OPTIMAL PLACEMENT AND SIZING OF ELECTRIC VEHICLE CHARGING STATIONS ON DISTRIBUTION SYSTEMS FOR ENHANCED POWER SYSTEM STABILITY

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A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Electrical)

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April 2024

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **" Optimal Placement and Sizing of Electric Vehicle Charging Stations on Distribution Systems for enhanced power system stability."** was prepared by **Lau Tiong Kiang** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electrical) at Universiti Tunku Abdul Rahman.

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ABSTRACT

The integration of Electric Vehicle (EV) charging stations with power distribution networks is crucial for advancing sustainable transportation. This study addresses the vital need for optimal placement and sizing of EV charging stations to enhance power system stability. Failure to conduct these studies could lead to suboptimal network performance, increased power losses, and reduced reliability. As the demand for reliable and accessible EV charging infrastructure grows, challenges in grid integration become apparent, necessitating a thorough investigation into the optimal placement and sizing of these stations.

Using Electrical Transient Analysis Program (ETAP) Software and a modified IEEE 13-bus test system, the research investigates the impact of EV charging loads on network stability, power losses, and reliability. Detailed load flow analyses are conducted to assess different charging load scenarios, emphasizing the importance of prioritizing voltage stability to minimize power losses and ensure network reliability. A sequence algorithm systematically analyzes each bus in the distribution system, suggesting optimal locations for EV charging stations while considering load handling capability and network losses.

The study showcases the significance of correct sizing and placement of EV charging stations in improving overall system reliability and efficiency. These findings align with Malaysia's energy and transportation goals, supporting the transition to Electric Mobility outlined in the National Automotive Policy (NAP). By addressing critical technical and operational challenges, this research underscores the necessity of optimal sizing and placement of EV charging stations to optimize power system stability and efficiency in the evolving landscape of electric mobility, thereby contributing significantly to the sustainability of transportation infrastructure.

TABLE OF CONTENTS

DECLARATION	**ii**
APPROVAL FOR SUBMISSION	**iii**
ACKNOWLEDGEMENTS	**v**
ABSTRACT	**vi**
TABLE OF CONTENTS	**vii**
LIST OF TABLES	**ix**
LIST OF FIGURES	**x**
LIST OF SYMBOLS / ABBREVIATIONS	**xi**

CHAPTER

1	**INTRODUCTION**		**1**
	1.1	General Introduction	1
	1.2	Importance of the Study	2
	1.3	Problem Statement	3
	1.4	Aims and Objectives	4
	1.5	Scope and Limitation of the Study	5
	1.6	Contribution of the Study	6
2	**LITERATURE REVIEW**		**7**
	2.1	Introduction	7
	2.2	Electric Vehicle Charging System in malaysia	7
	2.3	Historical Trends and Future Forecasts	7
	2.4	Environmental Impact	8
	2.5	Impact of EV Charging on Power Systems	9
	2.6	Optimization Tecnniques for EVCS Placement and Sizing	10
	2.7	Justification for the Use of ETAP in This Study	11

3	**METHODOLOGY AND WORK PLAN**	**12**
	3.1 Electric Vehicle Charging Stations (EVCS) Types	12
	3.2 Software and Simulation Tool	12
	3.3 System Modeling	13
	3.4 Load Flow Analysis	17
	3.5 Optimization Technique	17
	3.6 Statistical Analysis	19
4	**RESULTS AND DISCUSSIONS**	**20**
	4.1 Introduction	20
	4.2 Load Flow Result Using ICE TYPE 2 EVCS	20
	4.3 Load Flow Result Using COMBO CCS TYPE2 EVCS	24
	4.4 Load Flow Result Using CHAdeMo EVCS	27
	4.5 Voltage Stability Result EVCS Connect to Buses	29
	4.6 Summary	31
5	**CONCLUSIONS AND RECOMMENDATIONS**	**33**
	5.1 Conclusions	33
	5.2 Recommendations for future work	34
REFERENCES		**34**

LIST OF TABLES

Table 3.1: Data on the Lines 15

Table 3.2: Data on the Buses 16

Table 4.1: Branch Losses connecting using IEC TYPE2 21

Table 4.2: Branch Losses connecting using CCS TYPE2 24

Table 4.3: Branch Losses connecting using CHAdeMO 27

LIST OF FIGURES

Figure 1: Types of EV Charging in Malaysia	12
Figure 2: Single Line Diagram for IEEE 13 bus distribution network	13
Figure 3: Flowchart of Sequence Algorithm	18
Figure 4.1: IEC TYPE2 Branch Losses Result in kW	22
Figure 4.2: IEC TYPE2 Branch Losses Result in kVAR	22
Figure 4.3: CCS TYPE2 Branch Losses Result in kW	25
Figure 4.4: CCS TYPE2 Branch Losses Result in kVAR	25
Figure 4.5: CHAdeMo Branch Losses Result in kW	28
Figure 4.6: CHAdeMO Branch Losses Result in kVAR	28
Figure 4.7: EVCS Connected to BUS1	30
Figure 4.6: EVCS Connected to BUS10	30

LIST OF SYMBOLS / ABBREVIATIONS

EV	Electric Vehicle
EVCS	Electric Vehicle Charging Station
kW	Kilowatt
kVAR	Kilovolt Reactive

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Electric Vehicles (EVs) have emerged as one of the critical aspects under transportation plan for sustainable development in Malaysia and rest of the world. Moving towards electric mobility requires the introduction of a strong electric vehicle charging station (EVCS) network integrated with the current electrical power distribution infrastructure.

In addition to being a historic point for renewable energy vehicle adoption, Electric Vehicle Charging Stations (EVCS) have a potential to be advantageous or disadvantageous to the stability and reliability of power systems. Therefore, the objective of this research will be of value in determining the best locations and sizes for Electric Vehicle Charging Stations (EVCS) in order to improve the stability of the power grid in Malaysia.

One significant issue that stands out in the declaration is the possible consequences of EVCS on the security and consistency of energy systems. Although the use of electric vehicles symbolizes a milepost for the acceptance of renewable energy cars, the global implementation of EVCS might cause several grids stress if it isn't cautiously prearranged and executed. Charging electric vehicles sometimes increases the capacity of an already stressed grid and can cause a major malfunction if not effectively configured.

A thorough investigation is necessary to address these concerns related to power supply and determine the precise spots and sizes for different projects supported by EVCS. Factors related to usage, infrastructure, or grid qualifications present a daunting task as it must be anticipated to have a positive and beneficial impact on grids' security and stability, rather than a negative one. Furthermore, technological advancements linked to smart charging and management related to de-managing demand is also another solution that can deny the influence of the electronic vehicle on power supply.

This study will propose the ideal arrangement including the exact positioning and proportions of EVCS which could minimize the negative impact to power distribution system along with the increase of use of EV.

The objective of this project is to study the optimum locations and sizes for Electric Vehicle Charging Stations (EVCS) in urban and rural power distribution networks of Malaysia, and also to study the effect of EV charging on the stability and dependability of these networks.

The project endeavors to make a significant contribution in the field of power system engineering by developing a model that can assist in strategic planning of Electric Vehicle Charging Station (EVCS) deployment by ensuring the power system stability without hampering the development of sustainable transportation in Malaysia.

1.2 Importance of the Study

The significance of this study is specifically important to Malaysia since it corresponds with the National Automotive Policy (NAP) of Malaysia which strives for the implementation of energy-efficient vehicles such as electric vehicles (EVs). The intent of the Malaysians government to reduce greenhouse gas emissions and lessen dependency on fossil fuels necessitates the enhancement of Electric Vehicle Charging Infrastructure. By optimizing the placement and sizing of Electric Vehicle Charging Stations (EVCS), this research is supporting directly the objectives of the NAP policy of Malaysia to increase the capacity of the power grid to accommodate the anticipated influx of electric vehicles. This research not just supports a sustainable transportation transition in Malaysian but contributes to the goals of the nation in energy efficiency and environmental sustainability. Hence, the study is needed to advice the policy decisions and investments in infrastructure to realize the vision for a green future transportation in Malaysia.

1.3 Problem Statement

Malaysia's concerns towards the adoption of the Electric Vehicles (EVs) are interrelated with larger multi-sector challenges in its transition towards sustainable transportation. In spite of having environmental and economic drivers to the uptake of these EVs, Malaysia's electric charging infrastructure (EVCS) is still at its infancy stage.

Limited accessibility to charging facilities in various regions is also one factor that discourages consumers to buy EVs because charging facilities in Malaysia is being rolled out at an slower pace as compared to excessive volume of new EV purchases.

