ELECTRIC VEHICLE CHARGING STATION WITH AN ENERGY STORAGE STAGE FOR SPLIT-DC BUS VOLTAGE BALANCING

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Abstract - *This project proposes a balancing approach for an electric vehicle bipolar dc charging station at the megawatt level, enabled by a grid-tied neutral-point-clamped converter. The study uses the presence of an energy storage stage with access to both of the dc buses to perform the complementary balance. It proposes a generic balancing structure that can achieve balance regardless the kind of energy storage system (ESS) employed. The aim is to reduce the hardware requirements of the system and maximize the usage of the ESS, whose main function is to perform the energy management related tasks. To meet this purpose, a three-level dc-dc interface is employed, allowing to compensate the dc currents with a single ESS. In order to prevent the appearance of even-order harmonics in the input current during asymmetrical operation, an alternative switching sequence for the central converter is proposed. Without altering the charging process of the ESS, it is possible to cover the whole load scenario without the need of a balancing circuit. Here the use of products such as both the rectifier and the fast chargers are used. In this project, simulation and experimental results are to be presented to validate the proposed balancing strategy.*

***Key Words*: EVC, Split DC Bus, Voltage Balancing.**

1. INTRODUCTION

Power electronics is the applications of solid-state electronics for the control and conversion of electric power. Power electronic converters to modify the form of electrical energy (voltage, current or frequency). Power ranges from some milliwatts (mobile phone) to hundreds of megawatts. The conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. Thus, the main metric of power electronics becomes the efficiency. The technology of power electronics and drives has gone through intense technological evolution during the last 30 years, although its history dates back for nearly a century. Many inventions in devices, components, circuits, controls, and systems have caused power electronics to emerge as a major technology in recent years. The invention of the bipolar junction transistor in 1948 was the beginning of semiconductor electronics. This device and semiconductor diodes spawned a revolution electronics. Drastic reduction in size, cost, and power consumption were achieved simultaneously with greatly increased equipment complexity and capability. The development of power FET has also an important impact on the power semiconductor industry.

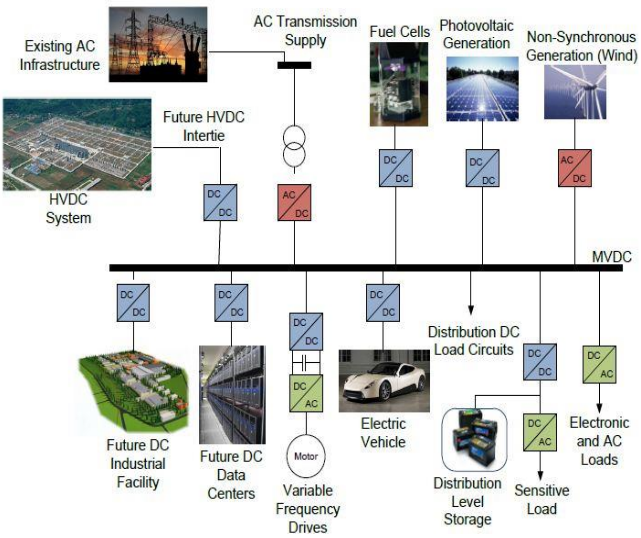

Fig. 1 - Medium Voltage DC (MVDC) System Architecture

1.1.1 Problem Descriptions

The use of net neutral current for analysis does not take into account of the effects of voltage drop due to the distribution of bipolar DC loads. This is analogous to voltage unbalance between single and 3-phase loads in AC networks. The existing methodologies mainly utilize iterative method such as the backward-forward sweep for analysis. The iterative method is designed for simple radial distribution systems and is popular due to its intuitive solution procedure. However, one main disadvantage of iterative methods is that the relationships among components are built by a direct observation. Power electronics is the applications of solid-state electronics for the control and conversion of electric power. Power electronic converters to modify the form of electrical energy (voltage, current or frequency). Power ranges from some milliwatts (mobile phone) to hundreds of megawatts. The conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. Thus, the main metric of power electronics becomes the efficiency. The technology of power electronics and drives has gone through intense technological evolution during the last 30 years, although its history dates back for nearly a century. Many inventions in devices, components, circuits, controls, and systems have caused power electronics to emerge as a major technology in recent years. The invention of the bipolar junction transistor in 1948 was the beginning of semiconductor electronics. This device and semiconductor diodes spawned a revolution electronics. Drastic reduction in size, cost, and power consumption were achieved simultaneously with greatly increased equipment complexity and capability. If the network is large, the preparation can be difficult, as can be observed in, and prone to errors or when the observed network is nonobservable such that the numbering of the “parent node” and “child node” arrangement is not easily constructed, iterative methods are not applicable. One example of non-observable network architecture is the ladder architecture when power sources are integrated at the opposite ends of a radial distribution.

