BioGecko
Vol 12 Issue 02 2023
ISSN NO: 2230-5807

Neural Network Controller Based Solid State Transformer For Fast Charging EV

[1]Chavale Sujatha, [2] Majeti Pavan Satya Manikanta, [3]Samudrala Saicharan, [4]Vinnakota Raja Srikar, [5]Nandru Jaga Jeevan
[1] Associate Professor, Department of EEE, SRGEC, Gudlavalleru,
[2] Undergraduate Student, Department of EEE, SRGEC, Gudlavalleru,
[3]Undergraduate Student, Department of EEE, SRGEC, Gudlavalleru,
[4]Undergraduate Student, Department of EEE, SRGEC, Gudlavalleru,
[5]Undergraduate Student, Department of EEE, SRGEC, Gudlavalleru,

***Corresponding Author Email – pavanmajeti10000@gmail.com**
Department of Electrical & Electronics Engineering, Seshadri Rao Gudlavalleru Engineering College, Gudlavalleru,AP-521356

Abstract: The use of Electric Vehicles (EVs) is rapidly increasing due to their eco-friendliness and cost-effectiveness. However, the slow charging time of EVs remains a major barrier for their widespread adoption. To overcome this issue, the main focus of this project design and implementation of a Neural Network Controller (NNC) based Solid State Transformer (SST) for fast charging of EVs. The proposed SST system consists of a high-frequency transformer, a power converter, and an NNC-based controller. The transformer is designed to operate at a high frequency of 10 kHz, enabling a reduction in the size and weight of the transformer. The power converter is used to deliver the high-frequency AC voltage generating by the transformer in-to the DC voltage that can be used to charge the EV battery. The proposed SST system offers several advantages over traditional charging systems, including higher efficiency, reduced size and weight, and improved power quality. The proposed system can also adapt to changes in the input voltage and current, making it suitable for use in different charging scenarios. Overall, this project proposes an innovative solution to improve the charging time of EVs by designing and implementing an NNC-based SST system. This project implemented on MATLAB/Simulink 2018a software.
Keywords:
Solid-state-transformer (SST), cascaded-H-bridge converter (CHB), DAB, level 3 fast charging, Neural Network (NN) Controller.

I INTRODUCTION

The goal of this project is to design and implement a neural network controller-based solid-state transformer for fast charging of electric vehicles (EVs). In recent years, EVs have become increasingly popular due to their environmental friendliness and low operating costs. However, one of the major challenges in the widespread adoption of EVs is the time it takes to charge them. Current charging technology relies on traditional transformers, which are limited in their ability to efficiently and quickly transfer power [1]-[3].
As oil supplies deplete, environmental concerns grow, and gasoline prices rise, the dependency on the gasoline supply chain increases. This has led to a greater focus on alternative automotive technologies such as electric, hydrogen, and biofuels [4]-[6].

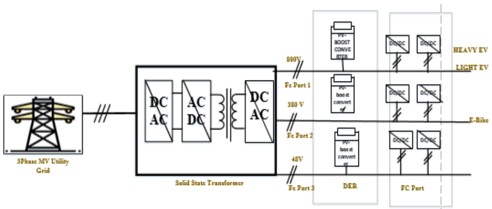


FIG. 1: BLOCK DIAGRAM OF EVCS.

The replacement of internal combustion engine cars with electric vehicles (EVs) has been a major area of focus, owing to their potential to significantly reduce emissions and contribute to cleaner energy production. As the demand for EVs grows, the need for effective power conversion and charging solutions becomes even more critical [7]-[10]. To this end, various studies have emphasized the advantages of using multilevel converters, such as the CHB converter, which offers benefits like low switching frequency, reduced device voltage rating, and lower filter inductor requirements. In order to connect to the medium voltage grid without a transformer, it is necessary to integrate A dual active bridge (DAB) connecting each sub-module (SM) capacitor of the first stage to the second stage [10]–[11]. To overcome this challenge, this project proposes the use of a solid-state transformer (SST), which is a power electronics-based device that can efficiently and rapidly transfer power. Furthermore, a neural network controller will be implemented to regulate the SST and optimize its performance. The neural network will be trained using data obtained from simulations and experiments to accurately predict the optimal operating conditions of the SST [12]–[15].

The ultimate goal of this project is to demonstrate the feasibility and effectiveness of using an SST and neural network controller to fast-charge EVs. This could significantly reduce the charging time of EVs and improve their convenience and usability, thus contributing to their widespread adoption and the reduction of carbon emissions from the transportation sector.

A transformer-less voltage grid is employed, and for Level 3 charging, a medium frequency transformer (MFT) provides the required galvanization isolation. The proposed NN-based topology for the control system is described in Section IV, while the results and discussion are presented in Section V. The study is organized as follows: Section I provides an introduction and literature review, Section II describes the system description, Section III outlines the control topology, and Section VI concludes the project. Finally, Section VII lists the references used in the study [16-21].

II. System Description:

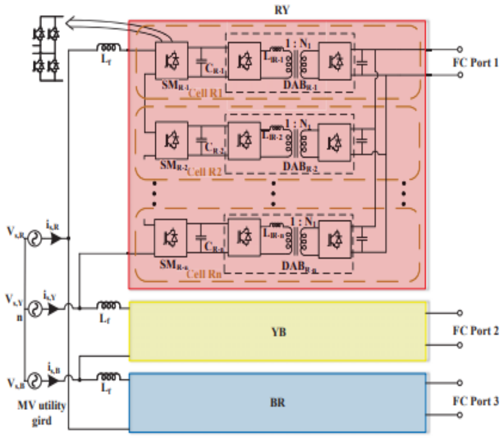


FIG. 2: DIAGRAM OF THE REVISED METHOD CHARGING POINT.

