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Impact Of Electrical Vehicle Charging Station And Fault Ride Through Capability Under Critical Voltage Conditions

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Abstract: The electric vehicle (EV) charging system requires a high-quality power supply to function correctly. The purpose of this study is to look at the impacts of voltage disruption on EV batteries and charging systems, as voltage quality is one of the primary issues in the distribution grid. To increase voltage quality, we also implemented a fault ride through capability (FRTC). The charging system consists of a DC-DC converter and a three-phase controlled rectifier. Lithium-ion batteries are used to simulate EV battery packs. The FRTC system is designed to improve voltage quality by utilizing a dynamic voltage restorer. It protects the charging system and EV batteries against dangerously excessive voltage sag levels. The performance of the proposed EV charging station (EVCS) was evaluated at voltage sag levels of 30%. Matlab/Simulink software was used to analyse the simulation data.

Keywords: Fault Ride Through Capability (FRTC), Electric Vehicle (EV) ,EV Charging Station (EVCS)

I. INTRODUCTION

C. W. Tan, S. Li, M. M. Rahman, and H. S. Das [1] proposed Transport electrification has been a major focus of research during the last 10 years. Traditional internal combustion engine vehicles are losing market share to electric vehicles (EVs). As EVs become more popular, the number of charging stations increases, which has a significant influence on the electrical infrastructure. Various charging strategies and grid integration techniques are being developed to mitigate the negative effects of EV charging while increasing the benefits of EV grid integration. This report provides a comprehensive review of the current situation of the EV market, standards, charging infrastructure, and the grid impact of EV charging. The article not only provides a comprehensive summary of key global EV charging and grid connectivity standards, but it also discusses the current condition of electric vehicles. Various EV charging infrastructure configurations are analysed and evaluated in terms of control and communication architecture. Various optimisation and game-based algorithms for EV grid integration management are investigated, and the responsibilities of EV aggregators and individual EV owners are considered while researching the electric power market. As the power grid evolves into the future energy Internet, the research particularly assesses how EV developments—such as shared mobility, autonomous driving, and connected vehicles—will affect EV grid integration. It also explores how EVs will affect and enhance the development of the future energy Internet. Finally, the obstacles and recommendations for improving grid integration and EV charging infrastructure are evaluated and summarised.

According to J. Xiong, K. Zhang, Y. Guo, and W. Su,[2] trendsetting countries have promoted or even implemented more electric vehicles (EVs) and other distributed energy resources (DERs) in their power systems. As a result of this transformation, distribution system planning and operation confront new and growing challenges as they adapt to the increasing number of DERs. Nonetheless, EVs may open up new opportunities and support the grid by providing a variety of local and worldwide power and energy-related services. This paper provides an analysis and description of the possible services accessible from EVs for distribution networks, known as EV distribution system services (EV-DSS). A full explanation of recent services and methodologies is offered, along with an assessment of EV-DSS maturity. Furthermore, difficulties and opportunities for future study are indicated, taking into account major subjects like as market framework design, economic assessment, battery deterioration, and the effects of EV service provided by transmission system operators on distribution networks. As a result, this article provides stakeholders with a tool for understanding the services that EVs can provide, as well as a thorough literature framework that can be used to guide future study. It is consistent with the current specifications to move forward with realistic EV-DSS implementations.
According to S. Rahman, I. A. Khan, A. A. Khan, A. Mallik, and M. F. Nadeem,[3] electric vehicles (EVs) have emerged as a viable alternative to internal combustion engines. Because of their high penetration rates, EVs have an

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impact on grid stability and power quality when added to existing distribution line infrastructure. Furthermore, EV charging loads differ from conventional permanent node-connected loads in that they are movable. Grid congestion and the resulting over/under compensations may result from solutions presented without taking these factors into account. Another emerging trend in the distribution system is the high penetration of renewable energy in the utility grid. Although these dynamics make stable grid operation difficult, they also provide opportunities to address some of the issues associated with EV load grid integration. As a result, the impact of adding EV charging load to the current low voltage distribution system must be evaluated using a variety of criteria, including the spread/peak demand of the load curve, power quality, voltage profile, and grid impact with various EV chargers. This study presents an in-depth analysis of the effects of EV integration at the component and system levels. The contribution of EV chargers to grid pollution and alternative solutions are discussed in order to assess the influence on power quality (at the component level). Various feeders and load curves are used to provide a full understanding of the necessity of EV load location, current load distribution, and the nature of EV charging load distribution. To aid comprehension, simulated case studies are utilised to supplement these discussions, which are then followed by a review of the available research. Finally, approaches for realistically simulating the moveable nature of EV demand and the potential for auxiliary solutions provided by distributed EVs are outlined.

