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Impact of EV Charging and Renewable Energy Integration on IEEE 14-Bus System Using ETAP

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Abstract: *The current research work focuses on investigating the effects of electric vehicle charging demand and renewable energy integration on the IEEE 14 bus power system using ETAP software. Load flow analysis using Newton Raphson method is performed to assess voltage profile, line losses, and system stability under different operating conditions. The results show that un-coordinated electric vehicle charging demand affects voltage profile and line losses, whereas electric vehicle charging demand along with renewable energy integration improves voltage profile significantly, and a significant improvement in power system performance is observed.*

Keywords: Electric Vehicles (EVs), Renewable Energy Sources (RES), IEEE 14-Bus System, ETAP, Load Flow Analysis, Voltage Stability, Smart Grid

I. INTRODUCTION

The gobal push toward sustainable energy solutions has spurred the increased adoption of Electric Vehicles (EVs) and Renewable Energy Sources (RES) in the power grid, presenting a transformative paradigm shift in the dynamics of electricity distribution systems. This study addresses the in-depth exploration of the individual and combined impacts of EVs and RES on the IEEE 14-Bus System, a critical benchmark in power system research. The integration of these technologies prompts a comprehensive investigation into their effects on line losses within the electrical grid.

As the world transitions toward sustainable energy, there is a challenge associated with the integration of EVs and RES, owing to their dynamic nature. EVs, due to their charging patterns, and RES, due to their intermittent nature, pose challenges to power systems. The overall problem is to determine the implications of integrating EVs and RES on line losses within the IEEE 14-Bus System. The dynamic nature of EVs and RES, owing to their variability and intermittency, respectively, could affect power flow patterns, resulting in increased line losses. This problem is significant to develop strategies for power systems, considering the widespread use of EVs and RES.

II. LITERATURE REVIEW

There are several research works carried out on the impact of electric vehicle (EV) charging and renewable energy source (RES) integration on power systems.

O. Gül in his research paper published in 2024 analyzed the impact of EV charging and renewable energy sources on the IEEE 14-bus system. The study showed that increased EV penetration leads to higher line losses and voltage deviations, especially under uncoordinated charging conditions.

A. Mousaei in his research work published in 2025 proposed a deep reinforcement learning-based approach for managing EV charging to improve voltage stability. The results demonstrated that intelligent control techniques significantly enhance system performance and reduce voltage violations.

R. Tonkoski in his research paper published in 2012 analyzed the impact of high photovoltaic (PV) penetration on distribution systems. The study found that improper integration can lead to voltage rise and instability issues.

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Various researchers have also utilized simulation tools such as ETAP to model and analyze power systems under different operating conditions. These tools provide accurate load flow analysis, voltage stability assessment, and loss calculations, making them essential for evaluating the impact of EV and renewable integration.

III. IEEE 14-BUS SYSTEM DESCRIPTION

The IEEE 14-bus system is a standard benchmark system used in power system analysis. It represents a portion of a real electrical power network and is widely used for simulation and research purposes.

The system consists of the following components:

14 buses – representing nodes where power is generated, consumed, or transmitted

5 generators – supplying electrical power to the system

11 loads – These consume power in real and reactive values

20 transmission lines – interconnecting the buses for power transfer.

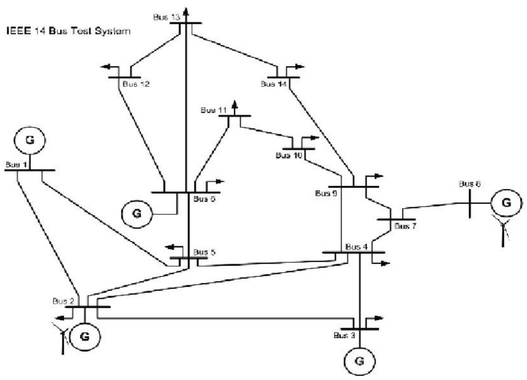

Fig 1: IEEE 14 Bus Test system

GENERATOR DATA

Bus Number	Power Rating (MVA)	Voltage Rating (KV)	Active Power (Pu)	Vo (Pu)	Q max (Pu)	Q min (Pu)	V max (Pu)	V min (Pu)
2	100	69	0.4	1.045	0.5	-0.4	1.0451	0.8
6	100	13.8	0	1.07	0.24	-0.06	1.0701	0.6
3	100	69	0	1.01	0.4	0	1.0101	0.6
8	100	18	0	1.09	0.2517	-0.06	1.0901	0.6

