


**IMPLEMENTATION OF ACR AND AVR CONTROLS FOR HIGH
VOLTAGE GAIN DC-DC CONVERTER**

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ABSTRACT

Step up power conversion is universally used in many applications. The application that uses step-up power conversion can be observed in renewable energy such as photovoltaic (PV) system, wind turbine, data center and Electric vehicle. There are many applications which use the DC-DC boost converter to get higher DC voltage from the low input voltage. In this project, Marx topology boost converter (MTBC) analyzed and proposed for conversion from low input dc voltage to high output dc voltage. (MTBC) depends on the principle of the Marx generator. The proposed (MTBC) is multi-stage and consist from 4-stage, by multistage of converter the stress in the components will be reduced, where the parallel charging at input side to reduce the current stress, and series discharging at output to reduce the voltage stress. The stress on the components of the converter will inversely proportional with a number of stages. By implementation of ACR and AVR combination with using PI control technique the output voltage can be controlled. Based on the simulation results the obtained output voltage 400V DC by boosting input voltage 48V DC and by using 4-stage proposed converter, but any drop in the value of input voltage will effect on the output voltage, so that when battery voltage drop to 40V the output will be 340V. After implementing the control system for the AVR and ACR and combine between them, it will be possible to obtain 400V from different value input voltage (40V, 45V, 55V), as well as for 450V and 500V output voltage.

ABSTRAK

Peningkatan kuasa digunakan secara meluas pada banyak aplikasi. Aplikasi yang menggunakan peningkatan kuasa boleh dilihat dalam tenaga boleh diperbaharui seperti sistem photovoltaic (PV), turbin angin, pusat data dan kenderaan elektrik. Terdapat banyak aplikasi yang menggunakan DC-DC boost converter untuk mendapatkan keluaran voltan DC yang lebih tinggi yang disebabkan voltan masukan yang rendah. Dalam projek ini, Marx topology boost converter (MTBC) dianalisis dan dicadangkan untuk penukaran daripada voltan masukan dc yang rendah ke keluaran voltan dc yang tinggi. MTBC bergantung kepada prinsip penjana Marx. Cadangan MTBC adalah multi-stage dan terdiri daripada 4 stage, di mana tekanan pada komponen dapat dikurangkan, di mana pengecasan selari di sebelah input untuk mengurangkan tekanan arus, dan pelepasan cas secara siri yang dikeluarkan pada output dapat mengurangkan tekanan voltan. Tekanan pada komponen penukar akan berkadar sebanding dengan beberapa peringkat. Dengan pelaksanaan kombinasi ACR dan AVR dengan menggunakan teknik kawalan PI, voltan keluaran dapat dikawal. Berdasarkan hasil simulasi, voltan keluaran 400 V DC dapat dicapai dan voltan masukan 48 V DC di mana menggunakan 4-stage converter yang dicadangkan, namun penurunan nilai voltan masukan akan mempengaruhi voltan keluaran, sehingga apabila voltan bateri jatuh ke 40 V output akan menjadi 340 V. Selepas melaksanakan sistem kawalan untuk AVR dan ACR dan menggabungkan di antara mereka, 400 V dapat diperoleh dari nilai voltan masukan yang berbeza (40V, 45V, 55V), serta voltan keluaran 450V dan 500V.

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LIST OF ABBREVIATION

V_{out}	-	Output voltage
V_{ref}	-	Reference voltage
V_{in}	-	Input voltage
PWM	-	Pulse Width Modulation
MOSFET	-	Metal Oxide Semiconductor Field Effect
CCM	-	Continuous Conduction Mode
DCM	-	Discontinuous Conduction Mode
MTBC	-	Marx Topology Boost Converter
PI	-	Proportional-Integral
AVR	-	Automatic Voltage Regulator
ACR	-	Automatic Current Regulator
CMC	-	Current Mode Control
VCM	-	Voltage Mode Control
β	-	Boost Ratio
D	-	Duty cycle
S	-	Switch
t_{on}	-	Time ON
t_{off}	-	Time OFF
L_{in}	-	Input inductance
ΔI_{in}	-	Input current ripple
L_{out}	-	Output inductor
C_m	-	stage capacitance