F. Abbas, L. Sang, M. U. Shahid, H. Tang, M. M. Khan, and S. Habib [4] propose The looming environmental challenges and growing worries about global energy crises are driving the need for new opportunities and technology to meet the significantly increased demand for energy. More sustainable and clean energy systems. This requires the development of electricity generation and transportation infrastructure. Electrification is one possible method for making transport networks more environmentally friendly and minimising the consequences of climate change. In accordance with a number of international standards and charging rules, this study investigates the present condition, most recent deployment, and tough issues in the deployment of EV infrastructure and charging systems. It also investigates the potential and consequences of EVs for society. A comprehensive assessment of EV charging systems employing battery charging methods is provided. In addition, the good and negative impacts of EVs are classified and thoroughly investigated. The benefits of corrective steps for negative impacts are highlighted. Bidirectional charging serves as the foundation of vehicle-to-grid technology. This paper discusses future research directions as well as the significant issues that are already being produced by the increased use of electric vehicles. This document is intended to serve as a useful and instructional one-stop resource for researchers interested in this topic.

According to R. El-Shatshat, A. Gaouda, and Y. O. Assolami, [5] climate change has increased the prevalence of plug-in electric vehicles (PEVs), solar photovoltaics (PVs), and energy storage systems in the residential sector. The inclusion of these resources with exact stochastic models is expected to have an impact on the appraisal of EDS assets. This study considers home prosumer ownership of PEVs and proposes a new paradigm for evaluating and improving voltage quality, distribution transformer (DT) overload, and ageing. The proposed study generates a probabilistic power flow to investigate the effects of PEVs, PVs, and traditional load stochasticity. In this study, a comprehensive secondary distribution system integrated into the EDS is used to model the house premises for supply. This work builds on prior research by including PEVspatial-temporal (SAT)-charging activities into evaluation models of DT overload and ageing, voltage imbalance, and voltage deviation. When compared to a simple model in the literature, the proposed framework gives DTs a more realistic life expectancy.

Z. Wang, X. Guo, J. Li, and X. Wang [6] hypothesise that voltage sags affect electric car chargers. They also propose a method for determining the least symmetrical voltage sag, during and after which charges can be kept steady. The suggested solution is based on electric circuits, small-signal stability, and restrictions with pulse-width modulation (PWM). Electrical distribution systems are designed to operate under certain sinusoidal voltage and current settings [7]. The increased use of non-linear load as a result of the adoption of new technologies has created a serious issue with power quality. Non-linear loads have a tendency to stress the system, resulting in equipment damage, current flowing through neutral conductors, distortion of current and voltage waveforms, overheating, and a loss in power factor [8]. Healthcare institutions often require high-quality power to run their loads more efficiently [9]. These medical facilities, however, have a wide range of load concentrations, including light, heavy, linear, non-linear, balanced, and unbalanced designs. They are also delicate, and the majority of them are managed digitally [10]. It is not recommended to undertake the standard trade-off between operation and control. Switched Mode Power Supplies (SMPS), which are less vulnerable to high power quality, are required for digital load control. Heavy loads such as X-ray machines, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scanners, lighting loads in operating rooms, and equipment in intensive care units (ICUs) and critical care units (CCUs) are significant sources of power pollution [11-13].

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Commercial utilities frequently connect large, inductive loads, which can cause voltage sag and swell while switching loads. Custom Power Devices (CPDs) can help to reduce these power quality issues [14]. Power quality can be increased by infusing either voltage or current into the system at the point of common coupling (PCC) [15]. This allows for the regulation of the terminal voltage, which improves the power factor. CPDs include devices such as Dynamic Voltage Restorer (DVR) and Distribution Static Compensator (DSTATCOM), among others.DSTATCOM injects the necessary reactive power to enhance performance and dependability. When large loads are rapidly removed, the DSTATCOM outperforms SVCs and other CPDs in voltage support. Across a non-linear operational range, the DSTATCOM perfectly adjusts its output current regardless of the AC system voltage [16]. The DSTATCOM can easily communicate with energy storage devices like fuel cells (FC), large capacitors, and batteries. It also has a perfect response time. In [17], a DSTATCOM interfaced with FC is proposed.

II. DESIGN OF PROPOSED EVCS

An illustration of the planned FRTC integrated EVCS concept is provided is shown in fig.1. This system consists of a DVR-based FRTC system, a chopper, and a regulated rectifier. The regulated rectifier converts the grid's alternating current into a specified direct current. The dc-dc converter converts the steady direct current supply into the appropriate voltage and current for battery charging. The DVR connects to the grid via the injection transformer. In the case of a grid supply breakdown, the DVR-FRTC technology is used to improve load voltage quality. Lithium-ion batteries are used in many EV battery pack models. The suggested EVCS's entire circuit diagram is demonstrated.

