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ANFIS Control Bidirectional DC-DC Converter for V2G and G2V Hybrid EV Charger

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ABSTRACT: This project introduces a novel wide-range high voltage gain bidirectional DC-DC converter designed for Hybrid Electric Vehicle (HEV) chargers capable of both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operation. The proposed converter aims to enhance the efficiency, voltage range, and bidirectional power flow capabilities compared to existing solutions. An Adaptive Neuro-Fuzzy Inference System (ANFIS) controller is incorporated to optimize the performance and control of the converter, ensuring precise and adaptive response to varying operating conditions. The entire system is modeled and simulated using MATLAB to validate its performance. A comprehensive comparison between the existing and proposed systems is presented, highlighting the advantages and improvements in the context of HEV charging infrastructure. The MATLAB simulations demonstrate significant improvements in terms of efficiency and voltage regulation under various load conditions. The ANFIS controller adapts to dynamic changes, providing robust control and minimizing energy losses. Additionally, the proposed converter's ability to handle wide voltage ranges makes it highly suitable for the fluctuating demands of HEV chargers.

KEYWORD: EV, Matlab, V@G, G2V, HEV charging , ANFIS controller

I. INTRODUCTION

Hybrid energy source electric vehicles (EVs), whose power system consists of high energy density batteries and high power density super capacitors, as shown in Fig.1, are an import part of the drive toward lower-carbon and lower-pollution transportation systems. The battery bidirectional dc-dc converter (BDC) maintains a stable dc bus voltage, and the motor is driven by the power from the dc bus through the inverter. The working conditions of EVs produce high-frequency dynamic power demands during acceleration and regenerative breaking. To reduce stress on the battery and improve overall system efficiency, these high peak power demands can be serviced by a super capacitor. In order to make full use of the power capacity of the super capacitor and to exploit its high power density characteristic, it is necessary to dynamically match the wide voltage range of the super capacitor with the constant dc bus voltage. Accordingly, the bidirectional power interface between the super capacitor and the dc bus requires a wide voltage gain range. Bidirectional dc-dc converters can be divided into two categories: isolated and non-isolated converters. Isolated converters can achieve a high voltage gain by using a transformer with a large turns ratio, but usually cannot provide a high voltage gain range (i.e. ratio between maximum and minimum output voltages) with high efficiency. The bridge converters (e.g. dual active bridge) are the most common type of isolated converters, where the voltage stresses experienced by the power switches are equal to the output voltage. Non-isolated bidirectional dc-dc converters include the conventional two-level Buck/Boost converter, Cuk/Sepic/Zeta converters, multi-level converters, coupled-inductor converters, switched-capacitor and switched-inductor converters, etc. The conventional bidirectional Buck/Boost converter can realize bidirectional power flows between the low voltage side (LVS) and the high voltage side (HVS), but the converter is subject to extreme duty cycles when a wide voltage gain range is required. In addition, the voltage stresses across power switches are as high as the voltage on the HVS. Although the Cuk/Sepic/Zeta converters can achieve a wide voltage gain range without operating under extreme duty cycle conditions, the power conversion efficiency is limited by their cascaded structures. Multi-level dc-dc converters greatly reduce the voltage stresses across power switches by employing more power switches, however, additional hardware as well as more complex control strategies are required . Coupled-inductor dc-dc converters can achieve a high voltage gain by adjusting the turns ratio of the coupled inductors, but the order of the converter will be higher, which demands a more complicated control system. In some cases, transformer leakage inductance results in voltage spikes across the power switches, requiring additional components to absorb the leakage inductance energy. Coupled inductors can also impose complex requirements on the design of the magnetic elements. Switched-inductor bidirectional dc-dc converters can achieve a wide voltage gain range without extreme duty cycles. However, the use of multiple inductors limits the power density of the converters. Switched-capacitor dc-dc converters are simple in structure and relatively easy to extend; in these converters, the capacitors transfer energy through different paths during charging and discharging processes to obtain a

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high voltage gain. The voltage gain can be increased by cascading basic switched-capacitor cells in, but the range of the voltage gain is limited: it can only be an integer multiple and has no dependency on the duty cycle. Two output capacitors are connected in series to increase the voltage gain range in. However, the input and output do not share a common ground and the required output capacitance is relatively large. Coupled inductors are charged in parallel and discharged in series in to improve the voltage gain of the converter, however, the leakage inductance can cause voltage spikes across power switches if snubber circuits are not included. In addition, this type of converter does not have a common ground between the input and output. In, a structure in which a switched-inductor and a switched-capacitor are connected in series is proposed to increase the voltage gain. However, the series structure of the inductor and capacitor can generate oscillating current, and a large inductance is required to reduce the current ripple on the LVS. A hybrid bidirectional dc-dc converter serving as an interface between two dc voltage buses in dc micro grids is proposed in Although the switched-capacitor cell gives the advantage of a high voltage gain, the power switch between the input and output grounds generates a high-frequency potential difference. In addition, the voltage stresses across the power switches remain high which limits its applications. In order to tackle some of the shortcomings of previously proposed circuits, this paper proposes a three-phase interleaved bidirectional dc-dc converter suitable for use as the super capacitor interface in hybrid energy sources EVs. This circuit has a wide voltage gain range and so can provide the dynamic matching between the super capacitor voltage and the constant dc bus voltage. Additionally, a three-phase interleaved structure based on switched-capacitor cells greatly reduces the current ripple on the LVS, as well as reducing the voltage stresses across the power switches. The SCIB converter is easy to extend and has an absolute common ground between the input and output. Thus, the main advantages of the SCIB converter include wide range of voltage gain, reduced current ripple and voltage stress of the power switches and good topology scalability.
Electric vehicles (EVs) have emerged as a pivotal technology in the global transition towards sustainable and clean transportation. Central to the functionality of EVs is the charging infrastructure, which includes various types of chargers and converters designed to efficiently manage the flow of electricity between the grid and the vehicle. Among these technologies, the bidirectional DC-DC converter has gained significant attention for its ability to facilitate Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) interactions. This dual functionality not only allows for the charging of EVs but also enables EVs to discharge power back into the grid, thereby supporting grid stability and energy management.

1.2 Importance of Bidirectional DC-DC Converters

The bidirectional DC-DC converter is crucial in the context of V2G and G2V hybrid EV chargers. Unlike traditional unidirectional chargers, which only allow power to flow from the grid to the vehicle, bidirectional converters support power flow in both directions. This capability is essential for V2G applications, where the energy stored in the EV's battery can be used to supply power back to the grid during peak demand periods or emergencies. This bidirectional flow of energy enhances the flexibility and resilience of the power grid while also providing economic benefits to EV owners through potential energy cost savings and incentives.

1.2.1 Challenges in Designing Bidirectional DC-DC Converters

Designing an efficient and reliable bidirectional DC-DC converter presents several challenges. These include managing the different voltage levels between the EV battery and the grid, ensuring high efficiency to minimize energy losses, and maintaining system stability during bidirectional power flow. Additionally, the converter must handle varying load conditions and battery states, which requires sophisticated control strategies. Thermal management is also a critical concern, as bidirectional operation can lead to increased heat generation that must be effectively dissipated to prevent damage to the converter components.

