

**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING
ENTREPRENEURIAL DEVELOPMENT (AAMUSTED)
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
SITING AND SIZING OF AN ELECTRIC VEHICLE CHARGING STATION USING
META-HEURISTIC ALGORITHM [THE CASE OF AAMUSTED CAMPUS]**

NAME: JOCHEBED OGLIE AMPONSAH

INDEX NUMBER:7201200012

**A Dissertation Submitted to the Department of Electrical and Electronic
Technology Education,
Faculty of Technical Education, submitted to the School of Graduate Studies, in
partial fulfilment of the requirements for the award of the degree of Master of
Technology Electrical Power System Engineering in the Akenten Appiah-Menka
University of Skills Training and Entrepreneurial Development.**

OCTOBER 2023

DECLARATION

Student's Declaration

I, Jochebed Oglie Amponsah declare that this dissertation, except for quotations and references contained in the published works which have all been identified and duly acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE:

DATE:

Supervisor's Declaration

I hereby declare that the preparation and presentation of this work was supervised in accordance with guidelines for supervision of dissertation as laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

NAME OF SUPERVISOR: ALBERT K. AWOPONE (Dr.)

SIGNATURE:

DATE:

ABSTRACT

Electric Vehicle Charging Station(s) (EVCS) and their integration within the power distribution systems particularly on the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) campus. The challenges and opportunities related to the adoption of EVs on AAMUSTED campus electrical network are investigated including the sizing and placement of EVCS using the Particle Swarm Optimization (PSO) algorithm. The Electrical Transient Analyzer Program (ETAP) is utilized to model the 11kV distribution system at AAMUSTED. The optimized EVCS placement is assessed and compared to the existing system. The complexities and considerations of installing EVCS, tackling challenges related to power loss and voltage profile within the campus's distribution system are examined. The Backward/Forward Sweep (BFS) method analysis is employed to scrutinize the load flow, while the Particle Swarm Optimization (PSO) algorithm was used to ascertain the size and placement of EVCS using five distinct cases. The outcome illustrated the substantial impact of employing the PSO algorithm in the allocation and sizing of EVCS. The analysis of various scenarios on the AAMUSTED 11 kV distribution system demonstrates a favourable compromise to provide a balanced strategy for managing power losses and maintaining system stability.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to the Almighty GOD for providing me with knowledge, guidance, protection, strength, and blessings throughout the entire process of completing this dissertation.

I am grateful to my supervisor, Dr. Albert K. Awopone, for providing critical, analytical, and constructive feedback throughout the writing of this dissertation. I am indebted to, Dr Patrick Ayambire, Mr. Francois Sekyere, Engr. Prince Asabere, Engr. Isaac Prempeh for their directions, patience and guidelines throughout the dissertation and thank all the Electrical/Electronic Lab technicians of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development for their advice and motivation.

I would like to thank Mr. John Tamaklo a technician of AAMUSTED for his assistance in gathering the campus data during the project.

Finally, I acknowledge everyone who, in one way or the other, supported me during my studies, especially my lovely husband Mr. Richard Amponsah and my children for their support and encouragement.

DEDICATION

This dissertation is dedicated to my husband Richard Amponsah, my father Bishop Charles Amoo and Rev. Dr. Kobina Forson, for their love, prayers, support, sacrifice, motivation, and patience during the period of my study.

TABLE OF CONTENTS

DECLARATION	ii
Student’s Declaration	ii
Supervisor’s Declaration	ii
ABSTRACT	iii
ACKNOWLEDGEMENT	iv
DEDICATION	v
LIST OF TABLES	xi
LIST OF FIGURES	xi
CHAPTER ONE	1
INTRODUCTION	1
1.1. Background of study	1
1.2. Problem statement	4
1.3. Objectives	5
1.4. Significance of the study	6
1.5. Limitations of the study	6
1.6. Organization of the Study	6
CHAPTER TWO	8
LITERATURE REVIEW	8
2.1. Electric Power Distribution Systems	8

2.2.	EVCS Infrastructure.....	9
2.2.1.	EV Charging Technology	10
2.2.2.	EV Charging Levels	11
2.2.3.	Fast Charging Protocols.....	13
2.3.	Power Flow Methods	15
2.3.1.	Forward/Backward Sweep.....	15
2.4.	Metaheuristics Techniques.....	16
2.4.1.	Particle Swarm Optimization (PSO).....	16
2.5.	Research Works on EVCS	17
CHAPTER THREE		21
MATERIALS AND METHODS.....		21
3.0.	Introduction	21
3.1.	ETAP modelling.....	21
3.2.	The AAMUSTED Distribution Network.....	22
3.3.	System Modelling	25
3.4.	Objective Function Formulation	25
3.4.1.	Inequality Constraints.....	28
3.5.	Software Modelling.....	28
3.5.1.	Line and Bus Data of the AAMUSTED Distribution Network.....	29
3.6.	System Modelling: Electric Vehicle and Charging Facilities Load.....	30

3.7.	MATLAB Modelling.....	31
3.7.1.	Modelling of Particle Swarm Optimization Algorithm for Simultaneous Placement	31
3.8.	Validation of System Model	36
3.9.	Study Cases Definitions	37
3.10.	Summary of methodology	38
CHAPTER FOUR.....		40
RESULT AND DISCUSSION		40
4.0. CASES		40
4.1.	Base case: Existing Network Results	40
4.1.1.	Active Loss of Base Case	41
4.1.2.	Reactive Power Loss of Base Case.....	42
4.1.3.	Voltage Profile of Base Case.....	43
4.2.	Case 1: Integration of one EVCS	44
4.2.1.	Active Power Loss of Case 1	45
4.2.2.	Reactive Power Loss of Case 1	46
4.2.3.	Voltage Profile of Case 1.....	47
4.3.	Case 2: Integration of two EVCS.....	48
4.3.1.	Active Power Loss of Case 2.....	49
4.3.2.	Reactive Power Loss of Case 2	50
4.3.3.	Voltage Profile of Case 2.....	51

4.4.	Case 3: Integration of three EVCS	52
4.4.1.	Active Power Loss of Case 3.....	52
4.4.2.	Reactive Power Loss of Case 3	53
4.4.3.	Voltage Profile of Case 3.....	54
4.5.	Case 4: Integration of four EVCS	56
4.5.1.	Active Power Loss of Case 4.....	56
4.5.2.	Reactive Power Loss of Case 4	57
4.5.3.	Voltage Profile of Case 4.....	58
4.6.	Discussion of Base Case, Case 1, Case 2, Case 3 and Case 4.....	60
4.6.1.	Active Power Loss of Base Case, Case 1, Case 2, Case 3 and Case 4	60
4.6.2.	Reactive Power Loss of Base Case, Case 1, Case 2, Case 3 and Case 4.....	62a
4.6.3.	Voltage Profile of Base Case, Case 1, Case 2, Case 3 and Case 4.....	64
CHAPTER FIVE		69
SUMMARY, CONCLUSION AND RECOMMENDATION		69
5.1.	Summary of Findings.....	69
5.2.	Conclusion.....	70
5.3.	Recommendation.....	71
REFERENCES		73
APPENDIX.....		84
Appendix I, Verification of the existing system and simulated voltage data.....		84

Appendix II, Active Power Loss of Base Case, Case 1, Case 2, Case 3, and Case 4 86

Appendix III, Reactive Power Loss of Base Case, Case 1, Case 2, Case 3, and Case 4..... 87

Appendix IV, Voltage Profile of Base Case, Case 1, Case 2, Case 3, and Case 4..... 88

LIST OF TABLES

Table 3.1, Line and Bus data of AAMUSTED distribution system	29
Table 3.2, Characteristics of EV for fast EVCS modeled.....	31
Table 3.3, Study cases description.....	38
Table 4.1, The Summary Results of Base Case.....	44
Table 4.2, The Summary Results of Case 1	48
Table 4.3, The Summary Result of Case 2	52
Table 4.4, The Summary Result of Case 3	55
Table 4.5, The Summary Result of Case 4	59
Table 4.6, The Summary results of Base case, Case 1, Case 2, Case 3 and Case 4	66

LIST OF FIGURES

Figure 3.1, Line diagram of AAMUSTED distribution network.....	22
Figure 3.2, AAMUSTED campus distribution system	24
Figure 3.3, PSO search mechanism in multidimensional search space illustration.....	32
Figure 3.4, Flowchart of the proposed algorithm	35
Figure 3.5, Verification of the existing system and simulated data.....	36
Figure 4.1, Active power loss of base case.....	41
Figure 4.2, Reactive power loss of base case.....	42
Figure 4.3, Voltage profile of base case.	43
Figure 4.4, Active power losses of case 1	45
Figure 4.5, Reactive power loss of case 1	46

Figure 4.6, Voltage profile of case 1.....	47
Figure 4.7, Active power loss of case 2.....	49
Figure 4.8, Reactive power loss of case 2.....	50
Figure 4.9, Voltage profile of case 2.....	51
Figure 4.10, Active power of case 3.....	53
Figure 4.11, Reactive power of case 3.....	54
Figure 4.12, Voltage profile of case 3.....	55
Figure 4.13, Active power of case 4.....	57
Figure 4.14, Reactive power of case 4.....	58
Figure 4.15, Voltage profile of Case 4.....	59
Figure 4.16, Active power loss of Base Case, Case 1, Case 2, Case 3 and Case 4.....	60
Figure 4.17, Reactive power loss of Base Case, Case 1, Case 2, Case 3 and Case 4.....	62
Figure 4.18, Voltage profile of Base Case, Case 1, Case 2, Case 3 and Case 4.....	64

GLOSSARY

AAMUSTED: Akenten Appiah-Menka University of Skills, Training and Entrepreneurial

Development

AC: Alternating Current

BFS: Backward/Forward Sweep

CHAdeMO: Charge de Move

CS: Charging Station

CCS: Combo Charging System

DC: Direct Current

DG: Distributed Generation

EPRI: Electric Power Research Institute

EVCS: Electric Vehicle Charging Stations

EVTEC: Electric Vehicle Technology

EV: Electric Vehicles

ETAP: Electrical Transient Analyzer Program

GA: Genetic Algorithm

HPC: High-Power Charger

IPSO: Improved Particle Swarm Optimization

ICE: Internal Combustion Engines

IEC: International Electrotechnical Commission

kW: kilowatt

LV: Low Voltage

MATLAB: Matrix Laboratory

MoU: Memorandum of Understanding

NR: Newton-Raphson

PSO: Particle Swarm Optimization

p.u: Per Unit

ROB: Raynolds Okai Building

TEPCO: Tokyo Electric Power Company

V2G: Vehicle-to-Grid

VPD: Voltage Profile Deviation

CHAPTER ONE

INTRODUCTION

1.1. Background of study

Air and sound pollution, depleting fossil fuels, and climate change continues to motivate the search for new transportation solutions, while great concerns have been raised over the fast-diminishing rate of oil reserves in Africa and the world, research into Electric Vehicles (EV) is becoming increasingly popular (Schwerhoff, Gregory and Mouhamadou, 2019). Though during the manufacturing stage of Electric Vehicles, greenhouse gases are produced, and their carbon footprint is about 40% lower than the Internal Combustion Engines (ICES). The stated reasons make EV an ideal and realistic alternative to eliminate Internal Combustion Engines (ICE) soon (Gupta, Tyagi and Anand, 2021).

Electric Vehicles hold a promising future due to their high efficiency rate, low maintenance cost and zero-carbon emission. But because EV's have their own bottlenecks which comes in the form of high initial cost, limited driving range and limited charging infrastructure (Chen, Xu, Song and Jermittiparsert, 2019).

Driver range anxiety has also become a major obstacle for EV's, since drivers who opt for EV's may have concerns or issues with running out of power before getting to their desired destinations, other factors that may affect EV's may include temperature, battery charge, terrain, travelling speed (just to mention but a few) limited driving range may affect or discourage likely potential consumers from adopting EV's (Sahoo, Harichandan, Kar and Kumar, 2022).

To solve these issues and more, charging infrastructure has become more paramount to the development and large-scale deployment of EV's. These charging stations or infrastructure includes

battery charging stations and battery exchange stations. It is also quite important to have an adequate amount of optimally distributed and sized charging stations (Deb, Sachan and Zhimomi, 2021).

The current generation will need to improvise and to even improve way of life in terms of economic the current generation will need to improvise and to even improve way of life in terms of economic (initial investment cost, operating cost, and maintenance cost). Having in mind the electric grid, significant challenges will increase, because of increased installations of charging infrastructure. Power loss, voltage profile and system reliability are some of the factors that must be taken into consideration for a successful planning of an EV infrastructure (Gupta et al., 2021). Hence the optimal sizing and siting of an EV charging infrastructure is paramount for the successful deployment of EV's on AAMUSTED campus.

Optimal sizing and siting of EV infrastructure has been reported in literature and various methods have also been used. This dissertation seeks to review some of the previously reported works on sizing and siting of charging stations or infrastructure for EV's and hence continue to use the Akenten Appiah - Menka University of Skills Training and Entrepreneurial Development Campus (AAMUSTED) for a case study of a possible EV infrastructure, this dissertation will also use Meta-Heuristic Algorithm to model and ascertain the possible best location for an EV infrastructure for AAMUSTED campus, should it be possible to site on campus. The deployment of Electric Vehicle charging infrastructure is vital to the development of Electric Vehicles (EV's). Electric Vehicle Charging infrastructure, must contend with the growing population, change in market trends and other factors that affects EV adoption easily or directly (Pardo-Bosch, Pujadas, Morton and Cervera, 2021). EV infrastructure location problem has been widely discussed in a lot of literature. The site of EV charging infrastructure is most of the time based on minimization of the cost and maximization coverage of the charging stations or a combination of both. Electrical Vehicle sitting and sizing of

charging stations are generally modelled by considering the transportation network, the electricity distribution network or also a combination of the two. Several studies have been conducted on optimal EV charging station placement (Deb et al., 2018). These studies can be divided into methods based on the economic point of view and that of the engineering concepts. (Efthymiou, Chrysostomou, Morfoulaki and Aifantopoulou, 2017) proposed an Electric vehicle charging station placement method for an existing city traffic network, which was based on grid partitioning and was also intended to minimize transportation cost using Genetic Algorithm [GA] to access the charging station.

(Li, Yin, Su and Fan, 2020). method continues to consider traffic density and station capacity as constraints. Kameda and Mukai, (2011) came up with an optimization routine for locating the Charging Station [CS], that depended on taxi data and focused on local bus transportation system demand.

(Shareef, Islam, and Mohamed, 2016), proposed for a demand on the local bus transportation system to the route, but the results were mainly based on computer simulations which was without justification on a practical network. (Li et al., 2020) declared an optimal location CS based on construction (e.g., Land price) and maintenance cost and geographic information as constraint. (Shareef et al., 2016) the study utilized the standard particle swarm optimization algorithm (PSO) and improved particle swarm optimization (IPSO) algorithm by changing the inertia factor on an existing CS and then compared results. (Rastegarfar, Leon-Garcia, LaRochelle and Rusch, 2013) established a cost model with reference to total investment and operation cost for optimization. The approach considered geographic conditions, traffic, and local access to find optimal locations. A program developed in MATLAB was used to calculate the cost and optimum of combination of charging stations. (Dharmakeerthi, Mithulananthan, and Saha, 2012) developed an EV model that

used a combination constant power and voltage – dependent load to find the best location in a power grid based on voltage stability margins, grid power loss and cable flow ratings. Smart load management control scheme based on peak demand, shaving, voltage profile improvement and power loss minimization for coordinating multiple EV chargers while considering daily residential load patterns. (Dharmakeerthi et al., 2012) EVCS, siting and sizing is clearly difficult to assess or address systematically, considering every detailed parameter involved. A critical problem associated with EVs is that their high penetration causes significant issues on the power distribution system such as: power quality deterioration, enhanced damaged of line, downturn of distribution transformers, increased distortion, and higher fault current. (Brenna, Foiadelli, Leone and Longo, 2020). The charging circuits use a lot of rectification and circuits that produce harmonics and interference in the electrical distribution systems. This disadvantage among many others has been a reason most countries have not been able to implement and establish a large array of Electric Vehicle charging stations. Hence this dissertation seeks to site an EVCS on AAMUSTED campus, using Particle Swarm Optimization to find the possible best location of an EVCS considering the electrical distribution system and the road network of AAMUSTED campus.

1.2. Problem statement

Energy systems and technology require diverse sources of energy, of which most depend on fossil fuels. The increasing trends in technology alongside climate changes with respect to air pollution, greenhouse gases and the depletion of fossil fuels, coupled with the projection that oil reserves will soon have influenced electrical and renewable systems setup. (Shareef et al., 2016) Taking into consideration the stated reasons, it is beyond reasonable doubts that, the current generation will need to improvise and improve their way of life with regards to socioeconomic activities. Individuals may have to opt for what is economical and at the same time safe for society. As of 16th March 2022, the

price of fuel has shot up by 18.2% with the cumulative hike in 2022 at 53.9% in Ghana. With all these and more, there is the need for society to adopt to other means of transportation especially here in Ghana other than petrol or diesel driven cars.

Considering these, Africa will need to accept and embrace these new technologies embedded in transportation issues. The Asians, United States and so many developed countries have embraced these Electric Vehicles and have not regretted doing so. Ghana according to the Energy Commission have also accepted the idea of Electric Vehicles (EV) but have sustainable energy challenges. Especially with charging infrastructure and maintenance of the EV (Cape & Points, n.d.).

Common problems that could arise with the implementation of EVs on AAMUSTED includes high penetration that causes significant issues on the power distribution system such as: power quality deterioration, enhanced damaged of line, downturn of distribution transformers, increased distortion, and higher fault current. This can affect sensitive devices and equipment on the campus. This dissertation seeks to address the charging infrastructure of such vehicles focusing mainly on AAMUSTED campus, because of the high rise in the number of vehicles and people found on campus per session, in case our lecturers and some students decide to adopt EV. Efficient charging stations are needed in such instances, and charging station issues would have been solved by the end of this research work.

1.3. Objectives

The objective of this research is to;

1. model and analyze the AAMUSTED 11kV distribution system using the Electrical Transient Analyzer Program (ETAP).

2. optimize the placement and sizing of EVCS using the particle swarm optimization algorithm.
3. Conduct a comparative analysis of the existing system and the optimized system.

1.4. Significance of the study

Comprehensively studying of EV charging stations within the distribution system is fundamental to effectively manage the evolving energy landscape, reduce carbon emissions, enhance grid performance, and meet the growing demand for sustainable transportation.

The data from the study will encourage Electrical Vehicle producers and consumers to target the Ghanaian market and the study enlightens the viability of the system locally.

Lastly, the sizing of the system on the local distribution will give local energy management companies a fare idea on the current challenges and actions to take in future system improvement schemes to meet future power demands for electric vehicle sustainability.

1.5. Limitations of the study

This research work seeks to size and sight an Electric Vehicle Charging Station on the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development. Consequently, the data collection and analysis of the study was confined within the campus distribution system. As a result, the outcomes and findings are specifically applicable to AAMUSTED campus, Kumasi.

