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Study And Analysis of Power Electronics Solutions for Efficient Energy Conversion in Electric Vehicles

Gyaneshwari Sahu[1], Ritesh Diwan[2], Vandana A Chouhan[3], Rahul Shrivastava[4], M. Vijay Kumar[5], Usha Mehra[6]

[1,2,3,4,5,6]*Department of Electronics and Telecommunication Engineering, Raipur Institute of Technology, Raipur*

***Abstract*—This study provides an overview of power electronics systems in electric vehicles (EVs) and investigates methods for improving energy conversion efficiency using MATLAB/Simulink. It examines various EV components, addresses challenges in energy transfer, and evaluates power electronics for voltage control. Using MATLAB/Simulink, the study models and simulates a DC fast charging station, focusing on unity power factor analysis, isolated DC-DC converters, and front-end converters. The setup includes a grid as a three-phase voltage source, a DC fast charging station, and an EV battery pack with sensors for voltage and current measurements. Key components analyzed include filters, converters, inverters, and HF isolation transformers. The findings demonstrate that effective power electronics circuits achieve stable DC bus voltage and controlled charging, minimizing overcharging risks and ensuring consistent current supply, thereby enhancing battery longevity and safety. Insights from the battery terminal voltage fluctuations and charging process dynamics provide valuable information for optimizing EV battery performance and developing charging process optimization algorithms.**

***Index Terms*—Electric vehicles, Power electronics.**

I. INTRODUCTION

The secure and efficient recharging of electric vehicle batteries is essential for their development and operational effectiveness. The charging process is predominantly governed by power electronics systems, which play a crucial role in the control, conversion, and management of electrical energy. Power electronics play a crucial role in the fuelling systems of electric vehicles, applicable in both onboard and offboard configurations. Onboard adapters utilise power electronic converters, including AC-DC converters, to transform mains AC electricity into a DC voltage appropriate for charging the vehicle's battery. This involves a DC-DC conversion process subsequent to rectification to control the current flow to the battery and achieve the required voltage level ensuring that the charging process follows the battery's charge profile. This profile typically consists of phases of constant voltage and constant current, which are necessary for maintaining the battery's health and longevity. Power electronics play a critical role in off-board charging systems, such as DC fast-charging stations. The power electronic converters in these systems convert the AC supply into a high-voltage DC output, which eliminates the need for an integrated charger and facilitates direct battery charging. Power electronics utilise advanced control methods to manage the charging rate and protect the battery from potential damage.

II. LITERATURE REVIEW

Amjadi et. al. [1] This work provides a comprehensive analysis and unique controller design for a hybrid switched-capacitor bidirectional DC/DC converter. The circuit integrates voltage reduction, elevation, and bidirectional power transfer capabilities into a unified design. The innovative control technique, which incorporates a constant input current waveform in both buck and boost modes, offers several advantages over a conventional buck converter. These include straightforward control, minimal electromagnetic interference, reduced source current ripple, and effective regulation capabilities, all of which contribute to enhanced dynamics.

Awasthia et. al. [2] the necessity for alternative transportation methods arises from the rapidly growing population in India, with electric vehicles becoming the favored choice. The main issue is the negative impact of inadequately designed charging stations on the power distribution system. This document examines the optimal design parameters for charging station infrastructure in the Indian city of Allahabad, focusing on aspects such as location and dimensions. A demonstration project for electric vehicle transportation is being implemented in this metropolis, recognised as one of the intended smart cities, under a Government of India initiative. A hybrid methodology integrating a genetic algorithm with an improved variant of the traditional particle swarm optimisation technique is employed to ascertain the optimal positioning of charging stations within the Allahabad distribution system. The particle swarm optimisation approach enhances the solution quality and algorithm performance by re-optimizing the sub-optimal solution for site and station size. A comparison will be conducted between the standard genetic algorithm and particle swarm optimisation, in addition to a comparison between the genetic algorithm and its enhanced variant. Simulated experiments performed on a real-time system in Allahabad city indicate that the technology discussed outperforms genetic algorithms and particle swarm optimisation regarding enhancements in voltage profile and quality.

