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Analysis and Implementation of Quadratic Boost Converter for Nanogrid Applications

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ABSTRACT: Quadratic boost converter is a newly proposed two stage boost converter with single switch topology. The converter will be used to boost the 18 volt DC battery voltage to 70 volts output level using a single switch in a geometric approach. The Quadratic boost converter for its application in 50W load is designed. The converter gains and passive elements values can be theoretically calculated using design equations. The performance of the designed converter is validated using matlab simulation. Furthermore, the feasibility of the proposed system is verified by a 50W prototype.

KEYWORDS: Boost converter, Conversion range, Quadratic boost converter.

I.INTRODUCTION

DC-DC converters are considered to be of great economical importance in today and are widely used at home solar systems to produce the desired output power. DC nanogrid is a low-power dc distribution system suitable for residential power applications. The average load demand in the nanogrid is generally met by the local renewable energy sources like solar, wind, etc. An energy storage unit is also required in the nanogrid to ensure uninterruptible power supply to the critical loads and to maintain power balance in the system. Fig.1 shows the general architecture of a nanogrid, consisting of both ac and dc loads. The diode D in figure is associated as a series blocking diode in order to avoid reverse power flow. As the dynamic behaviours of all the different units of nanogrid are not uniform, they are interfaced to a common dc bus using power electronic converters, solar panel as an energy source, a storage unit and some dc and local ac loads. The Fig.1 incorporates three different power converter stages to interface with the renewable energy resources for ac as well as dc loads.

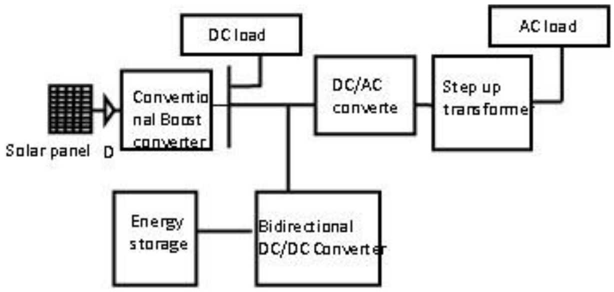

Figure 1: General architecture of a solar microgrid

This paper analyse and implement a new double stage boost converter with single switch is developed which has the same voltage gain as the series connection of two boost converters and termed as quadratic boost converter (QBC).Fig.2 shows quadratic boost based dc nanogrid, where there is no need to incorporate step up transformers and conversion range is large compared to conventional boost converters.

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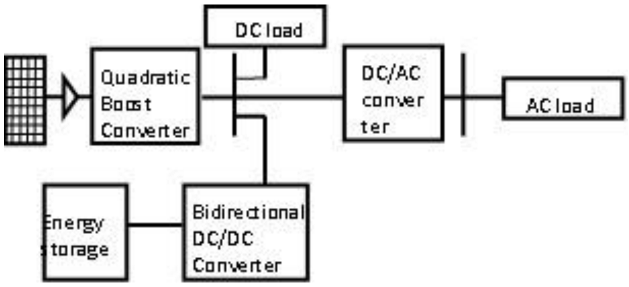

Figure 2: Modified schematic of solar microgrid

II. LITERAURE SURVEY

There are several DC-DC converter configurations were already proposed such as Buck, Boost, Buck-Boost, SEPIC, CUK, etc. Boost and Buck converter configurations can increase and decrease the output voltages respectively, while the other converters can perform both functions. A DC-DC converter with a high voltage gain is desirable in many modern residential applications. Generally, when there is a need to step up a DC voltage, a boost converter is usually chosen. To achieve a high voltage gain, the duty cycle of the power switch of the boost converter must be large, resulting in high conduction losses and degrading the converters efficiency. The high duty ratio also limits the switching frequency of the converter because of the minimum OFF-time of the transistor switch. The large duty cycle also means the diode has less time to conduct; therefore the diode current becomes a narrow pulse with a high instantaneous value. This high diode current subsequently causes severed reverse recovery loss and EMI problem.

In order to overcome the above disadvantages of conventional boost converters, the obvious solution would be the use of transformers to get high voltage step-up ratio, such as forward or flyback converters. However they cannot be used in energy systems as they have low power ratings below 100 watt. As a result modified boost designs such as the half and full bridge converters can be used. Looking at the disadvantages of these converters one can see that they lack the ease of design factor and have lower efficiencies due to the use of transformers. Cascaded connection of two boost converter stages [1] can increase the voltage gain without extending the duty cycle. This cascaded technique requires more switches and suffers from low overall efficiency as a number of the cascade stages increases.

