Design and Analysis of Dual Inductor High Step-up DC-DC Converter Based on CockCroft-Walton Multiplier for Renewable Energy Applications.

R.Sundaramoorthi[1]
Assistant professor[1]
Department of Electrical and electronic engineering
Kings College of Engineering
Thanjavur – 613 303, India
email:*sundar20482@gmail.com*

R.Karthikeyan[2]
UG Student2
Electrical and Electronic Engineering
Kings College of Engineering
Thanjavur – 613 303, India
email:*srsnarenkarthi@gmail.com*

R.Rajadurai[3]
UG Student3
Electrical and Electronic Engineering
Kings College of Engineering
Thanjavur– 613 303, India
email:*rohitraja349@gmail.com*

P.Ramkumar[4]
UG Student4
Electrical and Electronic Engineering
Kings College of Engineering
Thanjavur– 613 303,India
email:*ramkumarking075@gmail.com*

***Abstract*— In this paper, a new converter design based on cascaded-diode capacitor structure has been proposed here. New proposed design contains two low voltage common-emitter switches with high step-up DC-DC converter that can be used as step-up power stage for low power renewable energy sources. In order to eliminated the problems such as voltage ripple and voltage droop a new design converter circuits which improves high voltage gain, continuous input current and higher efficiency in addition with design considerations and analysis of the converter is performed and discussed prototype design will demonstrate the functional analysis of the new converter.**

I.Introduction

Due to the advantages of solar energy (PV panels) and fuel cell stacks, such as availability, cost, and reliability, they have become two of the most popular renewable energy sources. However, due to the wide-range low DC output voltage of these types of green energy sources, employing a high voltage ratio boosting stage in the power electronic interface can be necessary in order to generate the required DC bus voltage for grid/utility connected dc-ac inverters.

[1]. Classical non-isolated converters are not practically applicable, as the voltage gain is limited at extremely high duty cycles due to the losses in the parasitic components and the problem of diode reverse recovery. Several high step-up DC-DC converter topologies have been proposed in the literature with three distinct configurations:

- Impedance -source networks converter.
- Transformer isolated (and inductor coupled) DC-DC converter.
- Switched capacitor Converters.

Recently, many industrial applications need non-isolated high step-up high efficiency DC/DC converters, such as dc back-up energy systems for UPS, renewable energy systems, fuel cell systems, and hybrid electric vehicles [1–6]. Step-up capability and efficiency are the two main concerns which determine the performance of these converters.

Theoretically, a continuous-conduction-mode (CCM) boost converter can realize high gain, but the voltage stresses on the switch and output diode are equal to the high output voltage, a usage of high-voltage rating devices. High-voltage rating switch means high on-resistance, so the conduction losses are large. Moreover, a high-voltage rating diode causes a severe reverse recovery problem, which gives a detrimental effect on the efficiency of the converter. Consequently, it is very difficult to satisfy high voltage gain ratio and high efficiency at the same time. In practice, the voltage gain ratio of a boost converter with high efficiency is limited to approximately four times [7]. Thus, the conventional boost converter would not be acceptable for these high step-up and high voltage applications.

In order to achieve high voltage gain conversion ratio with high efficiency, many transformer-based or couple-inductor-based topologies have been developed [9-23]. Transformer-based isolated converters can achieve high voltage gain conversion ratio with a reasonable duty ratio by selecting the turns ratio of the transformer properly. Compared with the voltage-fed converters, the current-fed converters are inherently suitable for high step-up applications because of their boost-type configuration [9-12]. However, they need snubbers to limit the voltage spike across the switches caused by the transformer leakage inductance and an auxiliary circuit is necessary for operation below 0.5 duty cycle [13, 14]. Moreover, these isolated converters need transformer and inductor, so the circuit volume is large.
Coupled-inductor-based converters are favorable candidates for their simple structure. Similarly, the coupled-inductor –based converters can realize high voltage gain conversion ratio easily by adjusting the turns ratio of the coupled-inductor. However, the leakage inductance of the coupled inductor induces high voltage spike on the switch, lead to

severe electromagnetic interference (EMI) problem and low efficiency. A resistor-capacitor-diode (RCD) snubber can be adopted to suppress the voltage spike, but the leakage inductance energy is dissipated by the resistor and the efficiency is lowered.

