loads, which are controllable and independent systemswhen they are either grid-connected or islanded. The micro-source can be DC source or as a high-frequency AC source. According to generation process micro-source categories are comprised of different renewable energy applications, such as solar-cell modules, fuel-cell stacks, and wind turbines.Micro-grid unit supplied by diverse micro-sources and high step-up converter is used to increase the output voltage level of the micro-source to 380 ~ 400 V for the DC interface to the main electricity source through the DC-AC inverter. Utility applications include uninterruptible power systems or utility voltage stabilizers in wind farms or photovoltaic (PV) plants [1].To obtain high voltage from low-voltage devices, or vice versa, cascaded and multilevel converters have been employed in the literature [1, 2]. The single solar-cell module or fuel-cell stack both are low-voltage sources, and thus a high step-up voltage gain DC-DC converter is required to regulate the voltage of the DC interface [2].

In this paper, a high step-up cascade converter based on the PID control is proposed. Replacing the step-up transformer with the boost-type structure, the proposed converter provide higher voltage ratio than that of the conventional boost converter and also facilitate relax switching operation. Thus, the proposed converter is suitable for power conversion applications where high voltage gain is desired. Moreover, the proposed converter operates in continuous conduction mode (CCM), so the switch stresses, the switching losses, and EMI noise can be reduced as well. The proposed converter deploys one MOSFET switches and three diodes which are working as unidirectional switches. MOSFET is used to control the inductor energy to obtain a boost performance. This will reduce the complexity and cost of the proposed converter because power semiconductor switches used are less.The technique is to minimize the DC-Link voltage unbalance, independently from the amplitude of the DC-Link voltage reference, and compensate the switching device voltage drops and on-state resistances [3,4]. Thus, it is essential to have a dc–dc converter as the output stage of the clean energy to provide a stable output voltage. The boost converter, also known as the step-up converter, is the basic dc–dc converter configuration with an output voltage higher than its inputvoltage, and it is also often used as the first stage of the clean energy power system to generate a higher regulated dc voltage for the later inverter utilization [4]. Previous research on various converters for high step-up applications has included analyses of the switched-inductor and switched-capacitor types [5], the boost type integrating with the switched- capacitor technique, the voltage-lift type [8, 9] the capacitor-diode voltage multiplier type [10], and the transformer less DC-DC converters [11]. The voltage gain of these converters is insufficiently convert to a suitable AC source as a model micro-source [1], in case of extremely high voltage gain is required, to using series connection of converter is able to reach much higher voltage gain. As known the efficiency and voltage gain of DC-DC boost converter are restrained by either the parasitic effect of power switches or the reverse-recovery issue of diodes. In addition, the equivalent series resistance (ESR) of capacitor and the parasitic resistances of inductor are also affecting overall efficiency. [5]. In recent years, extensive use of electrical equipment has imposed severe demands for electrical energy, and this trend is constantly growing. Consequently, researchers and governments worldwide have made efforts on renewable energy applications for mitigating natural energy consumption and environmental concerns. Among various renewable energy sources, the photovoltaic (PV) cell and fuel cell have been considered attractive choices. However, without extra arrangements, the output voltages generated from both of them are with rather low level. Thus, a high step up dc-dc converter is desired in the power conversion systems corresponding to these two energy sources. However, without extra arrangements, the output voltages generated from both of them are with rather low level. Thus, a high step up dc-dc converter is desired in the power conversion systems corresponding to these two energy sources.

Among these high step-up dc-dc converters, voltage-fed type sustains high input current ripple. Thus, providing low input current ripple and high voltage ratio, current-fed converters are generally superior to their counterparts. Moreover, the control methods for conventional dc-dc converters can easily adapt to them. However, for most of these cascaded structures, the voltage stress on each individual switch and passive element depends on the number of stages.

This paper presents a cascaded high step-up DC-DC converter to increase the output voltage of the micro source to a properly voltage level for the DC interface through DC-AC inverter to the main electricity grid.

II. PID Controller

The PID controller (also called aThree-Term Controller) actually incorporates what is effectively an amplifier. The output u of the PID controller is:

$$PIDoutput = K_P \times e + K_I \times \int edt + K_D \times \frac{de}{dt} \qquad (1)$$

Where, K_P, K_I and K_D are the Proportional, Integral and Derivative gains respectively. If K_I and K_D are both zero, the controller is just an amplifier with a gain K_P.