Another very important issue is that the present power grid has no capacity what so ever to handle multiple vehicle come in to have a level 2 or level 3 charge at the same time. As more electric vehicle hit the road, during the peak hours when ever one start to do a fast charge at the same time, the demand for electricity will go up, which might result in the central power station could not able to supply enough power. Again, if that happens to the power grid, it will definitely cause problem in term of power stability and supply. So, this lot of strategic planning to deploy the electric car charger host, which mean it must be deploy within the area where the existing power grid can be accommodated so as to not lower the reliability power performance.

Furthermore, EVCS deployment in Malaysia faces other challenges due to the absence of a solid policy framework and motivating factors to promote the adoption of EVs. Without massive investment in the charging infrastructure, and clear cut regulatory requirements for charging station, EV adoption will be slow. When the EV adoption is slow, the move to lower GHG emission may not be realized, and a sustainability levels Malaysia is dearly yearning to achieve may be overshadowed. Therefore, and in view of the electric mobility adoption challenges stated above, this study aims at understanding the technical viability of integrating EVs to the transportation market of Malaysia. By determining the optimal placement and sizing of EVCS under the realistic EV deployment scenarios, this research will develop strategies for an efficient and reliable integration of the EVs to Malaysia's transportation and energy system.

1.4 Aims and Objectives

The main aim of the study is to evaluate the existing EV charging infrastructure in Malaysia and propose optimization techniques by using ETAP IEEE 13-Bus system simulations for the EVCS placement and sizing. The objectives include:

1. Assessing the impact of EV charging on the existing power systems: Conduct a detailed analysis using ETAP to assess the impact of integrating EV charging station on grid stability, power quality and load in the IEEE 13-bus system.
2. Finding the best location to optimally place the EV Charging Stations: Using the ETAP simulation tools to identify the most effective locations for EVCS that would minimize losses in the grid, maintain voltage stability and the load across the grid.
3. Sizing of EV charging stations: To simulate the EVCS capacity to satisfy the charging demand but without causing any burden to the power grid, the load flow analysis in ETAP.

1.5 Scope and Limitation of the Study

This study focuses primarily on evaluating and optimizing the Electric Vehicle Charging Systems (EVCS) in Malaysia with respect to the existing infrastructure. This study has considered IEEE 13 bus system as the primary simulation model. IEEE 13 bus system is widely known for its utility in power system analysis and planning however this model does not represent the real world scenarios accurately. The limitations in this study arise from the same IEEE 13 bus system. Hence it should be noted that though the use of IEEE 13 bus system is clear for experimental purposes with precise control, IEEE 13 bus system does not extensively match the intricate operations of the Malaysian power grid concurrently handling the uncertainties, the various challenges faced by the EV charging infrastructure in Malaysia's different urban and rural areas. In order to warrant the validation and improve the research findings credibility, particularly in optimizing EV charging infrastructure in Malaysia, future work should involve data more reflective of real world condition. This involved obtaining granular data of user charging behavior and patterns, investigating the impact on grid stability by fast charging technology, analyzing the scalability of the EVCS network in align with the future massive EV uptake, as well performing macro economic and policy impact evaluations. These multiple-faceted and specialized investigations will guarantee that the strategies developed for EVCS placement and sizing are robust, economically viable and efficient in supporting Malaysian transformation into sustainable transportation while considering the ongoing technological and policy environments changes.

Although this technical study is comprehensive, its principal emphasis is on branch losses in the IEEE 13-bus system in connection with the assessing of the effects of Electric Vehicle Charging Stations (EVCS) on power systems. The author limits the scope of the research to branch losses, which represents part of the impacts of EVCS on the power system. However, a full perspective in the assessment of the impacts of EVCS on the overall performance and security of the power system is missing.

Key elements like voltage fluctuation, system reliability, and ability to manage peak load conditions are not fully investigated. Additionally, the study's dependence on simulated data may fail to produce enough evidence to accurately forecast real-world outcomes.

Because the IEEE 13-bus system is used for analytic simplicity, it is not an ideal representation of the dynamic and complex characteristics of the Malaysian power grid. Therefore, it does not tend to elucidate a diversified charging infrastructure's interaction with said national grids. Consequently, the conclusions of this study are not profoundly comprehensive enough to capture downstream aspects of the broader national grid's EVCS implications. To fill these deficits, forthcoming research should broaden its scope to consist of more than merely branch loss analyses. Instead, the research must feature a comprehensive appraisal of grid performance incorporating real world scenarios under the patronage of formidable EVCS. This increased rigor will ensure that the resultant insights and findings resonate with the greatest authenticity and depth.

1.6 Contribution of the Study

These findings are helpful for completing existing knowledge base and make available recommendations on optimizing EVCS. Moreover, it can assist different stakeholders such as policy makers, electricity grid planner or operator, and investors to have better understanding and to enhances the EV charging network in Malaysia. These recommendations can facilitate the adoption of electric mobility by the people in Malaysia. It also enhance the EV charging network in Malaysia without reaching to any misleading comparisons of result in a lack of feasibility.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The milestone deliverable is the Literature Review, a critical synthesis of the previous work done relevant to the whole project work. The objective of this milestone is to review the scholarly articles, books, business dissertations, conference proceedings and other research documents related to the challenges and solutions of the distribution grid's stability due to the integration of electric vehicle charging stations (EVCSs), to benefit the context of Malaysia.

2.2 Electric Vehicle Charging System in Malaysia

Currently, the three dominating EV architectures in Malaysia charging standards are IEC Type 2, Combo CCS Type 2 and CHAdeMO. IEC Type 2 connectors are able to support AC charging up to 22 kW for 230/400 V system(*Guru Swift EV Charger 22kW (32A | 3-Phase | Type 2 Plug) | EvGuru*, no date). On the other hand, Combo CCS Type 2(*EV Connectors - Type 1, Type 2, CCS, CHAdeMO, ChaoJi*, no date) brings DC fast-charging capability all the way up to 240 kW for rapidly charging with high power capability. Lastly, CHAdeMO is good for up to 400 kW of DC charging best suited for higher power charging needs(*What is CHAdeMO EV charging? - cinch*, no date). These standards are a combination of effective technology and regional preferences that will build the backbone of a global EV charger infrastructure by providing various vehicle inlets and preferences(Acharige *et al.*, 2023).

2.3 Historical Trends and Future Forecasts

The historical development of Electric Vehicle (EV) charging infrastructure in Malaysia has played a crucial role in driving the country's shift towards sustainable transportation. Initially, the emphasis was on forming a foundational network that catered to EVs in a budding market, primarily concentrating on urban spaces. With time, and with improvements in the charging systems, the infrastructure swayed to include slow and fast charging stations, indicating that the country possesses a larger EV charger network.

In the future, Malaysians want their country to be at the center of the electric vehicle industry. They've set 2030 as their target date for installing 125,000 electric charging stations(Syahirah and Farah, 2024). This huge number of charging spots will be essential as Malaysia runs to catch up with the growing trend of electric vehicle use.

There's more planning beyond the actual number of vehicles and the necessity of the power network to keep them happy. The future of plugging in for a charge in Malaysia seems almost certain to include Photovoltaic Electric Vehicle Charging Stations, PEVCS—also known as solar-powered charging stations. And to make sure there's enough power and people can actually get to the EVCS—electric vehicle charging stations—officials are considering what they call Multi-Criteria Decision-Making methods.

2.4 Environmental Impact

The environmental effects of installing and conducting charging stations for Electric Vehicles (EVs) are considerable. Initially, the primary goal of EVs is to reduce reliance on fossil fuels and decrease greenhouse gas discharges and to enhance air quality. Nevertheless, the ecological ramifications of setting up and running widespread EV charging infrastructure are intricate and multifaceted. The boom in intensified electricity usage for EVs can strain current power grids, forcing the power industry to install more energy sources. Inadvertently, this practice revitalizes the ordeals against current green power generation in producing the extra energy needed. Research, for example, those made public in the IEA's Global EV Outlook 2023, shows that environmentally friendly electric mobility needs an exhaustive merger of renewable power sources with charging infrastructure. Such research stresses the need to switch to solar and wind power necessary for an ever-growing number of recharging facilities to avoid the danger of an exacerbating carbon footprint brought about by escalated energy consumption(- International Energy Agency, 2023).In addition, the ecological consequences of manufacturing EV charging stations, distributing and using them, which include taking what is needed from the environment, and what should be done with them when they no longer work, are so huge, the only credible way to reckon the costs and benefits of the whole process is to do a lifecycle calculation. The lifecycle calculation can be, and indeed always is, carried out in different ways and with different goals in mind; first cost is only one measure, payback time another. But the true situation is massively more complex than that, and only the full lifecycle of a technology at every scale from the personal to the global really takes everything into account.

To summarize, transitioning to electric cars is a great opportunity for cutting greenhouse gases, but it also implies more electricity generation. It's essential that we use sustainable energy to get that power.