1.6. Organization of the Study

This research is made up of five chapters. Chapter one highlights the background of the study, problem statement, objectives, research questions, significance of the study, limitations of the study and organization of the study. Chapter two is the review of relevant literature in relation to the topic

under research. Chapter three outlines the procedures to achieve the objectives of this study while chapter four deals with the findings and discussion of the study. Finally, Chapter five entails summary, conclusion, recommendation, and areas for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1. Electric Power Distribution Systems

Electric power distribution systems serve as the critical bridge that connects power generation to the end-users, powering homes, businesses, and industries. As the energy landscape undergoes profound changes, distribution systems must adapt to incorporate renewables, improve efficiency, enhance resilience, and promote sustainability (Koirala et al., 2016). The literature on distribution systems is a testament to the dedication of researchers, engineers, and policymakers in addressing the complex challenges and seizing the opportunities presented by these essential networks. In the ongoing transition towards cleaner and more efficient energy distribution, the distribution system stands at the forefront, ensuring that the lights stay on, and homes stay powered.

As the demand for electric vehicles (EVs) continues to surge, the synergy between distribution systems and EVCS becomes evident. Distribution systems are essential for supporting the changing needs of the growing EV fleet, and the literature in this field underscores the necessity of enhancing efficiency and grid resilience (Sovacool, 2018). The dedication of experts and stakeholders in both sectors is notable, as they collectively strive to overcome the complexities and leverage the opportunities presented by the intersection of distribution networks and EVCS. In this era of transitioning toward cleaner and more sustainable energy distribution, the distribution system remains at the forefront, ensuring a reliable power supply not only for homes but also for the burgeoning electric vehicle infrastructure (Bonsu, 2020; Martinot, 2016).

2.2. EVCS Infrastructure

Electric Vehicle Charging Stations (EVCS) are a critical part of the electric vehicle ecosystem, providing the infrastructure necessary to support the growing number of electric vehicles on the road (Nasr, 2022). They contribute to reducing greenhouse gas emissions, dependence on fossil fuels, and air pollution by promoting the use of clean and sustainable electric transportation (Requia, 2018).

In this era, which is marked by an increasing concern for environmental sustainability, it is imperative to reduce carbon emissions. The electrification of transportation stands at the forefront of transformative change (Geels, 2018). Electric Vehicles (EVs) represent a pivotal technology in the quest to mitigate climate change, reduce air pollution and create a more sustainable urban landscape (Geels, 2018; Hou, Tang, Zhao, Zhang, Wang and Xie, 2021). As a result, the deployment of Electric Vehicle Charging Stations (EVCS) has become a critical endeavor in supporting the widespread adoption of EVs.

The transport sector is important for economic development, but it is also a major source of greenhouse gas emissions and air pollution (Geels, 2018). Electric vehicles (EVs) offer a cleaner and more efficient alternative to conventional vehicles, and their adoption is inevitable as the world transitions to low-carbon transportation (Requia, 2018; Hou, 2021). Ghana is one of the African countries with the highest potential for EV adoption, due to its relatively high electricity access rate and abundant renewable energy resources (Aboagye, Gyamfi, Oforu and Djordjevic, 2021; Ampah et al., 2022). However, the transition to EVs faces challenges, such as the need to provide enough electricity for charging stations.

Ghana can overcome these challenges by harnessing its renewable energy potential to meet the growing demand for EV charging. This dissertation delves into the intricate domain of siting and

sizing of EVCS on university campuses, with much focus on the application of metaheuristic algorithms. As electrification in transportation gathers momentum, universities are gradually recognizing the need to develop and expand their EV infrastructure to meet the growing demands of the students, faculty staff and visitors who choose to drive electric vehicles. While the benefits of this transition are numerous, the optimal placement and capacity planning of EVCS on campus (AAMUSTED) require a comprehensive analysis that balances accessibility, energy efficiency, cost effectiveness and environmental impact.

2.2.1. EV Charging Technology

Chargers serve as the essential devices responsible for transferring electrical power to recharge able batteries. Typically, they encompass a rectifier component, which plays a key role in converting incoming AC power into the DC format required to replenish the battery. Ongoing research into battery charging methodologies has yielded a diverse range of solutions. In the contemporary landscape, these approaches can be broadly categorized into three primary modes: conductive charging, inductive charging, and battery swapping.

Conductive charging operates by establishing a direct, tangible link between the charger and the electric vehicle, facilitating the transfer of electricity via conductive components like cables (Smith, 2020). This approach is not only extensively embraced but also valued for its widespread adoption and its reputation as a user-friendly and efficient means of recharging electric vehicle batteries. Notably, this solution is known for its simplicity and impressive efficiency. Several car models on the market, including the Nissan Leaf and Tesla, offer the option of conductive charging (Mohammed & Jung, 2021; Smith, 2020). With this setup, high-power charging is directly delivered to the vehicle's battery without requiring internal conversion.

Inductive charging, on the contrary, relies on electromagnetic fields for the transmission of power from the charger to the vehicle, eliminating the need for physical contact (Mohammed & Jung, 2021). This wireless charging method is gaining popularity due to its user-friendliness and its potential for integration into various settings. Unlike the previous system, it offers the advantage of all-weather safety as it operates without the use of cables, providing a consistently simplified charging process. In fact, the charging process can be initiated simply by parking the vehicle over a spot equipped with a wireless charger. This simplicity has prompted several automakers, including Audi, Mercedes, and Porsche, to announce plans for integrating wireless charging into some of their models (Mohammed & Jung, 2021). This technology opens various possibilities and has also drawn the interest of research institutions exploring its applications in public transport, particularly in electric bus charging.

Battery swapping presents an innovative solution that involves the replacement of a depleted or low-charged battery with a fully charged one, resulting in a substantial reduction in charging time. Although less commonly employed, this method brings valuable benefits in situations demanding swift turnaround, particularly within electric vehicle fleets. Nevertheless, challenges related to system management and other limitations have hindered the widespread adoption of this configuration, as noted by (Shareef et al., 2016). Tesla once offered a battery swapping option for the Model S, but it appears that the project has been discontinued, as reported by (Yin et al., 2020). It's worth mentioning that China currently boasts the highest number of batteries swapping stations worldwide, as highlighted by (Shareef et al., 2016).

2.2.2. EV Charging Levels

Diverse power configurations exist worldwide, shaped by unique network characteristics and standards in each country. Consequently, various categorizations and standards have been

established for electric vehicle charging classification. For instance, the Electric Power Research Institute (EPRI) and the Society of Automotive Engineers (SAE) have defined charging levels as AC Level 1, AC Level 2, and DC Level 1 and Level 2, as outlined in (Shareef et al., 2016) research. On the European front, the International Electrotechnical Commission (IEC) 61851-1 Committee, responsible for "Electric vehicle conductive systems," has identified four distinct modes based on power type, voltage, protective devices, and the presence of grounding or control lines. These modes are described by (Brenna & Gaurav, 2015):

- Mode 1 – This involves slow AC charging using a standard socket equipped with earth protection, limited to 16 A. It can be plugged into either a single-phase line (maximum voltage 250V) or a three-phase line (maximum voltage 480V) operating at 50/60 Hz. Mode 1 is commonly used in residential or workplace settings where vehicles are left to charge for extended durations.
- Mode 2 – AC slow charging also employs a standard socket with in-cable protection limited to 32 A. Both the vehicle and the connector feature a control pin, while the supply side incorporates an integrated control box.
- Mode 3 – AC charging is limited to 63 A and requires electric vehicle supply equipment (EVSE). The control is assigned to permanently installed equipment on the AC supply side, typically within the three-phase network. Public charging stations often feature this configuration, which is sometimes referred to as "semi fast."
- Mode 4 – DC fast charging employs an external charger and can be further categorized into DC Level 1 and DC Level 2. The control function extends to equipment permanently connected to the AC grid. The equipment converts AC power into DC. Mode 4 is known for its shorter charging times, typically around 30 minutes.

Additionally, the IEC committee has defined three types based on power (Sbordone, 2015):

- Slow charging: This type operates at a rated power lower than 3.7 kW, making it suitable for domestic applications.
- Quick charging: Characterized by a maximum power of 22 kW.
- Fast charging: This type operates at a rated power exceeding 22 kW.

Given the focus of this dissertation project on fast charging, the subsequent sections will exclusively discuss this charging level.

2.2.3. Fast Charging Protocols

Regarding fast charging systems, there is a notable lack of standardization. Presently, there exist four types of DC fast charging systems: CHAdeMO, Combo Charging System (CCS), Tesla Supercharger, and the Chinese system. The first three compete primarily in the North American and European markets. CHAdeMO initially emerged as a significant player, developed through a collaboration between TEPCO and Japanese automakers. It solely features the DC standard and currently operates at a limit of 50 kW, although there are ongoing efforts to develop 150 kW CHAdeMO (CHAdeMO-Conformity High-Power Charger Connector Assembly for Over 100 KW-Class EV Charge, 2019.; Sbordone et al., 2015; Youssef et al., 2018).

Following this, SAE introduced CCS, which integrates both AC and DC standards within a single unit (Shareef et al., 2016). Tesla, on the other hand, devised its own charging protocol, which is incorporated into all their Superchargers. Different vehicles employ various standard connectors; for example, Nissan supports CHAdeMO, while most other automakers endorse CCS. Presently, CHAdeMO remains the most widely used protocol. Tesla has developed an adapter that allows Tesla owners to connect to CHAdeMO chargers (Araya, 2020.; Okbe Kifle Habte, 2019.).

Many new chargers, Evttec and BMT, along with ABB, are designed with multiple sockets. This accommodates both CCS and CHAdeMO-equipped car owners, simplifying the recharging process. However, it appears that CCS is poised to become the predominant solution in the future. One reason for this shift is the fact that CCS currently supports higher power. Consequently, in Europe, a consortium of automakers is planning to establish a substantial HPC network based on CCS technology (Advanced IoT Solution for EV CHAdeMO Fast Charging Applied with Mobile Networks, 2019).

At present, the most powerful chargers available for light EVs have the potential to deliver up to 150 kW DC. Such systems are being installed by various companies, including Swiss firm EVTEC and DBT (Advanced IoT Solution for EV CHAdeMO Fast Charging Applied with Mobile Networks, 2019; Shareef et al., 2016). Nevertheless, the light electric vehicle that charges at the highest power currently is the Tesla Model S (or Model X), which can utilize the Tesla Supercharger network, offering a rated power of up to 145 kW (Lambert, 2016). However, future electric vehicles are expected to handle much higher charging powers. In November 2016, a group of major automakers (BMW Group, Daimler AG, Ford Motor Company, and Volkswagen Group) signed a Memorandum of Understanding (MOU) to develop a brand-independent network of ultra-fast charging stations. This project aims to construct approximately 400 ultra-fast charging sites in Europe, boasting power levels of up to 350 kW. The network will adopt the Combined Charging System (CCS) standard, compatible with the majority of current and future EVs (*Paribesh Ranabhat Secure Design and Development of IoT Ena-Bled Charging Infrastructure for Electric Vehi-Cle; Using CCS Standard for DC Fast Charging*, 2018). Fortum Charge & Drive also has plans to create a similar network. Specifically, the company intends to establish an HPC corridor

connecting Oslo, Stockholm, and Helsinki, offering a power output of up to 350 kW (Longo et al., 2017; Un-Noor et al., 2017).

2.3. Power Flow Methods

Load flow analysis is the backbone of power systems engineering, enabling engineers and system operators to ensure the reliable and efficient operation of electric power networks. It involves complex mathematical formulations and iterative techniques to calculate voltage magnitudes, phase angles, real and reactive power flows, and other critical parameters in power systems (Longo, 2017). These results are crucial for optimizing and maintaining the electrical grid while adhering to safety and operational constraints. The primary objective is to ensure the system's operational constraints, such as voltage limits and equipment ratings, are not violated. The load flow methods widely used for radial distribution systems are Newton-Raphson Method (NR), Adaptive Newton-Raphson, Fast Decoupled Load Flow, DC Load Flow, Forward/Backward Sweep, etc.

2.3.1. Forward/Backward Sweep

The Backward/Forward Sweep Load Flow Method is an iterative numerical technique used to solve power flow problems in radial distribution systems. It begins with two main sweeps.

The Backward Sweep starts at the furthest downstream nodes (loads) and moves backward toward the source (substation). At each step, the method calculates the voltage magnitude, phase angle, and power injections at the nodes. This phase enables the determination of the voltage at the substation bus.

After the Backward Sweep, the Forward Sweep begins at the substation and moves forward to the loads. During this phase, the method calculates the voltage drops along each branch and updates the node values. The Forward Sweep continues until it reaches the furthest load.

The Backward/Forward Sweep method efficiently calculates the power flow in radial distribution systems, as it progresses from the loads to the substation and then back to the loads. The method only requires local iterations at each node, significantly reducing computational complexity compared to traditional load flow methods.

2.4. Metaheuristics Techniques

Metaheuristics are high-level procedures designed to find approximate solutions to complex optimization problems (Khatri, 2012). Unlike exact algorithms that guarantee optimal solutions, metaheuristics explore the solution space to find near optimal or good solutions within a reasonable amount of time. These techniques are problem-agnostic and adaptable, making them suitable for a diverse set of optimization problems. Metaheuristic Algorithms, renowned for their capacity to tackle complex optimization problems, have gained prominence in recent years as valuable tools for addressing the siting and sizing challenges of EVCS. By drawing inspiration from natural processes and human problem-solving strategies, metaheuristic algorithms offer a more flexible and efficient approach to finding near-optimal solutions in the face of intricate, large-scale, and dynamic decision scenarios. The integration of these algorithms into the realm of EVCS planning, allows universities to navigate the complexities of site selection and charger sizing while considering factors such as campus layout traffic patterns, energy availability and user behavior.

2.4.1. Particle Swarm Optimization (PSO)

In 1995, Kennedy and Eberhart introduced the concept of Particle Swarm Optimization (PSO), a population-based meta-heuristic approach designed for optimizing nonlinear problems. PSO draws inspiration from the collective behavior of various animal communities (Okwu and Tartibu, 2021). Within this framework, individual creatures within these communities, referred to as particles or

agents, collectively constitute a population or swarm (Abebe, 2021; Maciej, 2013). PSO operates by simulating the movement of these individual animals as they search for optimal solutions to mathematical problems, akin to how flocks of birds or schools of fish forage for sustenance in expansive and sometimes dispersed environments (Okwu and Tartibu, 2021).

The fitness of each individual particle is determined by the objective function, a concept akin to the behavior of birds flocking together or fish schooling. This iterative search technique involves particles traversing a wide search space, guided by the objective function. This fundamental principle underpins the PSO algorithm. Each particle embarks on a journey through the entire space, navigating in unpredictable patterns while keeping tabs on the positions of neighboring particles and the best solutions it has encountered based on its own experiences. The swarm continually exchanges information regarding its most promising locations, responding to dynamic changes in their positions and velocities (Kumar et al., 2020; Okwu and Tartibu, 2021).

2.5. Research Works on EVCS

The advent of electric vehicles (EVs) has marked the dawn of a new era in transportation, characterized by a shift towards cleaner and more sustainable mobility. A key factor in facilitating the widespread adoption of EVs is the development of efficient and readily accessible Electric Vehicle Charging Stations (EVCS). The realm of research on EVCS is extensive and multifaceted, with scholars delving into various aspects encompassing technology, infrastructure, and integration with smart grids. In this section, we embark on a review of several seminal research papers within the domain of EVCS, elucidating their contributions and discerning potential avenues for further investigation.

(Saldaña, 2019) have meticulously conducted an exhaustive analysis of cutting-edge fast charging infrastructure for EVs. Their work encompasses an exploration of technological intricacies, adherence to standards, and the repercussions of these systems on the power grid. The research notably sheds light on the contemporary advancements in fast charging technology. Nevertheless, it falls short in the exploration of the economic and regulatory impediments associated with the deployment of fast charging stations.

In the study by (Afonso, 2020) ,the focus is directed towards scrutinizing Vehicle-to-Grid (V2G) frameworks as they pertain to the charging of EVs in smart cities. The research takes a comprehensive approach, dissecting the intricate interaction between EVs and the power grid, with a particular emphasis on their integration within smart grids. Regrettably, the research is deficient in its investigation of the cybersecurity challenges and data privacy issues that inevitably surface within the context of V2G interactions.

(Rashidzadeh-Kermani, 2018) present an optimal charging strategy tailor-made for electric vehicle aggregators, thoughtfully considering variables such as electricity pricing and the impact on battery longevity. The work deftly tackles the imperative matter of optimizing schedules for EV charging. However, there is a noticeable lacuna in the research concerning the real-world implementation challenges and the establishment of a bridge between theoretical frameworks and practical application.

The scholarly endeavor by (Zeng et al., 2017) is geared towards assessing the ramifications of a high influx of EVs into distribution systems. It proffers solutions to mitigate the constraints imposed on the grid by the widespread adoption of EVs, bestowing invaluable insights into the challenges arising from the proliferation of EVs. Yet, it inadvertently omits the focus on developing adaptive grid

management and control strategies that can adeptly accommodate the surge in EVs while ensuring the stability of the grid.

(Institute of Electrical and Electronics Engineers. Kerala Section. IA/IE/PEL Joint Chapter et al., n.d.) introduce a suite of optimal scheduling strategies for the charging of EVs and the operation of Vehicle-to-Grid (V2G) systems, with a view to maximizing the advantages reaped by EV owners and the grid. The research accentuates the economic benefits underpinning the integration of EVs with smart grids. Nonetheless, it bypasses the creation of user-friendly software interfaces for optimal scheduling, which would promote user involvement in the endeavor of grid balancing.

(Ji and Huang, 2018) engage in a comprehensive discourse on plug-in EV charging infrastructure, encapsulating discussions regarding technology, adherence to standards, and glimpses into future developments. The research aptly encapsulates the landscape of charging technologies. Yet, it neglects to delve into the exploration of advanced charging technologies, such as wireless charging and ultra-fast charging, which are essential in meeting the evolving needs of the burgeoning community of EV users.

As the evolution of electric transportation progresses, researchers are finding it increasingly imperative to leverage the potential of metaheuristic algorithms. These algorithms play a pivotal role in shaping decisions regarding the implementation of Electric Vehicle Charging Stations (EVCS) on campuses. Once again, this dissertation serves as a comprehensive exploration of the existing research within this domain. It also illuminates the methodologies, tools, and pertinent case studies contributing to the formulation of efficacious and sustainable EVCS solutions within the AAMUSTED campus.

The contemporary landscape of electricity utilities is characterized by mounting pressure to transition towards sustainable generation units. This shift is predominantly driven by global concerns surrounding emissions (Aktar et al., 2021; Kober et al., 2020; Newell et al., 2019; Wittmann et al., 2021). Consequently, the electrical energy sector has undergone substantial transformations. These changes are marked by a heightened emphasis on integrating smart grid technologies at various junctures in the power distribution system.

General Electric, in its reports, underscores the ongoing transition from an electricity system primarily reliant on large, centralized generation and transmission and distribution (T&D) technologies. The trajectory is shifting towards a network that encompasses distributed, digitally enhanced, and low-carbon technologies. The amalgamation of traditional and emerging elements, both physical and digital, alongside large, and small components, is coalescing to shape a novel power network for the twenty-first century (Kober et al., 2020).

