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Design and Simulation of Switched Capacitor for Voltage Boost Converter for EV

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Abstract

The concept focuses on using voltage boost converters specifically made for electric vehicle (EV) drives to simulate and design switching capacitors. In the past, standard boost and non-boost inverters have been used to assess the efficiency of electric vehicles. On the other hand, this proposal suggests using voltage boost converters to greatly increase the vehicle's speed and efficiency. The main goal is to maximise the converter topology's design parameters in order to achieve higher voltage-boosting capabilities and improve the vehicle's overall performance. The research intends to address issues with power delivery and power conversion efficiency through careful investigation and simulation. This research aims to push the boundaries of EV technology and aid in the creation of more effective and potent electric vehicles by utilising sophisticated switching capacitor techniques. The project's approach entails a thorough analysis of current converter topologies and design parameters, followed by in-depth simulation studies carried out with the use of suitable software programmes like Matlab. To maximise the efficiency of voltage-boosting, several parameters, including switching frequencies, capacitor values, and circuit designs, will be rigorously examined and optimised. The relevance of this notion is that it has the potential to introduce revolutionary voltage boost converter designs that are specifically tuned to the needs of electric vehicle drives, hence revolutionising the efficiency benchmarks of EVs. By conducting thorough testing and analysis, this research hopes to open the door for the electric car sector to widely embrace cutting-edge power conversion technology, which will ultimately result in more environmentally friendly and sustainable transportation options.

Keywords: *Switched capacitors, EV, Voltage Boost converters, Matlab, Inverters, Power Efficiency*

1. Introduction

In electronics, a voltage boost converter, sometimes referred to as a step-up converter, is essential because it raises the input voltage to a higher output level, which is necessary for powering devices that need higher voltage levels. It uses parts including an inductor, switch, diode, and capacitor to enable [1] Voltage conversion while operating on the concepts of energy storage and transfer. The converter operates in cycles between charging and discharging, storing energy in the magnetic field of the inductor during the former and releasing it to the output during the latter, producing an increased voltage. Though it may have drawbacks like low output current and voltage spike susceptibility, the converter's many advantages—such as voltage regulation, high efficiency, portability, and

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compactness—make it an essential tool for a wide range of electronic applications, from handheld devices to renewable energy systems and automotive electronics. [2] An inventive method of raising voltage levels in electronic systems is provided by switched capacitor voltage boost converters. They effectively elevate input voltages to desired output levels by using switches and capacitors, in contrast to conventional inductor-based boost converters. By carefully alternating the charge across the capacitors on a regular basis, switched capacitor converters may efficiently "step up" the voltage without the use of large inductors. [3] This method has a number of benefits, such as lower electromagnetic interference (EMI), easier design, and maybe improved efficiency in some applications. Switched capacitor converters have drawbacks despite these advantages, including a low output current capability and susceptibility to load fluctuations. However, continuous research and development continue to improve their functionality and increase their usefulness in a variety of electronic devices, especially those that need to be small in shape factors and precise voltage regulation. One major step towards improving the overall efficiency, performance, and range of electric vehicles (EVs) is the integration of a switching capacitor voltage boost converter. [4] EV makers may handle important issues in battery management and energy utilisation by utilising the special advantages of switched capacitor converters, such as their simplicity, compactness, and possible efficiency increases. With the ability to decrease size, weight, and cost while increasing engine efficiency, these converters provide an alternative to conventional boost converters. The incorporation of switching capacitor voltage boost converters gives an opportunity to optimise energy management systems, increase regenerative braking efficiency, and improve overall vehicle performance, particularly with the growing demand for electric vehicles (EVs) and the need to expand driving range. [5] The incorporation of cutting-edge technology like switching capacitor converters offers promise for advancing the design of electric vehicles and assisting in the general acceptance of sustainable transportation solutions as the EV industry continues to change. [6] Design of a Voltage Boost Converter Circuit shown in Figure 1.