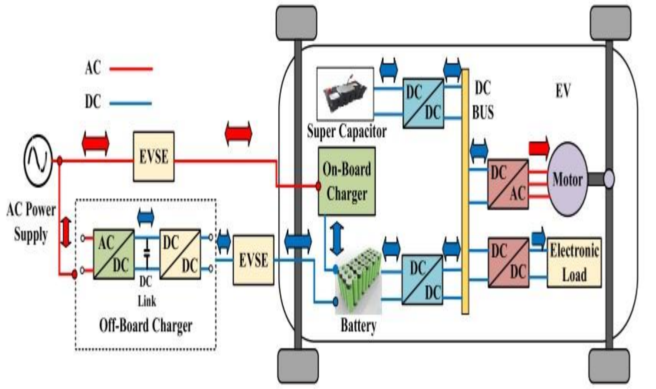

Fig.2 - Electric vehicle (EV) charging system including off-board and on-board charger

2. OPTIMIZATION-BASED MODELING

A binary integer load distribution model is developed to model the distribution of unipolar DC loads to either the positive or negative distribution pole of the 2-phase bipolar DC network. It is used with the power flow model to develop system voltage unbalance and power loss model for multiobjective optimization for the planning of 2-phase bipolar DC network. Binary Load Distribution Model In the 2-phase network, while a bipolar load is distributed by the bipolar pole, the unipolar loads can be distributed to either of the positive or negative pole distribution pole. Power electronics is the applications of solid-state electronics for the control and conversion of electric power. Power electronic converters to modify the form of electrical energy (voltage, current or frequency).Power range from some milliwatts (mobile phone) to hundreds of megawatts. The conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. Thus, the main metric of power electronics becomes the efficiency. The technology of power electronics and drives has gone through intense technological evolution during the last 30 years, although its history dates back for nearly a century. Many inventions in devices, components, circuits, controls, and systems have caused power electronics to emerge as a major technology in recent years. The invention of the bipolar junction transistor in 1948 was the beginning of semiconductor electronics. This device and semiconductor diodes spawned a revolution electronics. Drastic reduction in size, cost, and power consumption were achieved simultaneously with greatly increased equipment complexity and capability. As voltage unbalance occurs due to the serious asymmetrical loading of the unipolar loads, the unipolar loads are redistributed into 2 sets of load at roughly similar power levels defined as and such that serious asymmetrical loading does not occur.

2.1 Converter Topology

High-power charging is a challenging task due to high currents of several hundred amperes as well as a wide output voltage range. In order to simultaneously achieve a high efficiency and a high power density, non-isolated DC-DC converters are the most suitable topologies, since the isolation to the grid is realised in the AC-DC stage. In, several bidirectional non-isolated converters are compared, including cascaded buck-boost, half bridge, Cuk and SEPIC converters. Due to the low number and size of the passive components and the low conduction losses in the semiconductor devices, the half-bridge converter achieves the highest efficiency of the evaluated topologies.

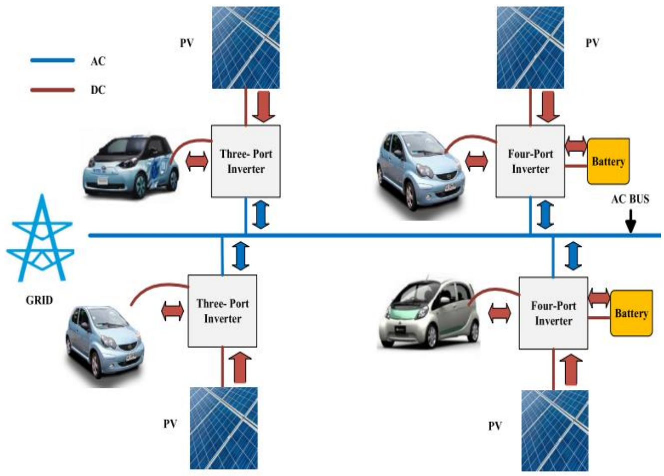

Fig.3 - EV off-board charging station including energy storage (ES) and PV panels based on the multiport inverter