CHAPTER THREE

MATERIALS AND METHODS

3.0. Introduction

This chapter highlights the data and modelling process employed in the study to attain the aim of the study. Raw data was collected from the Akenten Appia-Menka University of Skills and Entrepreneurial Development (AMUSTED) campus. The Electrical Transient Analysis Program ETAP was used to build a model from the gathered data. The data from ETAP was applied to a model in MATLAB in the placement of EVCS on the AAMUSTED campus using PSO. The results of the PSO implementation on the campus were used for the formulation of the objective function.

3.1. ETAP modelling

The researcher gathered the data and the route of the electrical distribution network from the AAMUSTED campus with the assistance of certified electrical technicians on campus. The distribution network of the campus is connected in a radial circuit. The gathered data included the voltages on each bus of the low voltage (LV) distribution network of the AAMUSTED campus, from the second week in February through to the third week in March 2023.

ETAP was employed to model the low voltage (LV) distribution network of the AAMUSTED campus and simulated data from the ETAP platform is applied to the MATLAB program to enhance the sizing and placing of EVCS on the AAMUSTED campus network. The AAMUSTED distribution network served as the model network or the base case for this research. The simulated

data included the line and bus data on the distribution network of the AAMUSTED campus network. Figure 3.1 below shows the line diagram of AAMUSTED distribution network.

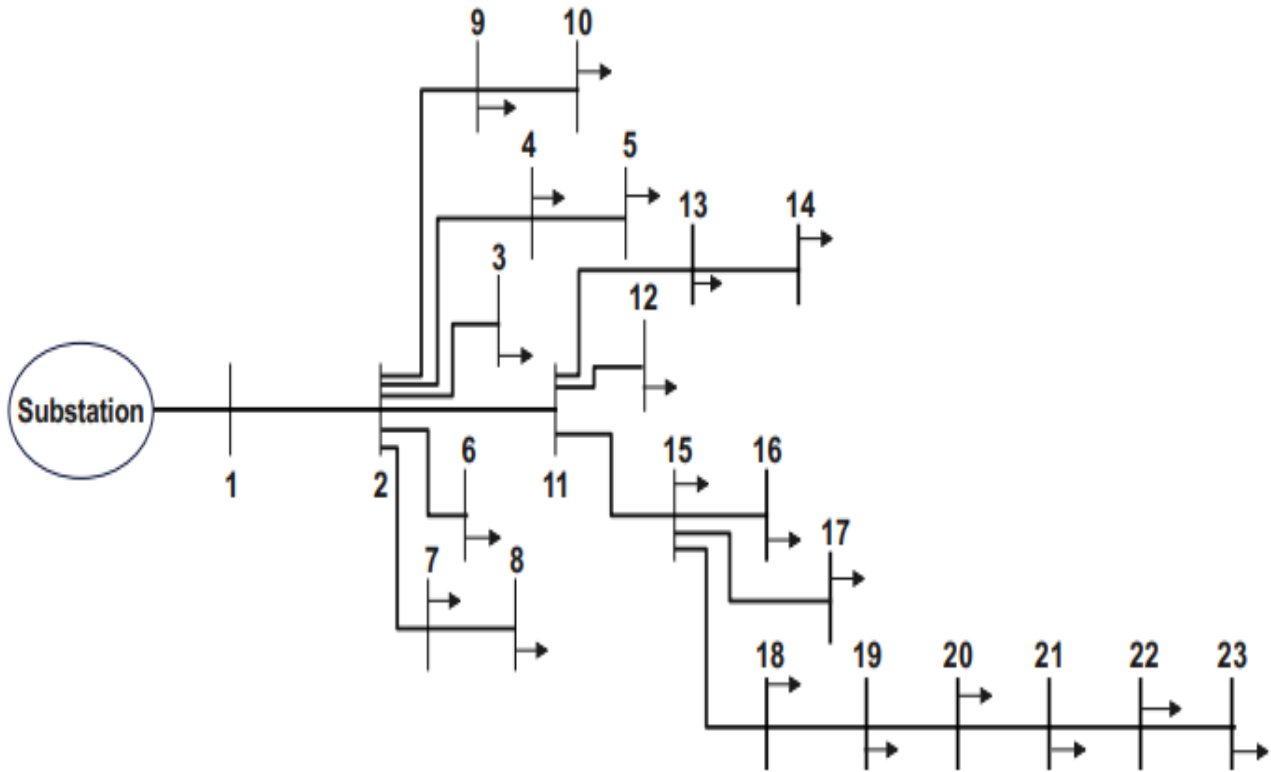


Figure 3.1, Line diagram of AAMUSTED distribution network

3.2. The AAMUSTED Distribution Network.

The Electricity Company of Ghana supplies power to the AAMUSTED campus through the Tanoso feeder and the Apatrapa feeder, both of which have an 11kV. After passing through several breakers and buses, the Tanoso feeder delivers power to the workshop transformer, which has a 500kVA rating.

The workshop transformer also supplies power to a load of 218.9 KW at the construction block and spans to some portions of Opoku Ware Hall with a load of 31.46 KW before serving the UBA bank with a load of 18.39 KW.

The workshop transformer also supplies power to a load of 478.1 KW at the administration block, 12.08 KW at Atwima Hall, and 57.1 KW at the University Clinic.

The basic school transformer, which has a 500kVA power rating and is only dedicated to supplying power to a load of 0.0199KW at university basic school, is also connected to the same Tanoso feeder. On the other hand, the Reynolds Okai Building (ROB) transformer is connected to the Tanoso feeder, which has a 500kVA power rating and provides supply to 87.03KW load at ROB lecture halls. The CBT block receives 89.52 KW of power from the ROB transformer in addition to the China block, which receives 0.0593 KW.

Additionally, Apatrapa feeder provides electricity to the autonomy transformer (500kVA), which in turn provides 467.3KW power to the autonomy hall, 25.6KW to the RG block, 3.86KW to the estate bungalow, 0.664KW of load to the RG Anex, 3.61KW to the credit union, 11.95KW to Frank Jay, and finally 20KW and 3.53KW to the respective halves of the Opoku ware hall and Tanoso estate.

ETAP software is used to model the system. The provided diagram in Figure 3.2 illustrates the distribution system within the AAMUSTED campus.

This diagram visually represents the layout and components of the distribution system employed within the campus premises. Figure 3.2 shows a diagram of the various elements involved in the distribution system, which may include transformers, power lines, and other relevant infrastructure. This visual representation helps to comprehend the physical arrangement and connectivity of the distribution system within the AAMUSTED campus, aiding in further analysis, planning, or optimization efforts related to campus utilities and resources.

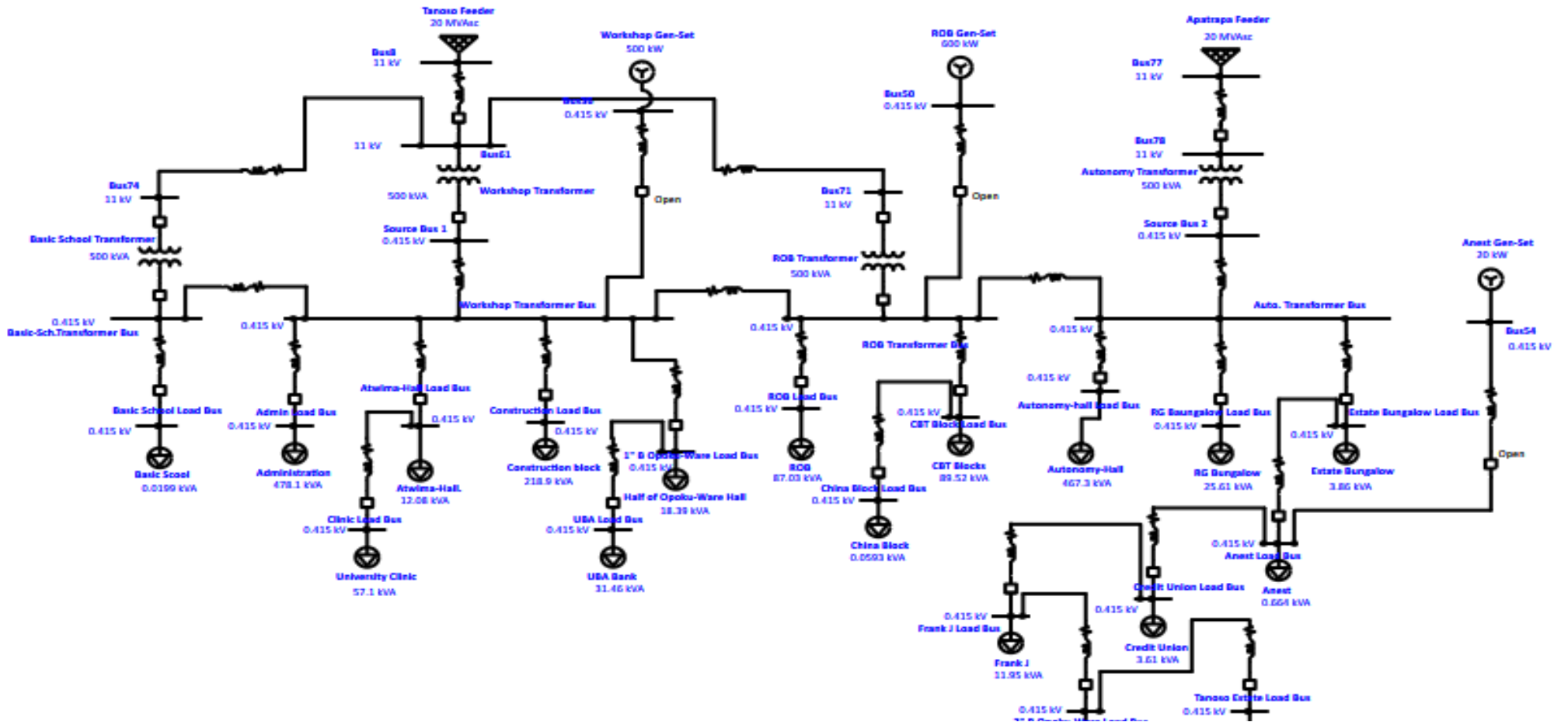


Figure 3.2, AAMUSTED campus distribution system

3.3. System Modelling

The distribution system was modelled from the electrical layout of the AAMUSTED campus distribution network. The power loss (active and reactive) and voltage profile improvement were employed as objective functions to generate the necessary system base data, and the Electrical Transient Analysis Program (ETAP) was utilized.

The simulated data were utilized as input for the MATLAB program designed to handle load flow and optimal allocation. The load flow technique was implemented using the Backwards-Forward Sweep algorithm, while an optimization technique was employed for sizing and placement of EVCS.

3.4. Objective Function Formulation

The Particle Swarm Optimization (PSO) algorithm was employed for selecting the position and size of the Electrical Vehicle Charging Station (EVCS). The best positioning and capacity for the EVCS inside the distribution system were found using PSO. It is essential to remember that voltage fluctuations and stability can be significantly impacted by power losses and voltage profiles that occur at the buses of the distribution system. Hence, expressed as:

$$f_1 = P_{loss} = \sum_{i=1}^n [(I_i^2 R_i) + (I_{EV}^2 R_{EV})] \quad 3.1$$

$$f_2 = VDI = \sum_{i=1}^n [|1 - V_i|^2 + |1 - V_{EV}|^2] \quad 3.2$$

f_1 and f_2 respectively represent the objective functions in Equations 3.1 and 3.2, I_i denotes current, n indicates the number of buses, and R_i symbolizes the resistance at the i^{th} bus.

Additionally, the variables $I_{EV}^2 R_{EV}$ is used to calculate the power loss associated with the charging stations as the current and resistance of the EV charging stations is respectively represented as I_{EV}^2 and R_{EV} .

Equation 3.2 shows the voltage profile deviation (VDI), which takes into consideration a voltage reference of 1p.u. V_i stands for the potential present on the i^{th} bus. n denotes the number of buses on the radial system, while i signifies the bus under study. V_{EV} indicates the voltage of the EVCS, and the difference between 1p.u and the voltage $(1 - V_{EV})$ of the charging stations is the absolute value.

The variance between the nominal voltage and the real system voltage is determined by the voltage deviation index. A Smaller voltage deviation index shows that voltage conditions are better for reliable operation (Le et al., 2007). The voltage deviation index is expressed as (Mokred et al., 2023; Oukennou et al., 2018; Ratra et al., 2018)

$$OOF = \text{Min}(w_1 f_1 + w_2 f_2) \quad 3.3$$

Where OOF is the overall objective function, and w_1 , and w_2 are the importance assigned to each objective function f_1 , and f_2 respectively.

At the nodes, considering the impact of voltages (V_i) and current flow (I_i) operational limitations, and EVCS as specified by (Abid et al., 2024; Balu & Mukherjee, 2023; Guo et al., 2023; Ray et al., 2023).

$$P_{AAMUSTEDdist} = P_L + P_{EV} + \sum P_d \quad 3.4$$

Here the active distribution power network of AAMUSTED ($P_{AAMUSTEDdist}$) is the same as the Input Power (P_{in}) while the supplied demand power to the loads is (P_d) considering the introduction of

EVCs on the Network, the total power generated (P_{Gi}) will be expressed as a function of the injected generation unit or units shown in (3.5)

$$P_{in} = P_L + \sum P_d - \sum_{n=1}^N PG_i + PG_{EV} \quad 3.5$$

PG_i is the injected active power at the bus i^{th} EVCs.

The power balance requirement is:

$$\sum_i^n PG_i - P_L - PG_{EV} = P_d \quad 3.6$$

$$\sum_i^n QG_i - Q_L - QG_{EV} = Q_d \quad 3.7$$

Where P_{Gi} is real power and QG_i is reactive power injected by EV at a specified bus (i^{th}), active power and reactive losses of the considered studied buses are respectively represented by P_L and Q_L , as both the active and reactive demand power are P_d and Q_d , the total number of buses is n .

The number of total EVCS placement modeled as

$$\text{Number of locations} = \frac{\text{maximum EVCS penetration}}{\text{maximum EVCS size}} \quad 3.8$$

The EVCS is modeled mathematically based on the average power demand (E_{hj}) of the station (Longo et al., 2017). In (3.9), $E_{h,max}$ is described as the maximum of E_{hj} in a given period. If $\Delta t = 1s$ then $Eg(t)$ becomes power. Also, since energy is expressed in kWh, Δt implemented in the model is $3600/\Delta t$. $E_{h,max}$ is the considered peak period from 6 am to 10 pm.

$$E_{hj} = \sum_{t \in h_j} (E_g(t) + E_{EV}(t)) \quad 3.9$$

$$E_{hj} \leq E_{h,max} - E_{EVj} \quad \forall j \in \text{month } m \quad 3.10$$

$E_g(t)$ is the grid energy consumed by the EVCS. E_{hj} is the hourly average power demand.

3.4.1. Inequality Constraints

Equations (3.8) to (3.13) express the problem's inequality restrictions.

The power system's generation operating limitations must match the required minimum and maximum power for EVCS allocation on a low voltage network.

$$P_{Gimin} \leq P_{Gi} \leq P_{Gimax} + P_{EV} \quad 3.11$$

$$Q_{Gimin} \leq Q_{Gi} \leq Q_{Gimax} + Q_{EV} \quad 3.12$$

EVCS installed capacity is the minimum power demand for 100 EVs from five manufacturers. This EVCS characteristic was adopted by (Balu & Mukherjee, 2023; Guo et al., 2023; Ray et al., 2023). The total demand for the station is limited to 688 KW.

$$EVCS_{total} \leq EVCS_d \quad 3.13$$

3.5. Software Modelling

MATLAB and ETAP were utilized as modeling tools in this dissertation. The low-voltage distribution network at AAMUSTED was particularly modeled using ETAP, and the best locations and sizes for quick Electrical Vehicle Charging Stations (EVCS) were determined using MATLAB.

Combining the features of these two software programs allowed for the effective distribution of EVCS and a thorough investigation of the distribution network, furthering the study's overall goals.

3.5.1. Line and Bus Data of the AAMUSTED Distribution Network

Due to the lack of an already-existing system in software structure, ETAP was ultimately selected to model the current AAMUSTED distribution network (Kumasi campus). The base case models for the AAMUSTED distribution system are available digitally through ETAP. The algorithm created in the MATLAB environment was then fed to the line and bus data that was collected from the ETAP model. An accurate adaptive Backward/Forward Sweep method with a precision level of 0.01 was selected to undertake power flow analysis. This method allowed for a detailed examination of the AAMUSTED distribution network's system performance while studying the power flow characteristics of the network. The line and bus data are shown in Table 3.1 below.

Table 3.1, Line and Bus data of AAMUSTED distribution system

Line Data				Bus Data		
From Bus	To Bus	R	X	Bus ID	kW	kvar
1	2	196.45	168.05	1	714.9	337.5
2	3	1892.47	2718.54	2	792.1	335.5
2	4	1419.35	2038.90	3	412.3	135.5
4	5	268.73	386.03	4	63.12	19.99
2	6	847.83	1217.91	5	51.82	17.03
2	7	1892.47	2718.54	6	197.8	65.01
7	8	946.23	1359.27	7	46.49	10.96
2	9	8989.22	12912.71	8	29.14	7.3
9	10	141.94	203.89	9	60.78	15.36
2	11	16370.43	14004.55	10	0.0197	0
11	12	141.94	203.89	11	238	65.58
11	13	1502.62	2158.52	12	81.43	26.77
13	14	5963.17	8566.11	13	80.58	34.3
11	15	5565.95	4761.55	14	0.058	0

15	16	141.94	203.89	15	509.8	163.1
15	17	3430.10	4927.35	16	437.7	127.7
15	18	6630.26	9524.40	17	24.47	4.97
18	19	3387.52	4866.18	18	42.38	12.25
19	20	2129.03	3058.35	19	38.02	10.75
20	21	7407.12	10640.35	20	36.98	10.03
21	22	956.64	1374.22	21	32.42	7.63
22	23	3643.00	5233.18	22	21.6	4.39
				23	3.24	0.657

The data for the lines and buses are shown in Table 3.1 above. This table offers extensive information and constitutes a reference for several line and bus parameters. Analyzing the provided data can provide helpful insights into the features and specifications of the lines and buses under review. This table is an essential tool for understanding and analyzing the electrical network, which makes it easier to plan and operate power systems effectively. A full evaluation of the line and bus configurations is possible because of the data's comprehensiveness, which guarantees that it covers all pertinent factors.

3.6. System Modelling: Electric Vehicle and Charging Facilities Load

The Electric Vehicle Charging Station (EVCS) is represented in the model as a load, considering the stochastic characteristics of EV charging (Guo et al., 2023; Ray et al., 2023). The system has a 975-kW capacity and can support charging for 25 EVs from five different manufacturers. Table 3.1 provides information regarding some available EVs (Wolbertus & Van den Hoed, 2019).

Table 3.2, Characteristics of EV for fast EVCS modeled.

TABLE III DESIGN FEATURES OF EVCS				
Electric Vehicle Model	Power Rating (kW)	No. of CP	Total Rating (kW)	Charging level
BYD E6	100	1	100	3
Changan Oshan	90	1	90	3
Tesla Model Y	250	1	250	3
Cherry 3XE	95	1	95	3
Xpeng GS 50i Smart	33	1	33	3
Electric Delivery Bike	30	2	60	3
Renault K-ZE	60	1	60	3
The total power rating of EVCS (kW)			688	

3.7. MATLAB Modelling

The MATLAB 2021 software is utilized for the optimal placement of Electric Vehicle Charging Stations (EVCS). This involved conducting load flow analysis and employing various optimization techniques. In this part, the modelling procedure for these optimization strategies is described in depth.

