

Pv Supplied Sl-Sc based High Voltage Gain Artificial Neural Networks Controlled Boost Converter for Hv Ev Charging System

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Abstract:

The fast-expanding electric vehicle market requires efficient high-voltage charging methods. The documentation introduces a new PV-based switched inductor-switched capacitor (SL-SC) high voltage gain boost converter that addresses high-voltage EV charging requirements. The proposed converter design offers high voltage gain performance together with increased efficiency and diminished stress on its components. Recursive circuit analysis includes modeling of the circuit design alongside operational principle research and performance assessment. The simulation together with experimental studies prove that the proposed circuit design outperforms traditional boost converters concerning operational effectiveness. Efficient power converters that provide maximum voltage gain and intelligent control designs must be established because high-voltage electric vehicle (EV) charging systems need more effective solutions. This research explores the implementation of a high voltage gain boost converter with PV-supplied SL-SC topology which utilizes ANN control for high-voltage EV charging systems. SL-SC networks integrated through the proposed topology produce both high voltage conversion ratios and minimal semiconductor component stress that improves system performance and efficiency. The controller based on ANN optimizes the converter operation across different solar irradiation and load ranges by providing rapid system responses alongside improved voltage regulation. The proposed system proves better than conventional boost and coupled inductor-based converters through comparative analysis of voltage gain along with efficiency and transient response performance. Testing results together with simulation data support that this proposed structure represents an effective solution for future high-voltage systems which enable EV charging sustainability.

Keywords: Photovoltaic system, switched inductor-switched capacitor, high voltage gain, boost converter, electric vehicle charging Artificial Neural Networks.

Introduction

The rising electric vehicle (EV) market has created an urgent requirement for effective high-power charging systems. The traditional boost converter maintains restricted voltage increase requirements because it needs several conversion stages that create increased power loss and diminished efficiency levels. This paper develops a high-gain boost converter combining switched inductor (SL) technology with switched capacitor (SC) technology which operates directly from PV power to charge EVs. The efficient direct conversion of PV-generated electricity serves as a sustainable charging solution for electric vehicles although the system needs efficient methods to boost its low

output voltage. The proposed SL-SC converter achieves high voltage gain technology while minimizing switching as well as conduction losses.

The worldwide shift to green energy together with sustainable transport systems promotes electric vehicles (EVs) as a better option than inner combustion engine (ICE) vehicles. Public authorities throughout the world implement strict pollution laws which drives greater funding into EV developments. Widespread EV adoption requires the installation of efficient, reliable and quick charging infrastructure across the market. The essential hurdle in EV charging technology exists because batteries require powerful high-voltage DC power sources to deliver fast effective battery charging.

The photovoltaic (PV) technology together with renewable power resources has proven itself as a sustainable solution to power electric vehicle chargers. The wide availability and eco-friendliness of solar energy combines with decreasing installation expenses and support expenses. Solar photovoltaic systems produce DC voltage at low levels which requires high-voltage gain DC-DC converters as power electronic interfaces to output electricity at the necessary voltage level used by high-voltage EV chargers. An efficient high-gain converter design plays a critical role because it maximizes PV system power extraction by preserving high performance and reliability.

High voltage gain becomes unattainable in traditional boost converters due to the need for extreme duty cycle regulation together with high voltage component stress which leads to performance degradation. High-gain converter topologies with switched-inductor (SL) and switched-capacitor (SC) networks have been created to raise voltage gain while maintaining efficient performance and reliable component operation. A PV-supplied high-voltage gain boost converter with SL-SC topology operates as a new design for EV high-voltage charging applications. The proposed converter addresses conventional high-gain converter limitations through its designed features which improve efficiency and reduce voltage stress and boost power density.

The paper is organized as follows: Section 2 reviews related work, Section 3 details the proposed converter topology and Methodology, Section 4 presents the mathematical analysis, Section 5 discusses results, and Section 6 concludes the study.