CHAPTER 1

INTRODUCTION

1.1 Background Studies

In contemporary electronic circuit usages, conversion from DC to DC applications plays a significant role. Beginning from domestic applications to industrial control various kinds of direct/indirect DC-DC converters are applied recently. Among those boosts, the converter devices are utilized fundamentally to step up the input voltage at the load end [1]. Boost Type DC-DC converter (BDC) has established varied usages in different types of voltage regulation areas like LED luminaries, laser power source and special mechanical manufacturing. Though, in view of its essential features like non-linearity and unstable zero dynamics, when taking capacitor voltage as output, its performances, particularly in dynamic response, are considerably limited as they are applied in fast voltage or recent tracking purposes [2]. DC-DC boost converters are the main element to interface power sources to the EV's dc-bus. In EVs, fuel cells (FCs) batteries and super-capacitors (SCs) are regularly applied as devices storing energy. Combining such energy sources causes FC-SC-battery hybrid power system (HPS) [3]. Several PV usages need a high-efficiency and high step-up voltage gain DC-DC converter for increasing and regulating the low DC voltage into an appropriate usage voltage. In addition, the inter-connection among the Photovoltaic panels and the load, the DC-DC converter additionally does the important function of boosting the PV system power outcome [4]. Several low voltage high current dc sources, such as an ultra-capacitor bank, NiMH battery and Li-Ion battery need high boost ratio DC-DC converters for transferring

their energy into higher dc systems. Though, it is challenging for designing a universal interface among these kinds of dc sources and higher voltage designs due to the high variation of input voltage and the high current needs [5].

A lot of applications like industrial, need to transform the low voltage to high-level voltage by an apply DC-DC converter. Some of them need (200V-400V) output voltage and the others like telecommunication systems, uninterrupted power supplies that need 380V by boost the 48V input [6][7]. By connecting the conventional DC-DC converters in cascade connection, the high voltage gain is realized, but because of high input current that causes high conduction losses and number of cascading connections, the efficiency will minimize. For a high boost ratio, these circuit configurations are not recommended. a Marx generator is one of the interesting structures which achieves a high boost ratio in the DC-DC converter. The target from the Marx generator is getting high voltage from a low input voltage. The principle of Marx impulse generator that applied in DC-DC converter high voltage gain, where minimization of current stress will be by parallel connection at the input side and voltage stress minimization will be by series connection at the output side [8]. In the proposed circuit the reduction for volume and inductance of the output inductor are obtained by apply interleaved switching scheme [9].

The control methods for DC-DC power converters are essentially categorized into 2 key collections as voltage mode control (VMC) and current mode control (CMC), there are various control methods has been created like digital controllers and sliding mode controller [10]. For keeping the constant output voltage of converter digital PI controller is applied using feedback signal that could be used with a microcontroller, fuzzy logic, FPGA or digital signal processing [11]. For organization DC-DC boost converter at the required output voltage, there are main challenges in implementing a humble output feedback PI controller, well-known in the electromechanical conversion community and power electronics, that is the existence of unstable zero dynamics in the converter model. So, earlier systems that propose classic PI controllers depend on a linear and small signal pattern analysis. These types of controllers are super sensitive to model uncertainties since the alteration of the operating point decrease the small signal model validation. A more stabilized to this issue has been supported by indirect regulation the output voltage through the input

inductor current in a cascaded PI controller's system [12]. Figure 1.1 explains the block diagram of project.

