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Research Article

# Analysis of Voltage Stability in Distribution System in Presence of Electric Vehicle and Distributed Generator

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## Abstract

Due to its advantages over fossil fuel-powered vehicles in terms of both economy and ecology, the employment of electric vehicles (EVs) has increased recently. As the market for EVs expands, the electric grid is facing more difficulties meeting the demand for EVs, particularly in the distribution networks. The negative effect of EV charging loads on the power system's operating parameters has been observed with the widespread revival of electric vehicles (EVs). Increased peak load demand, smaller reserve margins, voltage instability, and reliability issues are caused by the increase in charging station loads. The purpose of this work is to examine how the increase in loads from EV charging stations affects the distribution network's voltage stability and power losses along with integration of Distributed generator in the system. The complete analysis is carried out on the practical 39-bus radial distribution network for increase in load due to interconnection of electric vehicle to the grid for three different types of EV charger for various load conditions. The results indicates that with DG integration system can withstand the increase in load due to EV connection up to a certain load level, above which, the increase in EV load results in voltage stability problem and increase in system losses. Finally the results indicate that, the performance of Distribution system in terms of voltage and losses depends on placement of DG and electric vehicle in the system.

## Keywords

Distribution Network, Electric Vehicles, Charging Station, Distributed Generation, Photovoltaic System, Power Loss, Voltage Stability

## 1. Introduction

The use of electric vehicles (EVs) has increased recently. The possible benefits of EVs, such as guaranteeing energy security and lowering greenhouse gas emissions, are what led to this surge. Future power systems will face challenges due to the accommodation of electric vehicles [1]. A high rate of EV adoption raises the need for electricity, which in turn causes increased power losses and voltage fluctuations on the power networks [2]. Many factors, including EV adoption rates, drivers' working hours, and daily trip distance, influence the de-

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mand profile with high EV deployment rates. We must simulate the demand for EVs while taking into account the uncertainty related to these variables in order to comprehend the effect of EVs on power systems [3].

Numerous methods of charging and grid integration are being developed to reduce the drawbacks of EV charging while also maximizing the potential benefits of EV grid connection [4, 5].

The need cannot be satisfied by the energy that is currently accessible; in the future, electric vehicles will use more energy than a regular domestic appliance, industry, etc. Vehicle charging may result in power flow violations and voltage dips on the Distribution System (DS) [6].

When DS peak load demand and EV charging occur simultaneously due to unregulated charging, the distribution network will experience a load effect [7]. Distribution networks (DNs) are increasingly using Distributed Generation (DG) sources as a result of the rising demand for electrical energy. The size and location of DGs will affect the voltages and losses of the power distribution system [8].The DS's efficient operation depends on the DGs' optimal scheduling because of the erratic nature of the EV load demand on different charging patterns [9].

Numerous academics have looked into the possible effects of EV charging station loads on distribution networks' voltage profiles [10, 11]. The authors in [12] examined how EV charging station loads affected a low voltage distribution network for varying EV penetration level.

However, it was found that the node with several charging stations had a somewhat impaired voltage profile, and the system's weak buses' voltage profiles also degraded as a result of the heavy loads from EV charging stations [13].The effect of EV charging loads on a typical distribution network with 14 buses was examined by the authors in [14]. It was determined that when EV penetration increased, the transient voltage stability index deteriorated.

In [15, 16], the effect of EV charging loads on the distribution network's voltage stability was examined. According to the results of [17, 18], the majority of distribution networks could tolerate EV penetration for certain level. Several studies show how EV charging loads negatively affect several distribution network parameters, such as peak load, harmonics and voltage profile [19, 20]. In [21, 22], the impact of non-linear EV charging loads on the distribution system's power quality was examined. It was shown that the harmonic distortion caused by the EV loads reduced the lifespan of distribution network assets. The impact of uncontrolled EV charging on the daily load profile was examined by the authors in [23, 24]. It was also demonstrated how adding coordinated charging improved the load profile [25, 26]. The charging station load effect on the distribution system along with integration of renewable energy resources are explained in [27, 28].

The impact of EVs on a practical distribution system is thoroughly examined in this study. The impact of EV load and DG presence on voltage stability and losses are analyzed in the distribution system.

