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A Literature Review on High Gain dc-dc Boost Converter

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Abstract-In the recent years the use of commercial sources like coal, diesel, nuclear etc have been increased. In the coming years the conventional sources may evanesce. So, now the prime concern of the engineers and researchers are shifted towards the non-conventional sources such as solar plants, fuel cells, batteries, wind power etc. But the problem in most of these sources is deliver very low and unstable voltage and such sources are not good for commercial use. So, to utilize these non-conventional sources it is required to tie the supply to grid. dc-dc converters are widely used in PV applications. Many researchers presented advancements in dc-dc converter topologies in literature. This paper presents the wide review on recent topologies of dc-dc converters.

Index Terms-High gain dc-dc boost converter; high voltage gain; interleaved boost converter; magnetic coupling; switched inductor; multi-level; multistage; switched capacitor; voltage multiplier cell.

1. INTRODUCTION

Industries have very much requirement of dc-dc converters in now days. Variable dc source improves the performance of industrial applications. Various dc-dc boost converters are available for conflicting power conversion applications. These *dc-dc converters* are very famous in non-conventional sources as well as most popular in medical, physics, military etc. Basically boost converters having high demand where high dc voltage is required [1]. Based on these requirements this paper presents different techniques for obtaining high gain than normally boost converters.

Non-conventional energy sources increases the electrical power magnitude. Solid fuel creates pollution so power converter topologies are very useful for next stage of power generation. The PV panels gives the output voltage in order of 20-60V. dc-dc boost converters are widely applied for interfacing between the PV panels and inverter-load combination. In PV panel high boost up is required for voltage gain. Full bridge inverter requires approx 380 volts for input [2].

2. VOLTAGE BOOSTING TECHNIQUES

There are many voltage boosting techniques are available now days. This paper presents these different types of voltage boosting techniques, their advantages, disadvantages and applications.

2.1. *Multistage technique*

This technique employs the combination of various stages of converters in miscellaneous connection. This method consists of cascaded, interleaved and multilevel converter techniques. The voltage gain of these techniques increases exponentially or linearly based on the based method.

2.1.1. *Cascaded Converters*

Bidirectional power flow capability is the basic requirement of dc-dc converters. Due to this property regenerative energy can be absorbed and stored in the energy storage system. Besides of this some application requires overlapping input-output voltage limit.

Middle inductor is used in cascaded buck-boost converter. This topology is shown in fig.1. In this technique an interfacing inductor is used between input and output stages [3].

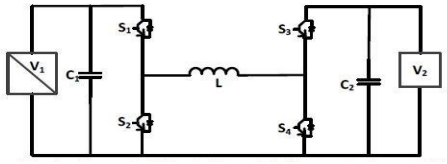

Fig.1 Cascaded Buck Boost Inductor

The voltage of battery is typically much lower than the bus voltage of DC with a high voltage stage in the vehicles driven by electricity. But the overlapping may happen between the battery voltage and the dc bus voltage which depends on the battery's characteristics and its design of the system. So it is also a prime concern of the researcher, the converter must able to carry the voltage of output side and input side with the range of overlapping.

The cascaded proportional integral control may lead to system unstable during operating time. So to maintain the system stability, Mukherjee et. al. [4] taken a series connected dc-dc topology.

The cascaded converters have been typically classified in three types in the literature,

a. Some type of sources in converters like batteries [5-10], fuel cells and super capacitors [11]-[12].
b. Different types of sources in converters, like stand alone photovoltaic system with battery, or solar/wind hybrid energy system [13]-[16].
c. Varying operating conditions at same type of sources in converter the varying conditions may be the photovoltaic panels under different partial shading [17]-[18].

A duty cycle based model predictive control (DC-MPC) technique proposed by Wei et. al [19] to achieve input voltage sharing (IVS) and output voltage sharing (OVS) for an input series output series (ISOS) converter. Wei et. al also proposed a discrete time optimized model of an input series output series type converter and the optimized duty cycles for input voltage sharing and output voltage sharing are predicted with a cost function. The proposed technique compared with the conventional proportional integral (PI) controller based technique. According the comparison of results the proposed duty cycle based MPC technique is better for input voltage sharing and output voltage sharing due to its simplicity, lower cost and higher dynamic performance.

Fig.2. shows the schematic diagram of hybrid cascaded dc-dc converter. As the Fig.2.shows a poly phase converter, in which each phase is controlled by a controllable switch and constructed by switches and energy storage device. The energy storage devices can store some amount of energy from one dc side to other dc side with the help of switches. The poly phase arrangement is modification of single phase switching action and overcome the problem of energy flow interruption in single phase switching action [20].