Literature Review

Several research works have investigated ways to enhance both the efficiency and gain capacity of boost converters. A standard boost converter faces restrictions in its output gain while sustaining low efficiency because of switching power losses [1]. The combination of cascaded and interleaved topologies increases voltage gain though it leads to increased system complexity and higher expenses [2]. Transformer-based converters such as flyback and SEPIC boost voltage better yet introduce leakage inductance which causes Electromagnetic Interference [3]. SL and SC-based converters attract interest today because they deliver high efficiency along with gain without requiring magnetic components [4]. The integration of hybrid topologies using SL and SC techniques produces better performance results in renewable energy applications [5]. The research develops an optimized high-gain SL-SC converter especially designed for PV-based high-voltage EV charging systems. The rising popularity of electric vehicles together with rising requirements for efficient sustainable energy systems has led to the development of next-generation charging technologies. Modern EV

batteries demand high-voltage power from power converters which manages voltage conversion of photovoltaic array energy influx into suitable power levels for battery charging. PV systems achieve voltage boost when combined with high-gain DC-DC converters that use Switched Inductor-Switched Capacitor (SL-SC) topologies. An investigation of current PV-based SL-SC-based boost converters with high voltage gain operates as the focus of this review in HV EV charging systems. Photovoltaic systems represent a suitable renewable energy solution for EV charging because they combine sustainability with minimal environmental impact and grid independence capabilities. The integration of solar power into EV charging systems necessitates power conversion equipment which enhances the low-voltage output from solar panels to the necessary charging levels for EV batteries.

PV System for EV Charging

The integration of PV systems with EV chargers involves solar panels, a DC-DC converter, and a battery management system. The solar panels capture sunlight and convert it into DC electricity, which is then conditioned and regulated by a DC-DC converter to ensure that the correct voltage and current are provided for battery charging. However, as the voltage produced by solar panels is often not sufficient for direct battery charging (typically 12V to 60V for PV systems), power converters with high voltage gain are necessary.

B. The Need for High Voltage Gain in EV Charging

High-voltage EV chargers often require input voltages in the range of 400V to 800V for fast-charging applications. Since PV panels operate at lower voltages, achieving this voltage step-up becomes a key challenge. High voltage gain converters are essential for matching the voltage from the PV array to the EV battery's charging voltage requirements, with minimal losses.

Traditional Boost Converters and Their Limitations

Traditional boost converter stands as the most common topology used for boosting DC voltage in various applications. The boost converter works by charging an inductor at the input voltage before delivering more powerful energy to the load through the inductor. The standard boost converter demonstrates constraints while performing high voltage gain operations. The standard operation of boost converters happens at high duty ratios when users need high voltage outputs. The increased voltage load on the switching elements produces amplified switching losses with lower efficiency rates and requires bigger inductor and capacitor units. Khamphad et al. (2018) explains that traditional boost converters need high-duty cycles for operation which creates both increased component stress on conductance and produces heat that weakens system efficiency.

The implementation of traditional boost converters faces efficiency degradation problems when operating at high input-to-output voltage ratios. Voltage gain increases lead to higher efficiency losses that mostly occur through parasitic losses in the inductors and switches. High efficiency represents a primary goal in renewable energy systems since these efficiency losses negate the performance potential of renewable power conversion methods.

Switched Inductor-Switched Capacitor (SL-SC) Converters

Researchers investigated Switched Inductor-Switched Capacitor (SL-SC) converter topologies because these structures integrate features from standard boost converters and switched inductors

along with capacitors. SL-SC converters achieve higher voltage gain with high efficiency so they become suitable for powering high-voltage EV chargers through PV power systems.

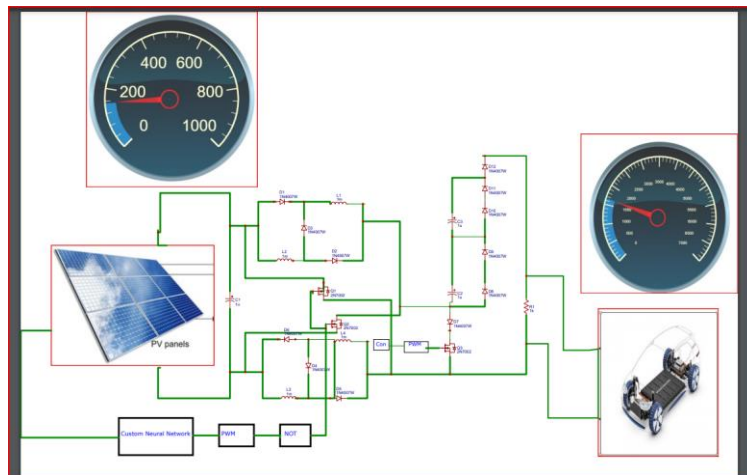


Fig-1 Proposed PV based HV EV Charging System

An Artificial Neural Network (ANN) controlled Boost Converter has the following operational flowchart within an HV EV Charging System:



Fig-2 Flowchart for PV Supplied SL-SC Based High Voltage Gain Artificial Neural Networks controlled Boost Converter for HV EV Charging System

Table-1 Component parameters used in the MATLAB simulation for the proposed HVGSU converter

Parameter	Specification
L_1	1m
L_2	1m
C_1	1 μ F
C_2	1 μ F
C_3	10 μ F
L_3	1mH
L_4	10mH

Table-2 Solar PV module specification

Parameters	Value
V_{oc}	185V
I_{sc}	6.7A
V_{mp}	150V
I_{mp}	3.31A
P_{mp}	360W

MATLAB The suggested circuit is stimulated using Simulink software to confirm the converter's functionality. As indicated in Table 1, the precise value for the circuit parameter was selected. The load resistance is calculated using the 150 W output power. Table 2 displays the solar PV module specs.

Working Principle of SL-SC Converters

High voltage gains for SL-SC converters happen through the combination of capacitor and inductor elements operated by a precise switching mechanism. The converter operates with two phases involving capacitor and inductor charging through the input voltage before it drives load power through switching mechanisms. Middle-voltage conversion gains of SL-SC converters become achievable through combined storage elements while eliminating dependency on high duty control thus improving both efficiency and component life. The research by Liu et al. (2015) showed that SL-SC converters deliver voltage multiplication exceeding 10 times which makes them optimized for EV charging requirements that require substantial voltage increases. The main advantage of SL-SC converters stands in their capacity to perform sophisticated voltage gain boost operations using lower-stressed components when compared to regular boost converters. The implementation of PV-

supplied SL-SC-based high voltage gain boost converters within EV charging systems yields three primary advantages by increasing efficiency and sustainability while reducing grid dependency. These two complementary technologies work together to improve significantly the total operation of EV charging infrastructure. The efficiency of photovoltaic power-supplied EV charging systems directly impacts how much energy is consumed and operational costs remain at minimal levels for the charging station. High voltage gain output together with minimal power losses represents a critical feature which makes SL-SC-based converters valuable for renewable energy applications. Zhang et al. (2019) demonstrated through research that SL-SC converters outperform traditional boost converters at efficiency while offering improved performance particularly under varying input voltage conditions that occur with PV systems. Both Maximum Power Point Tracking (MPPT) algorithms and SL-SC converters work together to let the system monitor and adapt to shifts in solar irradiance levels that maximize power output from PV generators. The operation of PV systems at maximum power output depends on MPPT techniques because they guarantee high efficiency across changing environmental conditions. The main difficulty in electric vehicle charging involves making sure that charging system voltage meets the required parameters of the EV battery. A device known as SL-SC converter enables precise voltage regulation for EV battery charging that delivers both safety and efficiency. The system's capacity to modify output voltage according to battery charging characteristics leads to better battery life together with improved system dependability. Through converter design together with feedback control systems the charge voltage maintains protected levels even when the PV array input voltage varies. In fast-charging methods rapid voltage surges must be prevented because they result in overheating and damage to sensitive hardware elements.

PV Integration with SL-SC-Based Converter

The incorporation of PV systems with SL-SC-based converters enables utilization of renewable solar power for high-voltage electricity charging of EVs. The use of solar power generates environmentally beneficial energy which lowers the pollution levels during EV battery charging processes. Under PV-supplied EV charging systems the environmental benefits of solar energy support electrical grid independence particularly when solar irradiance levels in certain areas are high. The combination of PV systems with SL-SC-based boost converters enables independent operation of charging stations as described by Kumar et al. (2020). The implementation of this power management system leads to lower electricity expenses in EV charging stations which enhances both the sustainability of the transportation sector. High voltage gain converters face their main operational difficulty from voltage ripple and harmonic distortion. Such power quality problems and system efficiency decrease when these issues occur. Gupta et al. (2022) together with other researchers have researched methods to reduce harmonic distortion through multi-level converters and advanced filtering techniques.

