

Modelling and Implementing an Isolated Bidirectional DC-DC Converter with the PSO Algorithm for Electric Vehicle Power Management

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ABSTRACT

Once clean, renewable energy sources are used to charge the batteries in electric vehicles (EVs), the vehicles can produce zero gas emissions, greatly improving the environment. EVs and other distributed energy storage devices can be used in a smart micro grid to deliver energy to the loads throughout highest times, reducing the impact of load shading and improving the quality of the electricity. To achieve these goals of energy balance between EVs, the grid, and renewable energy sources, an isolated DAB DC-DC converter is required. This paper develops an optimized isolated DC-DC converter for controlling power flow in multiple directions in an EV. This converter contains a dc-dc bidirectional converter, dual active bridge converters. To control the power flow between the EV and the battery, particle swarm optimization is also created. A bidirectional DC-DC converter may be used in the proposed method to link the EV battery and provide bidirectional power flow capability. MATLAB is used to implement the suggested method and performance metrics are taken into account while evaluating presentations. Additionally, it is compared to particle swarm optimization's (PSO) more conventional methods.

Keywords: Triple active bridge, Modified coati optimization algorithm, bidirectional DC-DC converter, particle swarm optimization (PSO), solar energy

I. INTRODUCTION

Electric vehicles (EVs) have gained popularity globally over the past 20 years due to their perceived ability to lower the release of greenhouse gases in the transportation sector [1]. New research also shows that EVs might soon fully replace traditional vehicles that use internal combustion engines (ICEVs). This means there is a need to build charging stations everywhere to meet the large amount of electricity needed to charge these vehicles. However, as more EVs are on the road, there is a growing problem with the infrastructure needed to charge them [2]. It might become more difficult and not be the best option to charge these vehicles using the current electric infrastructure. Therefore, a dependable, environmentally

friendly EV charging system that runs on renewable energy sources is becoming more and more necessary [3].

Switching to grid-based charging solutions can help reduce the pressure on traditional power grids and support a cleaner, more sustainable transportation industry [4,5]. Researchers who study power electronics for EV systems have written many papers on this topic [6]. In this paper, we look at various types of isolated multiport converters that are based on multi-port designs. Using the idea of interleaving can improve the efficiency of an isolated multiport converter [7]. The output power of a multi-port converter is controlled and regulated using a single-leg active switching parameter. In the EV discussed here, a DC/DC converter has been developed to analyse how energy moves between the electrical grid and the power source. The number of switches in this converter depends on how many battery modules it has [8]. For example, if there are 'n' battery designs, the system needs '2n' switches to work properly. To regulate power flow between the battery and the grid and avoid problems like overcharging the grid or excessive current in the battery during high power periods, a new energy management method based on MCOA has been proposed [9]. This paper's primary contribution is as follows: In this study, an optimised isolated DC-DC converter that can control power flow in both directions in an EV is created. This converter includes a bidirectional DC-DC converter, a unidirectional DC-DC converter, a multi-port dual active bridge converter, and TAB.

The OC also regulates the flow of electricity between the battery and the EV. The power flow is accomplished by the utilisation of the MCOA. The MCOA selects the optimal gain level for the converter. The suggested approach may link the EV battery and provide bidirectional utilising a bidirectional DC-DC converter to transfer electricity. The article's remaining content is arranged as follows: The system's architecture and overview are given in Section 2. The controller design section is in part 3.

The paper's conclusions and the simulated results are shown in Sections 4 and 5.

A. Existing Works

Fuzzy Logic Control:

Overview: Fuzzy logic control uses reasoning similar to how humans think to handle uncertain and complex situations in a system. It is especially helpful when it's hard to create exact mathematical models. Designing a fuzzy logic controller involves creating a group of rules and functions that describe how the system should behave. This process can be complicated and take a lot of time. Computational Demand: Applying fuzzy logic in real-time can require a lot of computing power, especially in systems that switch quickly and often. Research covers a variety of linear controllers, including proportional-integral (PI), proportional-resonant (PR), and H infinite controllers.

There's also talk about improving controllers using soft computing methods. Jemin Woo and others [10] have suggested a method called stochastic dynamic programming for managing power in zero-emission zones. This method tries to improve how hybrid electric vehicles (HEVs) charge. It uses information about what might happen in the future, based on a Markov chain, to predict driver behavior and create the best control strategies. The controller also considers how far the vehicle is from a zero-emission zone to help with efficient charging. Compared to other methods that don't take distance into account, this approach can improve fuel efficiency by up to 21%.

Vinoth Kumar Manickam and colleagues have developed a systematic approach to employing power generators, EV chargers, and battery chargers as backup power sources for electrical systems [11].

This is due to EVs' capacity to generate, store, and use energy. With this functionality, EV chargers can function in both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes at any power level. This lets EVs do more than just charge, such as help control voltage, reduce reactive power, and lower harmonic distortion in the grid.

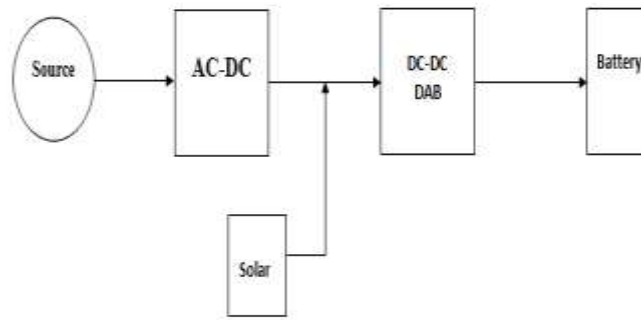


Fig. 1 proposed block diagram

The Assailant Inspired Chimp Optimization Algorithm (AICHOa) is a new method that helps improve the performance of a PI controller by using ideas like voltage synchronization, RPC, and reducing THD. Teja Barker and others [12] have created a well-designed charging station that works closely with precision to improve how electric vehicles charge and how the grid is managed using neural networks. This is achieved by combining ANFIS technology for voltage-controlled MPPT with Type 3 and Type 2 controllers.