III. DC-DC Boost Converter

The basic configuration of a boost converter has the diode integrated into the converter. Here all equations 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: $I_{OUT\ (max)}$

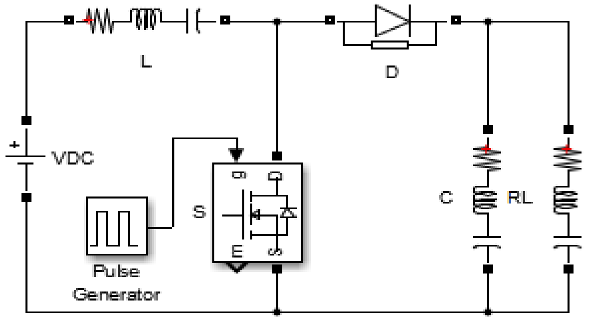

Fig.1. Boost Converter Power Stage

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.

$$\delta = 1 - \frac{V_{in(min)} \times \eta}{V_{OUT}} \qquad (2)$$

$V_{IN\ (min)}$ = 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.

$$\Delta I_L = \left(\frac{V_{in(min)} \times \delta}{f_s \times L} \right) \qquad (3)$$

$V_{IN\ (min)}$ = minimum input voltage
δ = duty cycle calculated in Equation 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.

$$I_{max\ out} = \left(I_{LIM\ (min)} - \frac{\Delta I_L}{2} \right) \times (1 - \delta) \qquad (4)$$

$I_{LIM\ (min)}$ = minimum value of the current limit of the integrated switch
ΔI_L = inductor ripple current
δ = duty cycle

If the calculated value for the maximum output current of the converter, I_{MAXOUT}, 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_{MAXOUT} 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.

If the calculated value is above the maximum output current of the application, the maximum switch current in the system is calculated:

$$I_{SW\ (max)} = \frac{\Delta I_L}{2} + \frac{I_{out(max)}}{(1 - \delta)} \qquad (5)$$

ΔI_L = inductor ripple current
$I_{OUT\ (max)}$ = maximum output current

This is the peak current, the inductor, the integrated switches and the external diode has to withstand.The lower the inductor value, the smaller is the solution size. Note that the inductor must always have a higher current rating than the maximum current given in Equation 4 because the current increases with decreasing inductance.

For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L = \left(\frac{V_{in} . \delta}{\Delta I_L . f_s} \right) \qquad (6)$$

To reduce losses, Schottky diodes should be used. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(\max)}$$

I_F = average forward current of the rectifier diode

$I_{OUT\ (max)}$ = maximum output current necessary in the application

Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem.

The other parameter that has to be checked is the power dissipation of the diode. It has to handle:

$$P_D = I_F \times V_F$$

I_F = average forward current of the rectifier diode

V_F = forward voltage of the rectifier diode

If the converter has external compensation, the compensation has to be adjusted for the used output capacitance. With internally compensated converters, the recommended inductor and capacitor values should be used or the recommendations in the data sheet for adjusting the output capacitors to the application should be followed for the ratio of L × C.

With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

$$C_{OUT(\min)} = \frac{I_{OUT(\max)} \times \delta}{f_s \times \Delta V_{OUT}} \quad (7)$$

$C_{OUT\ (min)}$ = minimum output capacitance

The ESR of the output capacitor adds some more ripple, given with the equation:

$$\Delta V_{OUT(ESR)} = ESR \times \left(\frac{I_{OUT(\max)}}{(1-\delta)} + \frac{\Delta I_L}{2} \right) \quad (8)$$

$\Delta V_{OUT\ (ESR)}$ = additional output voltage ripple due to capacitors ESR

ESR = equivalent series resistance of the used output capacitor

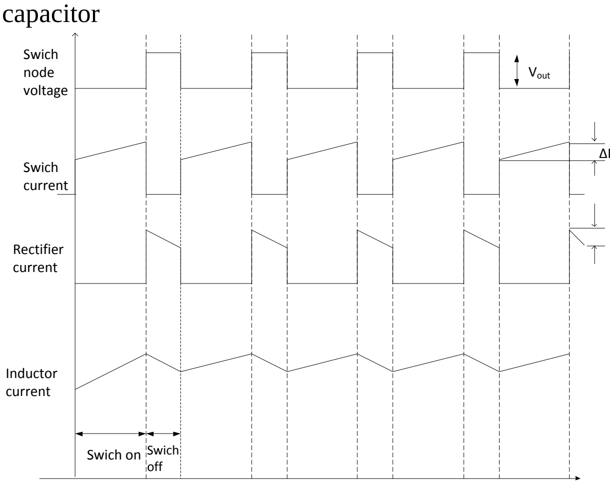

Fig.2.Continuous Conduction Mode(CCM) waveforms.

IV. Cascade DC-DC 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 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.

