Impact Study of Electric Vehicle Charging on Thimphu Distribution Network

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Abstract
Since the introduction of electric vehicles (EVs) in Bhutan in 2014, the number of EVs in the country has increased to 581 by 2023, according to the Bhutan Construction and Transport Authority (BCTA). This demand would pose challenges to power utility (BPC). It is therefore important to assess whether the existing low voltage (LV) distribution network can handle this additional load from EV charging stations. This paper evaluates the impact of EV loads to the LV distribution network of Thimphu, by modeling and simulating the LV networks using DIgSILENT PowerFactory. Using the one-year load data of 2023, the quasi-dynamic analysis is carried to investigate the daily, weekly, monthly and yearly variation of networks parameters and loading profiles with more focused to the networks connected with EV loads. Key factors considered were bus voltage profiles, transmission line and transformer loadings. The analysis from the seasonal variations in EV charging habits indicated that there is currently no significant impact of EV loads on the networks except Changedaphu substation and its interconnected lines and transformers tend to overload in winter especially during peak hours.

Key Words: *Electric vehicle, Quasi-Dynamic simulation, DIgSILENT Power Factory, Load profiles, Shunt capacitor*

1. INTRODUCTION

With the financial support from United Nations Development Programme (UNDP), Bhutan has increased the import of electric vehicles aiming to become less dependent on fossil fuels and have zero emissions as a country by 2050 (UNDP, 2019). With the inception of piloting electric vehicles in 2014, the number of EVs on the road has significantly increased with more than 500 EVs plying the Bhutanese roads. A study conducted for Bhutan by the South Asian Association for Regional Cooperation (SAARC) calculated that in 2030, a low EV adoption scenario would require around 47 electric vehicle charging stations (EVCS) while a high EV adoption scenario would need about 104 EVCS (BPCL, 2021).

Although Bhutan has cheap hydro-power for EV charging, increasing demand for electricity now raises questions on the operational capacity of the distribution network. Integrating many electric vehicle charging stations into the grid could drastically disrupt the ability to distribute load which is likely to cause higher net losses and different load patterns (Chophel et al., 2020). Uncoordinated charging may result in voltage deviation, heavier grid loss, and poor transmission efficiency, which may compromise the stability of power systems (Liu et al., 2015).

It is predicted that the grid would be more burdened in the summer than in the winter as more electric vehicles (EVs) are integrated. Risk is negligible at low EV penetration rates, but as penetration rate of EV increases, adverse impacts on grid becomes more concerning. Fast-charging stations should be placed close to substations because this lowers power losses and enhances the voltage profile of the grid. The study looks into how distribution network voltages are affected by residential EV charging and finds that secondary voltages are affected more than primary voltages. It identifies variables that affect voltage drops, such as the size of the EV charger and the proximity to service transformers. While conventional approaches, such as enlarging transformers and time-of-use (TOU), scheduling provides better solution for the grid stability (Dubey & Santoso, 2015). These studies make it clear that an increase in the demand from EV users will raise the need for electric vehicle charging stations, which could strain the electrical distribution system. Therefore, there is a need to investigate the stability of current distribution network.

2. METHODOLOGY

An appraisal study of the existing Thimphu distribution network is carried out with modeling the network in DIgSILENT Power Factory, using network data provided by Bhutan Power Corporation Limited. The steady state load flow analysis is carried out to assess the existing line loadings, load flow demand, bus voltage profile and the grid losses which also validates the network model for the dynamic load flow analysis. With the load data for 2023, the network model is simulated for voltage profile, line losses and loading on a daily, monthly, and annual basis. As a result of the quasi-dynamic simulation, low voltage buses of Thimphu Distribution network were identified and some mitigation strategies for reducing grid voltage violations were proposed.