R.S. Bajpai and others [13] have developed an adaptive sliding mode controller to handle energy storage units and electric vehicles across different power generation and demand situations. This controller uses a decentralized approach to manage how power is shared between micro grid DC-link EVs and energy storage units. To show how effective the sliding mode controller is for battery charging, they compare it thoroughly with fuzzy logic control.

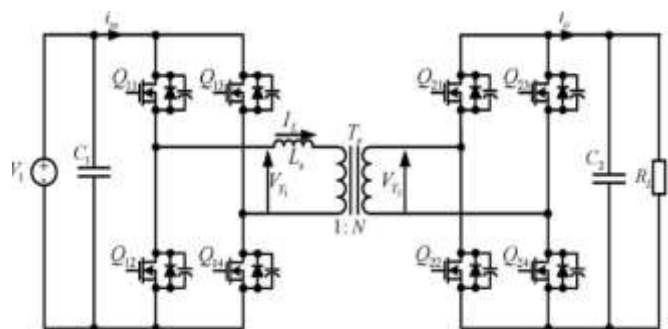


Fig.2. Architecture of the proposed model

Figure 1 shows the suggested model block diagram. The remainder of the document is structured as follows: Section II discusses the DAB and provides a detailed mathematical analysis for the computations of the RMS current and active power flow. Section III provides a detailed description and mathematical analysis of the PSO topology, along with a closed-loop control technique to determine the

optimal operating point for each DAB. The steady state analysis of the DAB results with PSO concluded on the project in Section V is provided in Section IV.

II. PROPOSED SYSTEM

A. Proposed DC-DC converter

Energy scarcity and environmental issues have become more important in recent years. The pollution from car exhaust has gone up because more people own cars, which has pushed for faster changes in how cars get energy. Traditional electric vehicle (EV) energy storage systems use batteries, but they have some problems. When an EV is speeding up or accelerating, the battery's power density isn't enough to meet the high power needs. Also, the EV's energy demand goes up when more battery cells are added. This study recommends a good charging and discharging controller for EVs and an optimised isolated DC-DC converter to improve power management and establish a fast-charging system. Figure 2 incorporates a bidirectional DC-DC converter, a dual active bridge, and another bidirectional DC-DC converter with to fully run the converter.

Figure 3 illustrates the DAB equivalent circuit using simple harmonic analysis, using a simple AC source for either side of the DAB.

It is possible to see the RMS phasor of the primary voltage component on both sides (1 and 2), V_1 and V_2 . The fast-charging system helps improve the charging and discharging process, which helps maintain the battery. The electric car may use grid power if its battery is unable to sustain the load. This is achieved by developing a controller that supports the optimised isolated DC-DC converter. The main purpose of power management and oversight is to match the energy demand while accounting for the battery's charging and discharging controller, which is overseen by MCOA.

The suggested way to make the battery last longer is through energy management and charging using a discharge controller, which reduces the risk of overcharging and damaging the battery. There are two ways to use the grid to help improve the battery. In condition 1, the battery gets charged via the grid when it is

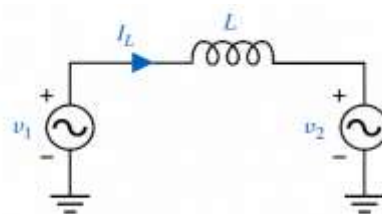


Fig. 3 The analogous circuit for DAB fundamental harmonic analysis

when the battery is overcharged and to store excess energy. The sections that follow display the system model and system modelling.

III. THEORY AND CALCULATION

A. Modelling of Electrical Vehicle

When driving at different speeds, an electric vehicle needs some energy to speed up and slow down. The amount of energy an EV uses depends on how much power the vehicle needs. Also, there are other forces that affect how the vehicle moves, like rolling friction and air resistance. These forces are influenced by several factors, such as tire pressure, the shape of the vehicle, the type of road, the width

of the tires, and the front area of the car. The vehicle experiences a total force that causes changes in speed, and this force is connected to the current speed and can be calculated fairly easily. Usually, the driving force is used to figure out how much energy the vehicle needs. The difference between rolling resistance, resultant force, and aerodynamic resistance is what determines the energy needs of electric vehicles.

$$DF = RF - AR - RR \quad (1)$$

The following formula is used to get the EV's RR:

$$RR = (1 + kv^2) \quad (2)$$

In this case, the rolling resistance coefficient is denoted by G , the vehicle mass, V is the vehicle speed, M is the standard gravity acceleration, and M is the low-speed resistance coefficient. The low-speed coefficient is calculated and expressed as follows following the validation of the drag racing test:

$$F_{to} = vb^2 \cdot 2gst \quad (3)$$

Here, vb is the vehicle's starting speed, and st is its rolling distance. For an EV traveling regularly on the road, the low speed with RR coefficient is perceived as falling between 0012 and 0014.

$$AR = 1/2 \rho c_x a v^2 \quad (4)$$

$$e = DFs/\eta \quad (5)$$

$$p = DFv/\eta \text{ or } P = e/T \quad (6)$$

The air density is represented by ρ , the longitudinal direction is represented by c_x , which is associated to the forms and ranges of the vehicle, the vehicle coefficient of frontal superficial location is represented by A , and the vehicle speed is represented by v . The EV's driving force, energy, and instantaneous power required to describe route S in a given length of time are calculated using the thermal resistance parameter, the vehicle's instantaneous velocity, and the assumed drive architecture efficiency within the designated stage.