The proposed model for the FCS is shown in Fig. 1, first converter covert the power AC-DC and second converter convert the power DC-AC. Here dual active bridge (DAB) is a type of power converter that can convert high voltage DC power to low voltage DC power, or vice versa, with high efficiency. It consists of two active bridges, which are connected by a high frequency transformer. The active bridges are made up of four switches each (usually MOSFETs or IGBTs), which are arranged in a bridge configuration. Each active bridge is connected to its own DC power source (usually a battery or a DC power supply), and the transformer is connected between the two bridges. When the switches in one of the active bridges are turned on, current flows through the primary winding of the transformer and induces a voltage in the secondary winding. The voltage induced in the secondary winding is then rectified by the switches in the other active bridge, and the resulting DC voltage is output to the load.

The DAB offers a number of advantages over other power converter topologies, including high efficiency, low electromagnetic interference (EMI), and the ability to operate at high frequencies. It is commonly used in applications such as electric vehicle charging, renewable energy systems, and industrial power supplies.

Front-end CHB rectifier

A front-end CHB (Capacitor-Clamped H-Bridge) rectifier is a power electronic circuit used for AC-DC power conversion in high-power applications. It is a type of multi-level converter that uses a series of capacitors to create voltage levels between the positive and negative rails of the DC output voltage. The CHB rectifier consists of an H-bridge inverter on the input side, which is connected to the AC power source, and a set of capacitors and diodes on the output side, which are connected in a specific configuration to generate the desired DC voltage. The CHB rectifier has several advantages over traditional single-level rectifiers, including higher efficiency, lower harmonic distortion, and reduced stress on the power supply and other components. It is commonly used in applications such as renewable energy systems, electric vehicles, and industrial motor drives.

A. An isolated BDC

The IBDC is built using a DAB, which is formed by coupling two H-bridges with a medium frequency transformer. This configuration not only provides the necessary isolation for voltage transformation but also enhances the converter's voltage transformation ratio. The main emphasis is on the control strategy for the IBDC, which is designed to regulate the dc voltage and maintain power balance across the three-phase output.

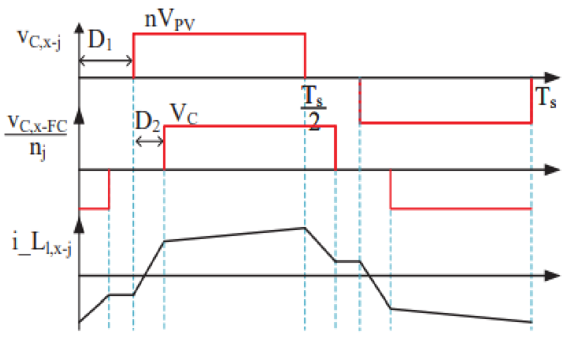


FIG. 3 GATE PULSE OF DAB CONVERTER

An isolated bi-directional converter (BDC) is an electronic device that is used to convert electrical power from one form to another, while also providing electrical isolation between the input and output circuits.

Unlike traditional converters, which typically convert power in only one direction, bi-directional converters can convert power in both directions, allowing energy to flow back and forth between the input and output circuits. Isolation is provided by using a transformer or some other form of isolation circuitry, which prevents electrical noise or voltage transients from being transferred from the input to the output circuit.

Isolated bi-directional converters are commonly used in a wide range of applications, including renewable energy systems, battery energy storage systems, electric vehicles, and other power conversion applications where high efficiency and reliable power conversion are required.

$P = \frac{nV_{c,x-j} \times V_{c,x-FC}}{4L_{l,x-j} \times f_s} \times \{2\Delta_2 - 2\Delta_2^2 - \Delta_1^2 \quad 0 < \Delta_1 < \Delta_2 < 1$

$\{2\Delta_2 - 2\Delta_2\Delta_1 - \Delta_2^2 \quad 0 < \Delta_2 < \Delta_1 < 1$ (1)

The expression" n "indicates the turn ratio of the MFT, whereas fs defines the switching frequency of the system," is one way to put it.

III. CONTROLING PART OF EVCS

The phrase "The whole control system of the FC station is composed of two essential components: control of the front-end cascaded converter and control of the IBDC" may be rephrased as follows:

The FC station's comprehensive control system consists of two main elements, is charge of controlling the IBDC and the front-end cascaded converter.

Control Topology of Front-end CHB converter

Both grid synchronisation operation and power balancing management are included in the control strategy for the CHB converter, as shown in Figure 4.

(i). Grid Synchronization Controller:

A Grid Synchronization Controller measures the frequency and voltage of the electrical grid and adjusts the output of the renewable energy source to match it. This ensures that the renewable energy source is synchronized with the grid and can feed power into it safely and efficiently.

$[\, D_{dj} \quad D_{qj} \,] \begin{bmatrix} i_{j,d} \\ i_{j,q} \end{bmatrix} - 3C_{x-j} \frac{d}{dt} v_{c_{x-j}} - 3i_{DAB} = 0$ (2)

The average capacitor voltage VC, represented in d-q notation, can be expressed in terms of the modulation index D, as well as the filter resistance R_f and inductance L_f, in the synchronously rotating reference frame.