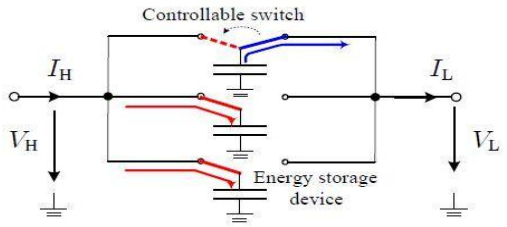

Fig.2HCDC

2.1.2.*Interleaved Converter*

The traditional bidirectional buck-boost (CBB) converter is low cost non-isolated and simple construction. Chen et. al.[21] proposed a topology consists bidirectional buck-boost converter with the coupled inductor. Mohammadi et. al.[22] proposed the family of soft switching bidirectional converters with high ZVS range. Non-isolated bidirectional dc-dc converters have been discussed in [23]-[25].

Bahrami.H [26] et.al proposed a novel technique which provides reduced ripple current during the operating at the battery side in the high current inductors, soft switching and high VGR. This topology is the combination of interleaved cascaded buck-boost converters and the DAHB converter. In series connection the voltage stress on main switches reduced and voltage gain increased.

Xuefenget.al [27] has presents A High Gain Input-Parallel Output-Series DC/DC Converter with Dual Coupled-Inductors. This topology also has a voltage multiplier module. The primary windings of two coupled inductors are parallel connected for sharing the input current and for reducing the input current ripple. On the other hand this converter has the all features of interleaved series connected output capacitors for large output voltage, less ripples in voltage output and less switch voltage stress. The secondary sides of two-coupled inductors are also connected in series with a regenerative capacitor with a diode for increasing the output voltage. The active switches become ONN at zero current and the diode's reverse recovery problem increases due to leakage inductance of the coupled inductors. The energy of leakage inductance can be recycled in this converter.

Hu.et.al [28] proposed an isolated ultra high step up dc-dc converter in matrix transformer configuration for increasing the power level and improving the fault tolerant by a fly back converter. Fault tolerant capability can be increased in this case. Voltage stress on switching element and transformer size can be reduced easily in this technique.

Prabhalaet.al [29] proposed a dc-dc converter with high voltage gain and two input boost stages. It is inspired from a Dickson Charge Pump [20]. The voltage multiplier cells are used to increase the voltage gain. The voltage gain is depending on number of stages and duty cycle of the input stage.

Zhang et.al [30] proposed an interleaved switched capacitor bidirectional dc-dc converter with wide voltage range for energy storage system. In this technique an interleaved structure is added in the LV side to reducing the ripples of current by LV side. Similarly a series connected structure is adopted on HV side of converter for achieving the voltage gain. These converters also have high efficiency.

2.1.3.*Multilevel Converter*

As the HVDC system is very popular, the voltage source converter based high voltage direct current system also gaining importance. Voltage source converter based HVDC has more advantages as compared to thyristor based HVDC system. It has active and reactive power control, black start of converter, high output voltage and current with no ripple. These types of converters also have some disadvantages e.g. switching losses and less fault tolerant capability to dc side fault. For removing all these problems some multilevel converters have been introduced [31]-[37]. Out of these converters the

modular multilevel converter has gaining more importance compared to others because of its low dv/dt, low harmonics, scalability and modularity. It also has low switching losses.

Fault tolerant capability is more in important in converters which is a reason for high attention towards fault tolerant multilevel converter for HVDC applications. These topologies use full bridge sub module. Due to this, this topology uses large number of semiconductor switches. Mathew et. al [38] presents a generalized cross connected sub module with less number of switches with same features of FBSM as shown in Fig.3.

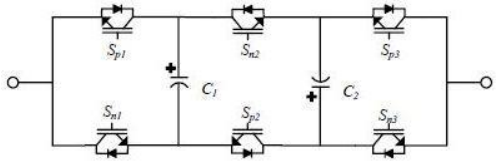

Fig.3 5 level X-SM structure

2.2. *Switched Capacitor (Charge pump)*

Non-conventional sources like solar and fuel cell preferred low voltage range for operation but grid tied systems requires high voltage range. These high voltage ranges affects the efficiency. To overcome the low efficiency problem Das et. al [39] proposed a novel high voltage gain with high efficiency dc-dc converter, based on coupled inductor, intermediate capacitor and leakage energy recovery technique. For reducing the losses the input energy of converter is stored in coupled inductor and intermediate capacitor in lossless manner.