Electricity is stored on a large scale (greater than 1kW) in various ways including pumped hydro, secondary battery technologies (Lead-Acid, Nickle-Cadmium, Sodium-Sulfur), and compressed air energy storage (CAES). Secondary battery technologies range in maturity from commercial and industry tested installations to those that are still in research and development; however, these technologies have not gained widespread use due to not meeting the fundamental requirements of high capacity and long discharge times whilst remaining cost effective or without special site considerations. The primary drawback to mechanical forms of energy storage such as pumped hydro, and CAES, is that they both require special geological locations to be feasible, and many times these locations are far from where the storage is needed. The operation of the EVCS when interconnected with the MVDC network and when powered via an ideal voltage source was compared. The operation of the EVCS was identical regardless of the source; due to the isolation capabilities of the bidirectional DC-DC converter. Through the use of limited power sources in the MVDC network case limitations of the bidirectional DC-DC converter were identified. In particular, the need to add a pre-charge circuit was highlighted.

3. SYSTEM ANALYSIS

With a modular approach and proper design, the power rating of the rectifiers can be raised to meet the requirement of dc fast charging. Also, a technical comparison among the validated ac-dc rectifiers. A non-isolated dc-dc converter is well-suited for a charging station where the line-frequency transformer exists before the ac-dc power stage. The voltage in the input side of the dc-dc converter in dc fast charging is typically higher than the EV battery voltage. Therefore, a single-phase buck converter can theoretically be used for charging the EV.

3.1 Study of Existing System

Conventional charging is expected to remain as the preferred charging method, and also the fast-charging process of the EV batteries is still not a widespread practice among the owners, Conventional two-level voltage source converter might arise, however it has a limited capacity to fulfill power ratings, power quality and efficiency requirements due to semiconductors voltage/currents Limits. Other works propose the use of a 12-pulse diode bridge rectifier, improving its harmonic performance through the use of an active filter stage. In a smart microgrid, combining EVs and renewable energy sources including energy storage units provides electricity to the loads during peak hours resulting in minimization of load shedding and additionally.

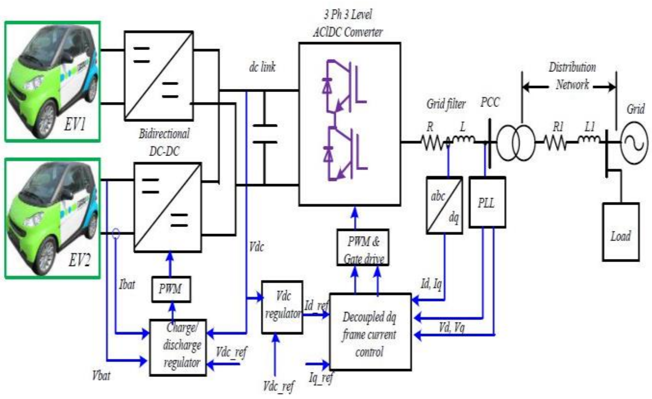

Fig. – 4 The proposed conversion system

3.2 Proposed System

A three-level dc-dc converter will be used as the dc-dc stage. This choice is further justified by the reduced voltage stress on the switching devices, allowing the use of conventional low voltage- rated switches; improved output current waveform and improved efficiency in comparison to conventional two-level based topologies. It consists of an isolation transformer, an inductive input filter and the central NPC converter in the ac side, while the dc side has the IGBT based three-level dc-dc stage feeding an ultra-capacitor ESS, and the resistive loads for each bus, both of them connected through a solid-state relay in order to force the asymmetrical operation.

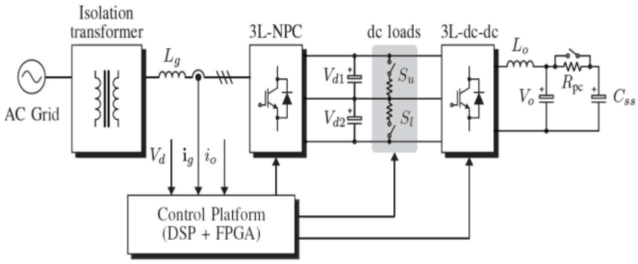

Fig.5 - Block Diagram

3.3 EV Charging Station

The grid-connected EV-charger station was composed of three main parts: a number of EV chargers, a power converter for grid interface, and a controller for system integration. Each EV charge regulator consists of a PWM DC/DC voltage source converter, which is referred to as the EV-side converter in this paper. The three-phase grid voltage is rectified to a DC voltage by utilizing a three-phase three- level rectifier/inverter. Electric vehicles are connected to the DC-bus through an EV charger and in parallel with each other.

