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ASSESSMENT OF ELECTRIC VEHICLE CHARGING STATION EFFECTS ON DISTRIBUTION SYSTEM POWER QUALITY

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Abstract
The rapid adoption of electric vehicles (EVs) has significantly increased the demand for charging infrastructure worldwide. Although Electric Vehicle Charging Stations (EVCS) contribute to environmental sustainability and reduced greenhouse gas emissions, their large-scale integration into power distribution networks introduces several power quality challenges. This paper presents a comprehensive analysis of the impact of EV charging stations on power quality parameters such as voltage fluctuations, harmonic distortion, power factor deterioration, voltage sag, voltage swell, and system imbalance. Different types of EV chargers, including slow charging, fast charging, and ultra-fast charging systems, are analyzed to assess their effects on electrical distribution systems. Simulation studies are carried out under various loading conditions to evaluate Total Harmonic Distortion (THD), voltage regulation, and reactive power requirements. The study further investigates mitigation techniques such as active power filters, smart charging strategies, renewable energy integration, and energy storage systems to improve overall power quality performance. The results demonstrate that proper control and management strategies can significantly reduce the adverse effects of EV charging stations on modern power systems.

Keywords: Electric Vehicles, EV Charging Station, Power Quality, Harmonic Distortion, Voltage Sag, Smart Charging, Active Power Filter.

I. INTRODUCTION

The increasing demand for sustainable transportation has accelerated the deployment of electric vehicles across the globe. Governments and industries are promoting EV adoption to reduce carbon emissions and dependency on fossil fuels. Consequently, a large number of EV charging stations are being integrated into existing electrical distribution networks. However, the rapid expansion of EV charging infrastructure presents several operational challenges to utility systems, particularly in terms of power quality.

Power quality refers to maintaining voltage, current, and frequency within acceptable limits to ensure reliable operation of electrical equipment. EV charging stations, especially fast charging stations employing power electronic converters, introduce harmonics, reactive power demand, voltage fluctuations, and load imbalances into the power grid. These disturbances may adversely affect the performance of sensitive loads and reduce the efficiency and reliability of the electrical network.

This paper analyzes the major power quality issues caused by EV charging stations and investigates suitable mitigation approaches for enhancing power system performance.

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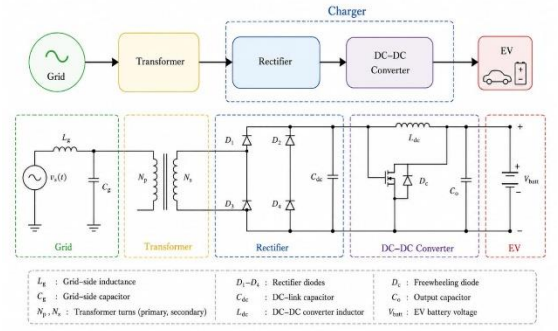


Fig.1: Block diagram and circuit diagram of an Electric Vehicle Charging Station.

II. LITERATURE REVIEW

Several researchers have investigated the impact of EV charging on distribution networks. Earlier studies primarily focused on load demand and transformer overloading, while recent research has emphasized power quality assessment and mitigation.

- Conventional EV charging systems introduce harmonic currents due to rectifier and inverter switching operations.
- Fast charging stations significantly increase peak demand and voltage deviations.
- Smart charging techniques have demonstrated considerable improvements in load balancing and grid stability.
- Renewable energy-assisted charging stations have shown potential for reducing grid stress and improving power quality.

Despite significant advancements, challenges remain in ensuring stable operation under high EV penetration levels.

III. POWER QUALITY ISSUES IN EV CHARGING STATIONS

A. Harmonic Distortion

Power electronic converters used in EV chargers generate harmonic currents that distort the supply waveform. Harmonic distortion causes:

- Increased transformer losses
- Excessive heating of electrical equipment
- Reduced power factor
- Malfunction of protection devices

The Total Harmonic Distortion (THD) is calculated as:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \times 100\%$$

According to IEEE Standard 519, THD should remain below specified limits to maintain acceptable power quality.