2.5 Impact of EV Charging on Power Systems

The information provided in the guide on electric vehicle (EV) charging and the impact on power systems has been at a pretty high level(Tasnim *et al.*, 2023)(Bass and Zimmerman, 2013), getting enough information to help guide the objective and focus of the whitepaper; however, a review of the literature on EV charging on power systems have several important things that need to be considered to maintain the stability and functionality of the power distribution network(der, no date).

EV charging can bring significant load to power systems, which can lead to higher peak demands(Gilleran *et al.*, 2021; Suski *et al.*, 2021). In addition to peak demands, high charging demand can also lead to voltage sags and frequency deviations. Studies carried out on the integration of EV charging with the grid has shown there is a need for robust grid management systems to be put in place to handle the unpredictable and intermittent demand for EV charging(Ikechukwu *et al.*, no date).To limit adverse or negative impacts toward the grid stability, there are a number of strategies that reviewed in the literature, which are; smart charging strategies, demand response program, and vehicle to grid technologies. Standardization in charging method is necessary in order to ensure a compatibility and safety to any Electric Vehicle and Charging Station, as mentioned in the literature.

In addition, the literature indicates that there is a dialogue as to what are the regulatory frameworks and economic incentives that would motivate an upgrade in the power system to handle a growing penetration of EVs(Sierzchula *et al.*, 2014). There is a call for joint effort between the electric utility providers, EV manufacturers and policymakers in order to make sure EV charging stations are properly integrated so they don't jeopardize the stability of the power system(Energy Agency, 2021).

2.6 Optimization Techniques for EVCS Placement and Sizing

Optimal deployment of Electric Vehicle Charging Stations (EVCS) is important for the effective integration of EV charging infrastructure into the power distribution networks(Chen *et al.*, 2021). This section aims to optimize the placement and sizing of EVCS to ensure the stability and efficiency of power system, particularly in the Malaysian context. The objective is to minimize power losses and ensuring voltage stability(Khasanov, Kamel and Abdel-Mawgoud, 2019), while considering the economic and spatial constraints of the distribution system. The approach will involve utilizing analytical and computational techniques to identify optimal EVCS locations and sizes that will maintain the reliability and efficiency of the power grid despite the additional loads from EV charging. This study intends to prioritize a balance optimization process that minimizes the negative impacts to the power grid to further promote the widespread adoption of electric vehicles(Ahmad *et al.*, no date; Chen *et al.*, 2021).

The teaching-learning-based optimization (TLBO) method(Krishnamurthy *et al.*, 2023), which simulates a classroom's teaching and learning process, is among the most notable optimization techniques. This method promotes iterative improvement in solution quality, with the "teacher" phase refining the overall solution and the "learner" phase refining individual solutions. By considering various constraints such as cost, power loss, and voltage stability, this method can successfully tackle the optimization challenges posed by EVCS placement and sizing.

In addressing EVCS optimization issues, other methods, such as genetic algorithms (GA)(Korotunov, 2020), particle swarm optimization (PSO)(Liu *et al.*, 2021)(Mavrovouniotis, Ellinas and Polycarpou, 2018a), and ant colony optimization (ACO)(Mavrovouniotis, Ellinas and Polycarpou, 2018b), can be used. These methods provide a stochastic search procedure that helps find optimal solutions and solutions close to optimal, thereby effectively dealing with various constraints and multiple objectives set in the EVCS deployment scenario.

2.7 Justification for the Use of ETAP in This Study

The Electrical Transient Analyzer Program (ETAP) is a robust simulation tool used in this study for load flow analysis and to simulate the electrical behavior of power distribution systems with EV charging loads. The choice of ETAP is justified by its comprehensive analytical capabilities, user-friendly interface, and widespread acceptance in electrical engineering research and practice(Shanmugam, Vannarath and Dhandapani, 2022).

ETAP stands out for its ability to accurately model and analyze the performance of electrical power systems under various conditions, including the integration of EV charging stations. Its advanced simulation modules enable the detailed examination of voltage stability, power losses, load distribution, and overall system efficiency, making it an invaluable tool for this research.The decision to employ ETAP is further supported by a critical review of its previous applications in similar studies, where it has proven effective in assessing the impacts of EV charging on power distribution networks. By facilitating a comprehensive analysis of different EVCS configurations, ETAP allows for a nuanced understanding of their implications for grid stability and efficiency. This justification underscores ETAP's role in advancing the study's aims of optimizing EVCS placement and sizing for improved power system performance(Rizwan *et al.*, 2021)(Mainul Islam, Shareef and Mohamed, 2018a).

CHAPTER 3

MATERIALS AND METHODS

3.1 Electric Vehicle Charging Stations (EVCS) Types

Electric Vehicles Charging Stations series were introduced into the system in specific bus locations. The charging stations were modelled based on the type of the connector such as IEC Type 2, Combo CCS Type 2 and CHAdeMO, and their power demand characteristics were reflected on the appropriate load models. The model of the charging stations took into account the AC/DC power requirements, voltage level, and maximum current ratings based on the standard specifications.

Connector Type	Connector	AC/DC Power	Charging Standard			Vehicle inlet
			Voltage (V)	Current (A)	Power (kW)	
IEC Type 2		AC charging 1Phase/ 3 Phase	230 V ac / 400 V ac	Up to 32 A ac	Up to 22 kW	
Combo CCS Type 2		DC charging	Up to 400 V	Up to 400 A dc	Up to 240 kW	
CHAdeMO		DC charging	Up to 1000 V	Up to 400 A	Up to 400 kW	

Figure 1. Types of EV Charging in Malaysia. (*GUIDE ON ELECTRIC VEHICLE CHARGING SYSTEM (EVCS)*, no date)

3.2 Software and Simulation Tool

To simulate the electric behavior of the power distribution system including Load flow analysis, ETAP (Electrical Transient Analyzer program) software was used. ETAP has the advantage of having advance analytical modules and being user friendly which could include whole building from End to End as ETAP could generate analytical report.

3.3 System Modeling

The study is based on the modified IEEE 13-bus test system. This system is also a typical distribution feeder that it has different types of load demand, etc. to develop concerning standards for purchase criteria for resilience systems, such as IEEE 1366. This test system was environment on ETAP software including all the relevant electrical components such as the transformers, lines, loads, and other generating sources.

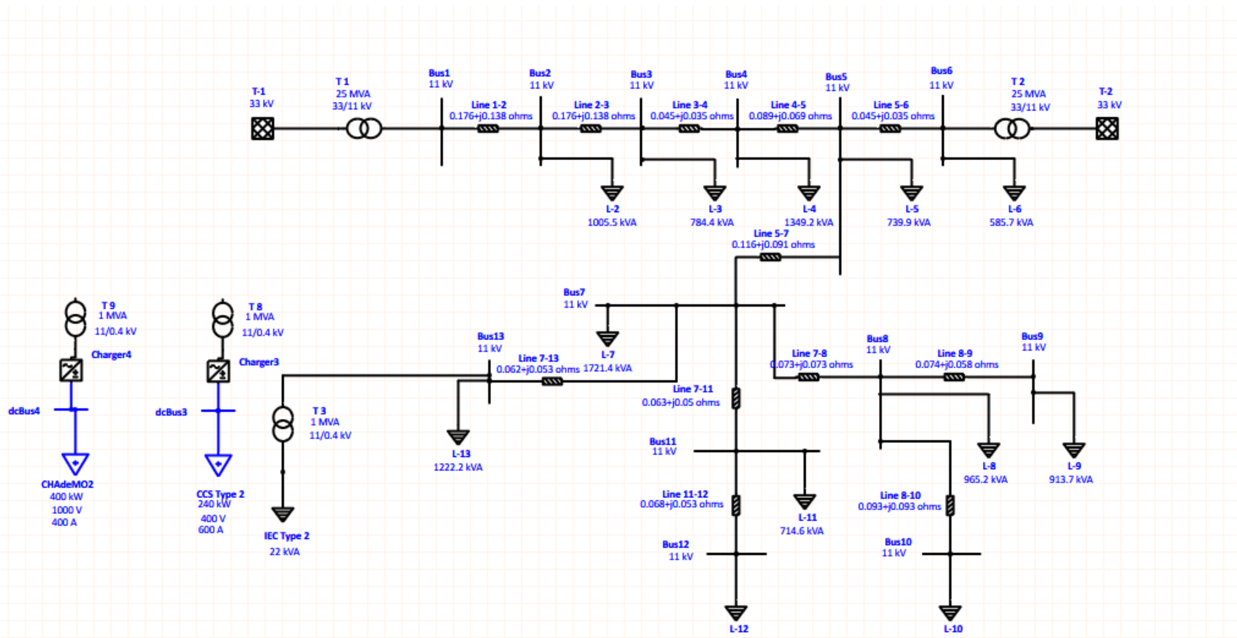

Figure 2. Single Line Diagram for IEEE 13 bus distribution network.(Mainul Islam, Shareef and Mohamed, 2018b)

The transformers (T1, T2, T3): T1 and T2 change the high voltage level brought from the grid (33kV) into a lower one for distribution (11 kV). Each transformer's power is 25 MVA for T1 and T2. T3 is a transformer attached to the EVCS (Electric Vehicle Charging Station).