3.7.1. Modelling of Particle Swarm Optimization Algorithm for Simultaneous Placement

The PSO algorithm technique was designed by Kennedy and Eberhart in 1995 (Okwu & Tartibu, 2021). The position and velocity of a particle are respectively expressed as x_i^k and v_i^k the preceding solution is solved using the previous best solution ($pbest_{id}$). Equation (3.30) and (3.31) are used to

improve the individual best to achieve the global best in the iterative form (Haider et al., 2021). The location of the individual particle is:

$$x_{id}^{k+1} = x_{id}^k + v_{id}^{k+1} \quad 30$$

$$i = 1, 2, 3 \dots N_p, \quad d = 1, 2, 3 \dots N_g$$

The member of the particle is N_g . N_p represents the swarm population. Equation (3.31) is the velocity of a particle as:

$$v_{id}^{k+1} = w \times v_{id}^k + C_1 \times \text{rand}() \times (pbest_{id} - x_{id}^k) + C_2 \times \text{rand}() \times (gbest_d - x_{id}^k) \quad 3.31$$

For each new solution during iteration, the inertia is updated and evaluated using () as:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad 3.32$$

Where, w_{min} and w_{max} are the minimum and maximum inertia weights respectively and $iter$ and $iter_{max}$ are the present and maximum iteration. Each particle is represented in the diagram as shown in Figure 3.7 (Abdulrazzaq, 2015; Rajpoot et al., 2017).

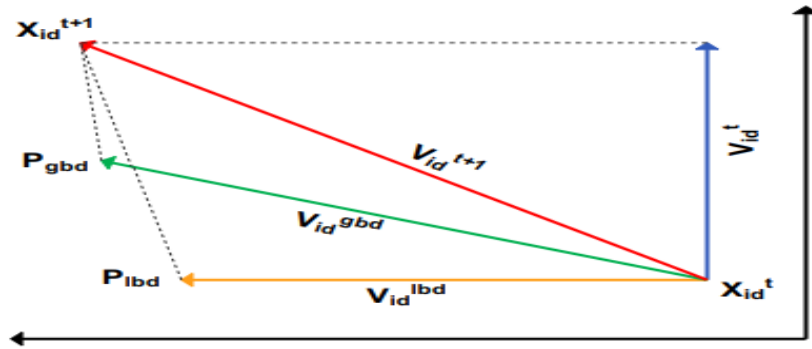


Figure 3.3, PSO search mechanism in multidimensional search space illustration.

3.7.2. PSO Parameters

The fundamental elements of the PSO algorithm encompass particle velocity, random values, weight coefficients, inertial weight, and termination criteria. Particle velocity represents a technique within the PSO algorithm that is confined within set boundaries. The fitness function is influenced by parameters V_{\max} and V_{\min} , outlining the exploration area between the present and target positions. If the number of particles is limited, the process of particles converging towards desired solutions takes more time (Shobana et al., 2019). Random values, falling within the range of 0 to 1, contribute to the stochastic nature of the PSO algorithm.

Stochastic weight coefficients are embodied by social and cognitive acceleration. When outcomes yield high values, particles unexpectedly converge towards the intended regions. On the other hand, lower values allow particles to roam widely before being pulled closer. These parameters can be configured within the range of 1 to 2. The introduction of inertia enhances both local and global searches. Initially set at a higher value, the inertia weight gradually decreases during the optimization process. Equation (3.32) adapts the inertia weight (w) between 0.2 and 0.9. The termination criterion is met through a combination of iterations and tolerances of the objective function. To ensure solution accuracy, the concluding requirement involves a maximum count of iterations.

3.7.3. PSO implementation procedure

Every particle in the PSO possesses a vector with real values. Each parameter subjected to optimization corresponds to a dimension within the problem space. The PSO stages are as follows:

Step 1: Starting

Initialize the iteration counter at 1 in order to create a dimension for n-particle through randomization. The calculation of objective functions involves the random initiation of starting velocities for each particle, alongside the establishment of lower and upper boundaries.

Step 2: Establish the iteration tally ($iter = 1$).

Step 3: Set the tolerance ($maxiter > iter$).

Step 4: Formulation of objective function

Step 5: Upgrading of both local minimum and the global minimum of particles.

Step 6: Update particle velocity and position of each particle using equation (3.54) and (3.55) respectively.

Step 7: Update the iteration counter ($iter = iter + 1$).

Step 8: If criteria are satisfied, go to step 7 or else go to step 2.

Step 9: Stop/end if the particle generated optimal solution.

The assessment of the network's operational traits and performance is significantly influenced by the system process. The system process in this study is visually depicted in Figure 3.4. The flowchart below explains the step-by-step approach utilized to achieve the research's objective.

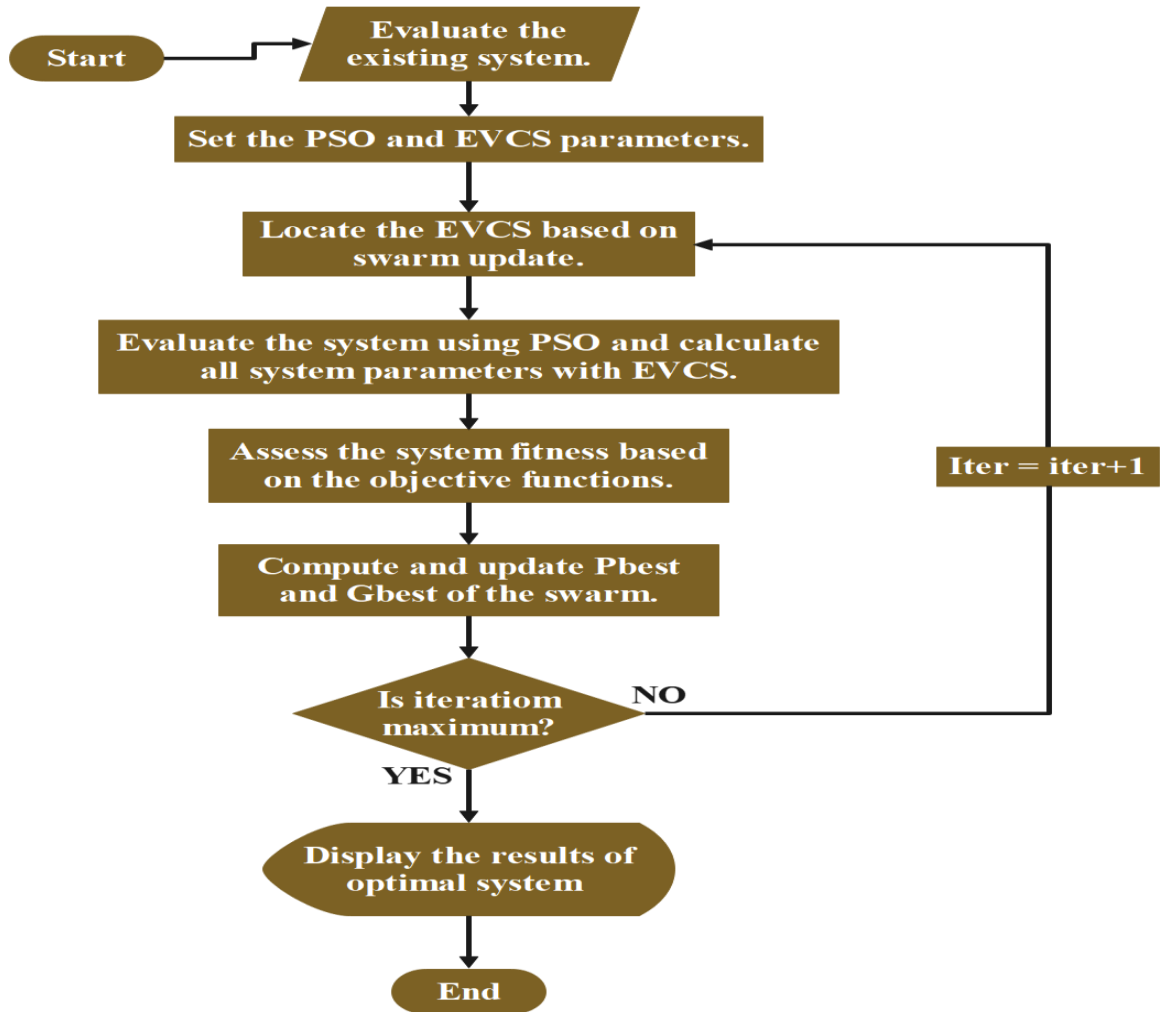


Figure 3.4, Flowchart of the proposed algorithm

The flow chart above shows the step-by-step approach to achieve the aim of this research. Firstly, it was initiated by reading the bus and line data values from the network provided and run load flow using Backward/Forward Sweep method and recorded as base case. After the base case, the parameters of PSO would initialize to locate the EVCS on the vulnerable buses based on swarm update and run load flow using PSO algorithm and calculated the system parameters with EVCS. The iteration is set to maximum number of 100 to know the optimal location and size of EVCS on system buses.

3.8. Validation of System Model

The study adopted the empirical, comparison and simulation validation methods. In terms of the empirical validation the adopted methodologies used in this research have been used for optimal allocation in other studies (Balu & Mukherjee, 2023; Guo et al., 2023; Khatri et al., 2012; Longo et al., 2017; Oukennou et al., 2018; Un-Noor et al., 2017).

The optimization techniques adapted for the research have been previously used for allocation in other areas in power system voltage profile improvement such as network reconfiguration, storage allocation and DG units and capacitor banks placement. The PSO has been used for optimal placement of DG units using the backward/forward load flow technique. This research applied the PSO algorithm for the placement of EVCS. The data for the AAMUSTED distribution network was compared with ETAP simulated data in. The existing AAMUSTED distribution voltages and ETAP simulated voltages were compared in figure 3.7.

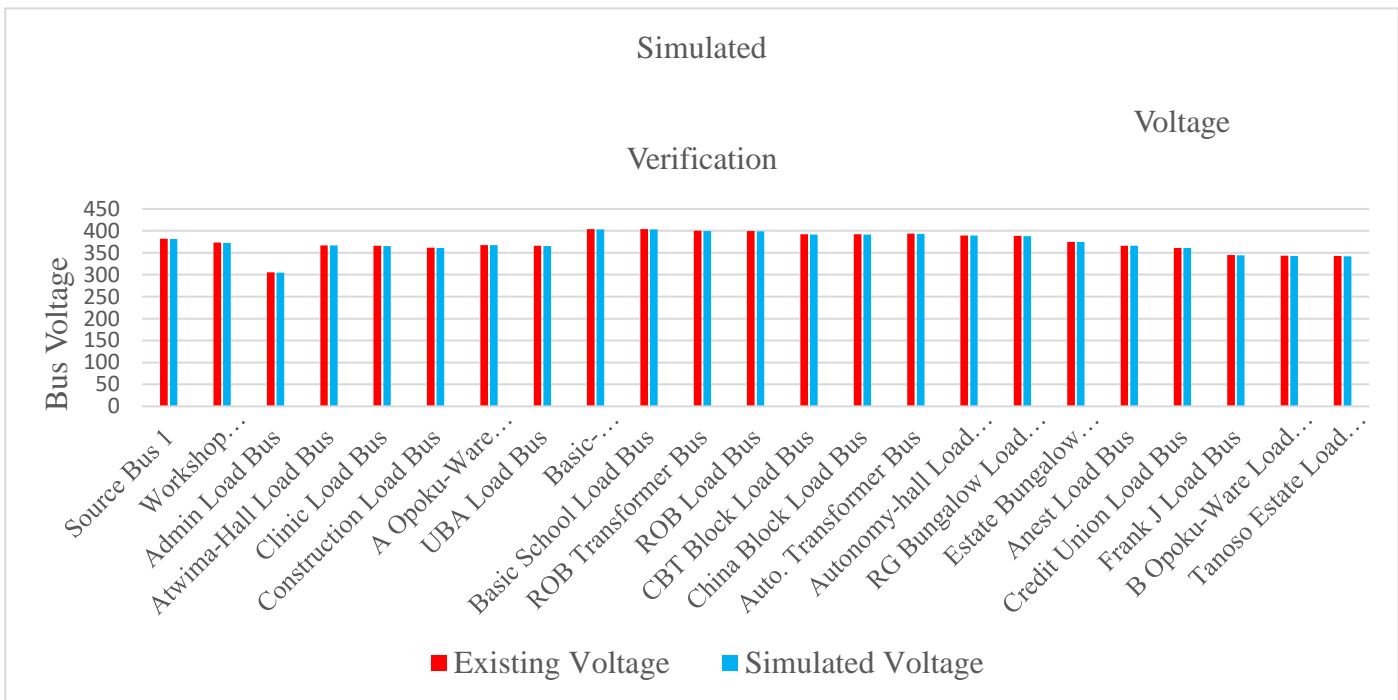


Figure 3.5, Verification of the existing system and simulated data.

In terms of validation by the simulation method, the ETAP was used to extract the base case for the AAMUSTED campus network. The results from the ETAP simulation are compared to the real data received at the various buses in the real system. The error margins are within the acceptable limits for the IEC standard. The error margins for bus voltages ranged from 0.1 to 2.8. The field data, simulated data, and error margins are provided in figure 3.6. A Pearson correlation value of 0.877 was found when comparing field data to ETAP simulation data. Therefore, the ETAP has a 95% degree of confidence, according to the simulated data. The nature of the voltage profile followed the same pattern for both simulated and measured data for the worst-performing buses and the best-performing buses. Appendix I presents the detailed information.

3.9. Study Cases Definitions

The selection of the study cases was guided by existing literature, with the intention of aligning the outcomes of the proposed method with established research findings. A significant body of prior research has extensively explored Electric Vehicle Charging Stations (EVCS), as evidenced by studies conducted by (Ampah et al., 2022; Ji & Huang, 2018; Mohammed & Jung, 2021; Prempeh et al., 2023.). These specific cases were deliberately chosen to empirically validate the influence of EVCS on the distribution system. The selected study cases encompass a diverse array of scenarios, all of which were simulated to comprehensively analyze the impact of EVCS on the AAMUSTED campus network in Kumasi, as detailed in Table 3.3 below.

The **Base case** comprises a load flow study conducted to assess the behavior of the distribution system under standard operating conditions, without the inclusion of EVCS technology. This preliminary analysis establishes a baseline against which the effects of EVCS in subsequent cases can be measured and evaluated. By studying the system's performance in the absence of EVCS, researchers gain valuable insights into the influence of integrating this technology into the

distribution system. The outcomes derived from the base case serve as a pivotal reference point for comprehending the consequences of EVCS implementation in the subsequent study scenarios.

The AAMUSTED campus distribution system in Kumasi was equipped with EVCS technology. This case specifically concentrated on determining the ideal placement and capacity of a single EVCS as **Case 1**, two EVCS as **Case 2**, three EVCS as **Case 3** and four EVCS as **Case 4** within the base case configuration. The primary aim of these integration was to evaluate the influence of EVCS on the voltage profiles at individual buses and the losses experienced in the distribution lines.

Table 3.3, Study cases description

Scenario	Technology	Comment
Base case	-	Existing system without EVCS integration.
Case 1	One EVCS	Integrated one EVCS into the AAMUSTED distribution system.
Case 2	Two EVCS	Utilized two EVCS technology in the AAMUSTED distribution system.
Case 3	Three EVCS	Three EVCS were integrated in the AAMUSTED distribution network.
Case 4	Four EVCS	Deployed four EVCS within the AAMUSTED distribution system.

3.10. Summary of methodology

The section describes the modelling process and data used in a study on the placement of electric vehicle charging stations (EVCS) on the AAMUSTED campus network. The study collected raw data from the AAMUSTED campus (Kumasi) to create a network model using the Electrical Transient Analysis Program (ETAP).

The data from ETAP was then used in MATLAB to simulate the placement of EVCS on the campus network using the Particle Swarm Optimization (PSO) technique. The PSO technique was also used

to create the objective function, which is a mathematical representation or measure that encapsulates the desired goals or criteria for the specific problem or scenario at hand.

CHAPTER FOUR

RESULT AND DISCUSSION

In this chapter, the findings of the AAMUSTED 11kV distribution system are presented. To evaluate the effectiveness of the proposed approach, five cases were examined: the system without EVCS (used as the base case), with one EVCS (used as the Case 1), with two EVCS (used as the Case 2), with three EVCS (used as the Case 3) and with four EVCS (used as the Case 4). The Backward/Forward Sweep power flow analysis technique was utilized to investigate the voltage profile, power losses (active and reactive). The optimization procedure was carried out to know the optimal placement and sizing of EVCS using MATLAB R2021a software. These results provide insight into integrating EVCS in the AAMUSTED 11 kV distribution system.

4.0. CASES

4.1. Base case: Existing Network Results

To evaluate the operational effectiveness of the AAMUSTED 11 kV distribution system, a load flow analysis was undertaken on the existing system, serving as the foundational scenario where integration of EVCS was not considered. This study encompassed an assessment of both active and reactive power losses, as well as the voltage profiles across the various buses. The findings of this investigation showed that the AAMUSTED 11 kV distribution system has a total active power loss of 103.171 kW and the total reactive power loss amounting to 137.8 kvar. Furthermore, the voltage level on buses 9 and 10 was found to be the highest at 0.973 p.u.

4.1.1. Active Loss of Base Case

The provided data represents active power values associated with different line IDs in a power system. These values play a crucial role in understanding the distribution and consumption of electrical power within the system. To guarantee the system operates at its best, it's crucial to minimize power losses. To accomplish this, the cumulative power loss across all line sections was computed and examined. Figure 4.1 depicts the active power losses in the AAMUSTED 11 kV distribution system when EVCS integration is absent. This assessment aids in pinpointing system zones that could benefit from EVCS integration.

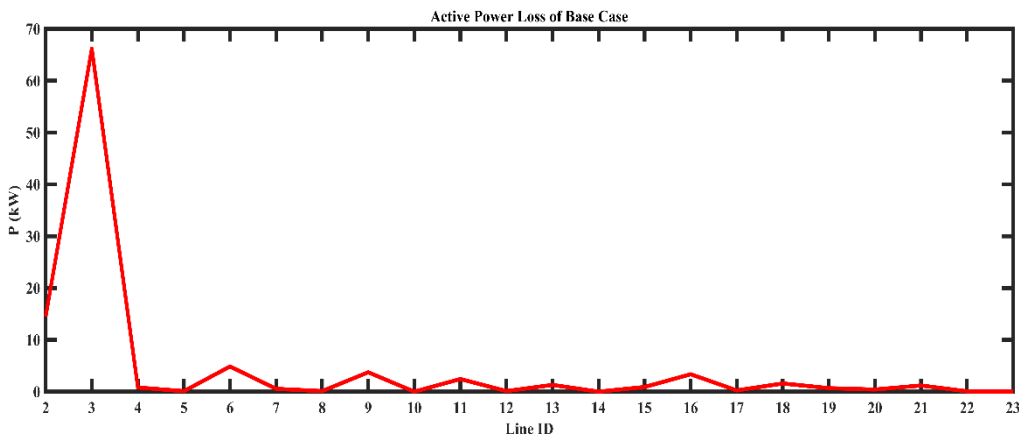


Figure 4.1, Active power loss of base case.

