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Review Article

A Review of Comprehension and Operation of DC/DC Converters Precisely Voltage Multiplier and Voltage Lift Converters

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Abstract - *Converters in power electronics play a significant part in the power conversion of distributed generation and grid-connected systems. This paper gives comprehension analysis and operation of various non-isolated step-up DC/DC converters for renewable energy applications using voltage multiplier or/and voltage lift techniques to attain higher voltage gain. An isolated converter structure mainly comprises a transformer which is associated with high cost, complexity, leakage inductance, losses and EMI problems with the decrease in the efficiency of the converter, hence the operation of several DC/DC converters precisely voltage multiplier and voltage lift converters are discussed with relative simulation results obtained.*

Keywords - *Voltage lift technique, Voltage multiplier technique, Voltage lift and voltage multiplier technique, DC/DC boost converter, Photovoltaic system.*

1. Introduction

Power electronics have transformed the life of humankind in power generation, transportation and distribution systems with various industrial measures. Photovoltaic (PV) systems have enormous progress and installation among different renewable energy systems. Still, as the PV panel output voltage is low, a boost DC/DC converter is necessary to increase the PV panel output voltage [1]. The manufacturing information for global cell production varied between 140 and 160GW in 2020, and the details of the production of PV cells in the world indicate a 12% increase compared to 2019. "Solar becomes the new king of electricity…" is the heading given according to the "World Energy Outlook Report" (WEO 2020) in October 2020 [2]. India announced a target of renewable energy of 450 GW by the year 2030, out of which 280 to 300 GW is anticipated to come from solar in 2021; 49 GW of solar PV was installed and, in the country, solar installations increased quickly from 2010 to 2020 [3]. There is the requirement for an interface like DC/AC, or DC/DC converter between the sources of electrical energy of utility supply, PV panels, battery etc. and receiving end as electrical equipment load requirements are not compatible with sources always for effective utilization of these energy sources [4].

Using isolated converters of bridge structures comprises a complex transformer that uses a large number of components and makes the converter expensive [5-6]. To achieve low and high voltage conversion ratios, a high-frequency transformer with coupled inductor has been used [7]. The main problems associated with these converters are high complexity, cost and large leakage inductance of the transformer, along with the rise in the peak voltage of the switches [8]. Some converters, like current-fed push-pull or flyback converters, can attain higher voltage gain. Still, we obtain low converter efficiency due to the transformer leakage energy, EMI problems, large switching losses, high voltage stress and high-power losses. However, the leakage energy can be used to attain soft commutation, but the voltage stress is large with the rise in the cost and the complexity of the circuit as the volume, weight and losses of the transformer are one of the constraints [9-11]. Hence, in renewable energy systems, non-isolated converters with lower volume, weight, cost and modest structure are extensively used [12]. Classification of various non-isolated step-up DC/DC converters discussed in this paper are as shown in Fig. 1 comprising of Boost converter_VM, Boost converter M_VMC, Boost converter_ cascade VMC, Basic 4-stage Cockcroft-Walton VM, 4-stage Symmetrical VM, 4-stage Hybrid Symmetrical VM, Series-connected VM, Self-lift Luo converter, Interleaved quadratic boost converter,