Baha et. al. [3] Hybrid, plug-in hybrid, and electric vehicles (HEVs, PHEVs, and EVs) represent a category of automotive products designed to enhance vehicle fuel efficiency. Nonetheless, these vehicles necessitate a greater upfront financial commitment compared to conventional cars. The reduction in petrol consumption and enhancement of efficacy yields economic advantages that are distributed among society, manufacturers, customers, and policymakers. The importance of PHEVs, EVs, and HEVs in future vehicle fleets has been assessed by stakeholders through an analysis of the proliferation rate of these technologies within the automotive sector. This research provides a comprehensive review of the existing literature concerning the analysis of HEV, PHEV, and EV penetration rates, detailing their methodologies and recommendations. This research employs a range of analytical and computational techniques to investigate consumer adoption of these technologies across various macroeconomic and policy environments. The findings of this investigation are evaluated and integrated to highlight the benefits and drawbacks of the field, as well as to suggest further strategies for improving advanced technology car market modelling practices. The authors suggest integrating improved interfaces with consumer surveys, modelling automaker's behaviours, assessing the impact of federal and state policies on automotive markets, analysing competition among technologies, evaluating market volume, classifying vehicles, and conducting sensitivity analysis of model parameters in the context of HEV, PHEV, and EV penetration rates.

Pages et. al. [4] The development of alternative energy sources for automobiles has become essential due to the limited availability of fossil fuels, the impacts of climate change, and the implementation of emissions regulations over the past century. This has led to significant interest in hybrid electric vehicles (HEVs). Hybrid electric vehicles (HEVs) consist of electric apparatus, power electronic devices, and an internal combustion engine. This study presents an in-depth analysis of hybrid electric vehicles (HEVs), focusing specifically on electronic control devices, energy management strategies, and hybrid configurations. Each configuration is delineated with its respective advantages and disadvantages. The classification and detailed explanation of the current HEV propulsion control methods are presented. The electronic control components utilised in the development of hybrid electric vehicles (HEVs) are detailed. An evaluation of the latest technological advancements and forthcoming challenges for HEVs is conducted.

Bhaskar et. al. [5] The output voltage of fuel cells is generally moderate, making it an unsuitable approach for generating high voltage in automotive applications when connecting multiple fuel cells in series. Consequently, it is essential to utilise a DC-DC converter that offers a high voltage conversion ratio along with multiple output functionalities to support various high-voltage auxiliary loads. They present a unique Single Input Double Output L-L converter (SIDO L-L converter) designed to support high-voltage auxiliary loads in fuel cell vehicles. The document includes a detailed block diagram and explanation for the SIDO L-L converter, along with an analysis of the transition states and their unique waveforms. The analysis focusses on the voltage conversion ratio for Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM), followed by a discussion on the operation of both modes. The advantages of the proposed SIDO L-L converter are highlighted through a comparison with existing high voltage DC-DC converters. The theoretical analysis is supported by the results obtained from the design and performance of the proposed converter, which have been validated through numerical simulation and hardware implementation.

Bhaskar et. al. [6] The objective of this research is to enhance the output voltage magnitude of fuel cells (FCs) to address their limited generating capacity. The standard technique for generating high voltage in various automotive applications involves a cascaded or parallel connection method, which is highly complex. In this context, electronic power converters present a practical solution owing to their compact size and cost-effectiveness. DC–DC converters with double or multiple output configurations and high voltage step-up capabilities are essential for simultaneously powering multiple high voltage loads. This article outlines the development of advanced double-stage double output (DSDO) DC–DC converters designed to provide a fuel cell vehicle system with multiple high-voltage loads. This research involves the construction of four DSDO DC–DC converters: DSDO L–L, DSDO L-2L, DSDO L-2LC, and DSDO L-2LC. Diverse reactive networks constitute the fundamental framework for each converter. An in-depth analysis of the conceptual operation, primary power circuitry, and calculation of the output voltage gain is presented, supported by reliable evidence. The proposed converters are assessed against newly developed designs and possible parallel configurations of conventional converters. The results of our experimental prototype and comprehensive numerical modelling validate our theoretical predictions, confirming the configuration's appropriateness for real-time application in fuel cell technologies for more-electric vehicles.

III. OBJECTIVES

The purpose of this work is to present an overview of power electronics systems in electric cars and to investigate methods for improving energy conversion efficiency using MATLAB/Simulink.