B. Modelling of Battery

Because of its life cycle, lithium-ion batteries are frequently seen in electric automobiles. The internal resistance model is taken into consideration for simulating lithium-ion batteries due to its accurate and straightforward information representation. [15] The resistance that is inside model of the battery is composed of a perfect cell with internal resistance and a resistance model with a series cell.

$$P_B = V_{OC} I_B - R_{IN} I_B^2 \quad (7)$$

$$I_B = \frac{V_{OC} - \sqrt{V_{OC}^2 - 4P_B R_{IN}}}{2R_{IN}} \quad (8)$$

$$V_B = V_{OC} - R_{IN} I_B \quad (9)$$

$$V_B = \frac{V_{OC} - \sqrt{V_{OC}^2 - 4P_B R_{IN}}}{2} \quad (10)$$

The internal resistance of the battery changes depending on whether it is charging or draining. The following is the formula for output power, terminal voltage, and battery current:

The open circuit voltage in this instance is represented by V , and the internal resistance by R , the terminal current by I , the terminal voltage by V , and the battery output power by P . One can estimate the amount of energy saved by calculating the amount of charge that is still usable in the battery. A battery's available charge at its maximum charge capacity is known as its state of charge (SOC). One indicator of charging loss is the columbic efficiency. The battery's state of charge (SOC) during charging and draining is represented by the dynamic equation below:

$$SOC = \begin{cases} -\frac{I_B}{c_{ah}} & I_B \geq 0 \\ -\frac{c_{eff} I_B}{c_{ah}} & I_B < 0 \end{cases} \quad (11)$$

In this case, I_B is the battery temperature, c_{jh} is the battery's maximum capacity, and cef is the Coulombic efficiency.

C Switching Operation

The converter's switching process can be separated into the following six operation modes, as seen in Fig. 3:

(1) Mode 1 ($t_0 - t_1$)

The inverse of the inductor current i_L is shown in Fig. 3a. At t_0 , S_1 and S_2 are active in the fundamental bridge, while S_5 and S_7 are activated in the additional bridge.

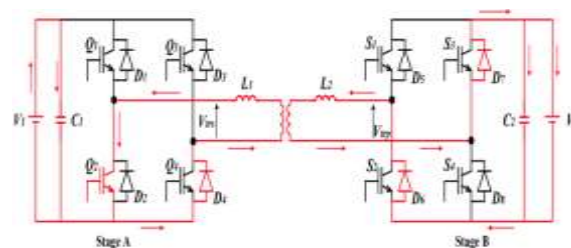
The river flows through S_5 and D_7 in the secondary bridge and through S_2 and D_1 in the primary bridge, depending on the direction of the current. The inductor has a steady current flowing through it at $i_L = i_{L0}$ since V_{h1} and V_{h2} are now zero, resulting in zero voltage through L .

(2) Mode 2 ($t_1 - t_2$)

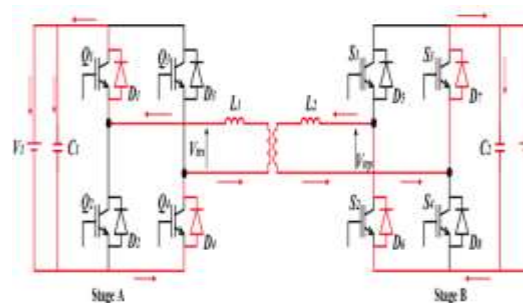
The mode 2 equivalent circuit is shown in Figure 3b. The current continues to flow negatively. We have activated S_1 , S_4 , S_5 , and S_7 . The river flows through S_5 and D_7 in the secondary bridge and through D_1 and D_4 in the primary bridge, based on where the current is flowing. The voltage via L is clamped to V_1 since V_{h1} is clamped to V_1 while V_{h2} is still zero. In this mode, the current decreases linearly and can be expressed as follows:

(3) Mode 3 ($t_2 - t_3$)

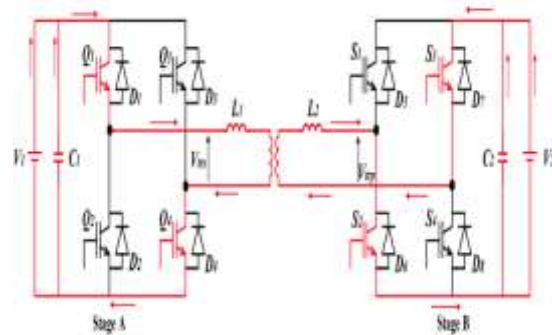
The mode 3 equivalent circuit is seen in Figure 3c. The polarity of the current shifts from negative to positive. S_5 and S_6 are turned on in this mode, but S_1 and S_4 remain on. The river flows via S_1 and S_4 in the major bridge and through D_5 and D_6 in the secondary bridge, depending on the direction of the current. V_{h2} is clamped to nV_2 , whereas V_{h1} remains at V_1 . As a result, $V_1 - nV_2$ is the clamped voltage via L .