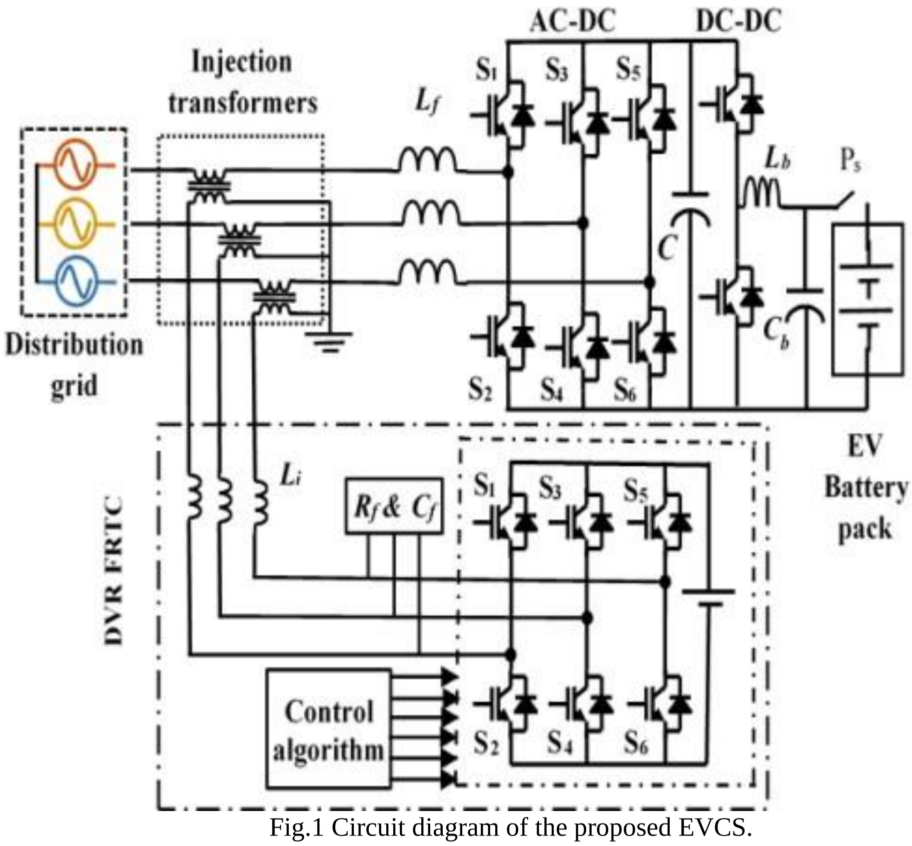

Fig.1 Circuit diagram of the proposed EVCS.

2.1 Design of Electric Vehicle Charger

The EV charger's architecture incorporates both the chopper and the controlled rectifier. The inductive filter connects the rectifier input to the utility grid. The rectifier's output voltage should be low enough to avoid needless switching losses and high enough to provide effective dynamic control. The following formula is used to estimate the DC voltage:

$$V_{dc} = \frac{2\sqrt{2}V_{L-L}}{\sqrt{3}m} \quad (1)$$

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where V_{LL} represents the line voltage and m denotes the modulation index. To prevent over modulation, adjust m to 0.9 and set $V_{L\text{–}L}$ to 415 V. Vdc is so calculated to be 752 V and chosen to be 750 V. The filter capacitor (C) eliminates waves in the rectifier's output voltage. The required value of the filter capacitor is calculated using the following formula.

$$C = \frac{P_{dc}}{V_{dc} \times 4\pi \times f \times \Delta V_{dc}} \quad (2)$$

where Pdc is the rated direct current power (14 kW), Vdc is the ripple voltage, and f is the grid frequency (50Hz). Vdc is comparable to 1.5 percent of the rectifier's output voltage. C is determined to be 2862 µF and chosen as 3300 µF. The battery is linked to the rectifier's output terminals via a chopper. It generates the required voltage and current for battery charging and regulates the rectifier output voltage. The chopper's inductor (Lb) and capacitor (Cb) have been identified.

$$L_b = \frac{D(V_{dc} - V_b)}{f_s \times \Delta I_L} \quad (3)$$

$$C_b = \frac{\Delta I_L}{8 \times f_s \times \Delta V_b} \quad (4)$$

where V_b is the output ripple voltage, D is the duty ratio, and V_b is the battery voltage. The switching frequency is f_s, and the ripple current is I_L.

2.2 Lithium-ion Battery Design

The lithium-ion battery has more advantages like high energy density and specific power. Thus, it is more preferred for EV applications. The dynamic equations of the battery for charging and discharging.

$$V_{nl} = V_0 - R_i i - K\frac{Q}{q + 0.1Q}\overset{*}{i} - K\frac{Q}{Q - q}q + Ae^{-Bq} \quad (5)$$

$$V_{nl} = V_0 - R_i i - K\frac{Q}{Q - q}\overset{*}{i} - K\frac{Q}{Q - q}q + Ae^{-Bq} \quad (6)$$

where A is the exponential voltage (V), B is the exponential capacity (Ah−1), Q is the maximum battery capacity (Ah), i is the battery current (A), i ∗ is the low-frequency current dynamics (A), Vo is the battery nominal voltage (V), q is the extracted capacity (Ah), and K is the polarisation constant (Ah−1).
The battery state of charge (SOC) is calculated by

$$SOC = \left(1 - \frac{1}{Q}\int_0^t i(t)dt\right) \times 100 \quad (7)$$

The 0% SOC denotes that the battery is empty, and 100% SOC represents that the battery is full.