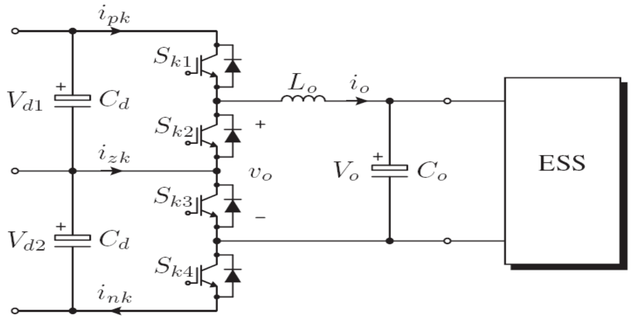

Fig. 6 - Circuit Diagram

At the grid-side controller, the three-level AC/DC inverter/converter is controlled by keeping a constant DC-bus voltage and regulating reactive power supplied to/ delivered from the grid by the three-phase three-level (TPTL) rectifier. for the three-level converter also aims to keep the DC- bus voltage level at the required value and forces the grid current to be approximately sinusoidal and in phase with the grid voltage. Therefore, this means unity-power-factor condition. A power controller was developed for optimization of the fuel economy.

3.3 Charging Station Control Strategy

Battery Charging/Discharging Requirements The battery is considered a vital device in EVs. Batteries can store the electrical energy in the form of chemical energy through charging and release the stored energy by internal chemical reactions through the discharge process. The charging and discharging process of a battery bank could be influenced by many factors, such as reactant concentration, temperature, and range of reaction. Thus, a corresponding energy management strategy of charging or discharging should be pursued and developed to extend the lifecycle of the EV battery and maintain the battery working with a higher performance. Typical recommended guidelines that should be followed for discharging regulation of an EV battery include maximum continuous discharging current and maximum 30 s discharging pulse current. Those two limits are usually specified by the battery manufacturer to protect the battery from excessive discharging rates that could damage the battery or decrease its capacity. The proposed bi-directional PWM DC/DC converter will be utilized to charge/discharge the EV battery, and the voltage level of Vd will be large. In the case where Vd is low, the performance of that power converter will worsen. However, the first specification suggests the maximum desired current at which the battery can be continuously charged or discharged. It determines the maximum continuous power that the EV battery can deliver to the grid in the case of V2G mode.

4. SIMULATION DIAGRAM

The proposed system was simulated using MATLAB/SIMULINK software package, which is the most powerful tool in designing power electronic systems. In this chapter the Simulink diagram, data used for simulation and the output for various inputs are presented. The system level interaction and operation of the electric vehicle charging station with and without interconnection to the full MVDC network will be evaluated during the EVCSs various modes of operation. The electric vehicle charging station has two primary modes of operation, when serving purely as a load (charging of electric vehicles and PV array ON or OFF) and when acting as a source of generation (no EVs present and PV array ON). In this chapter, two models will be referenced, the interconnected model, in which the EVCS is connected to the MVDC grid model, and the non-interconnected model, in which the MVDC grid is represented by an ideal voltage source. The two different models are utilized to validate the use of an ideal voltage source as an appropriate representation of the MVDC grid.

In effect of the battery chargers (synchronous buck converter) operation during a battery pole to pole (short circuit) fault is explored. In particular the ability of the converter to block or propagate the transmission of faults based off of the power electronic switching control is investigated. The proposed bi-directional PWM DC/DC converter will be utilized to charge/discharge the EV battery, and the voltage level of Vd in Figure 3 will be large. In the case where Vd is low, the performance of that power converter will worsen. The proposed bi-directional PWM DC/DC converter will be utilized to charge/discharge the EV battery, and the voltage level of Vd in Figure 3 will be large. In the case where Vd is low, the performance of that power converter will worsen. In, the continuous conduction mode (CCM) and discontinuous conduction mode (DCM) operation of the bidirectional DC-DC converter is discussed as it is not emphasized in literature. In order to accurately simulate and capture the power electronic switching, a small time step is utilized (12μs). A larger solution time step of (30μs) is necessary to reduce the amount of memory required.