1.3 V2G and G2V Technologies

V2G technology allows EVs to interact with the power grid in a dynamic way. When connected to a V2G-capable charger, an EV can provide services such as peakshaving, load leveling, and frequency regulation. This interaction is facilitated by bidirectional DC-DC converters, which convert the DC power from the EV battery to AC power compatible with the grid, and vice versa. G2V technology, on the other hand, involves the traditional charging process where electricity from the grid is used to charge the EV battery. The integration of V2G and G2V functionalities in a single hybrid EV charger represents a significant advancement in EV charging technology.

1.4 Hybrid EV Chargers

Hybrid EV chargers, equipped with bidirectional DC-DC converters, play a vital role in the smart grid ecosystem. These chargers not only provide a means to charge EVs but also enable the utilization of EV batteries as distributed energy storage systems. This capability is particularly beneficial in scenarios where renewable energy sources, such as solar and wind, are integrated into the grid. By storing excess renewable energy in EV batteries and discharging it back

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to the grid when needed, hybrid EV chargers help to balance supply and demand, reduce reliance on fossil fuels, and enhance the overall efficiency of the power grid

1.5 Technical Considerations for Bidirectional DC-DC Converters

1.5.1 Voltage Level Management

One of the primary technical considerations in the design of bidirectional DC-DC converters is managing the voltage levels between the EV battery and the grid. EV batteries typically operate at lower voltages compared to the grid, which necessitates the use of step-up and step-down conversion techniques. Ensuring a seamless transition between these voltage levels without significant energy losses is critical for the efficiency of the converter.

1.5.2 Efficiency and Loss Minimization

Efficiency is a key parameter in the performance of bidirectional DC-DC converters. High-efficiency converters reduce energy losses, lower operating costs, and minimize heat generation. Achieving high efficiency requires the use of advanced semiconductor devices, optimized control algorithms, and effective thermal management solutions.

Control Strategies

Effective control strategies are essential for the stable operation of bidirectional DC-DC converters. These strategies must ensure smooth power transfer between the EV battery and the grid, manage dynamic load conditions, and respond to fluctuations in grid voltage and frequency. Advanced control techniques, such as model predictive control and fuzzy logic control, are often employed to enhance the performance and reliability of bidirectional converters.

1.6 Applications of Bidirectional DC-DC Converters.6.1 Residential Charging Stations

Bidirectional DC-DC converters are increasingly being integrated into residential charging stations, enabling homeowners to participate in V2G programs. This integration allows EV owners to use their vehicles as backup power sources during outages, reduce electricity bills through peak shaving, and support the grid by providing ancillary services.

1.6.2 Commercial and Industrial Settings

In commercial and industrial settings, bidirectional DC-DC converters facilitate large-scale V2G applications. Businesses can leverage the energy stored in their EV fleets to manage energy costs, support renewable energy integration, and enhance grid stability. Additionally, these converters enable the development of smart microgrids, where EVs play a central role in energy management.

1.6.3 Renewable Energy Integration

The integration of renewable energy sources, such as solar and wind, with bidirectional DC-DC converters enhances the flexibility and reliability of the power grid. By storing excess renewable energy in EV batteries and discharging it during periods of high demand, these converters help to smooth out the variability of renewable energy generation and reduce the need for fossil fuel-based peaking power plants.

II. LITERATURESURVEY1.

1. Shouxiang Wang, Haiwen Chen "A novel deep learning method for the classification of power quality disturbances using deep convolutional neural network"2019. This paper proposes a novel full closed-loop approach to detect and classify power quality disturbances based on a deep convolutional neural network. Considering the characteristics of power quality disturbances problem, a unit construction which consists of 1-D convolutional, pooling, and batch-normalization layers is designed to capture multi-scale features and reduce overfitting. In the proposed deep convolutional neural network, multiple units are stacked to extract features from massive disturbance samples automatically. Comparisons with other state-of-the-art deep neural networks and traditional methods proves that the proposed method can overcome defects of traditional signal process and artificial feature selection. Considering microgrid is an important development form of multi-energy system and an essential part of smart grid, a typical simulation system is constructed to analyze the causes of power quality problems in microgrid and the field data from a multi-microgrid system are used to further prove the validity of the proposed method.

2. Oludamilare Bode Adewuyi, RyutoShigenobu, KazukiOoya, TomonobuSenjyu, Abdul MotinHowlader "Static voltage stability improvement with battery energy storage considering optimal control of active and reactive power injection"2019.

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Voltage stability analysis and improvement remain a major concern of power system operators due to the recurrent risk of voltage collapse. Many approaches have been used to analyze voltage stability but an approach that can directly indicate the closeness of power system to voltage collapse can be used to optimally plan for the improvement of the power system voltage stability condition when compensation devices are to be deployed. In this study, optimal active and reactive power compensation was performed on a continuously loaded power system, using the battery energy storage system (BESS). In order to achieve this, a voltage stability evaluation model which contains information concerning the active and reactive power flow along the transmission line was adopted.

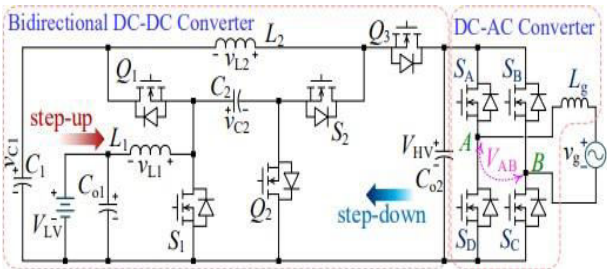
3.JunGao, LuyunGan,FabiolaBuschendorf "Omni SCADA Intrusion Detection Using Deep Learning Algorithms",2019.

In this article, we investigate deep-learning-based omni intrusion detection system (IDS) for supervisory control and data acquisition (SCADA) networks that are capable of detecting both temporally uncorrelated and correlated attacks. Regarding the IDSs developed in this article, a feedforward neural network (FNN) can detect temporally uncorrelated attacks at an F1 of 99.967±0.005% but correlated attacks as low as 58±2%. In contrast, long short-term memory (LSTM) detects correlated attacks at 99.56±0.01% while uncorrelated attacks at 99.3±0.1%. Combining LSTM and FNN through an ensemble approach further improves the IDS performance with F1 of 99.68±0.04% regardless the temporal correlations among the data packets.

4. Xinyu Wang, XiaoyuanLuo, Mingyue Zhang "Distributed detection and isolation of false data injection attacks in smart grids via nonlinear unknown input observers"2019.

To detect the FDIAs more quickly and avoid missed detection, an adaptive threshold is computed to replace the traditional precomputed threshold. A distributed isolation scheme against the FDIAs is proposed with two steps, by considering the exchanged information of adjacent grid subareas. In the first-step, each local control center of subareas is to isolate the possible actuator attack set via the proposed local attack signature judgment logic matrix. In the second-step, the possible subarea attack set is isolated by the established global attack signature judgment logic matrix. The distributed isolation logic decision against the FDIAs relays on the combination of isolation results in the first-step and second-step.