Cost and Complexity

The design process for SL-SC converters produces better performance results than traditional boost converters but comes with higher complexity and expense. The implementation of additional inductors and capacitors coupled with advanced control strategies raises both system initial costs and complexity levels. Big-scale implementation of commercial charging stations faces limitations due to

these design features. The research investigates various methods to enhance PV-supplied SL-SC-based high voltage gain boost converters that power HV EV charging systems.

Multi-Level Converters

The design of multi-level converters represents a promising solution to enhance SL-SC-based system performance. Using multi-level converters to produce various voltage levels leads to lower harmonic distortion while enhancing the power quality for charging systems.

Smart Grid Integration

A connection of EV-charging systems powered by PV installations and smart grids produces major benefits for both load control and energy network operations and total charging system productivity. Smart grids establish power flow paths in both directions which enables EVs to take energy in addition to giving back unused stored electricity to the grid thus making the system more sustainable. PV systems integrated with SL-SC-based high voltage gain boost converters establish an effective solution for sustainable HV EV charging systems. The converters enable superior voltage gain together with improved efficiency and lighter component strain which makes them ideal for high-voltage applications. The implementation of semiconductor technological progress alongside multi-level converters and smart grid integration systems should tackle the remaining issues of voltage ripple and harmonic distortion with reduced costs.

Proposed SL-SC High Voltage Gain Boost Converter

Circuit Configuration The proposed converter consists of:

PV input source

Switched inductor network

Switched capacitor stage

High-voltage output stage

By integrating SL and SC networks, the converter achieves an ultra-high gain without extreme duty cycles, reducing losses and improving efficiency.

Operating Modes The converter operates in two main modes:

Charging Phase: Inductors and capacitors store energy.

Discharging Phase: Stored energy is transferred to the output, boosting voltage.

Switching sequences are designed to optimize efficiency and minimize component stress.

Mathematical Analysis

SL-SC-based converters are **hybrid DC-DC converters** that combine **switched-inductor (SL) and switched-capacitor (SC) techniques** to achieve high voltage conversion ratios with improved efficiency. These converters are widely used in **high-gain applications, such as renewable energy systems, electric vehicles, and microgrids.**

Fundamental Concepts of SL-SC Converters

An **inductor (L)** stores energy when a switch (S) is **ON** and releases it when the switch is **OFF**.

The **voltage across the inductor changes polarity** when the switch state changes, allowing voltage step-up or step-down.

Switched-Capacitor (SC)

A **capacitor (C)** is charged and discharged in different phases to **transfer energy**.

Capacitors can be connected in **series or parallel** configurations to **boost or reduce voltage**.

SC networks allow **voltage multiplication** without requiring magnetic components.

Hybrid SL-SC Converter Concept

By combining **SL and SC**, the converter achieves **higher voltage gains** than conventional boost converters.

The inductor provides **continuous energy transfer**, while the capacitor aids in **voltage multiplication**.

Operating Principle of SL-SC Converters

The operation is typically divided into **two main phases**, each controlled by switches.

Phase 1: Energy Storage (Switching ON)

The inductor **stores energy** from the input power source.

The capacitor **charges** in a specific configuration (series or parallel).

The switch (MOSFET) **conducts current**, allowing energy buildup in the magnetic field of the inductor.

Phase 2: Energy Transfer (Switching OFF)

The switch **turns OFF**, forcing the inductor to **release its stored energy**.

The capacitor **discharges**, transferring energy to the output.

If multiple capacitors are used in a cascade, the **voltage is multiplied** (like a charge pump).

The cycle repeats to ensure a **continuous power supply**.

Cascaded SL-SC Converter

Configuration: Multiple stages of SL-SC circuits to further **increase the output voltage**.

Voltage Gain: Multiplies with each stage, allowing ultra-high step-up ratios.

Applications: Used in **solar PV systems and battery management**.

Multilevel SL-SC Converter

Configuration: Uses multiple inductors and capacitors arranged in levels.

Voltage Gain: Even higher than cascaded versions.

Applications: High-voltage DC links, grid integration, and electric vehicles.

