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Original Article

A New Hybrid Structure for Bidirectional DC-DC Converters with High Conversion Ratios for Electric Vehicles using War Strategy Optimization-WSO

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Abstract *- This work uses War Strategy Optimization (WSO) to build a new hybrid design for electric vehicle bidirectional DC-DC converters with high conversion ratios. Low voltage load on semiconductors, high voltage conversion ratios, a steady current at the low voltage port, and a steady potential differential between the lower voltage and the high voltage ports' grounds are some of the features of the suggested converter. The converter's efficiency is raised by using synchronous rectification. The primary benefit of the suggested structure is that it may be utilized with various energy sources with various voltage-current characteristics. Furthermore, the battery may be charged in breaking mode because of the bidirectional nature of the proposed design. New energy automobiles are increasingly using the method for energy storage that is a hybrid of "fuel cell/power battery plus supercapacitors" to improve the powertrain's longevity and dynamic performance. This converter is a great substitute for DC-DC converters because of its high voltage gain and the aforementioned characteristics for electric vehicles. The WSO approach showed that charge prices dropped by 12.45% and 3.61%, respectively, while waiting times dropped by 11.17% and 39.09%; these findings imply that the WSO algorithm has the potential to increase both the efficacy and affordability of EV management systems, particularly in scenarios with inadequate charging infrastructure. The charge and discharge states can produce the highest efficiency, 98%, respectively, based on experimental results.*

Keywords *- Bidirectional DC-DC converters, Electric Vehicles, War Strategy Optimization (WSO), High voltage conversion ratio, Energy management.*

1. Introduction

Distributed Energy Resource (DER)-enabled DC grids are currently being viewed as a dependable and effective substitute for AC networks [1]. Better power quality results from DC grids' lack of reactive power and harmonic currents, in contrast to AC grids' [2, 3]. Controller design for DER is easier than for AC grids since DC systems do not regulate frequency or reactive power [3]. In today's DC applications, conventional converters like buck, boost, buck-boost, etc., usually perform badly. As a result, a lot of research has been done recently to create novel DC-DC converter topologies that meet modern standards for performance [4]. They do, however, demonstrate that they are combined in this composite battery charging system to create a small, light EV charger. The charger being three H-bridge converters are used in the description; these include inductors, a high-frequency power converter and selective switching [5]. The ability of Electric Vehicles (EVs) to supply DC microgrids with auxiliary power services permits EVs to be powered by the electric utility, allowing for efficient and clean battery-powered transportation. [6]. Another difficulty in this area is controlling these gadgets. Therefore, for the development of DC MGs, an appropriate configuration and an effective control strategy are required. Using solar Photovoltaic (PV) as the producing source and a supercapacitor and battery for storage, this work introduces a novel framework for DC MG [7]. The advantages of the converter that is being demonstrated include mutual ground. Additionally, the converter's efficiency is increased by applying synchronous rectification technology [8]. The suggested converter is resistant against DC-side flaws, has a straightforward design, and can control bidirectional power flow. The dynamic model that was created indicates that because that rotates [9]. Due to the wider range of driving conditions for vehicles, the guarantee that the vehicle bus voltage and the electrical power from the power source or SC voltage may be successfully matched when operating conditions change [10]. Creating a new hybrid converter structure that integrates cutting-edge optimisation methods like WSO for bidirectional DC-DC converters with high conversion ratios, especially for electric vehicle applications, represents a research gap in this field. This will entail investigating innovative converter topologies and effective optimisation techniques and tackling real-world issues, including component reliability and thermal management in dynamic EV operating environments.

The main contributions of the paper are as follows:

- An analysis is conducted on the classification and derivation of bidirectional DC-DC topologies.
- Effective electrical energy transmission is possible with this converter technology.
- The converter system operates with good stability due to the control method.
- By employing the converter electrical vehicle war strategy optimization algorithms.

The paper is organised as follows: the 1st section introduces the topic and explains the need for this endeavour. The 2nd part contains the related works. The paper's suggested methodology is presented in Section 3. The results and discussion are in the 4th part. Lastly, the conclusion is included in section 5.

2. Related Works

Kumar, G. et al. (2020) [11]. Research efforts to improve the DC-DC converters' dependability are still scattered and extremely restricted. Since semiconductor technology is developing quickly, DC-DC converters come in many topologies with a wide range of capabilities and operating principles. Improving the dependability of all kinds of DC-DC converters remains a difficult undertaking. The most brittle parts of converter circuits are power switches, which are inevitably vulnerable to system malfunctions.

