EVs Grid Integration Performance Evaluation and Congestion Prevention

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Abstract

The ecosystem friendly and socio-economical merits of Electrical Vehicles (EVs) have enhanced its application globally. Although it is widely argued that EVs grid integration undermines power system security, reliability and upsurge electricity consumption, but the benefits in emission reduction is enormous, which conforms to the Asian Pacific Partnership on Clean Development and Climate agreement with US. However, the purpose of this study is to evaluate the impact of EVs on Medium Voltage (MV) distribution network: voltage stability and thermal overloading of transformers and cables on an IEEE 14-Bus system. The proposed method is a holistic approach in which the impact on the steady state operation of individual components (EV charger, load, transformers and buses) of the system would be investigated for reliability. A load flow analysis would also be conducted on the network for power loss evaluation. However, the anticipated results of this study show that integration of large number of EVs to grid system increased line losses, transformer and cable overloading, and reduced system stability, hence, the needed for architecture compensation cannot be overemphasized. Therefore, the results after Bus compensation should show improved system stability, voltage profile, reduced thermal loading and congestion.

Specific Objectives

- To investigate the state-of-art of EV technology.
- To demonstrate how EV grid integration impacts distribution network voltage stability and thermal loading of transformers.
- To evaluate and mitigate power losses associated with EV grid integration.
- To develop a model for MV distribution network power flow stability with high integration of EVs.

Introduction

EV grid integration is currently gaining popularity and in due diligence various literatures have explored its associated shortcomings, such as power quality, losses, stability, demand imbalance, system overloading problems, etc., details in [1] – [4]. Some of these shortfalls have been likened to EV load charging mode which could be substantially different from the regular loads [5]. A panacea to these EV charging glitches include the use of optimal time-of-use schedule to effectively move the EV load charging to off-peak load periods [6] and smart EV charging to optimally distribute the energy among EVs and reduce the impact on grid [7]-[9].

Although many literatures have extensively investigated the impact of EV grid integration but there is still a gap in analyzing in totality the extent of thermal loading, power losses and to develop an accurate model for EV grid penetration power flow stability.

System description

The IEEE 14 bus system used in this study has a total generating capacity of 272.4MW, 259MW connected traditional load and 7MW EV load distributed over 6 fleet operator stations (Buses 4,5,9-12) with total of 175 battery charging units of 40kW each.

It is important to note that the power transformers in the network shown in figure 1 are assumed to be operating at rated value under steady state condition. According to reference [10], operation in line with these conditions is comparable to operation in continuous ambient temperature of 30℃ for air cooled power transformers. However, ambient temperature is key in determining transformer thermal loading since operating temperature is ambient temperature plus temperature rise due to load. This means that transformer thermal loading capability defers from location to location even when operating at the same load level.