2. Experimental Methods or Methodology

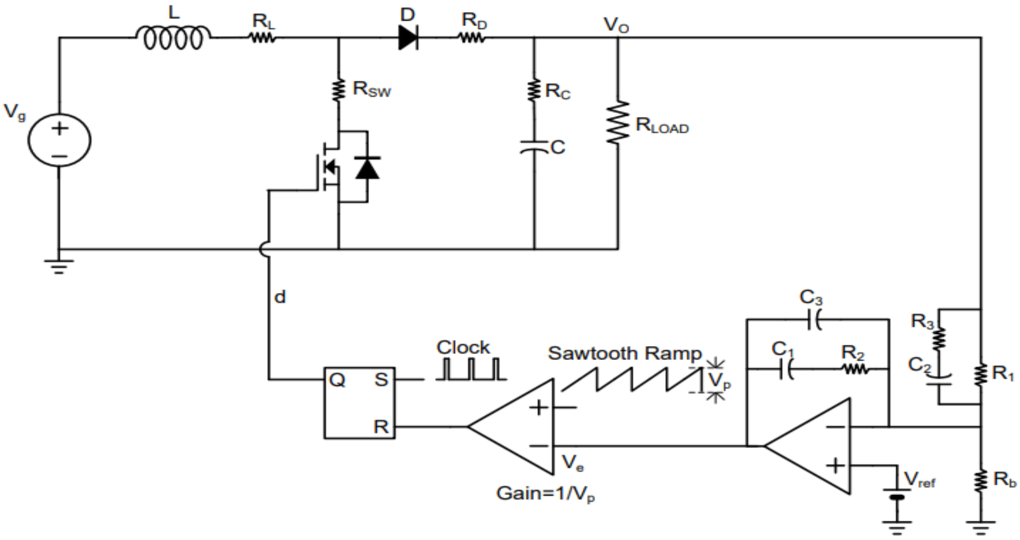

Figure 1 Design of a Voltage Boost Converter Circuit

A transistor switch, diode, inductor, capacitor, and other electronic parts work together to orchestrate the voltage boost converter's basic concept of energy transmission. The switch is closed during the charging phase, allowing the input voltage to energize the inductor and promote the build-up of

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energy in its magnetic field. [7] When the switch is opened again, the inductor's magnetic field collapses, causing a voltage spike between its terminals. The diode rectifies the resulting voltage increase, allowing the stored energy to leak into the output capacitor and load. An output voltage greater than the original input is produced by the consistent and effective stepping up of input voltages caused by the cyclical interaction of these phases. Boost converters work by alternating between these charging and discharging phases, which raises the input voltage level to a higher output voltage level. The ratio of the inductor's on-time to its off-time, the input voltage, and the properties of the circuit's component parts all influence [8] the output voltage. The boost converter is a useful part of many electronic devices and systems that need higher voltage levels for effective functioning because of this mechanism, which enables the boost converter to deliver a consistent output voltage even when the input voltage changes. To the best possible way. [9] Design of switched capacitor for voltage boost converter circuit are shown in Figure 2.