(ii). Power Balancing Control:

Power balancing control is a method used to maintain the balance between the generation and consumption of electrical power in a power system. This is important to ensure the stability and reliability of the power grid, as any imbalance between power supply and demand can cause voltage and frequency fluctuations, which can lead to blackouts and damage to electrical equipment. The main aim of the control system is to ensure that power is distributed evenly among the three phases. To accomplish this, the delta-connected clusters of the converter produce a zero-sequence current. The ZSC required to balance the power distribution is shown in the phasor diagram of Figure 5.

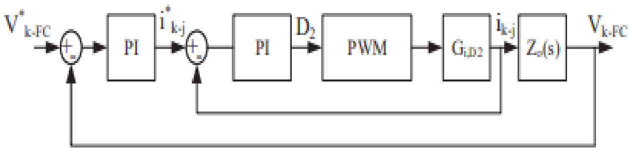


FIG. 4: THE CONTROLING PART O/P SIDE DAB

The control strategy for injecting the required ZSC is displayed in the balancing controller section of Figure 4. This strategy enables the determination of the imbalance ratio of each cluster, namely AB, BC, or CA.

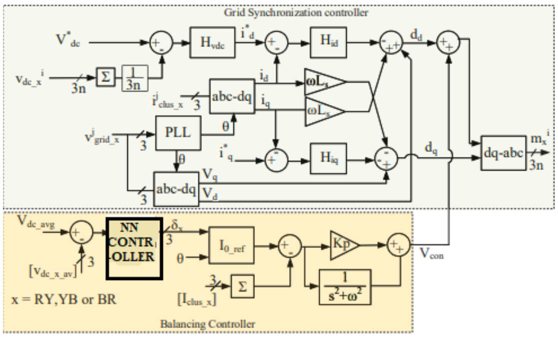


FIG. 5 SHOWS THE FRONT-END CONVERTER CONTROL SCHEME.

IV. PROPOSE NN BASED TOPOLOGY

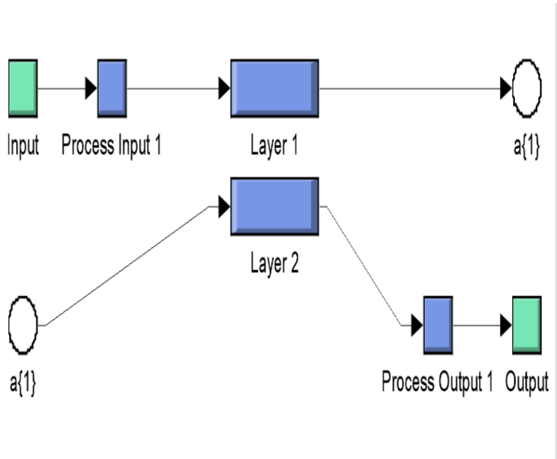


Figure 6: Structure of NN Controller

In this study, an architecture based on a neural network (NN) is utilized to regulate the voltage on the DC connection. The structural layout of the NN controller is illustrated in the accompanying graphic.

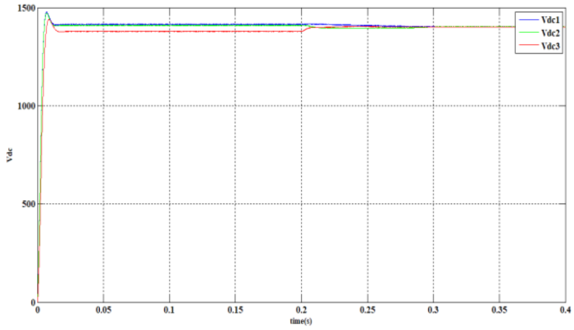
A neural network is a machine learning architecture inspired by the organization and functionality of the human brain, and is comprised of interconnected layers of nodes or neurons. The nodes in the input layer of a neural network are responsible for receiving input data, whereas the output layer's nodes generate the network's output. The hidden layers, which are positioned between the input and output layers, execute a sequence of mathematical operations on the input data and produce the final output. Large datasets can be used to train neural networks, allowing them to identify patterns and relationships within the data. Throughout the training procedure, the weights and biases of the neurons in the network are tuned to minimize the disparity between the anticipated output and the real output. Back propagation is a common technique used to accomplish this process.

Neural networks have very applicable v-cycle based model-based-development, and game playing. They are also used in many industries, such as finance, healthcare, and manufacturing, to make predictions, classify data, and detect anomalies.

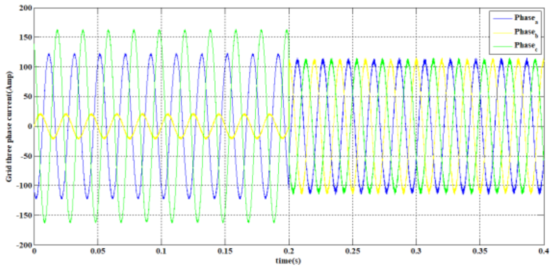
V. RESULTS & DISCUSSION:

The simulation studies focus on an 11kV MV grid-connected FC station with a capacity of 1.2 MVA. The Simulink model for the proposed system is shown below Section B.