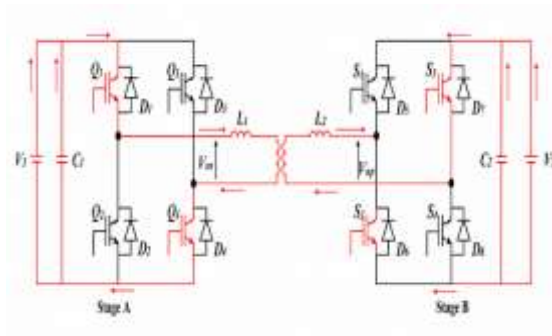
(a) Mode1:



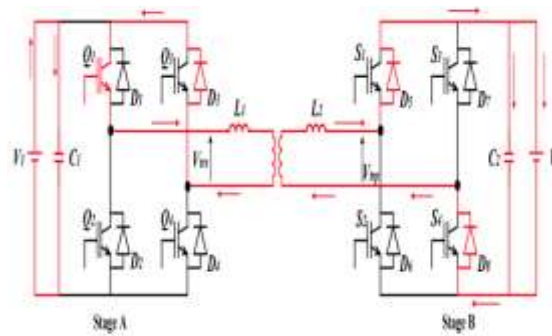
(b) Mode2:



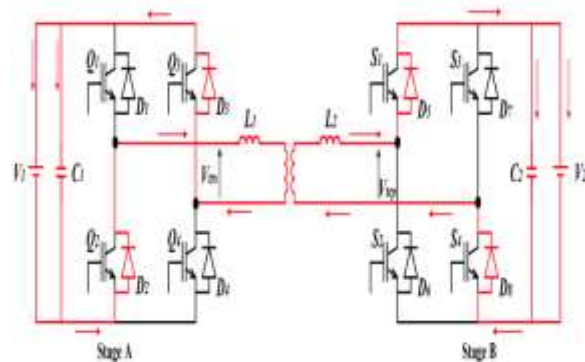
(c) Mode 3:



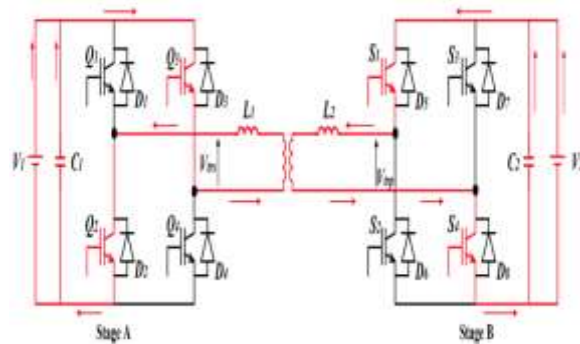
(d) Mode 4:



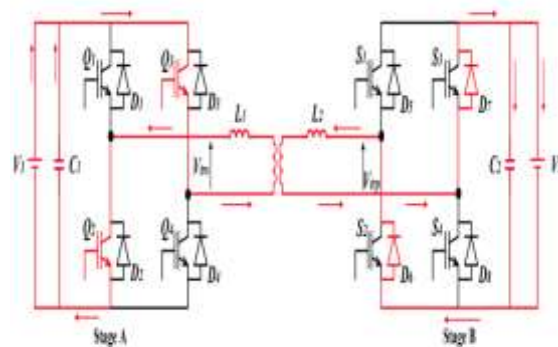
(e) Mode 5:



(f) Mode 6:



(g) Mode 7:



(h) Mode 8:

Fig.4 Individual Bidirectionnel Converter Opération Mode

(4) Mode 4 ($t_3 - t_4$)

Mode 4's comparable circuit is shown in Figure 4d. Mode 4 is similar to mode 1; the waveforms in Fig. 5 show that i_L is in the positive direction. S3 and S4 are activated at t_3 , whereas S8 and S6 are activated. The current flows via S4 and D3 in the major bridge and through S8 and D6 in the secondary bridge, based on which way the water is flowing. Since V_{h1} and V_{h2} are zero, there is no voltage through L, and the current is fixed at $i_L = i_{L3}$.

(5) Mode 5 ($t_4 - t_5$)

The mode 5 equivalent circuit is shown in Figure 3e. The current continues to be good. The switches S6 and S8 are turned on, and S2 and S3 are switched on as well. The current flows via S8 and D6 in the secondary bridge and through D2 and D3 in the major bridge, based on where the current is flowing. The voltage across L is clamped to $-V_1$ when V_{h1} is clamped to $-V_1$ but V_{h2} is still zero.

(6) Mode 6 ($t_5 - t_6$).

The analogous circuit for mode 6 is depicted in Figure 3f. The polarity of the current shifts from positive to negative. The switches S7 and S8 are still in the ON position, as are S2 and S3. The river flows via S2 and S3 in the major bridge and through D7 and D8 in the secondary bridge, depending on the direction of the current. While V_{h2} is clamped to $-nV_2$, V_{h1} remains at $-V_1$. As a result, $-V_1 + nV_2$ are the clamped voltage via L.