• Buses (Bus1, Bus2, etc.): Act as junction points where multiple lines connect. The voltage measurement of each bus is 11 kV.

• Lines (Line 1-2, Line 2-3, etc.): Carry electricity between the components, with notation of their impedance (resistance and reactance) to compute the voltage drop down and the power flow.

• Loads: Represented by triangles pointing downwards, showing the power draw on the system (e.g., 1005.5 kVA at Bus2).

• EV Chargers (IEC Type 2, CCS Type 2 and CHAdeMO.): Specific loads for electric vehicles with their transformer ratings and types. There are also CHAdeMO, CCS Type 2 and IEC Type 2 chargers with respective power ratings.

Table 3.1. Data on the Lines.

BUS	Positive Sequence Impedance			
ID	R	X	Y	Unit
Line 1-2	0.176	0.138	0	Ohm
Line 2-3	0.176	0.138	0	Ohm
Line 3-4	0.045	0.035	0	Ohm
Line 4-5	0.089	0.069	0	Ohm
Line 5-6	0.045	0.035	0	Ohm
Line 5-7	0.116	0.091	0	Ohm
Line 7-8	0.073	0.073	0	Ohm
Line 7-11	0.063	0.05	0	Ohm
Line 7-13	0.062	0.053	0	Ohm
Line 8-9	0.074	0.058	0	Ohm
Line 8-10	0.093	0.093	0	Ohm
Line 11-12	0.068	0.053	0	Ohm

Table 3.2. Data on the Buses.

BUS	LOADING	
ID	MW	Mvar
Bus1		
Bus2	0.890	0.468
Bus3	0.628	0.470
Bus4	1.112	0.764
Bus5	0.636	0.378
Bus6	0.474	0.344
Bus7	1.342	1.078
Bus8	0.920	0.292
Bus9	0.766	0.498
Bus10	0.662	0.480
Bus11	0.690	0.186
Bus12	1.292	0.554
Bus13	1.124	0.480

3.4 Load Flow Analysis

The comprehensive load flow analysis conducted in this examination was an extensive appraisal of the power distribution system's capability to cater to the supplementary rise in demand from Electric Vehicle (EV) charging stations. By mimicking power flow, voltage outlines, and system squander, underneath fluctuating contingencies, with and sans the EV charging loads, the investigation dissected the system's stability and effectiveness.

This paper utilized the Electrical Transient Analysis Program, specifically implementing a modified IEEE 13-bus test system to model the network under study. They meticulously examined various potential scenarios ranging from minor to substantial EV integration, exploring the diverse charging load concentrations that could result.

The purpose of the analysis was to achieve a detailed comprehension of how varying electric vehicle charging requirements could impact the system's operational capacity, bringing to the fore significant impacts by altering voltage levels and pinpointing bottlenecks where existing losses could be magnified. The study's comprehensive investigation of these future-changing circumstances was pivotal in guaranteeing that the integration of electric vehicle infrastructure is both sustainable and unhampered by instability or inconsistency in the existing power network.

3.5 Optimization Technique Using Sequence Algorithm

The Sequence Algorithm represents an intentional, methodical method for refining the EVCS network. It is constructed to tackle the intricate problem of integrating EVCS into current delivery channels for energy in a manner that keeps pace with or improves network effectiveness.

The process begins at the outset, at bus1, where initial conditions are set. Typically, the BUS variable is initialized to zero to indicate the starting point.
The BUS variable is then increased, indicating that the algorithm is moving on to the next bus in the system. This mirrors the 'sequential' methodology, which requires the analysis to move

through the network one bus at a time.

Assessment: At each bus, the algorithm examines key performance indicators, such as loss of energy, voltage stability and capacity of the EV.

Outcome Preservation: Every bus evaluation's outcome is preserved. This information serves as the foundation for determining whether a bus can serve as a connection point to an EVCS.

Cycling: The program first checks whether the last bus in the sequence (bus13 in this scenario) has been assessed. If not, it cycles through, increases the BUS variable, and repeats the evaluation for the subsequent bus.

Optimizing and Choosing: The algorithm will utilize the data obtained after assessing all the buses to work out the best positions for a limited number of VDUs. The decision-making criteria which the algorithm could use are the cutting of power losses, keeping the voltage within certain stability values, and avoiding system overloads.

The outcome is a list of potential locations for placing EVCS on buses. The algorithm also proposes the most suitable size of the EVCS for each bus.

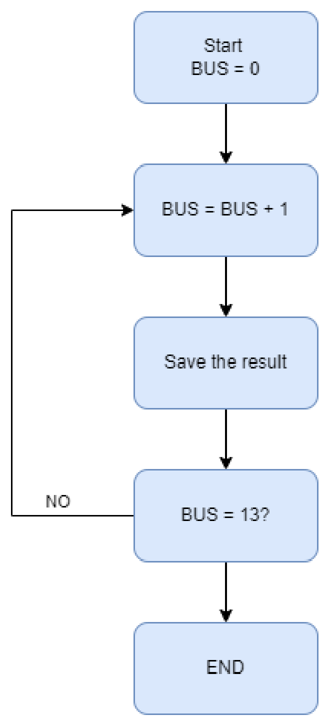

Figure 3 Flowchart of Sequence Algorithm.

3.6 Statistical Analysis

To make a meaningful conclusion from results, different simulation scenarios result were statistically analyzed a number of times, comparing various baseline scenarios with those of distributions which contains various configurations of EV charging stations.

In conclusion, this study has developed an optimal strategy for integration of EV charging stations into existing power distribution network with ensured system stability, reliability, and readiness toward the growing adoption of electric vehicles.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

The incorporation of EVCSs into the electric power distribution system by means of a modified IEEE 13-bus test system is discussed here. The ETAP software is used to perform the analysis and validate three different types of EVCS, namely IEC Type 2, Combo CCS Type 2, and CHAdeMO, connected to different buses of the network. Voltage stability, power loss, load distribution, and overall performance of the system under different EV charging load are the key parameters that were investigated. Three types of EVCS were added to the system then the load flow results, bus loading summary, branch losses, generation, overall and demand loadings are observed and analyzed. Unbalanced load flow scenarios are also discussed to evaluate the power quality and system reliability when the EV charging activity is included in the distribution system.

4.2 Result Using IEC TYPE 2 Connect to Buses

This section describes the result obtained from the ETAP simulation tool. In the simulation, an Electric Vehicle Charging Station (EVCS) was connected to the different bus and the operation of the existing electrical distribution system is studied before and after connecting a charging station to it. After simulation, various result has been obtained regarding, how the connecting a charging affect the grid system. The non-EV branch loss in the system is 145.1kW and 405.4kVAR

Table 4.1 Branch Losses connecting using IEC TYPE2.

1EV			5EVs			10EVs		
	Branch Loss			Branch Loss			Branch Loss	
BUS ID	KW	kVAR	BUS ID	kW	kVAR	BUS ID	kW	kVAR
bus1	145.0	406.1	bus1	144.9	409.1	bus1	145.2	413.7
bus2	145.2	406.3	bus2	145.9	410.2	bus2	147.2	415.9
bus3	145.4	406.5	bus3	145.9	410.2	bus3	148.6	417.7
bus4	145.4	406.5	bus4	146.7	411.3	bus4	148.8	418.1
bus5	145.4	406.6	bus5	146.8	411.6	bus5	149.0	418.6
bus6	145.3	406.5	bus6	146.3	411.3	bus6	148.0	418.0
bus7	145.7	406.8	bus7	148.1	412.5	bus7	151.6	420.5
bus8	145.7	406.8	bus8	148.4	412.8	bus8	152.2	421.0
bus9	145.7	406.8	bus9	148.5	412.9	bus9	152.4	421.2
bus10	145.7	406.8	bus10	148.5	412.9	bus10	152.5	421.2
bus11	145.7	406.8	bus11	148.3	412.7	bus11	152.1	420.5
bus12	145.7	406.8	bus12	148.5	412.8	bus12	152.4	421.0
bus13	145.7	406.8	bus13	148.5	412.8	bus13	151.9	420.7