C.S. Lai and colleagues (2020) [12]. The research on the definitions and domains of smart cities is presented at the beginning of this article. The well-known guidelines for smart cities will be provided to help you better grasp the idea. Meaningful comparisons between the implementation of smart cities are made possible by well-specified criteria. This assessment emphasises how crucial technical standards are to deploying smart cities. This document provides an overview of the latest advancements in smart city standards. Metwly, M. et al. (2020) [13]. This paper first examines the main topologies presented in recent research; completely integrated have been developed using either permanent magnet motors or induction motors. Topologies that need little to no hardware reconfiguration are given particular attention. In 2020, Monteiro V. et al. [14]. An EV's DC interface between the AC electricity grid and a Renewable Energy Source's (RES) DC link interface are all managed by the proposed MF-EVCS. These are novel features. Monteiro V. et al. (2019) [15]. Improved vehicle-for-grid (iV4G), the suggested operating mode, is closely tied to how the EVs operate and seeks to compensate for power quality issues related to reactive power and current harmonic distortion.

V. Rathore and associates (2022) [16]. The suggested topology reduces the size of the inductor. It does away with the requirement for an extra clamping circuit that supplies power to the load structures by employing dual current route inductor structures. Without the use of hybrid switched-capacitor techniques or Voltage Multiplier Cells (VMC), the suggested converter can produce a sizable voltage gain.

Jarrahi M et al. (2020) [17] have recommended using DC-DC converters in power conversion solutions for energy management, which is growing in popularity. These converters are utilised in a growing number of DC-based applications, including LED lighting, electric vehicles, energy storage systems, and consumer electronics (laptops, smartphones, etc.). Dependability and efficiency are crucial in this situation. Enhancing the reliability of all types of DC-DC converters is made more difficult by the fact that they might have an infinite number of distinct topologies, each with unique functionalities and principles of operation.

Bhargav, R et al. (2019) [18]. have proposed a novel approach to fault localisation and detection for a microgrid network with Low Voltage direct current (LVdc). While high-resistance ground faults are recognised by measuring ground current at the relay position, low-resistance faults are identified by monitoring voltage across the inductor. The fault site is then calculated using an iterative process that compares the measured fault current value with the analytically computed fault current. Caseiro L et al. (2021) [19]. have suggested providing full-rated post-fault operation; the solution may fix open-circuit faults in all semiconductors (IGBTs and diodes) of all converters in the system, including the DC-DC converter.

This method implements very particular fault correction by utilising the flexibility of Finite-Control-Set Model Predictive Control. By enabling the conditional exclusion of the switching states impacted by each fault, this kind of control enables the converter to use these states in all other circumstances while avoiding them when the fault affects their output. Georgious, R et al. (2020) et al. [20]. have reported that in electrical and Hybrid Electric Vehicles (HEVs), a storage system is connected to a DC-link via a power converter topology known as the buck-boost method. In the event of a short circuit fault at the DC-link, this design can safeguard the energy storage devices. MATLAB/Simulink simulation demonstrations of the control schemes are provided to verify the control's behaviour.

3. Proposed System

Numerous interfaces for power electronics, such as Electric Vehicles (EVs), Battery Energy Systems (BES), PV/wind Distributed Generation (DG), bidirectional Grid-Connected Converters (GCCs), and others, are included in a typical dc-microgrid layout, as seen in Figure 1. A high-voltage DC connection connects them, allowing DC household appliances to get power straight from the bus. The primary purpose of GCCs in this system is to maintain a constant dc-bus voltage, even when the system can normally access a mass of BES, to guarantee the dependability of operation for dc-microgrids. By enabling EVs to be supplied with electricity by the utility, DC microgrids can benefit from the auxiliary power services that EVs can offer. This enables clean and effective battery-powered transportation.