A variant Dickson converter is proposed [40] as the name (n/m) X converter. This configuration can give the required voltage gain with high efficiency.

Many other advantages and limitations of converters based on switched capacitor based circuits have been discussed in [41]-[43]. Dickson based converters gives best performance as compared to these switched capacitor based converters [44].

The (n/m) X converter is derived from a common structure of (k/m) X is shown in Fig.4. There are n arms and n legs in this converter which become total 2n limbs. Each arm has a series combination of two capacitors [45].

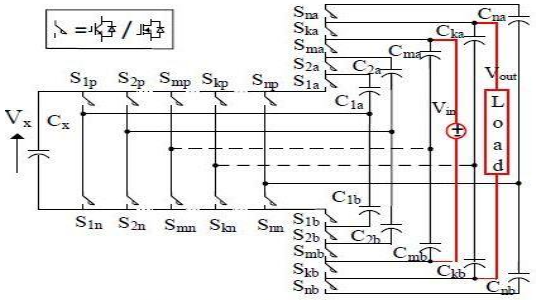

Fig.4 A generic (k/m) X Converter

2.3. *Voltage Multiplier technique*

400 V DC supply system gaining most popularity now days because of their higher efficiency, better reliability and most economically as compared to ac supply system [46]-[49]. Telecommunications, data communications, commercial and residential are the best example of dc distribution system [50]-[52]. In dc supply system or dc distribution systems, the most challenging task is dc-dc converters for 400 V systems. The range of PV panels is between 20 V to 40 V DC. For boosting up these voltages high duty ratio is required which results high voltage stress on components, voltage ripples and low efficiency.

For overcome these drawbacks [53]-[56] have been proposed topologies for dc-dc boost converters followed by the voltage multiplier cells. Based on this technique Table I showing the comparison of different converters with respect to number of components, voltage gain and voltage stress on switches.

Bin et. al [53] proposed a hybrid converter for high voltage gain but gives low output voltage as compared to its own VM circuit. It also has a large ripple in input current. Table 1 shows the comparison of different converters based on voltage gain and components used. The table has been formed using topologies presented in literatures [53]-[56].

Table 1: Comparison of different converters

Topology	[53]	[54]	[55]	[56]
No of Switches	1	1	2	2
No of Inductors	1	1	2	2
No of Capacitors	4	3	3	3
No of Diodes	4	3	3	4
Vout/Vin	$\frac{3-D}{1-D}$	$\frac{2}{1-D}$	$\frac{3+D}{1-D}$	$\frac{1}{D(1-D}$
Vswitch/vout	$\frac{1}{3-D}$	$\frac{1}{2}$	$\frac{1}{3+D}$	(1-D)D
Input Current	Discontinuous	Continuous	Discontinuous	Continuous

Gang et. al [54] proposed switched capacitor based converters which also boost the low voltage comparatively to its component count. A switched capacitor base converter is proposed by YU et. al [55] which produce ripples In input current in discontinuous form. Rosas-caroet. al [56] proposed a transformer less converter which gives continuous input current but high stress is experienced by switches higher than two third of the voltage. A new converter topology is produced by Baddipadiga et. al [57] in which the input side consist a two phase interleaved boost converter and output side having a

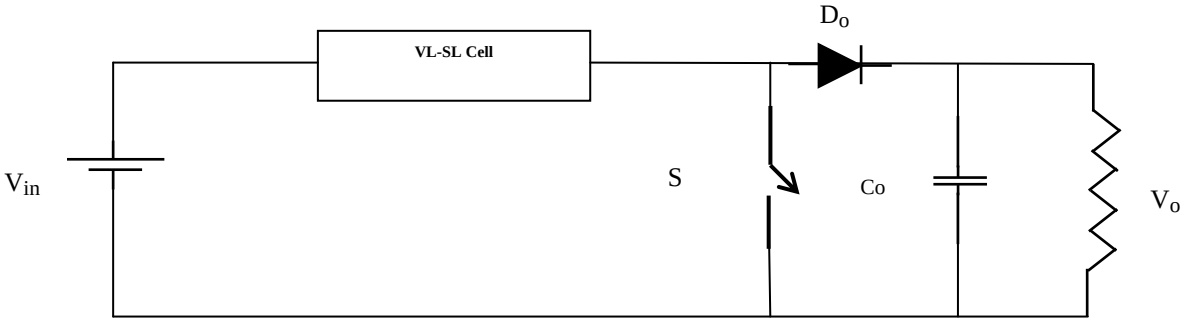

Fig.5 Voltage Lift Technique

Dickson charge pump based voltage multiplier.
This converter is most useful for 400 V dc bus. This converter also has a tendency to extract power from both single source and two independent sources. Due to low voltage rating of capacitors for VM, these converters leads towards the size reduction.