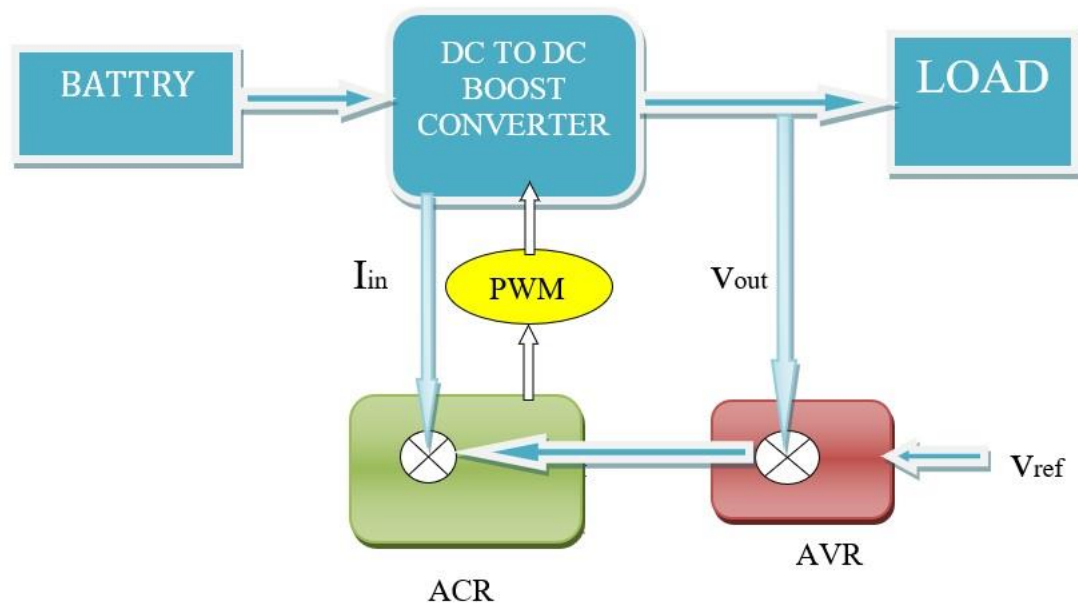


Figure1.1: Block Diagram of project

1.2 Problem Statements

A traditional DC-DC boost converter and the other structures of DC-DC converters in charge of high losses. It suffers from current stress because of the large input current as a result of that high conduction and copper losses occur, and the output voltage stress is very high due to the high output voltage. Some topology is needed to be taken to reduce the losses. Hence, by applying Max topology boost converter (MTBC) its reduction will be possible where a parallel connection is applied at input side in order to reduce the current stress while a series connection is applying in output side to reduce the voltage stress and this lead to a reduction in losses. The undesirable feature of this topology is uncontrolled output voltage. A multi-stage Marx topology converter of this project with implementation AVR at the output side and ACR at the input side with using PI control technique can control the output voltage. as a result, the converter is operated in a good performance and the highly efficient.

1.3 Objectives of the Study

- To reduce current stress at input side and voltage stress on switching devices and capacitors by adopting multi-stage dc to dc boost converter structure.
- To control output voltage and input current by implementing of ACR and AVR to achieve balanced input current and constant output voltage.

1.4 Scope

To perform the obvious targets, the scope could be presented as follows:

- 1- The multistage is adopted for converter designed and main components selection.
- 2- The switching scheme is identified by utilizing a synchronized switching scheme and the mode operations.
- 3- The concept of control technique is clarified which is a combination of the AVR and ACR with a PI control technique.
- 4- The MTBC 4-stage simulated and tested using MATLAB software Simulink.
- 5- Parameters comparison among the MTBC and conventional DC-DC converter in terms of current at the input side and the voltage across the capacitor (voltage rating) at output side are concerned.
- 6- ACR and AVR have been established and simulated by MATLAB program.
- 7- AVR and ACR combination established and simulated by MATLAB program Simulink and the performance of MTBC have been analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introuction

The DC-DC boost converter could be commonly utilized in applications like EV, telecommunication, DC-DC transmission line. Many structures in past researchers are able to produce high voltage. Each structure has its own features. The important data and information for previous studies are very necessary to build a good literature review for this project.