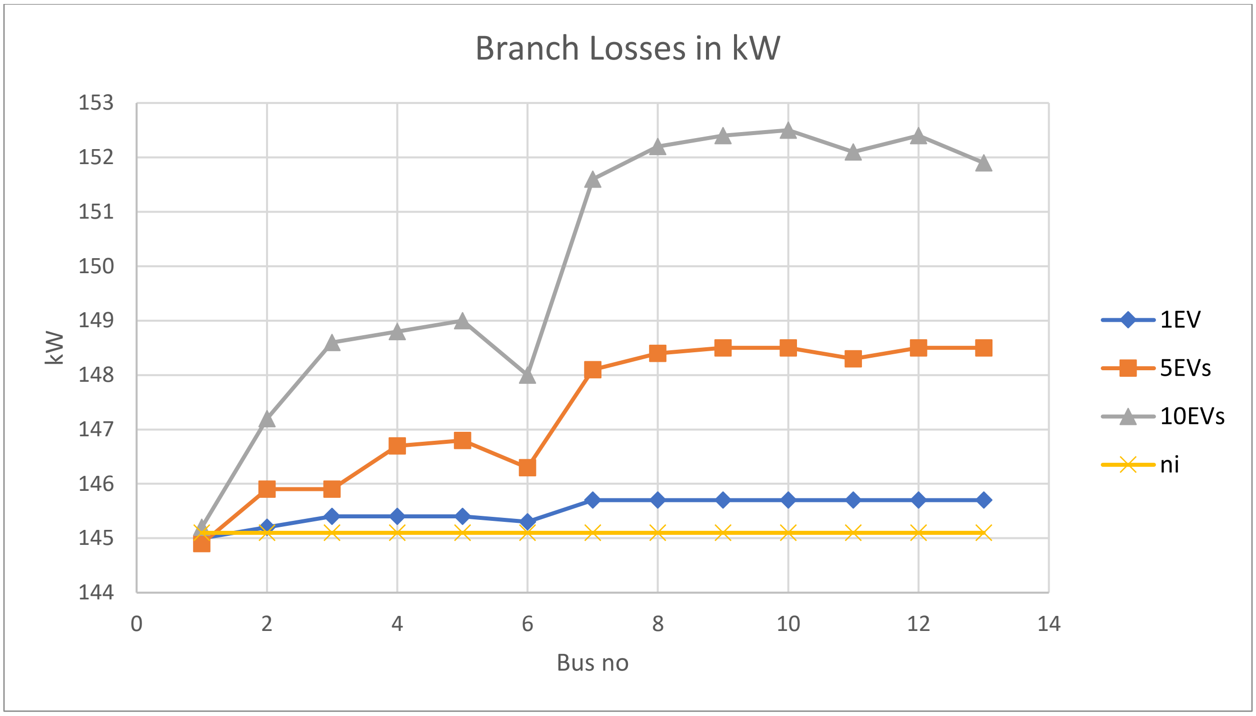

Figure 4.1 IEC TYPE2 Branch Losses Result in kW.

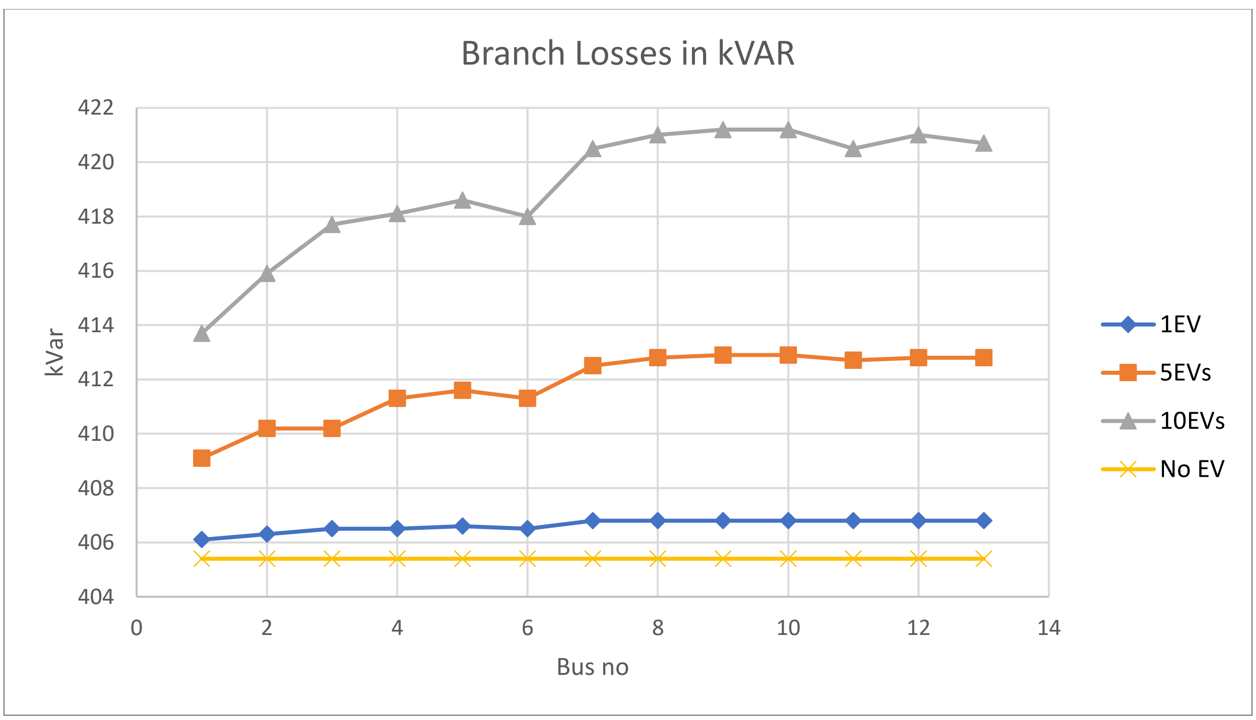

Figure 4.2 IEC TYPE2 Branch Losses Result in kVAR.

With one electric vehicle (EV) charging, the observed increase in load compared to the baseline is negligible in both kilowatts (kW) and kilovolt amperes reactive (kVAR), which implies that the power system has the unused capacity to take on one EV without much of a burden.

When 5 EVs are charging simultaneously, there is a minor increase in kW and kVAR across the buses, indicating that the power system can handle multiple EVs, but the compounded effect begins to be noticeable.

The cost of charging 10 EVs is a 0.1 kW to 7.4 kW increase in kW and a 8.3 kVAR to 15.8 kVAR increase in kVAR, compared to the baseline. This means that even with multiple EVs charging at the same time, the impact is still moderate, and the energy grid can sustain this load conveniently with proper plan and implement of load management strategies.

4.3 Result Using CCS TYPE 2 Connect to Buses.

Table 4.2 Branch Losses connecting using CCS TYPE2.

1EV			5EVs			10EVs		
	Branch Loss			Branch Loss			Branch Loss	
BUS ID	kW	kVAR	BUS ID	kW	kVAR	BUS ID	kW	kVAR
bus1	145.7	420.1	bus1	201.1	566.5	bus1	490.9	1063.9
bus2	149.2	424.1	bus2	221.7	589.6	bus2	525.5	1130.1
bus3	151.7	427.4	bus3	235.7	608.1	bus3	530.0	1138.9
bus4	152.1	428.1	bus4	238.0	611.9	bus4	529.1	1148.0
bus5	152.4	428.9	bus5	238.7	616.4	bus5	501.9	1129.3
bus6	150.5	427.8	bus6	228.1	609.8	bus6	610.3	1223.6
bus7	157.1	432.7	bus7	267.8	640.8	bus7	637.6	1254.9
bus8	158.2	433.8	bus8	275.7	649.2	bus8	637.6	1254.9
bus9	158.7	434.2	bus9	279.9	652.9	bus9	655.9	1273.4
bus10	158.7	434.3	bus10	280.8	654.7	bus10	660.7	1282.2
bus11	157.9	433.3	bus11	273.5	645.8	bus11	630.6	1243.6
bus12	158.4	433.8	bus12	278.3	649.9	bus12	649.6	1202.4
bus13	157.6	433.1	bus13	271.8	644.6	bus13	626.6	1240.8