2.3 Design of DVR-Based FRTC System

The DVR-based FRTC system is mainly composed of a three-phase voltage-source converter, an injection transformer, an interfacing inductor, a ripple filter, and a dc voltage source. The power rating (VA) of the voltage-source converter and injection transformer of the DVR is calculated.

$$S_{DVR} = 3 \times V_{VSC} \times I_{VSC} \quad (8)$$

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Where V_{vsc} and I_{vsc} are the voltage and current rating of the voltage-source converter. V_{vsc} for the unity power factor load can be calculated by the following equation:

$$V_{VSC} = \sqrt{V_r^2 - V_a^2} \quad (9)$$

Where Vr represents the rated source voltage and Va denotes the actual source voltage during sag. The interface inductor (Li) for the voltage-source converter of the DVR is approximated using the DVR's ripple current and is expressed as follows:

$$L_i = t_r \times 0.866 \times m_D \times \frac{V_{Ddc}}{(6 \times a \times f_{Ds} \times \Delta I_r)} \quad (10)$$

where tr represents the injection transformer turns ratio, mD is the DVR modulation index, Vdc is the DVR dc-link voltage, a f is the overloading factor, fDs is the DVR switching frequency, and Ir is the ripple current. The ripple filter of the DVR can be approximated using

$$f_{RF} = \frac{1}{2 \times \pi \times R_f \times C_f} \quad (11)$$

Where f_{RF}, R_f, and C_f represent the ripple filter frequency, resistance, and capacitance, respectively.

III. PROPOSED CONTROL TECHNIQUE

For the converters used in the DVR-FRTC integrated EVCS to function successfully, appropriate control strategies are required. A variety of control approaches for the rectifier have been proposed, including direct power control (DPC), voltage-oriented control, and virtual flux DPC (VFDPC) methodology. Both the DPC and VFDPC techniques make use of a variable switching frequency. It requires a fast CPU and complicates the filter design. Nonetheless, the VOC technique has a set switching frequency. As a result, filter design becomes less complicated. It also provides better static performance and faster dynamic response thanks to the internal current control loop. As a result, the rectifier in this work employs a VOC method. Figure 2 depicts the rectifier control technique (VOC).

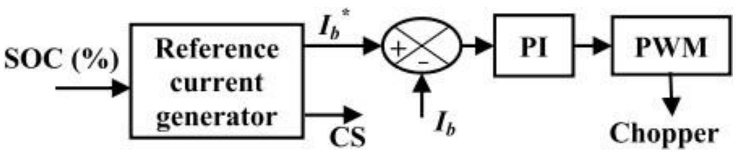

Fig. 2(a) Control technique of the chopper.

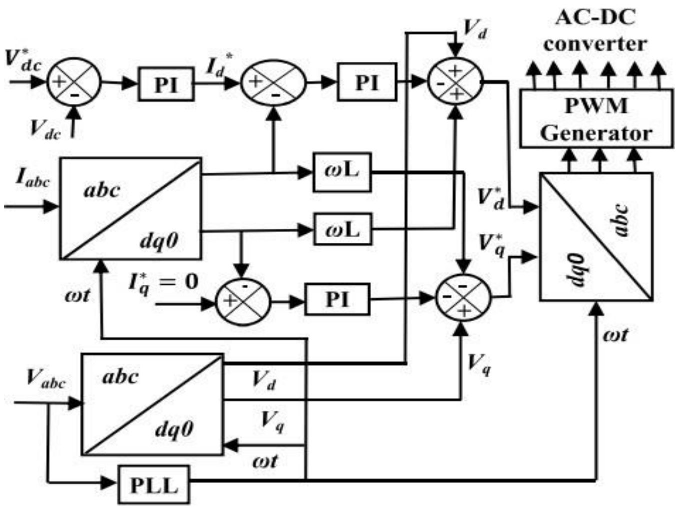

Fig. 2(b) Rectifier control strategy.

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The chopper's control strategy is determined dependent on the battery charging process. The many battery charging methods include constant power (CP), constant voltage (CV), trickle current (TC), constant current (CC), taper and float charge, and CCCV charging. The CC approach causes overcharging of the battery, while the CV method takes longer to charge the battery. TC charging is used to charge the battery at a lower current rate. Lead-acid batteries are appropriate for float charging. On the other hand, the CCCV approach is generally used in electric car applications since it charges the battery via CC until it reaches 80% SOC and then switches to CV mode. As a result, the CV approach charges the remaining 20% of SOC. The fact that CV charging takes three times longer than CC charging has a direct impact on CCCV charging efficiency. To overcome this restriction, the chopper employs a multistep CC technique. The helicopter's control method is demonstrated.