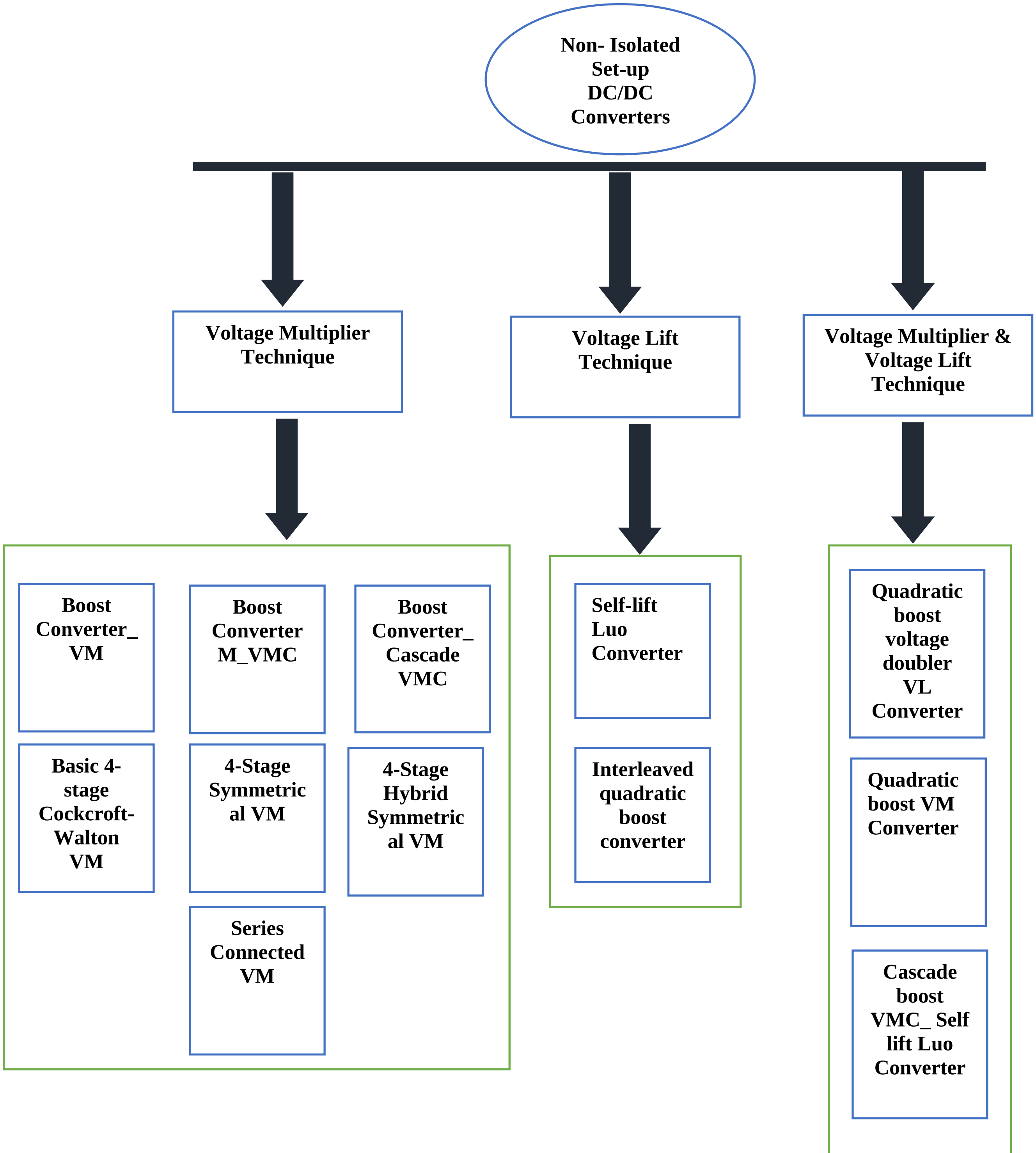


Fig. 1 Classification of non-isolated step-up DC/DC converters

Quadratic boost VM converter, Cascade boost VMC_self lift luo converter and Quadratic boost voltage doubler VL converter.

Numerous applications are driven by voltage storage elements, battery energy storage arrangements, renewable energy systems, interruptible power supply and fuel cells that require high step-up DC/DC converters. To attain a high voltage ratio, high duty cycle values have to be set, which increase the loss and, in turn, reduces the efficiency; hence voltage lift- (VL) and voltage multiplier- (VM) methods can be adopted with the integration of non-isolated DC/DC boost converters to obtain new operational characteristics. The main advantages of using the voltage multiplier technique are the operation of circuits where the isolation is not required with high efficiency, reduced maximum switch voltage, high static gain, zero current switch in "ON" state, and the effects of the diode reverse recovery current can be reduced with small inductance. Hence the drain to source voltage and "ON" state resistance of switches can be reduced with lower conduction losses of the switches. Also, it can function as a regenerative clamping circuit where difficulties of EMI generation can be reduced [13].

High voltages are required in various applications, like travelling wave tube amplifiers. Hence voltage multiplier cells (VMC) can be used to enhance the DC output voltages in low-frequency rectifiers and high-frequency DC/DC isolated converters, by which problems related to high voltage high-frequency power transformers can be reduced [14]. An interleaved boost converter to step up the voltage with a voltage multiplier and coupled inductors was proposed, increasing the voltage gain and mitigating the current ripple [31].

In recent years, in the design of electronic circuits, the voltage lift method is an eminent technique successfully and extensively used in DC/DC converter applications and converters to obtain high voltage gain of the circuit. Luo converters use extra energy storage elements, and a series of positive output Luo converters are proposed, like quadruple lift boost converters, re-lift and self-lift converters, to increase the output voltage and overcome the effects of the parasitic elements [16]. In [17], a converter with elementary super lift Luo configuration of positive output was proposed using the MATLAB/Simulink platform. The combination of the voltage lift technique with a voltage doubler was used in [18 -20]. To increase the gain of the converter, a non-isolated quadratic boost converter using the dual voltage lift method was proposed, which had various advantages as the gate drive requirements were reduced with lower voltage stress on the switch to reduce the switching loss and enhance the efficiency and voltage gain [32].

An alternative method of increasing the output voltages was by connecting several voltage multiplier stages in series to obtain higher static gain or by using a cascaded boost converter, which contains two traditional boost converters without using extreme duty ratio to reduce switching losses mainly due to the power dissipation in the switches [22].

2. Methodology of DC/DC Converters

2.1. Voltage Multiplier Converters

In the paper [23], analysis of a high static gain and efficiency with a compact equipment step-up DC/DC converter where there is no requirement of isolation, along with the practical results and design procedure obtained from the prototype, are presented using the voltage multiplier cells with the benefits of depreciation of zero current turns "ON", maximum switch voltage and the effects of the reverse recovery current in diode. It also functions as a regenerative clamping with EMI and layout problem reduction, as in Fig. 2a-b.

Fig. 2c shows a proposed topology with various advantages but with higher voltage stress on the capacitors. A modified topology with a voltage multiplier technique and integrated interleaved multiphase boost converter was proposed for high-power applications [24].

The development of the cockcroft walton voltage multiplier is widely used to attain high voltages and rectifier applications even after a decade. This paper assesses various versions of voltage multipliers, as shown in Fig. 2d-g. The features like output voltage, rise time, cost and ripple are compared along with the number of components and the complexity of the analysis, and this information gives the possibility to compare the voltage multiplier circuits for better performance and designer costs compared to others and can be able to select a suitable circuit for the required applications. The simulation results are verified with Basic 4-stage Cockcroft-Walton VM, 4-stage Symmetrical VM, 4-stage Hybrid Symmetrical VM, and Series-connected VM for comparison [25].

2.2. Voltage Lift Converters

Two types of models of the Luo converter were constructed in the MATLAB/ Simulink platform. One was the open model, as shown in Fig. 2h, and the other one was a closed loop with a PI controller. Both the model design being the same with an equal number of components, the voltage boosting capability was increased in the converter [26].