Each time interval's switching conditions are examined, and i_{L1} is computed for each as indicated below;

Mode 1 (t₀ – t₁):

$$i_{L1}(t) = i_{L1}(t_0) + \frac{nV_2}{L_1}(t - t_0)$$

Mode 2 (t₁ – t₁'):

$$i_{L1}(t) = i_{L1}(t_1) + \frac{V_1 + nV_2}{L_1}(t - t_1)$$

Mode 3 (t₁' – t₂):

$$i_{L1}(t) = i_{L1}(t_1) + \frac{V_1 + nV_2}{L_1}(t - t_1')$$

Mode 4 (t₂ – t₃):

$$i_{L1}(t) = i_{L1}(t_2) + \frac{V_1 - nV_2}{L_1}(t - t_2)$$

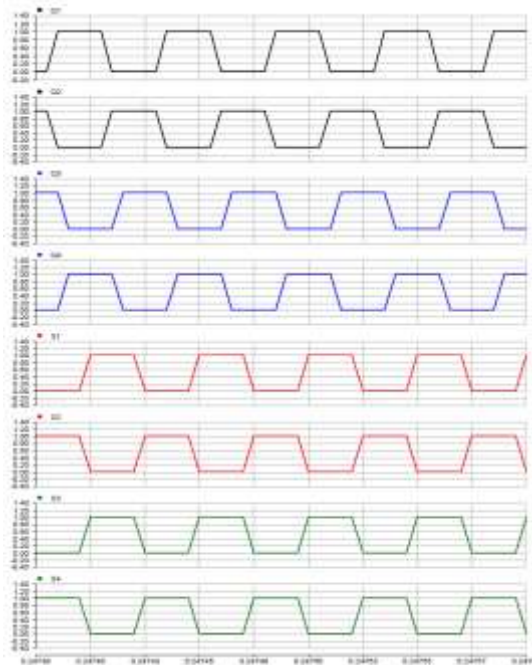


Fig 5. Switching conditions of the each time intervals in different modes.

Mode 5 (t₃ – t₄):

$$i_{L1}(t) = i_{L1}(t_3) + \frac{-nV_2}{L_1}(t - t_3)$$

Mode 6 (t₄ – t₄'):

$$i_{L1}(t) = i_{L1}(t_4) + \frac{-V_1 - nV_2}{L_1}(t - t_4)$$

Mode 7 (t₄' – t₅):

$$i_{L1}(t) = i_{L1}(t_3) + \frac{-nV_2}{L_1}(t - t_3)$$

Mode 8 (t₄' – t₅):

$$i_{L1}(t) = i_{L1}(t_5) + \frac{-V_1 + nV_2}{L_1}(t - t_5)$$

C. PARTICLE SWARM OPTIMIZATION (PSO)

An apparatus that converts high-pressure steam's thermal energy into mechanical energy that rotates parts is called a steam turbine. It is used in many power plants, whether they use coal, oil, or nuclear fuel. Usually, it spins at 3600 revolutions per minute, but in nuclear plants, it runs slower, at 1800 revolutions per minute. Controlling the turbine is very important because it needs to start up slowly to avoid breaking and also needs precise control to match the electricity demand. The control system and the safety features are separate but use some similar parts, like the controller or governor, the actuator with a lever, and a series of valves. The governor is responsible for keeping the speed steady throughout the operation. It gets information from the generator, the turbine shaft, the steam pressure coming into the turbine, and the pressure of the steam leaving the turbine.

If the group's chromosomes are highly similar and their overall fitness is high by the conclusion of the process, the two primary processes in genetic algorithms—crossover and mutation—do not necessarily produce better results.

Kennedy and Eberhart developed a contemporary algorithm known as PSO, which draws inspiration from the way fish and other animals move in groups.

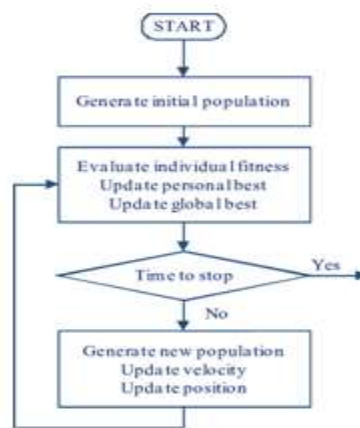


Fig. 6 Flowchart for particle swarm optimization algorithm.

Birds flying in groups and fish swimming together follow certain rules that help them move in a coordinated way without bumping into each other.

A particle swarm optimization (PSO) flowchart shows how the algorithm works.

It starts by creating a group of particles. These particles then keep updating their positions and speed based on what they have learned individually and what the best performer in the group has found. This continues until a stopping condition is satisfied, such as completing a specific number of steps or identifying a workable solution.

This natural behavior is used to solve difficult problems with PSO.

PSO is a simple and efficient method that works well for complex problems. Compared to genetic algorithms, PSO is quicker and tends to find good solutions faster. It also has a good balance between exploring new solutions and finding the best one. In PSO, each particle moves through the problem space, searching for the best possible solution by following the best particles it has found so far.



Tools for Design Optimization

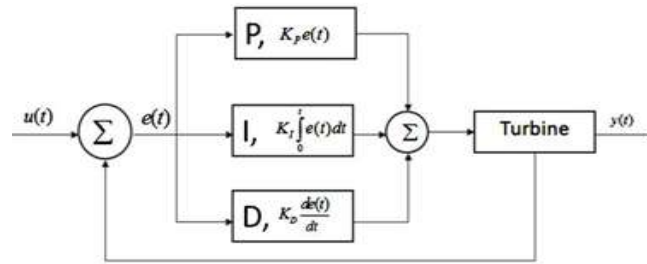


Fig.8 Block diagram of a PID control

In this article, the PID controller is optimised to achieve optimal plant behaviour. The optimiser is used to determine the optimal solution for the PID control gains. K_p , K_i , and K_d . When choosing an optimizer, intelligent optimization techniques are suitable options. Tools from Particle Swarm Optimization (PSO) are used in the suggested methodology. Numerous simulations of both approaches have been carried out in order to examine the efficacy of using PSO in relation to Genetic Algorithm (GA), and the outcomes are contrasted.