2.2 DC-DC converter

The power converters become common at present because it utilizes in several areas [13]. The different levels of voltage can be produced by dc to dc converter either high or low voltage level, depending on the kind of application [14]. Implement the inductive and capacitive filter, as a result of High-frequency switching. The other choice by using the transformer to obtain the desired voltage [15]. Figure 2.1 explains the block diagram of the DC-DC converter.

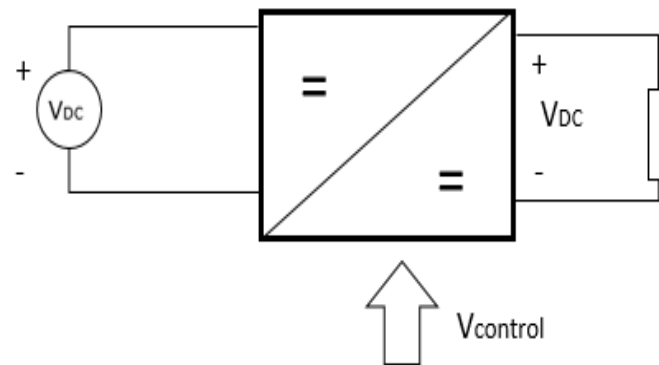


Figure 2.1: The basic of the DC-DC converter block diagram

2.3 Applications of high voltage gain DC-DC boost converter

High step-up voltage gain DC-DC converter is suggested to match the needed voltage level [16]. For instance, the operating voltage needed in high-intensity discharge lamps to automobile headlamps [17]. High voltage DC-DC Converters are additionally applied in UPS, industry testing and renewable energy [18]. Moreover, for getting a low THD level and high value of PF in boost PFC systems, it is important for getting a high level of AC voltage [19]. And in X-ray power generator, computer periphery, servo-motor drives they could be applied additionally in control systems, PV designs battery charger units, fuel-cell-based energy conversion [20].

2.4 Conventional DC-DC boost converter

The design of this converter includes input voltage, an inductance, S_n switch, D diode, and C capacitor that connected with a resistance R in parallel. The good converter should be fast in performance. Examples of switching devices which have faster performance compared with other MOSFET, IGBT, and BJT. The operations of charging and discharging of inductor depend on a switch when being in OFF or ON. If the switch ON the inductor is charging and the diode will be reversed biased. In OFF state of the switch, the diode is in forward biased and the energy stored in inductor transmitted to the output circuit [21].

During charging the inductor become as load, but in discharging will be like a source. the mode operation of DC-DC converter is continuous conduction mode and

discontinuous conduction mode [22]. The unwanted characteristics of this type of DC-DC converter, the high losses due to the high current of input from low voltage and the components of the converter are illustrated in Figure 2.2.

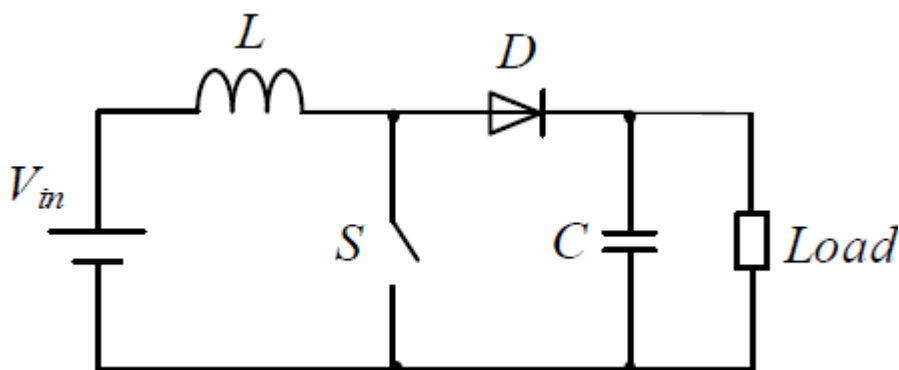


Figure 2.2: Conventional DC-DC boost converter.