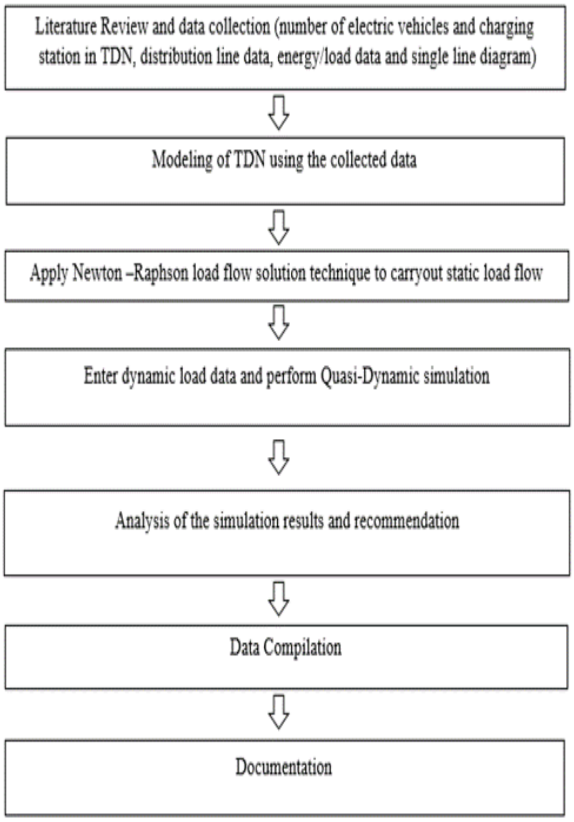

Fig.1: *Methodology adopted in this study*

2.1 EVCS status as 2024.

There are 13 EV charging stations (EVCS) with Level 2 and Level 3 chargers located across Thimphu catering to a total load power of 2170 kW.

2.2 EV Charging Pattern

Details on EV charging was collected from EV owners in order to observe the charging pattern of EVs in Thimphu. The number of charging events in a week is shown in the Table 1, where the electric vehicles are plugged in for short periods of time in case of DC fast chargers. Fast charging is convenient since it happens mostly in the 2-3 hours that comprises 36.84% of all weekly charging events. The next highest is for 3-5 hours at 31.83% showing moderate usage of Level 2 AC type charge. The longer durations, 5-8 hours and 8–12 hours are for home charging.

Table 1: *Number of charging events in a week*

Plug-in time(h)	No. of Charging events in a week	Percentage (%)
2-3	14	36.84
3-5	12	31.83
5-8	7	18.42
8-12	5	13.15

EV chargers are free, but there is some evident user pattern regarding charging time in Thimphu as shown in Table 2. Most EVs charge at night, with 54.55% occurring at night, 27.27% in the evening, and 18.18% in the morning.

Table 2*: EV charging in percentage*

Charging time	Percentage (%)
Night	54.5454
Evening	27.2727
Morning	18.1818

3. RESULTS AND DISCUSSIONS

3.1. Static load flow analysis

Static load flow simulation is done for the load data of peak season and lean season for the year 2023. For the validation of network, the actual data obtained from the BPC and the simulated values were compared and the percentage error was checked using the MAPE method. A small percentage error of 1.664% was found when the simulated and real bus voltage readings were compared. This small error implies that the simulation results and the real-time data are almost exactly the same.

3.2. Voltage profile for the 33kV and 11kV buses

From the static load flow simulation result at 8 PM on January 1, 2023, the total grid load during peak season was 59.57 MW, with 840 kW of grid loss. Voltage profiles for the 11kV and 33kV buses is shown in Fig. 2 and Fig. 3. Voltage levels are categorized into three states under clause 5.5 of the Bhutan Grid Code 2024:

Normal (0.95 to 1.05 times normal values), Alert (0.9 to 1.1 times nominal values), and Emergency (beyond 0.9 to 1.1 times nominal values). Seems to be two tables?

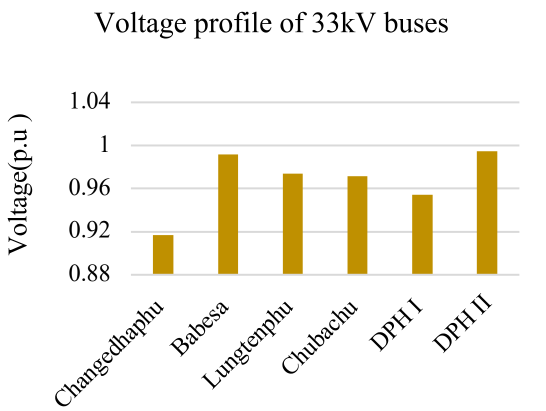

Fig.2: *Voltage of 33 kV buses*

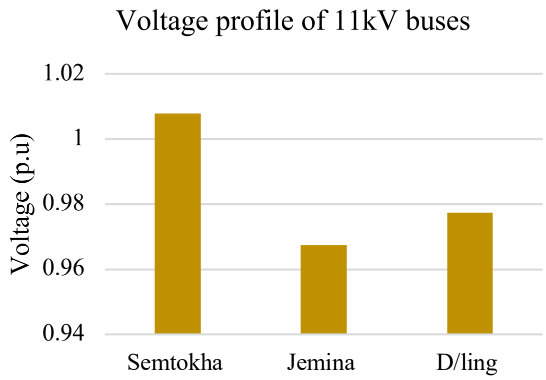

Fig. 3: *Voltage profile of 11 kV buses*

All bus voltages were found to be within acceptable limits as shown in the Fig. 2 and 3, with the exception of the 33kV bus at Changedaphu, which is at 0.916 p.u. Problems with format of Fig 1 and Fig 2.