The following are the study's primary goals:

1) Examine several EV configurations and their components, such as batteries, power converters, electric motors, and control systems.
2) To comprehend the difficulties associated with effective energy transfer from source to wheels in an EV.
3) To evaluate the use of power electronics such DC-DC converters and inverters for consistent voltage control, reduced harmonics, and lower losses.
4) Using MATLAB/Simulink, model and simulate various converter and inverter topologies in order to discover optimal designs.

IV. METHODOLOGY

This simulation model consists of the analytical approach result outcomes that are applied for the performance testing of the DC fast charging station model in this Electric vehicle model. It is conducted through the MATLAB simulink model, which provides the detailed analytics and also creates the proper performance analytics for the quantitative analysis of the applied model. Where the unity power factor analysis, isolated DC to DC converter and the front-end converter process is analyzed. Through this improvised model that varies through their different levels also could be analyzed for their fidelities. These components play the pivotal role in this conversion process of AC supply energy to the grid that needs the DC voltage to uphold this EV model with the implemented battery pack reviews.

Simulation set up

The DC fast charging model could be advocated based on the analysis of the various parts embedded in this model. Thus, the model consists of various components like the DC fast charging station, the grid and the EV battery pack model. The grid is mainly modeled for the three phase conscience voltage sources that represent the AC supply. This helps to incorporate the DC fast charging process through the implementation of Power electronics circuits that helps to convert the ac supplier voltage into DC voltage. This DC voltage is needed for the EV battery pack. This EV battery pack is also modeled in the series connections associated with the various battery cells, that also could be measured on behalf of the sensors that also measures the terminal output current and voltage.

Components:

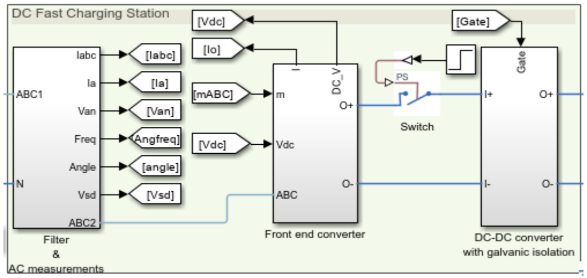

Figure 1: DC Fast charging station

It is the fast-charging model for the DC-to-DC energy convertor.

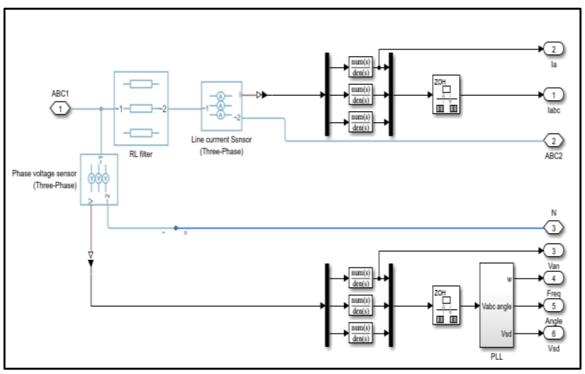

Figure 2: Filter and AC measurement

It is the sub part of this DC fast charging station that addresses the Filters and AC measurements for the regulation factors. These components of the fast-charging process create the filter harmonics along the line current and also applies the measurement factors for the three-phase line current and supply voltages.

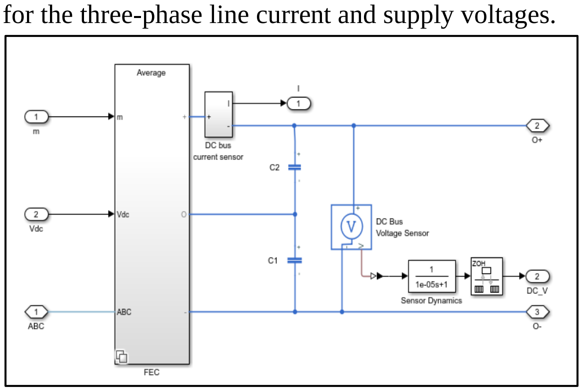

Figure 3: UPF Front-end Converter

It is the UPF front end converter in the applied DC charging station model. The Unity power factors that help to analyze the front-end converters are the main components that apply the control over the resultant output voltage at the 800 volts. The three levels of fidelity are also applied where the model implementations are done through these converter circuits, that applies the three levels of fidelity like the average fidelity, three level inverter fidelity and the two-level inverter fidelity.