To attain high voltage gain, a non-isolated interleaved quadratic boost with voltage lift technique was established, as shown in Fig. 2i. The main necessary facts of the projected interleaved quadratic boost converter are the component count was reduced to obtain a reduced structure, the low ripple in the output waveforms and conversion ratio was higher hence in sustainable energy microgrids this converter finds its application. A closed-loop control technique was used for regulating the converter. The converter presentation under dynamic conditions was outstanding. The converter input voltage was varied for line regulation characteristics with a nominal value of 380V in a significantly less time duration with slight undershoots and overshoots [27].

2.3. Voltage Multiplier and Voltage Lift Converters

A DC/DC converter with required characteristics like low voltage stress on switching devices, high voltage gain with fewer components and continuous input current has been proposed. Using only two inductors, this converter has a quadratic gain making the circuit less bulky and to obtain the required output voltage; the duty ratio was varied over a wide range. The chief advantages of the presented analysis, like the converter control, were easy, and for a duty cycle within 0.5, the voltage stress on switches was less, with the voltage gain being 10 times more and higher efficiency which was much higher than the traditional quadratic boost and quadratic boost converter. The input current was continuous without needing a snubber circuit, as shown in Fig. 2j [33].

A non-isolated high step-up DC/DC cascaded with voltage uplift cell, boost circuit, and self-lift Luo converter with modified voltage multiplier circuit was presented with the non-pulsating input current. The voltage ratio was increased by 9 times the input voltage of the duty cycle of 50%, as in Fig. 2k. Different parameters like the functional details, the current of inductors, the voltage of the capacitors and the relation of the non-ideal voltage ratio were discussed. PLECS was used for simulation to obtain a voltage ratio at 50% duty ratio, and it was concluded that the converter could be used for high step-up voltages [29].

The converter's duty ratio must be high to gain high voltage. Hence the switch with "ON" state resistance and a high voltage rating will be essential, as the voltage stress on the switch is equivalent to the high output voltage, which produces complex conduction losses in power devices and induces high current ripple resulting in lower converter efficiency. Two traditional boost converters were cascaded with a switch, the voltage lift circuit and cascaded it with a voltage multiplier circuit at a lower duty ratio. The voltage gain can be improved, as shown in Fig. 2l. The M+1 boost factor can increase the number of cascaded voltage multiplier cells, and "M is the number of voltage multiplier cells". The voltage multiplier cell had been referred to as a voltage doubler circuit to increase the voltage gain twice by which the whole converter gives eight times the voltage of a traditional quadratic boost converter with the reduction in the switch voltage stress to the semi of the output voltage. PSIM was used for simulation in a continuous conduction mode of operation [30].

3. Method of DC/DC Converter Configurations

Several DC/DC converters which are non-isolated using voltage multiplier or/and voltage lift methods to attain higher voltage gain are discussed with the corresponding circuit configurations as shown in Fig. 2a - 2l. The DC/DC converters have designed values for the parameters as per the circuits mentioned in the references.

