https://doi.org/10.1051/epjconf/202635101016

Analysis of Load Profile in the presence of EVs & DERs

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Abstract. This Paper examines the effects of electric vehicles (EVs) and distributed energy resources (DERs) on distribution networks. The impact of these integrations on load profiles is the main topic of the study. To maximize the load profile, the study focuses on scaling DERs and EV charging/discharging techniques. To measure their individual and combined effects on load variability, system characteristics such as load profile, EV charging pattern. The suggested method for enhancing the load profile and lowering network losses with the irregular electricity produced from DERs and electric vehicle integration has been validated through the analysis of a mathematical model with system & operational restrictions. The analysis's findings demonstrate that effective EV integration and DER capacity enhance the load profile, enhance voltage control at different distribution network nodes, and significantly lower network losses.

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1 Introduction

To forecast load profiles in 2026, it is necessary to simulate the intermittent nature of sustainable energy resources (SERs) and the chaotic behaviour of electric vehicles (EVs). Global electricity demand is predicted to increase by 3.4% by 2026, with wind and solar power accounting for approximately 20% of generation. By 2026, up to 116 million EVs—a 30% increase over 2025—are expected to be on the road worldwide. By the middle of 2026, it is anticipated that renewable energy would overtake coal as the world's main source of power. Demand spikes will become sharper and more varied when super-fast chargers (350 kW+) & smart energy management systems become widely used. It is a challenging procedure that mostly depends on mathematical modelling, data-driven methods, and sophisticated simulation platforms to predict the electrical load profile with the inclusion of electric vehicles (EVs), & small energy resources (SERs), like home solar PV and energy storage. To preserve grid stability, the combined effect creates a dynamic & highly changeable load curve that calls for advanced management techniques.

2 Impact on the Grid

Even minor increases in overall energy consumption can result in a 26.10% increase in the generating capacity needed due to uncoordinated charging, which raises peak load.[1] In the year 2026, Vehicle- to-Grid (V2G) and Vehicle- to-Home (V2H) technologies will be sufficiently developed to use parked EVs as sources of energy during peak hours, which will lead to Demand Shifting and assist balance the grid.[2,3] Without optimal charging, load consequences are very localized, and in high-growth EV scenarios, certain grids would not be able to survive into 2026 due to Localized Strain.[4]

Peak demand is usually increased by uncoordinated EV charging, particularly in residential areas when people come home from work in the evening (e.g., 5 PM to 10 PM). Transformers and feeders may have local problems as a result, such as voltage dips and heat stress. SERs, like rooftop solar panels, can reduce the daytime net load by injecting electricity into the grid during the day.[5-7] However, the inconsistent and weather-dependent character of renewable energy sources adds unpredictability and can complicate supply and demand management.

To shape the load curve and increase overall system efficiency, EVs can be incorporated as flexible loads or portable energy storage (also called Vehicle-to-Grid, to use extra solar power throughout the day while discharge during peak night time hours. This is known as the Combined Effect.[6,7,8] The random behaviour of various drivers (arrival times, journey distance, State of Charge, etc.) & meteorological variables that impact solar power are frequently modelled using Monte Carlo simulations. This produces a variety of potential load situations as opposed to a single prediction point. By considering factors like plug-in time, battery state of charge (SoC), & daily mileage, Monte Carlo simulations are utilized in stochastic modelling to create EV charging/discharging profiles.[9,10,11]

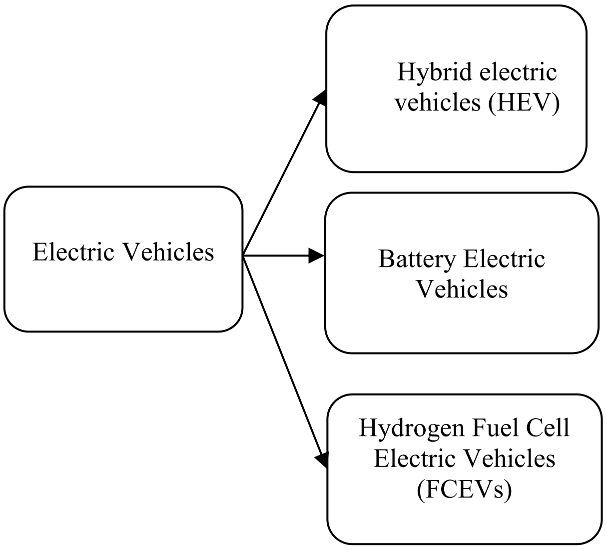

Fig. 1. Shows Types of EVs

Electric road vehicles are a broad category of environmentally friendly vehicles that are powered only by electricity and intended for usage on roads and highways.[12] The most popular of them are electric automobiles, which offer a sustainable substitute for conventional gasoline-powered vehicles, improving urban mobility's cleanliness and environmental friendliness. While electric trucks are essential in the logistics and freight sector, providing electric solutions for moving products, cutting emissions, and promoting a more sustainable future, electric buses provide effective and environmentally friendly urban public transit. When taken as a whole, these electric road cars represent a substantial change toward greener and more ecologically conscious modes of transportation.[13-16]

2.1 System Constraints

When modelling and assessing the system, it is important to consider the constraints of the load profile analysis considering the integration of distributed energy resources and electric cars.[17] These limitations guarantee that the system responsiveness and load profile meet operational and technical specifications.[18] The load profile study has considered the following limitations:

2.2 Capacity Constraints

DER Capacity: DERs' capability is constrained. This limits DERs' overall generation to the installed capacity constraints.

