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Impact of Electric Vehicle Charging Station on Harmonics and Voltage Stability of Grid System using MATLAB Simulink

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Abstract

The minimal to virtually negligible environmental footprint associated with electric vehicles (EVs) has generated considerable interest among researchers, sparking extensive and ongoing investigations. The focus of this research pertains to the charging infrastructure, with active exploration of fast chargers, wireless charging technologies, and various methodologies aimed at expediting the charging process. The proliferation of EVs poses a significant challenge to the harmonic and voltage stability of grid systems. As the adoption of EVs increases, the dynamic and non-linear nature of their charging and discharging processes introduces potential disturbances to the grid, leading to harmonic distortions and voltage fluctuations. In this paper, the impact of electric vehicle charging stations on grid system is analyzed in terms of harmonics and voltage stability. The results derived from Simulink for THD values increase when increase EV from 1 to 4 EV. For 1 EV, THD values 14.9% then for 4 EV, the THD values 27.2%. The harmonic pollution associated with EVs dependent on the number of EVs and the charging method. If many EVs are charging in the same area, then the harmonic pollution in that area will be more. The simulation study of DC fast charging using Simulink in MATLAB has provided valuable insights into the impact of EVs charging stations on the grid system, with a specific focus on voltage stability and harmonic distortion.

1. Introduction

Malaysia aims to transition towards EVs to achieve carbon neutrality by 2050 [1]. Despite positive strides, a key concern among Malaysians is the insufficient number of public charging stations. Currently, there are around 900 EV charging stations, and the government aims to install 10,000 by 2025 through collaborative efforts [2]. The Ministry of International Trade and Industry (Miti) projects providing up to 4,000 charging stations by 2023. As of 2022, Malaysia has over 15,000 plug-in hybrids, hybrids, and fully electric vehicles on the road, with more than 10,000 registered with the Road Transport Department. Proton reports a 3.4% year-on-year growth in EV penetration. Despite the environmental benefits, the integration of EVs into the power system poses challenges. In China, issues like off-control transient voltage stability have arisen due to dynamic loads and power electronics devices [3].

The widespread adoption of EVs, especially through centralized charging, can lead to power quality problems such as harmonics and voltage fluctuations in the distribution network. The main objective is to analyse the harmonic and voltage stability of power systems due to the EVCS integration. Studies indicate challenges like voltage drops, transformer overloading, system incapacity, harmonics, and increased losses [4]. Shifting EV charging to off-peak hours has been identified as a solution, but it remains a primary difficulty. The nonlinear properties of EV chargers can produce harmonics, impacting the voltage profile and decreasing the efficiency of distribution transformers. This degradation in electricity quality can harm power devices and affect the overall stability of the power system [4] [5]. To address these issues, there is a need to develop a model of DC Fast Charging for EV Charging Stations using MATLAB Simulink to analyze and optimize harmonic and voltage stability in power systems due to EV integration [6].

Numerous seminal studies have significantly contributed to advancing our understanding of the influence exerted by EVCS on power quality, thereby providing foundational insights for contemporary initiatives [7]. In the research conducted by Ashish Kumar, Sujit Roy, and Md. Raju Ahmed, the deployment of MATLAB simulations proved instrumental in scrutinizing the implications of electric vehicles on the electricity distribution network, uncovering critical issues such as the overloading of distribution transformers, the presence of harmonics, distorted voltage profiles, and consequential power losses. This study probed the consequences of EV charging station congestion, encompassing issues such as harmonic penetration, voltage unbalance, and the influence on distribution transformers [8]. A noteworthy aspect of this investigation was the strategic integration of renewable resources to mitigate power quality issues. The presented tabular synthesis succinctly encapsulates outcomes from antecedent experiments dedicated to exploring the impact of EVCS, serving as an invaluable quick-reference tool for comprehensively understanding the collective research insights regarding the overarching influence of EVCS on electric vehicles [9].

2. Materials and Methods

The main content methodology for this project is focusing on the development model of DC Fast Charging of Electric Vehicle Charging Station (EVCS) by using MATLAB Simulink.

2.1 Mathematical Modelling

Initiating the exploration of mathematical modeling for Electric Vehicle Chargers (EVCs), a comprehensive approach involves formulating equations that capture the dynamic interactions between charging stations, power grids, and the electric vehicles themselves. By delving into mathematical representations, we can gain insights into the complex systems.