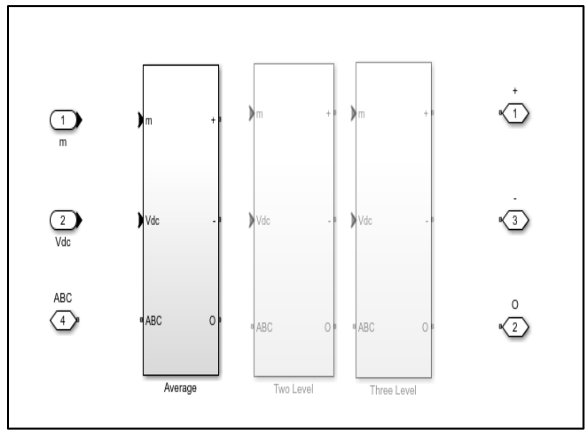

Figure 4: The converter circuit for Three level fidelity

It is the three-level fidelity model associated with converter circuital components.

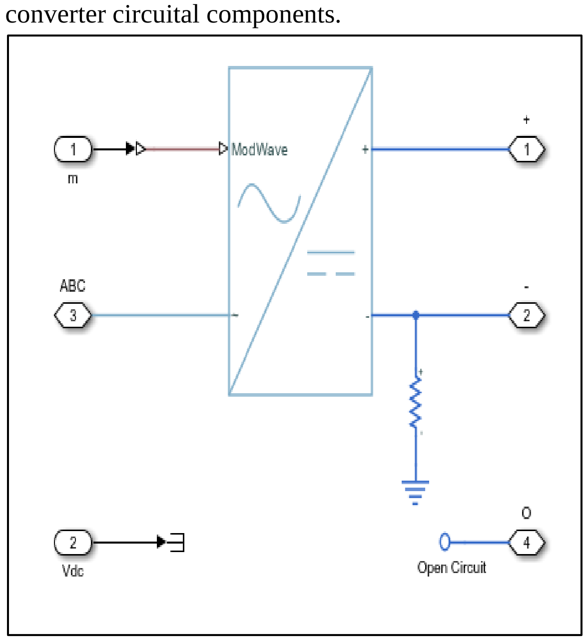

Figure 5: Average Fidelity model

It is the average fidelity model in this DC fast charging model.

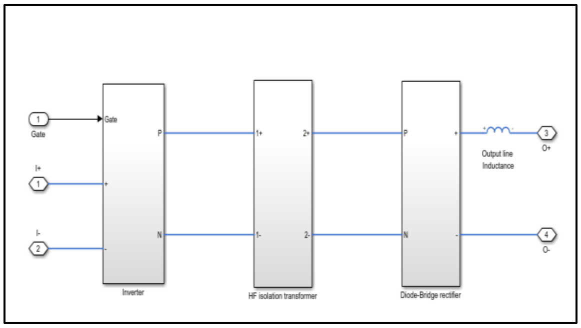

Figure 6: Isolated DC to DC converter with Galvanic isolation for constant supply of charging current to the EV battery

It is the Isolated DC to DC converter model that applies the galvanic isolations among the particular three parts that holds the consistent supply of the charges and also provides the stability in this EV battery. These components supply the consistent current source to the EV battery pack. It consists of more important sub parts like the inverters, diode to bridge rectifiers and the HF isolation transformers for this proposed isolated model of DC-to-DC converter.

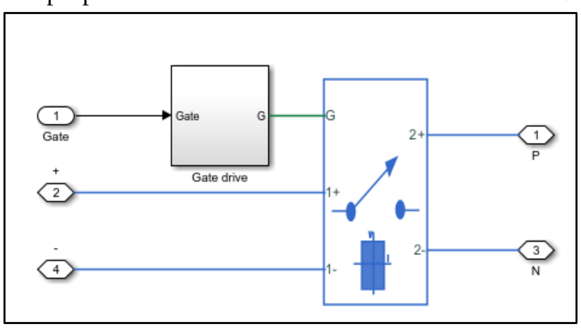

Figure 7: Inverter

It is the Inverter in the applied model.