III.QUADRATIC BOOST CONVERTER

In PWM (square-wave) dc-to-dc converter topologies, dc conversion ratio M is a function of duty ratio D of the active (transistor) switch. Both minimum and maximum attainable conversion ratios are limited in practical converters. M_{max} is limited by the degradation in efficiency as duty ratio D approaches 1. On the lower end, minimum ON-time of the transistor switch results in a minimum attainable duty ratio and, consequently, in a minimum conversion ratio M_{min}. Conversion range can be extended significantly if conversion ratio M has a quadratic dependence on duty-cycle. Quadratic boost converter (QBC) is a modified step up converter [2] with single switch and better conversion ratio.

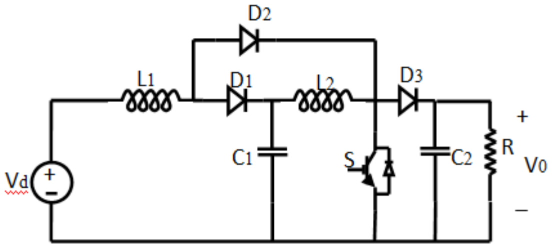

Figure 3: Quadratic boost converter

The circuit diagram of a quadratic boost converter [3] is shown in Fig 3. The circuit comprises of a single power MOSFET switch, S, two diodes, D_1 and D_2, two capacitors, C_1 and C_2, two inductors L_1 and L_2 and a load resistor R.

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The circuit operation is strictly based on the assumption that the switch S is ideal in operation and capacitors C_1 and C_2 is assumed to be large so that the voltage across the capacitors V_{C1} and V_{C2} are nearly constant over a switching period. When the switch is ON: The equivalent circuit schematic of the QBC during the ON state is shown in Fig 3.2.when switch S is turned on D_2 is forward biased, whereas D_1 and D_3 reverse biased. Currents are supplied to L_1 and L_2 by V_{in} and C_1 respectively.

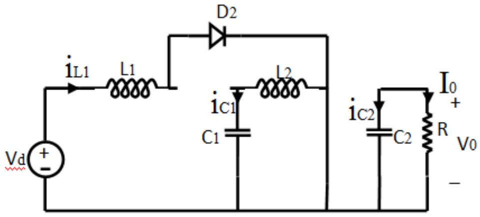

Figure 4: Quadratic boost converter when switch is ON

When the switch is OFF: The way of operation and current flow direction of QBC during OFF state is shown in Fig 3.3. In this condition D_1 and D_3 are forward biased, whereas D_2 reverse biased. L_1 and L_2 are charging C_1 and C_2 respectively. During this state, i_{L1} and i_{L2} is decreased

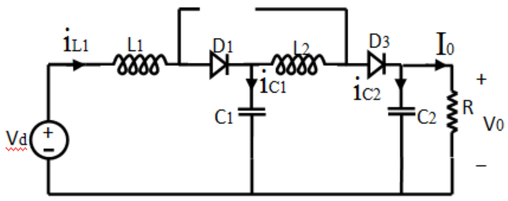

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Figure 5: Quadratic boost converter when switch is OFF

IV. STEADY STATE ANALYSIS OF QBC

The basic circuit of QBC constitutes a boost converter with an assumption of purely resistive load, ideal switch and a constant instantaneous input voltage Vd .Since in steady state operation [3] the waveforms must repeat from one time period to next, the integral of the inductor voltage V_{L1} and V_{L2} over one time period must be zero.

$$\int_0^{Ts} V_{L1} = 0 \ldots\ldots\ldots\ldots (1)$$

$$\int_0^{Ts} V_{L2} = 0 \ldots\ldots\ldots (2)$$

The expansion of the above two equation gives voltage gain equation as shown in Equation (3)

$$\frac{V_0}{V_d} = \frac{1}{(1-D)^2} \ldots\ldots\ldots\ldots (3)$$

At steady state the net charge in the capacitor current is zero. In other words integral of each capacitor current over one switching period Ts must be zero.

