

Impact of Unrestrained Electric Vehicle (EV) Taxing at Fast Charging Stations (FCS) on Distribution Systems with and Without Wind Production: An Assessment of Optimal Planning

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Abstract

This paper investigates the impact of unrestrained Electric Vehicle (EV) charging at Fast Charging Stations (FCS) within distribution systems, considering the integration of wind power generation. The study explores the effect of EV charging patterns and wind power variability on system operation, with a particular focus on the IEEE 123-node distribution system. The system's response to different levels of wind power penetration and the optimal planning of FCS locations are analyzed through multiple scenarios. By employing a probabilistic model for wind speed and incorporating different configurations of wind generators, the study examines how the combination of FCS and wind generation can affect the operational dynamics and economic performance of the distribution grid. The results offer insights into the interactions between renewable energy sources and EV infrastructure, highlighting potential benefits and challenges in future grid integration.

Keywords: *Electric Vehicles, Fast Charging Stations, Wind Power, Distribution Systems, IEEE 123-Node, Power Grid Optimization, Charging Infrastructure, Wind Speed Estimation, Weibull Distribution, Grid Impact*

1. Introduction

1.1 Background and Motivation

The increasing penetration of Electric Vehicles (EVs) is driving the need for an efficient and sustainable charging infrastructure. Fast Charging Stations (FCS) are essential for reducing charging times and ensuring the widespread adoption of EVs. However, unrestrained EV charging at these stations can introduce substantial load fluctuations, posing challenges for grid stability and efficiency.

Figure 1.1 displays the FCS schematic design, which demonstrates that EVs are powered by DC-DC converters and that the setup only needs one AC-DC Grid Tied converter to implement a DC bus. Through a straightforward DC-DC converter, the DC bus makes it easier to link the Renewable Energy Sources (RESs) producing units directly. The power from the distribution grid is stepped down to the voltage levels of EV batteries using a three-phase transformer. A three-phase AC/DC converter creates a DC bus by converting AC power to DC power. Using DC/DC converters, EVs are linked to the DC bus for charging.

This research focuses on understanding the interaction between EV charging, wind generation, and distribution systems, examining how these elements affect system operations under varying scenarios of wind generation and EV charging demand.

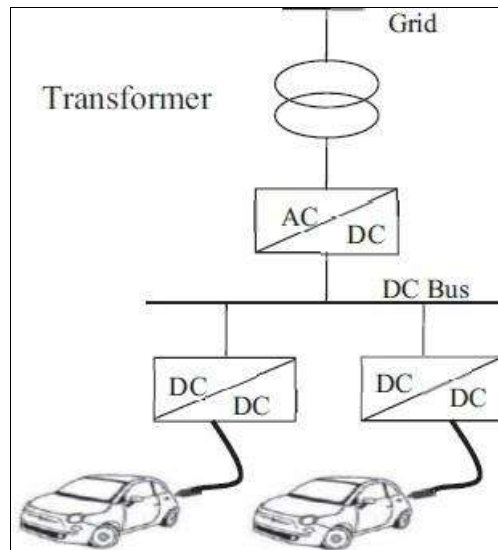


Figure 1.1: The schematic diagram of FCS

In [1], Mota L. et al. used an accurate load model to get a realistic system analysis. His model's goal was to maximize operational costs while preserving system dependability and security.

A collection of clearly specified EVs was created in [2] in order to examine their energy storage and consumption in relation to highly electrified road traffic. To assess the effects of growing EV load and the possibility of integrating residential and EV load, the same criteria have been applied to the residential load profile of the European Union.

Comparative studies for a variety of charging techniques, including smart charging, uncontrolled public charging, off-peak household charge, and uncontrolled domestic charging, have been conducted in [3]. Using a constant power load model and taking into consideration limitations on the system's ability to provide energy for EV recharging, Mullan J. et al. assessed the possible effects of EV charging on the Western Australian electrical grid in [4]. In [5], Li.G. et al. used the probabilistic power flow load model to examine how PHEV charging affects the electrical distribution system. Using level-1 charging, the multistage ZIP EV load model for the Nissan Leaf was created in [6]. The Nissan Leaf with level-1 charging was comparable to the Constant Current load model, according to the results. The utilization of Electric Vehicle Supply Equipment (EVSE) in Nissan Leaf homes is compiled by Stephen Schey et al. [7]. Two metrics—the charging demand and the charging availability—have been used to construct the data aggregation model for analyzing EV charging usage. A thorough load model has been built in [8] to examine the effects of Plug in Hybrid Electric cars (PHEV) on distribution systems. This model takes into account factors like as battery capacity, state of charge (SOC), the number of electric cars, the amount of penetration over the next several years, and the energy consumption of daily journeys. In [9], a multistage time-variant ZIP EV load model is put out for precise EV battery charging analysis. Power usage, grid voltage, and EV SOC have all been taken into consideration in the presentation of an accurate

voltage dependent FCS EV load model. By taking into account the limitations of the power converter that links the battery to the electric grid, Purvins et al. have presented an accurate EV charging method [10]. The various voltage dependent EV load models have been introduced in [11] to analyze the change of power losses and voltage deviation in distribution systems.