The following is a summary of the work's contributions in this paper:

1) Thorough examination of how the demands from EV charging stations affect the distribution network's voltage stability.
2) Optimal Placement of the DG in the distribution network based on Loss sensitivity factor method.
3) Optimal Placement of the charging stations in the distribution network based on Voltage deviation index.
4) Comparative evaluation of the EV charging load on several distribution network factors, including power losses, reliability, and voltage stability.

## 2. Problem Formulation

In this study, the supply interruption problem occurred in a real distribution network is presented. The 11Kv feeder of Gejjenalli industries emanating from 110/11KvAlkola substation, shimoga is taken for analysis. The daily peak load of the feeder is 1.907 MW and 0.6 Mvar and the system is facing voltage stability problem under peak load condition. A base case model of Real Distribution Network was developed in Power world simulator (PWS) software and is shown in Figure 1.

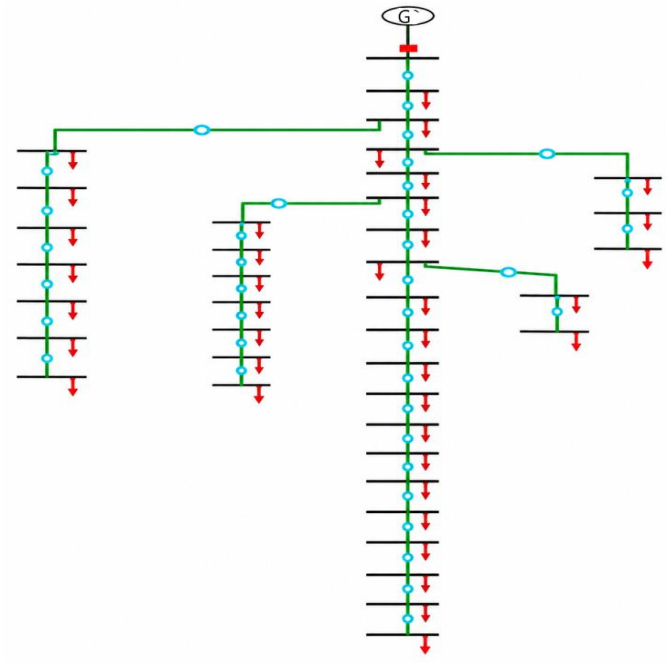



***Figure 1.*** *Practical 39-bus distribution system.*

The voltage profile of the real distribution system under peak load condition is shown in Figure 2, it shows that the voltage profile in some of the buses is very low and is below acceptable limit and further loading due to connection of

charging station may lead to voltage stability problem, therefore consumers connected to this feeder are facing power interruption at regular intervals.

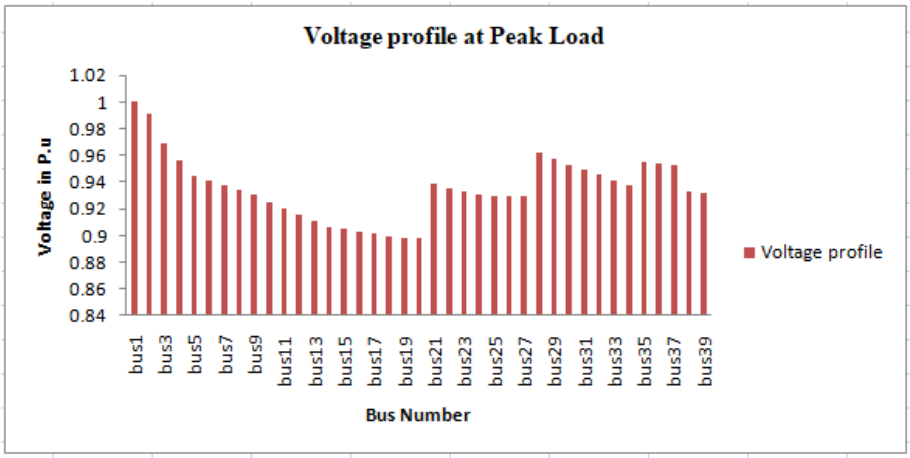



***Figure 2.*** *Volatge profile at peak load for practical distribution system.*

## 3. Proposed Methodology

### 3.1. For Finding Optimal Position of DG

The voltage stability problem that is occurring in selected practical system can be solved by placing DG in the system, the most suitable DG for this feeder is solar PV generation, which can supply the power during peak load, so that power interruption to the consumer can be avoided. The important point is that finding optimal position and size of DG is important in order to reduce losses and improve the voltage profile in distribution system. The standard voltage limit considered in this analysis is given by