2.5 Non-isolated and isolated DC-DC converter

There are 2 main groups of DC-DC converter, the isolated DC-DC converter and non-isolated DC-DC converter. Transmitting power from the input part to the output part by the transformer is performed by using an isolated DC-DC. Push-pull converter, forward converter, and fly-back converter consider as examples for the isolated DC-DC converter. Meanwhile, direct power transfer will be possible to apply the non-isolated dc to dc converter [23]. An instance of the non-isolated dc to dc converter that generally applies in applications is a buck-boost converter, buck converters and boost converters [24]. Maximize or minimize transformer input voltage has been done by regulating the turn ratio [25]. The 'isolation' signifies to the barrier of electrical voltage that exists among the output and input of the DC-DC converter. The withstanding of barrier arrives in thousands of volts, depends on kind of standard. The isolated DC-DC converter is bigger and heavier than a non-isolated DC-DC converter [8]. Voltage rising across switch will occur due to the transformer leakage inductance [26].

The non-isolated DC-DC converter directly converts voltage from the DC input to the DC output, it is famous as a conventional DC-DC converter. This kind of converters categorized into two kinds which mostly use in applications [27]. Buck converter is one of these kinds, it transforms from the high level of voltage to the low

level [28]. The low input voltage applications as a battery charger, laptop adapter mostly use buck converter [29]. Meanwhile, the most popular DC-DC converters is the boost converter, it transforms the voltage from low level to high level, it is famous as the step-up DC-DC converter [30].

2.6 Traditional and extra high voltage gain DC-DC converters

Traditional DC-DC (boost) converters are famously used in HV (high voltage) applications, with limited performance because of low efficiency, less output voltage transfer gain, complexity in control. The technique of lift voltage a famous way widely utilized in the design of the electronic circuit and effectively implemented in DC-DC converter applications. Output voltage increases proportionally with step-up stages number. The above limitations have eliminated by design extra high voltage dc to dc converter from classical converter, by implementing additional passive (inductor/ capacitor) components the voltage increase in a simple geometric progression. as a result, enhancement of the voltage gains as per power-law terms. The performance of this DC-DC extra high voltage converter posse advantageous in comparison to classical DC-DC version as follows:

- High voltage transfer ratio gain (k).
- Wide range of control with lower ripple at the output.
- High power density and high efficiency.
- One sensor is needed for Closed-loop compensator [31].

2.7 Quadrupler Interleaved Boost Converter

The structure of this converter able to improve low voltage to a higher level [32]. High voltage gain can achieve by applying this structure. The quadrupler interleaved boost converter is an adjustment from two phases interleaved boost converter[33]. Figure 2.3 illustrates the circuit of the converter. Figure 2.3 demonstrates that the design includes 2 inductance, 4 diodes, 2 Metal oxide semiconductor FET as well as 4 capacitors [34]. In quadruple interleaved boost converters have extra 2 capacitor and 2 diodes from 2 phase interleaved boost converter as illustrated in Figure 2.4. However, by this structure high voltage is possible to obtain, to realize the condition

of the continuous current mode, the D value which refers to the duty cycle should be above zero point five. Meanwhile discontinuous current mode (DCM) will happen if the value of D reduces lesser than zero point five, and no energy could be transmitted among inductor, capacitor and side of load in this state [32][34].