Based on the information provided in Figure 4.1, the AAMUSTED 11 kV distribution system experienced a total active power loss of 103.171 kW. The results revealed that lines 10, 14, 23, 22, 5, 8, 12 and 19 were the ones with the lowest power losses in the system. The buses with the highest losses are 3, and 6 and these losses were attributed to the load demands on the AAMUSTED network which have an impact on network performance and efficiency.

4.1.2. Reactive Power Loss of Base Case

Due to the nature of the loads in the distribution system, particularly the heating loads, there is a high demand for reactive power. Figure 4.2 illustrates the reactive power losses in each line of the AAMUSTED 11 kV distribution system when EVCS integration is not implemented. The losses in these lines are attributed to the inductive loads in the system, which increases the demand for reactive power.

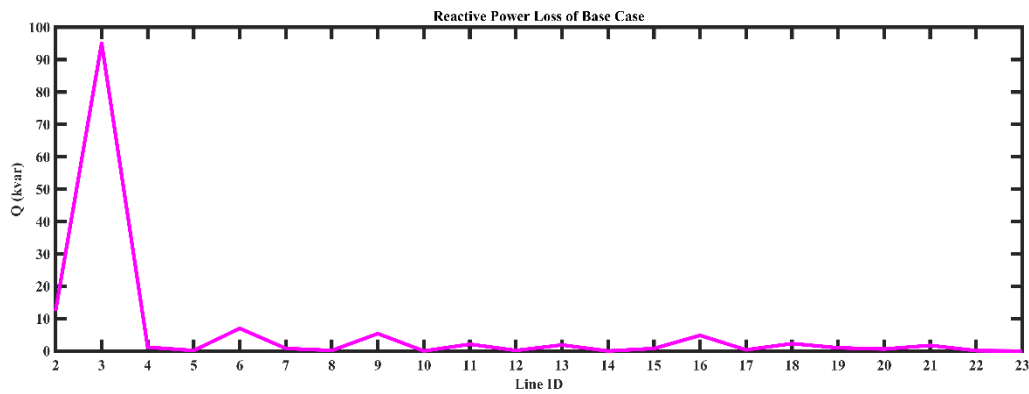


Figure 4.2, Reactive power loss of base case.

Based on the information presented in Figure 4.2, the reactive power losses in each line of the AAMUSTED 11 kV distribution system without EVCS integration have been determined, and the total reactive power loss is 137.82 kvar. As it was revealed, several lines (14, 10, 23, 22, 5, 12 and 8) in the distribution system have been identified as the ones experiencing lower losses. Lines 3, 6 and 16 attributed high demand for reactive power due to the usage of inductive loads, especially air conditioning and electronic devices.

4.1.3. Voltage Profile of Base Case

Using the BFS load flow method, the voltage profile of every bus in the AAMUSTED 11 kV distribution system was assessed before EVCS integration. Bus 3 exhibited the lowest voltage of 0.734 p.u. The voltage drop was observed to be in direct proportion to the load demand. Improving the distribution system's voltage profile can significantly boost its performance while also reducing losses. To demonstrate the voltage profile without EVCS integration, Figure 4.3 has been presented.

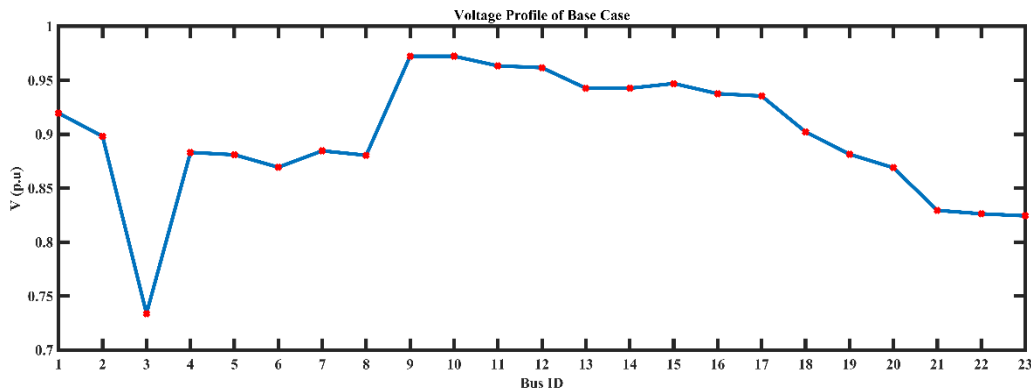


Figure 4.3, Voltage profile of base case.

The voltage profile of each bus in the AAMUSTED 11 kV distribution was analyzed using the BFS load flow method before the integration of EVCS. The voltage drop was proportional to the length of the distribution line and load demand. Improving the voltage profile of the distribution system is crucial for enhancing its performance and reducing losses. The results, as shown in Figure 4.3, revealed that Bus 9 and 10 had the highest voltage performance, followed closely by buses 11, 12, 13, and 14 which have less load demand. On the other hand, the two buses with the lowest voltage performance were 3, and 6. Comparing the results to the IEC 60038-2009 standard revealed that many bus voltages fell within the limit of 10% for system bus voltage (Standard & Horizontale,

2009a). This voltage profile indicates that the network experiences less loss, as the required margins fall within a 10% range.

The results of the base case, which did not involve the integration of EVCS, have been summarized in Table 4.1. This table presents a comprehensive overview of the total active and reactive power losses in the system and the voltage profile at all buses after conducting a power flow analysis. It gives a clear picture of the state of the AAMUSTED 11 kV distribution. The information provided in the table is vital in identifying the key areas that require attention.

Table 4.1, The Summary Results of Base Case

Parameters	Base Case
Total active power loss (kW)	103.171
Total reactive power loss (kvar)	137.8
Minimum voltage (p.u.)	0.734 at bus 3
Maximum voltage (p.u.)	0.973 buses of 9 and 10

4.2. Case 1: Integration of one EVCS

In this section, the integration of one EVCS on the AAMUSTED 11 kV distribution system were analyzed with the aim of assessing the voltage profile of each bus and power losses. The analysis of Case 1 active and reactive losses and voltage profiles of the distribution system is presented in this section.

The main goal of this research is to assess the impact of power losses and voltage profile at each bus of the distribution system. In Case 1, one EVCS was integrated at bus 17 with capacity of 100 kW in the AAMUSTED 11 kV distribution system.

As a result of the integration, there was a significant increase in both active and reactive power losses by 97.28% and 99.96%, respectively. The voltage profile was also decreased, which will ultimately lead to an increase in losses.

4.2.1. Active Power Loss of Case 1

The integration of one EVCS into the AAMUSTED 11 kV distribution system resulted in an increase in total active power loss. In Case 1, the total active power loss increased to 3891.971 kW. This information is presented in Figure 4.4, which provides a visual representation of the active power losses after the integration of one EVCS. The increase in active power loss has a negative impact which can lead to inefficient distribution system, that can translate into energy cost for the power system.

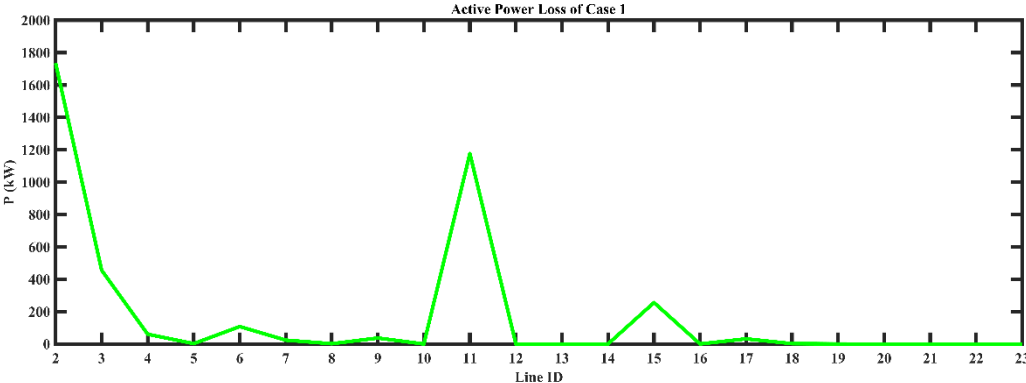


Figure 4.4, Active power losses of case 1

Figure 4.4 above shows the result of active power losses for each line in a power system. This section discusses Case 1 in which one EVCS was integrated into the AAMUSTED 11 kV distribution system. Lines 2, 3, 11, and 15 have the highest power losses, indicating that they are the most inefficient buses in the system. On the other hand, lines 5, 8, 10, 12, 13, 14 and 23 have the lowest power losses, indicating that they are experiencing less significant distribution losses in the system.

The main objective of this case was to assess the impact of total active power loss in the system. The results of this case showed that the integration of the one EVCS led to a significant increase in the total active power loss, by 97.28% compared to the Base Case.

4.2.2. Reactive Power Loss of Case 1

After integrating the single EVCS into the AAMUSTED 11 kV distribution system, the total reactive power loss was significantly increased to 321779.808 kvar. The changes in reactive power loss are presented in Figure 4.5, which visually represents the data on reactive power losses after the integration of the single EVCS. The increase in reactive power loss is a negative outcome, as it leads to a more inefficient distribution system.

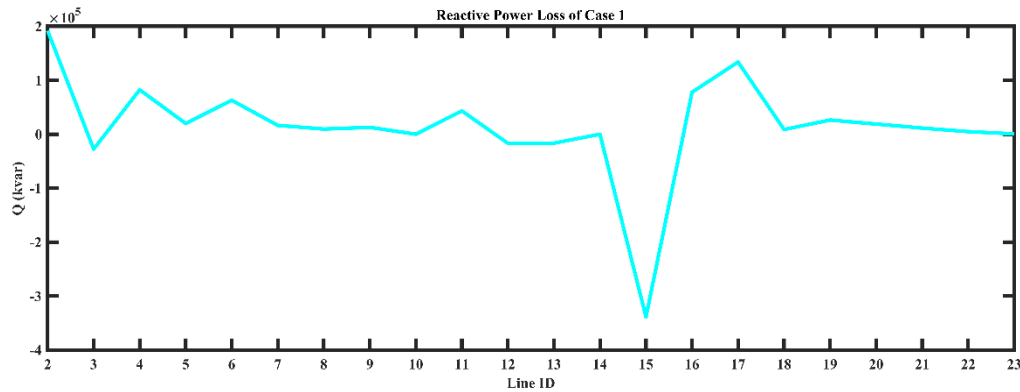


Figure 4.5, Reactive power loss of case 1

The results show the reactive power loss at each line in the power system. The reactive power loss is a measure of the amount of power that is consumed by the system without contributing to useful work. From Figure 4.5, it revealed that some of the buses have very high reactive power losses, such as lines 2, 4, 6, 11, 16 and 17, indicating low power factor and voltage regulation at those locations. On the other hand, line 15 is having a low reactive power loss.

4.2.3. Voltage Profile of Case 1

After the integration of the single EVCS, the voltage profile was analyzed, and the results were presented in Figure 4.6. The figure provides a visual representation of the voltage profile after the integration of the one EVCS on the AAMUSTED 11 kV distribution system.

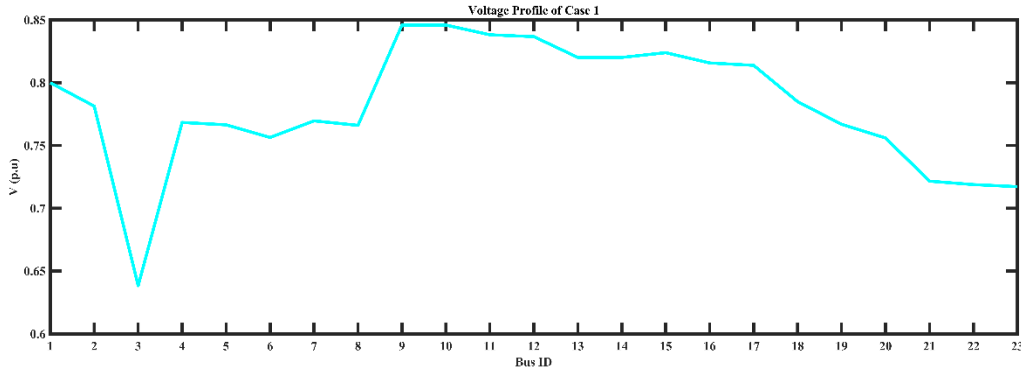


Figure 4.6, Voltage profile of case 1

The voltage magnitudes at the buses within the AAMUSTED 11 kV distribution system deviate from the permissible range of 1 per unit, as outlined by the standards (Standard & Horizontale, 2009). Figure 4.6 illustrates this deviation from the permitted range, highlighting the necessity of voltage management and optimization strategies to ensure reliable and efficient system performance.

Table 4.2 serves as a comprehensive summary, derived from the power flow analysis conducted in Case 1. This tabular presentation provides an all-encompassing insight into the overall active and reactive power losses encountered in the section, along with the extreme points of the observed voltage profile on different buses during the analysis.

Table 4.2, The Summary Results of Case 1

Performance Measurement	Case 1
Minimum Bus Voltage (p.u.)	0.677 at bus 3
Maximum Bus Voltage (p.u.)	0.846 at bus 9 and 10
Total Active Power Loss (kW)	3891.971
Total Reactive Power Loss (kvar)	660417.221
Optimal Size (kW)	100
Location of EVCS (Num_Bus)	17
Number of EVCS	1
Active Power Increase Percentage	97.28%
Reactive Power Increase Percentage	99.96%

4.3. Case 2: Integration of two EVCS

In this segment, an examination was conducted into the incorporation of two EVCS within the AAMUSTED 11 kV distribution system. The objective was to evaluate the voltage profile at each bus and to analyze power losses. The scrutiny of active and reactive losses and voltage profiles within Case 2 of the distribution system is presented within this section.

The fundamental aim of this study is to gauge the ramifications of power losses and voltage profiles at each bus within the distribution network. In Case 2, the integration involved two EVCS units situated at the same bus 3, each with a capacity of 100 kW, within the AAMUSTED 11 kV distribution system.

The outcome of this integration was noteworthy, resulting in a substantial surge in both active and reactive power losses by 97.75% and 99.95%, correspondingly. Concurrently, the voltage profile experienced a reduction, which, in turn, is poised to magnify the overall losses within the system.

4.3.1. Active Power Loss of Case 2

The inclusion of two EVCS within the AAMUSTED 11 kV distribution system yielded a rise in the overall active power loss. In Case 2, the cumulative active power loss surged to 4595.882 kW. This data is visually presented in Figure 4.7, offering a graphical depiction of the active power losses post the integration of a pair of EVCS units. The escalation in active power loss carries an undesirable implication, potentially leading to an inefficient distribution system, thereby translating into increased energy costs for the power system.

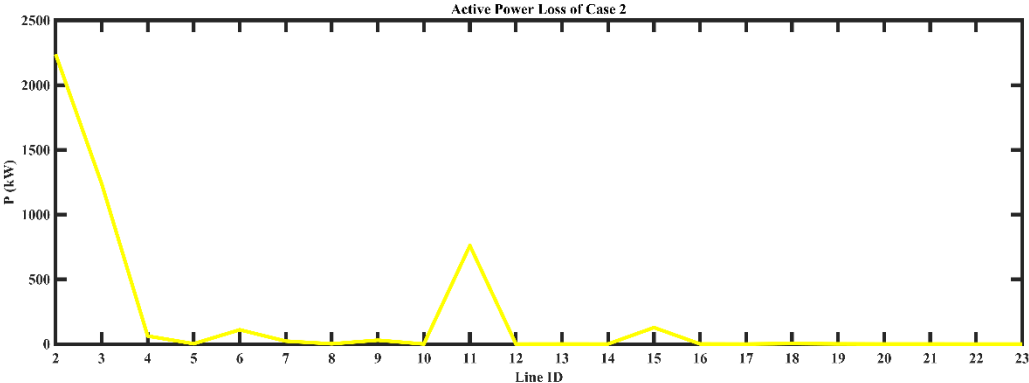


Figure 4.7, Active power loss of case 2

The visual depiction provided in Figure 4.7 offers insight into the active power losses associated with individual lines within the power system. This section dives into Case 2, which involves incorporating two EVCS units into the AAMUSTED 11 kV distribution system.

Lines 2, 6, 11, and 15 are identifiable by their elevated power losses, highlighting their role as less efficient nodes within the system. Conversely, lines 5, 8, 10, 12, 13, 16, 20, 22, and 23 showcase

relatively diminished power losses, suggesting a reduced impact of distribution losses along these lines within the system.

The principal goal of this scenario was to assess the extent of the influence on the overall active power loss within the system. The outcomes emerging from this analysis reveal a significant finding: the integration of two EVCS units led to a pronounced escalation in the total active power loss when compared to the baseline conditions.

4.3.2. Reactive Power Loss of Case 2

The integration of two EVCS into the AAMUSTED 11 kV distribution system resulted in a significant increase in total reactive power loss. Figure 4.8 shows the changes in reactive power loss after the integration of EVCS which marked by a sharp increase in losses.

The integration of EVCS into a distribution system can lead to an increase in reactive power loss, as EVCS draws a large amount of reactive power.

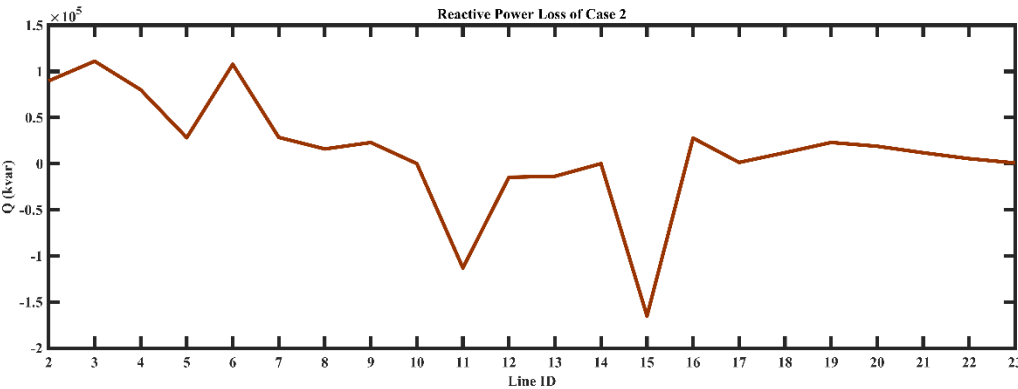


Figure 4.8, Reactive power loss of case 2

The findings presented in Figure 4.8 show that the incorporation of EVCS into the AAMUSTED 11 kV distribution system has significantly increased the reactive power losses. It was discovered that

lines 11 and 15 had the least reactive losses. On the other hand, the values obtained from lines 2, 3, and 6 point to the highest losses of reactive power.

4.3.3. Voltage Profile of Case 2

Figure 4.9 presents the voltage profile analysis of the AAMUSTED 11 kV distribution system after integrating two EVCS. The voltage profiles were examined to evaluate the impact of the integrated EVCS on distribution system.