$$0.94. \leq Vi \leq 1.06 \quad (1)$$

When the size of the DG is changed from $P_{DG1}$ to $P_{DG2}$, the variation in power loss is from $P_{L1}$ to $P_{L2}$, and the formula to determine the Loss sensitivity factor (LSF) for a specific system is given by

$$\frac{dP_L}{dP_i} = \frac{P_{L1} - P_{L2}}{P_{DG1} - P_{DG2}} \quad (2)$$

The aforementioned equation is used in this study to calculate the sensitivity factor for each bus. Afterwards, the bus with the highest sensitivity is determined, and buses with sensitivity factors that are remarkably near to the highest value are selected for analysis. To find the power loss at each of these selected buses, adjust the DG size by using high values. For every DG size, the optimal location is on the bus with the least loss, the optimal DG size is associated with that generation.

The procedure for the Proposed Methodology is shown in Figure 3.

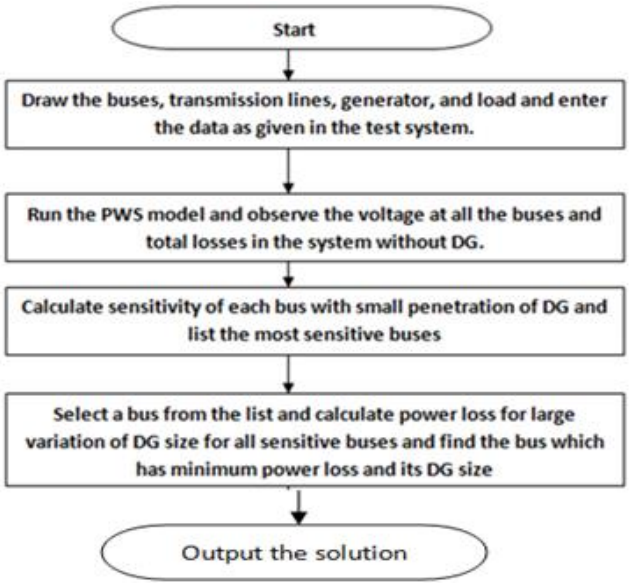



***Figure 3.*** *The Methods of Computation for the Suggested technique.*

### 3.2. For Finding Potential Position of EV Charging Station

There could be negative effects on the system voltage profile from the penetration of EV charging in the distribution system, such as a decrease in voltage stability. In this analysis voltage deviation index (VDI) parameter is considered for the placement of charging station at the various buses in the distribution system. The integration of EV loads into the grid can

have a substantial impact on VDI. Any deviation of the voltage value from its base or nominal value can be used to define the absolute value of VDI.

$$VDI = \left| V_{base} - V \right| \quad (3)$$

The main aim here is to discover the optimal buses for electric vehicle station placement by recognizing strong and wea buses in the distribution system depending on the voltage at the buses on the basis of VDI values. Strong buses are defined as those with lower deviation index values, and weak buses are defined as those with greater deviation index values. The chosen method uses system data to determine which buses are strong and weak. The EV charging station load can be selected in such a way that connection of charging station load at a particular bus should not lead to the voltage stability problem in the system. The flow chart to find strong and weak buses is shown in Figure 4.

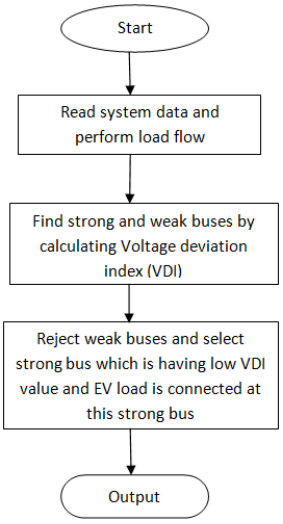



***Figure 4.*** *Flowchart to find strong and weak bus in the distribution system.*

***Table 1.*** *Specifications for EV charging stations (14).*

| Charging Level | Voltage Level | Power Level |
|---|---|---|
| Level 1 | 120 V AC | Up to 1.8 kW |
| Level 2 | 208-240 V AC | Up to 19.2 kW |
| 1) Level 3 (DC Fast charging) | 2) 480 V DC | 3) 50 kW -150 kW |

The specifications for EV charging stations in terms of voltage and power are given in Table 1.

