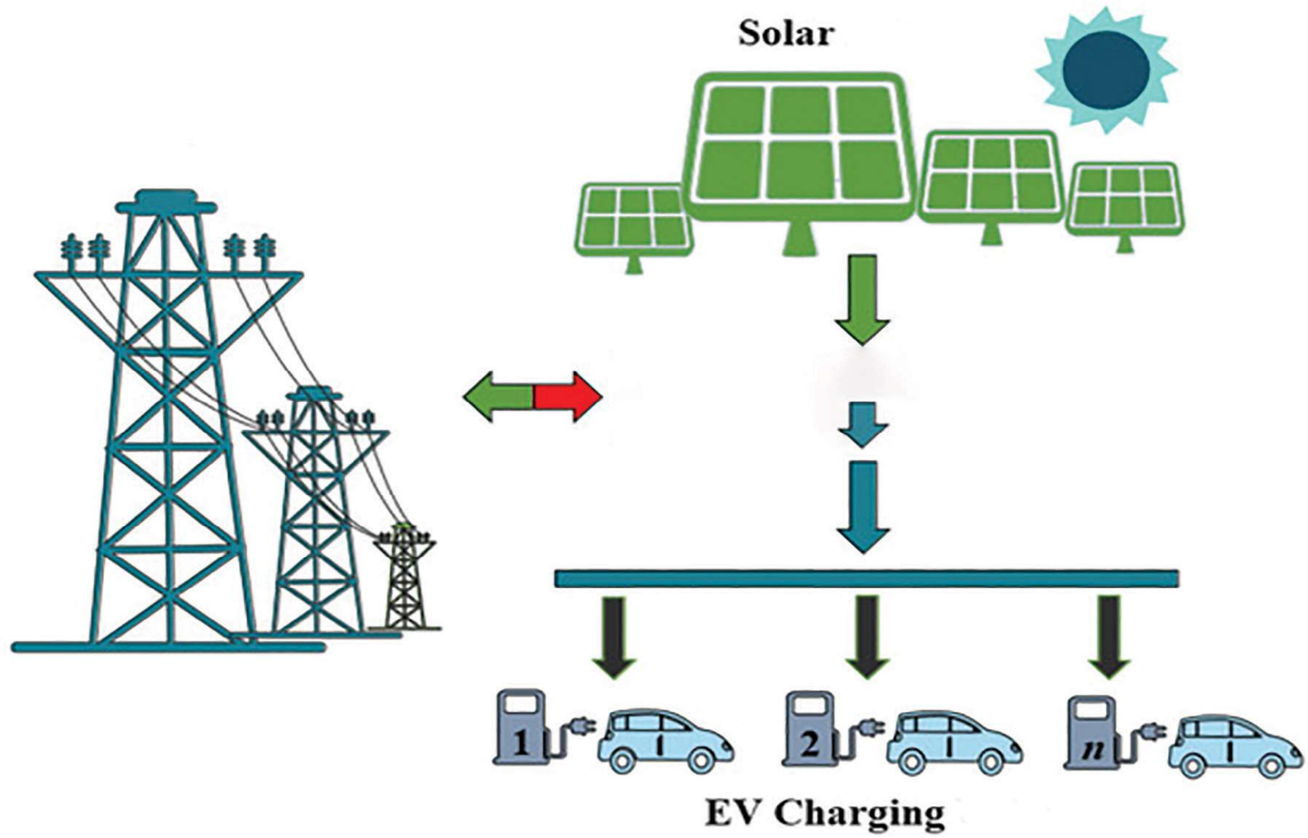

Assessing the impact of integrating electric vehicles and solar rooftop photovoltaic system into the power distribution network

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Abstract—This paper presents our analysis of the impact of integrating electric vehicles (EVs) and rooftop photovoltaics (RTPVs) on power system distribution feeders at the 11 kV level. For the assessment, we selected a sample urban feeder that served both domestic and commercial consumers within Bengaluru city limits. The EV demand projection was considered on the basis of a report by the Indian Institute of Technology, Kanpur, whereas the RTPV potential was estimated using CSTEP's Rooftop Evaluation for Solar Tool. The feeder was modelled and simulated using the Electrical Transient Analyzer Program software tool. Various load-flow scenarios were run to analyse the feeder capability for integrating EVs and RTPVs for the horizon year 2025. The simulation results revealed that the selected feeder would be critically loaded due to the EV charging demand during the evening peak hours. With the optimal integration of RTPVs and daytime EV charging, the increased demand can be met without augmenting the feeder capacity.