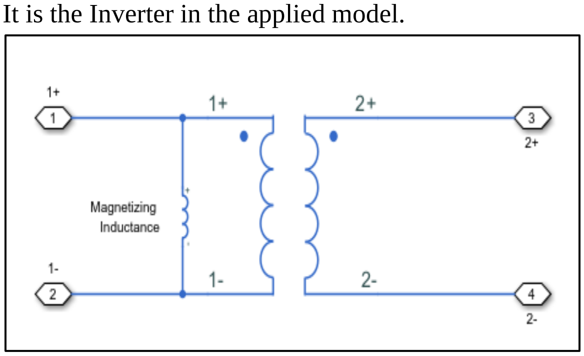

Figure 8: HF Isolation transformer

It is the second part of the Isolated DC converters that holds the HF isolation factors for the proper transformation of the electric charges.

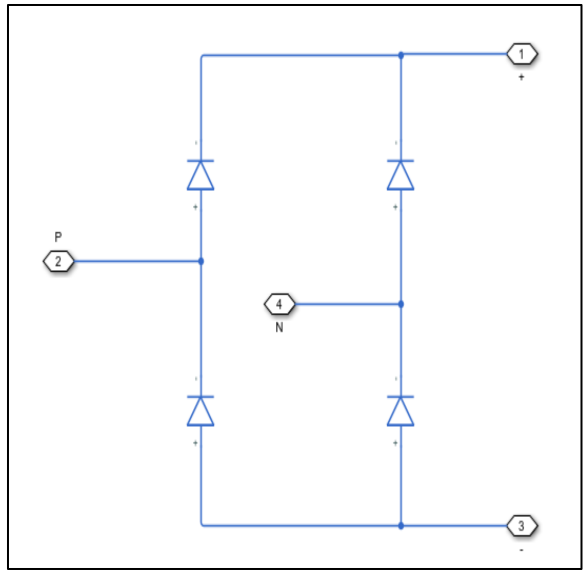

Figure 9: Diode Bridge Rectifier

It is the diode bridge rectifier which helps in the DC-to-DC conversion in this applied EV battery model.

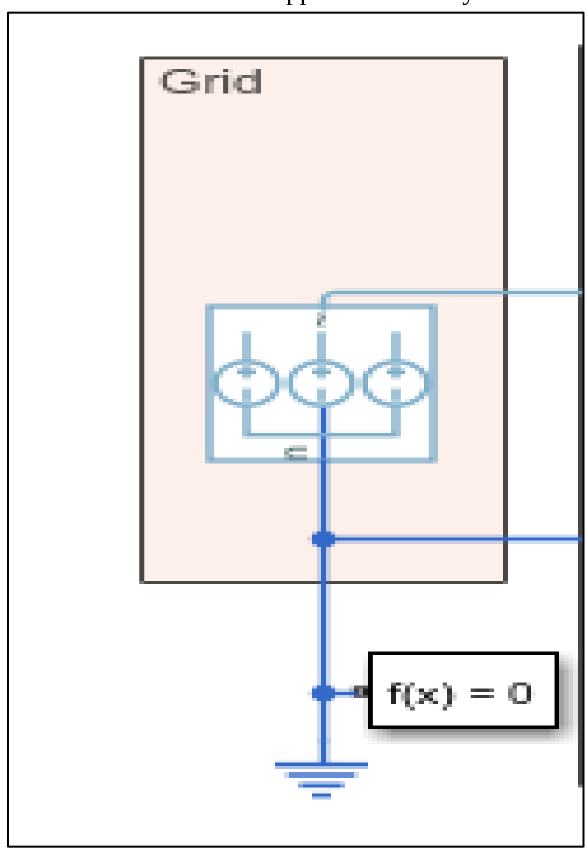

Figure 10: Grids

It is the grid that provides the supply charge for the conversions.

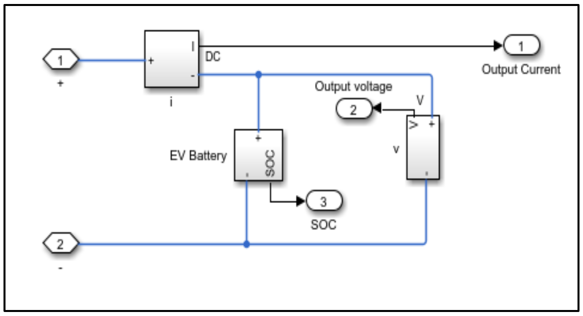

Figure 11: EV battery Model

It is the EV battery model that consists of the infrastructure for the applied DC bus voltage and current with the battery terminal voltage and charging current in this DC conversion model. The EV battery pack model is the parts where the battery cells are connected along with the series connections and also could be arranged along with the sensors that apply the measuring components for the battery terminal voltages and also could be managed for the output current values.