IV. RESULTS AND DISCUSSIONS

This section examines and validates the suggested method's performance. The suggested technique was created to enhance EV battery rapid charging. By considering the suggested quick charging controller, this suggested process extends battery life.

The battery is managed by the rapid charging controller to increase its lifespan. During charging and discharging, this controller enables suitable EV load demand adaption. The implementation of the proposed method in MATLAB is evaluated through performance analysis and comparison. The comparison of the suggested technique is verified using the design parameter assumption. By considering the EV load, the performance estimation of the battery and the recommended controller is validated.

Table-I
Simulation parameters

Input voltage	400
Inductance	10mh
Capacitance	100micro F
Battery SoC	60%
Switching frequency	1000F
Solar voltage	100v

a. Simulation with fuzzy

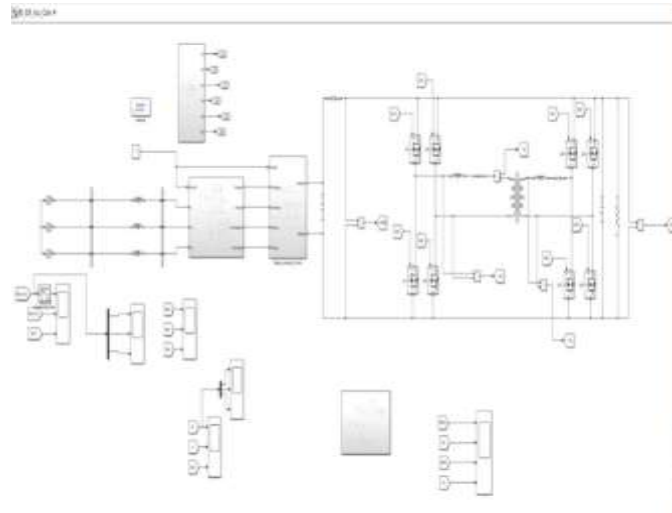


Fig. 9 Simulink full diagram

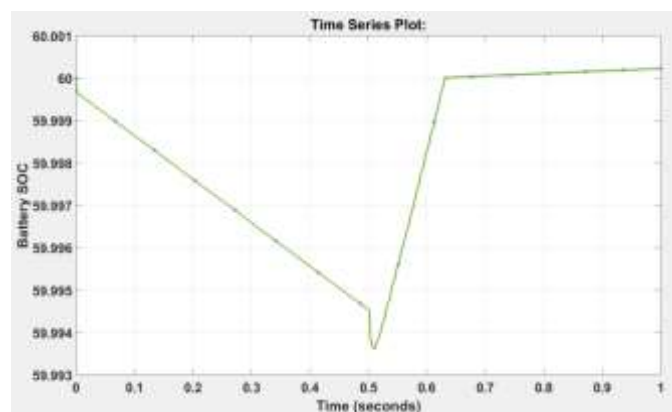
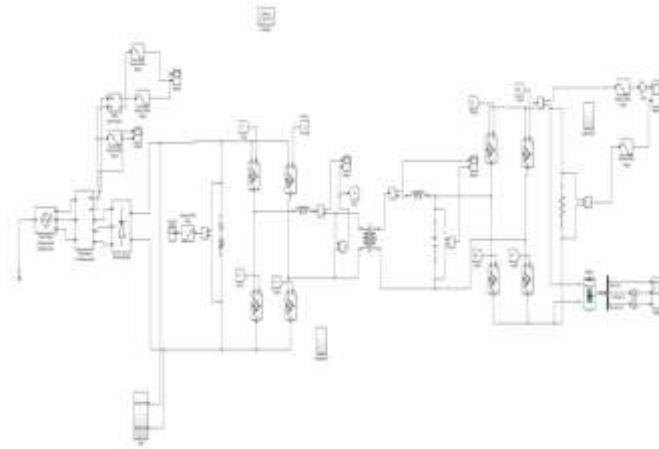


Fig. 10 Battery soc

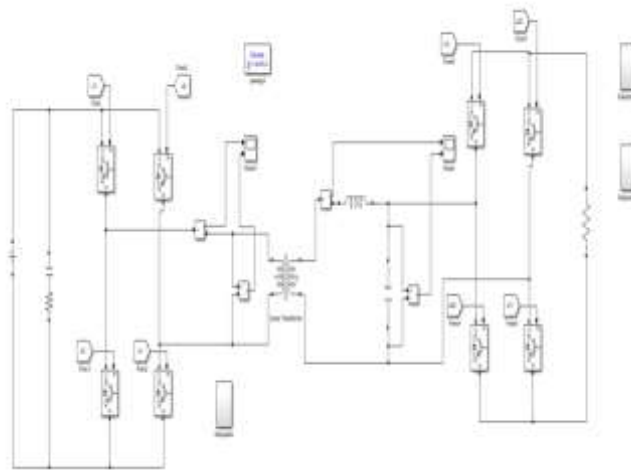
This section examines and validates the suggested method's performance. The suggested technique was created to enhance EV battery rapid charging. By considering the suggested quick charging controller, this suggested process extends battery life. The rapid charging controller controls the battery to extend its life. This controller allows for appropriate EV load demand adaptation during charging and discharging. Performance analysis and comparison are used to assess the suggested method's MATLAB implementation. The comparability of the suggested approach is verified using the design parameter assumption.