2.1.1 Power Demand

Electric Vehicle battery takes charge from the power distribution system. The increased power demand affects the stability of the system due to non-linearity. The power demand by an EV can be expressed as in equation (1) [7]

$$P_{EV} = \mathrm{C_{Batt}} * \left((\mathrm{SOC_{max}} - \mathrm{SOC_{min}})/\mathrm{T_d}\right) \quad (1)$$

where C_{Batt} is the battery capacity, T_d is the duration of charging. Battery SOC is a factor whether the EV takes high or small power.

As shown as in equation (2) [7], the gross power demand of the EVs is the summation of individual power demand of all EVs which likely signifies.

$$P_{\mathrm{Gross}} = P_{EV} \quad (2)$$

2.1.2 Harmonics

This analytical approach, as referenced in studies [7] and [8], provides a quantitative measure of the overall harmonic content in the electrical signals, offering valuable insights into the potential challenges and deviations from ideal sinusoidal waveforms.

$$THD_i = \frac{\sqrt{\sum_{n-2}^{N} I^2 n}}{I_1} x\ 100\% \quad (3)$$

$$THD_v = \frac{\sqrt{\sum_{n-2}^{N} V^2 n}}{V_1} x\ 100\% \quad (4)$$

The Total Harmonic Distortion (THD) for the current and voltage are respectively expressed by equation (3) and (4) [8].

2.1.3 Transformer Overloading

Integration of more EVCS on a single distribution transformer creates stress on transformer winding which reduces the power delivery capacity of transformer [21]. Presence of harmonic current and harmonic voltage creates load loss and no-load loss respectively [22]. This harmonic must be within the withstand capability of transformer known as K-factor. The mathematical model of K-factor is given as in equation (5) [7]

$$K_{factor} = \sum_{n=1}^{N} n^2 \left[\frac{I_n}{I_R}\right]^2 \quad (5)$$

where the n^th harmonic component, I_n, and the rated load current, I_R, are correspondingly represented by the brackets. Overheating in the transformer is caused by the presence of excessive harmonic current, which also shortens the transformer's lifespan.

2.1.4 Filter Parameter of AC-DC Rectifier

AC-DC diode bridge rectifier converts AC into pulsating DC which has ripples in it. To reduce these ripples filter capacitor should be added to the output of the bridge rectifier. The filter capacitor value can be calculated by equation (6) [18]

$$C_{filter} = \frac{V_{dc}}{R_{eff} x 2 x V_r (p-p) x f} \quad (6)$$

where $R_{effbuck}$ the effective resistance of buck converter and the battery and $V_{r(p\text{-}p)}$ is the allowable peak to peak ripple in the voltage. Here we have taken a 3% ripple in the voltage to be allowable.

2.1.5 Filter Parameter of DC-DC Buck Converter

The filter parameter of the buck converter should have values that are greater than those considered crucial. Calculations can be made to determine the critical value of the inductor and capacitor using the following equation (7) and (8) [18], where L_{cr} is the critical inductance of the filter and C_{cr} is the critical capacitance of the filter.

$$L_{cr} = \frac{(1-D)*R}{2f} \quad (7)$$

$$C_{cr} = \frac{(1-D)}{16f^2 L_{cr}} \quad (8)$$

2.2 Block Diagram

Based on Fig. 1, the development of DC fast charging using Simulink in MATLAB, the process typically begins with modeling the grid connection, where the electrical power is sourced. It simulates the power flow through a transformer to step up or down the voltage levels as needed.

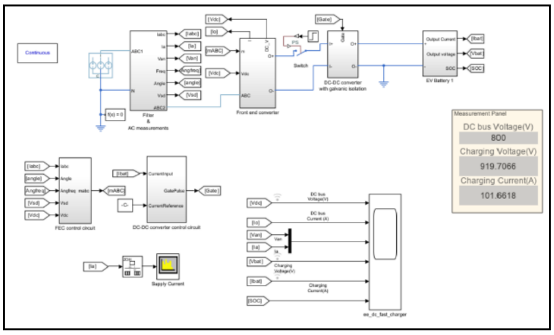


Fig. 1 *Design of block diagram for EVCS in Simulink MATLAB.*

A resistive-inductive (RL) filter is then implemented to reduce harmonic distortions and enhance the power quality. AC measurements are integrated to monitor key 40 parameters such as voltage and current. The simulation then progresses through the rectification stage, where an AC-to-DC rectifier is modeled to convert alternating current to direct current. Following this, a DC-DC rectifier is designed to regulate the voltage to meet the changing requirements. Galvanic isolation is often included to ensure electrical safety and protect sensitive components. Finally, the battery for electric vehicles is incorporated into the model, allowing to analyze the charging process, assess the system's efficiency, and optimize control algorithms to achieve fast and reliable charging.