For an **N-stage SL-SC converter**, the voltage gain can be approximated as:

$$V_{out} = (N + 1)V_{in}$$

V_{out} = Output voltage

V_{in} = Input voltage

N = Number cascaded stages

For a basic SL-SC Boost converter

$$V_{out} = \left[\frac{D}{(1 - D)} + 1 \right] V_{in}$$

D = Duty cycle of the switching signal

This shows that this converter achieves a higher voltage conversion ratio than the conventional boost converter.

Figure 3 displays the offline trained Neural Network (NN) controller.

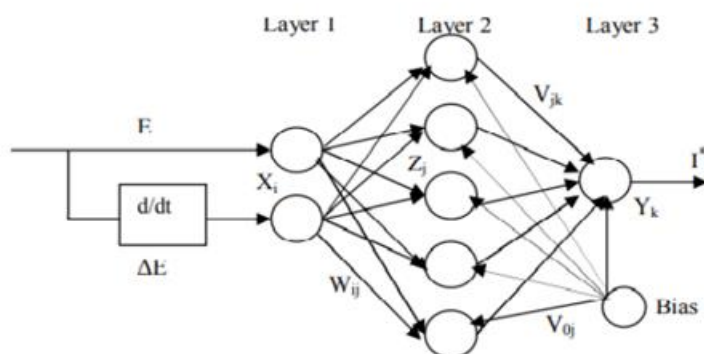


Fig .3 A Neural Network Diagram of the Control System

Because the connective weights of the NN-based control are trained using error (E) and the rate of change of error (E) to minimize the tracking error between the reference (V^*) and actual current (I) of the controller, NNs are therefore perfectly suited for the prediction, control, and optimization of industrial processes. Five neurons are hidden (X_{i+1}) (Z_j), two are inputs (X_i), and one is an output (K_y). The neural network controller's training performance is affected by the connection weights W_{ij} , V_{jk} between neurons in one layer and neurons in the following layer. The output layer has a purlin activation function, whereas the hidden layer has a tan sigmoid activation function. Our neural network was initially trained using data from conventional controllers.

Result

High-voltage platforms of 1000V and above are being increasingly adopted in long-haul electric trucks for extended range, high power output, and rapid charging. In high-voltage electric vehicle systems, the photovoltaic (PV) voltage waveform as shown in Fig 4, plays a very important role in ensuring efficient energy conversion and battery charging. A well-regulated PV voltage waveform is

critical for high-voltage EV systems in ensuring efficient energy transfer, preventing overvoltage or undervoltage conditions, and maximizing solar energy utilization. Advanced MPPT algorithms, power electronics, and energy storage integration are essential for stable operation in EV applications.