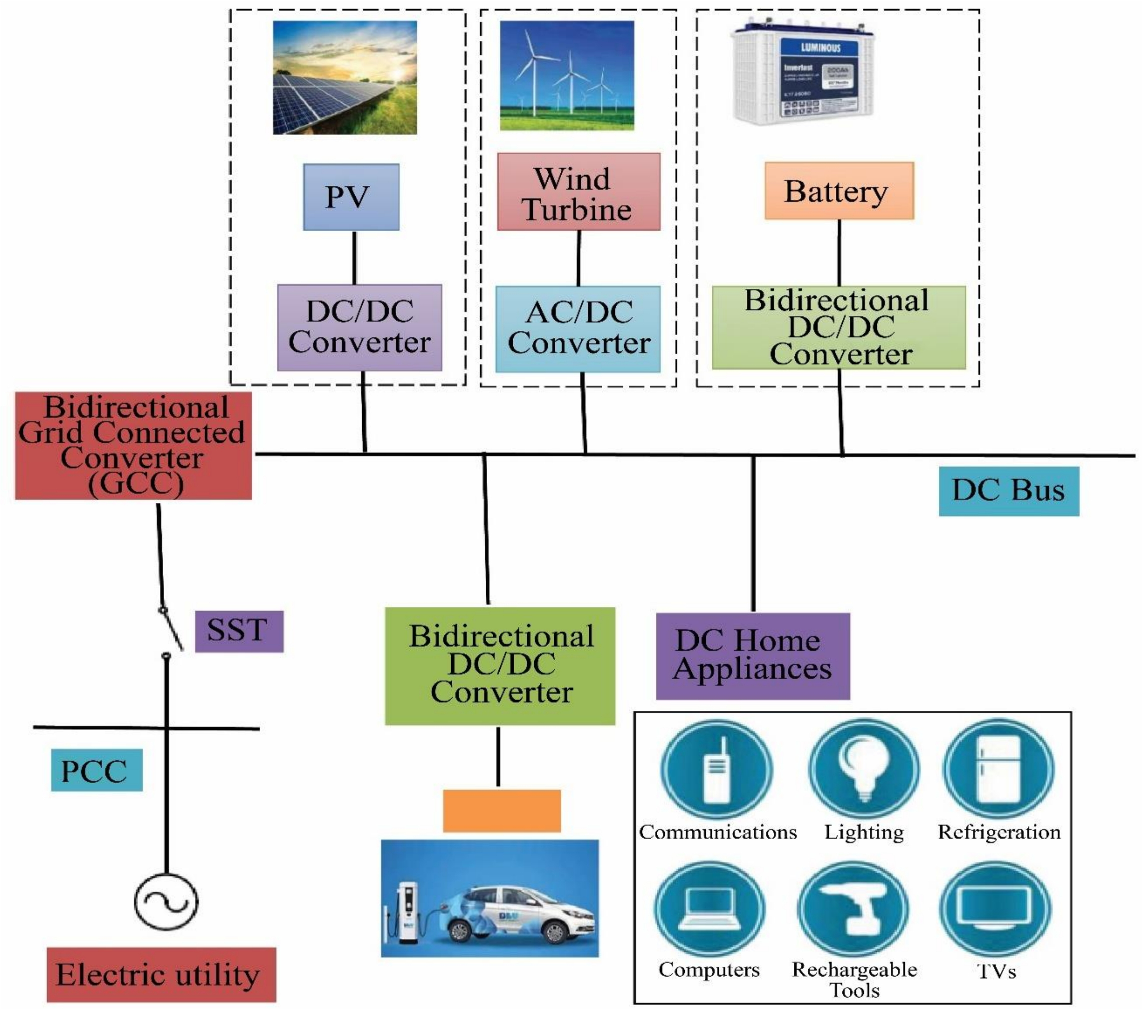

Fig. 1 Proposed Block Diagram of Bidirectional DC-DC Converter for Electric Vehicles

A bidirectional DC/DC converter (BDC) with a high voltage conversion ratio is typically needed for both bucks and boost operations in dc-microgrid systems when there is a significant voltage differential between the dc-bus, BES, and EV battery. For non-isolated applications, BDCs with coupled inductors offer less complicated winding topologies and lower conduction losses compared to isolated versions.

3.1. DC-DC Converter

The various EV power supply configurations show that the DC-link module is necessary for connecting at least one battery, the FC, the DC/DC converter, or a supercapacitor. Electrical engineering uses a particular type of power converter called a DC-to-DC converter. It is an electric circuit that converts a source that transfers Direct Current (DC) between voltage levels by momentarily holding onto incoming energy before releasing it at a different voltage to the output. Figure 2 depicts the drive mechanism of the electric vehicle. Either electric field storage components (capacitors) or magnetic field storage devices (inductors, transformers) can be used for the storage. With DC/DC converters, only power may be moved from the input to the output. However, nearly all of the bi-directional DC/DC converter topologies are possible. The ability of a bi-directional converter to transmit electricity in either direction is advantageous for applications that need regenerative braking.

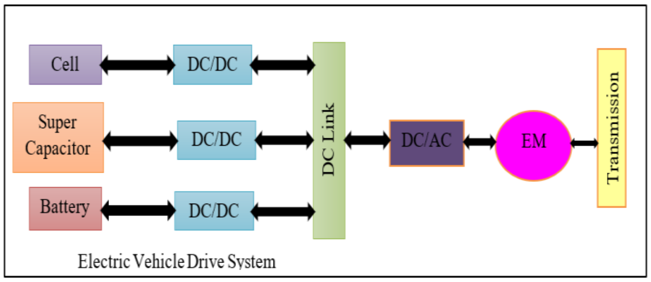

Fig. 2 Bock diagram of DC-DC converter

3.2. AC/DC Converter

To guarantee its performance and safety, AC-DC converters need to abide by safety standards and laws like UL, CE, and FCC. All things considered, AC-DC converters' efficiency, safety, and performance are crucial in a wide range of applications and sectors. The DC circuit is designed to ensure that the rectification and filtering procedures are completed correctly. If the DC voltage source is not constant, a laptop cannot be charged properly. The rectifier's primary function is to manage the output current or load. The rectifier's output is then connected to the filter. As is well known, a filter is only a device that transforms unidirectional AC voltage back into pure DC voltage by filtering out ripples.