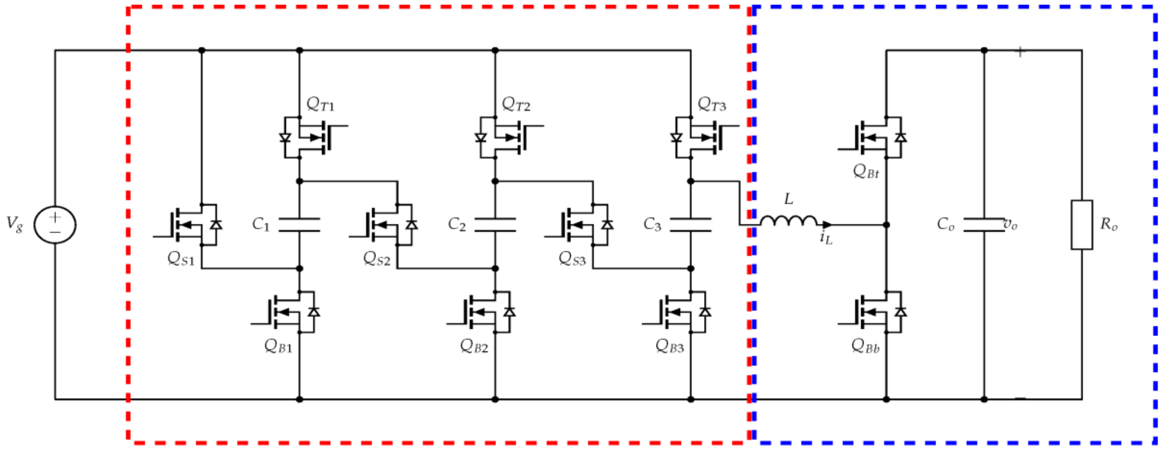

Figure 2 Design of Switched Capacitor for Voltage Boost Converter Circuit

Different from conventional boost converters, the switched capacitor voltage boost converter uses the periodic transfer of charge across capacitors to effectively raise voltage levels. Switched capacitor converters use capacitors and switches in a particular arrangement to store and transmit energy, in contrast to typical converters that rely on inductors. It works by applying an input voltage across a sequence of capacitors and then switching between connecting and disconnecting them via switches. [10] The capacitors are linked in parallel to the input voltage source during the charging phase, which enables them to build up charge. The capacitors are then rearranged in series during the discharging phase, which makes it easier for the stored charge to be transferred. Because switched capacitor converters produce a voltage increase at the output without the need for large inductors, they are especially useful in situations where high efficiency and small size are critical. [11] Furthermore, a variety of methods may be employed to regulate and control the voltage output of switched capacitor converters. To get the intended output voltage, this may include changing the capacitor ratios or the duty cycle of the switches. [12] Feedback control systems can also be used to provide accurate regulation and stability under various operating situations. Switched capacitor converters are ideal for a wide range of electronic applications due to their inherent simplicity, compactness, and potential high efficiency. Switched capacitor voltage boost converters are an attractive option for effectively and efficiently raising voltage levels while satisfying the strict size and performance criteria in contemporary electronics, from energy harvesting to portable devices and power management systems. [13] A switching capacitor-based voltage boost converter can be included into

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an electric vehicle (EV) to improve performance in a number of important areas. First off, the converter makes the best use of the energy at hand by effectively raising the voltage from the EV's battery pack to meet the needs of high-voltage components like electric motors and power electronics. This increases the vehicle's overall efficiency and range. Switched capacitor converters' lightweight and compact design also makes it possible for them to be seamlessly integrated into the EV's engine, which helps to lower weight and improve vehicle dynamics. For the EV driver, this means better acceleration, handling, and overall driving enjoyment. Additionally, [14] the converter's precision control and regulation capabilities aid in voltage stabilization, guaranteeing dependable and constant operation of vital vehicle systems even in the face of fluctuating load circumstances. All things considered, the addition of a switching capacitor-based voltage boost converter to an EV marks a significant development in terms of improving its functionality, efficiency, and performance, which will hasten the acceptance and adoption of electric vehicles. [15]

3. Results and Discussion

3.1 Boost Converter Simulation

A DC-DC converter architecture called a boost converter, often referred to as a step-up converter, is used to raise the input voltage to a higher output voltage level. An inductor, a switch (often a transistor), a diode, and a capacitor make up its fundamental topology. In order for the switch to function, an input voltage must be placed across the inductor, and it must regularly turn on and off. The inductor stores energy in its magnetic field when the switch is closed. The falling magnetic field then causes a voltage to be induced across the inductor when the switch is opened, producing a voltage boost. The stored energy may then pass through the output capacitor and load thanks to the diode's conductivity, which keeps the output voltage steady. This looping procedure makes the boost converter to efficiently step up the input voltage, making it suitable for various applications where a higher voltage level is required. Simulation of a Boost Converter circuit in Matlab are shown in Figure 3.

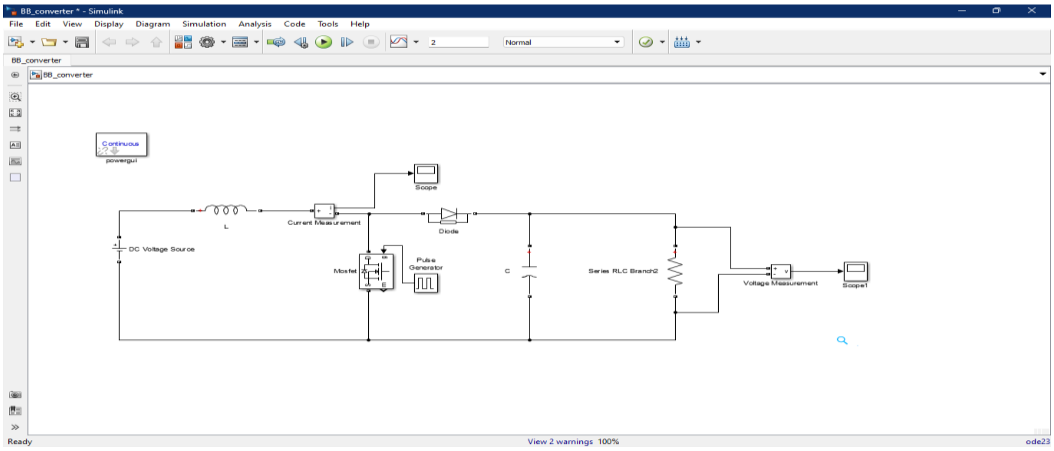

Figure 3 Simulation of a Boost Converter circuit in MATLAB

3.2 Output waveform of a Voltage Boost converter

The switch (transistor) is closed at first. This makes it possible to apply the input voltage across the inductor. Consequently, current begins to flow through the inductor, creating a magnetic field and allowing the inductor to store energy. The diode is reverse-biased during this phase, which stops electricity from going to the output. The switch is then turned on. This causes the inductor's magnetic field to collapse, which causes a voltage to be applied across it in the opposite direction. A voltage boost is generated across the inductor terminals by this event. When the diode is forward-

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biased, the inductor's stored energy may release through the output capacitor and load. Output waveform of a Boost Converter are shown in Figure 4.