Keywords—feeder, electric vehicle, rooftop photovoltaic, distribution transformer

I. INTRODUCTION

Emerging technologies that employ renewable energy sources are crucial for India's clean energy transition. However, because their inclusion involves a changeover, these technologies have to work alongside conventional systems till the required infrastructure is ready for their large-scale employment. Therefore, while integrating these technologies into a system, it is necessary to understand their impact on it. In this study, we focussed on two emerging technologies, electric vehicles (EVs) and rooftop photovoltaic (RTPV), and assessed their impact on the distribution network infrastructure in terms of the feeder capacity, loading of distribution transformers (DTs), and feeder losses. Although several studies have highlighted the potential of EVs and RTPVs, few have assessed their impact on the grid. Hence, we planned to conduct a feeder-level power flow analysis.

Considering the potential growth of EVs in the urban sector, an 11 kV urban feeder was selected for the analyses in Bengaluru city. The 11 kV Hanumanthappa/F-05 feeder, which emanates from the Jayanagar 66/11 kV GIS substation, has a total feeder length of 4.54 km and 52 DTs (11/0.44 kV). Our study assessed the effect of integrating the projected EV and RTPV capacity into the Hanumanthappa feeder for the horizon year 2025.

II. PROCESS AND METHODOLOGY

A. Data collection

A field survey was conducted to collect the relevant data for the 11 kV Hanumanthappa feeder. The survey traced the feeder path from the substation to the DT level and collected information on the conductor type and capacity, technical parameters of cables/overhead lines, details of the 52 DTs, DT Lifecycle Management System (DTLMS) code, energy consumption, and geo-location (latitudes and longitudes) of the assets. Using this geo-location, a GIS mapping tool [1] was developed to obtain the length of cables/overhead lines. The screenshot of the tool is given in Fig 1.

Fig 1: Snapshot of GIS mapping of the sample feeder

B. Estimation of RTPV potential

To calculate the RTPV potential on the rooftop of consumer premises, which are connected to specific DTs across the Hanumanthappa feeder, CSTEP's Rooftop Evaluation for Solar Tool (CREST) was used [2]. It is an in-house built tool that assesses the solar potential of rooftops in cities using light detection and ranging. This tool identifies precise locations for installing rooftop photovoltaic (RTPV) systems on buildings (Fig 2). In terms of technical innovation, this exercise accounts for the shadows cast by neighbouring obstacles on individual rooftops while estimating the RTPV and subsequent power generation potential.

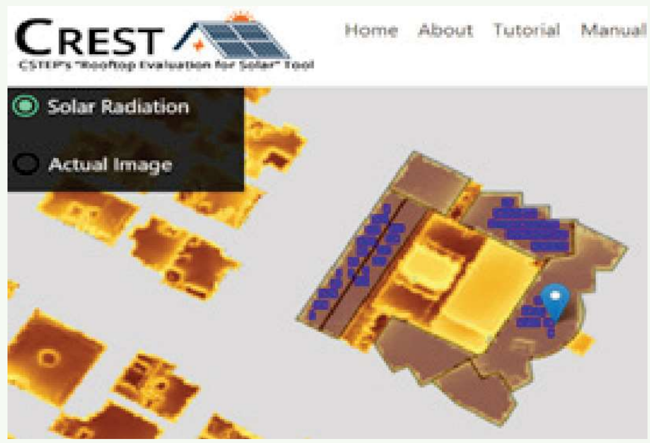

Fig 2: Snapshot of CREST tool

C. Power system model

The entire feeder, along with the loads for each DT, was modelled using the Electrical Transient Analyzer Program power system simulation software. Fig 3 shows the snapshot of the feeder model.