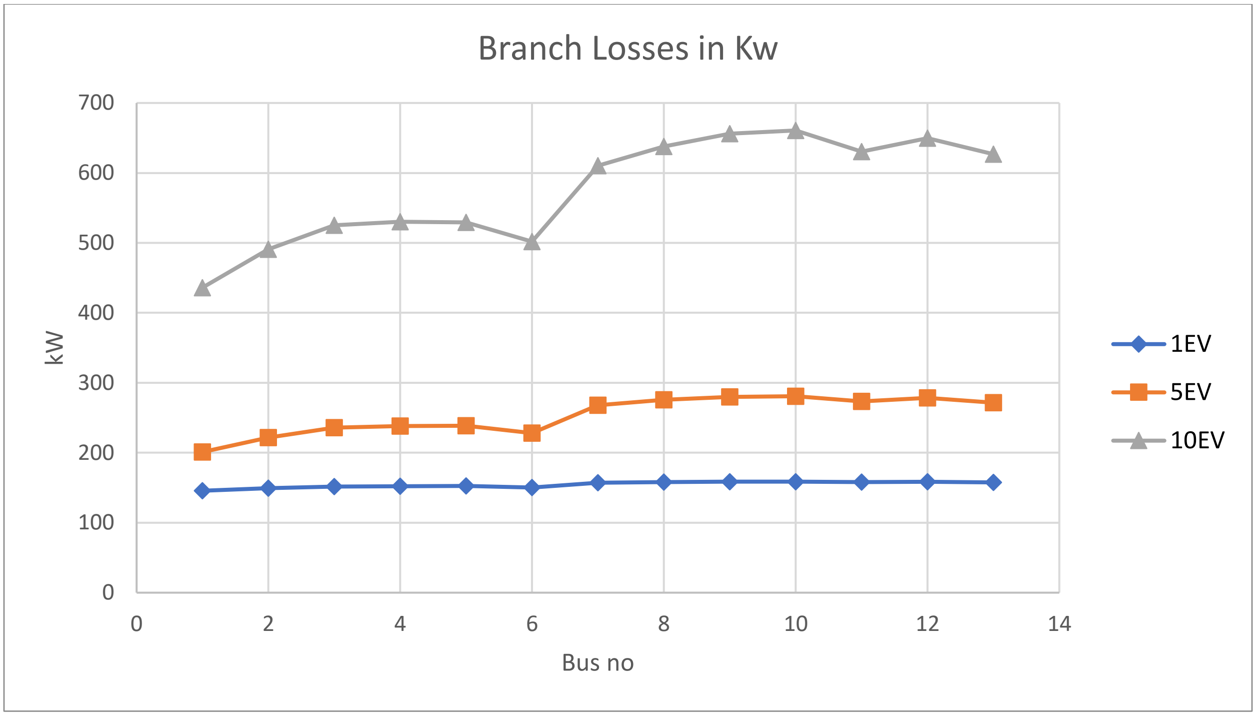

Figure 4.3 CCS TYPE2 Branch Losses Result in kW.

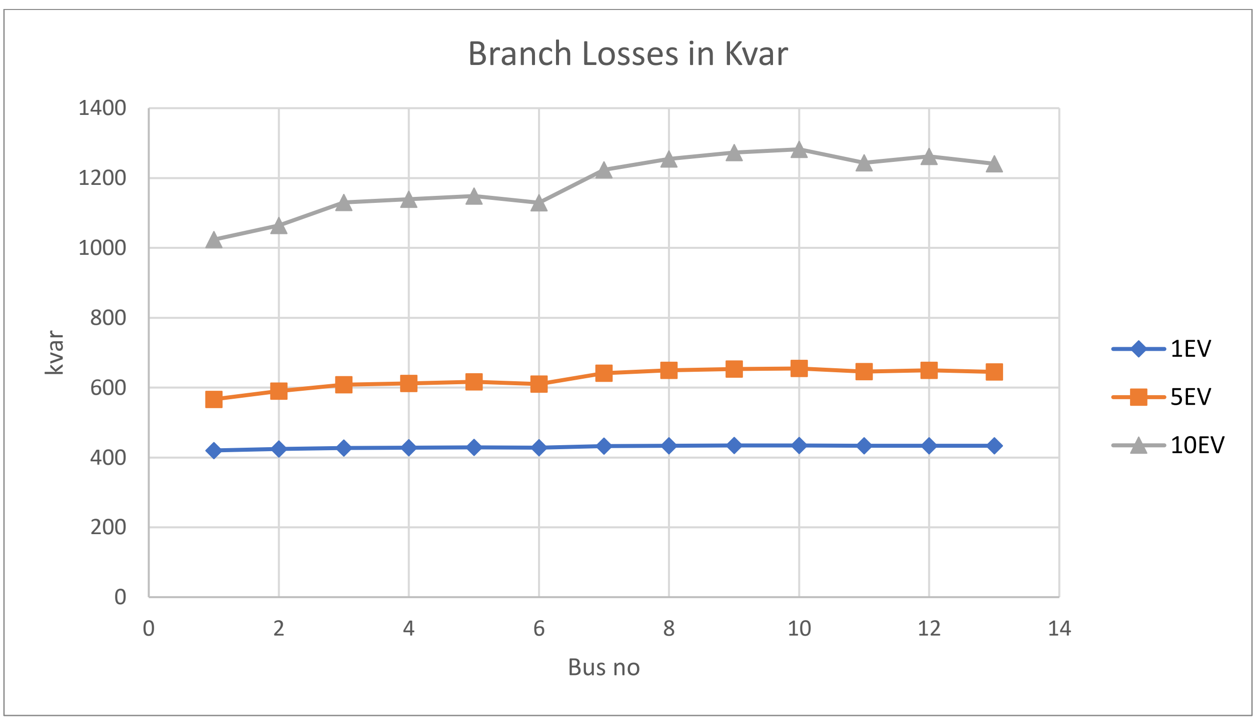

Figure 4.4 CCS TYPE2 Branch Losses Result in kVAR.

When a single electric vehicle (EV) charges, its impact is slightly greater than that of an IEC Type 2 vehicle charger. But any differences are manageable for today's power grid.

When 5 electric vehicles are connected to the grid for charging, the kilowatts and kilovolt-amperes reactive values show a considerable increase compared to a lower power level of 2.3 to 7 kW. This clearly indicates the growing impact on the grid because of the faster charging capability of CCS Type 2. This suggests a call to the necessity of robust grid management and upgrade to the infrastructure, especially in locations where fast charging stations are implemented.

When 10 electric vehicles are charging, the additional kilowatt losses range from 345.8 to 515.6, and kVAR losses from 658.5 to 876.8. These amounts of electricity indicate high strain on the electrical system, a demand that may have to be alleviated through extensive upgrades or in an orderly manner through smart grid solutions.

4.4 Result Using CHADeMO Connect to Buses

Table 4.3 Branch Losses connecting using CHAdeMO.

1EV			5EVs			10EVs		
	Branch Loss			Branch Loss			Branch Loss	
BUS ID	kW	kVAR	BUS ID	kW	kVAR	BUS ID	kW	kVAR
bus1	148.8	434.3	bus1	331.3	827.5	bus1	1394.9	2701
bus2	154.7	441.1	bus2	372.4	872.7	bus2	1588.0	2931.9
bus3	159.0	446.7	bus3	398.8	908.1	bus3	1696.1	3086.5
bus4	159.7	447.9	bus4	402.7	915.0	bus4	1706.0	3108.7
bus5	160.1	449.3	bus5	402.7	922.7	bus5	1687.0	3112.5
bus6	157.0	447.4	bus6	382.1	909.0	bus6	1595.7	3024.8
bus7	168.3	455.9	bus7	462.3	976.0	bus7	2059.2	3568.6
bus8	170.2	457.8	bus8	481.0	996.8	bus8	2274.3	3868.4
bus9	171.0	458.5	bus9	492.7	1008.1	bus9	2496.0	4170.2
bus10	171.1	458.8	bus10	495.6	1013.5	bus10	2595.9	4330.5
bus11	169.6	457.0	bus11	476.1	989.0	bus11	2217.5	3776.2
bus12	170.6	457.8	bus12	488.6	1000.7	bus12	2411.8	4036.3
bus13	169.1	456.6	bus13	473.0	986.8	bus13	2203.2	3762.7