Grid Capacity: The overall load that can be handled is limited by the supply system, transmission, and distributing networks' available capacity.

2.3 Operational Constraints

Charging Time: EVs have different charging time options, influenced by user preferences and operational constraints.

EV Charging Stations: The load profile and charging pattern can be greatly impacted by the availability of electric vehicle charging stations.

2.4 Technical Constraints

- Voltage and Frequency Limits: The voltage and frequency should be within permissible limits to support reliable operation of the supply system.

- DER capacity and control: The operations of DERs depend upon the technical parameters, including voltage and power factor regulation, grid interconnection standards, and reactive power capabilities [19].

$$\text{Generation of DER} \leq \text{DER Maximum Capacity} \quad (1)$$

- Power Balance Constraint: Power usage, EVs, and DER capacity need to be balanced with grid power. One way to express the power restriction is as:

$$\text{Total Supply Grid} = T_L + L_{EV} + L_{DER} \quad (2)$$

Where T_L represent total load, which is the sum of L_{EV} which is the electric vehicle load and L_{DER} which is the load of the DER.

- EV Charging Constraint: To prevent overloading the electrical grid, EV charging speeds are subject to restrictions. This restriction can be expressed as:

$$\text{Charging Power (Max)} \geq \text{Charging Power} \quad (3)$$

2.5 Energy Constraints:

- Energy Storage Capacity: The battery's size may limit how much energy can be delivered or stored in a given length of time.

2.6 Environmental Constraints:

The system considers the quantity of greenhouse gas emissions through the emission rules.

3 Mathematical Modelling

A thorough system is necessary in order to offer a mathematical representation of all the elements related to load analyzing in the instance of EVs and DERs, along with equations and limitations. [17-20] Key components are modelled mathematically using the following methodology:

i. Electric Vehicle Load: A power demand function that depends on a variety of factors, including charging power (CP), charging time factor (CT), and the number of EVs (N), may be used to depict the load profile of EV charging. Here, the charging profile (1/CT) shows the percentage of the maximum charging power used at each time t.

$$L_{EV}(t) = CP * N_{EV} * (1 / CT) \quad (4)$$

ii. Distributed Energy Resources (DERs): The capacity factor (CapF) and available DER capacity (C) can be used to simulate the power generation from distributed energy resources (P_{DER}), such as wind turbines or solar photovoltaic (PV) panels. In this case, CapF stands for the DER output profile, which establishes the percentage of maximal output capacity used at each time t.:

$$P_{DER}(t) = CapF * C \quad (5)$$

iii. Total Load: The base load, EV charging load and DER power generation make up the total of all loads acting on the system. The formula for figuring out the total load at every moment t is:

$$\text{Base load}\,(t) + L_{EV}(t) + P_{DER}(t) = T_L \quad (6)$$

The following criteria to generate the load profile to observe the influence of EVs and DERs while considering occupancy and weather changes [19, 20].

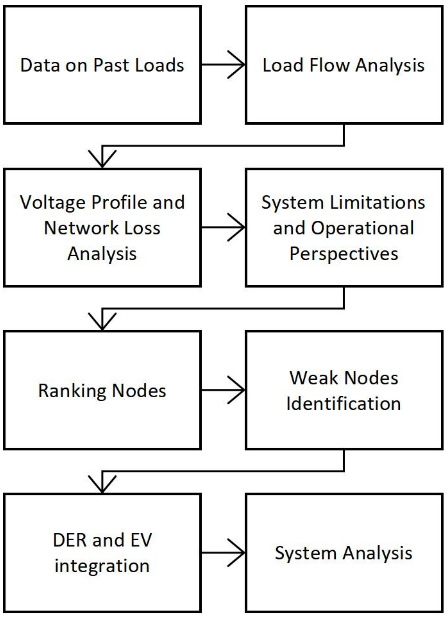

Fig. 2. Shows Analyses of Load profile

Additionally, the suggested method uses EVs and DERs to analyse load. To analyse load, data is gathered, processed, and divided. Results are examined and performance is assessed. This methodical methodology guarantees a comprehensive assessment of the procedure. [21]

So that, total power input to the grid can be written as follows:

$$Pw_{in} = Pw_{spv} + P_{wbt} + Pw_{ug} \quad (7)$$

Total input power can also be written as

$$Pw_{in} = Pw_{out} + Pw_{loss} \quad (8)$$

Therefore, grid efficiency can be writtenas

$$\eta_{grid} = \frac{Pw_{out}}{Pw_{in}} = \frac{Pw_{in} - Pw_{loss}}{Pw_{in}} = 1 - \frac{Pw_{loss}}{Pw_{in}} \tag{9}$$