## 4. Results and Discussion

### 4.1. Case-1: Practical System Analysis Incorporating the DG Unit

Figure 5 Shows the simulation model of a real-world feeder using Power World Simulator (PWS) software with DG. The ideal location and size of the DG are determined using the projected LSF method. The bus 16 location is the best one found in this process, and the size of the DG is 0.507 MW. In this scenario, the solar PV module can be utilized as a DG unit to lessen the peak load on the central grid.

The losses of the system with and without DG are also given in the Table 2 and are observed that losses considerably decrease with the optimal placement of DG in the practical system.

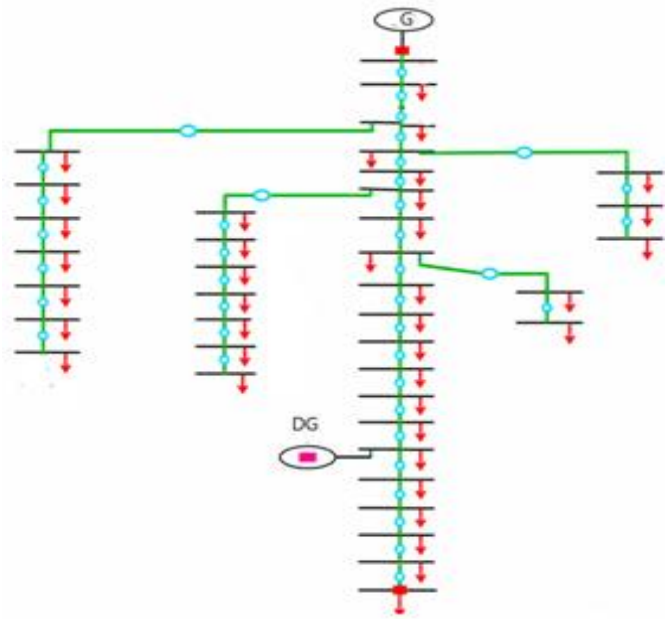



***Figure 5.*** *Practical 39-bus distribution system with DG.*

*Table 2. Results with and without DG in practical system.*

| Cases | Without DG | With DG |
|---|---|---|
| DG Position | --- | 16 |
| Active power loss KW | 0.0853 | 0.0708 |
| Reactive power loss in KVAR | 0.0647 | 0.0408 |
| DG Size in MW | ----- | 0.6 |
| $P_{Loss}$ Reduction in% | ----- | 4.74 |
| 4) $Q_{Loss}$ Reduction in% | 5) ----- | 6) 4.43 |

The voltage profile after DG placement is also improved and is within the acceptable limit at all the buses and is shown in Figure 6.

