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Analyzing the Impact of Electric Vehicle Charging On Grid Congestion and Load Management

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Abstract *– This paper presents a the increasing adoption of electric vehicles (EVs), it is imperative to comprehend their influence on the power grid for efficient load management and grid stability. This paper employs a comprehensive approach to examine the ramifications of EV charging on grid congestion. Utilizing real-world data from charging stations, grid operations, and EV usage patterns, we model and simulate the charging behavior of a diverse fleet of electric vehicles.*

The proposed methodology involves Our findings reveal distinct patterns of grid congestion during peak charging periods and identify potential challenges in load management the implications of different charging strategies, such as smart charging and time-of-use pricing, in mitigating grid congestion. Additionally, the role of energy storage systems in optimizing load distribution and enhancing grid resilience.

Through a combination of statistical analysis and simulation studies, we provide insights into the dynamic relationship between EV charging patterns and grid congestion. Our results inform policy recommendations and technological interventions aimed at enhancing the integration of electric vehicles into the existing power infrastructure while ensuring reliable and efficient load management. This research contributes to the growing body of knowledge on sustainable transportation and provides a foundation for stakeholders; this enables policymakers and utilities to make well-informed decisions in response to the growing adoption of electric vehicles.
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Keywords: Electric Vehicles, grid congestion, load management, impact of electric vehicle charging on grid congestion and load management etc.

I. INTRODUCTION

The widespread adoption of electric vehicles (EVs) is ushering in a transformative era in the automotive industry, promising reduced greenhouse gas emissions and a shift towards sustainable transportation. However, as the number of EVs on the roads continues to rise, it brings forth new challenges, particularly in the realm of energy infrastructure

A primary consideration revolves around the implications of electric vehicle charging on grid congestion, emphasizing the essential need for efficient load management strategies.

The conventional power grid was designed to handle predictable and centralized energy consumption patterns. The integration of large numbers of EVs introduces a dynamic element, as their charging patterns are often influenced by individual preferences and real-time factors. This has the potential to strain local grids, leading to congestion during peak charging times.

The objective of this study is to conduct a comprehensive analysis of the diverse impact of electric vehicle charging on grid congestion and to investigate innovative strategies for efficient load management. By understanding the intricate relationship between EV charging behavior and grid dynamics, we can develop solutions that optimize energy distribution, ensure grid reliability, and minimize the need for costly infrastructure upgrades.

The present worldwide transportation sector accounts for 24% of carbon dioxide (CO_2) emissions stemming from fuel combustion [1]. In response to this environmental impact, various organizations advocate for a transition away from fossil fuel vehicles, leading to a swift shift in the transportation sector towards the electrification of vehicle fleets [2]. Electric vehicles (EVs) have garnered global popularity owing to their diminished emissions, and progress in battery technology has expanded their driving range.

A. Electric Vehicles

The pressing necessity to diminish CO_2 emissions in the transportation sector has led to a substantial rise in the embrace of electric vehicles (EVs). Presently, the global market is witnessing a significant surge in the sales of both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). In Sweden, the expansion of PHEVs has outpaced that of BEVs. From 2018 to 2021, PHEVs surged from 36,000 to 146,000, whereas BEVs increased from 12,000 to 80,000 [7]. On a global scale, BEVs have exhibited higher growth compared to PHEVs. According to the International

Energy Agency (IEA) 2021 Outlook, there was a 14.54% rise in BEVs and a 1.41% increase in PHEVs in 2020 compared to 2019. In line with stated policy scenarios, it is anticipated that EVs (excluding two/three-wheelers) will constitute 7% of the on-road vehicle fleet globally by 2030 [8].