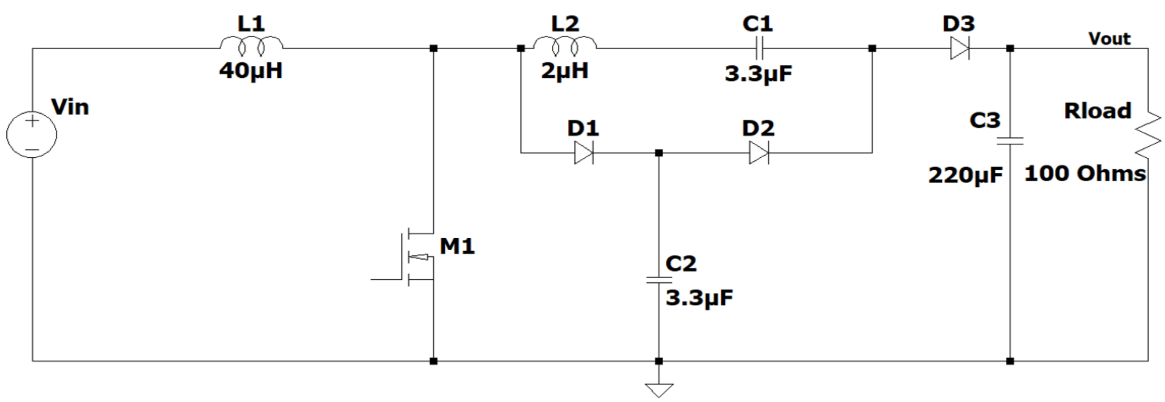


Fig. 2a Boost converter _VM

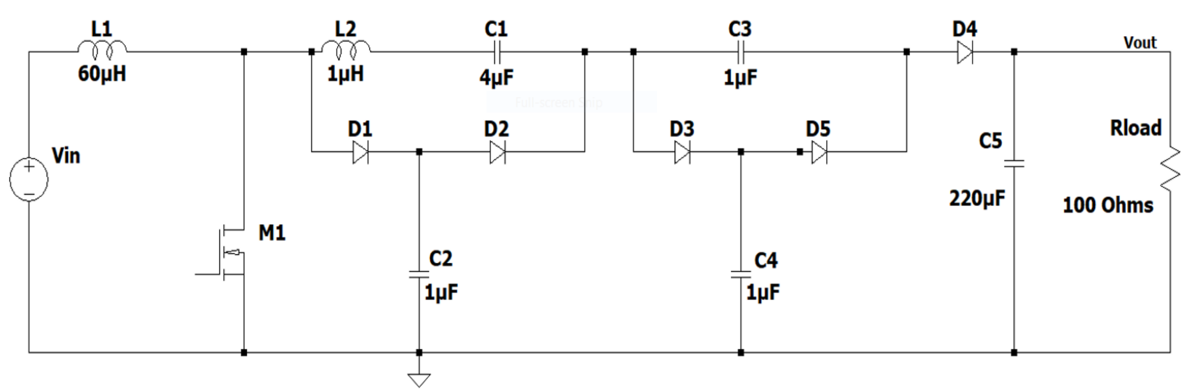


Fig. 2b Boost converter M_VMC

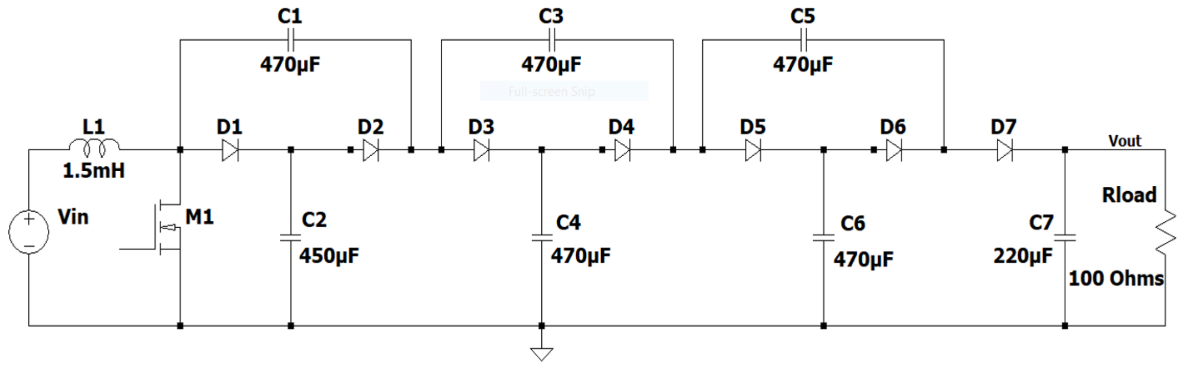


Fig. 2c Boost converter_ cascade VMC

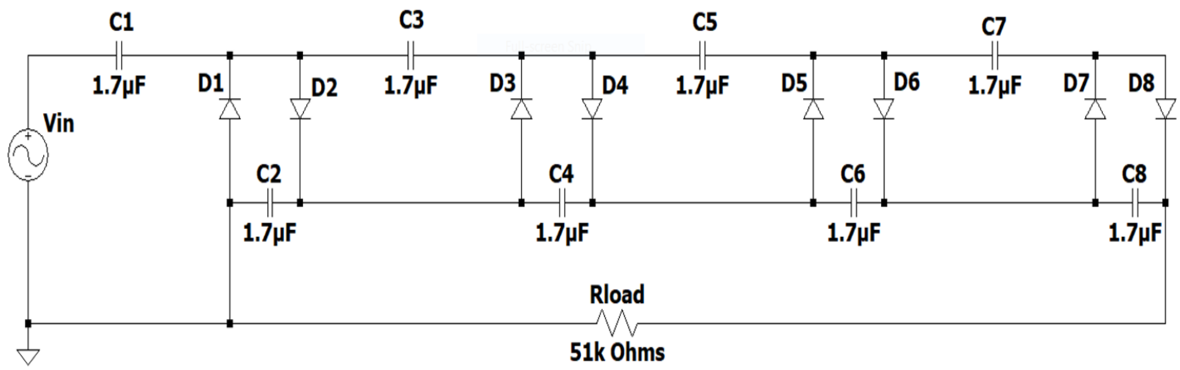


Fig. 2d Basic 4-stage Cockcroft-Walton VM

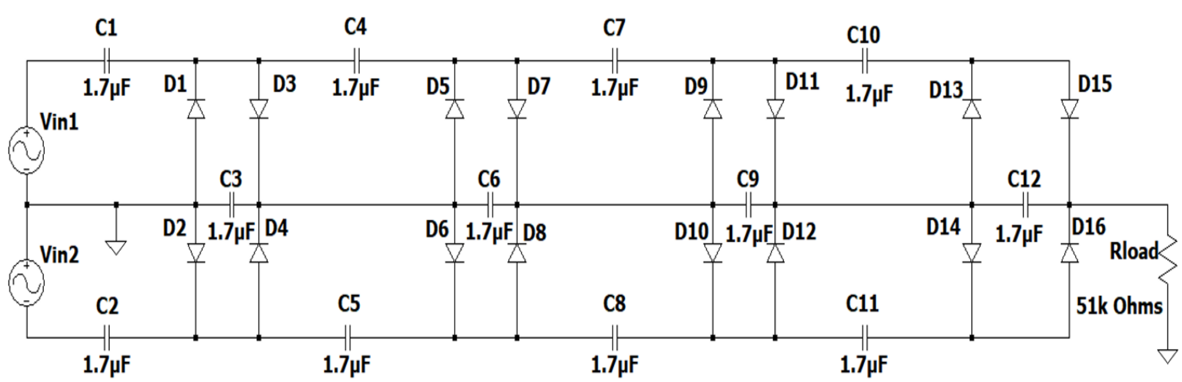


Fig. 2e 4-stage Symmetrical VM

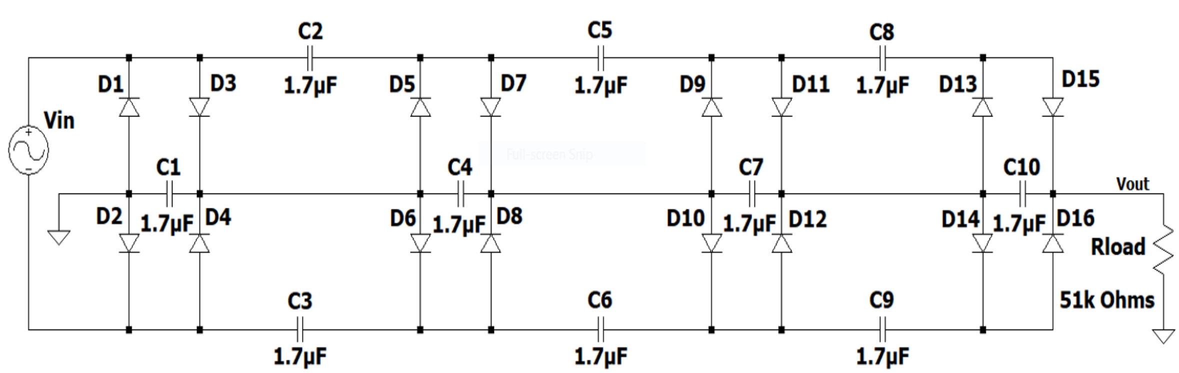