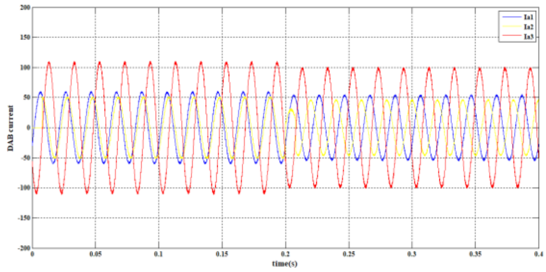
A. PI CONTROLLER BASED RESULTS:


Vdc1
Vdc2
Vdc3
Vdc
time(s)

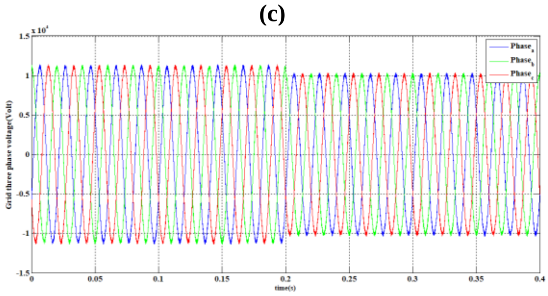
(a)


Phase_a
Phase_b
Phase_c
Grid three phase current(Amp)
time(s)

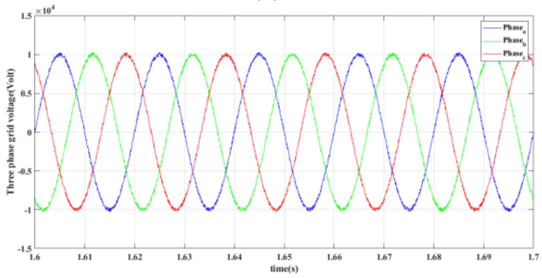
(b)


Ia1
Ia2
Ia3
DAB current
time(s)

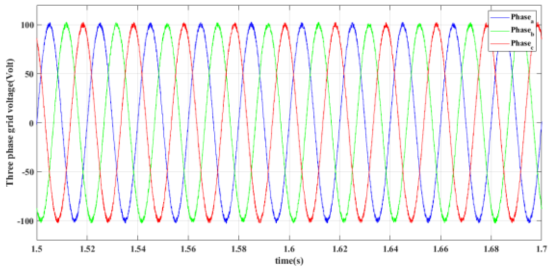
(c)


Phase_a
Phase_b
Phase_c
Grid three phase voltage(Volt)
time(s)

(d)

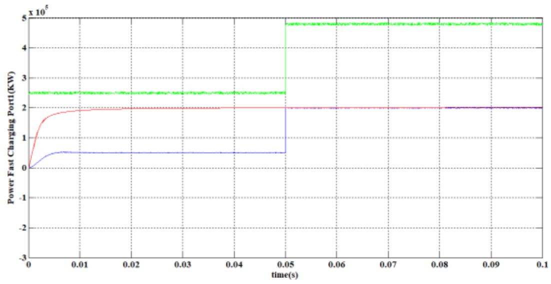

Phase_a
Phase_b
Phase_c
Three phase grid voltage(Volt)
time(s)

(e)

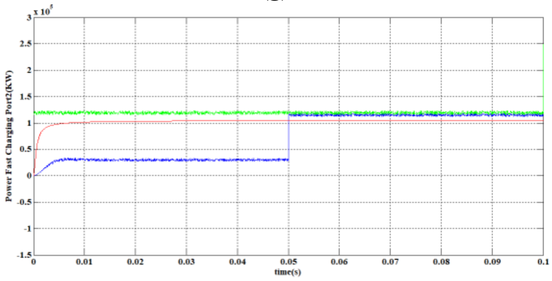


(f)

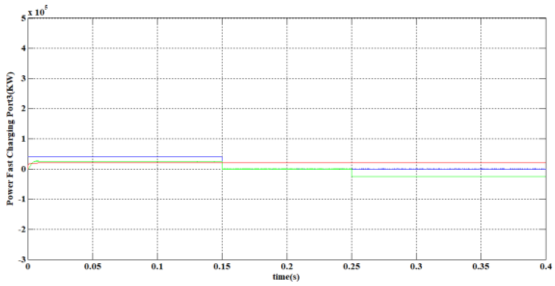
Fig. 6 illustrates the simulation results with the balancing controller activated at 2 seconds. The following parameters are analysed: (a) the average voltage of the capacitors in each phase. (b) The grid currents prior to the activation of the balancing controller. (c) The cluster currents prior to the activation of the balancing controller. (d) The grid voltages. (e) The voltage is present at the input of the CHB. (f) The obtained currents from grid are after the activation of the balancing controller.