5. Thus automatic and intelligent algorithm- based methodologies are in practice for the detection, recognition and classification of power quality events. This approach may help to take preventive measures against abnormal operations and moreover, sudden fluctuations in supply can be handled accordingly. Disturbance types, causes, proper and appropriate extraction of features in single and multiple disturbances, classification model type and classifier performance, are still the main concerns and challenges. In this paper, an attempt has been made to present a different approach for recognition of PQDs with the synthetic model based generated disturbances, which are frequent in power system operations, and the proposed unique feature vector. Disturbances are generated in Matlab workspace environment whereas distinctive features of events are extracted through discrete wavelet transform (DWT) technique FayyazJandan,SyedAbid Ali Shaha "Recognition and Classification of Power Quality Disturbances by DWT-MRA and SVM Classifier"2019.



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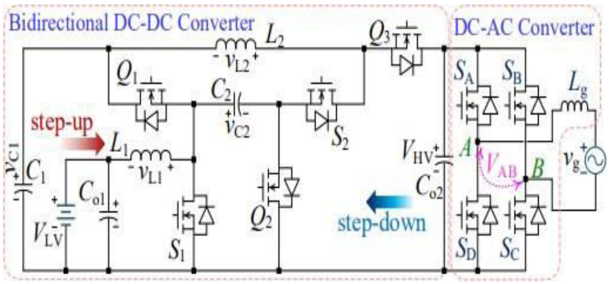
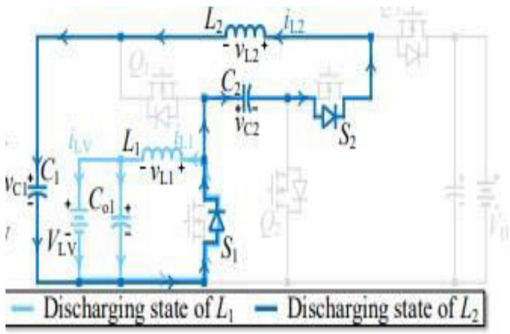
III. SYSTEMIMPLEMENTATION



PROPOSEDBIDIRECTIONALCONVERTER

STEP DOWN MODE- 1 CCM and DCM [0−t1]:
In this interval and according to Fig. 1, Q1, Q2 and Q3 are turned on while S1 and S2 are turned off. In this period, L2 is charged by the input dc source and the released energy from C1. Thus, the current through L2 increases, whereas the energy of L1is increased fromC2.

STEPDOWNMODE-2
CCM [t1−Ts]and DCM[t1−t2]:



Contrary to state 1, during this interval as shown in Fig. 2,Q1,Q2andQ3areturned off whereas the body diodes of S1and S2 are conducting. The inductor L2 releases its energy into the capacitors C1 and C2. Similarly, theenergyofL1isreleasedtotheVLVside.

STEPDOWNMODE-3
State 3DCM [t2−t3]:
According to Fig. 3, in this mode, the current through inductor L2meets zero at time t2 and the current through L1 meets zero at time t3, both before the end of the switching period.
State4 DCM [t3−Ts]:
In this mode, all of the power switches are turned off. The current through inductors meets zero. At the end of this interval, a complete period $_{Ts}$ has been passed.

STEPUP MODE-1
State1 CCM and DCM [0−t1]:
In this interval and according to Fig. 4, S1 and S2 are both turned on while Q1, Q2 and Q3 are turned off. In this state, L1 is charged by the input dc source. Thus, the current throughL2 increases, whereas the energyofL2isincreasedfromC1andC2.

STEPUP MODE-2
State2 CCM [t1-Ts] and DCM [t1-t2]:
Contrary to state 1, during this interval as shown in Fig.5, S1 and S2 are turned off whereas the body diodes of Q1, Q2 and Q3 are conducting. The inductor L1 releases its energy into the capacitors C2. Similarly, the energy of L2 is released to the VHV side.

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MODELLING

The DAFB-based bidirectional EV battery charging system configuration is shown in Fig. The system is mainly composed of bidirectional DC/AC converter followed by a HF transformer feeding a bidirectional AC/DC converter, which in turn charges the EV battery. The DAFB system bi-directional power-flow between the grid and the battery is controlled by adjusting the phase shift (φ)between the two bridges' gate control signals. Notice that an outer control loop uses a proportional–integral (PI) controller to regulate the So C% of the EV battery.

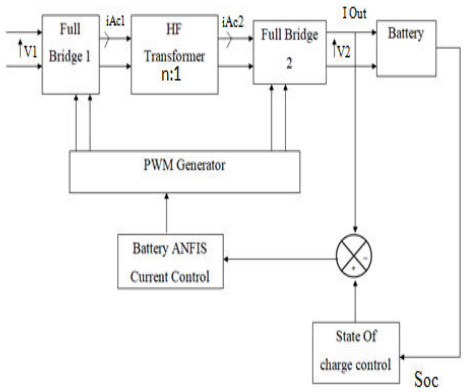

Fig3.5: Proposed block Diagram

3.4 THE WORKING PRINCIPLE OF THE PROPOSED SYSTEM IS BASED ON TWO MAIN OPERATIONAL MODES:

V2G and G2V. In the V2G mode, the system is designed to convert the 42V DC input from the vehicle's battery to a 250V AC output that can be injected into the grid. This mode enables the vehicle to act as a power source, supplying energy back to the grid when required. Conversely, in the G2V mode, the system converts the 230V AC from the grid to 42V DC to charge the vehicle's battery. This bidirectional functionality is crucial for supporting the dynamic needs of HEV chargers.

3.4.1 V2G Mode

In the V2G mode, the bidirectional DC-DC converter operates as a boost converter. The key components involved in this mode include a DC input source, power switches, inductors, capacitors, and the ANFIS controller. The 42V DC input from the vehicle's battery is fed into the converter. The boost converter steps up this voltage to 250V DC using inductive energy storage and release cycles controlled by the power switches.

The ANFIS controller plays a critical role in this mode by adjusting the duty cycle of the power switches to maintain the desired output voltage. It continuously monitors the input and output voltages and adapts its control strategy to achieve high efficiency and stable operation under varying load conditions. Once the 250V DC is achieved, it is inverted to 250V AC using an inverter circuit, making it compatible with the grid's AC voltage requirements. The MATLAB simulation for the V2G mode involves modelling the boost converter, the inverter, and the ANFIS controller. The simulation scenarios include varying the load and input conditions to evaluate the performance and robustness of the converter. The results demonstrate that the proposed system efficiently converts the 42V DC to 250V AC with minimal energy losses and high voltage regulation accuracy.

3.4.2 G2V Mode

In the G2V mode, the converter operates as a buck converter. The main components in this mode include the AC input source from the grid, rectifiers, power switches, inductors, capacitors, and the ANFIS controller. The 230V AC from the grid is first rectified to 230V DC using a rectifier circuit. This DC voltage is then fed into the buck converter, which steps it down to 42V DC suitable for charging the vehicle's battery.

The ANFIS controller again plays a pivotal role by adjusting the duty cycle of the power switches to ensure the output voltage remains at 42V DC. It adapts to changes in the grid voltage and the state of charge of the battery, ensuring efficient and safe charging. The controller also protects the system from overvoltage and overcurrent conditions by

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dynamically adjusting the control parameters. The MATLAB simulation for the G2V mode includes modeling the buck converter, the rectifier, and the ANFIS controller. Various scenarios are simulated, such as changes in the grid voltage and battery state of charge, to validate the system's performance. The results indicate that the proposed converter can effectively step down the 230V AC to 42V DC with high efficiency and stable operation.