Fig. 2f 4-stage Hybrid Symmetrical VM

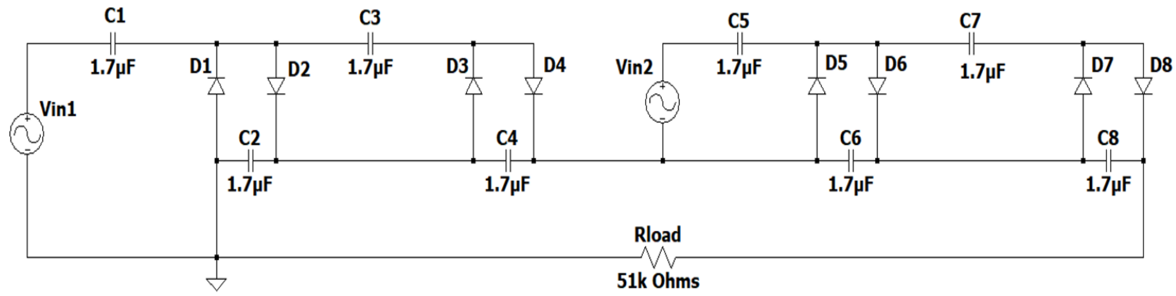


Fig. 2g Series-connected VM

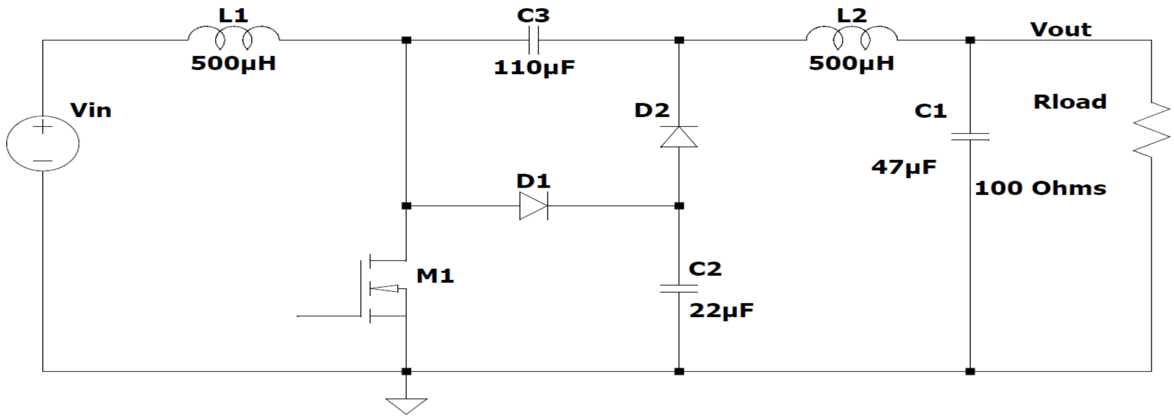


Fig. 2h Self-lift Luo converter

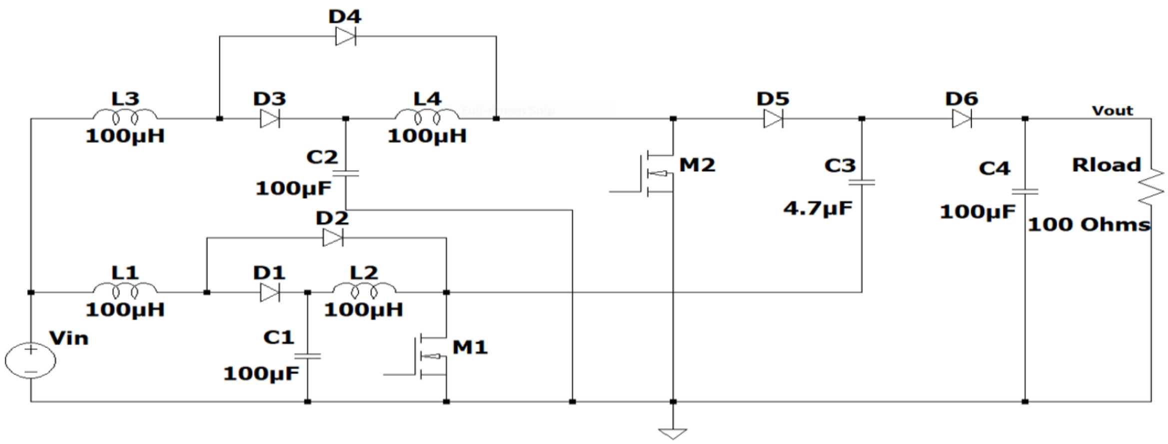


Fig. 2i Interleaved quadratic boost converter

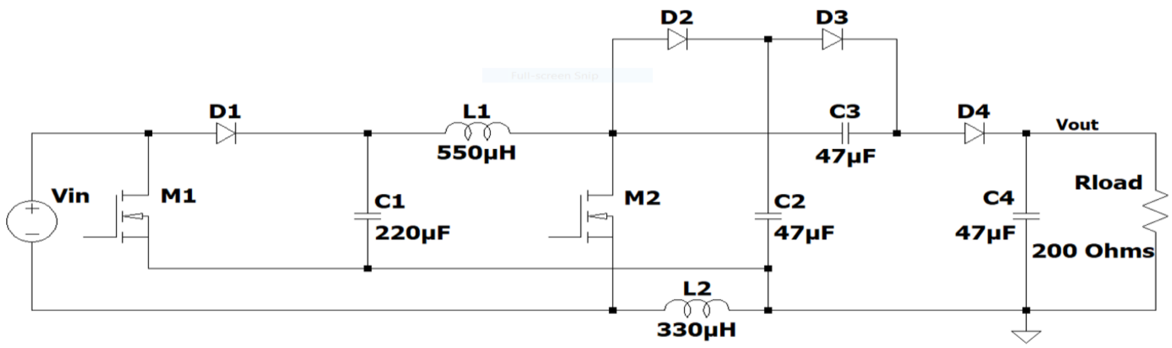


Fig. 2j Quadratic boost VM Converter

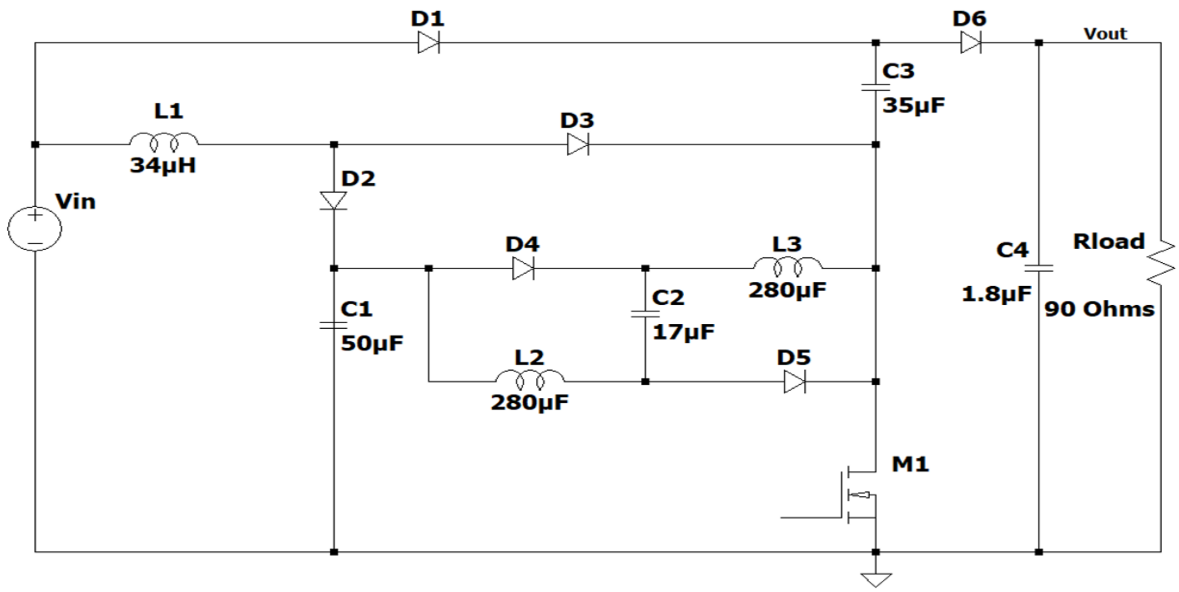