(g)

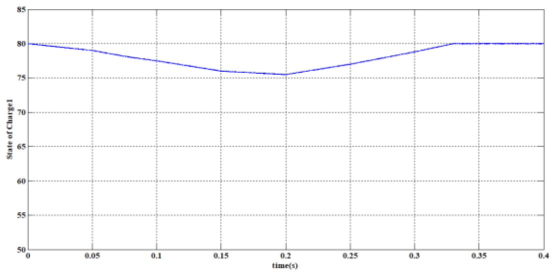


(h)

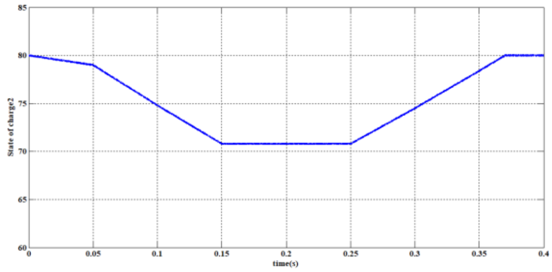


(i)

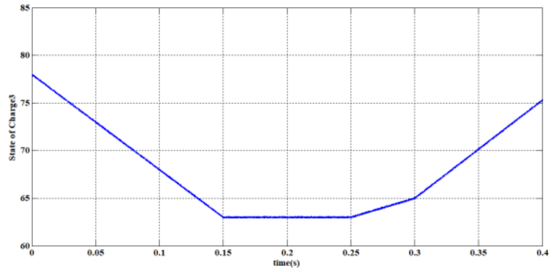
Figure 7 illustrates the power readings taken from three fast charging ports: (g) the 800 V FC port, (h) the 400 V FC port, and (i) the 48 V FC port.



(j)

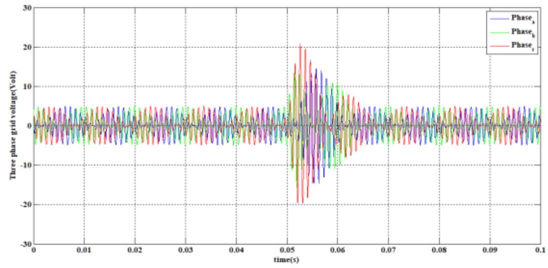


(k)

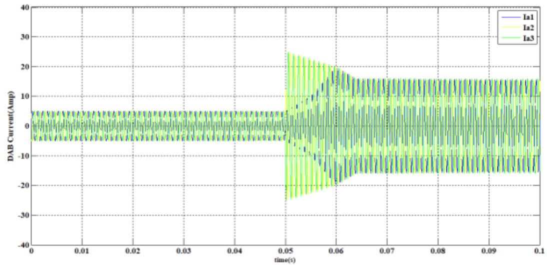


(l)

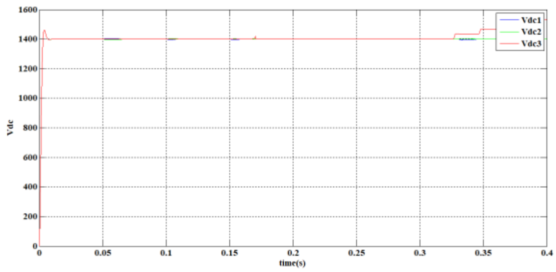
Fig. 8 shows the variation of State of Charge (SOC) of batteries at three different fast charging ports: (j) 800V FC Port, (k) 400V FC Port, and (l) 48V FC Port.



(m)



(n)



(o)

Figure 9 depicts three different aspects: (m) Grid Currents, (n) Cluster Currents, and (o) Average Capacitor Voltages of each cluster.

B. NEURAL NETWORK BASED RESULTS

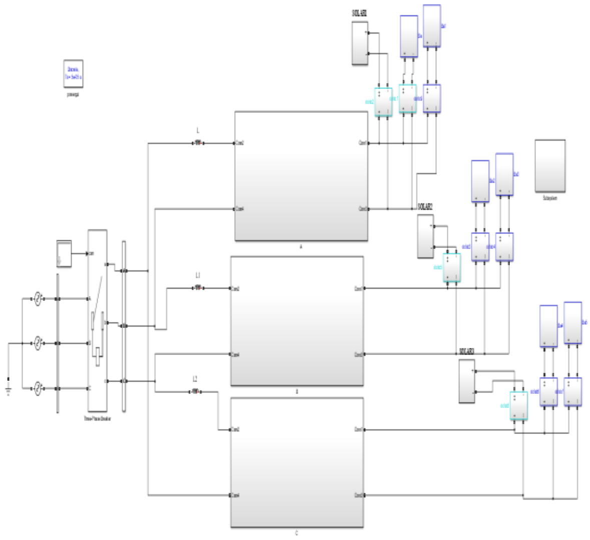
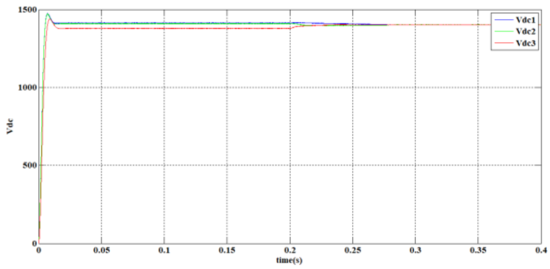
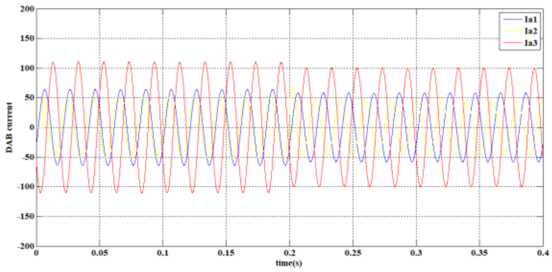