V. RESULTS AND DISCUSSION

This simulation result obtains the sim scape output that provides the comprehensive overview about the behavioral aspects of this charging process. The various key parameters by testing include the DC bus current, DC bus voltage, charging current and the battery terminal voltage for the measurement factors.

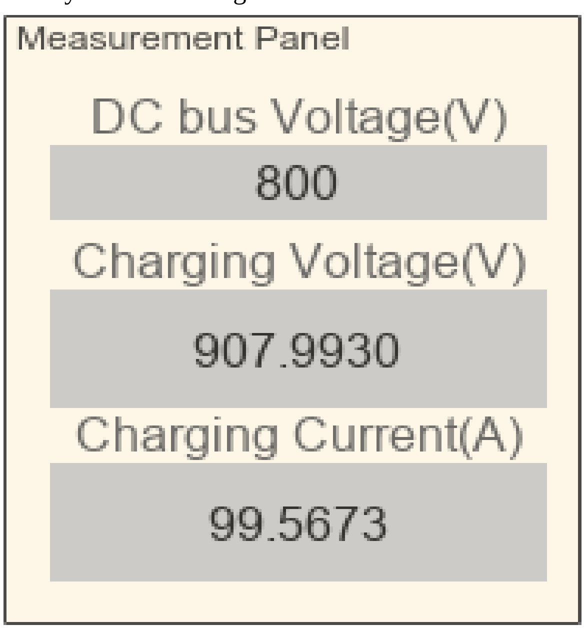

Figure 12: Measurement Panel

Through the implemented measurement panel, the measurement of the applied charges, the DC bus voltage, charging voltage and the charging current could be measured.

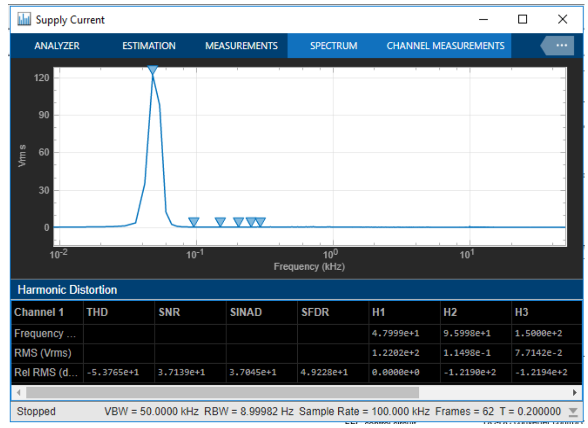

Figure 13: The Outcome for the measurement of Supply current spectrum

It is the output measures from the applied supply current spectrums where the frequency, root mean square value of the applied voltage and the real time root mean square value could be evaluated through this statistical channel spectrum analysis.

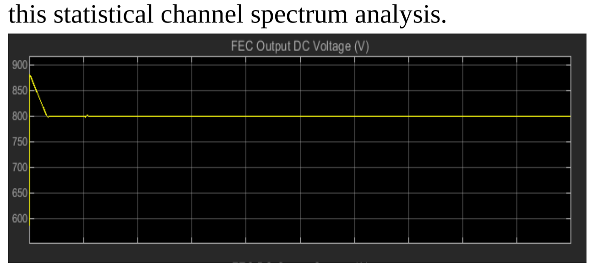

Figure 14: DC output Voltage

It is the DC output voltage that is gained from the applied model grid input charges.

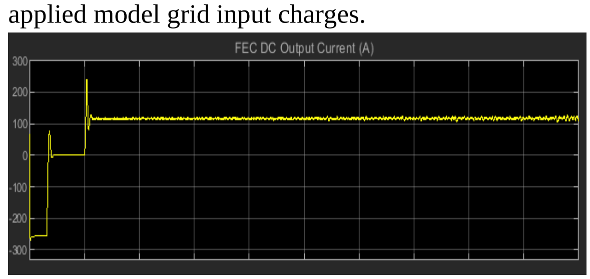

Figure 15: DC Output Current

It is the DC current output from the applied scope value. This current is transmitted from the applied grid in the front-end current distribution process.