2.3 Methods

Fig. 2 shows the process flowchart of the system.

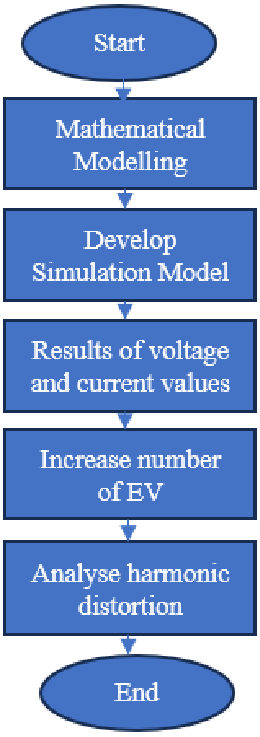


Fig. 2 *Flowchart of the system*

3. Results and Discussion

3.1 Developed simulation model of block diagram

Fig. 3 present a block diagram representation of the simulation model that was generated in MATLAB Simulink. The development of a complete EVCS simulation mode is still in its very preliminary phases here.

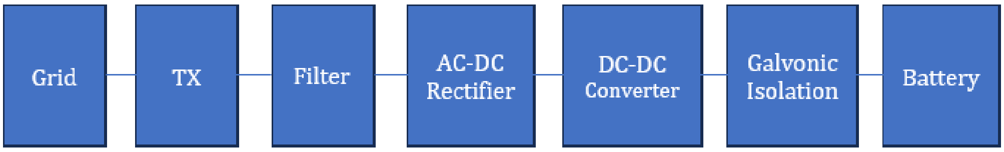


Fig. 3 *Block diagram of EVCS*

Creating a simulation model for an Electric Vehicle Charging Station (EVCS) involves constructing a block diagram that comprehensively captures the interplay of critical components in the charging system. The model includes representations of the power grid, transformer for voltage regulation, an RL filter to eliminate high-frequency noise, an AC measurement module for monitoring parameters, an AC-DC rectifier for converting power, a DC-DC converter for voltage adjustment, galvanic isolation to enhance safety, and the electric vehicle battery as the energy storage unit. This integrated simulation enables a thorough analysis of the charging station's performance, allowing for optimization of energy transfer efficiency, identification of potential issues, and the development of control strategies to enhance the overall reliability and functionality of the EVCS.

3.2 Performance of EVCS for 1 EV

The depicted figure below highlights the performance for a singular EV charged, offering a detailed insight into the system's operation concerning an individual EV.