Fig. 2k Cascade boost VMC_self lift luo converter

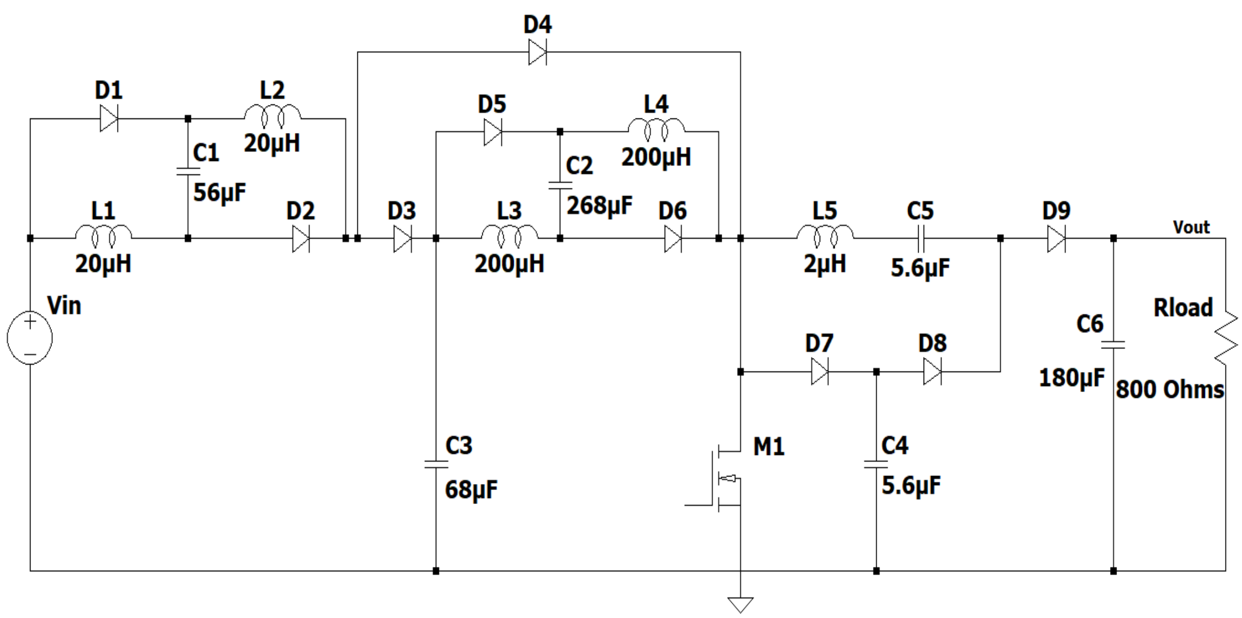


Fig. 2l Quadratic boost voltage doubler VL converter

4. Results and Discussion

4.1. Operational results of DC/DC Converters

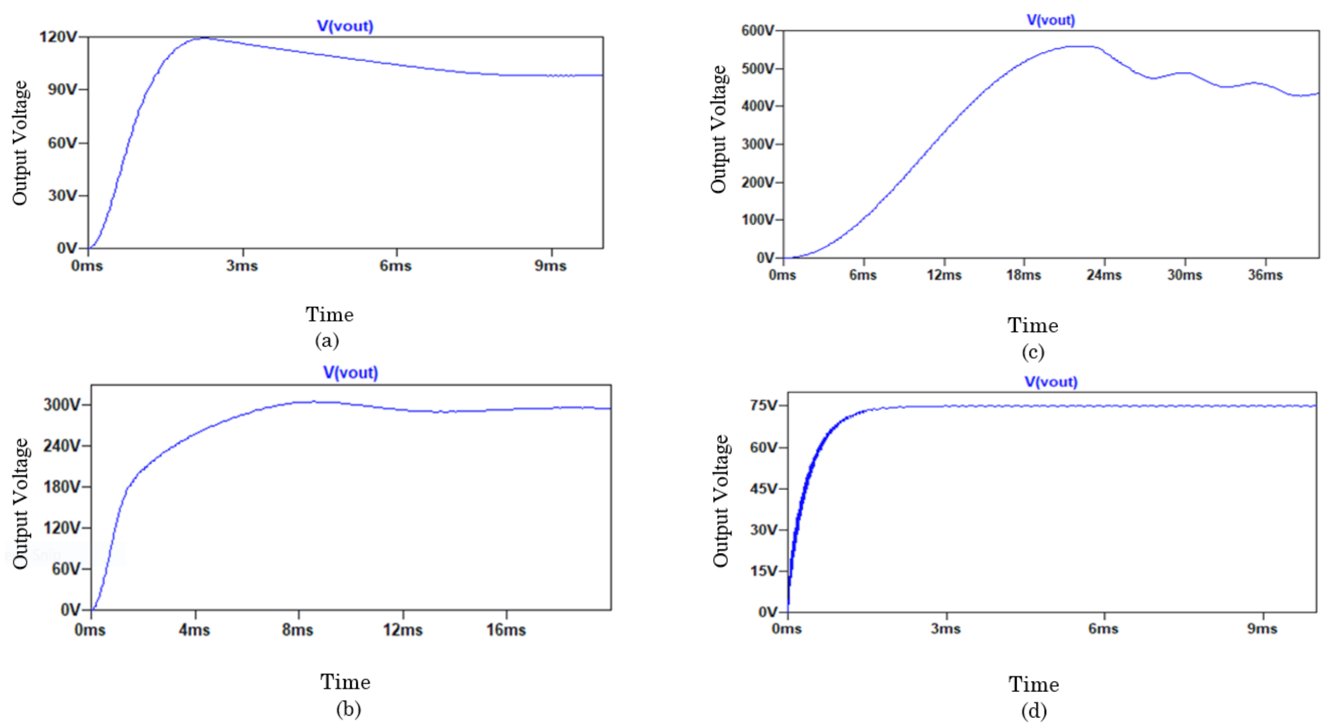
The simulation results obtained in LTspice XVII for various DC/DC converters using voltage multiplier or/and voltage lift converters are tabulated as in Table 1 and analyzed by the input and output voltages of the circuit along with details of components inductor (L), capacitor (C), diode (D) and switch used, duty ratio (D), switching frequency (fs) and voltage gain for various converters.

4.2. Simulated graphs of DC/DC Converters

The simulated output voltage waveforms of various DC/DC converters are shown in Fig. 3a-l supporting the analysis.