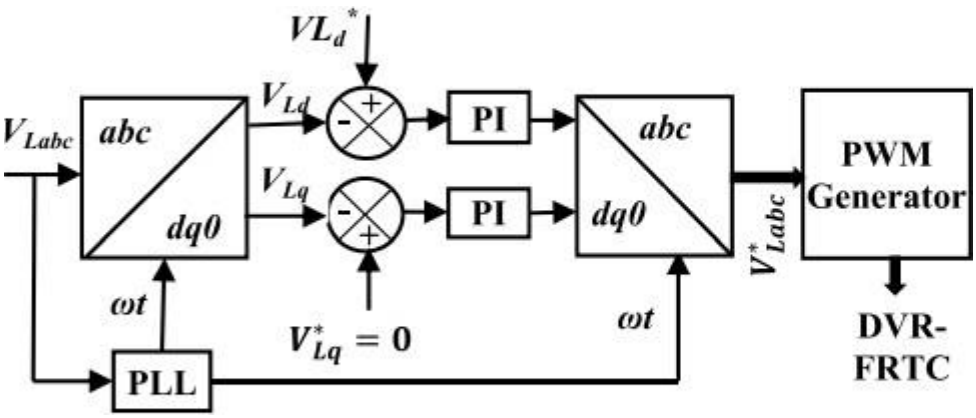

Fig. 3 Control technique of the DVR-FRTC system.

Because the reference signal generation method dictates the DVR's performance, the control algorithm is the most important part of the DVR-FRTC system. Time- and frequency-domain control methods include SRF theory, PQ theory, unit template theory, single-phase DQ theory, neural networks, adaptive detection theory, Fourier series, Kalman filter, wavelet transform, and discrete Fourier transform. The DVR is controlled using time-domain techniques, while the power quality is monitored with frequency-domain techniques. The SRF theory-based control algorithm is one of the most widely used ways for controlling DVRs. As a result, the DVR-FRTC system employs the SRF control algorithm. It displays the SRF control algorithm.

V. SIMULATION RESULTS & DISCUSSIONS

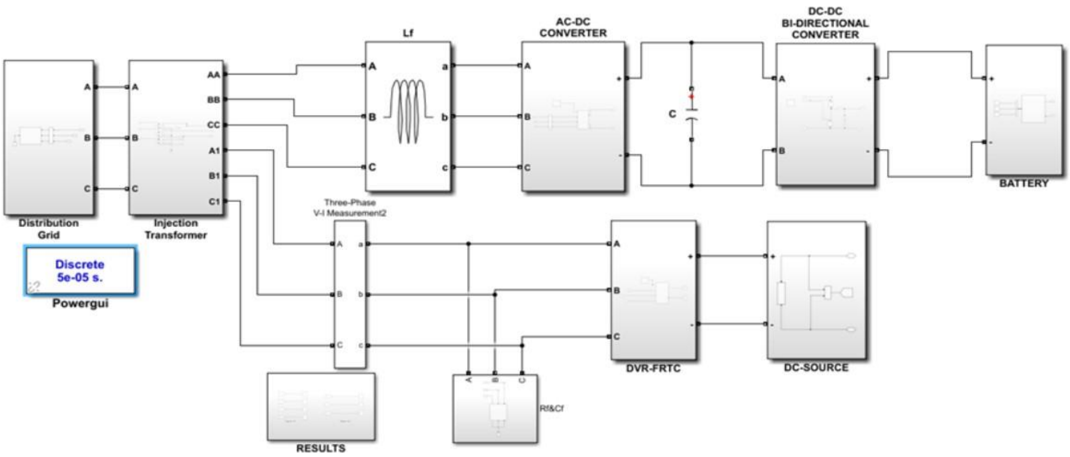

Fig. 4. simulation model of ANFIS function.

The simulation diagram of proposed system is shown in fig.4. this simulation diagram consists of grid, Injection transformer, AC-DC converter, DC-DC converter, DVR-FRTC and DC source.

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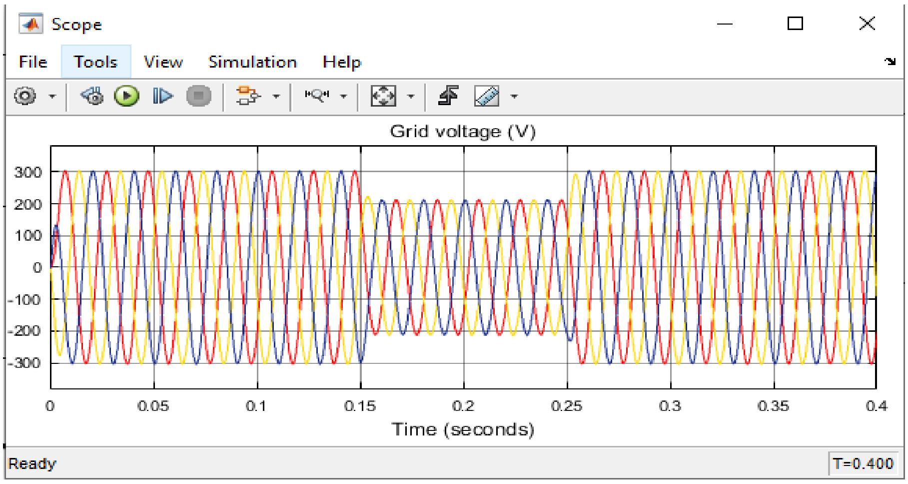

Fig. 5. Grid Voltage.