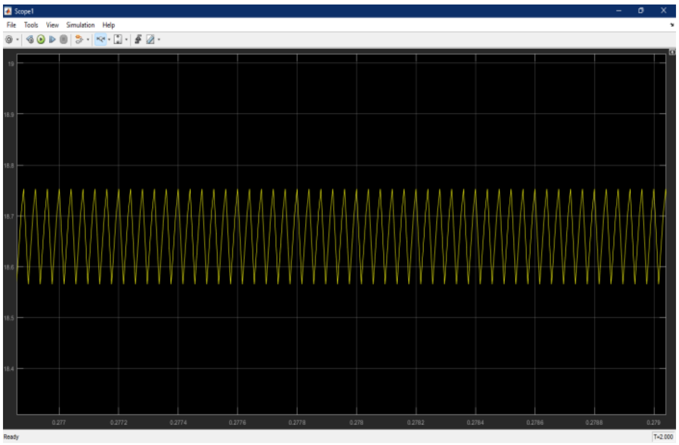

Figure 4 **Output waveform of a Boost Converter**

3.3 Simulation of a Switched Capacitor Voltage Boost Converter

Switched capacitor converters effectively raise voltage levels by using switches and capacitors as opposed to standard boost converters, which rely on inductors. First, the input voltage is passed via a set of capacitors that are organised in a certain way. Switches are used to connect and detach these capacitors in turn, transferring charge between them in a cycle. The capacitors are linked in parallel to the input voltage source during the charging phase, which enables them to build up charge. The stored charge is essentially "pumped" through the series arrangement by altering the connection pattern, increasing the output voltage. Because switched capacitor converters increase voltage without the need for inductors, they are especially well-suited for applications that need great efficiency and compact size. By changing the capacitor ratios or the duty cycle of the switches, the converter's output voltage may be regulated. Furthermore, feedback control systems may be used to precisely manage the output voltage, guaranteeing stability and dependability throughout a range of operating circumstances. Simulation of a Switched Capacitor Voltage Boost Converter circuit in Matlab are shown in Figure 5.

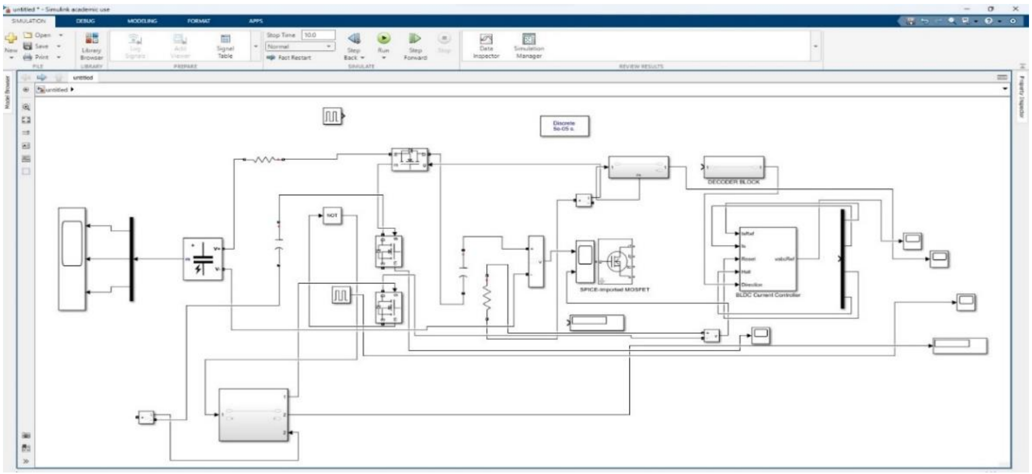

Figure 5 **Simulation of a Switched Capacitor Voltage Boost Converter circuit in MATLAB**

3.4 Output waveform of a Switched Capacitor Voltage Boost Converter

The voltage that has been raised above the input voltage level is the output of a switching capacitor voltage boost converter. Switched capacitor converters accomplish voltage boosting by periodically transferring charge across capacitors, in contrast to conventional boost converters that rely on inductors for energy storage and transmission. Switches are used to regulate the connection and disconnection of a series of capacitors that are subjected to an input voltage

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during operation. The converter essentially 'pumps' the stored charge to raise the output voltage by first connecting the capacitors in parallel to the input voltage source and then rearranging them in series. Output Waveform of a Switched Capacitor Voltage Boost Converter are shown in Figure 6.