B. Voltage Sag and Voltage Swell

Fast EV chargers draw large currents during charging operations, resulting in temporary voltage reductions known as voltage sag. Sudden disconnection of chargers may produce voltage swell conditions.

Effects include:

- Equipment malfunction
- Reduced motor efficiency
- Lighting flicker
- System instability

C. Power Factor Deterioration

Most EV charging stations operate with nonlinear loads, causing increased reactive power demand and reduced power factor.

Low power factor results in:

- Higher transmission losses
- Increased utility penalties
- Reduced system efficiency
- Additional transformer loading

D. Voltage Flicker

Rapid variations in charging power levels produce voltage fluctuations that lead to visible light flickering and reduced consumer comfort.

E. Load Imbalance

Single-phase residential EV charging systems often create unequal loading among phases, leading to:

- Neutral current increase
- Transformer overheating
- Voltage imbalance
- Reduced equipment lifespan

IV. EV CHARGING STATION CONFIGURATION

The analyzed EV charging station consists of:

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- Three-phase utility grid
- AC/DC rectifier
- DC-link capacitor
- DC/DC converter
- Battery charging system
- Measurement and control unit
- Power quality monitoring system

The charging station operates under different charging levels:

Charging Type	Power Rating	Charging Duration
Level-1	1–3 kW	8–12 hours
Level-2	7–22 kW	2–8 hours
DC Fast Charging	50–350 kW	15–60 minutes

V. SIMULATION MODEL AND METHODOLOGY

The proposed analysis is performed using MATLAB/Simulink under different operating scenarios.

Simulation Parameters:

Parameter	Value
Grid Voltage	415 V
Grid Frequency	50 Hz
Fast Charger Rating	100 kW
DC Bus Voltage	800 V
Battery Capacity	60 kWh
Switching Frequency	10 kHz

Test Cases:

1. Base load operation
2. Single EV charging
3. Multiple EV charging
4. Fast charging station operation
5. Peak loading conditions

Power quality indices such as THD, voltage regulation, power factor, and harmonic spectrum are analyzed.

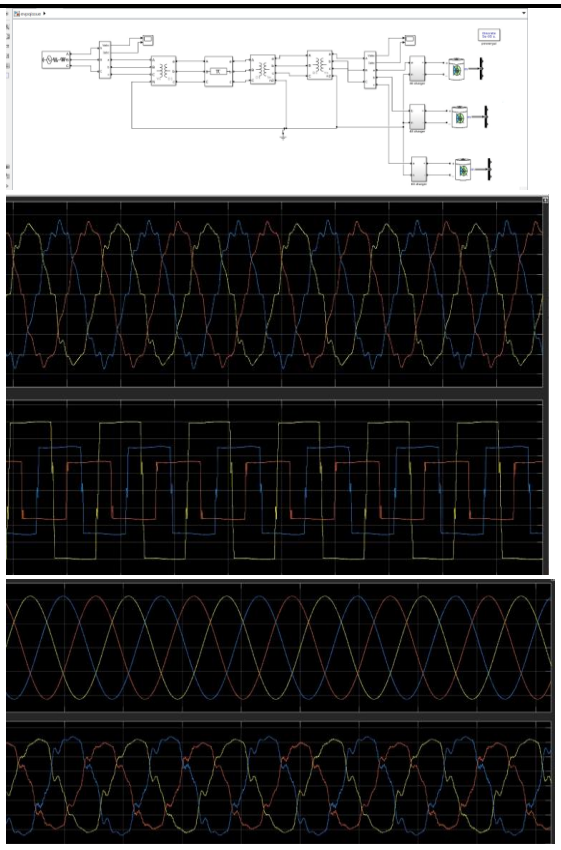


Fig. Converter output waveform.

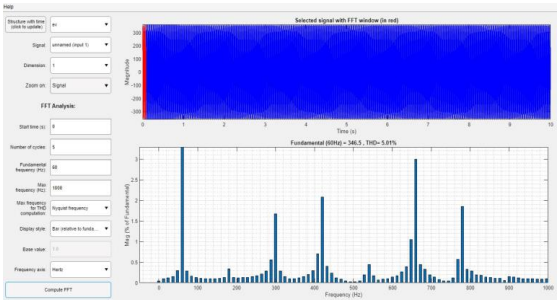


Fig. 7. Harmonic spectrum after mitigation.