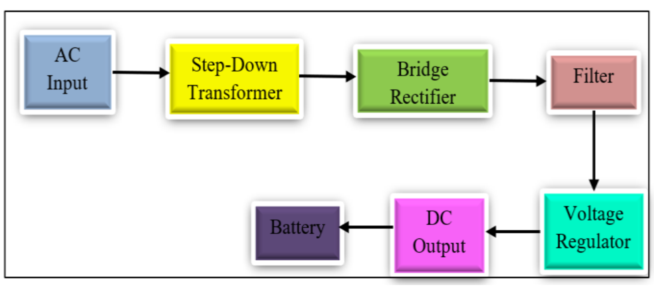

Fig. 3 Block diagram of AC/DC converter

The DC output voltage (Vo) typically ranges from 3 to 24 volts, depending on the electrical application. An AC-DC converter block diagram is shown in Figure 3. A silicon diode is quite useful in this case because of its non-linear features, which are those current flows for one voltage polarity but zero for the other.

3.3. Bidirectional DC/DC Converter

A battery-powered electric vehicle's bi-directional dc-dc converter drive system. A closed-loop mechanism for controlling speed is developed and implemented using a PI controller for the proposed battery-fed electric vehicle. The size is reduced by the entire driving system, as well as the cost and complexity of a vehicle system solely powered by electricity.

Figure 4 shows the proposed DC motor drive powered by a bi-directional DC-DC converter. The diode that is not parallel D_1 acts as the diode in boost mode in this architecture and Q_2 is modulated to enable the boost converter to function. The anti-parallel diode D_2 acts as the buck-mode diode, and the topology modulates Q_1 to operate as a buck converter when the power flow direction is reversed. It should be mentioned that the current directions of the inductor in the two modes are opposing. To accomplish both driving and regenerative braking of the motor, a novel control model is created utilising a PI controller. This variant uses a lithium-ion battery to validate the motor's performance in both driving and regenerative modes. When it comes to various driving speed commands, this controller produces satisfactory results.

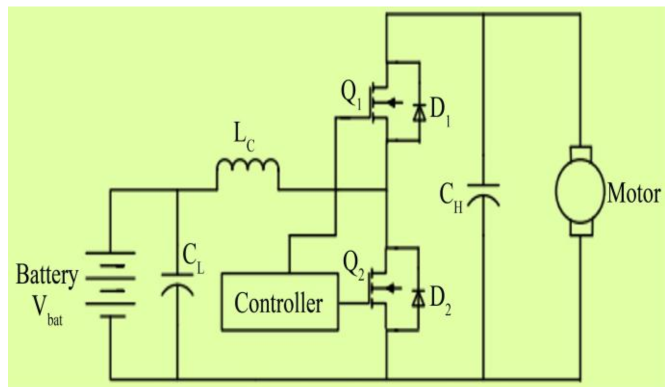

Fig. 4 Bidirectional DC-DC converter with battery and DC motor

3.4. Mathematical Modelling

3.4.1. Photovoltaic Panel Modelling

A 30° angle is formed by the panels with respect to the south. Equation (1) provides the modelled equation for the PV system's output power.

$$P_{pv_{out}}(t) = P_{(pv_{rated})} \times \frac{G_{(t)}}{1000} \times [1 + \propto_t ((T_{amb} + (0.03125 \times G_t)) - T_{C_{STC}} \quad (1)$$

Where $P_{(pv_{rated})}$ $\propto_t$ is the temperature coefficient. T_{amb} is the manufacturer's modellable, and NOCT is the ambient temperature (in °C).

$$T_{C(STC)} = T_{amb} + G_t \times \left(\frac{NOCT-20}{800}\right) \quad (2)$$

Furthermore, the Nominal Operation Cell Temperature (NOCT) value was subtracted to arrive at the value 0.03125 ◦C.

3.4.2. Wind Turbine Modelling

Three fundamental parts make up a wind turbine: the rotor, which contains the blade and frame, and the generator, complete with controls and a gearbox. The model equation for the WT's output power is shown in Equation (3).

$$P_{WT} = \begin{cases} 0 & v(t) \leq v_{cut-in} \; or \; v_{(t)} \geq v_{cut-out} \\ p_r \frac{v(t)-v_{cut-in}}{v_r - v_{cut-out}} & v_{cut-in} < v < v_r \\ p_r & v_r < v(t) < v_{cut-out} \end{cases} \quad (3)$$

The variables v_{cut-in} and $v_{cut-out}$ represent the corresponding cut-in and cut-out speeds. PWT rated wind speed specified by the manufacturer, is the WT's generated output power. Equation (4) shows how adjusting for hub height can result in more precise output power from

$$\text{WT}.V_2 = V_1 * \left(\frac{h}{h_{ref}}\right)^{\alpha} \quad (4)$$

The symbol for wind speed (m/s) is V_2 and V_1.