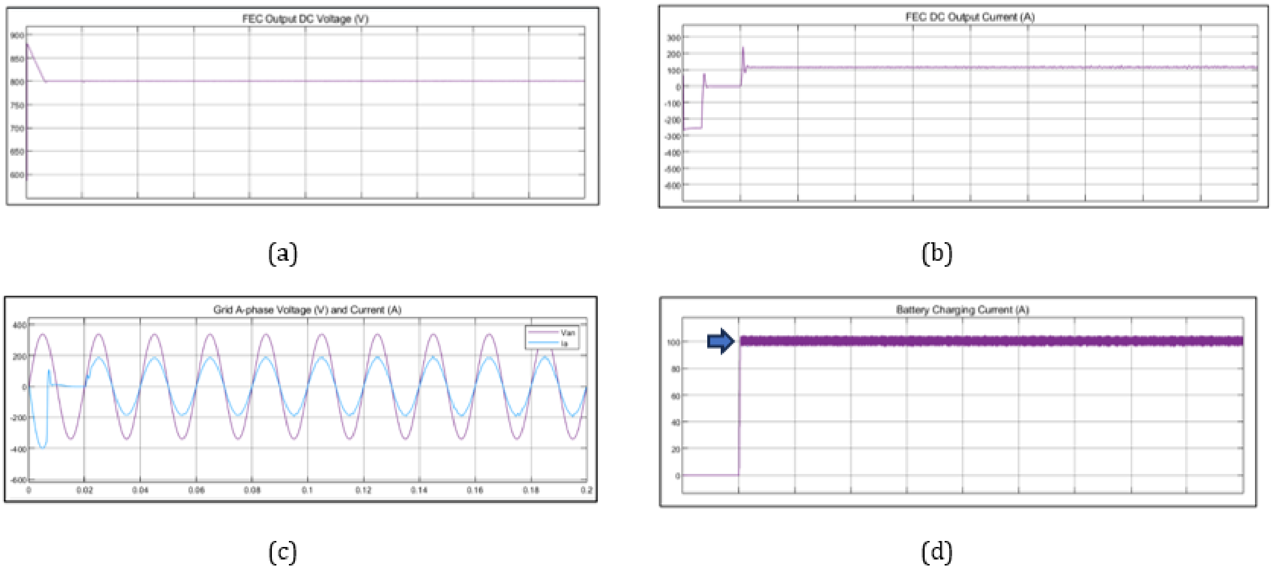


Fig. 4 *Performance of EVCS for 1 EV: (a), (b), (c) and (d) [10]*

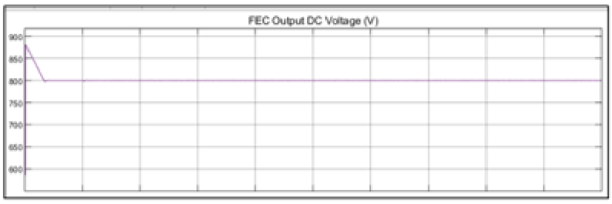
In the output voltage graph of the Front-End Converter (FEC), there is an initial increase surpassing 800V, followed by intermittent fluctuations before eventually reaching a steady state. This pattern indicates transient phases in the FEC's operation [8], highlighting moments of voltage variation before achieving a stable and consistent output as shown in Fig. 4(a). For Fig. 4(b), initially the unstable waveform may represent fluctuation in the received data. However, as the FEC algorithm operates and corrects these errors over time, the DC current stabilizes, resulting in a constant waveform [7].

Based on Fig. 4(c), representation of both the current and voltage waveforms suggests that the FEC is operating favorably. The voltage waveform demonstrates a stable and expected behavior, subsequently stabilizing after a few cycles. Similarly, the current waveform exhibits a well-defined pattern, starting from zero and reaching a peak of 400 in a single cycle. The coherence between the current and voltage waveforms indicates a harmonious interaction within the FEC, reflecting a well-controlled and effective operation with consistent output characteristics. In Fig. 4(d), charging a rechargeable battery with a constant current is a technique employed to consistently supply a steady electric current, thereby avoiding overcurrent charging situations [8]. As an illustration, the charging current for a 100AH battery must not surpass 30A. Additionally, during cycling charging, it is essential to impose a restriction on the maximum voltage delivered by the charger [Chengjoseph, “Maximum charging current - the key factor to improve battery charging efficiency [11].

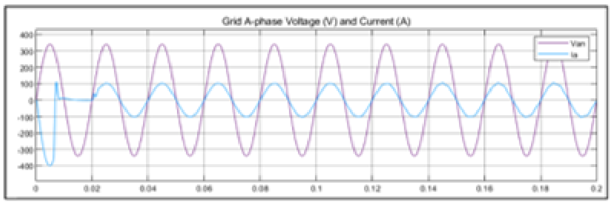
3.3 Performance of EVCS for 4EV

In Fig. 5(a) representation of the Front-End Converter (FEC) output voltage, an initial surge exceeding 800V is observed, followed by intermittent fluctuations before converging into a stable state. This observed pattern underscores transient phases in the FEC's operational dynamics, signifying instances of voltage variation prior to achieving a consistent and steady output, as depicted in Fig. 5(c).

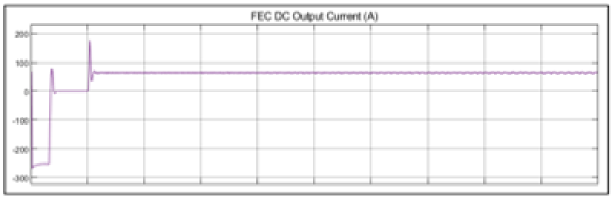
In the context of Fig. 5(b), the initial irregular waveform may denote fluctuations in the received data. However, as the FEC algorithm iteratively operates and rectifies these anomalies over time, the DC current undergoes stabilization, resulting in the manifestation of a persistent and uniform waveform.