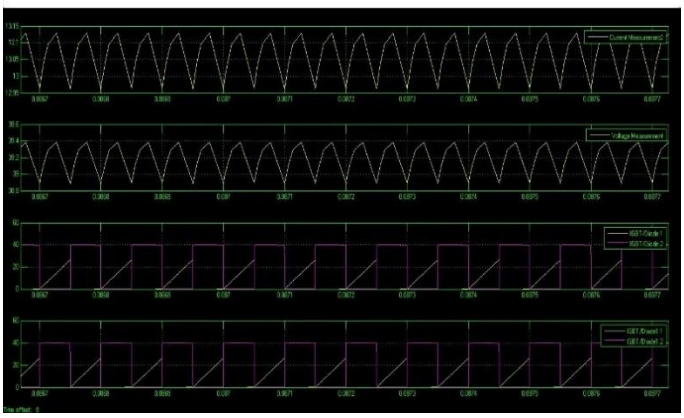

Figure 6 Output Waveform of a Switched Capacitor Voltage Boost Converter

3.5 Mathematical Calculations and Analysis

i. **When the capacitor is charging:**

Vbat = vcap
Vcap = Saia + Sbib + Scic
When the capacitor is discharging:
Vbat = vcap
v = 2Vbat,
Vcap = Saia + Sbib + Scic

ii. **The reference voltage for the measurement of each wave:**

VrefTs = Vxtx + Vyty + V0t0
Vxtx = V11t11 + V12t12
Vyty = V21t21 + V22t22

iii. **Boost converter modulation factor:**

$$A = \begin{cases} 0, & 0 \le M_i \le \frac{1}{\sqrt{3}} \\ \sqrt{3}M_i - 1, & \frac{1}{\sqrt{3}} < M_i \le \frac{2}{\sqrt{3}} \end{cases}$$

where the modulation M_i is defined as

$$M_i = \frac{|\mathbf{V}_{ref}|}{V_{bat}}.$$

iv. **Voltage drops in capacitor:**

$$\Delta v_{cap} = \frac{i_{cap} t_{dch}}{C},$$

v. **Maximum Voltage generated:**

$$\Delta V_{max} = \frac{3AM_i I}{4Cf_{sw}}.$$

vi. **Charging time:**

$$\begin{aligned} t_{ch} &= \frac{t_0}{2} + (1-A)t_y \\ &= \frac{T_s}{2} - \sqrt{3}T_s M_i \left[\frac{1}{2}\sin(\frac{\pi}{3} - \theta) - (\frac{1}{2} - A)\sin(\theta)\right]. \end{aligned}$$

vii. **Minimum charging time**

$$t_{ch-min} = \begin{cases} \frac{1}{2}T_s(1 - \frac{3}{2}M_i), & 0 \le A < \frac{3}{4} \\ \frac{T_s}{2} - \sqrt{3}T_s M_i & \\ \left[\frac{1}{2}\sin\left(\frac{\pi}{3} - tan^{-1}(\frac{4A-3}{\sqrt{3}})\right) - \right. & \\ \left. (\frac{1}{2} - A)\sin\left(tan^{-1}(\frac{4A-3}{\sqrt{3}})\right)\right], & \frac{3}{4} \le A \le 1. \end{cases}$$

viii. **To calculate Power loss in output generation:**

$$P_{R-losses} = \frac{1}{R}\left(\frac{3AM_i I}{4Cf_{sw}}\right)^2.$$

Conclusion

The problem of effectively raising voltage levels in electronic systems may be revolutionized with the switched capacitor voltage boost converter. Using controlled switching and the principles of charge transfer between capacitors, this converter reduces the size and weight of its design by doing away with the bulky inductors. This benefit is especially noteworthy in the context of contemporary electronics, where energy efficiency and space restrictions are critical. Furthermore, the converter's adaptability makes it possible to integrate it into a variety of applications with ease, improving their operation and performance, from portable gadgets to renewable energy systems. Additionally, the voltage boost converter with switched capacitors exhibits remarkable efficiency and accurate voltage control capabilities. Its effective charge transfer across capacitors guarantees that there is little energy lost during voltage conversion, which raises the efficiency of the system as a whole. Furthermore, even in the face of dynamic load situations, steady output voltage levels are guaranteed by the precise control mechanisms of the converter, which enable correct

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voltage regulation. The switched capacitor voltage boost converter is still a key element advancing power electronics innovation, opening the door for increasingly compact, dependable, and efficient electronic systems as electronic systems need to become more efficient and smaller.

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