$$\int_0^{Ts} i_{c1} = 0 \ldots\ldots\ldots\ldots (4)$$

$$\int_0^{Ts} i_{c2} = 0 \ldots\ldots\ldots\ldots (5)$$

By expanding the above equation the value of inductor current I_{L1} and I_{L2} is obtained as follows,

$$I_{L1} = \frac{I_0}{(1-D)^2} \ldots\ldots\ldots\ldots (6)$$

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$$I_{L2} = \frac{I_0}{(1-D)} \dots\dots\dots\dots (7)$$

V. SIMULATION AND EXPERIMENTAL RESULTS

The Quadratic boost converter was analysed by MATLAB Simulink model. The circuit parameters for the simulation are listed in Table 1. For the purpose of designing the passive components, the ripple contents in the inductor currents have taken to be 6% and 3%, and the ripple ratio in capacitor voltage have been taken to be 6% and 3%, respectively, at the rated power.

Table 1: Design Parameters

Parameter	Values
Power rating	50W
Input voltage	18V
Output voltage	70V
Switching Frequency	10kHz
Input Inductor	2.6mH
Inductor 2	3.9mH
Capacitor 1	33µF
Capacitor 2	10µF

The steady state behaviour of the QBC can be analysed by open loop MATLAB Simulink model. Fig.6 shows the simulink block diagram of a quadratic boost converter.

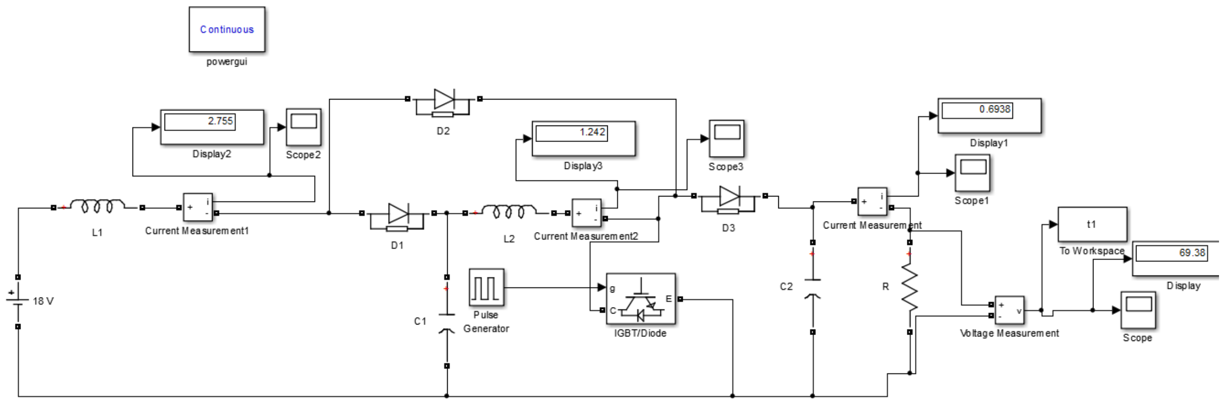

Figure 6: MATLAB/SIMULINK model of QBC

Fig.7 illustrates the relation between the input and the output voltages of the converter. The curve represents the boosted output voltage with a value of 70V which is equal to the theoretical value.

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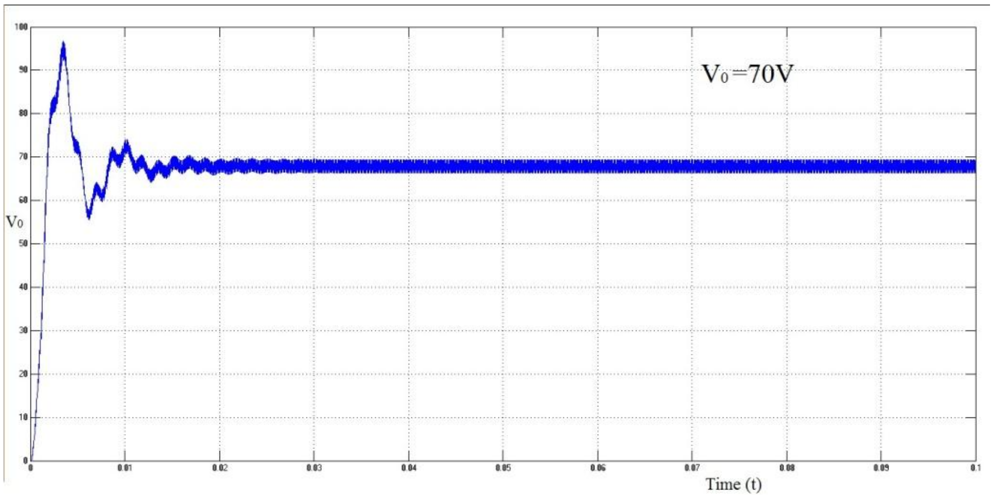

Figure 7: The output voltage of QBC

Fig.8 illustrates the converter currents waveforms in which the converter output current equals 0.6A, the inductor currents I_{L1} and I_{L2} are 2.7A and 1.4A respectively.