3.4.3. Battery modelling

With an electrical circuit made up, it is a common energy storage device made up of an electrical source and a capacitor. C. The battery's State of Charge (SoC) varies with time and can be written as follows: dictates when it charges and discharges.

$$SOC_{bat} = SOC_{bini} - \frac{1}{C_{cap}} \int_0^t I_{bat} dt \quad (5)$$

Where SOC_{bini} is the battery's initial SoC at t = 0 s and C_{cap} is the capacitor's capacity.

Rechargeable power sources like batteries provide electricity according to their weight. The battery functions as an auxiliary supply in this suggested HESS. A DC-DC boost converter that operates in both directions allows electricity to flow both ways for charging and discharging.

Table 1. Title of the table

Item	Specifications
Rated Voltage	115V
Rated Capacity	4.4 Ah
Number of Cells	32
Dimensions	417*304*135 mm
Power	15kW
Weight	14kg
Specific Power	1071.4W/kg
Specific Energy	36.14 Wh/kg

3.4.4. Converter Modelling

AC and DC components; the converter is described in Table 1. This analysis considers solar PV panels (DC), batteries that generate DC output, and household (AC) requirements.

$$P_{inv}(t) = \frac{P_L^m(t)}{\eta_{inv}} \quad (6)$$

3.4.5. Grid Modeling

If the battery bank and RESs cannot fulfil the load requirements, the grid can make up the difference in electricity. The amount of money earned from energy sales to the utility grid can be calculated using Equation (7).

$$R_{grid} = \sum_{t=1}^{8760} rate_{feed-in} \times E_{grid}(selling) \quad (7)$$

3.5. High Conversion Ratio for Electric Vehicles

3.5.1. Voltage Conversion Ratio

In charge state, V_H is the input and V_L is the output determined by the principle of voltage-second balancing in L_1 and L_2, the ratio of conversion of voltage M_d in command state is as follows:

$$M_d = \frac{V_L}{V_H} = \frac{D_d}{4} \quad (8)$$

In Equation (2), D_d are the switches that are in use during Q1 and Q2's duty cycle. As may be observed, the charge state Compared to the conventional buck converter, Likewise, V_L is the input and V_H is the output according to the idea of voltage-second balancing in L_1 and L_2, the voltage conversion ratio M_b can be acquired in the discharge condition as follows:

$$M_b = \frac{V_H}{V_L} = \frac{4}{1-D_b} \quad (9)$$

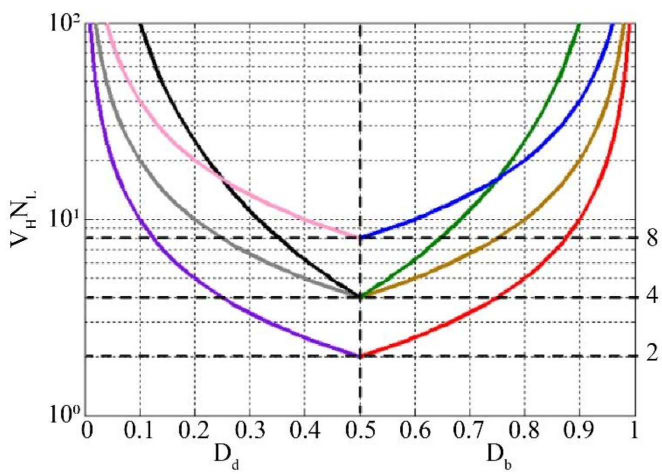

Fig. 5 Comparing the voltage conversion ratios generated by the converters and the BDC under study

Where D_b represents the active switches' duty cycle. Q_3 and Q_4. It is evident that in the discharge state when compared to the conventional BDC and the preceding BDC, Figure 5 demonstrates that the examined BDC can either require a lower duty cycle to provide the same voltage conversion ratio from the active switches or it can generate a greater ratio of voltage conversion while keeping the duty cycle constant. Additionally, the examined BDC's voltage conversion ratio is higher than the BDC's within the specified tolerable range of 25% to 75% duty cycles.

3.6. War Strategy Optimization-WSO

The WSO algorithm, which seeks to minimise the overall trip duration, waiting time, and charging expense, is the source of the EV charge scheduling algorithm. The objective function (F) can be expressed using Equation (10).

$$F = w_1 . T_{total} + w_2 . W_{total} + w_3 . C_{total} - w_4 . G_{stability} \quad (10)$$

Where $T_{total} = \sum_{i=1}^{N} T_i$, is the sum of all (N)travel times for EVs, including time spent charging.

$$W_{total} = \sum_{i=1}^{N} W_i$$

All EVs' wait times at charging stations, $C_{total} = \sum_{i=1}^{N} C_i$ is the overall cost of charging all EVs,

$$G_{stability} = \frac{1}{T} \sum_{i=1}^{N} \left(1 - \frac{\sum_{i=1}^{N} P_{charging}, i(t)}{P_{grid,\max}(t)}\right) \quad (11)$$

is the grid stability metric, w_1, w_2, w_3 and w_4 are the Component Weight Charging station capacity for each charging station j, at any time t:

$$\sum_{i=1}^{N} x_{ijt} \le Capacity_j \quad (12)$$

Where x_{ijt} is a binary variable that indicates if, at time (t), EV

EV battery constraints

$$0 \le SOC_i(t) \le 1 \text{ for all i and t} \quad (13)$$

Where $SOC_i(t)$ is EV (i)'s charge state at time (t), normalised between 0 and 1.