3.3. Transformer loading for all substations

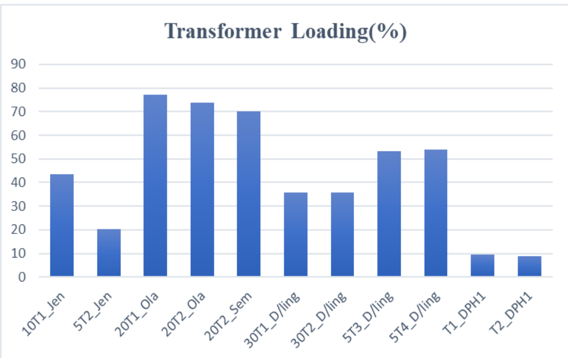

Fig.4: *Transformers loading profile*

Transformer loading of all the substations are within limits, staying below 80%. Fig. 4 illustrates the loading profiles of various transformers. The Olakha and Simtokha substations are loaded nearer to its limit while the DPH1 is lightly loaded showing nonuniformity in the distribution of loads.

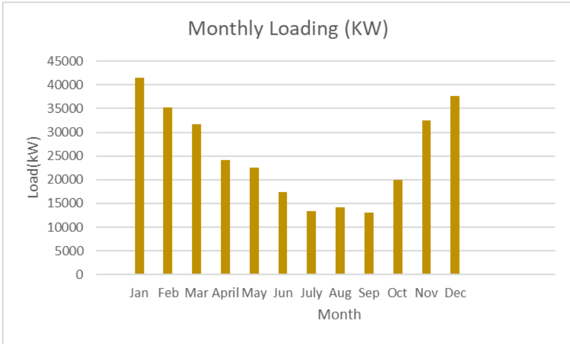

Fig.5: *Monthly load profile of Thimphu network*

3.4. Monthly network loading for the year 2023

The monthly loading of the Thimphu network for 2023 is illustrated in Fig. 5. It is observed that the network experiences heavy loads during the winter months of November, December, January, February and March, while the summer months show lighter loads.

3.5. Seasonal grid loading and voltage profile for complete one year (2023)

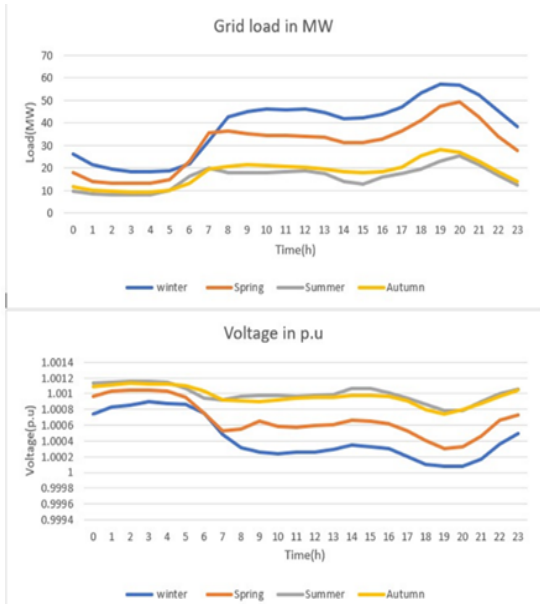

Fig.6: *Daily Load and Voltage profiles of Thimphu network*

Fig. 6 presents the voltage profile and grid load of the Thimphu Distribution Network for the entire year of 2023. The data reveals that bus voltages are often higher during the summer compared to the winter. Voltage levels generally remain between 0.95 and 1.05 p.u. The peak load period, typically lasting four to five hours, occurs in the evening and at night—coinciding with the time when electric vehicles (EVs) are being charged. The grid load during these periods rises significantly due to the increasing number of EVs, many of which are primarily charged towards evening and night hours.

3.6. Grid losses for the year 2023

Throughout the year, the average grid loss of the Thimphu Distribution Network ranges from 500 to 900 kW, as illustrated in Fig. 7.