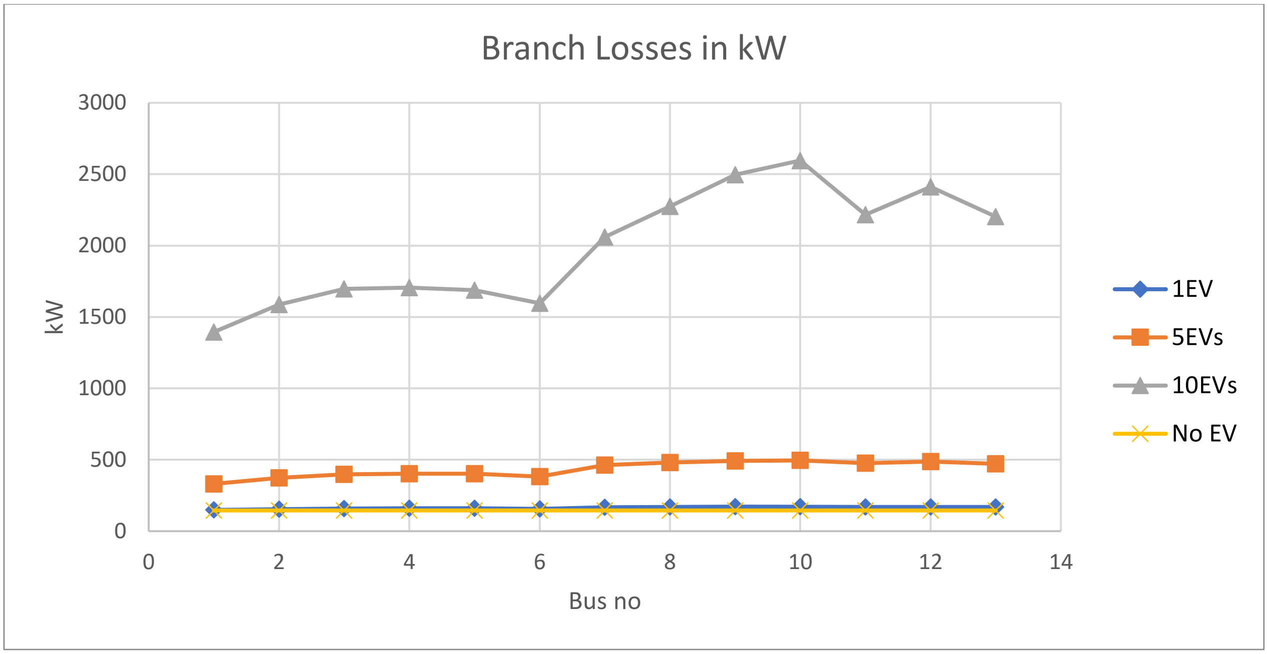

Figure 4.5 CHAdeMo Branch Losses Result in kW.

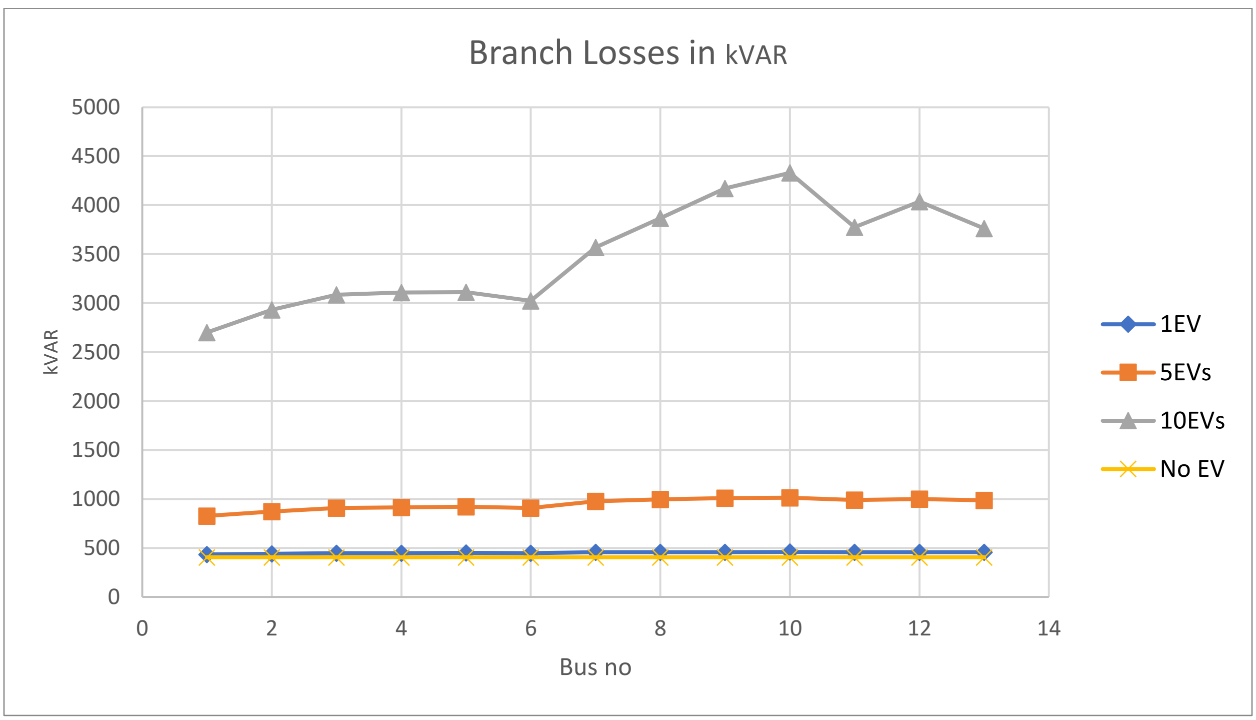

Figure 4.6 CHAdeMO Branch Losses Result in kVAR.

Once 5 electric vehicles are charging, the load increases considerably, with the kilowatt input rising notably, indicating an increased demand for power. This could conceivably begin to exert pressure on grid capacity.

When 10 EVs are charging, the kW surge is massive, ranging from about 1249.8 to 2450.8, and kVAR from 2295.6 to 3925.1. These numbers are well above the baseline and suggest that without significant upgrades to the grid, smart management of charging and possibly installing electricity storage systems, the grid might be seriously strained.

4.5 Voltage Stability Result EVCS Connect to Buses

Bus 1 and Bus 10 were chosen for testing voltage stability in the presence of EVCS because of their potential to reflect severe situations in terms of branch losses within the distribution network. Bus 1 is distinguished by its low branch losses, making it a good candidate for EVCS integration without putting a pressure on the grid. This makes it an excellent option for the initial deployment of EVCS, as well as a benchmark for best-case grid performance situations. Bus 10 is chosen based on its significant branch losses, which pose a worst-case scenario that tests the grid's ability to maintain voltage stability when subjected to extra load from EVCS. Analyzing voltage stability at Bus 10 reveals the grid's constraints as well as the improvements or management tactics required to handle high-demand scenarios, especially when quick charging technologies such as CCS Type 2 and CHAdeMO are introduced.