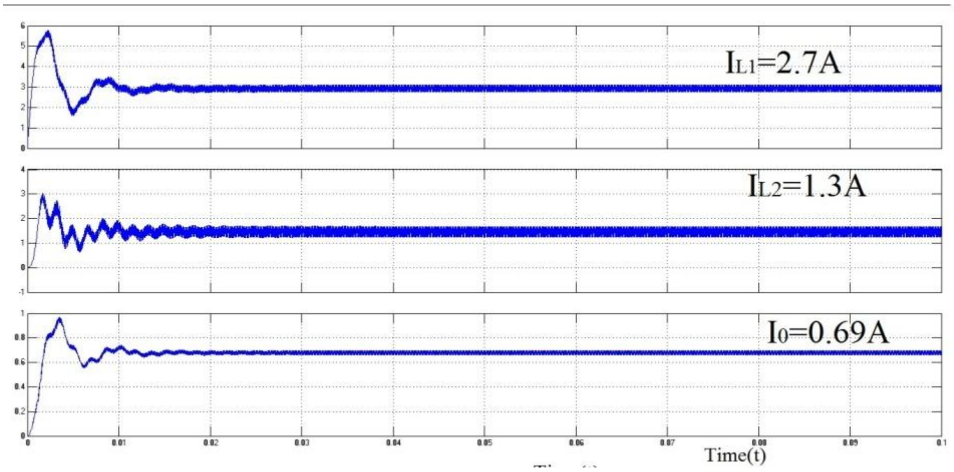

Figure 8: Quadratic boost converter currents

In order to verify the circuit operation and confirm the simulation results a prototype is built and lab tested. The converter is supplied with a constant source voltage of 6 volts and loaded with a 60 watt light bulb. Fig.3.4 shows the built circuit in which L_1 =2.6mH,L_2=3.9Mh,C_1=33 μF ,C_1=10 μF and D=0.5.

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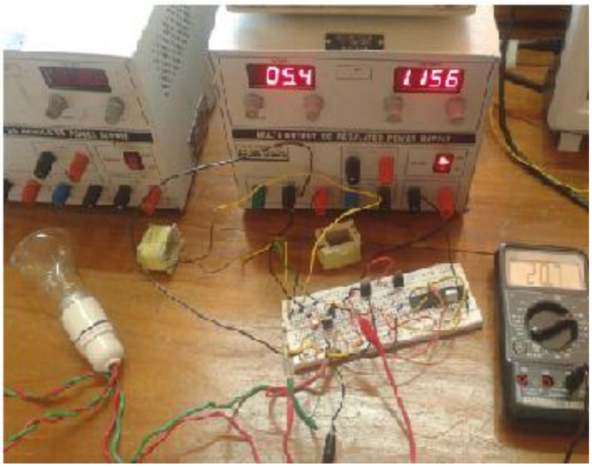

Figure 9: Experimental prototype of QBC

One of the most important parameters of power electronic circuits is their efficiency. Efficiency can be computed by comparing the circuit output power to the power delivered by the supply using the following equation:

$$Eff = \frac{P_0}{P_{in}} = \frac{V_0 \times (1-D)^2}{V_{in}} \dots\dots\dots\dots..(8)$$

$$Eff = \frac{20.7 \times (1-0.5)^2}{5.4} = 95.83\ \%$$

VI. CONCLUSION

Compared to basic converter topologies, quadratic boost converter posses quadratic conversion ratio which offers significantly wider conversion range. As far as conversion efficiency is concerned, it is quite clear that a single-stage converter is always a better choice than a two-stage converter. Therefore, the quadratic converters are proposed and intended for applications where conventional, single-stage converters are inadequate. The designed QBC circuit is simulated by MATLAB Simulink model and the results were verified by successfully building a 50W laboratory prototype.

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