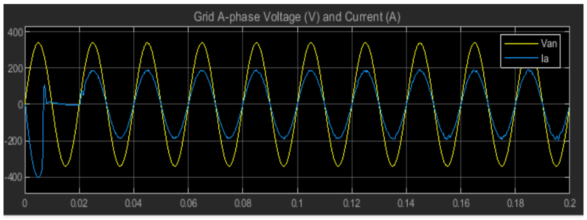

Figure 16: Grid A-phase Voltage and Current

It is the A-phase voltage and current frequencies that overlaps and creates the transient distributions of this applied model with the waves of the charges carried from the applied grid charges.

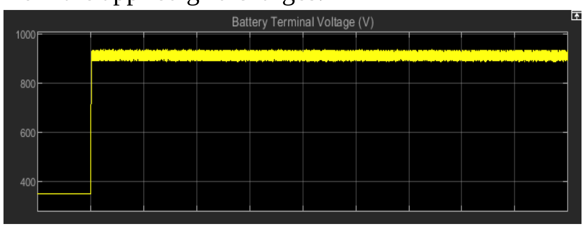

Figure 17: Battery Terminal Voltage

It is the terminal voltage output in the applied battery in this model.

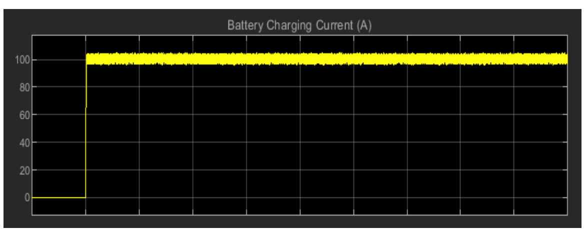

Figure 18: Battery Charging Current

It is the battery charging model that shows the current output in this applied model.

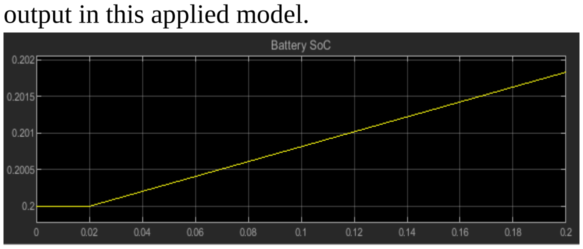

Figure 19: Battery SoC

It is the battery SoC model outcome for the DC converter model. From the applied plots the distribution of the current and the DC bus voltage could be analyzed that indicates the stability and controlled state of the applied model that suggests to the circuital implementations through the power electronics components. Thus, through the implementation of the effective conversion of the AC supply energy acquired from the grids could be transferred into the DC voltage in the EV battery pack is specifically demonstrated. The application of the DC bus current that illustrates the flow of the charges through this charging process is also demonstrated here. The charging currents and the terminal voltages acquired from the batteries also could be analyzed, which offers insights into the charging process and also addresses the dynamics in the charging process and also describes the different states of the EV battery. By applying this battery terminal voltage, the corresponding variations through the entire charging process also could be advocated for the exhibited current analytics and also could be engaged into this model that reflects the performance analytics through these charging current plots that reflects the crying rates of the charges that shows this process inside the EV battery pack.

VI. CONCLUSION

Through implementing the stable DC bus voltage that includes the observatory simulation outcomes and it also indicates the efficient effectiveness of the applied power electronics circuital system, that consists of the EV battery pack and it helps to convert the AC supply voltage into the DC voltage from the grids. This helps to get the stability that is very important for this system and it is done by minimizing the risk of overcharging of the battery and also helps to provide the controlled and consistent charging experiences over this model.

This controlled supply of charges and currents is also helpful for emphasizing the successful operations of the unity power factors for the front-end converter as well as for the isolated DC to DC convertors. Here the consistent current supply is paramount and also helpful for optimizing the safety as well as the charging time with the longevity of the electric vehicle battery.

From the battery terminals the fluctuation results of the voltage also could be analyzed during this power acquiring or charging mode. That offers the insightful impacts for the dynamic changing characteristic of the EV batteries. Through this process the insightful variations in the essentialities could be advocated that helps to develop the algorithmic impacts of the charging process optimization. Hence, by taking the concepts about the electric vehicle batteries and the factors involved in this process that creates the account for the state of the battery that may further affect the performance is also analyzed in this paper.

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