IV. CONTROLALGORITHM

The control algorithms of the two converters is different in each of the two possible operation modes (G2V, V2G) are described as

Grid-to-Vehicle (G2V) Operation Mode

During this operation mode the full-bridge AC-DC bidirectional converter operates as active rectifier with sinusoidal current and unitary power factor. There visible DC-DC converter operates as buck converter. In order to accomplish with the maximum amplitude of the individual current harmonics specified by IEC 61000-3-2 standard, it is mandatory that the full-bridge AC-DC bidirectional converter controller must be synchronized with the power grid fundamental voltage. Therefore, a single-phase Phase-locked Loop (PLL) is the first algorithm implemented by the digital controller. To accomplish with this requirement a single-phase PLL in the α-β coordinates is used. This algorithm produces two sine-waves with unitary amplitudeshiftedby90º: pl l_{α} and pl l_{β}. When the PLL is synchronized with the power grid, the signal pll_{α} corresponds to the direct component of the power grid fundamental voltage. This signal is used as input to the subsequent digital control algorithms.

The second control algorithm is responsible to calculate the reference current or the full-bridge AC-DC bidirectional converter. The amplitude of the reference current is achieved through the division of the reference active power by the power grid voltage, affected by the pl l_{α}signal. The reference active power is obtained through a PI controller designed to keep the DC link voltage regulated. In Fig. 3 it can be seen the control block diagram to generate the current reference (iS*). This current control uses the circuit model parameters and the information from previous sampling to calculate the and can be resumed by:

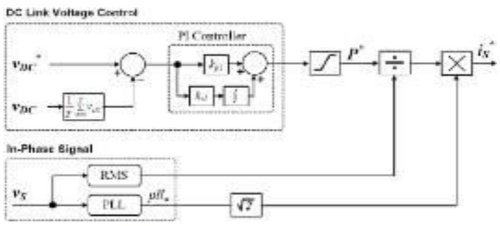

Fig:3 Control block diagram to generate the current reference of the full-bridge AC-DC bidirectional converter.

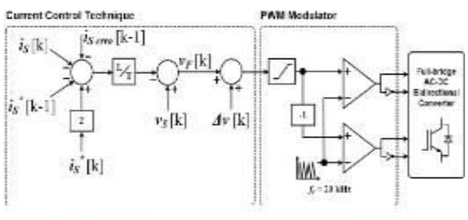

Fig:4 Control block diagram of the current control technique

The reversible DC-DC converter is controlled in both Constant currentandconstantvoltagestagesasshowninFig.5. During the constant current stage the reference current (iTB*) is compared with the actual current (iTB).The obtained current error feeds a PI controller that adjusts the output duty- cycle through a PWM modulator with a triangular carrier of 20 kHz. When the maximum voltage value recommended by the batteries manufacturer is reached the control algorithm changes to the constant voltage stage. In this stage a second PI controller is used to maintain constant the output voltage (vTB) of the reversible DC-DC converter according to the voltage reference(vTB*).

Vehicle-to-Grid (V2G) Operation Mode

The full-bridge AC-DC bidirectional converter operates as inverter with sinusoidal current and unitary power factor, and there visible DC-DC converter operates as a boost converter

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As in the G2V operation mode, in the V2Gmode the full-bridge AC-DC bidirectional converter must be synchronized with the power grid fundamental voltage. As a fore mentioned the synchronization is obtained through a single-phase α-β PLL in α-β coordinates. The active power to be delivered to the power grid is established as external input parameter received from a serial communication port in order to enable the collaborative integration of the EV in a smart grid context. Therefore, the control algorithm employed in theV2G operation mode is similar to the one used in the G2V operation mode.

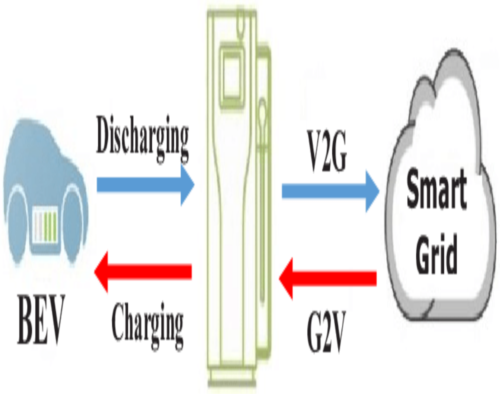

Fig 4.1: Energy flow during operating modes

Aiming to synthesize the reference current correspondent to the active power to be delivered it was also used a predictive current control In order to the full-bridge AC-DC bidirectional converter deliver back to the power grid the energy stored in the traction batteries, the DC link voltage must be slightly greater than the peak value of the power grid voltage. For such intent, there visible DC-DC converter has to operate as a boost converter, once the traction batteries voltage is smaller than the required to the DC link voltage. The traction batteries voltage does not suffer significant variation during short time periods, consequently the regulation of the active power delivered back to the power grid can be done by the absorption of a constant current from the traction batteries. However, as the batteries voltage decreases along the discharging process it is necessary to increase the reference current to maintain the active power constant. The division of the reference active power (P*)by the traction batteries voltage(vTB) results in the traction batteries reference current (iTB*).The error between this current (iTB*)and the actual current (iTB)feeds a PI controller that adjusts the duty-cyclefora20kHz PWM modulator , as showninFig.6.

4.3 ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS)

An adaptive Neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. The technique was developed in the early 1990s. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions. Hence, ANFIS is considered to be a universal estimator. For using the ANFIS in a more efficient and optimal way, one can use the best parameters obtained by genetic algorithm

The adaptive network-based fuzzy inference systems (ANFIS) is used to solve problems related to parameter identification. This parameter identification is done through a hybrid learning rule combining the back-propagation gradient descent and a least-squares method.

ANFIS is basically a graphical network representation of Sugeno-type fuzzy systems endowed with the neural learning capabilities. The network is comprised of nodes with specific functions collected in layers. ANFIS is able to construct a network realization of IF / THEN rules.

Consider a Sugeno type of fuzzy system having the rule base
If x is A1and y is B1, then $f_1= c_{11}x+c_{12}y+c_{10}$
If x is A2and y is B2, then $f_2= c_{21}x+c_{22}y+c_{20}$
Let the membership functions of fuzzy sets Ai, Bi, i=1,2, be , $\mu_{Ai}\mu_{Bi}$.
In evaluating the rules, choose product for T-norm (logical and).

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Evaluating the rule premises results in

$$w_i = \mu_{A_i}(x)\mu_{B_i}(y),\ i = 1,2.$$

Evaluating the implication and the rule consequences gives

$$f(x,y) = \frac{w_1(x,y)f_1(x,y) + w_2(x,y)f_2(x,y)}{w_1(x,y) + w_2(x,y)}.$$

Or leaving the arguments out

$$f = \frac{w_1 f_1 + w_2 f_2}{w_1 + w_2}$$

This can be separated to phases by first defining

$$\overline{w}_i = \frac{w_i}{w_1 + w_2}$$

Then f can be written as

$$f = \overline{w}_1 f_1 + \overline{w}_2 f_2$$

All computations can be presented in a diagram form. ANFIS normally has 5 layers of neurons of which neurons in the same layer are of the same function family.