Further, total power output from the grid can be written as

$$Pw_{out} = Pw_{ev} + Pw_{non-ev} \tag{10}$$

Or $Pw_{ev} = Pw_{out} - Pw_{non-ev}$ (11)

Or $Pw_{ev} = Pw_{in} - Pw_{loss} - Pw_{non-ev}$ (12)

Pw_{spv} - power supply from solar photovoltaic systems (DER)
Pw_{bt} - power coming from the battery storage unit into the charging network
Pw_{ug} - electricity input from a different utility grid
Pw_{in} - total input of grid power
Pw_{out} - total amount of power generated by the grid
Pw_{loss} - overall grid power loss
Pw_{ev} - charging load for electric vehicles
Pw_{non-ev} - electric load on charging stations different than that of EVs

Thus, the aim of the designing will be to:
(i) MaximizePw_{ev} = maximize (Pw_{out} - Pw_{non-ev})

(ii) MinimizePw_{loss} ; $Pw_{in-min} \leq Pw_{in} \leq Pw_{in-max}$

To make well-informed decisions on system design, infrastructure upgrades, and demand-side management strategies, this study methodically assesses how modifications to key components impact load profiles. The analysis starts by describing the present load profiles and identifying the key factors that influence them in a methodical manner. A range of real-world situations are created to mimic the evolving energy situation. Thorough data gathering, including surveys, historical data, and sophisticated modelling techniques, serves as the foundation for additional study.

4 Load Flow Analysis

The following are the fundamental load flow equations for a radial distribution system:
(1) Node voltage equations, for the substation:

Vn= Vn_{slack}
$\theta_n = \theta_{slack}$

(2) The power flow equations can be written as:

$$P_{nm} = |V_n| * |V_m| * (G_{nm}*\cos(\theta_n - \theta_m) + B_{nm}*\sin(\theta_n - \theta_m)) \tag{13}$$

$$Q_{nm} = |V_n| * |V_m| * (G_{nm}* \sin(\theta_n - \theta_m) - B_{nm}* \cos(\theta_n - \theta_m)) \tag{14}$$

Where:

P_{nm} , Q_{nm} are the real and apparent power injections at node n.
$|V_n|$, θ_n are the angle and voltage strength at node n.
$|V_m|$, θ_m are the linked node m's voltage strength and angle.
G_{nm} , B_{nm} are the branch linking nodes n and m's conductance and susceptibility.

5 Results

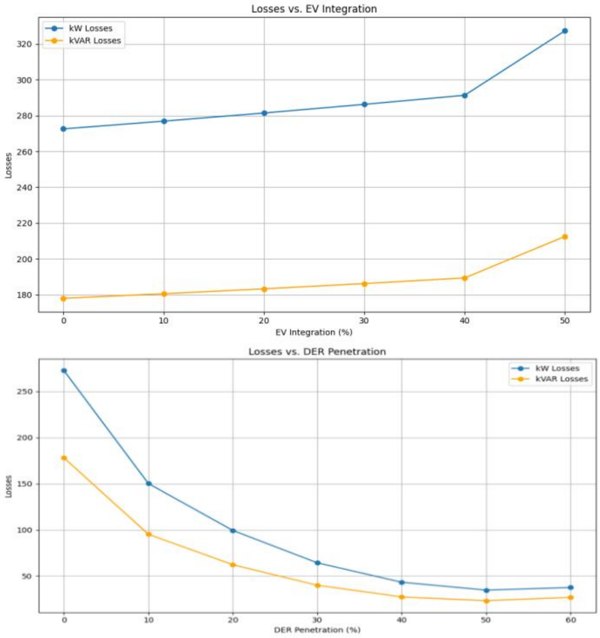

Fig. 3. Shows the EV and DER vs Losses

The graph {a} illustrates how actual and reactive losses progressively increase with the degree of integration of electric vehicles (EVs). Losses clearly increase as the EV integration hits the 40% mark. Maintaining an ideal level and configuration of EV penetration is crucial to reducing the losses. As DER (distributed energy resources) penetration rises, the graph (b) shows a pattern of both reactive and active power losses that consistently decrease. Once DER integration reaches 50%, the graph indicates an alteration in this trend. The right degree and configuration of DER penetration must be considered in order to maximize loss reduction.

6 Conclusion

This study has looked at how the load profile of distribution networks is affected by the integration of electric vehicles (EVs) and distributed energy resources (DERs). System load, DER capacity, and EV charging/discharging patterns have all been examined. According to the analysis results, increasing DER penetration results in larger network losses, although integrating DERs enhances the load profile and voltage stability up to an ideal capacity. The proposed study shows that the voltage profile and efficiency may be improved by combining smart EV charging procedures at different distribution network nodes with the best possible DER capacity. Planning the distribution network layout is necessary, nevertheless, in order to improve DER capacity.

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