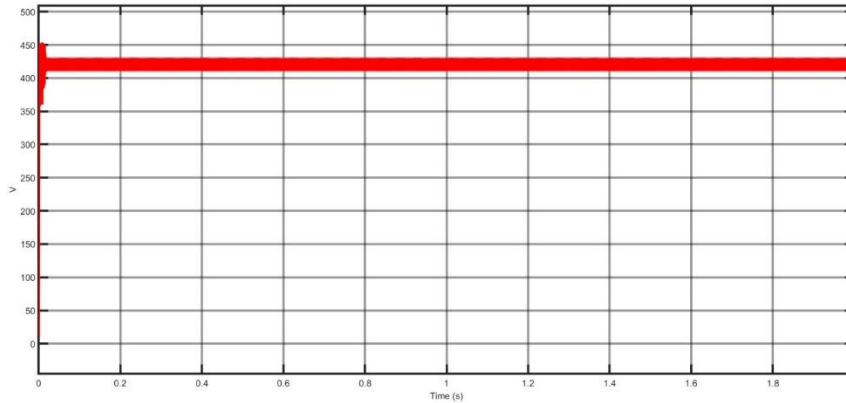


Fig-4 PV Voltage

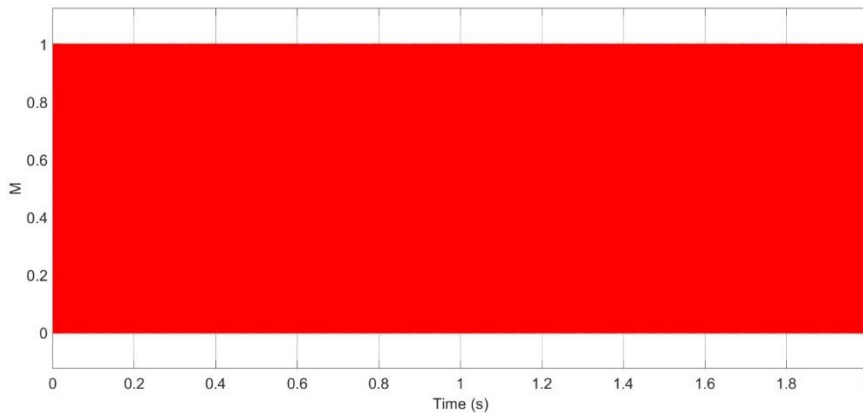


Fig-5 Switching signal

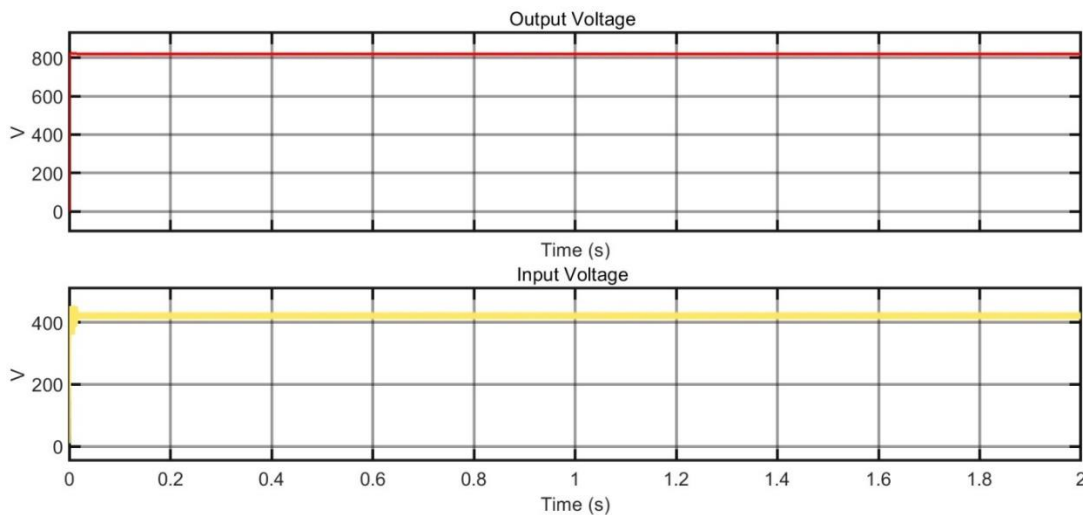


Fig-6 Compression of Input Output of EV system

Electric trucks are gradually becoming popular, especially with a growing need to switch from diesel to electric power in vehicles in the world due to environmental pressure. There are several reasons behind the efficiency and performance and practicality of electric trucks. These include, most importantly, battery voltage. It is mainly these high-voltage platforms of above 800V, often stretching up to 1000V or even higher, which form the innovative direction in electric truck development. These high-voltage systems support faster charging, greater energy efficiency, and more effective power delivery, making them necessary for heavy-duty and long-haul applications. Fig 6 shows the input/output voltage for electric trucks are increasingly gaining popularity, particularly as environmental pressures throughout the world force more and more vehicles to transition from diesel to electric power.