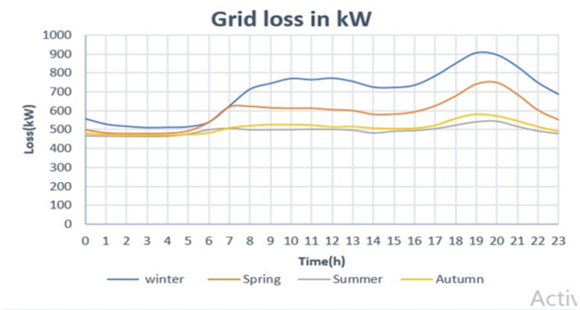

Fig.7: *Grid power loss (kW) of Thimphu network*

3.2.4 Voltage profile for the 33kV and 11kV buses

As anticipated from the results of the seasonal voltage profile evaluation of the 11kV substations, the voltage levels across the 11kV buses remain within acceptable limits. Fig. 6 below illustrates the 11kV bus voltages.

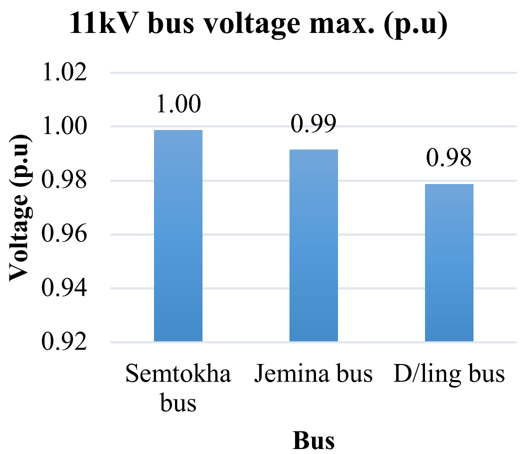

Fig.8: *Voltage profile of 11kV buses*

As shown in Fig. 8, the voltage profiles of the 33kV buses in the simulation for the entire year 2023 are all within allowable limits, except for the 33kV bus at Changedaphu, which has a voltage profile of 0.93 p.u., indicating that this bus is either weaker or heavily loaded.

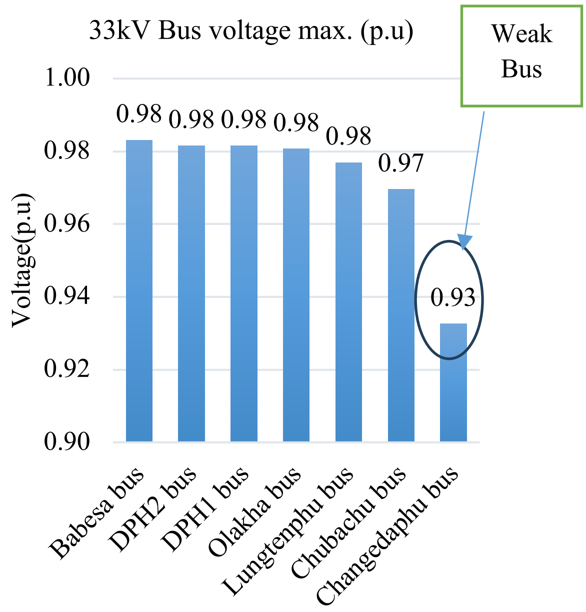

Fig.9: *Voltage profile of 33kV buses*

4. CONCLUSION

This paper presents the results of an impact analysis on the electric vehicle (EV) load on the existing Thimphu Distribution Network. The study involved quasi-dynamic and static load flow simulations to examine voltage profiles and loading. Analysis of EV charging patterns revealed that most EVs are charged between 6 and 9 p.m., coinciding with peak load hours. This peak load period in the evening and night, when EVs are primarily charged, significantly influences load patterns.

Seasonal analysis showed that winter loads are higher than in other seasons, while summer loads are lower. Daily load variation peaks in the evening and night, aligning with EV charging times. All substations connected to EV charging stations (EVCS) maintained voltage stability between 0.95 p.u. and 1.05 p.u., except for the Changedaphu substation, which consistently operates at a lower voltage around 0.9 p.u., indicating an alarming status. Additionally, lines connected to the Changedaphu substation, especially the one linking Motithang to Changangkha, were found to be overloaded, exceeding the line loading limit.

Overall, the simulation results indicate that network instabilities are minimal with the current number of EVs, with the notable exception of the Changedaphu substation, which experienced low voltage violations.

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