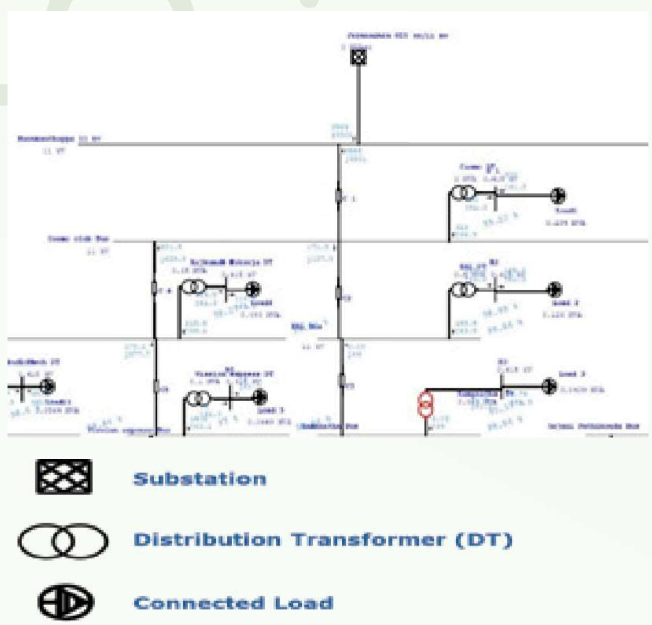

Fig 3: Snapshot of the feeder modelled using the Electrical Transient Analyzer Program

D. Power flow analysis

This analysis was performed to benchmark the model for a particular instant in April 2019 to mimic the real-time loading conditions. The benchmarking was performed by comparing the real-time power flows with the simulation results. This was followed by the analyses for the horizon year 2025 considering different load-generation scenarios using the Newton–Raphson method.

III. DATA ANALYSIS AND ASSUMPTIONS

An hourly load profile of the feeder was analysed for a typical day in April 2019, showing an evening peak of 3.9 MW at 1900/2000 hours and a morning peak of 3.8 MW at 1200 hours. Off-peak hours were observed from 0100 to 0600 hours, as shown in Fig 4.

For the analysis, we considered the following parameters:

- A growth of 40% in the EV load by 2025 in Bengaluru [3]. An additional EV load at the evening peak in 2025 is 1.9 MW for the particular feeder.
- A battery capacity of 3, 9, and 30 kWh for EV two, three, and four wheelers, respectively. In the EV fleet, two, three, and four wheelers account for 88%, 1%, and 11%, respectively.
- A compound annual growth rate (CAGR) of 3.2% for peak demand forecast for Bengaluru during 2024–2025 [4] and feeder loading of 4.7 MW at 1900/2000 hours at evening peak scenarios.
- A morning peak on the feeder of 4.6 MW at 1200 hours in April 2025 for RTPV scenarios.
- A feeder maximum loading capacity of 6.8 MW.

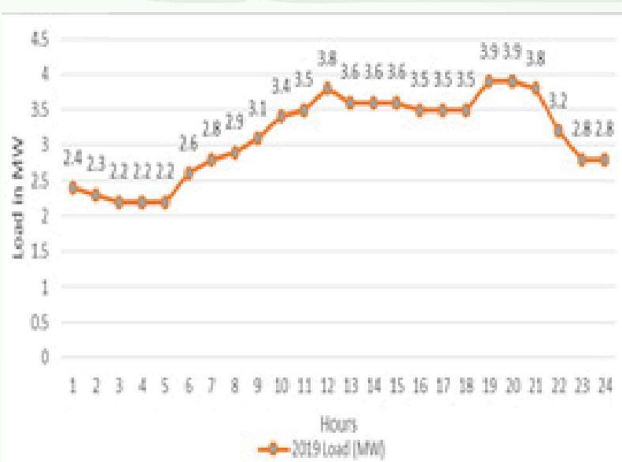

Fig 4: Hourly load profile of Hanumanthappa feeder

IV. SCENARIO DETAILS

As summarized in Table I, the following scenarios were analysed:

1. Base case: Feeder analysis for 2019 network conditions.
2. Business as usual (BAU) – 2025: Forecasted demand growth of CAGR 3.2% for base case scenario, without EVs and RTPVs.
3. BAU – 2025 with EV: BAU demand, with estimated EV demand.
4. BAU – 2025 with RTPV: BAU demand, with total RTPV generation equal to 90% of total DT loading and estimated EV demand.
5. BAU – 2025 with RTPV: BAU demand, with total RTPV generation equal to 80% of the total DT capacity and estimated EV demand [5].