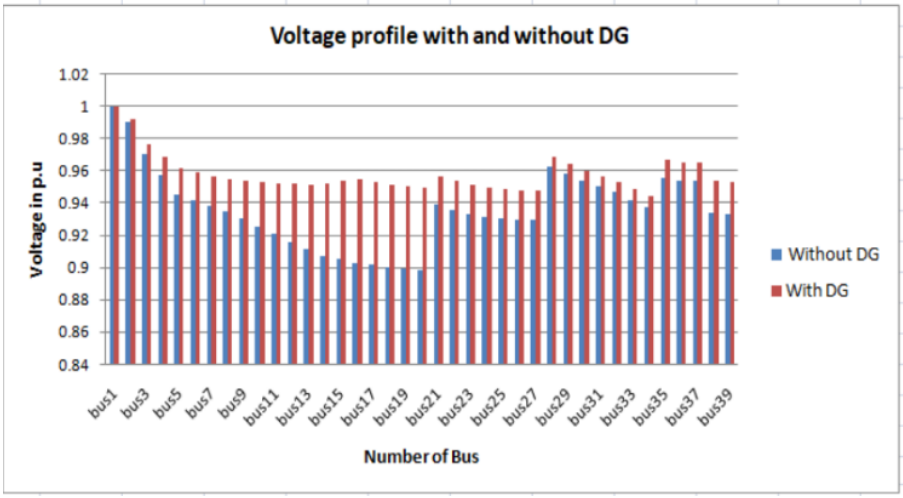



*Figure 6. Voltage profile with and without DG in distribution system.*

## 4.2. Case-2: Practical System Analysis with Placement of EV Charging Station and DG

By applying the VDI formula given in equation (3), the strong bus is found at bus 28, where the EV charging station is placed for different load conditions. The variation in voltage for various EV load conditions is analyzed in the system. If the EV load is increased without placing the DG, then the voltage at many buses will be below acceptable limit and it will lead to voltage instability in the system. The voltage profile analysis with EV charging station for various load level without DG is shown in Figure 7. It can be observed in the diagram that the voltage at many buses is below acceptable limit for load up to 40% of base load, which results in voltage instability in the system; if load increases further it may lead to voltage collapse in the stystem. This problem can be solved with placement of EV charging station along with DG placement at optimum position; therefore the load can be increased up to certain level due to EV connection with integration of DG without violating voltage stability limit and is shown in Figure 8. As shown in the Figure 8, the voltage level in the system is within allowable limit, if the EV load increased is up to 30% of the base load with DG placed in the system at bus 16 with size of 0.507 MW which is calculated from LSF method as explained in section 3, further increase in load will result in voltage instability in the system. Therefore there is a limit in the system to increase the load, above which it is not possible to increase the load due to voltage instability problem.

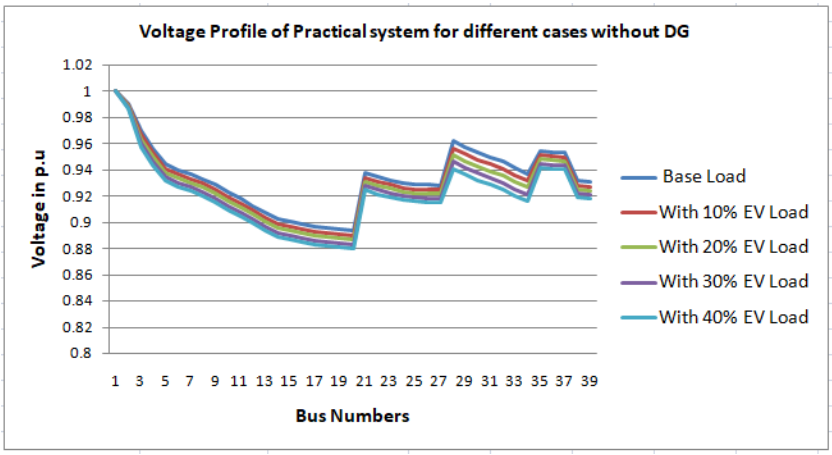



*Figure 7. Voltage profile for various cases without DG.*

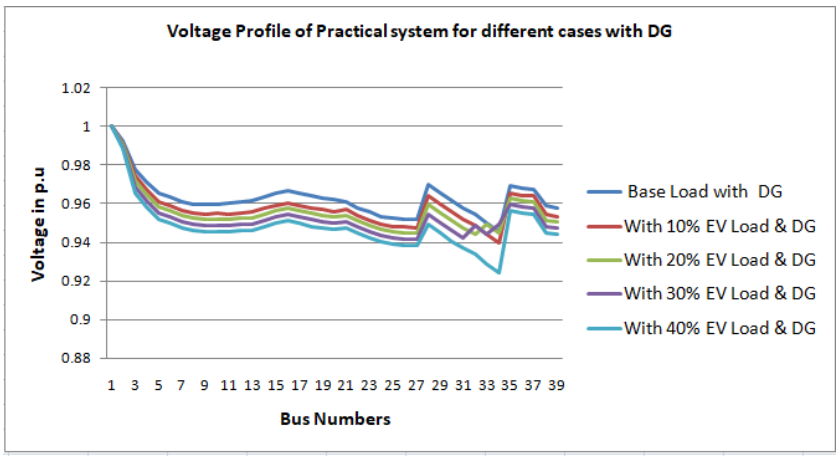



*Figure 8. Voltage profile for various cases with DG.*

The active and reactive power losses under various EV load conditions, both with and without DG integration, are illustrated in Figures 9 and 10, respectively. As observed from these Figures, the placement of a DG alongside the EV load results in significantly lower active and reactive power losses compared to scenarios where the EV load is connected without a DG.This demonstrates the effectiveness of DG integration in reducing system losses and enhancing overall efficiency under increased EV load conditions.