The battery's and the suggested controller's performance calculations are validated by taking the EV load into account.

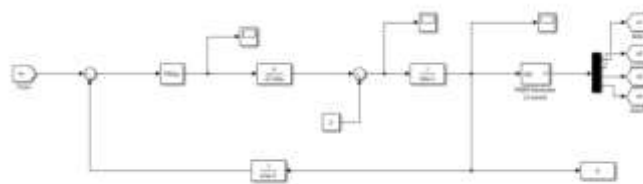
b. Simulation with PSO



(a)



(b)



(c)

Fig.11(a) Simulink full diagram (b) DC-DC diagram (c) control diagram

Figure 11 displays the Simulink diagram for the suggested methodology. Initially, the EV is designed with load conditions connected to speed. After the vehicle load, energy is used and the battery is charged and discharged.

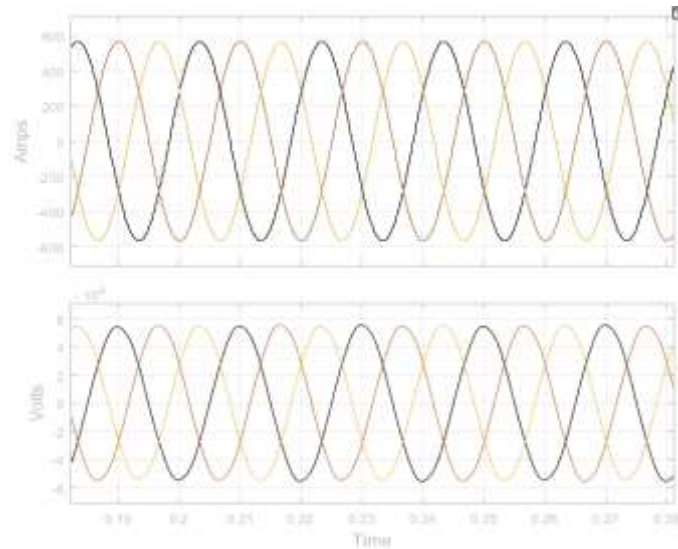
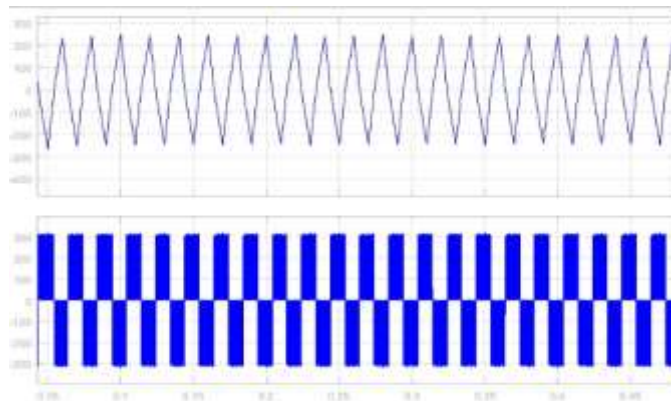
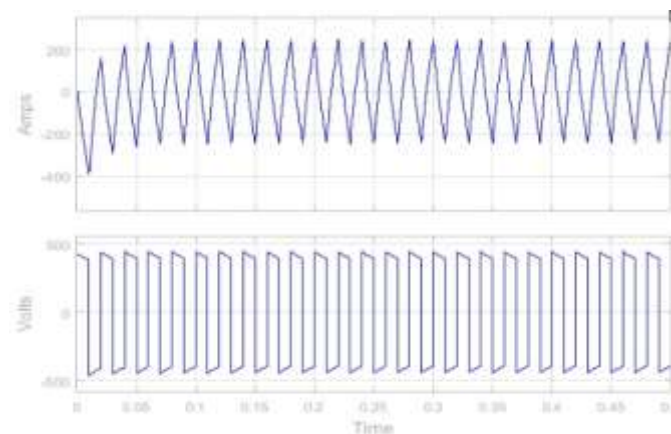


Fig. 12 grid input voltage

Figure 11 displays the Simulink diagram for the suggested methodology. Initially, the EV is designed with load conditions connected to speed. After the vehicle load, energy is used and the battery is charged and discharged.



(a)



(b)

Fig. 13 (a) primary voltage and current, (b) secondary voltage

Figure 13 displays the HB1 provided ac values, and the input voltage is 400dc.

Similarly, the EV uses less energy and goes more slowly because it is fuelled by HB2 to the battery. Devices that store energy in batteries are utilised to balance the load. To make up for the required load, the battery charges and discharges continually.

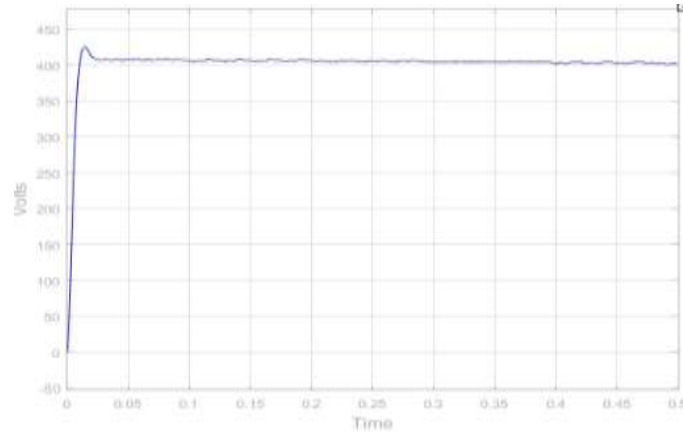


Fig. 14 Dc voltage

After converting the AC voltage to DC and sending it via the grid to the electric vehicle for charging, the bidirectional inverter DC-link voltage of 400V is displayed in fig. 14 above.