Power density of a DC/DC converter is mainly depends on the size of magnetic components. To improve the power density of a converter, size of the magnetic components need to be reduced. In conventional high voltage gain coupled inductor converters [12], [13], coupled inductor transfer its energy to output during only one switching state (either on or off state). Hence to obtain high voltage gain, coupled inductor need to store high amount of energy which leads to the selection of large magnetic core. Hence in ZVS converters the core size should be optimizes to construct the coupled inductor.

Switched Capacitor Converter has attracted attentions due to its important property: no contribution of magnetic components [14], [15]. This characteristic qualifies it to target at higher power density and full monolithic combination compared with traditional inductor-based converter [16-18]. The main drawback is that it brings the concerns of narrowed regulation capability and pulsating input current [19], also the capacitors charge quickly, reaching saturation, rendering it difficult to control the process is slower only if the capacitor is charged by a current source.

Integrating a switched-capacitor circuit and coupled inductor topology have been proposed in [20-24]. This integration eliminates the problem of pulsating input current. The leakage energy of the coupled inductor causes high voltage spikes on switches, therefore a passive clamp circuit must be used to recycle the energy to the load. In the switched-inductor configurations against the coupled inductors there is no leakage inductance so voltage stress across the switches would be reduced [25], however in high power applications using several inductors in converter would increase the cost and reduce the power density. Several switched-inductor and switched-capacitor structure to extend the voltage gain has been discussed in [26]. Combination of switched-inductor, switched-capacitor with classical converters such as Buck, Boost, Buck-Boost, and SEPIC have been discussed in [15] that result in improving the output voltage gain and reduce voltage stress across the semiconductor switches. Capacitor diode voltage multipliers (CD-VM) can be categorized as switched capacitor configuration [27]. Among various types of CD-VM [28], half wave Cockcroft–Walton Voltage Multiplier (CW-VM) developed in 1932, is the most common CD-VM circuit and has been widely used in several applications such as telecom equipment, X-ray systems, and lasers. Recently, employing such DC voltage multipliers in renewable sources are considered because of several advantages as follows:

- Low and uniform stress per stage on diodes and capacitors.
- Wide range of multiplication stages is achieved.
- Compactness, low weight, and cost efficiency.
- Negative output through reversing diode pola

In conclusion, the current-fed CD-VM structure is an appropriate choice which can be used as the boosting stage of the power electronic interface of low-voltage renewable energy resources. Several types of CD-VM are presented in the literature [30-33]. However, some topologies [30]–[31] suffer from the fact that, as the number of stages increases, the component stresses increase as well. A single input current-fed structure for DC/DC and AC/DC conversion is proposed [33] that provides low current ripple and uses four low-voltage MOSFETs. In this paper, a new current-fed high step up converter utilizing a current-fed CW-VM is presented, which employs two common source switches, and two inductors in the structure. The low voltage stress on the switches allows the use of low voltage MOSFETs improving both efficiency and reliability.

II. Proposed Converter Design Block Diagram

There are three basic and well known single-ended current-fed DC-DC converters: BOOST, SEPIC, and CUK. The common attribute of these three converter topologies is the existence of the input inductor, which makes it possible to draw continuous current from the input voltage source. The proposed converter applies the same topology to reduce input current ripple.

Similar to a push-pull converter, the proposed converter uses two inductors, with the switches working complementarily. By cascading diode–capacitor or diode-inductor cells in the DC-DC converters, a simple and robust structure with high voltage gain is generated called a voltage multiplier.