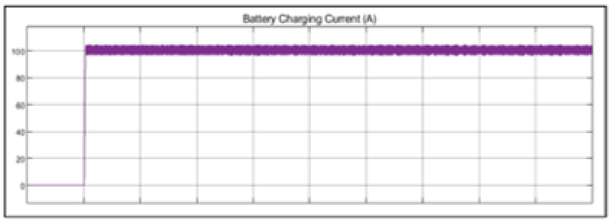
(a)



(b)



(c)



(d)

Fig. 5 *Performance of EVCS for 4 EV, (a), (b), (c) & (d)*

3.4 Data from Measurement Panel for EVCS

Table 1 provides data on Electric Vehicle Charging Stations (EVCS) for both single and four electric vehicles, offering a detailed comparison of their respective attributes. It highlights key information pertaining to the charging infrastructure for these two scenarios.

Table 1 *Data from measurement panel of EVCS*

Number of EV		Parameter	Value
1		DC Bus Voltage	800V
		Charging Voltage	645.5827V
		Charging Current	52.5839A
4	EV1	DC Bus Voltage	800 V
		Charging Voltage	469.68 V
		Charging Current	21.16 A
	EV2	DC Bus Voltage	796.25 V
		Charging Voltage	452.32 V
		Charging Current	19.83 A
	EV3	DC Bus Voltage	785.24 V
		Charging Voltage	441.25 V
		Charging Current	16.25 A
	EV4	DC Bus Voltage	749.55 V
		Charging Voltage	412.74 V
		Charging Current	14.96 A

The reduction in current and voltage values within Electric Vehicle Charging Stations (EVCS) observed in MATLAB simulations with an escalating number of electric vehicles (EVs) can be ascribed to heightened demand on the charging infrastructure. The introduction of additional EVs amplifies the aggregate load on the charging station, leading to a decrement in the accessible current and voltage levels allocated to each individual vehicle. This phenomenon underscores the impact of increased EV presence on the overall capacity of the charging infrastructure, resulting in a proportionate decrease in current and voltage values to meet the growing demand within the operational limitations of the system.

3.5 Comparison of Total Harmonic Distortion

The harmonic pollution associated with EVs dependent on the number of EVs and the charging method. If a large number of EVs are charging in the same area, then the harmonic pollution in that area will be more as shown in Table 2.

Integral to electric vehicle (EV) chargers, power electronic converters play a pivotal role in the energy conversion process. The majority of power grids distribute energy in the form of alternating current (AC), yet EV batteries predominantly store energy in the direct current (DC) format. While certain advanced fast-charging EV stations directly provide DC power, the conventional approach involves the conversion of grid AC power to suit the storage requirements of EV batteries. Throughout this conversion process, the rapid switching actions of the converter give rise to non-sinusoidal currents, introducing harmonic distortion. These harmonics, occurring as multiples of the base frequency, have the potential to disrupt the normal operation of electrical components within EV chargers, highlighting the significance of managing harmonic content for the optimal performance and longevity of the charging infrastructure.

Table 2 *Harmonic Current Magnitude (A)*

Number of EV	Fundamental	3rd	5th	I_{rms}	THD
1	27.4	3.92	1.31	27.7	14.9%
4	13.2	3.64	0.80	13.7	27.2%

4. Conclusion

In summary, the development of a Simulink model for DC Fast Charging in Electric Vehicle Charging Stations using MATLAB has been successfully completed. The model, created on the Simulink platform, offers a dynamic representation of the charging system, allowing for the examination and optimization of charging algorithms, control strategies, and system configurations. It provides valuable insights into performance metrics, such as charging time, energy efficiency, and voltage/current profiles. This simulation-based approach contributes to refining charging station designs and establishes a foundation for future research in electric vehicle infrastructure. Additionally, the analysis of harmonic and voltage stability resulting from EV integration using MATLAB Simulink has been effectively achieved. The study provides a comprehensive understanding of the dynamics introduced by EVs, emphasizing the significance of considering harmonic distortions and voltage fluctuations in power system planning. The insights gained highlight the need for mitigation strategies to ensure a seamless coexistence of EVs within the grid, advancing our comprehension of challenges posed by EV integration and paving the way for measures to maintain power system stability.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author attests to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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