Fig 2: IEEE 14 Bus Generator Data

LOAD DATA

Bus Number	Power Rating (MVA)	Voltage Rating (kv)	Active power (pu)	Reactive power (pu)	V max (pu)	V min (pu)
11	100	13.8	0.035	0.018	1.2	0.6
13	100	13.8	0.135	0.058	1.2	0.6
3	100	69	0.942	0.19	1.5	0.8
5	100	69	0.076	0.016	1.2	0.6
2	100	69	0.217	0.127	1.2	0.8
6	100	13.8	0.112	0.075	1.5	0.6
4	100	69	0.478	0.04	1.2	0.6
14	100	13.8	0.149	0.05	1.2	0.5
12	100	13.8	0.061	0.016	1.2	0.6
10	100	13.8	0.09	0.058	1.2	0.6
9	100	13.8	0.295	0.166	1.2	0.6

Fig 3: IEEE 14 Bus Load Data

Line Detail

From Bus	To Bus	Power Rating (MVA)	Voltage Rating (kV)	Frequency Rating (Hz)	R (Pu)	X (Pu)	B(Pu)
2	5	100	69	60	0.05695	0.17388	0.03400
6	12	100	13.8	60	0.12291	0.25581	0.00000
12	13	100	13.8	60	0.22092	0.19988	0.00000
6	13	100	13.8	60	0.06615	0.13027	0.00000
6	11	100	13.8	60	0.09498	0.19890	0.00000
11	10	100	13.8	60	0.08205	0.19207	0.00000
9	10	100	13.8	60	0.03181	0.08450	0.00000
9	14	100	13.8	60	0.12711	0.27038	0.00000
14	13	100	13.8	60	0.17093	0.34802	0.00000
7	9	100	13.8	60	0.0000	0.11001	0.00000
1	2	100	69	60	0.01938	0.05917	0.05280
3	2	100	69	60	0.04699	0.19757	0.04380
3	4	100	69	60	0.06701	0.17103	0.03460
1	5	100	69	60	0.05403	0.22304	0.04920
5	4	100	69	60	0.01335	0.04211	0.01280
2	4	100	69	60	0.05811	0.17632	0.03740
5	6	100	69	60	0.0000	0.25202	0.00000
4	9	100	69	60	0.0000	0.55618	0.00000
4	7	100	69	60	0.0000	0.20912	0.00000
8	7	100	18	60	0.0000	0.17615	0.00000

Fig 4: IEEE 14 Bus Transmission Line Data

IV. METHODOLOGY

4.1 Simulation Tool: ETAP

ETAP (Electrical Transient Analyzer Program) is used for the modelling and simulation of the IEEE 14-bus system. It is a powerful and widely used software tool for analyzing electrical power systems with high accuracy and efficiency.

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In this study, ETAP is utilized to perform load flow analysis, evaluate voltage profiles, and determine system losses under steady-state operating conditions. The software provides an intuitive graphical interface for developing single-line diagrams and conducting detailed simulations.

The following features of ETAP are employed in this analysis:

1. Newton-Raphson Load Flow Analysis

Used for solving nonlinear power flow equations. Provides fast convergence and high accuracy

2. Single -Line Diagram Modelling

Graphical representation of the IEEE 14-bus system. Simplifies system visualization and component connectivity

3. Scenario-Based Simulation

Allows analysis under different operating conditions. Helps in studying system behavior for varying loads and generation

4. Voltage and Loss Monitoring

Enables observation of voltage magnitude at each bus. Calculates real and reactive power losses in transmission lines.