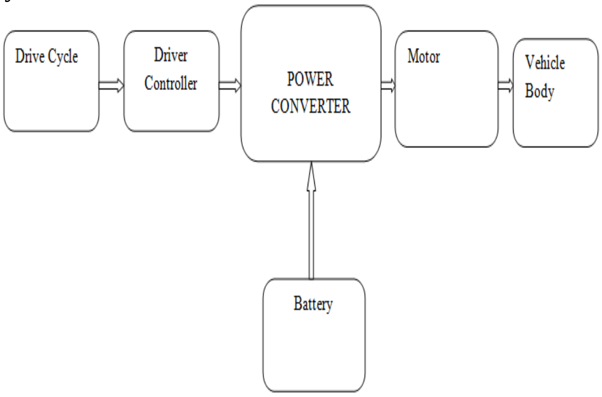

Fig 1 Electric Vehicles

Vehicle Body: Vehicle body is simply the frame of the vehicle which includes components such as wheels, chassis, transmission system, axles etc. Simulink readily has a "Vehicle body" block under simscape library where we can feed parameters such as mass of the vehicle, Drag , Pitch etc. The actual vehicle body also includes wheels which is also available in the simscape library as "Tires(Magic Formula)". Other than these components, we can also include simple gear block to simulate the transmission system.

Motor: The motor within an electric vehicle serves as the apparatus that transforms electrical energy from the battery into mechanical energy, propelling the wheels..

Battery: Like the petrol or diesel in the IC engine vehicles, the source of fuel for the electric vehicle is the battery..

Power Converter: Power converter can be regarded as the brain or processing unit of an electric vehicle. It basically consists of power electronic devices. It is the one which **enables the control** of an Electric vehicle.

II . GRID CONGESTION

Grid congestion refers to a situation in an electrical power grid where the demand for electricity exceeds the available capacity, leading to limitations in the transmission and distribution of power. This condition can result in various undesirable consequences, such as voltage fluctuations, power outages, and potential damage to the grid infrastructure.

Several factors contribute to grid congestion, including:

- **High Demand:** When the electricity demand surpasses the grid's capacity to deliver power, congestion can occur. This is often the case during peak hours when industries, businesses, and households simultaneously require significant amounts of electricity.
- **Limited Transmission Capacity:** Insufficient transmission infrastructure or bottlenecks in the grid can restrict the flow of electricity between different regions. This can lead to congestion as power struggles to move from areas with surplus generation to those with high demand.
- **Renewable Energy Integration:** The growing incorporation of renewable energy sources, including wind and solar power, may also add to grid congestion. These sources often generate power in locations with abundant natural resources but may be distant from population centers, requiring efficient transmission to meet demand.
- **Infrastructure Constraints:** Aging or inadequate grid infrastructure can limit the grid's ability to handle increased demand or integrate new technologies. Upgrading and expanding the grid infrastructure become essential to alleviate congestion.
- **Operational Challenges:** Operational issues, such as equipment failures, maintenance, or unexpected events like severe weather conditions, can strain the grid and contribute to congestion.

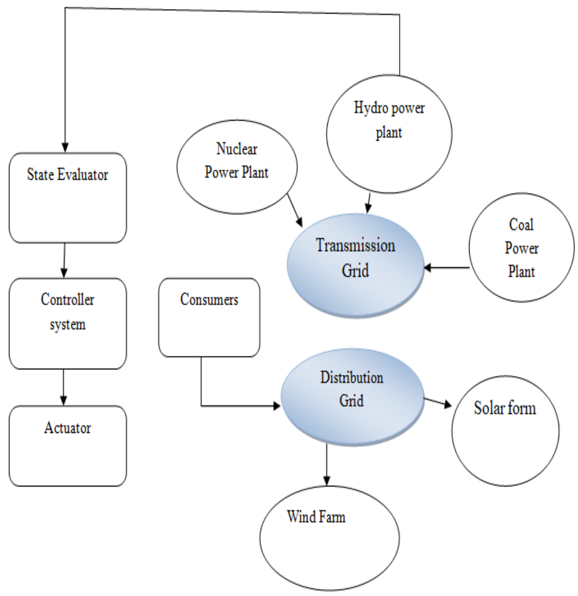

Fig 2 Grid Congestion

Grid congestion occurs when the demand for electricity surpasses the available capacity of the transmission and distribution infrastructure within an electrical power grid. This can lead to various issues, including voltage instability, increased system losses, and the potential for blackouts.

Grid congestion typically occurs during periods of high electricity demand, such as extreme weather conditions (hot or cold temperatures), increased industrial activity, or other factors that cause a surge in power consumption. It can also result from limitations in the capacity of transmission lines, transformers, and other components of the power grid.