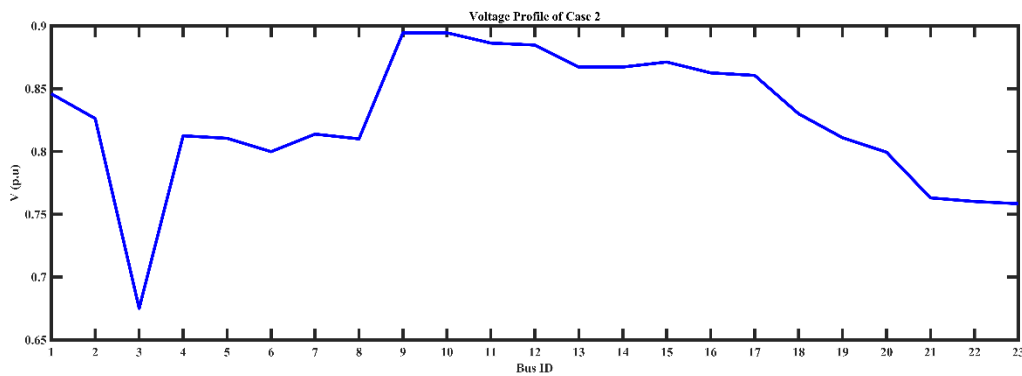


Figure 4.9, Voltage profile of case 2

The voltage levels at most of the buses in the AAMUSTED 11 kV distribution system are less than 1 p.u., which is outside of the permitted range (Standard & Horizontale, 2009a), as shown in Figure 4.9. Buses 9 and 10 have voltages that are relatively near to the nominal value, showing that there is only a slight voltage loss in those locations. The fact that Bus 3 has the lowest voltage in the system is a drawback because it increases the risk of brownouts and blackouts.

The outcomes of Case 2 are summarized in Table 4.3, which can be found below. After doing the power flow analysis, here is an extensive overview of the active and reactive power losses that happened in this section as well as the voltage profile that transpired on buses.

Table 4.3, The Summary Result of Case 2

Performance Measurement	Case 2
Minimum Bus Voltage (p.u.)	0.675 at bus 3
Maximum Bus Voltage (p.u.)	0.904 at bus 10
Total Active Power Loss (kW)	4595.882
Total Reactive Power Loss (kvar)	277548.98
Optimal Size (kW)	100 for each bus
Location of EVCS (Num_Bus)	3 and 3
Number of EVCS	2
Active Power Increase Percentage	97.75%
Reactive Power Increase Percentage	99.95%

4.4. Case 3: Integration of three EVCS

This section of the study examined the impact of integrating three EVCS into the AAMUSTED 11 kV distribution system. The goal was to evaluate the power losses on lines and voltage profile at each bus. The study found that the integration of three EVCS resulted in a significant increase in both active and reactive power losses, by 97.62% and 99.91%, respectively. The voltage profile also experienced a reduction, which is likely to lead to further increases in power losses.

4.4.1. Active Power Loss of Case 3

The incorporation of three Electric Vehicle Charging Stations (EVCS) into the AAMUSTED 11 kV distribution system led to a rise in the overall active power loss. In Case 3, the collective active power loss escalated to 4337.402 kilowatts (kW). Figure 4.10 shows a graphical representation of the active power losses. This elevation in active power loss carries an unfavorable implication, which could potentially result in a decline in efficiency within the distribution system.

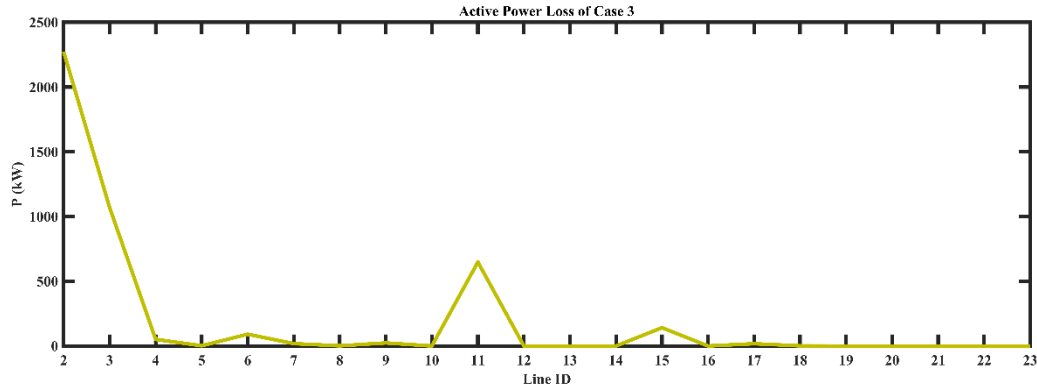


Figure 4.10, Active power of case 3

Figure 4.10 shows the active power losses associated with individual lines within the AAMUSTED 11 kV distribution system in Case 3, which involves incorporating three EVCS units. Lines 2, 3, 6, 11, and 15 have the highest active power losses, which indicates that they are less efficient lines within the system. The integration of the three EVCS units led to a pronounced escalation in the total active power loss when compared to the reference system.

The main goal of this scenario was to assess the extent of the influence of three EVCS on the overall active power loss within the system. The results of the analysis show that the integration of three EVCS units led to a significant increase in the total active power loss, which makes the distribution system less efficient.

4.4.2. Reactive Power Loss of Case 3

The incorporation of three EVCS units into the AAMUSTED 11 kV distribution system led to a substantial rise in the total reactive power loss. This transformation in reactive power loss is displayed in Figure 4.11, illustrating a notable surge in losses after the integration of the three EVCS units.

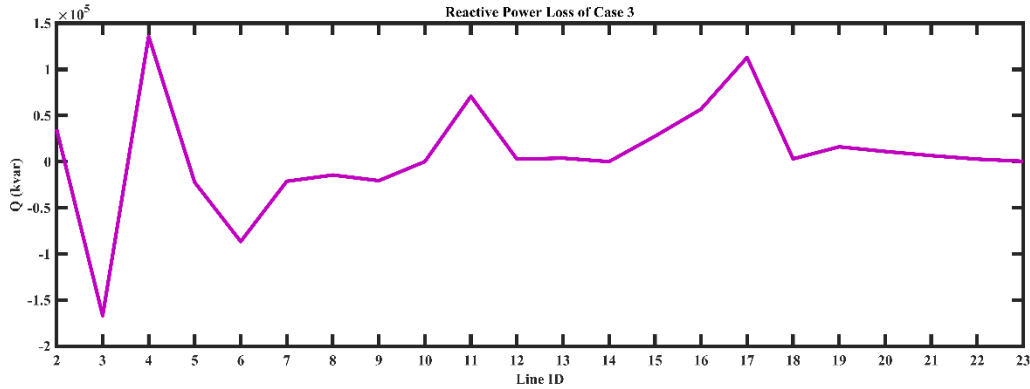


Figure 4.11, Reactive power of case 3

Figure 4.12 shows the reactive power losses associated with individual lines within the AAMUSTED 11kV distribution system in Case 3, which involves incorporating three EVCS units. Lines 2, 4, 11, and 17 had the highest reactive losses, while line 3 had the lowest losses. This indicates that the integration of three EVCS units increased the reactive power loss, compared with reference system but the increase was most pronounced on lines 2, 4, 11, and 17.

4.4.3. Voltage Profile of Case 3

After incorporating the three EVCS units, a comprehensive assessment of the voltage profile was conducted. The outcomes of this analysis are illustrated in Figure 4.13, providing a visual depiction of the voltage profile after the integration of the three EVCS within the AAMUSTED 11 kV distribution system.

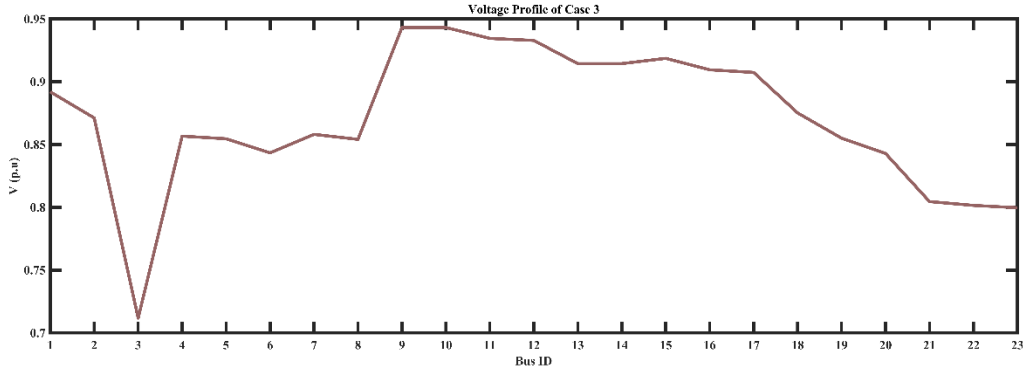


Figure 4.12, Voltage profile of case 3

In this case (Figure 4.13), the data shows that the voltage levels at most of the buses in the system are not close to nominal value (1 p.u.), indicating that they are not within the acceptable range (Standard & Horizontale, 2009a). However, there are a few buses, such as buses 9, 10, 11 and 12, which have voltages close to nominal value, indicating a minor voltage drop because of less load demand in those areas. On the other hand, bus 3 exhibited minimum voltage value in the system.

The results of Case 3 are summarized in Table 4.4. This table provides an overview of the active and reactive power losses, as well as the voltage profile, in the distribution system after the integration of three EVCS.

Table 4.4, The Summary Result of Case 3

Performance Measurement	Case 3
Minimum Bus Voltage (p.u.)	0.712 at bus 3
Maximum Bus Voltage (p.u.)	0.934 at buses 9 and 10
Total Active Power Loss (kW)	4337.402
Total Reactive Power Loss (kvar)	152703.9
Optimal Size (kW)	42

Location of EVCS (Num_Bus)	3, 17 and 3
Number of EVCS	3
Active Power Increase Percentage	97.62%
Reactive Power Increase Percentage	99.91%

4.5. Case 4: Integration of four EVCS

The impact of integrating four EVCS into the AAMUSTED 11 kV distribution system was investigated in this phase of the study. The purpose was to assess the power losses on lines as well as the voltage profile at each bus. The integration of four Electric Vehicle Charging Stations (EVCS) lead to a substantial rise in active power loss of 96.16% and a decrease in reactive power losses of 99.94%, based on the study. When compared to the base case, the voltage profile also decreased, which is likely to lead to further increases in power losses.

4.5.1. Active Power Loss of Case 4

The addition of four EVCS to the AAMUSTED 11 kV distribution system caused an increase in overall active power loss. In Case 4, the total active power loss reached 2690.188 kW. A graph of the active power losses is shown in Figure 4.10. This increase in active power loss has detrimental effects since it might cause the distribution system's efficiency to drop.

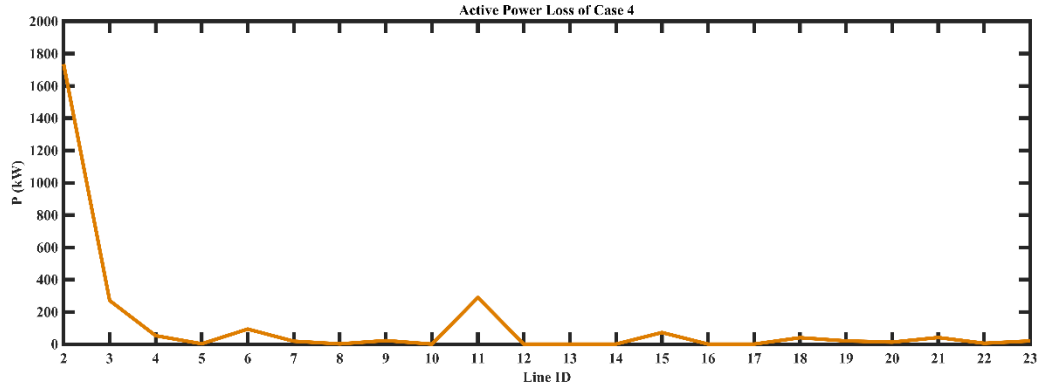


Figure 4.13, Active power of case 4

Figure 4.14 depicts the active power losses for each line in Case 4, which installed four EVCS units to the AAMUSTED 11 kV distribution system. Lines 2, 3, 6, 11, and 15 have the largest active power losses, indicating that they are less efficient than the remaining lines of the system. When compared to the reference system, the addition of the four EVCS units resulted in a considerable increase in total active power loss.

4.5.2. Reactive Power Loss of Case 4

The installation of four EVCS units on the AAMUSTED 11 kV distribution system reduced reactive power loss drastically because EVCS injected reactive power into the system. Figure 4.15 shows a significant reduction in reactive power losses after the four EVCS devices were installed. Reduced reactive power loss may result in voltage stability.

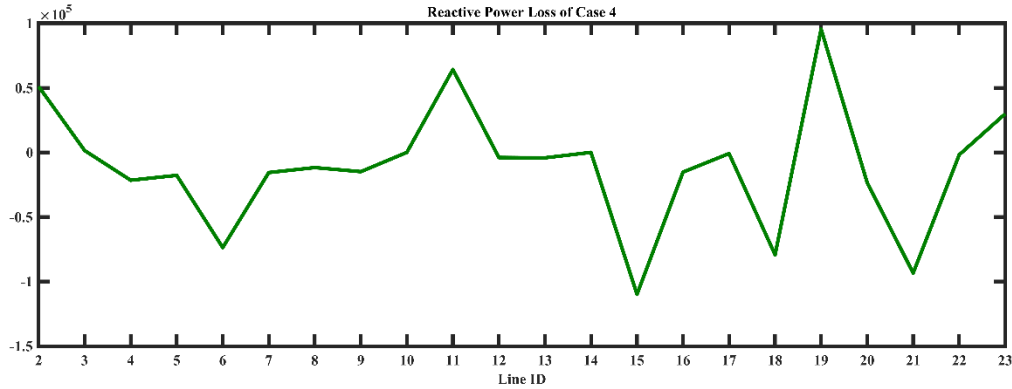


Figure 4.14, Reactive power of case 4

Figure 4.15 illustrates the reactive power losses across individual lines within the AAMUSTED 11 kV distribution system under Case 4, where the addition of four EVCS units occurred. Notably, lines 6, 15, 18, and 21 exhibited minimal reactive losses, whereas lines 11 and 19 registered the highest losses. This observation implies that the integration of four EVCS units contributed to a reduction in reactive power loss when compared to the baseline scenario.

4.5.3. Voltage Profile of Case 4

After adding the four EVCS devices, the voltage profile was thoroughly evaluated. The results of this analysis are depicted in Figure 4.16, which shows the voltage profile after the integration of the four EVCS into the AAMUSTED 11 kV distribution system.

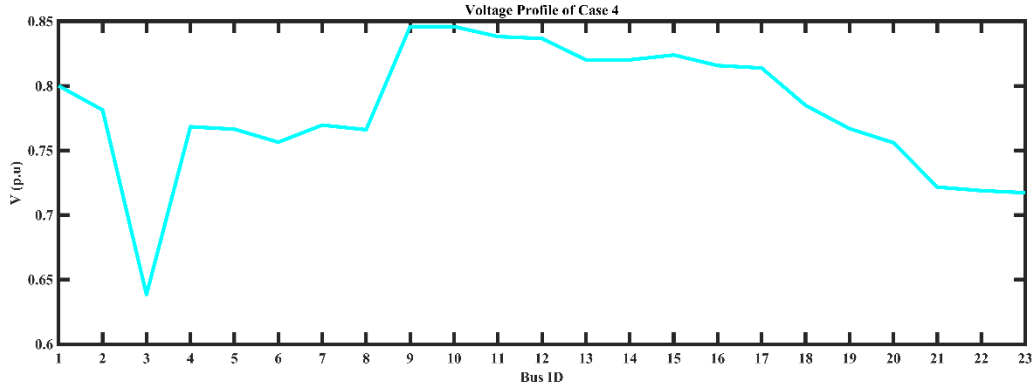


Figure 4.15, Voltage profile of Case 4

Figure 4.16 depicts the voltage range spanning from 0.726 p.u. to 0.963 p.u. Buses 9 and 10 exhibit the highest voltage value at 0.963 p.u., attributed to lower demand within their respective zones. In contrast, buses 3, 22, and 23 register lower voltage values of 0.726 p.u., 0.818 p.u., and 0.816 p.u. respectively, implying a decline in the system's voltage levels.

Table 4.5 summarizes the outcomes of Case 4, which comprised the integration of four EVCS units into the AAMUSTED 11 kV distribution system. This table summarizes the distribution system's active and reactive power losses, as well as the voltage profile, after the integration of four EVCS units.

Table 4.5, The Summary Result of Case 4

Performance Measurement	Case 4
Minimum Bus Voltage (p.u.)	0.726 at bus 3
Maximum Bus Voltage (p.u.)	0.963 at buses 9 and 10
Total Active Power Loss (kW)	2690.188
Total Reactive Power Loss (kvar)	-245287
Optimal Size (kW)	100

Location of EVCS (Num_Bus)	23, 23, 23 and 23
Number of EVCS	4
Active Power Increase Percentage	96.17%
Reactive Power Decrease Percentage	99.94%

4.6. Discussion of Base Case, Case 1, Case 2, Case 3 and Case 4

This section compares the five cases and evaluates the AAMUSTED 11 kV distribution system by examining the power losses (active and reactive) and voltage profile before and after the integration of Electric Vehicle Charging Stations (EVCS). The integration of EVCS in the AAMUSTED 11 kV distribution system in Kumasi has led to an increase in power losses and voltage drops.

4.6.1. Active Power Loss of Base Case, Case 1, Case 2, Case 3 and Case 4

Before the integration of EVCS, the total active power loss of the AAMUSTED 11 kV distribution system in Kumasi was 103.171 kW. After the integration of EVCS, the total active power loss increased significantly in all optimal cases. Figure 4.17 shows the active power losses for each case.

The integration of EVCS led to a major increase in active power loss.

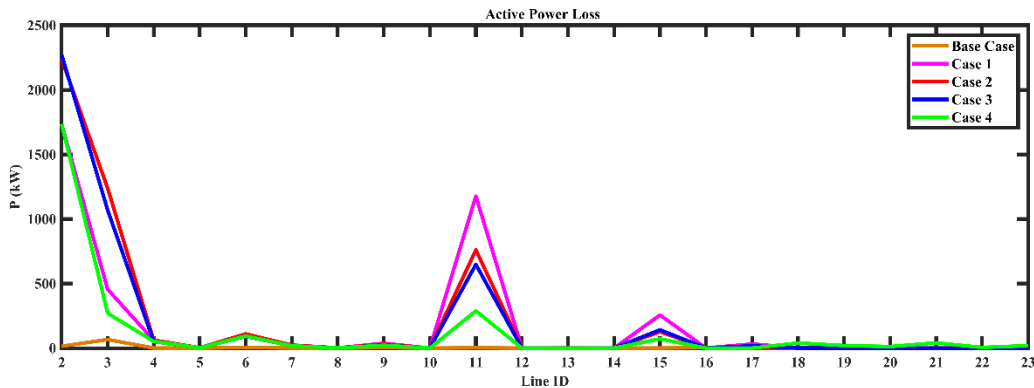


Figure 4.16, Active power loss of Base Case, Case 1, Case 2, Case 3 and Case 4

Figure 4.17 above presents a comprehensive comparison of active power losses across various lines within the AAMUSTED 11 kV distribution system under different integration scenarios of Electric Vehicle Charging Stations (EVCS). The analysis aims to evaluate the impact of EVCS integration on power losses and to identify trends within the system. Figure 4.17 clearly shows that the active power losses vary significantly among different lines for each integration case. For instance, in the Base Case, Line 3 has the highest power loss of 66.19 kW, whereas Line 10 experiences no power loss. In contrast, Line 11 witnesses a substantial power loss of 1176.537 kW in Case 1. Such variations highlight the influence of EVCS integration on power distribution and emphasize the significance of efficient integration strategies.