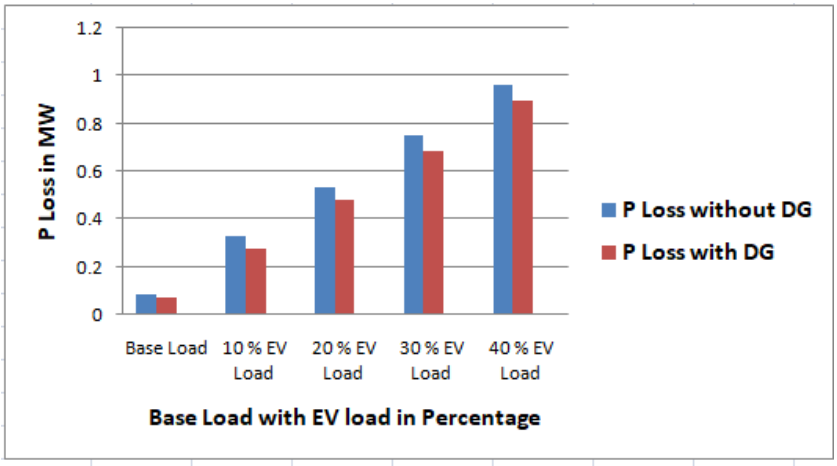



*Figure 9. Active power loss for various cases with and without DG.*

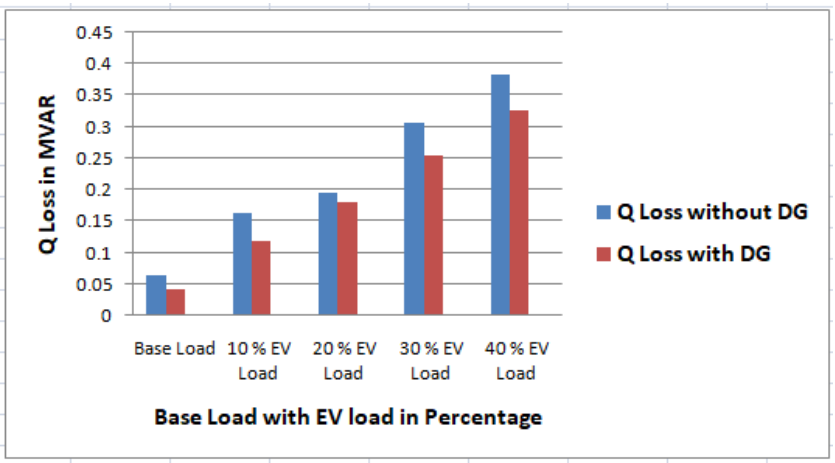



*Figure 10. Reactive power loss for various cases with and without DG.*

The type of charger, the output rating of charger, number of EV can be connected, charging time and its application for various load level are given in Table 3 to Table 6.

## 4.3. Case-A: 10% Increase in Load Due to EV Connection

Increase in Load =190 KW

*Table 3. The type of charger, rating of charger, number of EV, charging time and its application for 10% increase in load.*

| Type of Charger | Output rating of Charger | Number of EV can be Connected | Charging Time | Application |
|---|---|---|---|---|
| Level 1 | 2 KW | 95 | More than 12 hours | Residential |
| Level 2 | 6 KW | 31 | 6 to 8 hours | Residential/Commercial |
| 7) Level 3 | 8) 100 KW | 9) 2 | 10) Upto 1 Hour | 11) Commercial |

Case-B: 20% increase in load due to EV connection
Increase in Load=381 KW

*Table 4. The type of charger, rating of charger, number of EV, charging time and its application for 20% increase in load.*

| Type of Charger | Output rating of Charger | Number of EV can be Connected | Charging Time | Application |
|---|---|---|---|---|
| Level 1 | 2 KW | 190 | More than 12 hours | Residential |
| Level 2 | 6 KW | 63 | 6 to 8 hours | Residential/Commercial |
| 12) Level 3 | 13) 100 KW | 14) 4 | 15) Upto 1 Hour | 16) Commercial |