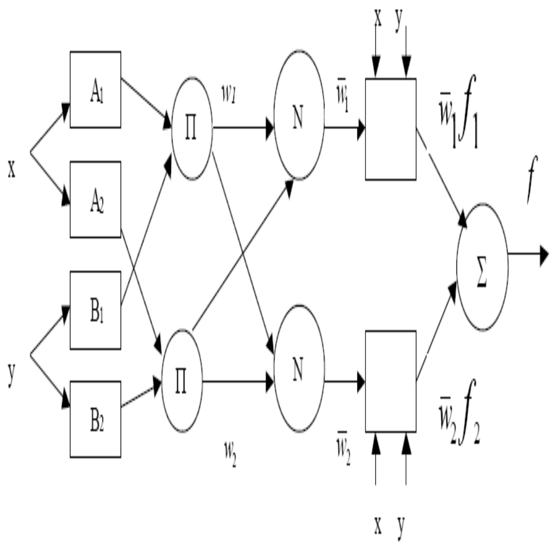

Fig 4.2: Structure of the ANFIS network.

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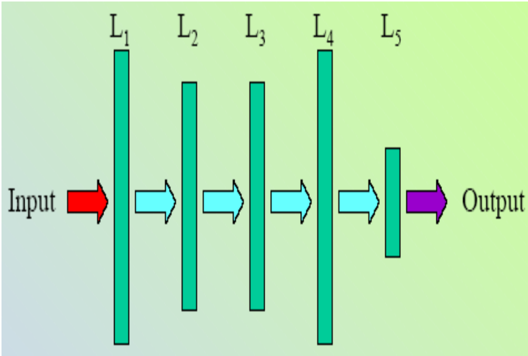
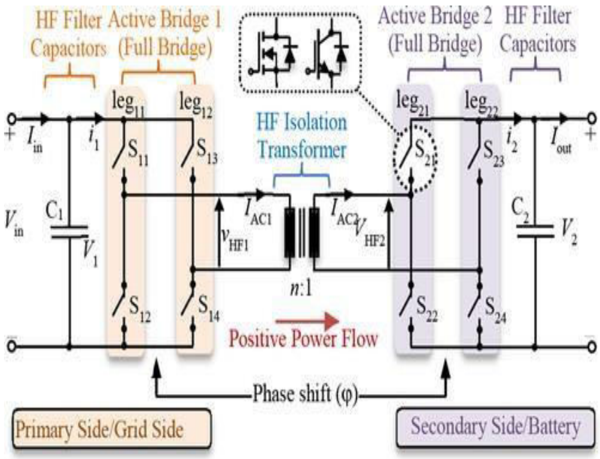


Fig 4.3 : ANFIS Architecture



Layer 1 (L1): Each node generates the membership grades of a linguistic label.
An example of a membership function is the generalised bell function:

$$\mu(x) = \frac{1}{1 + \left|\frac{x-c}{a}\right|^{2b}}$$

Where {a, b, c} is the parameter set. As the values of the parameters change, the shape of the bell-shaped function varies. Parameters in that layer are called premise parameters.

Layer 2 (L2): Each node calculates the firing strength of each rule using the min or prod operator. In general, any other fuzzy AND operation can be used.

Layer 3 (L3): The nodes calculate the ratios of the rule's firing strength to the sum of all the rules firing strength. The result is a normalized firing strength.

Layer 4 (L4): The nodes compute a parameter function on the layer 3 output. Parameters in this layer are called consequent parameters.

Layer 5 (L5): Normally a single node that aggregates the overall output as the summation of all incoming signals

4.1.1 The ANFIS learning algorithm

When the premise parameters are fixed, the overall output is a linear combination of the consequent parameters. In symbols, the output f can be written as

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$$f = (\bar{w}_1 x)c_{11} + (\bar{w}_1 y)c_{12} + \bar{w}_1 c_{10} + (\bar{w}_2 x)c_{21} + (\bar{w}_2 y)c_{22} + \bar{w}_2 c_{20}$$

Which is linear in the consequent parameters c_{ij} (i = 1,2¸ j = 0,1,2). A hybrid algorithm adjusts the consequent parameters c_{ij} in a forward pass and the premise parameters {a_i, b_i, c_i} in a backward pass (Jang et al., 1997). In the forward pass the network inputs propagate forward until layer 4, where the consequent parameters are identified by the least-squares method. In the backward pass, the error signals propagate backwards and the premise parameters are updated by gradient descent.

Because the update rules for the premise and consequent parameters are decoupled in the hybrid learning rule, a computational speedup may be possible by using variants of the gradient method or other optimisation techniques on the premise parameters.

V. DESIGNCONSIDERATIONS

5.1. TOPOLOGY

The overall topologyofatypicalEVG2VandV2Gapplications.
Theuseofthistopologyisproposedforapplicationswhereautomaticbidirectional power flow, power density, reliability, efficiency, and cost are the primary design considerations. The DAFB is composed of bidirectional DC/AC H-bridge converter followed by a high-frequency (HF)transformer feeding a bidirectional AC/DC H-bridge converter, which in turn charges the EV battery. The DAFB system bidirectional power-flow between the grid and the battery is controlled by adjusting the phase shift (φ) between the two bridges' gate control signals.

RELIABILITY

Reliabilitystudiesofpowerelectronicsconvertersfocusontheweakestelement in the system. Particularly, capacitors are considered as the most fragile part of the system. In fact, failures due to capacitors have the highest cost/failure ratio since they are difficult to detect and hence require a special attention. Particularly, when the capacitance requirement is large, it is inevitable to avoid using unreliable electrolytic capacitors because it is difficult to find commercial reliable non-polarized film capacitors with high capacitance values. Moreover, the high capacitance requirement is due to the low inertia of the system that causes second-order voltage harmonic to appear on the DC link Even though, this phenomenon is severe with single-phase systems, any system with an instantaneous power that is not constant would possess high input capacitance requirement to match this power mismatch. Consequently, the lifespan of the system is highly deteriorating din case the charger is constructed with single-phase topology.

However, the input capacitance could be reduced with single-phase systems by using an appropriate power-decoupling scheme Authors in reviewed the power decoupling methods that require extra switches and energy storage devices and provides a switchless power decoupling method. Yet, adopting a powered coupling control scheme would increase the complexity of overall battery charger Con-sequent, it is recommended to use the DAFB in a three-phase topology to minimize the DC-link capacitance requirement that would reflect positively on the system reliability

BATTERYLIFETIMECONSIDERATIONS

To assure the safe operation of the system and avoid damaging the battery due to over-charge or over-discharge, the system should monitor the So C% of the battery to select the appropriate operation mode .Fig.3depicts the different So C% level and the suitable V2G or G2V operation modes. Note that, in the range of 15–80%, the priority of the operation is set by the user. Meaning that, in normal operation, V2G mode would be set by a command that is provided by the SG; unless, the EV user pre-defined G2V priority for EV charging.