A comprehensive comparison of active power losses across different cases reveals intriguing insights. Notably, Case 2 demonstrates a substantial increase in power losses across several lines compared to the Base Case. However, Case 4 displays a mixed pattern, where some lines experience higher losses (e.g., Line 11 and Line 21) while others witness reduced losses (e.g., Line 3). This suggests that the integration of EVCS can have a complex and nonlinear impact on active power losses, requiring careful consideration during system planning.

The increase in active power losses observed in some cases, especially Case 1 and Case 2, could potentially result in reduced overall system efficiency. The introduction of EVCS may lead to increased load demand and altered load profiles, affecting power distribution characteristics. While the data focuses on active power losses, it's important to note that these losses can also influence the voltage profile of the distribution system. Increased losses may lead to voltage drops and potentially affect the quality of power supplied to consumers. The findings underscore the necessity for careful planning and optimization when integrating EVCS into the distribution system. To minimize power

losses and ensure optimal system performance, strategic placement, and sizing of EVCS units need to be considered.

In conclusion, Figure 4.17 illuminates the intricate relationship between EVCS integration and active power losses within the AAMUSTED 11 kV distribution system. The outcomes underscore the importance of informed decision-making in EVCS integration to mitigate adverse effects on power losses and maintain efficient system operation. Further analysis, including considerations of reactive power losses and voltage profile, would provide a holistic understanding of the system's response to EVCS integration. The values of Figure 4.17 can be seen in Appendix II.

4.6.2. Reactive Power Loss of Base Case, Case 1, Case 2, Case 3 and Case 4

This section of the study involved a detailed analysis and comparison of various cases of the reactive power losses in the AAMUSTED 11 kV distribution system located in the Kumasi, Ashanti Region. The findings are presented in Figure 4.17, which provides an overview of the reactive power losses for five different cases. The analysis of these cases helps to determine the level of reactive power losses in the system.

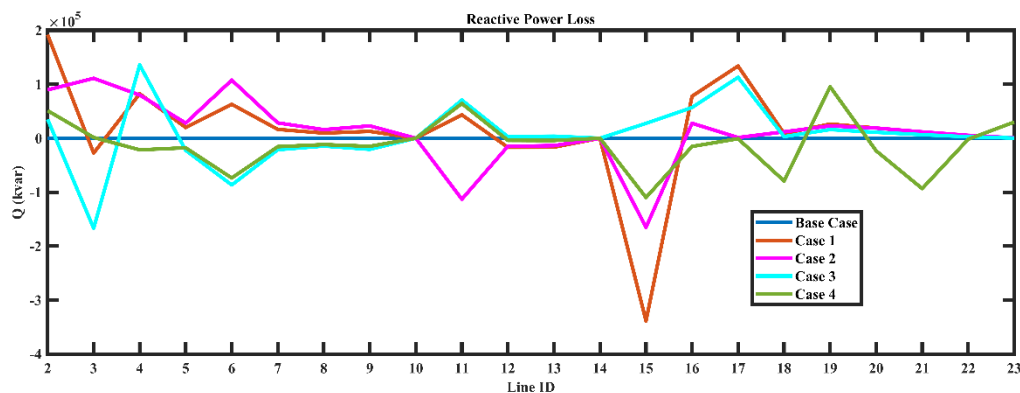


Figure 4.17, Reactive power loss of Base Case, Case 1, Case 2, Case 3 and Case 4

In-depth analysis and comparison of the reactive power losses across various lines in the AAMUSTED 11 kV distribution system under various EVCS integration scenarios are shown in Figure 4.18. The analysis aims to evaluate the impact of EVCS integration on reactive power losses, enabling a detailed examination of the system's behavior.

Figure 4.18 above reveals important variations in reactive power losses among different lines for each integration case. Notably, Line 3 stands out with contrasting reactive power loss values across different cases, including negative values in Case 1 and Case 3. This unique behavior warrants further investigation and potentially suggests a non-linear effect of EVCS integration on reactive power losses.

The comparison of reactive power losses across different cases highlights intriguing trends. For instance, Case 1 displays a remarkable increase in losses for Line 2, which indicates a substantial impact of EVCS integration. Conversely, Case 3 demonstrates drastic changes, including negative reactive power losses for certain lines, signifying potential improvements in system efficiency. Line 11 showcases significant changes in reactive power losses across different cases. The integration of EVCS leads to fluctuations in losses, with both positive and negative deviations. This behavior could be attributed to the varying load characteristics and network configurations at different integration points.

The diverse responses of reactive power losses to EVCS integration underscore the complexity of the distribution system's behavior. While some cases exhibit increased losses (e.g., Line 2 in Case 1), others demonstrate potential efficiency enhancements (e.g., Line 18 in Case 4). These findings emphasize the importance of careful planning and analysis for effective EVCS integration. Figure 4.18 highlights the need for tailored strategies when integrating EVCS into the distribution system.

The varying impact on different lines underscores the importance of strategically selecting integration points and capacities to minimize power losses and optimize system performance.

The data presented in Figure 4.18 further clarifies the complex relationship between EVCS integration and reactive power losses in the AAMUSTED 11 kV distribution system. The observed variations highlight the importance of conducting a thorough and complete analysis when designing EVCS integration to achieve optimal system performance and efficiency. The values of Figure 4.18 can be seen in Appendix III.

4.6.3. Voltage Profile of Base Case, Case 1, Case 2, Case 3 and Case 4

The integration of electric vehicle charging stations (EVCS) into the AAMUSTED 11 kV distribution system was conducted to assess its impact on the voltage profile. Before the integration of EVCS, the voltage profile on some buses in the system were within voltage requirements set by the IEC 60038-2009 standard (Ackermann & Knyazkin, 2002; Standard & Horizontale, 2009b). Figure 4.19 shows the voltage profile for the Base case, Case 1, Case 2, Case 3, and Case 4. The values of Figure 4.19 can be seen in Appendix IV.

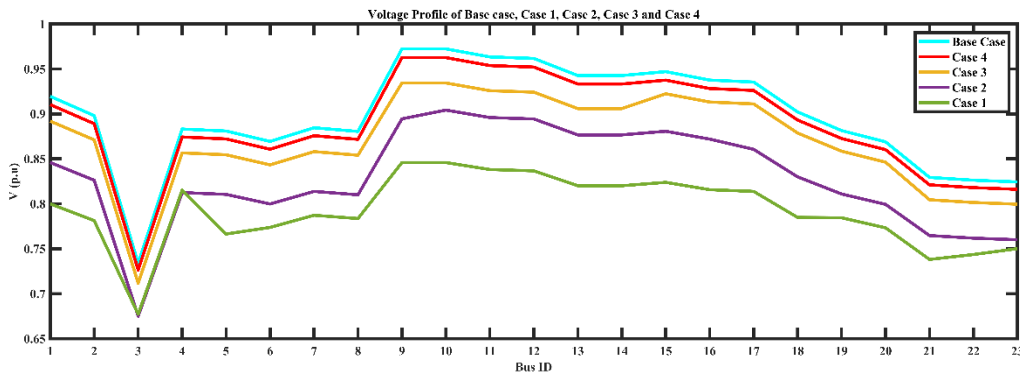


Figure 4.18, Voltage profile of Base Case, Case 1, Case 2, Case 3 and Case 4

Figure 4.19 offers a comprehensive analysis and comparison of the voltage profile across various buses within the AAMUSTED 11 kV distribution system under different scenarios of Electric Vehicle Charging Station (EVCS) integration.

The data provided in Figure 4.19 shows the overview of how the voltage profile varies across different buses in the distribution system for each optimal case. Notably, there is a systematic trend of decreasing voltage levels from Bus 1 to Bus 23 in all optimal cases, indicating a voltage drop within the system. The comparison of voltage profiles across different cases reveals interesting insights. In general, as the number of integrated EVCS units increases (from Case 4 to Case 1), there is a discernible trend of decreasing voltage levels across all buses. This trend emphasizes the potential impact of EVCS integration on the distribution system's voltage stability.

The dataset highlights that EVCS integration tends to lead to reduced voltage magnitudes across the buses. This decrease in voltage levels can have implications for the overall performance and reliability of the distribution system, potentially affecting the quality of power supply to consumers. The decline in voltage magnitudes is likely due to the increased load demand caused by the integration of EVCS. The voltage drop observed across the buses could indicate that the distribution system is operating close to its voltage limits, necessitating careful planning to ensure stable and efficient operation. The decreasing voltage profile raises concerns about voltage regulation, which is crucial for maintaining the quality of power supply. The data suggests that effective voltage regulation mechanisms may be necessary to mitigate the potential adverse effects of EVCS integration on voltage levels. Figure 4.19 underscores the importance of selecting optimal integration points for EVCS within the distribution system. This choice should aim to balance the demand for electric vehicle charging with the need to maintain acceptable voltage levels and system stability. The findings highlight the need for comprehensive planning and potential mitigation measures to

address voltage drop issues resulting from EVCS integration. This could involve strategies such as incorporating reactive power compensation devices or modifying EVCS operation patterns.

The results of the various cases are summarized in Table 4.6. The table provides a comprehensive overview of the active and reactive power losses, as well as the voltage profile, for each case.

Table 4.6, The Summary results of Base case, Case 1, Case 2, Case 3 and Case 4

Performance Measurement	Base case	Case 1	Case 2	Case 3	Case 4
Minimum Bus Voltage (p.u.)	0.734 at bus 3	0.726 at bus 3	0.675 at bus 3	0.712 at bus 3	0.726 at bus 3
Maximum Bus Voltage (p.u.)	0.973 at buses of 9 and 10	0.963 at buses 9 and 10	0.904 at bus 10	0.934 at buses 9 and 10	0.963 at buses 9 and 10
Total Active Power Loss (kW)	103.171	3891.971	4595.882	4337.402	2690.188
Total Reactive Power Loss (kvar)	137.8	660417.221	277548.98	152703.9	-245287
Optimal Size (kW)	-	100	100 for each bus	42	100
Location of EVCS (Num_Bus)	-	17	3 and 3	3, 17 and 3	23, 23, 23 and 23
Number of EVCS	-	1	2	3	4
Active Power Loss Percentage	-	97.35%	97.75%	97.62%	96.17%
Reactive Power Loss Percentage	-	99.96%	99.95%	99.91%	99.94%

Case 4, which involves the integration of four Electric Vehicle Charging Stations (EVCS) into the AAMUSTED 11 kV distribution system, can be justified as a favorable intervention among the cases based on several factors and considerations. While each case has its unique outcomes and implications, Case 4 demonstrates advantages that make it a viable option in these scenarios. Despite the increase in active power losses observed in Case 4, the magnitude of increase is relatively moderate when compared to the other cases. This indicates that the integration of four EVCS units has been managed more efficiently, resulting in a less drastic impact on active power losses

compared to other cases. This implies better load distribution and potential optimized operation strategies.

Case 4 shows a significant decrease in reactive power losses compared to the base case. This is a major benefit because reactive power losses can have a significant impact on the overall efficiency and voltage stability of the distribution system. The integration of four EVCS units in Case 4 appears to have led to more effective compensation of reactive power, resulting in improved voltage profiles. Although there is a decline in voltage magnitudes across all nodes in Case 4, as seen in Figure 4.19, this decline is relatively less severe compared to some of the other cases. This indicates that the voltage drops resulting from EVCS integration in Case 4 is more controlled and manageable. The voltage profile remains within nominal range, suggesting that the distribution system's stability is better maintained.

The results of Case 4 indicate that integrating four EVCS units could be a good compromise between meeting the demand for electric vehicle charging and maintaining acceptable voltage levels. This suggests that there is potential for optimization in terms of EVCS placement and operation strategies. With further refinement, Case 4 could offer a practical solution that minimizes losses while meeting the growing demand for EV charging. The outcomes of Case 4 show a balance between addressing increased load demand due to EVCS integration and maintaining voltage stability. While there are voltage drops, they are not extreme, which suggests that the distribution system is still functioning within a reasonable operational range. This equilibrium is crucial to ensure reliable power supply while adapting to the demands of electric vehicle charging. Figure 4.19 indicates that the voltage profile fluctuations in Case 4 are relatively less erratic compared to some of the other cases. This reduced volatility signifies a more controlled and predictable response to EVCS integration, which can contribute to enhanced system planning and operation.

In summary, while each case has its merits and challenges, Case 4 stands out as a potentially good intervention due to its relatively balanced approach in managing active and reactive power losses, mitigating voltage profile degradation, and maintaining system stability. Further optimization and fine-tuning of EVCS integration strategies in Case 4 could potentially lead to a more efficient and sustainable solution for accommodating electric vehicle charging within the AAMUSTED 11 kV distribution system.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

This chapter presents the concluding summary and recommendations for the research. The purpose of this chapter is to summarize the findings of the research and make recommendations for further studies. This section outlines prospective directives for future research. The insights derived from the analysis conducted before and after the integration of an Electric Vehicle Charging Station (EVCS), identified avenues for future investigation aimed at extending the current research findings and delve deeper into strategies for enhancing the electrical system's performance.

5.1. Summary

The first objective of this dissertation was to model and analyse the 11kV distribution system of Akenten Appiah Menka University of Skills Training and Development using the Electrical Transient Analyzer Program (ETAP), to achieve this objective, Raw Data was collected from AAMUSTED campus and was used to build a model in the Electrical Transient Analysis Program (ETAP).

The second objective of the study was to optimise the placement and sizing of EVCS using the particle swarm optimisation algorithm, in achieving the second objective, The ETAP data gathered from the model was then applied in MATLAB to optimize the size and the placement of Electric Vehicle Charging Stations (EVCS) on the AMUSTED campus using the particle swarm optimization (PSO) algorithm.

The third objective of the study was to do a comparative analysis of the existing system and the optimized system to enable the researcher to assess and compare the impact of EVCS on existing

and optimized system, so that active and reactive power losses and voltage profile of both systems could also be assessed.

5.2. Conclusion

The comprehensive findings of the study underscored the feasibility of implementing Electric Vehicle Charging Stations (EVCS) on the AAMUSTED campus using Particle Swarm Optimization (PSO), particularly given the intricate nature of the electrical distribution system and its non-linear response to EVCS integration. The campus's distribution system, consisting of the Tanoso and Apatrapa feeders, plays a pivotal role in supplying power to diverse buildings and facilities, making the study's insights crucial for sustainable energy management.

The analysis postulates a nuanced impact on the active power losses within the AAMUSTED 11kV distribution system after the incorporation of EVCS. Notably, Case 4 exhibited a more measured increase in losses compared to Cases 1 and 2, which experienced substantial increments. Such variations underscore the complexity of the system's response to EVCS integration and emphasize the need for tailored approaches in addressing power losses.

Reactive power losses exhibited diverse behavior across different lines and cases, with Case 4 standing out for a significant reduction in losses. Intriguingly, negative reactive power losses in some lines of Cases 1 and 3 hinted at potential efficiency improvements post-EVCS integration. However, the intricate interplay of these factors necessitates careful planning and optimization to fully harness the benefits while mitigating potential challenges.

The voltage profile analysis uncovered a systematic decline in voltage levels across buses as the number of integrated EVCS units increased, raising valid concerns about voltage regulation and stability. Notably, Case 4 emerged as a more favorable intervention due to its controlled and

manageable voltage drop, highlighting the importance of strategic planning to address voltage-related issues stemming from EVCS integration.

The study provides a robust technical justification for the integration of EVCS into the AAMUSTED campus network. The visual representation of the study's outcomes serves as a valuable tool for system analysis, planning, and optimization, ensuring that the integration aligns with the energy needs and sustainability goals of the campus community. The intricate insights derived from this research underscore the importance of a thoughtful and well-optimized approach to successfully integrate EVCS into complex electrical distribution systems.

5.3. Recommendation

The researcher used a combination of data collection, modeling, and optimization techniques to assess the impact of EVCS integration on the electrical distribution system of the AAMUSTED campus network.

Availability of the electrical Data for AAMUSTED campus was a critical challenge in the study. There is no data on the electrical layout of the campus. Data used in the study was collected from the various halls and blocks of the campus. The study recommends further studies to address the unavailability of sufficient data.

Further the researcher recommends a Ring Circuit layout for the campus distribution network, which deviates from the conventional Radial network. This strategic shift is aimed at boosting the systems resilience, which could ensure the continues supply of power in the event of a feeder failure.

Again, other studies could look at further optimization of EVCS placement and operation strategies which would focus on Case 4, so that a more efficient solution that minimizes losses while meeting

the growing demand of EVCS could be achieved. This will in turn explore advanced technologies and innovative solutions that would enhance the integration of EVCS into distribution systems.

Implementing Effective Voltage Regulation mechanisms that would mitigate potential adverse effects of EVCS integration on voltage levels, this may include incorporating reactive power devices or modifying EVCS patterns of operation. Continuous monitoring and analysis of the performance of the distribution system will enable adjustments and refinements to be made based on the changing demands and the data available.

One of the most important contributions of this dissertation is the identification of the complex and nonlinear relationship between EVCS integration and power losses. The researcher found that EVCS integration can lead to both increased and reduced power losses, depending on the specific integration scenario. This finding highlights the need for careful planning and optimization when integrating EVCS into existing electrical distribution systems.

Future research would be investigating the impact of EVCS integration on frequency stability, harmonic distortion, and voltage stability in the AAMUSTED campus distribution system. It could also explore the use of different metaheuristic optimization techniques in conjunction with distributed generation (DG) to improve the performance of the system.

Overall, this dissertation is well-written and informative, which makes a significant contribution to the academia, field of electrical engineering and government for decision making. The researcher's findings are valuable for future EVCS planning and integration efforts.