III. Method

The methodology applied in this study is grounded in prior research findings. Drawing on insights from earlier case studies, the study analyzes data from specific sources to discern the potential impacts of smart charging. Expanding upon this groundwork, the thesis investigates how the model performs under various charging scenarios. This section delineates the data modeling approach, considerations for residential load, charging schemes, and details the implementation of the model using Matlab.

The Matlab model treats Electric Vehicles (EVs) as objects for efficient sorting and storage. Figure 3 provides a general representation of the model. The inputs include the number of EVs, electricity prices, forecasted load from the local distribution network, plug-in and plug-out times of the EVs, and battery capacity. These inputs undergo processing through a smart charging algorithm, resulting in balanced load on the local distribution network while charging to 100% State of Charge (SoC) during periods when the electricity price is at its lowest. The model also allows for adjusting the weight between load balancing and electricity price.

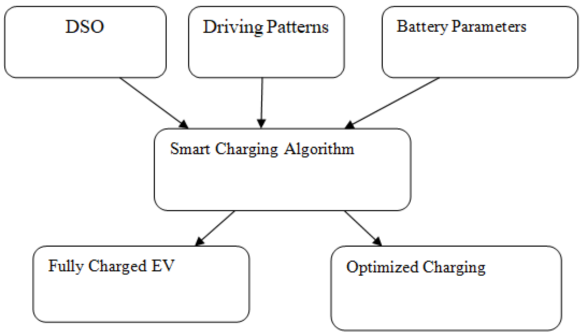

Figure 3: Visualization of the model configuration illustrating the inputs and outputs of the smart charging algorithm

The simulation model includes an apartment complex featuring one hundred residential units and fifteen Electric Vehicles (EVs), each equipped with dedicated Electric Vehicle Supply Equipment (EVSE) located in the parking area. Charging of the EVs commences upon connection to the EVSE and concludes when the EV is unplugged. The EVSEs are connected to the low-voltage network via the building, and communication is established among the EVSEs. To streamline the model, all EVs are assumed to possess a uniform battery capacity of 80 kWh.

EV Design in Simulink

The foundation of this research lies in a MATLAB/Simulink model. A corresponding electric vehicle (EV) model, incorporating an analogous battery model, has been developed within Simulink [14]. The core components of the electric vehicle (EV) drive module include the battery controller, battery, EV interface, motor, motor controller, and other relevant elements.

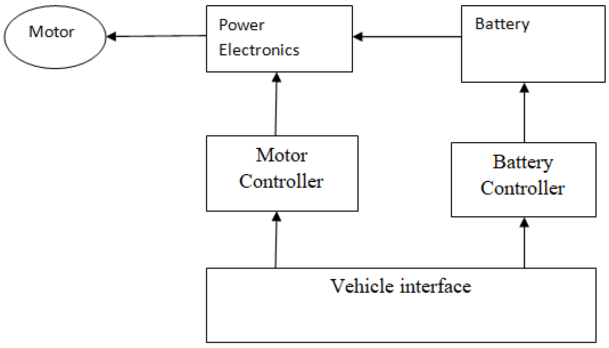

Fig 3: EV drive module

The battery was assigned a power rating of 40 kW, and its rated capacity was specified as 85 kWh. The simulation utilized a Lithium-ion battery. The Simulink simulation model was developed to represent the Electric Vehicle (EV) with its diverse components, and the values for these components were tuned to closely align with their real-world specifications.. The simulation aims to analyze the vehicle's performance by varying different unit parameters.

The Electric Vehicle (EV) model, along with its diverse components, was created and simulated using Matlab/Simulink. The subsequent section provides an overview of the foundational elements for electric vehicles, along with relevant parameters. Further exploration into the specifics of these blocks will follow