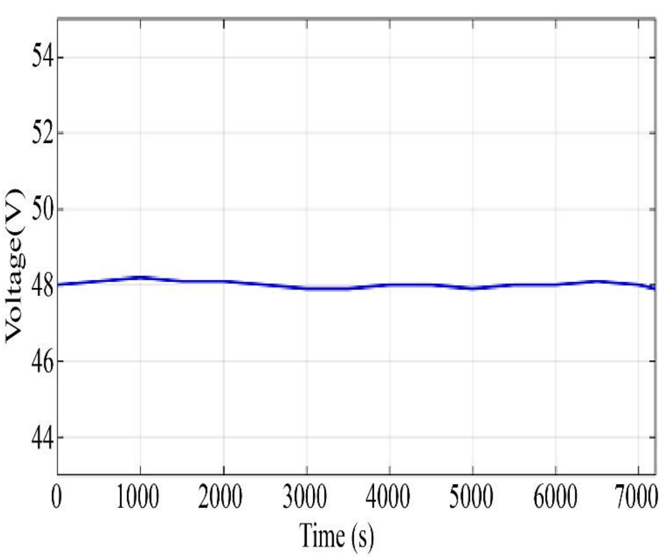

Fig. 6 DC Voltage

$$t_i^{start} \le Charging\ time\ of\ EV_i \le t_i^{end} foralli \quad (14)$$

Where t_i^{start} and t_i^{end} i ≤ are the latest and earliest periods that EVs can begin charging (i). Each Soldier's (EV) charging schedule place, including charging behaviours such as charging duration, charging time, and selected charging station, is assigned by the WSO algorithm.

The soldier's objective function determines their level of fitness. Subsequently, the WSO algorithm finds the best charge schedules to minimise (F) and meet the criteria.

4. Result and Discussion

It was discovered that the DC bus's voltage fluctuated between 47.86V and 48.13V while being within the limitations of the 48V DC bus voltage. The DC bus voltage for the two operating hours is shown in Figure 6.

The DC-BUS protects against mistakes caused by noise over the powerline by converting the digital input data into phase-modulated signals.

The fluctuations in voltage and current are roughly 2 volts and 10 amps, respectively. The outcomes show that the converter can comply with power needs due to its efficient control.

The enhanced dc/dc converter's efficiency at full load is shown in Figure 7, is roughly 83%."Regulation of electromagnetic compatibility."

It is evident that the regulations do not allow for the amount of conducted interference caused by the converter. Consequently, to comply with the standards, EMI filters must be inhibited.

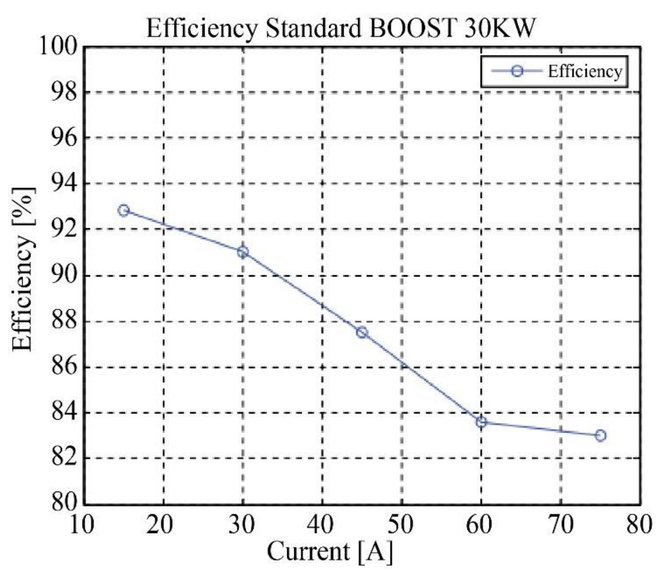

Fig. 7 Boost converter efficiency in relation to current load

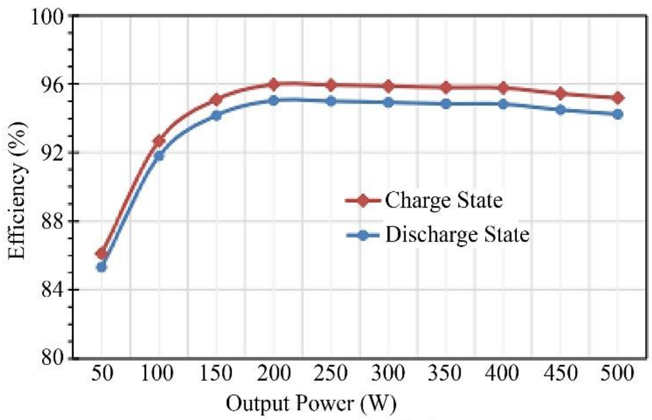

Fig. 8 Measured conversion efficiency of the studied BDC for low-side voltage V_L = 48 V and high-side voltage V_H = 385 V under different loads

In both the states of charge and discharge, Figure 8 summarises the measured conversion efficiency of the BDC under investigation. An accurate digital power meter (WT310) is used to assess the conversion efficiency of the experimental prototype system. Figure 8 shows that in the discharge condition, the maximum conversion efficiency was 95%, while in the charge state, it was approximately 96%.