Table 1. Operation details of voltage multiplier and voltage lift converters

Sl.No	Name of Converter	Number of Components				Duty Ratio D	V_{IN} (V)	V_{OUT} (V)	f_S (KHz)	Voltage Gain
		L	C	D	Switch					
1	Boost converter _VM	2	3	3	1	0.76	12	98	50	8.1
2	Boost converter M_VMC	2	5	5	1	0.76	24	305	50	12.7
3	Boost converter_cascade VMC	1	7	7	1	0.4	48	460	50	9.5
4	Basic 4-stage Cockcroft-Walton VM	-	8	8	-	-	10	73	-	7.3
5	4-stage Symmetrical VM	-	12	16	-	-	10	75	-	7.5
6	4-stage Hybrid Symmetrical VM	-	10	16	-	-	10	35	-	3.5
7	Series-connected VM	-	8	8	-	-	10	223	-	22.3
8	Self-lift Luo converter	2	3	2	1	0.63	12	44	50	3.6
9	Interleaved quadratic boost converter	4	4	6	2	0.65	24	237	40	9.8
10	Quadratic boost VM converter	2	4	4	2	0.55	20	388	50	19.4
11	Cascade boost VMC_self lift luo converter	3	4	6	1	0.56	5	45	60	9
12	Quadratic boost voltage doubler VL converter	5	6	9	1	0.4	25	390	50	15.6



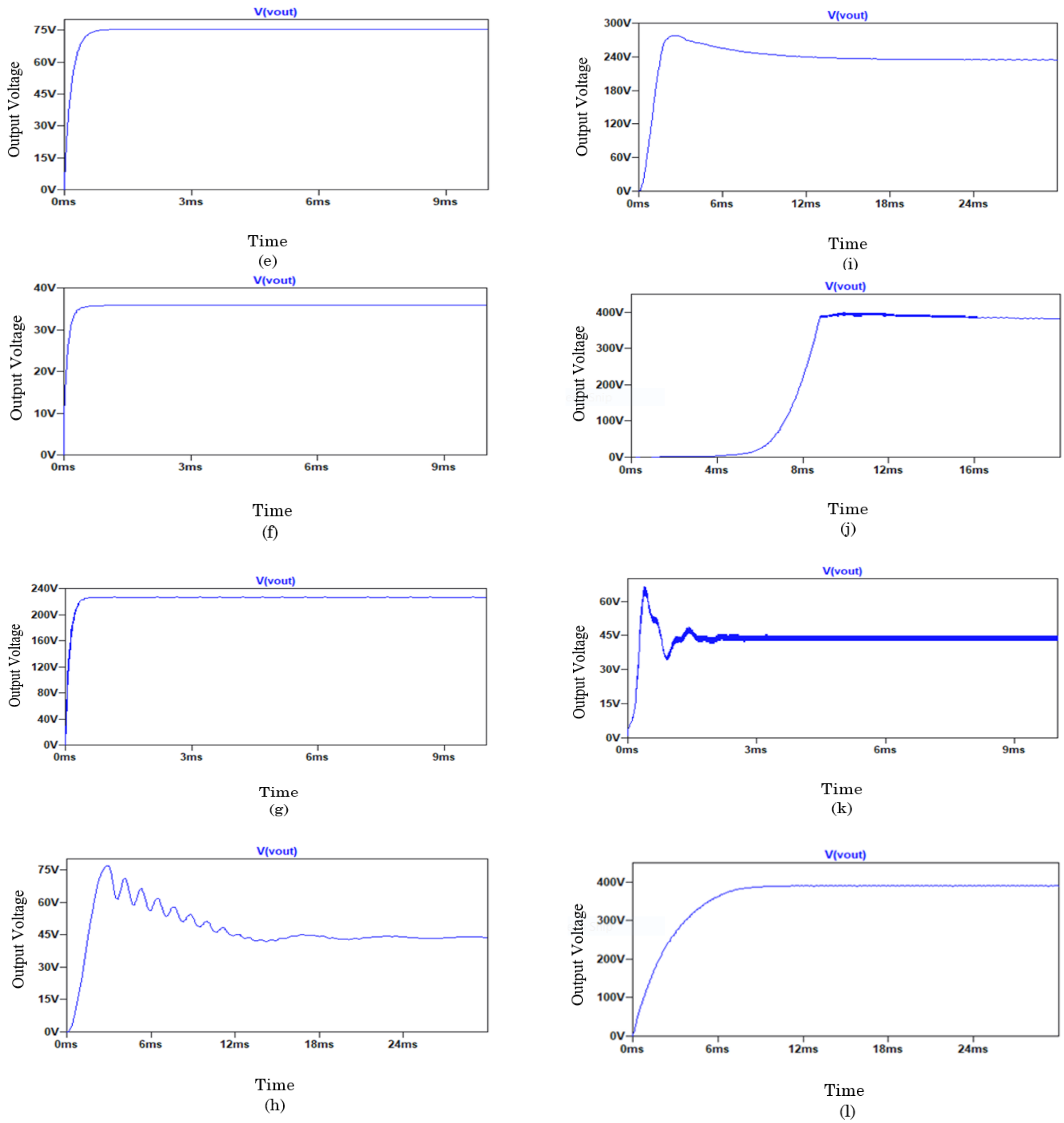


Fig. 3 Output voltage of the converters (a) Boost converter _VM, (b) Boost converter M_VMC, (c) Boost converter_ cascade VMC, (d) Basic 4-stage Cockcroft-Walton VM, (e) 4-stage Symmetrical VM, (f) 4-stage Hybrid Symmetrical VM, (g) Series-connected VM, (h) Self-lift Luo converter, (i) Interleaved quadratic boost converter, (j) Quadratic boost VM Converter, (k) Cascade boost VMC_self lift luo converter, (l) Quadratic boost voltage doubler VL converter.

5. Conclusion

This paper comprehended several non-isolated boosts DC/DC converter topologies using voltage multiplier or/and voltage lift techniques to obtain high voltage gain. The operation of these converters is analysed by comparing the number of components, duty ratio and switching frequency of the switch with the simulated output voltage. This information allows the comparison of various converters for better performances applicable in renewable energy system applications. The simulation results help to verify the analysis carried out for various DC/DC converters precisely with voltage multiplier and voltage lift techniques.

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