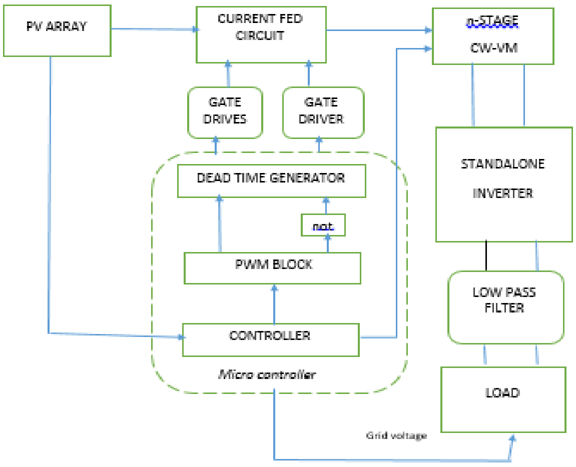

Fig 1: Block diagram

Using the most common type of cascaded diode– capacitor structure (Cockcroft Walton voltage multiplier) and current-fed two inductor topology, a non-isolated DC-DC converter is proposed in this paper. The basic configuration of the proposed converter is shown in Fig. 2, which is composed of two inductors (L1 and L2), two low voltage switches (S1 and S2), and an n-stage half wave CW-VM. S1 and S2 operate in a complementary mode, whit a sufficient overlap time for switching where the two switches should both be in the ON state. In an n-stage CW-VM, there *are N (= 2n)* capacitors and N diodes, divided into an odd group and an even group according to their suffixes.

III.Circuit Diagram

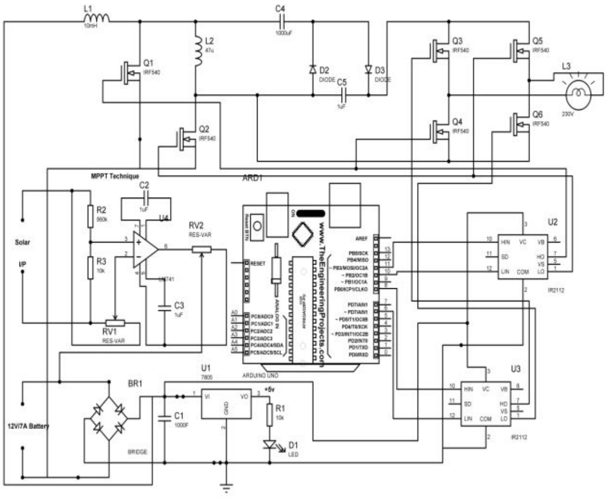

Fig 2: Circuit Diagram

IV. Principle & Operation

1) L1 and L2 Inductance

As the source current is equal to current through L1, the value of L1 is determined according to maximum allowed input current ripple (IL1(max)). Rewriting (16) for L1 gives the minimum required value of L1.

2) Capacitor Voltage Stress

In an n-stage CW-VM, assuming large enough capacitors, each capacitor theoretically supports the same voltage expect the first one, which has one half of the others. As a result, the voltage stress on each capacitor is Vo/n, except for in which the voltage stress is equal to (1-D)Vo/n.

3) Voltage and current stress of diodes

In the steady state operation, all of the diodes carry the same charge in the period, i.e., the same average current. Consequently, as IL1 average input current of CW-VM, the average current flowing in each diode during the period T.

4) Switch and diode Voltage and Current Stresses

From the operation principles, the maximum current and voltage stresses on both switches are Ipk and Vo/2n, respectively, where Ipk is the maximum peak value of the input current and is equal to $IL1(max)^+$.

5) Capacitance of CW-VM

The value of capacitors in the CW-VM is determined by the desired output ripple. According to the current-fed mode analysis presented in the voltage droop and ripple associated with each capacitor can be found by the charge and discharge behavior of capacitors under the steady-state condition. A detailed description of the relations for individual capacitors voltage ripples and the output voltage ripple are presented.