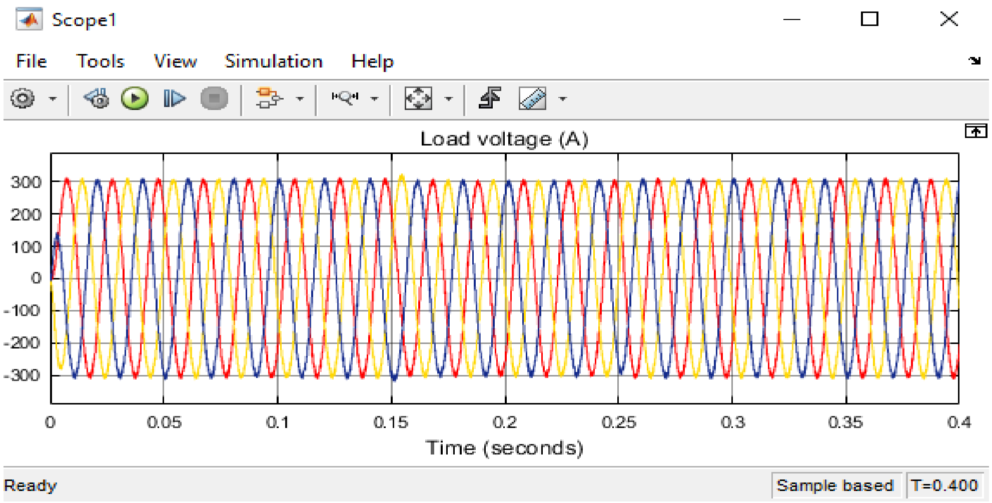

Fig. 6. Load Voltage.

Grid voltage and Load voltages are shown in figures 5 and 6 respectively. At 0.15 second grid voltage changes from 300 to 200 volts due to sag effect. After 0.25 seconds this voltage again retained to 300 volts.

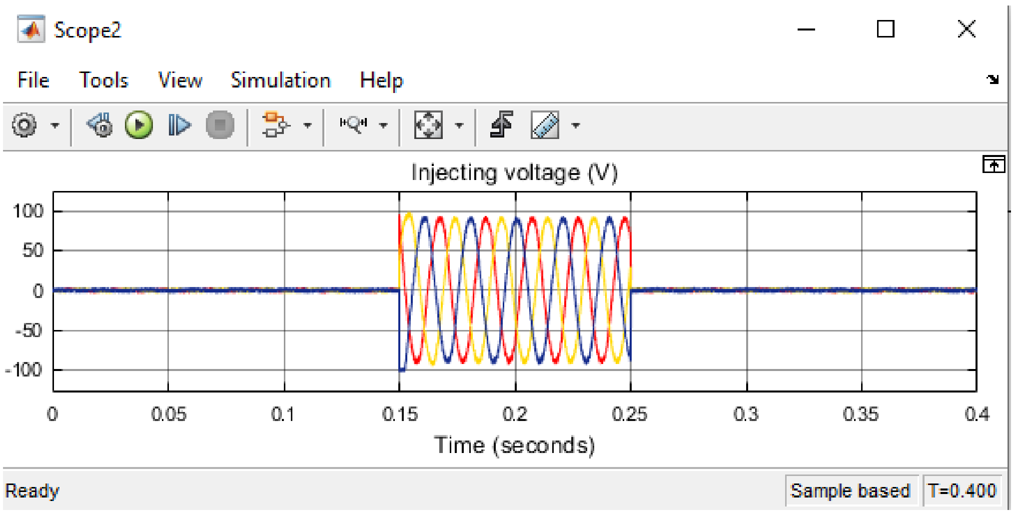

Fig. 7. Injected Voltage.

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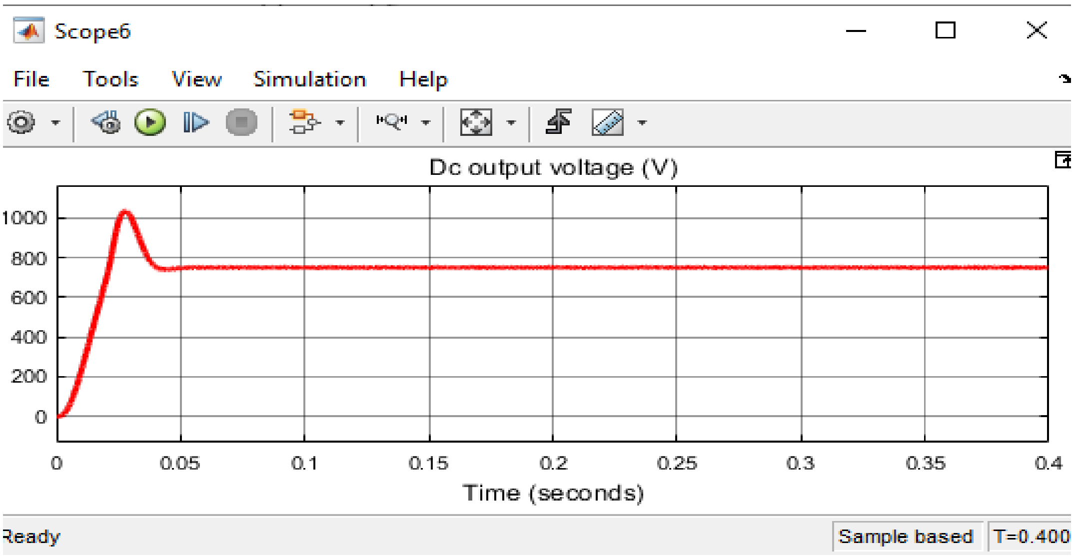

Fig. 8. DC output Voltage.