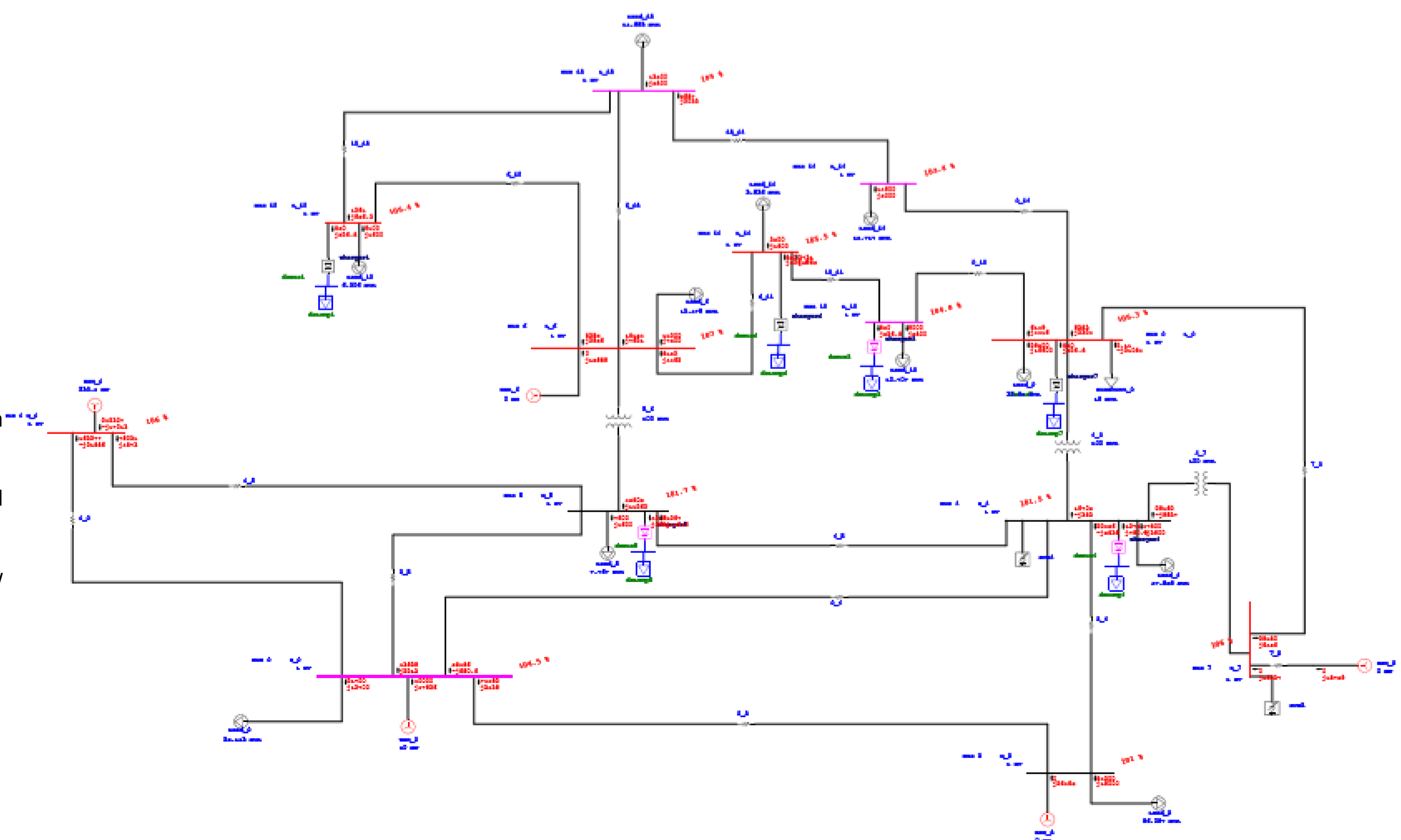

Fig. 1: IEEE 14 Bus Network with EV Integration Simulation Result

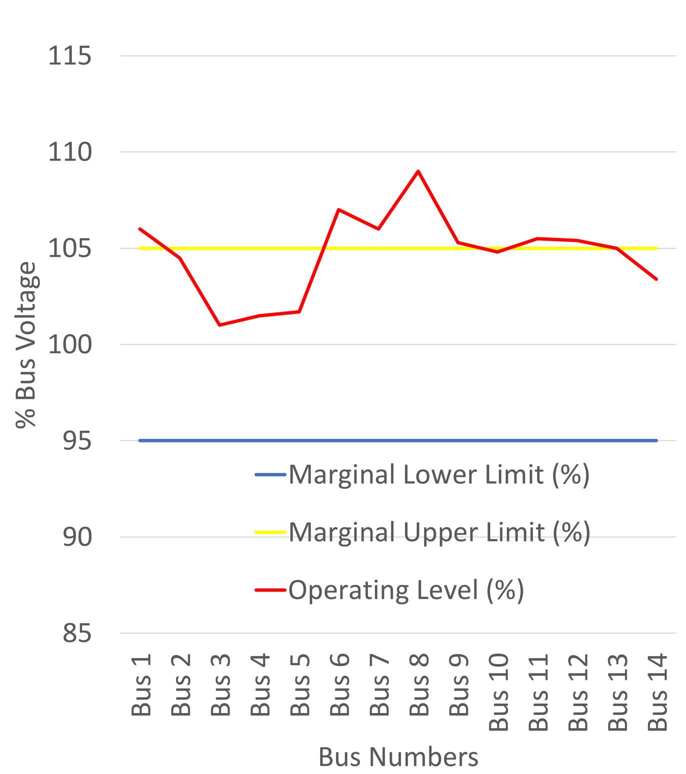

Fig. 2: Voltage Stability Result

Table 1: Transformer Loading Result

Transformer Placement	Electrical Loading (pu)		Thermal Life Expectancy loading (pu)	
	Without EV Load	With EV Load	Without EV Load	With EV Load
Bus 4_7	1.00	1.0295	1.1850	1.2200
Bus 4_9	1.00	1.0387	1.1850	1.2309
Bus 5_6	1.00	1.0381	1.1850	1.2301