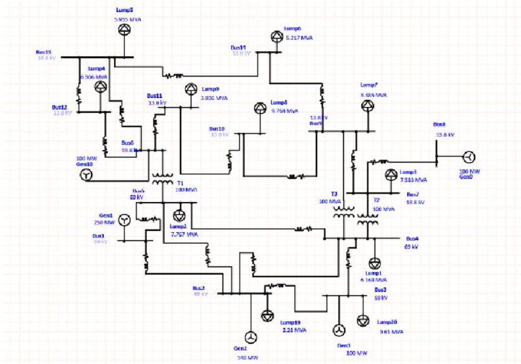

Fig 5: IEEE 14 Bus system using ETAP

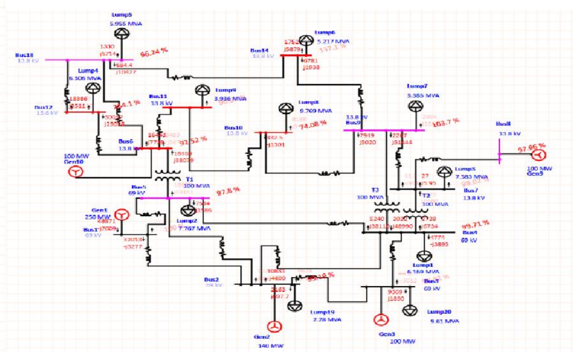

Fig 6: Load Flow Analysis of IEEE 14 Bus System

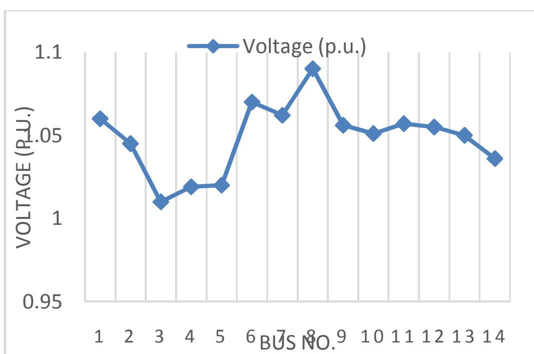

Fig 7: Voltage Pofile of IEEE14 Bus System

4.2 Integration of Solar PV at Bus 6 and Bus 12

Integration of renewable energy sources into conventional power systems is essential for sustainable and eco-friendly electricity generation. Among various renewable sources, solar photovoltaic (PV) systems are widely adopted due to their availability and low environmental impact.

In this study, solar PV units are integrated into the IEEE 14-bus system at Bus 6 and Bus 12 to analyze their impact on system performance.

4.2.1 Modified System.

In the modified configuration, solar PV units are integrated at Bus 6 and Bus 12, resulting in changes to the system structure and bus classifications.

Bus 6, which is originally a generator (PV) bus, is supplemented with solar PV generation. This enhances the active power injection at the bus while maintaining its voltage-controlled characteristics.

The bus, which was initially a load bus (PQ), is converted to a PV bus after incorporating a solar PV source. Therefore, Bus 12 changes from a purely load-consuming bus to a generating bus with a specified active power output and a controlled voltage magnitude. This introduces a new source in the system, which enables the analysis of its effects on voltage profile, power flow distribution, and overall system performance.