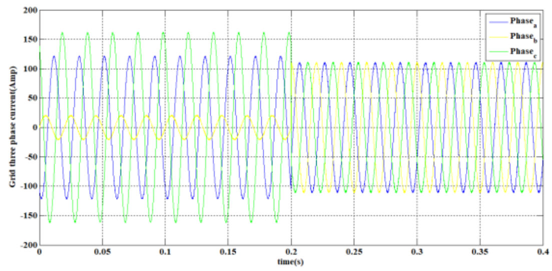
FIG 10: PROPOSED SIMULATION MODEL



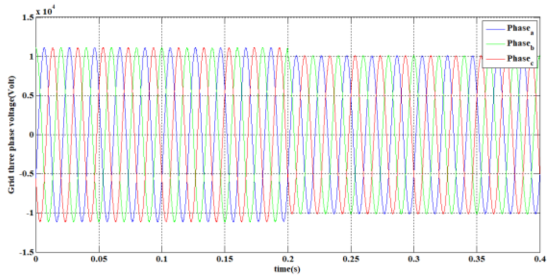
10.1



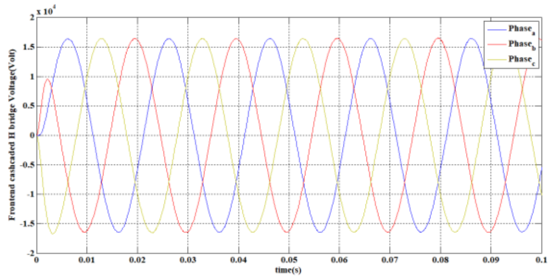
10.2



10.3

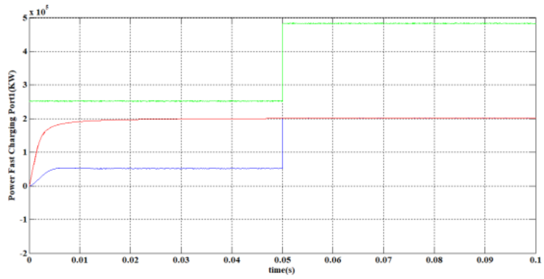


10.4

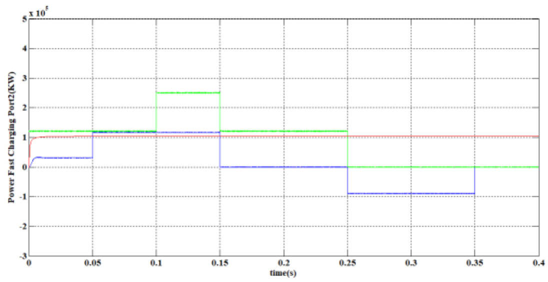


10.5

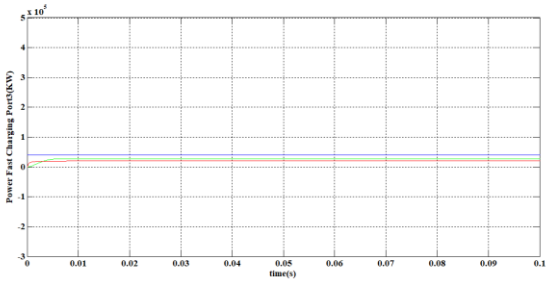
The figure above 10.1 to 10.5 indicates that NN controllers are superior to PI controllers in terms of performance. The effectiveness of the ZCS balancing controller is demonstrated in a simulation where a 48V FCP and an 800V FCP operate at their rated loads, and a 400V FC port generates a nominal power of 0.52 PU. Prior to the activation of the balancing controller (b) the clusters of SMs exhibit average capacitor voltages that deviate from their reference values, and the grid currents are unbalanced. The figure demonstrates how the ZCS balancing controller effectively resolves these issues. Figures 10.3 to 10.5 provide a close-up view of the grid voltage, CHB voltage, grid current (GC), and cluster currents (CC) following the activation of the balancing controller (t1)-(g). Despite the presence of unbalanced cluster currents, each SM cluster's capacitor voltage tends towards its reference value, and the PI controller is able to balance the grid currents. Moreover, a NN controller is employed to minimize harmonics and improve stability in comparison to the previously mentioned data.



10.6



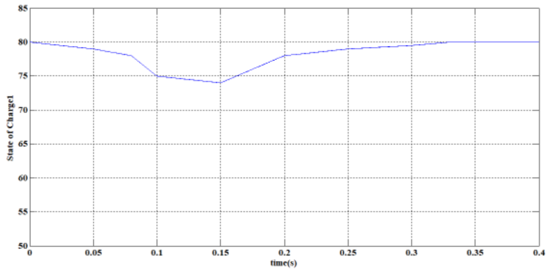
10.7



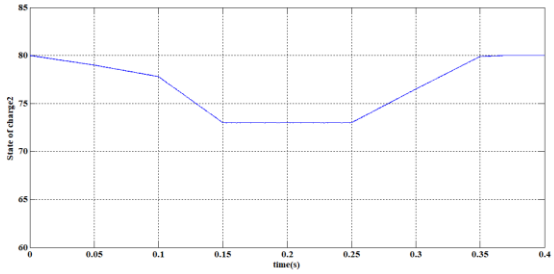
10.8

The control system's overall performance is evaluated in the range of results 10.6 to 10.8 using a charge profile that replicates real-world scenarios with unpredictable fluctuations. The simulation assumes that the photovoltaic components of each fuel cell port operate at their maximum power level during the test. Figure 8 illustrates three separate power variations: the power demands of the electric vehicle (EV) battery, the maximum power point (MPP) power generated by the photovoltaic (PV) system, and the power stored in batteries located at the 800V, 400V, and 48V fuel cell ports (FCP). The PV power output is also taken into account. In particular, the setup involves connecting one EV to the 400V FCP, another EV to the 800V FCP, and two EVs to the 48V FCP. One EV arrives at the 400V FCP after five minutes, and another at the 800V FCP after ten minutes. Typically, it takes 15 minutes to fully charge an EV, although this duration may vary based on the initial state of charge (SOC) of the EV battery.