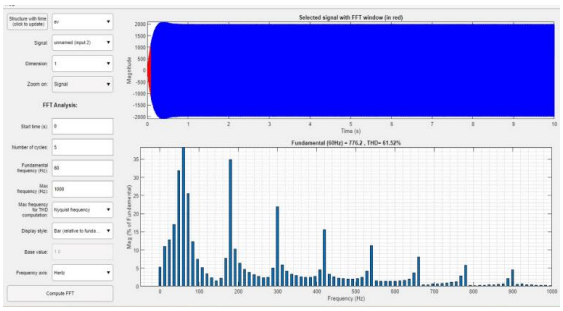


Fig. 6. Harmonic spectrum.

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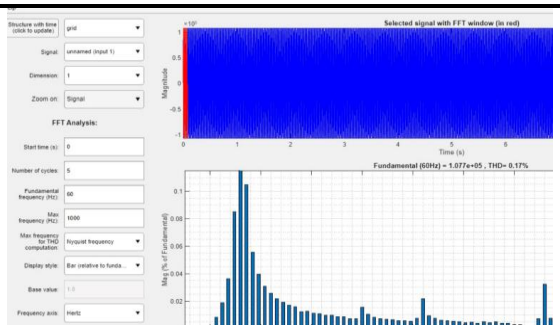


Fig. 5. FFT analysis after compensation.

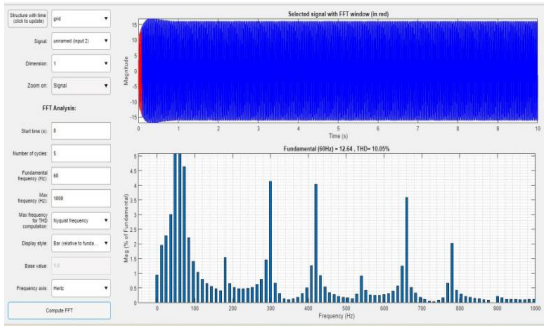


Fig. 4. FFT analysis before compensation.

VI. RESULTS AND DISCUSSION

Simulation results indicate that increasing EV penetration substantially impacts distribution system performance.

Case 1: Conventional Fast Charging Station

Parameter	Value
Current THD	18.4%
Voltage THD	7.2%
Power Factor	0.87
Voltage Sag	8%

The results exceed the permissible limits specified by IEEE standards.

Case 2: EV Charging with Mitigation Techniques

Parameter	Without Compensation	With Compensation
Current THD	18.4%	3.8%
Voltage THD	7.2%	1.9%
Power Factor	0.87	0.99
Voltage Sag	8%	2%

The implementation of compensation techniques significantly improves power quality performance.

VII. POWER QUALITY IMPROVEMENT TECHNIQUES

Several methods can mitigate EV charging station impacts:

A. Active Power Filters (APF)

- Eliminate current harmonics
- Improve power factor
- Reduce THD

B. Smart Charging Control

- Schedule charging during off-peak periods
- Reduce peak demand
- Balance network loading

C. Vehicle-to-Grid (V2G) Technology

- Supports grid regulation
- Provides reactive power compensation
- Enhances voltage stability

D. Renewable Energy Integration

- Solar PV-assisted charging stations reduce grid dependency
- Minimize power fluctuations
- Improve system sustainability

E. Battery Energy Storage Systems (BESS)

- Compensate transient power demand
- Improve voltage regulation
- Reduce network stress

VIII. CONCLUSION

This paper presented a comprehensive analysis of the impact of electric vehicle charging stations on power quality issues in modern distribution networks. The study revealed that large-scale EV penetration introduces several power quality problems, including harmonic distortion, voltage fluctuations, power factor deterioration, and load imbalance. Simulation results demonstrated that uncontrolled EV charging can significantly affect grid stability and operational efficiency. However, the

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application of active power filters, smart charging algorithms, renewable energy sources, and energy storage systems effectively mitigates these adverse effects. Future research should focus on intelligent charging management, AI-based control strategies, and integrated renewable energy systems for sustainable EV infrastructure development.

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