Fig 5.2:Operationmodesbased on battery SoC%

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ZVS, ZCS, AND EFFICIENCY CONSIDERATIONS

It is well known that the DAFB has inherent zero voltage switching (ZVS)capabilities in case the ratio of the voltages applied on the HF transformer sides is equal to the transformer ratio ZVS condition means that the turn-on losses are negligible and, therefore, efficiency is high. Never the less, many of the recent literatures on the DAFB configuration are focused on increasing the ZVS region. For instance, the author s in investigate the ZVS boundaries if a three-level modulation is adopted. Besides, the authors in provide a summary of different modulation schemes – extended phase shift (EPS) dual phase shift (DPS) , and triple phase shift(TPS)–that are often used with the DAFB to reduce the switching loss and extend the ZVS region. In addition, the authors in proposed anew modulation technique that is based on online optimization algorithm called half-bridge pulse-width-modulation-plus-phase-shift (HPPS) that is similar to TPS of Also, there are some other control schemes that are based on online frequency modulation control to optimize the AC-link reactance such as the control proposed by the authors Nevertheless, simply controlling the DC-link voltage to assure that the voltage applied on the HF transformer sides is equal to the transformer ratio would be sufficient to accomplish ZVS conditions

On the other hand, MOSFET's characteristics make them attractive to use in EV applications. As a result, reducing the components counts and cost and increasing the reliability. Additionally, the nature of the ZVS of the DAFB permits high switching frequency operation, which makes the MOSFETs an attractive option over IGBTs.

HFTRANSFORMERCOREMATERIALS

The HF transformer is required for both is oblation and voltage matching between the primary and the secondary sides of the DAFB. Usually, iron-based Nano crystalline soft-magnetic cores are preferred over ferrite cores because they have greater saturation magnetic flux density, higher magnetic permeability, higher Curie temperature, and lesser iron loss.

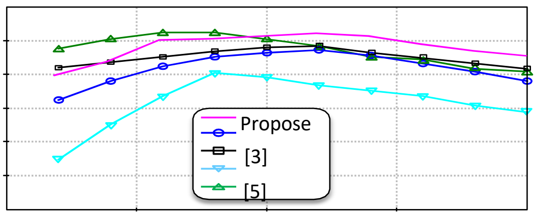
VI. ANALYTICALSTUDIES

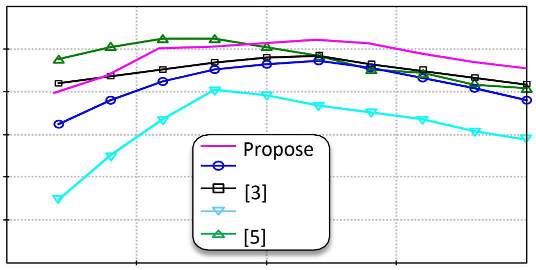
The supplementary information of "A Wide Range High Voltage Gain Bidirectional DC-DC Converter for V2G and G2V Hybrid EV Charger" is given here

ANALYZETHEVARIATIONOFTHEBATTERYSIDEVOLTAGE

The nominal voltage of a lithium-ion battery cell is 3.70V/cell. The nominal voltage is a function of anode and cathode

materials, as well as impedance. The voltage calculations include measuring the mid-way point from a full-charge of 4.20 V/cell to the 3.0 V/cell cut-off with a 0.5 A load. Therefore, the voltage across a lithium-ion battery is varies by varying of discharge capacity or state of charge (SoC). The expected variation of the voltage with SoC for a nominal 3.7 V/cell lithium-ion battery is from 4.2 V at full charge to a discharge cut-off voltage of 3.0 V. Therefore, for the application considered in this work, if the maximum value of LV side voltage is 40 V, the voltage might be expected to vary within a range of 28V to 40 V.





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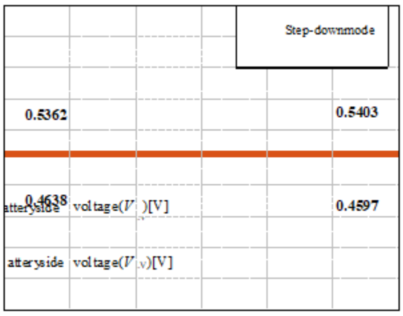
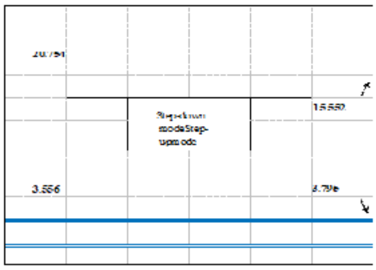
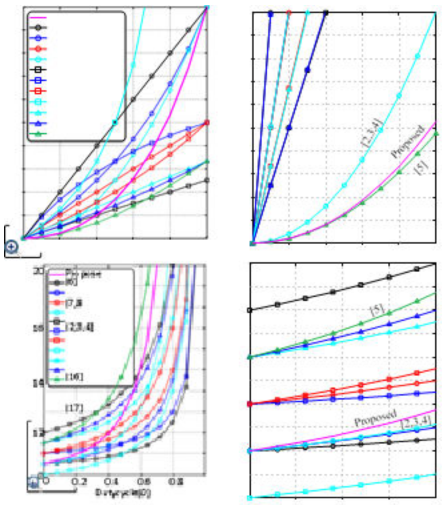




Duty cycle
b)total value of maximum current

OMPARISONOFCALCULATEDEFFICIENCY



The comparison is based calculations of losses in the various components of each converter, under the assumptions that all circuits use the same semiconductor devices, the on-inductor sand capacitor s equivalent is 100mΩ and 50 mΩ, respectively. All the voltage and current of elements are obtained from the simulation at different power levels. Calculating the efficiency of the power converter is very important to adequately design the cooling system, additionally, where the proposed topology has the maximum/minimum efficiency. The power loss of the converter $P_{Loss}$is described by (A.1), where P_M (con),P_M (sw),$P_{L(con)}$,$P_{L(core)}$,$P_{C(con)}$ and P_A are the conduction and switching losses of the five MOSFETs, the conduction and core losses of the two inductors, the conduction loss of the three capacitors and auxiliary power loss, respectively.

$$P_{loss} = P_{M(con)} + P_{M(sw)} + P_{L(con)} + P_{L(cor)} + P_{C(con)} + P_A$$

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COMPARISONOFVOLTAGEGAIN

The main features of proposed converter rather than all published bidirectional converters are provided the proposed converter offers the highest-wide voltage gain ratio than all of the other converters, which make the proposed converter an over solution for V2G and G2V applications

SYNCHRONIZEDRECTIFICATIONMODE

Fig. shows the principle of operation of the synchronous rectification (SR) for the proposed converter in the step-down and step-up modes.

In the step-down mode, and during the time delay t_d, the current must flow in the corresponding antiparallel diodes of $S_1$and S_2, as shown in Fig. Subsequently if $S_1$and $S_2$are turned on then the current will flow in the controlled power semiconductors S_1 and S_2 from source to drain due to their lower on-state resistance and on-state voltage drop using the gate signals.