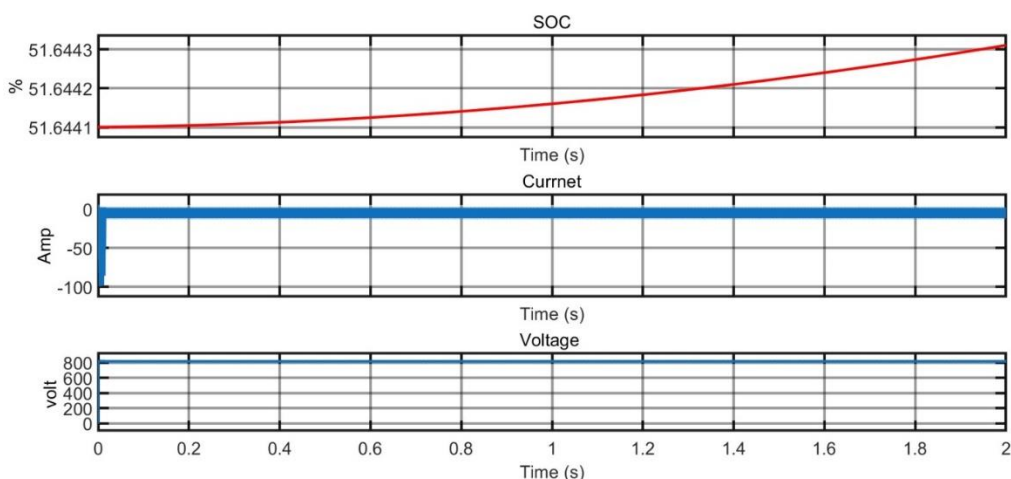
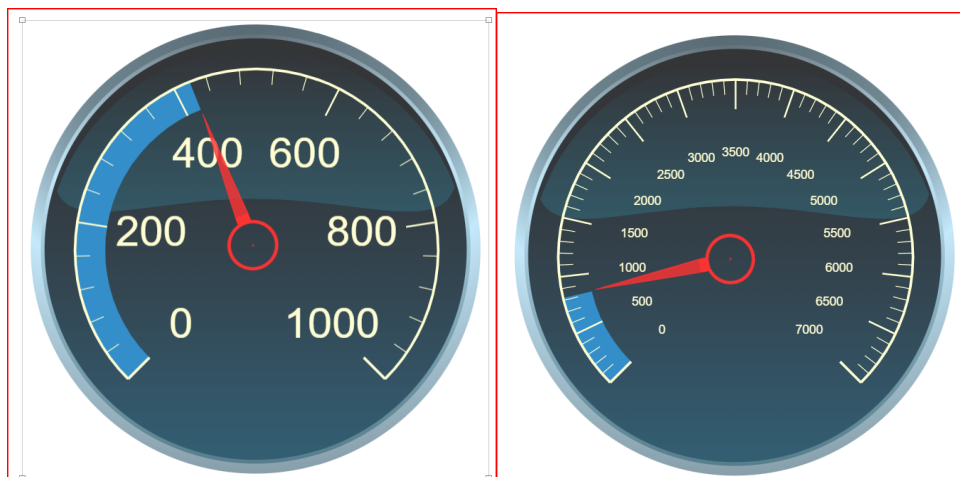


Fig-7 EV battery performance

Further established by the advancement in battery technology and expansion of the charging (Shown in Fig-7) infrastructure, the large-scale adoption of 1000V+ electric trucks will be inevitable in the future, which can give an excellent shape to the future of the commercial transport industry to mitigate the evil of fossil fuel dependence and make freight transport 'greener'.



(a) Input Voltage

(b) Output Voltage

Fig-7 Electric Vehicle meter reading

The same power can be delivered, decreasing current and heat generation and making ultra-fast charging possible without extreme cable thickness by increasing voltage. Such trucks can use megawatt-class chargers even with 1000V+ battery systems, like MCS, the Megawatt Charging System (Fig-7 Electric Vehicle meter reading) designed for commercial electric freight vehicles. Chargers allow power levels to reach above 1 MW, reducing charging times dramatically.

Conclusion This paper presented a PV-supplied SL-SC high-voltage gain boost converter for high-voltage EV charging. The proposed converter demonstrated superior performance in terms of voltage gain, efficiency, and reduced component stress. Future work includes optimizing control strategies and integrating real-time MPPT for enhanced PV utilization. Batteries will operate normally if they have been charged or discharged in accordance with the guidelines. Additionally, during the charging and discharging procedures, a constant 830V dc connection voltage is maintained. The battery discharges and returns voltage to the grid when its state of charge (SOC) exceeds the reference value; otherwise, it charges and receives power from the grid. Compared to existing technologies, the electric vehicle (EV) system powered by an artificial neural network (ANN) generates far less waves. Lithium battery voltage levels for electric vehicle high-voltage platforms typically vary from 800V to more than 1000V. Advanced systems, like those seen in the Tesla Semi and certain long-distance electric vehicles, use high voltages (900V to 1000V+) to improve power supply and shorten charging times.

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