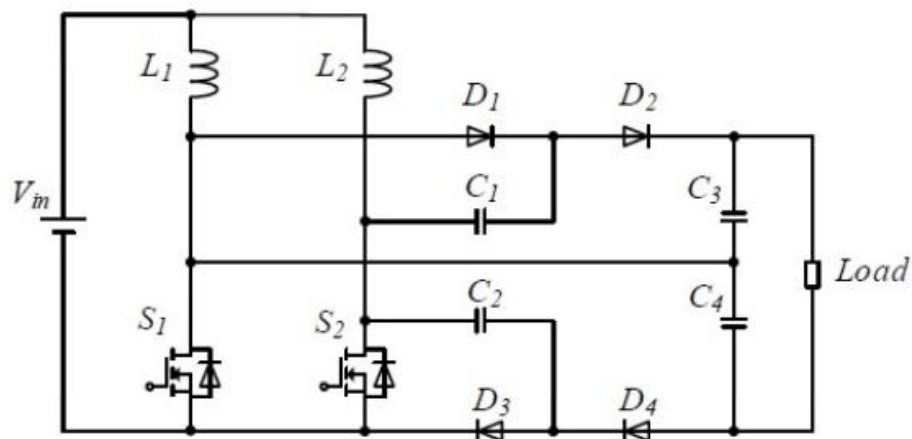


Figure 2.3: Quadrupler boost converter design

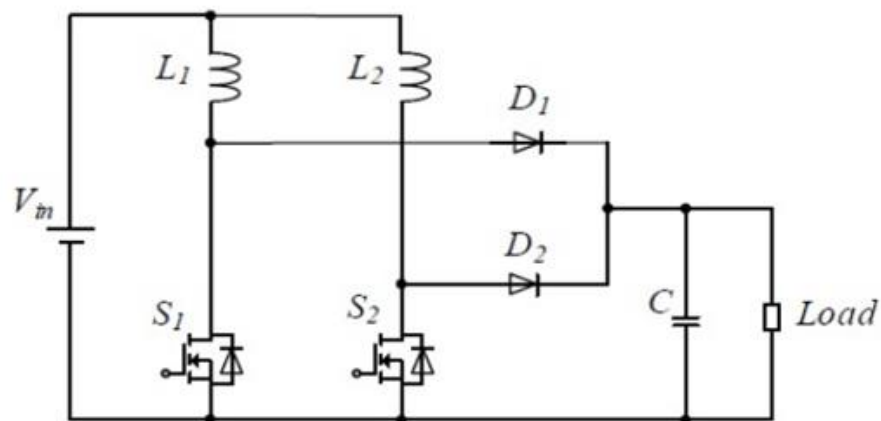


Figure 2.4: Quadrupler boost converter design.

2.8 Inductor-less Multi-stage Modlar Capacitor Clamped DC-DC Converter

This converter is an inductor less structure able to produce a high value of voltage gain. Energy transfer between input and output for this structure will be by using capacitors [35]. The output value of voltage is proportional with the converter's stages. One stage or modular block includes a capacitor with 3- switching devices [36]. Figure 2.5 explains single stage. Each stage of IMMCCC is able to produce output voltage value double value of input voltage. The getting of high voltage is possible by using IMMCCC without increase duty cycle value [35]. However, in this structure the output voltage will proportional with a number of stages, to reach the desired voltage should increase the number of stages with a constant duty cycle at 0.5.

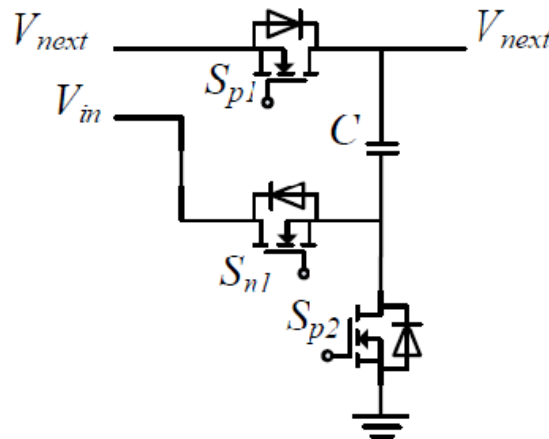


Figure 2.5: Modular structure of the IMMCCC

Number of the cascading stages depends on the desired output value of voltage. Figure 2.6 explains 3 stages of converter. The switching configuration is essential to get the required voltage. There is a difference among the even and odd numbers of the modular structure which linked in cascaded connection in switch configuration. In case the switching configuration is not correct the output will not be the require.