Simultaneously, the integration of renewable energy sources, particularly wind power, offers a promising solution to mitigate the environmental impact of transportation electrification[12]. However, the intermittent nature of wind generation introduces additional complexity in grid management, especially when combined with the dynamic demand of EV fast charging.

1.2 Objective

The primary objective of this study is to assess the impact of unrestrained EV charging at FCS on a distribution system with and without wind generation. The study considers different configurations of wind power integration, and the analysis is based on the IEEE 123-node distribution system. This paper explores how optimal planning of EV charging stations can support grid stability, reduce costs, and enhance the operational performance of the power distribution network.

2. Methodology

2.1 System Overview

The study uses the IEEE 123-node distribution system, which includes 85 load spots and 118 distribution lines[13]. The peak load of the system is 3855.257 kVA with a capacity factor of 0.9391. The system is initially analyzed without the inclusion of wind generation and then with varying levels of wind power integrated into the grid. The analysis focuses on the optimal placement of FCS, taking into account factors such as system load, transformer capacity, and wind speed variability.

2.2 Wind Generation Modeling

The kinetic energy of the wind is converted into mechanical energy that changes wind force into a torque acting on the rotor blades. The power generated by the wind will depend on the volume of the air, speed of air and mass of the air.

The power that can be extracted from wind is proportional to the cube of wind speed [14] given by equation 2.1.

$$P_{wind} \propto v^3 \text{-----}(2.1)$$

Wind generation is modeled using data from the Phoenix area in Arizona, U.S., for the year 2014 [15]. Hourly wind speed data for 365 days was collected and analyzed using the Weibull distribution, a commonly used model for wind speed frequency. The parameters of the Weibull distribution — shape and scale — were estimated for each hour, providing a probabilistic representation of wind speeds at each location.

Four scenarios of wind generation integration are considered in this study, with wind generators placed at different buses (nodes) in the distribution system:

1. Scenario 1: One wind generator installed at bus 42.

2. Scenario 2: Two wind generators installed at buses 42 and 57.
3. Scenario 3: Three wind generators installed at buses 42, 57, and 60.
4. Scenario 4: Four wind generators installed at buses 42, 57, 60, and 97.

Each scenario is evaluated with respect to its impact on wind power output, system load, and overall grid performance.

2.3 Wind Speed Estimation

To model the wind power output, wind speed data was extracted from Phoenix for 2014 [16]. The wind speed data was used to develop a Probability Distribution Function (PDF) for each hour of the day using the Weibull distribution. The shape and scale parameters of the Weibull distribution were estimated using the maximum likelihood method.

The total power loss (L_{AP}) for hour h , during the season ω due to FCS charging demand, is calculated as follows :

$$L_{TP}(h, \omega) = L_{GP}(h, \omega) + L_{AP}(h, \omega) \text{-----}(2.2)$$

Where L_{TP} is the total power loss including FCS load; and L_{GP} is the gross power loss with conventional load (without FCS load)

The distribution function allows for a detailed analysis of wind speed variations across different hours, which directly affects the variability of wind power output. The estimated wind speed for each hour of the day was used to calculate the expected wind power output for each scenario of wind generation integration.

2.4 Power Output Calculation

The wind power output is calculated using the wind speed and the specifications of the wind turbines used in the system. The characteristics of the wind turbine, including rated power, cut-in speed, and rated speed, are provided in Table 2.1.

Features	Values
Rated Power (<i>kW</i>)	250
Cut-in speed (<i>m/s</i>)	3
Rated speed (<i>m/s</i>)	7
Cut-out speed (<i>m/s</i>)	11

Table 2.1 : Characteristics of Wind Turbine

The expected power output for each scenario is calculated using the following equations:

$$P_{\text{wind}} = f(v) \text{-----}(2.3)$$

where P_{wind} is the wind power output and v is the wind speed. The function $f(v)$ represents the power curve of the wind turbine, which is dependent on the wind speed and the turbine's operational characteristics.

The expected power output for the 24-hour period is then calculated for each scenario, considering the variation in wind speed and turbine efficiency.

3. Result and Discussion

3.1 Optimal Planning of FCS and Wind Integration

The results highlight the importance of strategically locating FCS and integrating wind generation to optimize system performance. By carefully balancing the deployment of wind turbines and FCS, it is possible to reduce the impact of fluctuating wind power on grid stability while ensuring sufficient capacity to meet the increasing demand for EV charging.