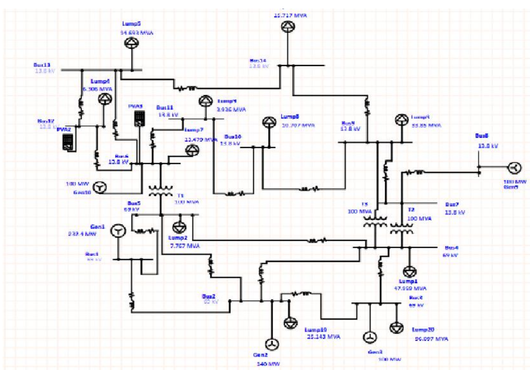

Fig 8: IEEE 14 Bus System using Solar PV Panel

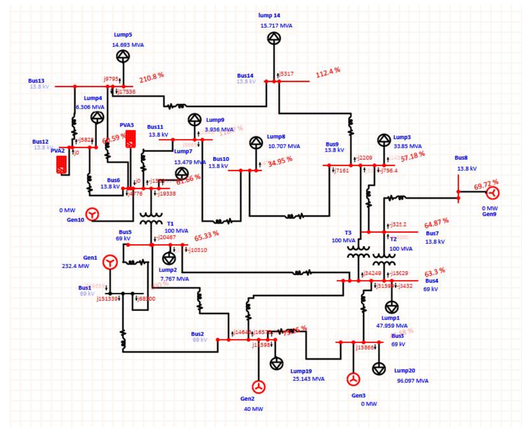

Fig 9: Load Flow on Solar PV Panel

4.3 Integration of EV Charging Stations at Bus 9 and Bus 14

The integration of Electric Vehicle (EV) charging infrastructure into conventional power systems is becoming increasingly important due to the rapid growth of electric mobility. EV charging stations introduce significant load demand and reactive power consumption, which may affect system stability and voltage performance. In this study, EV charging stations are modeled using the built-in EV charger component available in the ETAP simulation environment to analyze their impact on system performance. The ETAP EV charger model represents practical charging behavior, including AC–DC conversion, power electronic interface characteristics, reactive power consumption, and efficiency losses.

4.3.1 Modified System

In the modified configuration, EV charging stations are integrated at Bus 9 and Bus 14 of the IEEE 14-bus system, resulting in increased loading conditions and changes in system power demand. Bus 14, which is located at the weak end of the network, is connected to a fast EV charging station rated at 1.5 MW, while Bus 9 is connected to a medium-capacity charging station rated at 1.0 MW. Each EV charger is interfaced through a step-down transformer rated at 2 MVA (13.8/0.415 kV) at Bus 14 and 1.5 MVA (13.8/0.415 kV) at Bus 9 to match the low-voltage charging requirements.

The integration of EV charging stations introduces additional active and reactive power demand into the system. Bus 14 experiences significant voltage sensitivity due to its weak network location, while Bus 9 exhibits moderate loading effects. This modification introduces new load components into the system, enabling the analysis of their effects on voltage profile, power flow distribution, system losses, and overall network performance.