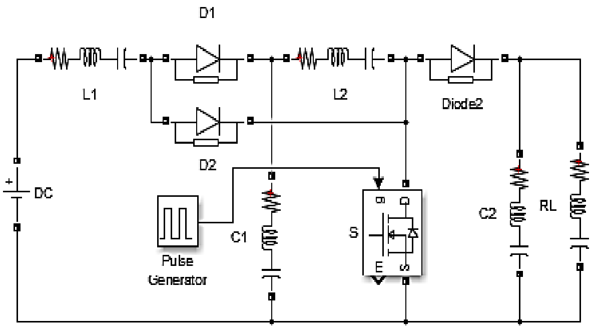

Fig.3. DC-DC Cascade Boost Converter with single switch

Here in the cascade dc-dc boost converter there are two inductors L_1 and L_2, two capacitors C_1 and C_2, three diodes D_1, D_2 and diode2 and single mosfet are imparted to design and the converter is preceded by the battery.

The DC source Vin (V_{DC}) and input-inductor L_1 are serially and still charged to capacitor C_1 with their energies. The energies stored in capacitors C_1 and C_2 are discharged to the load. This mode is end when switch S1 is turned on at the beginning of next switching period. As the switches are assumed to be ideal and switch S_1 is switched off then-

$$V_{L1} = V_{in} - V_{C1} \quad (9)$$

and

$$V_{C1} = \frac{V_{in}}{(1-\delta)} \quad (10)$$

The output voltage $V_{OUT} = V_{C01} + V_{C02}$ (11)

Where V_{C01} and V_{C02} are calculated according to the time-voltage balanced equation-

$$\int_0^{DT_S} V_{C1}\, dt + \int_{DT_S}^{T_S} (V_{C1} - V_{C01}) dt = 0 \quad (12)$$

$$\int_0^{DT_S} V_{C1}\, dt + \int_{DT_S}^{T_S} (-V_{C02}) dt = 0 \quad (13)$$

So $V_{C01} = \dfrac{V_{in}}{(1-\delta)^2}$ and $V_{C02} = \dfrac{\delta V_{in}}{(1-\delta)^2}$

Now the output

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$$V_{OUT} = \frac{(1+\delta)V_{in}}{(1-\delta)^2} \tag{14}$$

The output voltage is estimated according to equation (13).

When the open loop cascade converter is operated, the diode voltage , input output current exist which is shown.

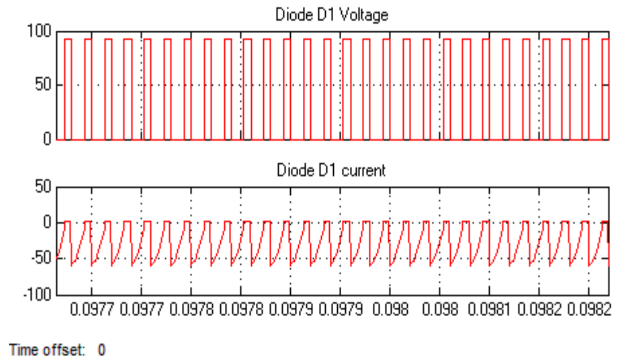

Fig.4. Diode D1 current

Diode current flows as the preceding circuit response. Figure 5 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.

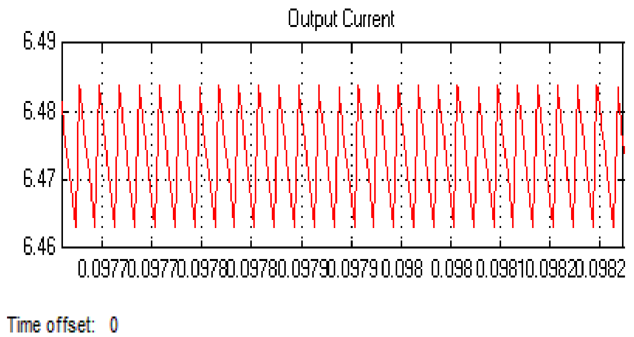

Fig.5. output current

The average output voltage shown in figure (6) is 161.8 volt. The minimum limit is 161.48volt while upper limit is 161.8 volt.

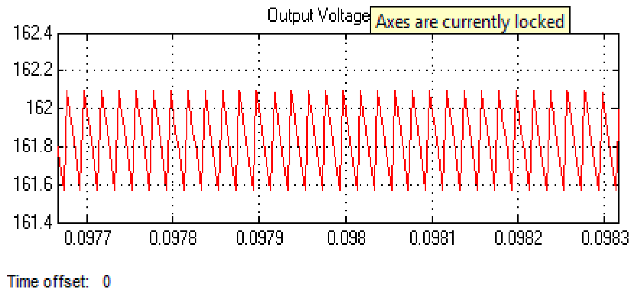

Fig.6. Output voltage

The closed loop lead-lag filter based, PID control of cascade converter is shown in figure (7).