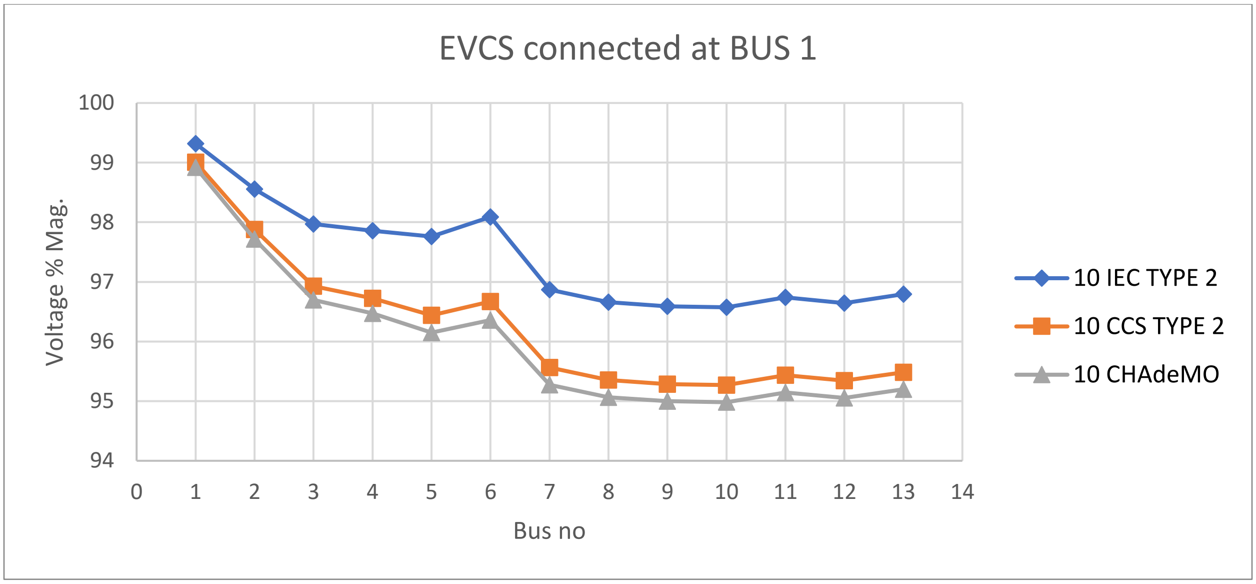

Figure 4.7 EVCS Connected to BUS1

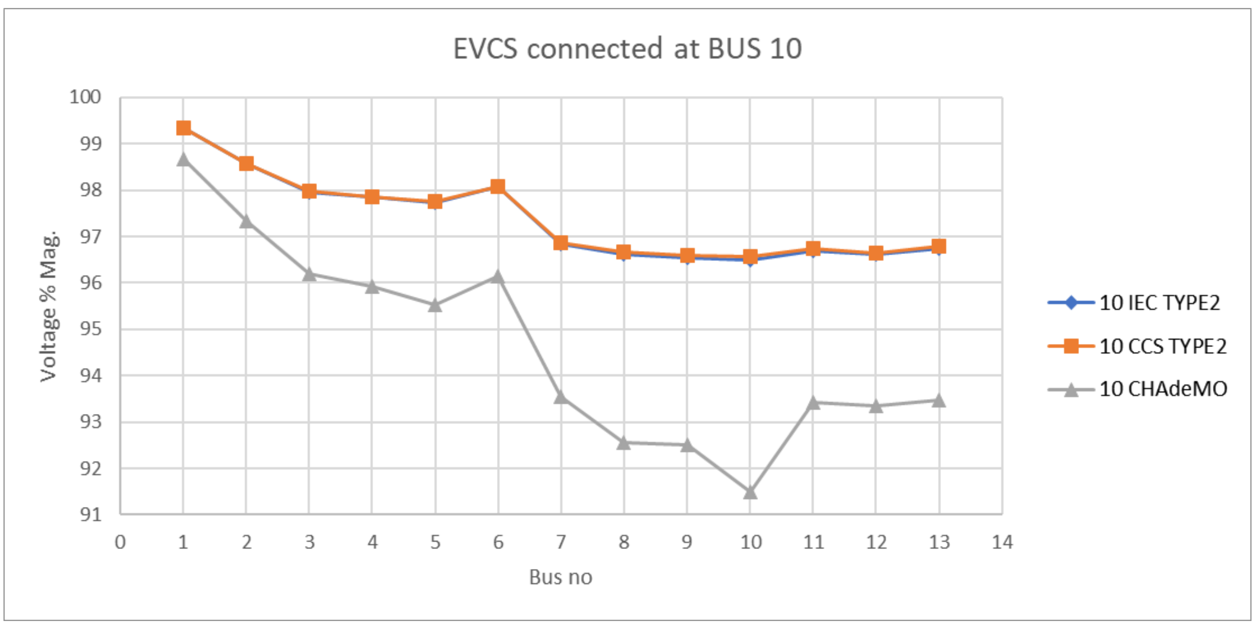

Figure 4.8 EVCS Connected to BUS10

The voltage stability investigation, which included 10 Electric Vehicle Charging Stations (EVCS), yielded varied results for each bus. Bus 1 maintained outstanding voltage stability, managing the increased load from 10 EVCS with little variations, demonstrating its viability for high-density EVCS implementation. Bus 10, on the other hand, showed substantial voltage instability when loaded with 10 EVCS, highlighting the need for infrastructure improvements to handle such a large concentration of charging stations. These findings emphasize the vital need of analyzing grid capacity and stability before expanding EVCS installations to ensure efficient and dependable electricity distribution.

4.6 Summary

Bus 1 is seen as the best place to put an Electric Vehicle Charging Station (EVCS). The main reason for this is that Bus 1 has low branch losses, showing that power can be delivered with high efficiency. This also means that energy waste is low, which makes more power available for the vehicles. On top of this, there is likely to be a strong, robust grid at Bus 1 that is stable enough to increase loads.

In contemplating the sort and quantity of EVCS, if IEC Type 2 stations are deployed, Bus 1 can support approximately 10 EVCS thanks to their proportionally lower electrical consumption, which has a lesser effect on the electrical grid. Regardless, when it comes to CCS and CHAdeMO chargers, they comparatively have higher electricity use and therefore possess an even larger impression on the grid. For this reason, it is roughly said that less than 5 EVCS works the best. The explanation is straightforward; these assorted designs mainly need to respect the electrical existing infrastructure and its partial compatibility with Bus 1's entire electrical capacity.

Installing 5 Electric Vehicle Charging Stations (EVCS) at Bus 1, particularly for CCS and CHAdeMO, it is the perfect option and stands at equilibrium on a scale of meeting immediate EV charging demand and grid stability. This number ensures that despite the charging for EVs the infrastructure in the grid does not incur extensive stress and efficiently utilizes the energy distribution without needing any reinforcement (up-gradation). Meanwhile, on the other reinforcement, more efficient chargers like IEC Type 2 will allow far more stations operating underscores the strong importance of choosing the right type of EVCS that harmonizes with the grid load capacity and current or future EV charging demand.

Ultimately, the decision to strategically position a maximum of ten IEC Type 2 or 5 CCS/CHAdeMO Electric Vehicle Charging Stations at Bus 1 is consistent with the grid's ability to accommodate more consumption and less voltage drop. This strategy maximizes the utility of current infrastructure, guaranteeing that adding charging stations fits seamlessly into the electricity network, ensuring an environmentally friendly and adaptive foundation for the expected surge in E-mobility.

Bus 1 is declared the best place for Electric Vehicle Charging Stations (EVCS) due mainly to its minimal amount of power loss from branches. This indicates efficient power delivery and shows that little energy goes to waste. The low branch loss at Bus 1 also ensures that the rate of the power available for the vehicle is significantly high, as well as being a reflection of the strong and stable grid infrastructure at Bus 1, which will be able to accommodate the new load without sacrificing grid stability.

Bus 1 would benefit from the use of IEC Type 2 stations because they use less electricity and do not require additional infrastructure to be invested into. Even though the station is not as efficient as it could be, it serves its purpose.

By using this strategic approach, we can make sure that electric car charging can easily work with the power grid and prepare for environmental sustainability. We anticipate more people using electric cars, so we also need to be sure that if power lines break or malfunction, it won't make the whole power grid unstable.

Chapter 5

Conclusions and Recommendations for Further Works

5.1 Conclusions

Using ETAP simulations, the placement and sizing of Electric Vehicle Charging Stations (EVCS) were analyzed on a modified IEEE 13-bus distribution system to determine their possible effects they may have on the grid. Different types of EVCS placements were analyzed such as IEC Type 2, CCS Type 2, and CHAdeMO on each bus. The best setup was determined to be IEC Type 2 Charging Stations, positioned at Bus1. IEC Type 2 Charging Stations at Bus1 offered the greatest decrease in branch losses and provided the greatest improvement to the power factor. IEC Type 2 Charging Stations are positioned at a good location on the system where little to no impedance between the point of common coupling (PCC) and the charging stations are achieved.

In addition it can be observed that the impact between Single phase to single phase charger, Three phase to single phase charger, and three to three phase chargers is less than +10%, this observation which means the impact on the grid is roughly feasible and appeared to be consistent across all the charger of EVs indicating that the grid have sufficient capability to accommodate EV charging without need of significant upgrading the network capacity but proper planning will be vital in the design and placement of the EVCS. In this study, the uniform impact percentage between different charger types is observed which laptops the EVCS charger manufacturers to provide higher loading without significant need to cause network reinforcement.

Given the relatively minimal grid impact of other charger types and the optimal disposition of the IEC Type 2 EVCS at Bus1, it is highly promising for the future of electric vehicle charging infrastructure. It should be possible to expand charging infrastructure in a way that is mindful of the need to maintain and bolster grid stability and efficiency.

5.2 Recommendations for Further Works

In order to advance research on Electric Vehicle Charging Stations (EVCS), there are several key areas that future work should address. To begin, a more thorough examination of user charging behavior using detailed data will aid in refining optimization models and ensuring that they are reflective of real-life circumstances. Integrating EVCS with renewable energy sources, such as solar and wind, will reduce the carbon footprint associated with electric vehicle charging and promote sustainability. Smart grid technologies are vital for the efficient management of the increased load that results from EV charging. Moreover, advanced load management strategies, real-time monitoring, and demand response programs are examples of the kinds of methods for effectively managing the additional load.

Understanding the financial components of deploying Electric Vehicle Charging Stations (EVCS) involves a necessity to integrate economics and policy studies. This necessitates a good understanding of cost-benefit analysis, investment strategies, and the impact of regulations in supporting the growth of the charging infrastructure. The importance of understanding the scalability of the EVCS network cannot be overstated. With an expected dramatic increase in the use of electric vehicles, knowing the current electrical grid capacity and planning for necessary upgrades are unavoidable. Grid stability and reliability have to date been an overlooked consideration, in favor of hyper-focusing on EVCS expansion. Important facts to ponder are: what is the impact of EVCS on grid stability and reliability? With large EV penetrations? This must be an area of future focus.

To tackle the intricate challenges of incorporating electric vehicle charging infrastructure into the urban environment and energy grid, it will be vital for engineers, town planners, decision makers and other interested parties to come together. Furthermore, any future research should focus on looking into new charging technologies, such as wireless charging, ultra-fast charging, or vehicle-to-grid systems in order to enhance the efficiency and ultimately user-friendliness of the charging network in an effort to drive towards a more sustainable future for electric vehicles.

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