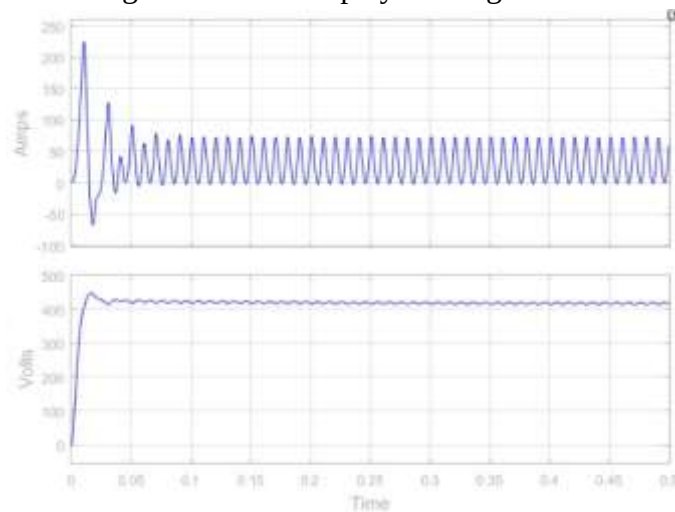


Fig.15 output voltage

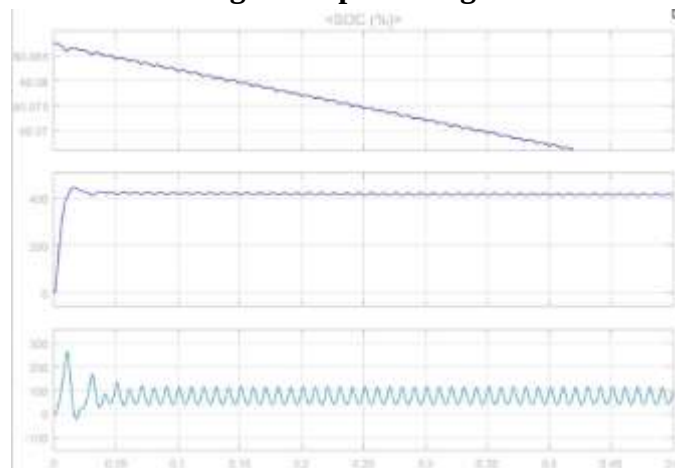
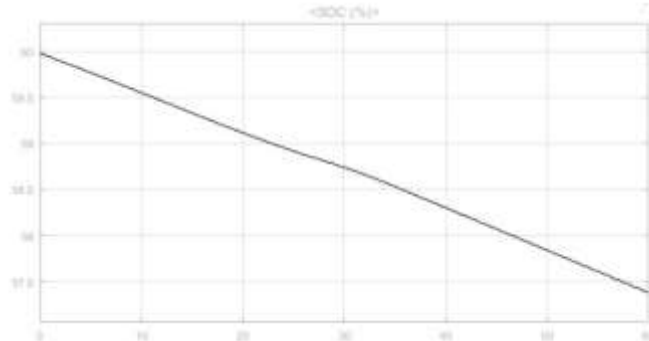


Fig. 16 battery voltage and soc

Figure 16 above, which examines battery SOC draining situations for times $t=0$ to 0.5 seconds, shows that the battery is in a discharging condition with 60.09% to 60.07.



(b)

Fig. 17 Battery soc comparison

This process causes problems with the EV's battery and shortens its lifespan. The purpose of the quick charging controller was to enhance battery performance. Electrical losses from batteries, generators, motors, and overall losses are among the different kinds of losses connected to an electric vehicle load.

TABLE -2

Comparison between FUZZY and PSO controller

	FUZZY	PI with PSO
Input voltage	400	400
Dc link voltage	290	310
Battery SOC	60 – 59.4	60.09-60.06
Battery voltage	400	400
Battery Current	40	40
Primary voltage	400	300
Secondary voltage	400	400

Simulation studies show that Particle Swarm Optimisation (PSO) consistently outperforms fuzzy controllers in terms of solution quality, convergence speed, and robustness.

This suggests that PSO has the potential to be a dependable optimisation method for the real-world applications listed in Table 2.

V. CONCLUSION

The goal of this study is to employ an isolated and optimised DC-DC converter to change the direction of an electric vehicle's (EV) power flow. Bidirectional DC-DC, unidirectional DC-DC, and dual active bridge (DAB) converters are among the different types of this converter.

Another key function of this converter is managing the power flow between the battery and the EV. The DAB converter was chosen for its ideal gain parameter. The suggested approach allows electricity to flow both ways by connecting the EV battery to a bidirectional DC-DC converter. The suggested method

was tested in MATLAB, and performance metrics were considered during the evaluation. The method was also compared with traditional approaches like PSO and fuzzy logic. The battery life was taken into account during the assessment, and the proposed method achieved a long battery life of 7800 cycles, which is better than traditional methods. In the future, the PSO method will be used for real-time evaluation.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Dr. [Guide Name] for his technical assistance and during the planning and execution of this work. We also thank [Institute Name]'s Department of Electrical and Electronics Engineering for providing the tools and space needed to conduct this study.

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