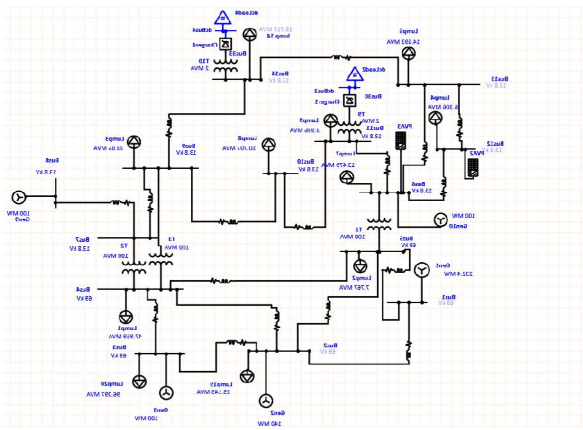

Fig 10: IEEE 14 Bus System using EV chargers

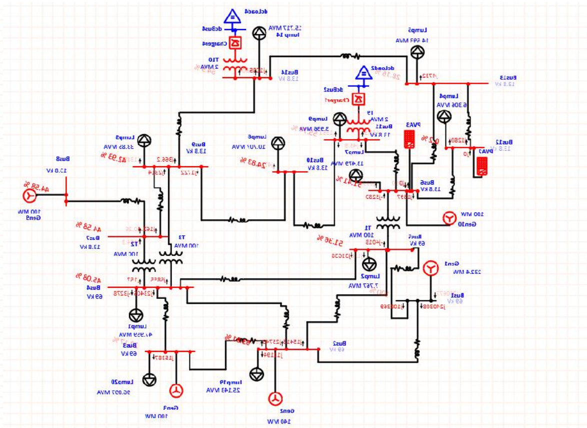

Fig 11: Load Flow on EV chargers

V. RESULT AND ANALYSIS

The integration of solar photovoltaic (PV) generation at Bus 6 and Bus 12 in the modified IEEE 14-bus system has a significant impact on system performance. The results obtained from load flow analysis are discussed as follows:

Parameter	Without EV	With EV	Difference / Observation
Total Demand (MW)	~48.87 MW	~340.68 MW	Massive increase in total demand owing to EVs
Total Reactive Power (Mvar)	~ -2.009 Mvar	~280.54 Mvar	More reactive power demand
Total Apparent Power (MVA)	~48.91 MVA	~441.32 MVA	System loading increased drastically
System Losses	~107 kW / 155 kvar	~106396 kW / 349847 kvar	Massive increase in losses with EV
Number of Iterations	1	5	system more complex/stressed
Voltage Condition	Mix of under & over voltage	Mostly under-voltage across buses	Voltage profile worsened
Transformer Loading	Within limits (T1, T2, T3 normal)	T9 & T10 overloaded (>100%)	Overloading due to EV
Line Loading	Moderate	Higher loading & losses	Increased stress on lines
Bus Loading	Lower loading	Higher loading (many near/at 100%)	Heavy loading due to EV
Overload Devices	Minimal	Chargers, PV arrays, generators overloaded	EV introduces heavy stress
Power Factor	~0.99 (Leading)	~0.94 (Lagging)	PF worsens with EV load

Table 1: Comparative Generation & Demand Data

VI. CONCLUSION

In this research, the effects of integrating electric vehicles into the IEEE 14 bus system in terms of performance are examined via the load flow analysis technique. The results show without doubt that incorporating EVs into the power system brings about changes in operating parameters. A remarkable increase in the load demands causes higher power flows and increased losses in terms of both active and reactive power.

Furthermore, the high demand for reactive power due to EV integration causes the degradation of the system power factor and voltage profile. Many of the buses experience undervoltages, thus implying the lack of enough voltages in order to have voltage stability. Furthermore, many key system components like transformers and charging units are exposed to overloading.

The above results suggest that the integration of large numbers of electric vehicles into the current power infrastructure may bring about heavy burden to the systems. Thus, necessary actions should be taken to mitigate this problem. Some of these actions may involve the use of reactive power compensation devices and coordination in electric vehicles' charging.

VI. SCOPE FOR FUTURE RESEARCH

Further research could encompass the use of renewable power sources, intelligent charging methods, as well as the utilization of modern control methodologies like the application of FACTS devices to counter the drawbacks of EVs.

VII. ACKNOWLEDGMENT

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REFERENCES

[1] A. M. Shaheen *et al.*, "Electric vehicles with renewable energy integration in power systems: Challenges and future directions," *Energy Reports*, 2025.

[2] S. Ikram, K. Rehman, M. Altamash, J. Miraj, Design of Radial Distribution System to Study Load-Flow and Short Circuit Analysis Using ETAP Software. Pak. J. Eng. Technol. 7, 42–49 (2024).

[3] Wadibhasme, S. K., and Rane, P. R., "IEEE 14 Bus System Power Quality Disturbance Analysis," *IOSR Journal of Engineering*, presented at the International Conference on Innovation & Research in Engineering, Science & Technology (2019).

[4] Author, A. A., Author, B. B. *International Journal of Advance Engineering and Research Development (IJAERD)*, Special Issue SIEICON-2017, April 2017.

[5] C. S. Hiwarkar *et al.*, "Load flow analysis on IEEE 14 bus system," *International Journal for Research in Applied Science and Engineering Technology*, 2022