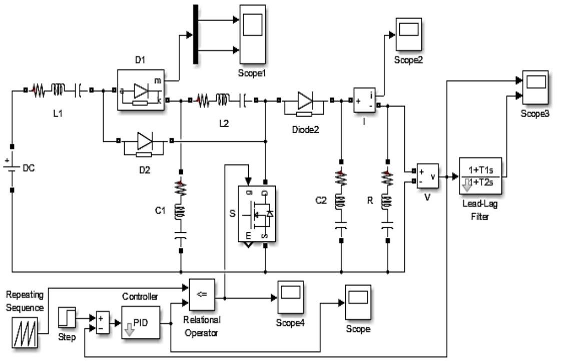

Fig.7. DC-DC Cascade Boost Converter with PID Controller

The output current of proposed cascaded dc-dc boost converter is shown in figure 8. Maximum current is about 25 ampere while minimum current is 2 ampere. The average current is nearly 10 ampere.

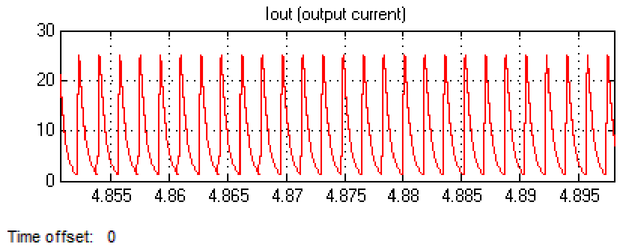

Fig.8. Output Current ofproposed converter

In figure 9 the 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.

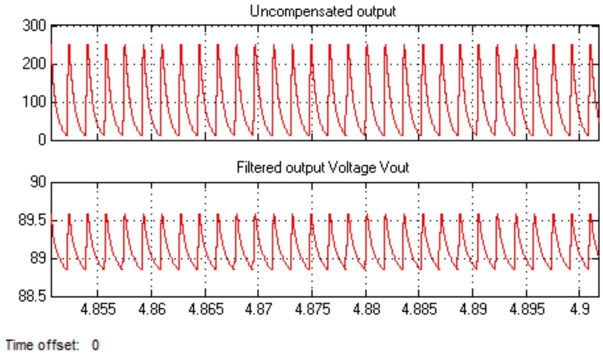

Fig.9. output voltage of proposed converter

In figure 10 the PID controller response is shown, which is pulse form of .0015 second. the switch is operating at 1KHz.

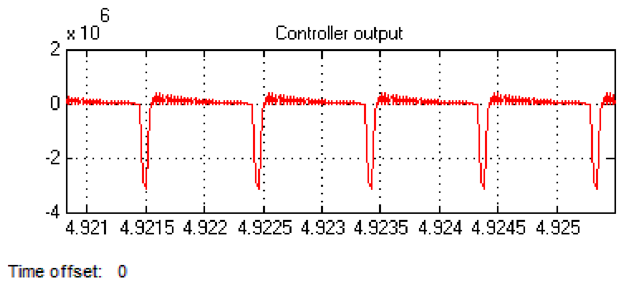

Fig.10. PID Controller response

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The diode voltages and current shown in figure 11, from the wave forms it is very clear that the diode is acting as switch also and helping to energies inductor L1 for certain duration.

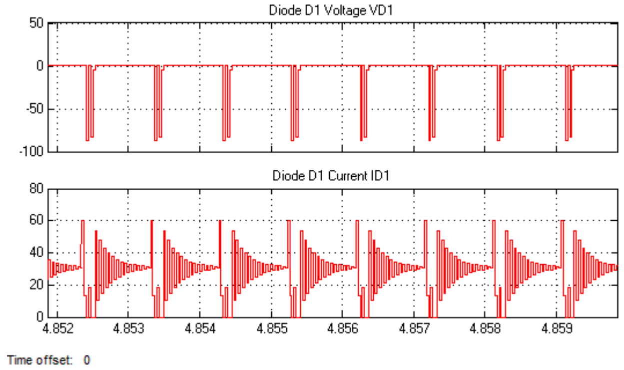

Fig.11. Diode D1 Current and voltages wave form

V. Conclusion

A cascaded boost converter isimplementedand the complete circuit driven by a single switch and achieved high step-up voltage gain, the voltage gain is many times than input. The energy of inductor of the converter can be recycled, which is effectively constrained the voltage stress of the main switch S1 and benefits the very low on-state resistance $R_{DS\ (ON)}$ can be selected. As long as adding 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 to reaching higher efficiency.

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