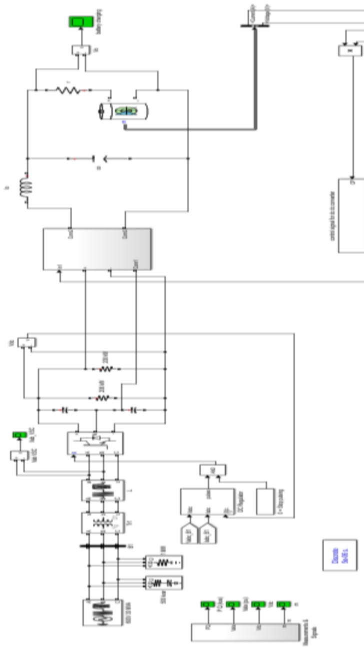

Fig.7 - Simulation Diagram

4.1 Result and Discussion

Operation of the individual components was validated independently. The operation of the electric vehicle charging station is validated in all modes of operation, when serving purely as a load (charging electric vehicles), serving purely as a source (supplying power to grid) and combinations of the two. System level simulation of the EVCS, confirms intermeshed component operation, reveals interactions between parallel connected converters, and is utilized to validate the use of an ideal voltage source as an accurate representation of the MVDC grid due to the isolation capability of the isolated bidirectional DC-DC converter. In this chapter, two models will be referenced: the interconnected model, in which the EVCS, is powered via direct connection to the MVDC grid model, and the non-interconnected model, in which the MVDC grid is represented by an ideal voltage source. The simulation of the EVCS capturing the various modes of operation is run for 2.1 seconds and follows the operating regime presented.