2.4. *Switched Inductor and Voltage Lift technique*

For increasing the output voltage in dc-dc boost converter, voltage lift is one of better and approved method or technique. A capacitor is charged to a certain value by source voltage in this technique. After that the output voltage is boosted with voltage of charged capacitor. On adding more capacitor the voltage level can be increased more. When two capacitors are used, it is called re-lift, on three capacitors it become triple lift and similarly quadruple-lift technique [58]. Luo et. al [59] introduced some boost converters based on this technique. Zeta, Cuk and SEPIC converters have been used with Voltage Lift technique [60]. Fig.5 shows the basic structure of VL technique.

2.5. *Magnetic Coupling*

Magnetic coupling is most preferred boosting technique. It can be used as both non-isolated and isolated dc-dc converter. There are some coupled-inductor based dc-dc converters have been designed to offer the freedom from the complexity of the switch duty cycle [61]-[68]. Due to leakage inductance of coupled inductor high voltage spikes occurs on device.

It also induces large energy losses. RCD snubbers can control the voltage variation or current and clamp voltage overshoot. RCD snubbers are composite of resistor, capacitor and diode. Leakage energy is still dissipated in this case so that these converters are also proposed [65]-[66]. In this case the number of switches increases which results the complexity in the circuit. Wai.et.al [67] proposed a passive regenerative snubber. This converter has higher voltage gain than others which are based on coupled inductor technology. In the same channel khalizadeh [68] et. al. proposed a converter with single switch by using three winding coupled inductor. Leakage energy of the inductor can be reused in this converter and also reverse recovery problem of diode can be reduced. This converter is designed for high voltage gain with high power density and efficiency. It consists of a single switch and two voltage multiplier cells. Besides this it is also have two regenerative snubbers for high voltage conversion, recycling the energy of stray inductance and reducing the voltage spike.

3. Comparison of Different Techniques

Table 2: Comparison of different techniques

Voltage Boosting Technique	Advantages	Disadvantages	Appropriate applications
Multi-Stage/-Level	Compatible structure, High power density, stable and efficient and High voltage/current ratio.	Complicated control technique, more numbers of components, and comparatively heavy, large and heavy.	HVDC transmission, Renewable energy system, Photovoltaic, fuel cells, dc grids, large power dc supply, electric vehicle, hybrid electric vehicle and fuel cell electric vehicle, and Space automation.

Switched Capacitor (Charge Pump)	Cheap, Light weight, Small size, high power density and Fast response.	Comparatively complicated modulation, Sensitive to the ESR of capacitors and Lack of output voltage regulation.	Energy accumulation, Mobile displays (AMOLED), Automotive and vehicular applications and High gain dc-dc applications.
Voltage Multiplier	High voltage capability topology, Cell based structure, and also it can be integrated to various converters.	High voltage stress on components, and need several cells for high voltage applications.	X-ray, laser, Military, plasma research and particle accelerator.
Switched Inductor and Voltage Lift	High boost ability, and biddable in many converters.	Need more passive elements, and not suitable for high power applications.	Mid-range dc-dc converters and High gain dc-dc applications.
Magnetic Coupling	High design freedom, Versatile in boost ability due to tunable, turns ratio of magnetic coupling, Switch can be implemented at the low voltage side help to reduce conduction losses and High efficiency in soft switched type.	Negative effects of leakage inductance, High voltage spike, and Relatively bulky.	High power/voltage DC supply, High voltage applications (military, physics), DC micro grids, Telecommunication and data centers, Bidirectional (FC, PV, UPS, P-EV, H-EV, V2G), Regenerative (elevator, tram/trolleybus), and Avionic and space.

4. Conclusion

This paper presents a literature review of different topologies of dc-dc converter which are discussed in several international journals such as IEEE, IET, SCI and many other international journals. These converters were studied for better understanding about converter techniques and their applications. This study also gives the information about the best converter topology with high voltage gain, less ripples, and high efficiency. These converters have applications in solar PV, electric vehicle and some other applications. Many of these converters have been tested with hardware and real time simulators. Also these are tested with applications like solar and electric vehicle etc.

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