The battery's SOC change under various cycle circumstances and operation modes is shown in Figure 10. The effect at the charge-sustaining stage can be successfully realised by maintaining the SOC at roughly 65%, and the SOC performance is at its most stable when operating in this manner. The average SOC of the battery at the charge-sustaining stage is used to analyse the stability of the SOC under various operating modes.

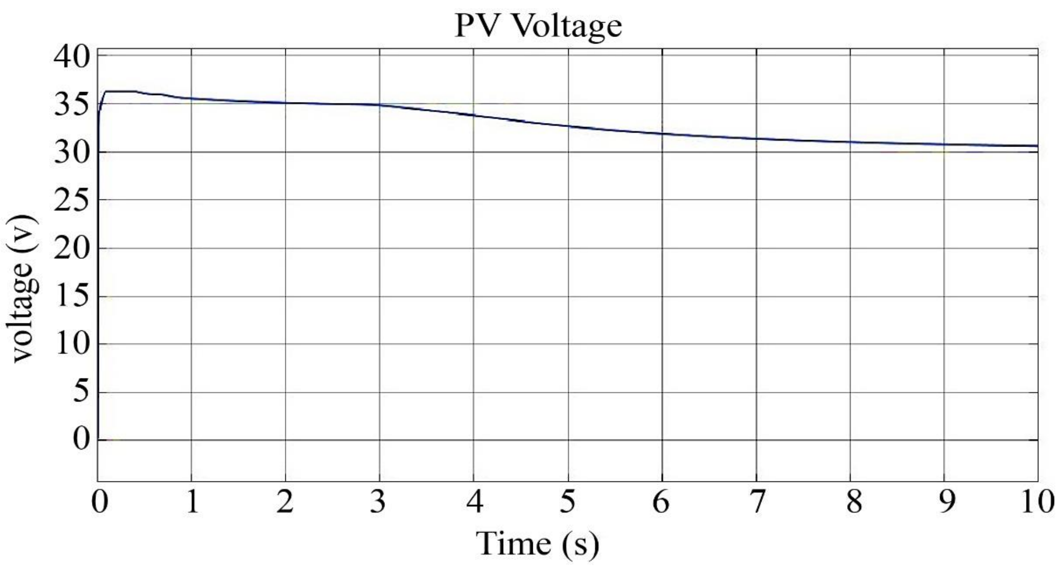

Fig. 9 Output Voltage Waveform of Solar PV

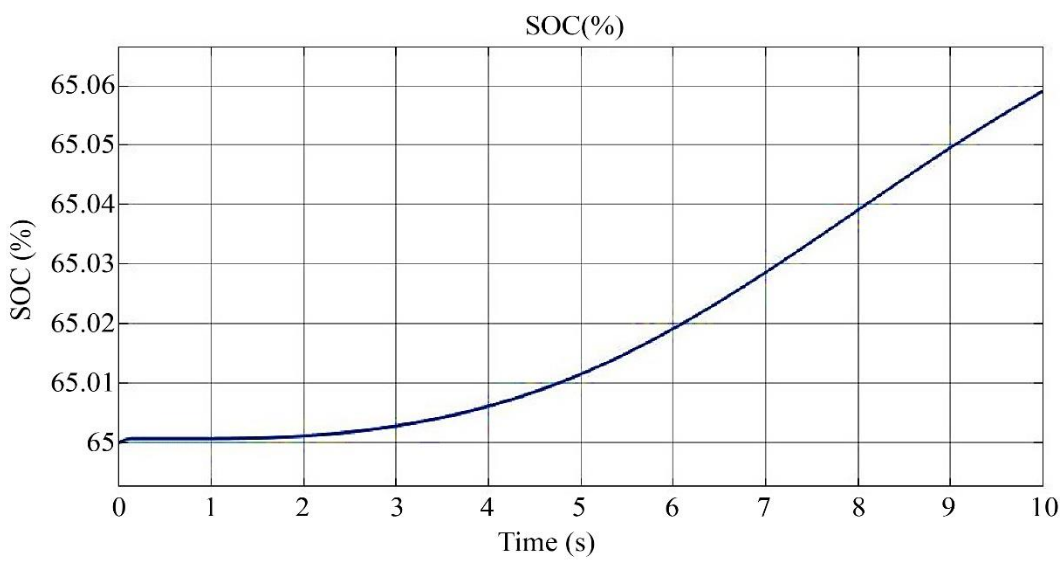

Fig. 10 State of charge waveform of battery

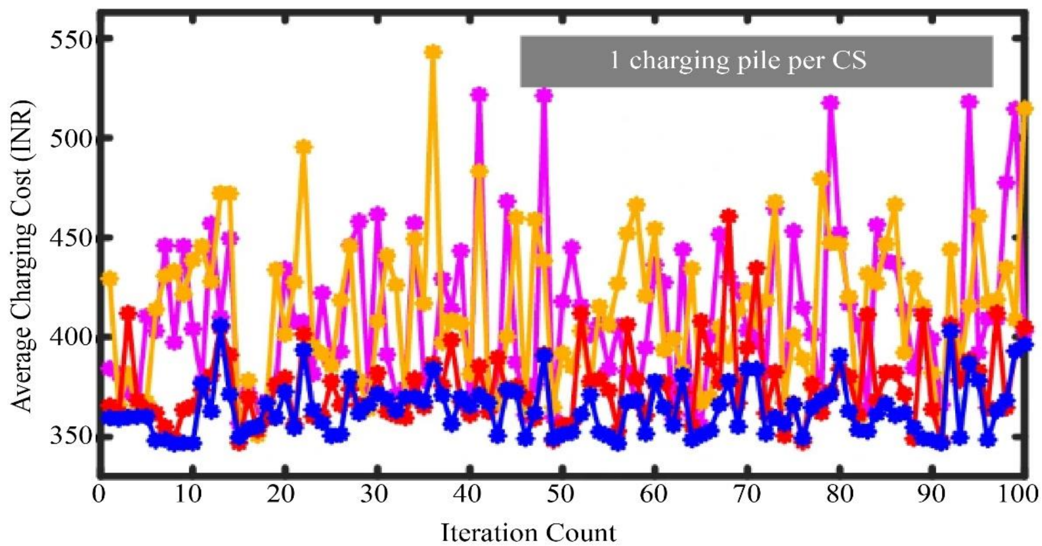

Fig. 11 Proposed War Strategy Optimization (WSO)

Table 2. Comparison Table of Proposed System with Existing Method

Reference	Methodology	Efficiency
Bento, F et al. [17]	Thus, the goal of this study is to introduce novel and straightforward fault detection and reconfiguration techniques that can boost converter reliability while preserving the fault-tolerant converters' economic appeal.	92.2%
Bhargav, R et al. [18]	The suggested technique can identify and locate DC faults with low and high resistance without using distant end quantities.	9.5%
Caseiro, L et al. [19]	To enable full-rated post-fault functioning, the suggested approach may fix all of the semiconductors (IGBTs and diodes) in every converter in the system, including the DC-DC converter, with open-circuit defects.	93.6%
Georgious, R et al. [20]	As a result, cars that run on fossil fuels have consequently been replaced by new energy-electric vehicles.	97.6%
Proposed	In this work, a new hybrid structure for bidirectional DC-DC converters with high conversion ratios for electric cars is developed using War Strategy Optimization (WSO).	98%

The output power of the DC-to-DC converter is displayed in Figure 9. where the power is estimated using the suggested methods. The voltage output using the suggested method is shown in this graph. This analysis shows that, in comparison to the current method, The recommended DC-to-DC converter's output power is increased. Figure 11.