The optimal placement of FCS should take into account factors such as traffic patterns, population density, and proximity to wind generation sites. Additionally, integrating advanced forecasting and energy management systems can help smooth out demand fluctuations and improve the efficiency of both wind generation and EV charging operations.

3.2 Wind Speed Distribution

The Weibull distribution provides a probabilistic model for wind speed across different hours.

Hour	Scale parameter	Shape parameter
1	5.4576	2.4013
2	5.4977	2.3621
3	5.5474	2.3057
4	5.5113	2.2472
5	5.4099	2.1983
6	5.2696	2.1261
7	5.1486	2.1051
8	5.057	2.1234
9	5.0155	2.1424
10	5.1097	2.1997
11	5.3078	2.3001
12	5.542	2.4455
13	5.7244	2.5492
14	5.8642	2.6163
15	5.9669	2.6542
16	5.9018	2.6359
17	5.732	2.5657
18	5.5859	2.4987
19	5.4783	2.4691
20	5.404	2.464
21	5.3615	2.471
22	5.3834	2.4635
23	5.4404	2.4497
24	5.48	2.4318

Table 3.1: Shape and Scale Parameters of Weibull Distribution Function

The estimated shape and scale parameters for each hour, presented in Table 3.1, show the variability of wind speed throughout the day. The scale parameter varies from 5.0155 to 5.9669, and the shape parameter ranges from 2.1051 to 2.6542. The maximum values of these parameters were observed during the 15th hour, corresponding to the highest mean wind speed of the day. Conversely, the minimum values were observed during the 9th hour, which also coincided with the lowest mean wind speed.

3.3 Expected Wind Power Output

The expected wind power output for each scenario is shown in Figure 3.1. As the number of wind generators increases, the variation in expected wind power output also increases. This is due to the combined effect of multiple turbines and the varying wind speeds at different times of the day. The output is observed to be highest during the 15th hour, with a significant drop in power during the 9th hour, reflecting the influence of wind speed fluctuations.

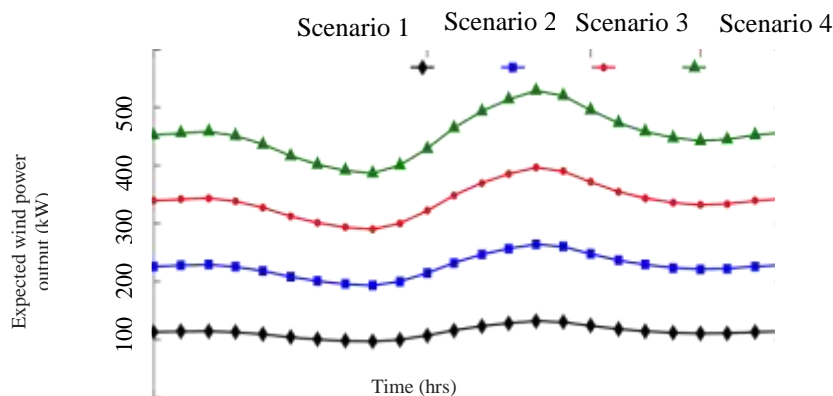


Figure 3.1: Daily Expected wind power output

The expected wind power output also shows a clear correlation with the number of wind generators deployed in the system. As more generators are added, the overall power output becomes more stable, but the system also experiences greater fluctuations in output as a result of wind variability.

3.4 Impact of EV Fast Charging on System Operation

The integration of EV fast charging at FCS affects the distribution system's operation by introducing fluctuating demand patterns. The unrestrained charging behavior leads to peak demand at FCS locations, which can cause voltage drops, overloading, and reduced system efficiency.

When wind generation is included, the variability in wind power output can either help mitigate or exacerbate these effects. For instance, during times of high wind generation, the system may be able to absorb the additional load from EV charging without overloading the grid. However, during periods of low wind power, the increased load from EV charging can exacerbate voltage issues and reduce the system's reliability.

3.5 Challenges and Future Work

Despite the promising results, several challenges remain in the integration of EV charging infrastructure and renewable energy sources. The primary challenge is the unpredictability of both EV charging demand and wind power output, which requires sophisticated forecasting techniques to manage.

Future research should explore the role of energy storage systems in mitigating the effects of wind variability and unrestrained EV charging. Additionally, the impact of varying wind turbine characteristics and the integration of other renewable energy sources (such as solar power) should be investigated to create a more resilient and sustainable energy grid.

4. Conclusion

This study demonstrates the critical role that both EV fast charging stations and wind power generation will play in the future of smart grid systems. By considering the optimal placement of FCS and the integration of wind generation, it is possible to reduce costs, improve grid stability, and accommodate the growing demand for electric transportation. Further research into grid optimization techniques, forecasting models, and energy storage solutions will be essential to realizing the full potential of these systems.

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