Case-C: 30% increase in load due to EV connection
Increase in Load = 572 KW

*Table 5. The type of charger, rating of charger, number of EV, charging time and its application for 30% increase in load.*

| Type of Charger | Output rating of Charger | Number of EV can be Connected | Charging Time | Application |
|---|---|---|---|---|
| Level 1 | 2 KW | 286 | More than 12 hours | Residential |
| Level 2 | 6 KW | 95 | 6 to 8 hours | Residential/Commercial |
| 17) Level 3 | 18) 100 KW | 19) 6 | 20) Upto 1 Hour | 21) Commercial |

Case -D: 40% increase in load due to EV connection
Increase in Load =763 KW

*Table 6. The type of charger, rating of charger, number of EV, charging time and its application for 40% increase in load.*

| Type of Charger | Output rating of Charger | Number of EV can be Connected | Charging Time | Application |
|---|---|---|---|---|
| Level 1 | 2 KW | 381 | More than 12 hours | Residential |
| Level 2 | 6 KW | 127 | 6 to 8 hours | Residential/Commercial |
| 22) Level 3 | 23) 100 KW | 24) 8 | 25) Upto 1 Hour | 26) Commercial |

As given in the above cases from Table 3 to Table 6 it is observed that,with level-1 charger more number of EV can be connected for charging, but it takes more time for charging compared to level-2 and level-3 charger.Level-3 charger is also called fast charger having maximum output rating, which takes upto one hour for charging of an Electric vehicle.

## 5. Conclusion

The surge in electric vehicles (EVs) offers a cleaner alternative for transportation, but their increasing charging demands are posing serious challenges to the power distribution infrastructure. As more EVs hit the road, EV charging stations are proliferating but the substantial electrical loads they draw can overload local distribution networks, causing voltage drops, harmonic disturbances, transformer stress and even reliability issues. This study conducted a comprehensive evaluation of how EV charging station loads affect voltage stability and power loss in the practical distribution network. The study also indicates that by placing DG at a particular position the negative impacts of EV charging stations such as voltage instability and losses can be reduced.

In this work,the optimal location and capacity of the Distributed Generator (DG) are determined using the projected Load Sensitivity Factor (LSF) method. Based on this analysis, Bus 16 is identified as the most suitable location, with the ideal DG size calculated to be 0.507 MW. In this context, a solar PV module can effectively serve as the DG unit, helping to reduce peak load demand on the central grid due to increase in EV connection. Also, using the Voltage Deviation Index (VDI) formula, Bus 28 is identified as the strongest bus in the network for placement of EV charging station. Therefore, the EV charging station is installed at this location under various load conditions.

Finally the results show that the combined placement of EV charging infrastructure with appropriately placed and sized DG helps to maintain system voltage within permissible limits when EV load is increased upto 30% of the base load. This coordinated approach enhances the hosting capacity of the grid for EV loads while ensuring voltage stability and loss reduction. However, beyond this threshold, voltage instability may arise along with loss increase, indicating the need for further system reinforcement or advanced control strategies. The study highlights the importance of strategic DG integration in supporting the growing demand from EV adoption in modern power systems.

## Abbreviations

| | |
|---|---|
| EV | Electric Vehicle |
| DG | Distributed Generation |
| PV, | Photovoltaic System |
| APL | Active Power Loss |
| RPL | Reactive Power Loss |
| VS | Voltage Stability |

## Author Contributions

**Rudresha Sogilu Jayappa:** Conceptualization, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing

**Gopinath Harsha Rajappa:** Data curation, Investigation, Methodology, Software, Writing – original draft

**Kiran Kumar Gama Ramaiah:** Conceptualization, Methodology, Resources, Software, Supervision, Validation

**Shruthi Shankarappa:** Conceptualization, Investigation, Methodology, Writing – review & editing

**Kalpana Shivashankar:** Conceptualization, Investigation, Methodology, Writing – review & editing

## Conflicts of Interest

The authors declare no conflicts of interest.

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