Injected voltage and DC output voltages are shown in figures 7 and 8 respectively. The sag is identified between 0.15 to 0.25 seconds, to maintain 300 volts at load. The voltage is injected by DVR; due to sag 100 volts dropped in load voltage. This 100volts during 0.15-0.25 seconds by DVR.

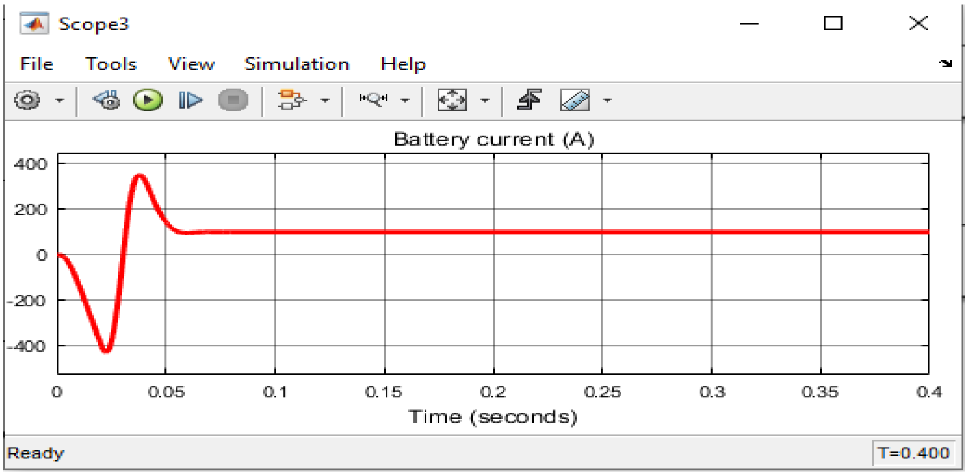

Fig. 9. Battery Current.

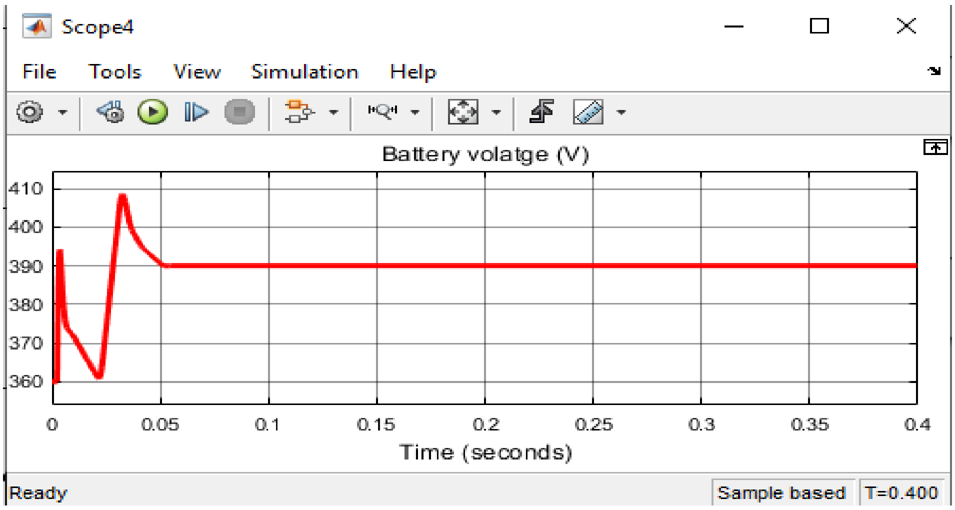

Fig. 10. Battery Voltage.

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Battery current and DC Battery voltages are shown in figures 9 and 10 respectively.

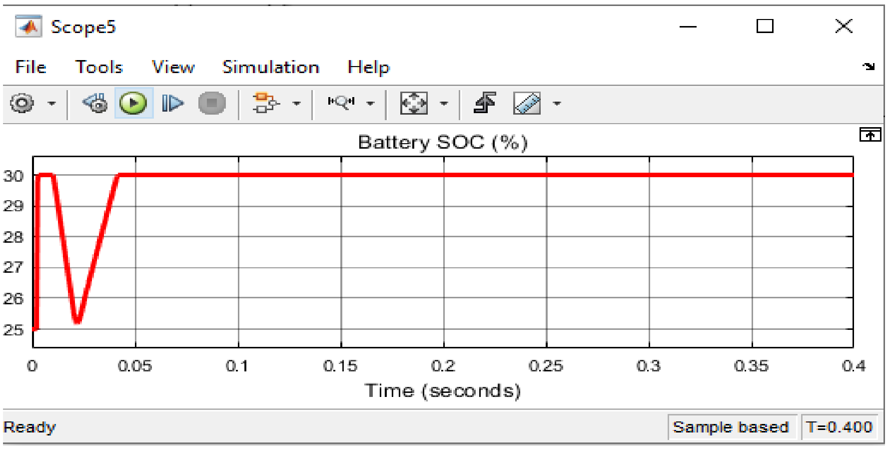

Fig. 11. Battery SOC.