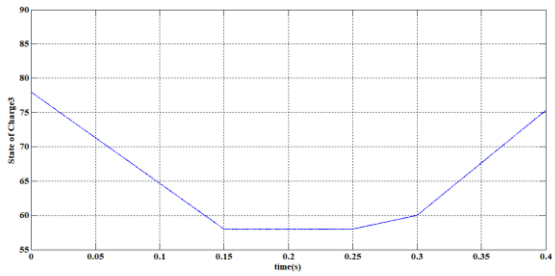
Under mode 1a, the FC station supplies power to charge one EV on each grid for 0 to 5 seconds, drawing from the installed PV and battery on each grid. At the 5-minute mark, the power consumption at the 800V and 48V FCPs exceeds the battery output at the 400V FCP, leading to some of the required power being sourced through circulating current. To maintain system stability, a PI controller and a neural network are employed. By utilizing a neural network to analyse the aforementioned data, it is possible to minimize harmonics and improve system stability.



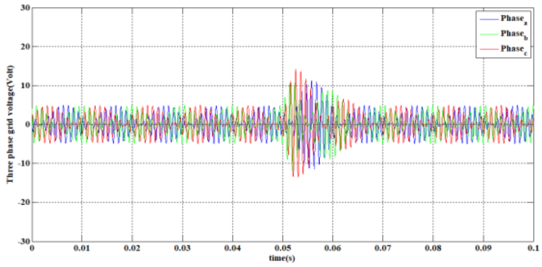
10.9



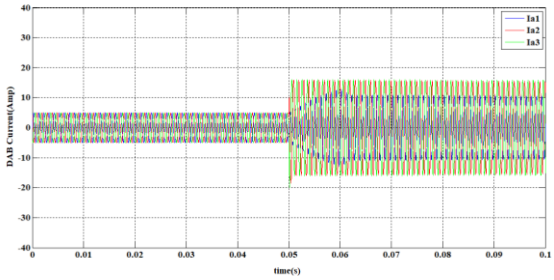
10.11



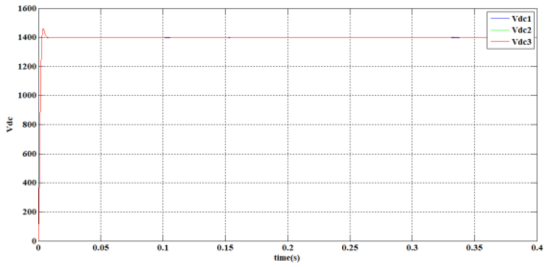
10.12



10.13



10.14



10.15

Each cluster's average capacity voltage is shown in Figure 10.13 and 10.15.

Figures 10.9 to 10.12 depict a neural network (NN)-based system for State of Charge (SOC) control, with SOC variation ranging from 20% to 80%. Figure 10.11 displays the grid current, delta cluster current, and typical SM capacitor voltages for each cluster. While the grid currents are balanced, the delta cluster currents are unbalanced. To maintain the S-M capacitor voltages at their reference values, a Proportional-Integral (PI) controller and a neural network have been implemented. However, based on data comparison, the utilization of a neural network results in reduced harmonics and improved stability.

VI. CONCLUSION:

Based on the research and development of a neural network controller based solid-state transformer for fast charging of electric vehicles, the following conclusions can be drawn:

1. The use of a solid-state transformer can significantly improve the efficiency and power density of EV chargers. Compared to traditional transformers, solid-state transformers offer higher efficiency, better control, and smaller size.
2. The neural network controller provides an intelligent way to control the charging process and optimize the power transfer. By using real-time data from the charging system and the grid, the controller can adjust the charging parameters to ensure safe and efficient charging.
3. The combination of solid-state transformer and neural network controller provides a powerful solution for fast charging of EVs. The system can provide high power density, high efficiency, and fast charging speeds, while also ensuring safety and reliability.
4. The development of this system is an important step towards the widespread adoption of EVs. Fast and efficient charging is critical to the success of EVs, and the use of solid-state transformers and neural network controllers can help to overcome the challenges of charging infrastructure.

Overall, the neural network controller based solid-state transformer for fast charging of EVs is a promising technology that has the potential to revolutionize the EV industry. With further research and development, this system could become the standard for fast charging of EVs, and help to accelerate the transition to a more sustainable transportation system.