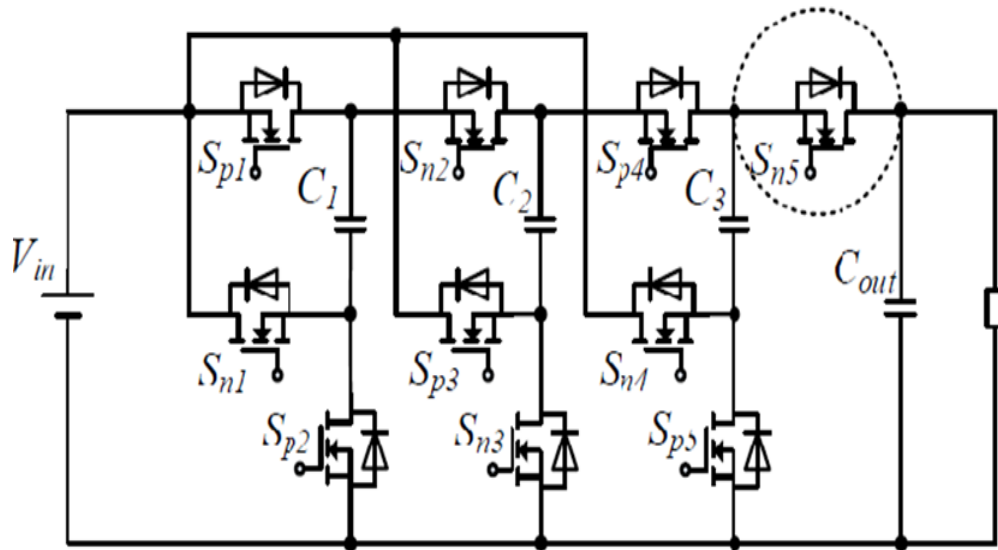


Figure 2.6: Three stage of the IMMCCC

2.9 High voltage converter structures

For obtaining a high value of voltage conversion percentage with a high level of efficiency, several high gain improvement methods were investigated. Each method has its special benefits and restrictions. The switched capacitor DC-DC converter could accomplish a high value of efficiency but has poor regulation capability and pulsating current. Introduction of a resonant switched capacitor converter could lessen the pulsating current but does not tackle the regulation problem [37]. Several applications are applied for getting high value of voltage accompanied with minimal of switches in order to increase efficiency value, they are explained as follows: A novel DC-DC converter topology is suggested which optimize the value of efficiency and lessen the value of voltage stress through the switches. DC-DC converters with a one switch are suggested that reduce the reverse recovery issues and losses resulted from switching. Transformer less DC-DC converters with a cascade method are suggested for reducing the current stresses and voltage values through the switches. Voltage multiplier with the interleaved converter is suggested in power administration solutions like EV. DC-DC converter with a coupled inductor is suggested for gaining high value voltage [38]. A soft method of switching in collaboration with PFC controller and pulse width modulation is presented for attaining high level of energy conversion efficiency with improved PF [39].

2.10 Marx Topology DC-DC Boost Converter

The structure is capable of producing a high voltage gain. [40]. And this converter considered one of the multilevel converters. The output voltage has a proportional relationship with a number of stage and duty cycle [8]. Figure 2.7 explains three stages of converter. From Figure 2.7, each converter's stage consists of 2 levels DC-DC boost converter [41]. The converter has been built on the Marx impulse generator principle where high dc voltage production from low dc voltage [42]. This concept is obtained by parallel charging of the capacitors and series discharging for the same capacitors. So through this configuration of capacitors, produces a high voltage from low input voltage [9].

Many traditional 2-level DC-DC boost converters will connect at the input side in parallel to minimize conduction losses and copper losses, while series connection will apply at the output side to minimize the voltage rating of stage capacitors. Moreover, the voltage stress of the lower switch device at the input side is the same at the output side. Therefore, low on-resistance semiconductors will implement in the structure. On the other hand, high voltage rating diodes will be used on the input side. However, The SiC diodes that characteristics such as low forward voltage and low reverse recovery time use at the present. That is lead to a high-efficiency boost converter [8].

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