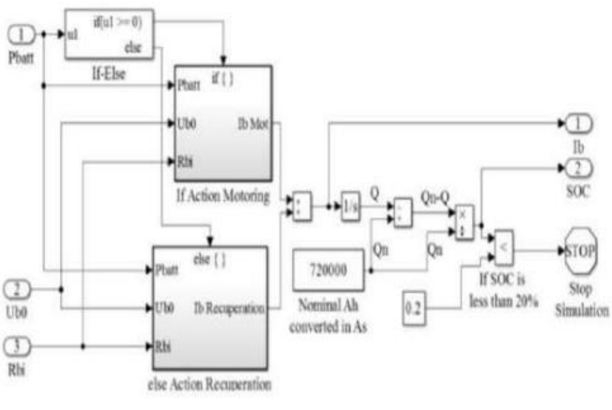

Figure 4: Battery model

IV. Result

A . Simulation

• The Simulink model comprises four primary components, namely:
• Power generation station
• Step-down transformer
• Electric Vehicle charging station
• Interconnected electrical loads encompassing both residential and industrial sectors

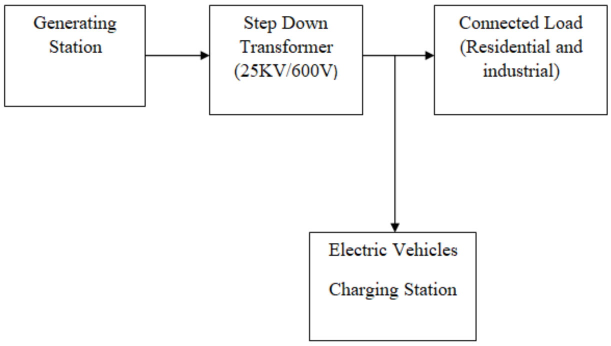

Figure 5: Block Diagram of Simulation Model

The adaptable power generation feature enables an exploration of the influence of electric vehicle (EV) charging on overall power consumption. Initially, a simulation was conducted with a total generating power of 15 MW, generated by synchronous machines. In this Simulink model, electric vehicles were charged using a 600 V AC

The power plant distributed electricity predominantly at 25 kV, subsequently lowered to 600 V using a step-down transformer. Importantly, the electric vehicle charging station was distinctly segregated from residential loads in this design, directly linked to the primary distribution grid.

Up to 100 vehicles were connected to the charging station, collectively drawing 4 MW of power from the grid. The simulation explored variations in the number of vehicles, ranging from a minimum of 2 to a maximum of 100, to analyze the charging effects.

Additionally, two types of loads were integrated into the main grid: residential and industrial. The simulation considered a total residential load of 10 MW and an industrial load of 0.16 MW. The power factor for the residential load was established at 0.95