6) Number of n-stage

It should be noted that in order to increase the dc gain by increasing n, the number of diodes in the CW multiplier will increase, and thus the conduction losses of diodes. This may result in decreasing overall efficiency. But it should be considered that, lower number of n, higher voltage stress on the MOSFET_s (requiring MOSFET with higher voltage rating) which result in increasing the power loss of MOSFETs (conduction and switching). Therefore, to find the appropriate number of n, trade off between power loss of diodes and MOSFET should be done.

V.Design & Analysis Considerations

$$V^0_{C1} = (1-D)\, V_{0/n} \tag{1}$$

$$V_{L2} = -V^0_{C1} \tag{2}$$

$$VL1 = Vin + V^0 c1 - Vo/n \tag{3}$$

$$VL2 = V0/n - V^0 C1 \tag{4}$$

$$DVin + (1-D)(VC1 - Vout/n) = 0 \tag{5}$$

$$D(-Vc\mathbf{1}) + (1-D)\,(Vout/n - Vc\mathbf{1}) = 0 \tag{6}$$

$$M(D) = Vout/Vin \tag{7}$$

$$IL1 = V^2 out/RVin \tag{8}$$

$$D(Il2) + (1-D)\,(Il1-Il2) = 0 \tag{9}$$

$$Il2 = (1-D)IL1 \qquad (10$$

Table 1.

DESIGN PARAMETERS

Symbols	Definitions	Values
V_{in}	*Input voltage*	12 V
V_{out}	*Output Voltage*	230 V
P_{out}	*Output Power*	100 W
L_1	*L_1 inductance*	100 µH
L_2	*L_2 inductance*	50 µH
C	*CW-VM capacitance*	220 µF
f_s	*Switching frequency*	100 kHz
R_{on}	*Switch ON-state resistance*	9.5 mΩ
R_{L1}	*L_1 winding resistance*	5 mΩ

R_{L1}	*L_2 winding resistance*	5 mΩ
V_D	*Diode forward voltage*	0.95 V
V_D	*Duty Cycle*	0.35

Table 2.
MAIN PARAMETERS OF CONVERTER PARAMETERS

Component	Type	Characteristics
SW1 & SW2	*Power* MOSFET	200 V , 20A R_{on} = 0.0095 Ω T_r= T_f=50 nsec
Diode	*Schottky*	250V , 10A V_f = 0.95 V @ 10A
Capacitors	*MKT*	1 μF Low ESL and ESR
Overlap time		300 nsec

The lack of common ground creates difficulties in the control circuit. The main problem is about the voltage feedback. In the circuits, with non-common ground structure, it is required to employ an isolated voltage feedback to implement the controller. Several approached can be used, such as: Linear optocoupler, V/f + f/V transformation, and Hall effect voltage sensor. Besides these techniques, a simple voltage feedback can be used in the proposed structure, not as accurate as the above-mentioned, but cost effective. The digital processor can measure the differential output voltage (V+-V-). Considering the fact that during SW1 is ON, V^-=0.

Regarding the main application of the converter in PV and fuel cells, the efficiency of the converter is calculated in a wide range (12 V to 24 V) as the output voltage of PV or fuel cell may vary. Fig. 9 illustrates that the efficiency is rather constant while the input voltage of converter varies.

VI COMPARISON WITH THE STATE OF THE ART CONVERTERS

In order to evaluate the proposed converter, four structure, with similar applications and the same number of passive elements, are selected [15]. The converters are switched capacitor Boost (SC-Boost), switched inductor (SL-Boost), switched capacitor Cuk (SC-Cuk), and switched inductor SEPIC (SL-SEPIC). The criteria considered for the comparison are voltage gain, pulsating on non-pulsating input current, number of semiconductor devices, and voltage stress on switches and diodes. The results are shown in Table 3. and Fig. 15.