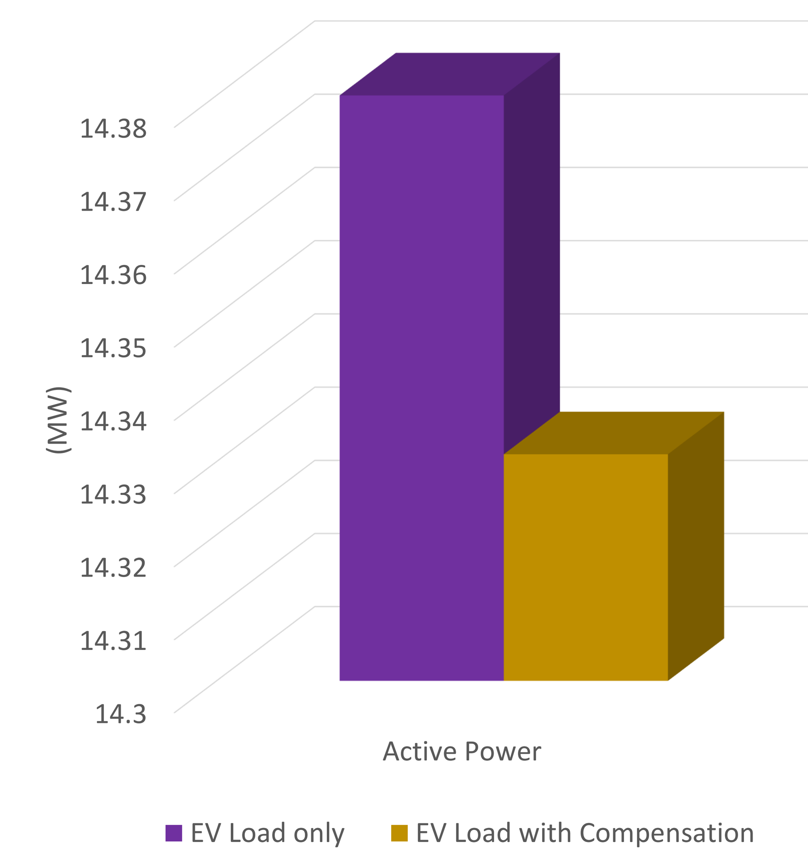

Fig. 3: Power Loss Result

Results

Figure 1 shows the load flow analysis result of the system under study. Stability violations can be seen from buses 1, 6, 7, 9, 11 and 12 with red indicators and marginal warning limit indicators in purple on buses 2, 10, 13 and 14.

Figure 2 shows the network voltage profile after the integration of EVs. Buses 1, 5 – 12 operated over the upper marginal limit of 105%, which depicts high system voltage instability and can lead to system voltage collapse if sustained for a long time.

The transformer thermal life expectancy loading deductions made in table 1 is subject to the US 2019 average temperature of 11.5℃ [11]. This shows that the higher the transformer loading the lesser the life expectancy.

Figure 3 shows that the higher EV grid penetration, the more the losses. But with the inclusion of capacitor shunt bank (SCB) compensator the losses reduced.

In conclusion, it can be deduced from the forgoing that EV grid integration undermines the system's power flow stability, enhances operating voltage violation, increases losses and transformer thermal loading. Also, optimal placement of the fleet operator stations on the bus improves the system's stability and reduces congestion. Fleet operator stations with higher EV load capacity are best located closer to the power source within the network.

However, not all the objectives of this research have been achieved and research is still ongoing to broaden the solution base especially in developing an accurate model for MV distribution network power flow stability with high EV penetration.

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