TABLE I. SUMMARY OF THE SCENARIOS CONSIDERED IN THE STUDY

Scenario	1	2	3	4	5
EV	No	No	Yes	Yes	Yes
RTPV	No	No	No	Yes	Yes

V. RESULTS AND DISCUSSION

The simulation results for the different scenarios are given in Table II.

TABLE II. SIMULATION RESULTS OF DIFFERENT SCENARIOS

Scenarios	Feeder loading (organic load)	EV load	RTPV power generation	Results
1	3.9 MW	n/a	n/a	• Feeder loaded up to 57% of its rated capacity. • Feeder can handle an additional load of 2.96 MW. • One DT is critically loaded.
2	4.6 MW	n/a	n/a	• Feeder loaded up to 68% of its rated capacity. • Feeder can handle an additional load of 2.16 MW. • One DT overloaded.
3	4.6 MW @ peak scenario	2.2 MW	n/a	• 380 EVs (total load 2.2 MW) can be connected for charging at peak instant. • Feeder critically loaded to 100% of its rated capacity. • Network strengthening is required to supply the projected demand. • Three DTs overloaded.
	2.7 MW @ off- peak scenario	4.2 MW	n/a	• 705 EVs (total load 4.2 MW) can be connected for charging at an off-peak instant. • Feasible time for charging the EVs is 2200–0800 hours.

4	4.6 MW @ daytime peak-load scenario	2.2 MW	4.1 MW	• During morning peak scenarios, RTPV (4.1 MW) meets most of the demand, and the rest is met through the grid (2.6 MW). • 4.29 MW of feeder capacity is available for EV charging. • Loading of the network elements are well within the acceptable limits.
5	4.6 MW @ daytime peak- load scenario	2.2 MW	9.6 MW	• 100% of feeder load met through RTPV generation. • Excess RTPV generation of 2.9 MW injected back to the grid substation; otherwise, this excess power can be utilized to charge higher EVs. • Loading of the network elements are well within the acceptable limits.

Thus, irrespective of EV integration, the load on the feeder increases in 2025. In scenario 3, an EV load of 2.2 MW, equivalent to 380 EVs (334 two wheelers, 5 three wheelers, and 41 four wheelers) can be charged at a peak instant, whereas at an off-peak instant, 4.2 MW of EV load, equivalent to 705 EVs (620 two wheelers, 10 three wheelers, and 75 four wheelers) can be charged.

As the feeder loading increases, the Transmission and Distribution (T&D) losses at the feeder level also increase. With the increase in load from 3.9 MW in scenario 1 to 4.6 MW and 6.8 MW in scenarios 2 and 3, respectively, the T&D losses increased from 0.78% to 0.94% and 1.34%, respectively.

The T&D loss (0.36%) in scenario 4 is comparatively negligible owing to the integration of RTPVs near the load centre. However, in scenario 5, the T&D loss is very high (1.18%), mainly owing to the excess RTPV generation (2.9 MW) exported back to the grid.

VI. CONCLUSION AND RECOMMENDATIONS

The analyses lead to the following conclusions and recommendations:

- A feeder-level analysis is mandatory for identifying the actual value of EV and RTPV that can be integrated at the feeder level.
- The high uptake of EVs warrants integrating RTPVs at the feeder level to ensure peak shaving.
- Daytime EV charging is recommended because RTPV generation is high during the day, enabling it to handle the increased load and thereby avoid additional infrastructure costs.
- For the successful integration of EVs and RTPVs into the grid, distribution companies should focus on load forecasting and the associated infrastructure planning.
- A dynamic web platform overlaid with the GIS mapping of feeders, which would help both stakeholders and prosumers identify the availability of DT's and assess the RTPV potential, should be developed.
- The CREST tool will help in identifying the potential of rooftop capacity across Bengaluru city for RTPV estimation.

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