All of the topologies have a non-pulsating input current and SL-Boost and SL-SEPIC have common ground. SC-Boost, SL-Boost, and SC-Cuk have a similar voltage gain while the proposed converter and SL-SEPIC have different characteristics. The output voltage gain of the converters versus duty cycle. It is worth to mention that for very high voltage gain, CWVM stages in the proposed converter can be increased, which improves power density and have cost advantages. Fig. 15 compared the calculated voltage gain of the proposed converter (with one and two CWVM stages) to the other structures. As it can be seen the voltage gain of the proposed converter is greater than the other converters for D<0.6, also employing higher number of CW stages will easily result in higher voltage gain than the others. The relations for Voltage stress on diodes and switches are illustrated in Table 3. which depend on output voltage, and number of CW-VM stages.

Table 3.
Comparison of the proposed topology with SC-Boost, SL-Boost, and SL-SEPIC.

Parameters	Proposed converter	SC-Boost	SL-Boost	SL-SEPIC
Vout/Vin	1/D(1-D)	1+D/1-D	1+D/1-D	D(1+D)/ 1-D
Iin	Non pulsating	Non Pulsating	Non pulsating	Non pulsating
Common Ground	No	No	Yes	Yes
Switch No	2	1	1	1
Diode No	2	2	4	4

VII.CONCLUSION

In this paper a new converter design step-up DC-DC converter topology has present here. The new converter features that several advantages such has high efficiency, input current and only two common-emitter switches in the structure. The proposed design is able to provided high voltage gain at high efficiency. In addition with design considerations, operating range, comparisons of proposed converter with existing design are discussed. Experimental design results have performed better results with theoretical analysis.

REFERENCES

[1] *] M. Das and V. Agarwal, "Design and analysis of a high-efficiency dc-dc converter with soft switching capability for renewable energy applications requiring*

high voltage gain," IEEE Trans. Ind. Electron., vol. 63, no. 5, pp. 2936–2944, May. 2016.

[2] *] Evran, F.; Aydemir, M.T., "Isolated High Step-Up DC–DC Converter With Low Voltage Stress," IEEE Trans. on Power Electron., vol.29, no.7, pp.3591,3603, July 2014.*

[3] *S. Sathyan, H. M. Suryawanshi, M. S. Ballal, and A. B. Shitole, "Softswitching dc-dc converter for distributed energy sources with high stepup voltage capability," IEEE Trans. Ind. Electron., vol. 62, no. 11, pp. 7039–7050, Nov. 2015.*

[4] *H.-W. Seong, H.-S. Kim, K.-B. Park, G.-W. Moon, and M.-J. Youn, "High step-up dc-dc converters using zero-voltage switching boost integration technique and light-load frequency modulation control," IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1383–1400, Mar. 2012.*

[5] *Mantovanelli, P.; Barbi, I., "A new current-fed, isolated PWM DC-DC converter," IEEE Trans. on Power Electron., vol.11, no.3, pp.431-438, May 1996.*

[6] *Kjaer, S.B.; Pedersen, J.K.; Blaabjerg, F.;, "A review of single-phase grid-connected inverters for photovoltaic modules", IEEE Trans. on Ind. Appicat., vol.41, no.5, pp. 1292- 1306, Sept.-Oct.2005.*

[7] *[7] T.-F. Wu, Y.-S. Lai, J.-C. Hung, and Y.-M. Chen, "Boost converter with coupled inductors and buck–boost type of active clamp," IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 154–162, Jan. 2008.*

[8] *[8] A. Ioinovici, "Switched-capacitor power electronics circuits," IEEE Circuits Syst. Mag., vol. 1, no. 3, pp. 37–42, Sep. 2001*

[9] *C. Young; H. Chen; M. Chen, "A Cockcroft–Walton Voltage Multiplier Fed by a Three-Phase-to-Single-Phase Matrix Converter With PFC," IEEE Trans. on Ind. Applicat., vol.50, no.3, pp.1994-2004, May-June 2014.*

[10] *S. R. Sanders, E. Alon, H. P. Le, M. D. Seeman, M. John and V. W. Ng, "The Road to Fully Integrated DC–DC Conversion via the Switched-Capacitor Approach," in IEEE Transactions on Power Electronics, vol. 28, no. 9, pp. 4146-4155, Sept. 2013.*