Similarly, in the step-up mode, during t_d, the current will flow in the corresponding anti parallel diodes of Q_1,$Q_2$and Q_3,as shown in Fig After wards, the current will flow in the controlled power semiconductors Q_1,Q_2 and Q_3using the gate signals

As a result, the controlled MOSFETs of S_1 and S_2 during step-down and Q_1,Q_2 and Q_3,during step-up modes, can be turned on and turned off with the zero voltage switching (ZVS).

The experimental waveforms of SR operation mode as shown in Fig.demonstrate that during step-down mode, after a time delay, the switches S_1 and S_2 are turned on and during step-up mode, the switches Q_1,Q_2 and Q_3areturnedonaftertimedelay.

VII. RESULTS

Simulation model

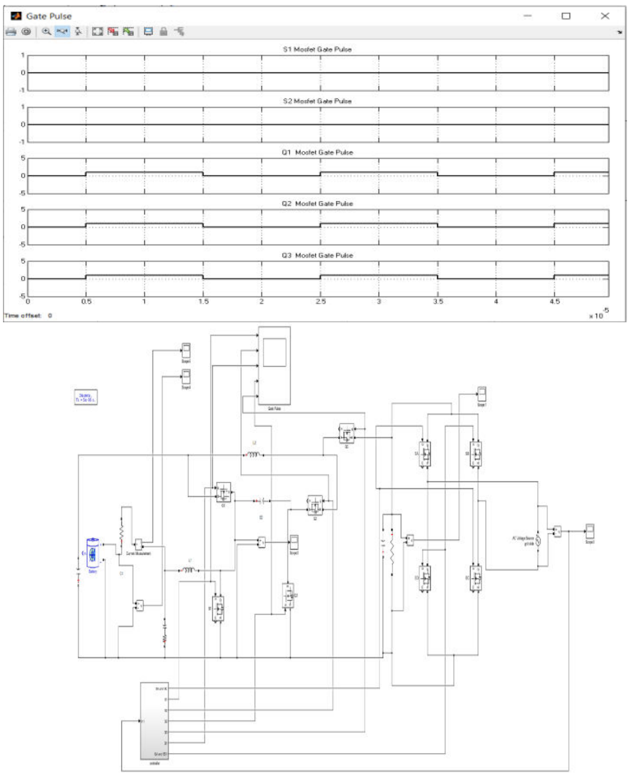

Fig 7.1: Simulation model in vehicle to gird and grid to vehicle using ANFIS

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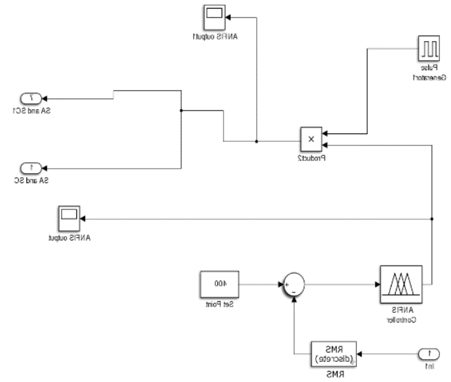

Fig 7.2: Simulation Model for ANFIS control for Matlab model

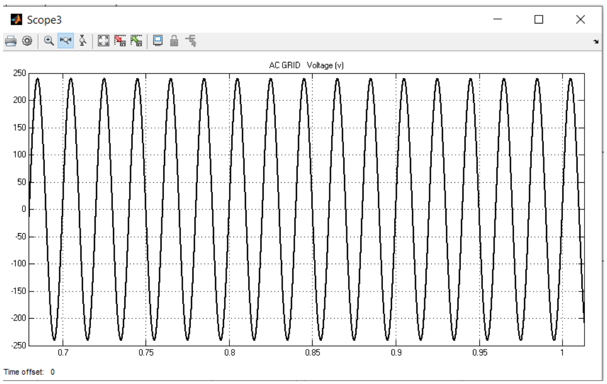

Fig 7.3: AC Grid Input voltage 230V

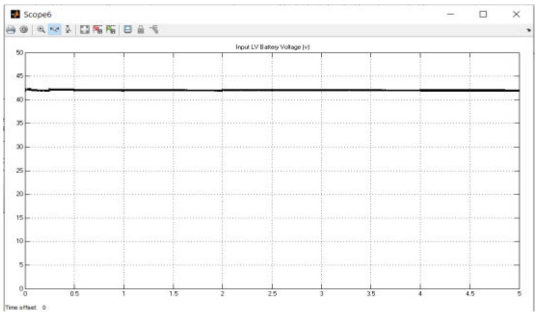

Fig 7.4: Battery Voltage

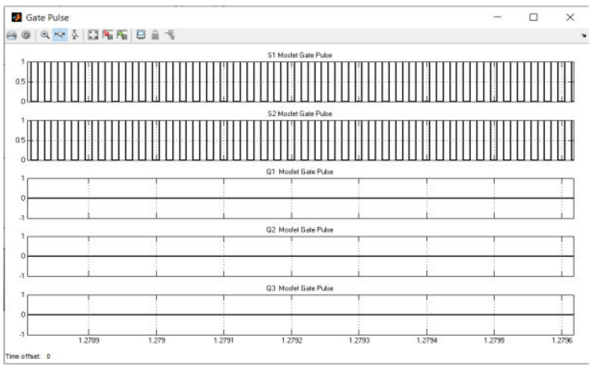

Fig 7.6: Gate pulse

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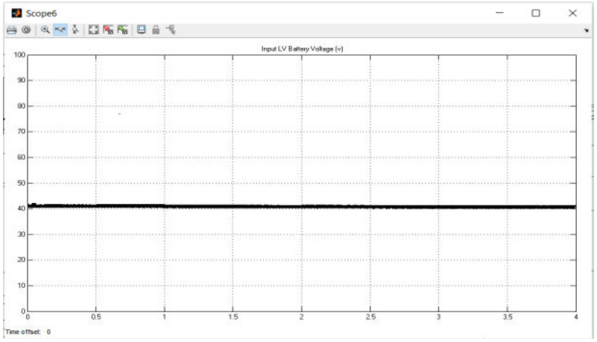