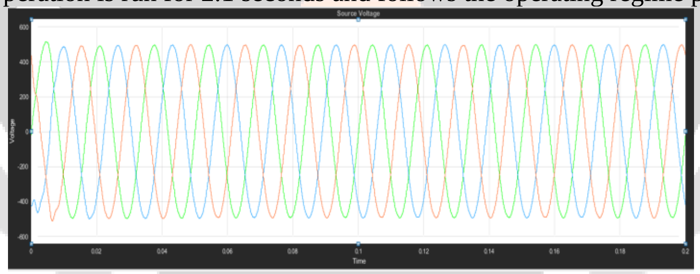

Fig.8 - Input Voltage

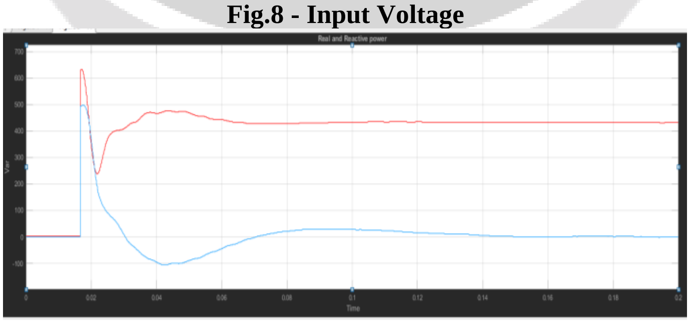

Fig.9 - Real and reactive power

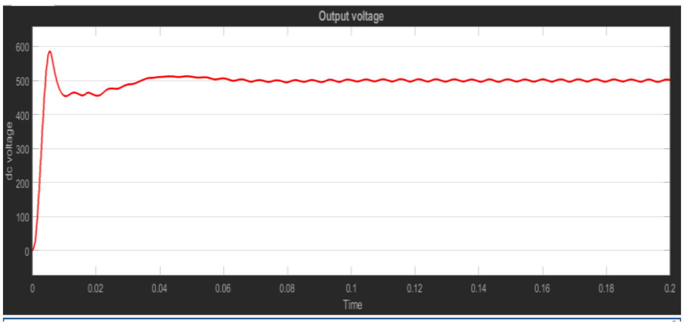

Fig. 10 Output dc voltage

The letters in the 'State' column are used to provide a visual cue in figures as to when mode transitions are occurring. In the interconnected model, the first 0.5 seconds of simulation time is necessary for the wind turbines to ramp up to full power operation. At 0.5 seconds (state B) in both models (interconnected and non-interconnected) the MVDC grid is connected to the EVCS system, and begins to charge the input capacitor of the bidirectional DC-DC converter. In the interconnected model, the MVDC bus reaches a steady state voltage of 4.25 kV. This steady state MVDC bus voltage is used as the input voltage in the non-interconnected model to maintain congruence between simulations. As previously discussed a pre-charge circuit was added to the bidirectional DC-DC converter. The pre-charge circuit is necessary because an uncharged capacitor is essentially a short circuit, and without a distinct pre-charge circuit the uncharged capacitor will collapse the MVDC bus. Through the addition of the resistors in series with the capacitor, the bidirectional DC-DC converters inrush current is limited. At 0.61 seconds (state C), the solar array is connected to the LVDC bus, and begins supplying 20 kW of power, this is highlighted in the power flow, the bidirectional DC-DC converter operating in boost mode will supply power to the MVDC grid while regulating LVDC bus voltage at 1 p.u. (800 VDC) with a 0.12 p.u. overshoot. Notice that is on a different time scale, this is to provide maximum resolution over the operating range of the LVDC bus. At 1.00 seconds (state D) the PV array turns off and the EVCS enters a standby mode in which minimal power is flowing in the system; notice that during this standby period the LVDC bus voltage, is regulated to 1.0 p.u. via the damping circuit, with a 0.11 p.u. transient overshoot. At 1.15 seconds (state E) the first EV begins charging at approximately 50 kW causing a 0.09 p.u. undershoot. At 1.20 seconds (state F), the PV array turns ON supplying 20 kW of power. Once again, the bidirectional DC-DC converter regulates the LVDC bus voltage to 1.0 p.u. with a 0.07 p.u. overshoot. At 1.35 seconds (state G), the second EV begins charging at approximately 50 kW causing a 0.06 p.u. undershoot. At 1.75 seconds (state H) the PV array turns off meaning that all 100 kW of load is being supplied via the bidirectional DC-DC converter. During this period the voltage ripple of the LVDC bus reaches 6.625%. Lastly, at 1.9 seconds (state I), EV 2 quits charging. Notice, that in both the non-interconnected and the interconnected models the bidirectional DC-DC converter is able to properly regulate the LVDC bus voltage, both with and without ideal input voltage. The bidirectional DC-DC converter is able to properly provide isolation between the load step changes occurring on the LVDC bus and the MVDC bus. The only perturbation of the MVDC bus voltage caused by the EVCS is when the bidirectional DC-DC converter input side pre-charge circuit turns off; the MVDC bus has a brief drop in voltage to 0.8 p.u. which corresponds a transient undershoot of .25 p.u., In this section the effect of a line to line fault (short circuit) at the input terminal of the electric vehicle battery during charging is investigated, in particular, the effect the synchronous buck converters power electronic switching state has on the propagation of the fault is examined. Figure 5-5 shows the EVCS system configuration at the time of the fault. All switches in the EVCS are closed and two EVs are charging at 50 kW, 20 kW of power is being supplied.

PV array with the remaining 80 kW of power being supplied by the MVDC grid, and the system is at steady state conditions. At 0.5 seconds, a short circuit is applied across the terminals of EV battery 1. At 0.6 seconds the synchronous buck converter stops power electronic switching with both switches open. At 0.7 seconds the fault is cleared. In a real-world application, the fault detection and operation stoppage of the synchronous buck converter would occur faster than 0.1 seconds

5. CONCLUSIONS

In this project, the use of electric vehicles (EVs) is proposed as a temporary power supply to support critical infrastructure during emergencies. The use of EVs and a community-level storage unit further enhances the resilience of the microgrid, by utilizing the available the electric vehicles, and by investing its storage unit. The charging reference current for each EV battery and the correspondent duty ratio for each power converter are determined in the Simulink model. The developed Simulink model of the controller also regulates the turn-on or turn-off periods of the switch connected to each EV battery. Hence, the charging controller can generate a turn-off signal when the charging stops or a fault is detected. Typical control strategy for three-level PWM rectifier/inverter was presented. The PI controller and PI-FLC controller are evaluated to verify the suitable controller for the EV charging station. A comparison between PI controller and Fuzzy controller demonstrate the superiority of proposed PI-Fuzzy over conventional PI for the same conditions. The simulation results show that the PI-FLC controller has better operation performance.

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