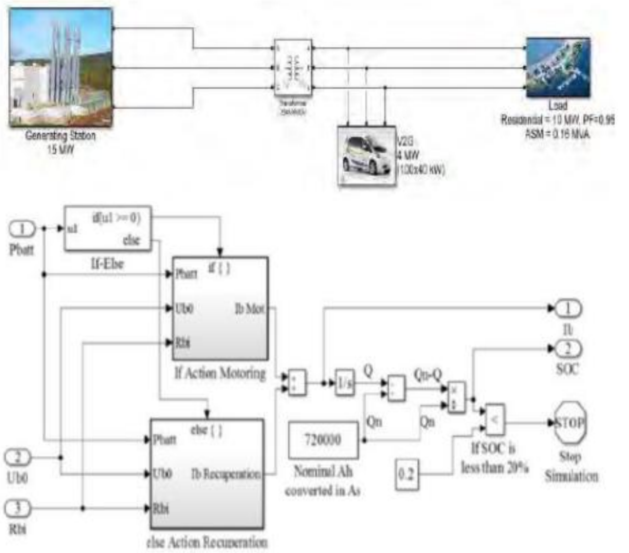

Figure 6: Overall MATLAB/Simulink model

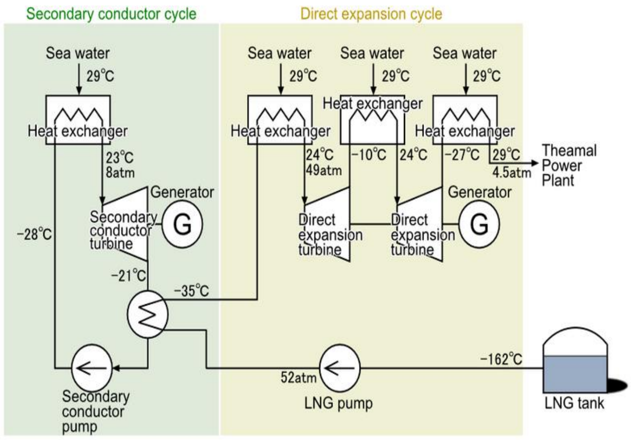

Figure 7 Generation Station Model

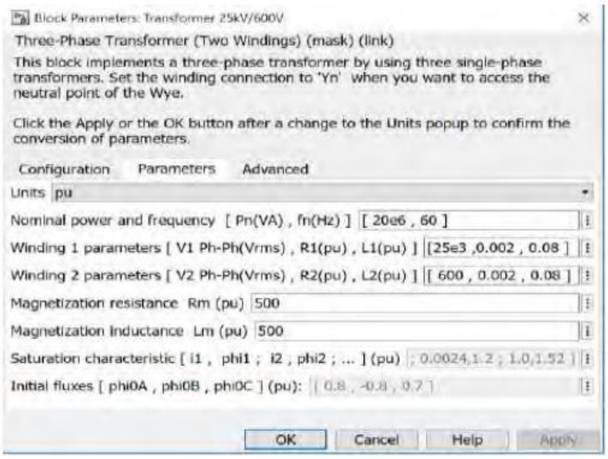

Figure 8: Transformer parameters

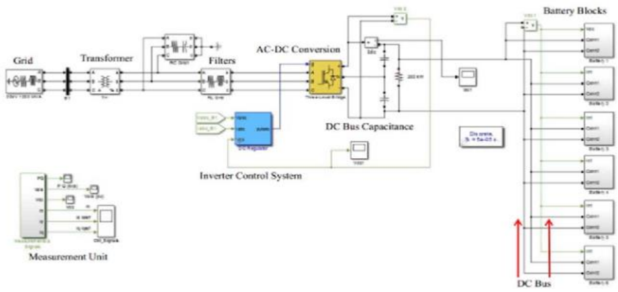

Figure 9: EV Charging Model

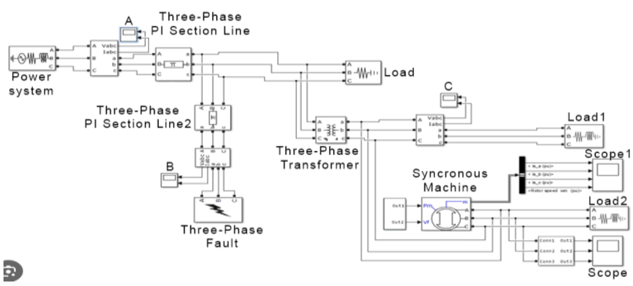

Figure 10 Model for Connected Load (Residential and Industrial)

Within this simulation model, power is fed into the distribution grid from fully charged vehicles through the utilization of Vehicle-to-Grid (V2G) technology. The system's efficiency is fixed at 90%, and the examination of charging effects involves the incorporation of five (5) charging profiles, thereby introducing variability in the number of vehicles within the system

V. CONCLUSION

This paper has focused on the influence of Electric Vehicle (EV) charging load on the utility grid. The analysis initiates at the circuit level, examining widely adopted EV topologies to establish a basis for comprehending grid-related challenges associated with diverse EV chargers. Following this, the attention turns to concerns linked to power quality and heating, arising from the harmonic current produced by EV chargers.

At the component level, this examination delves into the impact of a generalized Electric Vehicle (EV) load on two essential performance metrics of the utility grid: the voltage profile and the load curve of the distribution line. This investigation facilitates the identification of distinctive variances among different grid connections and underscores the imperative need for customized impact analysis in each scenario.

In conclusion, the study examines existing literature for proposed studies and analyses aimed at enhancing EV load modeling, managing peak loads within load curves, and improving grid performance through bidirectional power flow.

Addressing the impact of electric vehicle charging on grid congestion and load management necessitates a comprehensive and multi-dimensional strategy. Combining technological innovations, policy interventions, and community engagement can create a sustainable and resilient energy ecosystem that supports the transition to widespread electric vehicle adoption. Proactive planning and collaboration among stakeholders will be essential to address the challenges and harness the full potential of electric mobility.

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