The battery SOC and load voltage profiles are shown in fig.11 and 12 respectively.

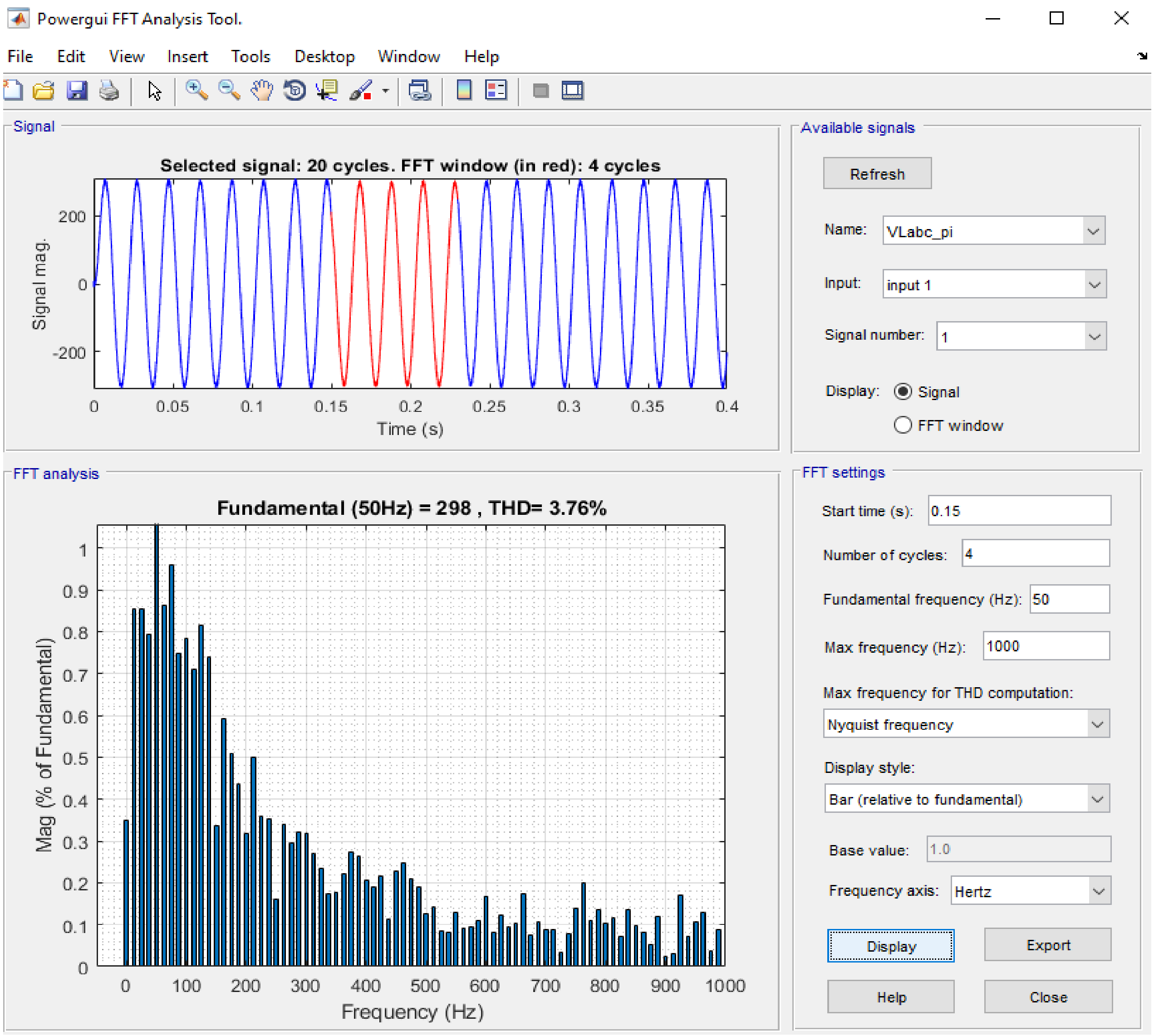

Fig. 11. THD of Load Voltage.

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VI. CONCLUSION

In order to enhance the load voltage quality, the DVR-FRTC system was implemented in this study after an examination of the effects of different voltage sag levels on the EV charging system and batteries. To conduct the simulation investigation, the system was simulated using the MATLAB/Simulink platform. System performance was assessed with and without the DVR-FRTC technology at 30% voltage sag levels. During 30% voltage sag, the charging system without DVR-FRTC operated in steady mode. However, because the DVR-FRTC system injects voltage during the sag period and maintains a constant load voltage, the charging system with DVR-FRTC operated in stable mode at all voltage sag levels. As a result, the system was consistently ran in stable mode. It improves the system's reliability and protects the EV batteries from voltage fluctuations. Future research in this area could look into the impacts of converter and battery components on health, both with and without the DVR-FRTC system.

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