VII. REFERENCES:

[1] Yu Du, Xiaohu Zhou, Sanzhong Bai, S. Lukic, and A. Huang. Review of non-isolated bi-directional dc-dc converters for plug-in hybrid electric vehicle charge station application at municipal parking decks. In Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE, pages 1145 –1151, 21-25 2010.
[2] D.M. Robalino, G. Kumar, L.O. Uzoechi, U.C. Chukwu, and S.M. Mahajan. Design of a docking station for solar charged electric and fuel cell vehicles. In Clean Electrical Power, 2009 International Conference on, pages 655 –660, 9-11 2009.
[3] S.G. Wirasingha, N. Schofield, and A. Emadi. Plug-in hybrid electric vehicle developments in the us: Trends, barriers, and economic feasibility. In Vehicle Power and Propulsion Conference, 2008. VPPC '08. IEEE, pages 1 –8, 3-5 2008.
[4] L. Dickerman and J. Harrison, "A new car, a new grid," IEEE Power Energy Mag., vol. 8, no. 2, pp. 55–61, Mar./Apr. 2010.
[5] Environmental Assessment of PEV Vehicles Volume 1: Nationwide Greenhouse Gas Emissions, Electric Power Research Institute (EPRI), Palo Alto, CA, USA, Jul. 2007, Tech. Rep.
[6] Y. Gao and M. Ehsani, "Design and control methodology of plug-in hybrid electric vehicles," IEEE Trans. Ind. Electron., vol. 57, no. 2, pp. 633–640, Feb. 2010.
[7] Renewables Global Status Report, Renewable Energy Policy Network for the 21st Century (REN21), Paris, France, 2013, accessed on Apr. 2013. [Online]. Available: http://www.ren21.net
[8] S. Rivera, W. Bin, S. Kouro, V. Yaramasu, and W. Jiacheng, "Electric Vehicle Charging Station Using a Neutral Point Clamped Converter With Bipolar DC Bus," IEEE Trans. Ind. Electron., vol. 62, no. 4, pp. 1999– 2009, 2015.
[9] N. Celanovic and D. Boroyevich, "A comprehensive study of neutralpoint voltage balancing problem in three-level neutral-point-clamped voltage source PWM inverters," IEEE Trans. Power Electron., vol. 15, no. 2, pp. 242–249, 2000
[10] A. Rufer, N. Schibli, and C. Briguet, "A direct coupled 4-quadrant multilevel converter for 16 2/3 Hz traction systems," in Proc. 6th Int. Conf. PEVD, Sep. 23–25, 1996, pp. 448–453.
[11] D. Dujic et al., "Power electronic traction transformer-low voltage prototype," IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5522–5534, Dec. 2013.
[12] F. Iov et al., "UNIFLEX-PM—A key-enabling technology for future European electricity networks," Eur. Power Electron. Drives Assoc. J., vol. 19, no. 4, pp. 6–16, Oct.–Dec. 2009.
[13] F. Iov et al., "UNIFLEX-PM—A key-enabling technology for future European electricity networks," Eur. Power Electron. Drives Assoc. J., vol. 19, no. 4, pp. 6–16, Oct.–Dec. 2009.
[14] H. Akagi and R. Kitada, "Control and design of a modular multilevel cascade BTB system using bidirectional isolated dc/dc converters," IEEE Trans. Power Electron., vol. 26, no. 9, pp. 2457–2464, Sep. 2011.
[15] T. Zhao, G. Wang, S. Bhattacharya, and A. Q. Huang, "Voltage and power balance control for a cascaded H-bridge converter-based solid-state transformer," IEEE Trans. Power Electron., vol. 28, no. 4, pp. 1523–1532, Apr. 2013.
[16] Y. Lee, A. Khaligh, and A. Emadi, "Advanced integrated bi-directional AC/DC and DC/DC converter for plug-in hybrid electric vehicles," IEEE Trans. Veh. Technol., vol. 58, no. 3, pp. 3970–3980, Oct. 2009.
[17] Y. Du, S. Lukic, B. Jacobson, and A. Huang, "Review of high power isolated bi-directional DC-DC converters for PHEV/EV DC charging infrastructure," in Proc. IEEE Energy Conversion Congr. Expo, Sep. 2011, pp. 553–560.
[18] X. Zhou, S. Lukic, S. Bhattacharya, and A. Huang, "Design and control of grid-connected converter in Bi-directional battery charger for plug-in hybrid electric vehicle application," in Proc. IEEE Veh. Power and Propulsion Conf., Sep. 2009, pp. 1716–1721.
[19] X. Zhou, G. Wang, S. Lukic, S. Bhattacharya, and A. Huang, "Multifunction bi-directional battery charger for plug-in hybrid electric vehicle application," in Proc. IEEE Energy Conversion Congr. Expo, Sep. 2009, pp. 3930–3936.
[20] S. Haghbin, K. Khan, S. Lundmark, M. Alakula, O. Carlson, M. Leksell, ¨ and O. Wallmark, "Integrated chargers for EV's and PHEV's: Examples and new solutions," in Proc. Int. Conf. Electrical Machines, 2010, pp. 1–6.
[21] M. Grenier, M. H. Aghdam, and T. Thiringer, "Design of on-board charger for plug-in hybrid electric vehicle," in Proc. Power Electronics, Machine and Drives, 2010, pp. 1–6.
[22] D. Thimmesch, "An SCR inverter with an integral battery charger for electric vehicles," IEEE Trans. Ind. Appl., vol. 21, no. 4, pp. 1023–1029, Aug. 1985.
[23] W. E. Rippel, "Integrated traction inverter and battery charger apparatus," U.S. Patent 4 920 475, Apr. 1990.
[24] H. C. Chang and C. M. Liaw, "Development of a compact switched reluctance motor drive for EV propulsion with voltage-boosting and PFC charging capabilities," IEEE Trans. Veh. Technol., vol. 58, no. 7, pp. 3198–3215, Sep. 2009.