Fig 7.7: Gate pulse

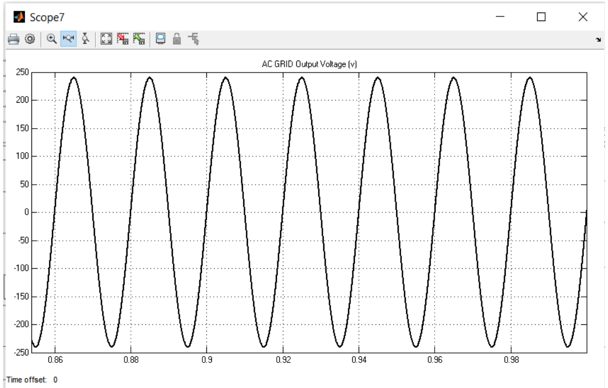

Fig 7.8: Battery Charging Output in Step down Mode

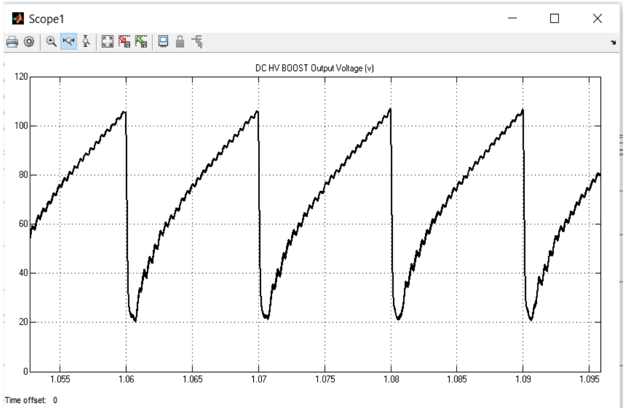

Fig 7.9: Output in DC High voltage Boost

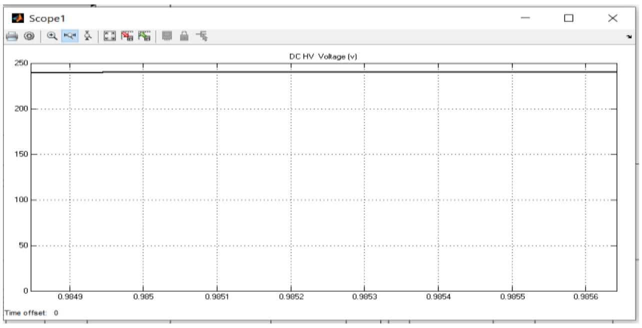

Fig 7.10: Output in Step up Mode DC 42 voltage to 250V DC.

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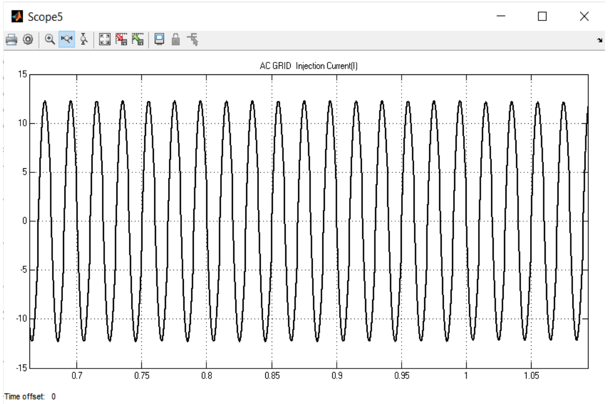

Fig 7.12: AC grid Voltage in 250VAC

VIII. CONCLUSION

In this project, a wide range high voltage gain bidirectional DC-DC converter for V2G and G2V applications is presented. This converter benefits from high step-down and high step-up voltage gains, high efficiency, low rating of switches, having common ground, and bidirectional capability. The proposed converter has utilized a dead-beat controller which ensures smooth and accurate current control for both directions of operation. The charge and discharge of the battery have been successfully demonstrated under both directions using the developed prototype. The advantages of the converter in terms of wider voltage range and higher SUF make it a more practical and versatile topology compared to previously published converters.

Moreover, the implementation of an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller for the charging system has been integrated. The ANFIS controller enhances the system by providing adaptive and intelligent control, leading to improved charging efficiency and battery life. This combination of a dead-beat controller for bidirectional current control and an ANFIS controller for the charging system ensures that the converter operates effectively and efficiently in a variety of conditions, further establishing it as a robust and versatile solution for modern V2G and G2V applications.

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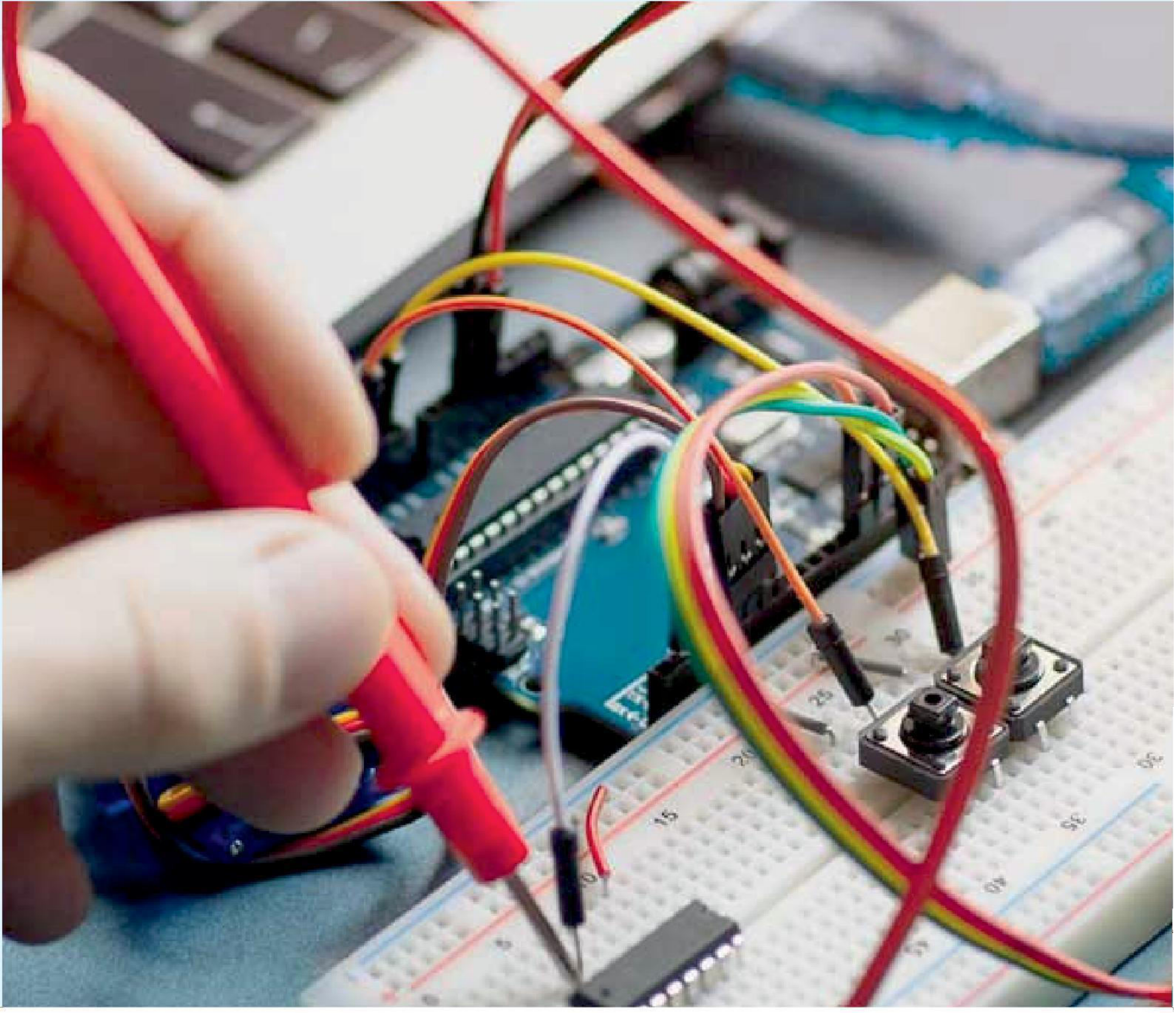

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