The WSO demonstrates its excellent performance in offering the lowest charging costs when 12 charging stations are anticipated to be used by 25 EVs with 1–4 charging heaps. The suggested WSO offers the 363.95 INR charge fee when 25 EVs are scheduled, considering each charging station has one charging pile.

5. Conclusion

The construction and management of an electric vehicle's bidirectional DC/DC converter are presented in this work. The bidirectional DC/DC converter's ability to charge batteries makes it special for use in electric vehicle applications, and it is governed by a single sliding mode control law. Electric vehicles and hybrid energy sources can, therefore, act as a power interface between the battery and supercapacitor stacks. Both driving and regenerative braking modes are used to analyse the converter's performance. Many contemporary electronic devices require AC-DC converters to function with DC power.

The WSO approach showed that charge prices dropped by 12.45% and 3.61%, respectively, while waiting times dropped by 11.17% and 39.09%. These findings imply that the WSO algorithm can potentially increase the effectiveness and affordability of EV management systems, particularly in scenarios with inadequate charging infrastructure.

The charge and discharge states can produce the highest efficiency, 98% and 98%, respectively, based on experimental results. In future work, multidisciplinary efforts in power electronics, optimisation algorithms, thermal management, and integration with EV systems will be necessary for hybrid architectures for bidirectional DC-DC converters with high conversion ratios. In addition to solving important issues with efficiency, power density, cost, and scalability, the use of War

Strategy Optimisation (WSO) presents a viable method for maximising converter performance. To make these systems viable for broad use in electric cars and other energy systems, more investigation and experimental verification are essential.

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