REFERENCES

- Abdulrazzaq, A. A. (2015). Improving the power system performance using FACTS devices. *IOSR Journal of Electrical and Electronics Engineering* Ver. IV, 10(2), 2278–1676. <https://doi.org/10.9790/1676-10244149>
- Abebe, B. (2021). September 2021 Adama, Ethiopia. In Adama Science and Technology University September (Issue September). Adama Science and Technology University September.
- Abid, M. S., Ahshan, R., Al Abri, R., Al-Badi, A., & Albadi, M. (2024). Techno-economic and environmental assessment of renewable energy sources, virtual synchronous generators, and electric vehicle charging stations in microgrids. *Applied Energy*, 353. <https://doi.org/10.1016/J.APENERGY.2023.122028>
- Aboagye, B., Gyamfi, S., Ofosu, E. A., & Djordjevic, S. (2021). Status of renewable energy resources for electricity supply in Ghana. *Scientific African*, 11, e00660. <https://doi.org/10.1016/J.SCIAF.2020.E00660>
- Ackermann, T., & Knyazkin, V. (2002). Interaction between distributed generation and the distribution network: Operation aspects. *Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference, 2(ASIA PACIFIC)*, 1357–1362. <https://doi.org/10.1109/tdc.2002.1177677>
- Advanced IoT solution for EV CHAdeMO Fast Charging Applied with Mobile Networks. (2019).
- Afonso, J. L., Cardoso, L. A. L., Pedrosa, D., Sousa, T. J. C., MacHado, L., Tanta, M., & Monteiro, V. (2020). A review on power electronics technologies for electric mobility. In *Energies* (Vol. 13, Issue 23). MDPI AG. <https://doi.org/10.3390/en13236343>

- Aktar, M. A., Alam, M. M., & Al-Amin, A. Q. (2021). Global economic crisis, energy use, CO2 emissions, and policy roadmap amid COVID-19. *Sustainable Production and Consumption*, 26, 770–781. <https://doi.org/10.1016/J.SPC.2020.12.029>
- Ampah, J. D., Afrane, S., Agyekum, E. B., Adun, H., Yusuf, A. A., & Bamisile, O. (2022). Electric vehicles development in Sub-Saharan Africa: Performance assessment of standalone renewable energy systems for hydrogen refuelling and electricity charging stations (HRECS). *Journal of Cleaner Production*, 376, 134238. <https://doi.org/10.1016/J.JCLEPRO.2022.134238>
- Araya, M. H. (n.d.). UNIVERSITY OF VAASA THE SCHOOL OF TECHNOLOGY AND INNOVATIONS COMMUNICATIONS AND SYSTEMS ENGINEERING.
- Balu, K., & Mukherjee, V. (2023). Optimal allocation of electric vehicle charging stations and renewable distributed generation with battery energy storage in radial distribution system considering time sequence characteristics of generation and load demand. *Journal of Energy Storage*, 59, 106533. <https://doi.org/10.1016/J.EST.2022.106533>
- Bidirectional Power Transfer between Grid and Electric Vehicle Batteries Okbe Kifle Habte. (n.d.). www.usn.no
- Bonsu, N. O. (2020). Towards a circular and low-carbon economy: Insights from the transitioning to electric vehicles and net zero economy. *Journal of Cleaner Production*, 256, 120659. <https://doi.org/10.1016/J.JCLEPRO.2020.120659>
- Brenna, M., & Gaurav, D. (2015). POLITECNICO DI MILANO School of Industrial and Information Engineering Impact of EV Charging Station on the Electric Distribution Grid.

- Brenna, Morris., Foiadelli, Federica., Leone, Carola., & Longo, Michela. (2020). Electric Vehicles Charging Technology Review and Optimal Size Estimation. *Journal of Electrical Engineering and Technology*, 15(6), 2539–2552. <https://doi.org/10.1007/s42835-020-00547-x>
- Cape, O., & Points, T. (n.d.). Drive electric initiative. 1–5.
- CHAdeMO-Conformity High-Power Charger Connector Assembly for Over 100 kW-Class EV Charge. (n.d.).
- Chen, Han., Nie, Jin., & Ye, Bichao. (2019). PSO-based Siting and Sizing of Electric Vehicle Charging Stations. *Journal of Physics: Conference Series*, 1346(1). <https://doi.org/10.1088/1742-6596/1346/1/012022>
- Deb, S., Sachan, S., & Zhimomi, T. (2021). Optimal Location of EV Charging Stations by Modified Direct Search Algorithm. *Smart Charging Solutions for Hybrid and Electric Vehicles*, 381–398. <https://doi.org/10.1002/9781119771739.CH15>
- Deb, Sanchari., Tammi, Kari., Kalita, Karuna., & Mahanta, Pinakeswar. (2018). Review of recent trends in charging infrastructure planning for electric vehicles. *Wiley Interdisciplinary Reviews: Energy and Environment*, 7(6). <https://doi.org/10.1002/WENE.306>
- Dharmakeerthi, C. H., Mithulanathan, N., & Saha, T. K. (2012). Modeling and planning of EV fast charging station in power grid. 2012 IEEE Power and Energy Society General Meeting, 1–8. <https://doi.org/10.1109/PESGM.2012.6345008>
- Efthymiou, Dimitrios., Chrysostomou, Katerina., Morfoulaki, Maria., & Aifantopoulou, Georgia. (2017). Electric vehicles charging infrastructure location: a genetic algorithm approach.

European Transport Research Review, 9(2), 1–9. <https://doi.org/10.1007/S12544-017-0239-7/FIGURES/5>

Geels, F. W. (2018). Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. *Energy Research & Social Science*, 37, 224–231. <https://doi.org/10.1016/J.ERSS.2017.10.010>

Guo, Z., Bian, H., Zhou, C., Ren, Q., & Gao, Y. (2023). An electric vehicle charging load prediction model for different functional areas based on multithreaded acceleration. *Journal of Energy Storage*, 73. <https://doi.org/10.1016/J.EST.2023.108921>

Gupta, Rudraksh. S., Tyagi, Arjun., & Anand. (2021). Optimal allocation of electric vehicles charging infrastructure, policies, and future trends. *Journal of Energy Storage*, 43, 103291. <https://doi.org/https://doi.org/10.1016/j.est.2021.103291>

Haider, W., Jarjees, S., Hassan, U., Mehdi, A., Hussain, A., Ondo, G., Adjayeng, M., & Kim, C.-H. (2021). Machines Voltage Profile Enhancement and Loss Minimization Using Optimal Placement and Sizing of Distributed Generation in Reconfigured Network. <https://doi.org/10.3390/machines9010020>

Institute of Electrical and Electronics Engineers. Kerala Section. IA/IE/PEL Joint Chapter, IEEE Industry Applications Society, IEEE Power Electronics Society, & Institute of Electrical and Electronics Engineers. (n.d.). IEEE PESGRE 2020: IEEE International Conference on “Power Electronics, Smart Grid and Renewable Energy”: 2-4 Jan 2020, Le Méridien Cochin, Kerala, India.

- Ji, Z., & Huang, X. (2018). Plug-in electric vehicle charging infrastructure deployment of China towards 2020: Policies, methodologies, and challenges. *Renewable and Sustainable Energy Reviews*, 90, 710–727. <https://doi.org/10.1016/J.RSER.2018.04.011>
- Khatri, A., Malik, H., & Rahi, O. P. (2012). Optimal design of power transformer using genetic algorithm. *Proceedings - International Conference on Communication Systems and Network Technologies, CSNT 2012*, 830–833. <https://doi.org/10.1109/CSNT.2012.180>
- Kober, T., Schiffer, H. W., Densing, M., & Panos, E. (2020). Global energy perspectives to 2060 – WEC’s World Energy Scenarios 2019. *Energy Strategy Reviews*, 31, 100523. <https://doi.org/10.1016/J.ESR.2020.100523>
- Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renewable and Sustainable Energy Reviews*, 56, 722–744. <https://doi.org/10.1016/J.RSER.2015.11.080>
- Kumar, B., Saw, B. K., & Bohre, A. K. (2020). Optimal Distribution Network Reconfiguration to Improve System Performances using PSO with Multiple-Objectives. *International Conference on Computational Intelligence for Smart Power System and Sustainable Energy, CISPSSE 2020*. <https://doi.org/10.1109/CISPSSE49931.2020.9212262>
- Li, Y., Wang, C., & Li, G. (2020). A Mini-Review on High-Penetration Renewable Integration Into a Smarter Grid. In *Frontiers in Energy Research* (Vol. 8). Frontiers Media S.A. <https://doi.org/10.3389/fenrg.2020.00084>

- Longo, L., Supervisor, S., Xylia, M., & Siöstedt, S. (2017). Optimal design of an EV fast charging station coupled with storage in Stockholm.
- Maciej Serda, Becker, F. G., Cleary, M., Team, R. M., Holtermann, H., The, D., Agenda, N., Science, P., Sk, S. K., Hinnebusch, R., Hinnebusch A, R., Rabinovich, I., Olmert, Y., Uld, D. Q. G. L. Q., Ri, W. K. H. U., Lq, V., Frxqw, W. K. H., Zklfk, E., Edvhg, L. V, ... (2013). فاطمی, ح. Synteza i aktywność biologiczna nowych analogów tiosemikarbazonowych chelatorów żelaza. Uniwersytet Śląski, 7(1), 343–354. <https://doi.org/10.2/JQUERY.MIN.JS>
- Martinot, E. (2016). Grid Integration of Renewable Energy: Flexibility, Innovation, and Experience. *Annual Review of Environment and Resources*, 41, 223–251. <https://doi.org/10.1146/annurev-environ-110615-085725>
- Mohammed, S. A. Q., & Jung, J. W. (2021). A Comprehensive State-of-the-Art Review of Wired/Wireless Charging Technologies for Battery Electric Vehicles: Classification/Common Topologies/Future Research Issues. *IEEE Access*, 9, 19572–19585. <https://doi.org/10.1109/ACCESS.2021.3055027>
- Mokred, S., Wang, Y., & Chen, T. (2023). Modern voltage stability index for prediction of voltage collapse and estimation of maximum load-ability for weak buses and critical lines identification. *International Journal of Electrical Power and Energy Systems*, 145. <https://doi.org/10.1016/j.ijepes.2022.108596>
- Nasr, T., Torabi, S., Bou-Harb, E., Fachkha, C., & Assi, C. (2022). Power jacking your station: In-depth security analysis of electric vehicle charging station management systems. *Computers & Security*, 112, 102511. <https://doi.org/10.1016/J.COSE.2021.102511>

- Newell, R. G., Raimi, D., & Aldana, G. (2019). Global Energy Outlook 2019: The Next Generation of Energy. www.rff.org/geo.
- Okwu, M. O., & Tartibu, L. K. (2021). Particle Swarm Optimisation. *Studies in Computational Intelligence*, 927, 5–13. https://doi.org/10.1007/978-3-030-61111-8_2
- Oukennou, A., Sandali, A., & Elmoumen, S. (2018). Coordinated Placement and Setting of FACTS in Electrical Network based on Kalai-smorodinsky Bargaining Solution and Voltage Deviation Index. *International Journal of Electrical and Computer Engineering (IJECE)*, 8(6), 4079. <https://doi.org/10.11591/ijece.v8i6.pp4079-4088>
- Pardo-Bosch, Francesc., Pujadas, Pablo., Morton, Craig., & Cervera, Carles. (2021). Sustainable deployment of an electric vehicle public charging infrastructure network from a city business model perspective. *Sustainable Cities and Society*, 71, 102957. <https://doi.org/10.1016/J.SCS.2021.102957>
- Paribesh Ranabhat Secure Design and Development of IoT Ena-bled Charging Infrastructure for Electric Vehi-cle; Using CCS Standard for DC Fast Charging. (2018).
- Prempeh, I., Kotawoke Awopone, A., Ayambire, P. N., & El-4 Sehiemy, R. A. (n.d.). Optimal Allocation of Distributed Generation Units and Fast Electric Vehicle Charging Stations for Sustainable Cities 2 3 Consent for Publication.
- Rajpoot, S. C., Rajpoot, P. S., Gupta, K., & Yadav, R. R. (2017). Design Modeling and Simulation of Fuzzy Controlled Svc for Long Over Head Transmission Line. *IOSR Journal of Electrical and Electronics Engineering*, 12(01), 01–15. <https://doi.org/10.9790/1676-1201040115>

- Rashidizadeh-Kermani, H., Najafi, H. R., Anvari-Moghaddam, A., & Guerrero, J. M. (2018). Optimal decision-making strategy of an electric vehicle aggregator in short-term electricity markets. *Energies*, 11(9). <https://doi.org/10.3390/en11092413>
- Rastegarfar, Houman., Leon-Garcia, Alberto., LaRochelle, Sophie., & Rusch, L. Ann. (2013). Cross-Layer Performance Analysis of Recirculation Buffers for Optical Data Centers. *J. Lightwave Technol.*, 31(3), 432–445.
- Ratra, S., Tiwari, R., & Niazi, K. R. (2018). Voltage stability assessment in power systems using line voltage stability index. *Computers & Electrical Engineering*, 70, 199–211. <https://doi.org/10.1016/J.COMPELECENG.2017.12.046>
- Ray, S., Kasturi, K., Patnaik, S., & Nayak, M. R. (2023). Review of electric vehicles integration impacts in distribution networks: Placement, charging/discharging strategies, objectives and optimisation models. *Journal of Energy Storage*, 72. <https://doi.org/10.1016/J.EST.2023.108672>
- Requia, W. J., Mohamed, M., Higgins, C. D., Arain, A., & Ferguson, M. (2018). How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. *Atmospheric Environment*, 185, 64–77. <https://doi.org/10.1016/J.ATMOSENV.2018.04.040>
- Sahoo, D., Harichandan, S., Kar, S. K., & S, S. (2022). An empirical study on consumer motives and attitude towards adoption of electric vehicles in India: Policy implications for stakeholders. *Energy Policy*, 165, 112941. <https://doi.org/10.1016/J.ENPOL.2022.112941>

- Saldaña, G., Martin, J. I. S., Zamora, I., Asensio, F. J., & Oñederra, O. (2019). Electric vehicle into the grid: Charging methodologies aimed at providing ancillary services considering battery degradation. In *Energies* (Vol. 12, Issue 12). MDPI AG. <https://doi.org/10.3390/en12122443>
- Sbordone, D., Bertini, I., Di Pietra, B., Falvo, M. C., Genovese, A., & Martirano, L. (2015). EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm. *Electric Power Systems Research*, 120, 96–108. <https://doi.org/10.1016/J.EPSR.2014.07.033>
- Schwerhoff, G., & Sy, M. (2019). Developing Africa's energy mix. *Climate Policy*, 19(1), 108–124. <https://doi.org/10.1080/14693062.2018.1459293>
- Shareef, H., Islam, M. M., & Mohamed, A. (2016a). A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. *Renewable and Sustainable Energy Reviews*, 64, 403–420. <https://doi.org/10.1016/J.RSER.2016.06.033>
- Shareef, Hussain., Islam, Md. Mainul., & Mohamed, Azah. (2016b). A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. *Renewable and Sustainable Energy Reviews*, 64, 403–420. <https://doi.org/https://doi.org/10.1016/j.rser.2016.06.033>
- Smith, K. A. (2020). *The Use of Direct Current Distribution Systems in Delivering Scalable Charging Infrastructure for Battery Electric Vehicles PhD Thesis.*
- Sovacool, B. K., Noel, L., Axsen, J., & Kempton, W. (2018). The neglected social dimensions to a vehicle-to-grid (V2G) transition: A critical and systematic review. In *Environmental Research*

Letters (Vol. 13, Issue 1). Institute of Physics Publishing. <https://doi.org/10.1088/1748-9326/aa9c6d>

Standard, H., & Horizontale, N. (2009a). INTERNATIONAL STANDARD INTERNATIONALE IEC standard voltages. <https://webstore.iec.ch/publication/72877>

Standard, H., & Horizontale, N. (2009b). INTERNATIONAL STANDARD INTERNATIONALE IEC standard voltages.

Un-Noor, F., Padmanaban, S., Mihet-Popa, L., Mollah, M. N., & Hossain, E. (2017). A comprehensive study of key electric vehicle (EV) components, technologies, challenges, impacts, and future direction of development. In *Energies* (Vol. 10, Issue 8). MDPI AG. <https://doi.org/10.3390/en10081217>

Wittmann, V., Arici, E., & Meissner, D. (2021). The nexus of world electricity and global sustainable development. *Energies*, 14(18). <https://doi.org/10.3390/en14185843>

Wolbertus, R., & Van den Hoed, R. (2019). Electric vehicle fast charging is needed in cities and along corridors. *World Electric Vehicle Journal*, 10(2), 1–13. <https://doi.org/10.3390/wevj10020045>

Yi, L. (n.d.). B2C Battery Swapping Model: A Supply Chain Innovation Perspective.

Yin, J., Su, B., Fan, C., & Li, Q. (2020). Location of the public service facilities in an urban comprehensive park using a multi-hierarchy and multi-constrained configuration model. *Journal of Urban Management*, 9(2), 205–215. <https://doi.org/https://doi.org/10.1016/j.jum.2020.04.001>

- Youssef, C., Fatima, E., Najia, E. S., & Chakib, A. (2018). A technological review on electric vehicle DC charging stations using photovoltaic sources. *IOP Conference Series: Materials Science and Engineering*, 353(1). <https://doi.org/10.1088/1757-899X/353/1/012014>
- Zeng, B., Feng, J., Zhang, J., & Liu, Z. (2017). An optimal integrated planning method for supporting growing penetration of electric vehicles in distribution systems. *Energy*, 126, 273–284. <https://doi.org/10.1016/J.ENERGY.2017.03.014>
- Zhao, J., Xi, X., Na, Q., Wang, S., Kadry, S. N., & Kumar, P. M. (2021). The technological innovation of hybrid and plug-in electric vehicles for environmental carbon pollution control. *Environmental Impact Assessment Review*, 86, 106506. <https://doi.org/10.1016/J.EIAR.2020.106506>

APPENDIX

Appendix I, Verification of the existing system and simulated voltage data

Bus	Bus ID	Existing Voltage	Simulated Voltage	Error Margin
Source Bus 1	1	381.8	381.6	0.2
Workshop Transformer Bus	2	373.2	372.7	0.5
Admin Load Bus	3	305.2	304.5	0.7
Atwima-Hall Load Bus	4	366.9	366.5	0.4
Clinic Load Bus	5	365.8	365.6	0.2
Construction Load Bus	6	361.3	360.8	0.5
A Opoku-Ware Load Bus	7	367.5	367.1	0.4
UBA Load Bus	8	366.1	365.4	0.7
Basic-Sch. Transformer Bus	9	403.8	403.5	0.3
Basic School Load Bus	10	403.8	403.5	0.3
ROB Transformer Bus	11	400.4	399.8	0.6
ROB Load Bus	12	399.8	399.1	0.7
CBT Block Load Bus	13	392.1	391.2	0.9
China Block Load Bus	14	392.1	391.2	0.9
Auto. Transformer Bus	15	393.5	393	0.5
Autonomy-hall Load Bus	16	389.6	389.1	0.5

RG Bungalow Load Bus	17	388.6	388.2	0.4
Estate Bungalow Load Bus	18	375.1	374.4	0.7
Anest Load Bus	19	366.1	365.8	0.3
Credit Union Load Bus	20	361.2	360.6	0.6
Frank J Load Bus	21	345.1	344.2	0.9
B Opoku-Ware Load Bus	22	343.3	342.9	0.4
Tanoso Estate Load Bus	23	342.3	342.1	0.2

Appendix II, Active Power Loss of Base Case, Case 1, Case 2, Case 3, and Case 4

From Bus	To Bus	Base Case	Case 1	Case 2	Case 3	Case 4
Source Bus 1	Workshop Transformer Bus	14.52	1735.895	2238.53	2273.318	1734.948
Workshop Transformer Bus	Admin Load Bus	66.19	455.565	1238.56	1068.493	269.986
Workshop Transformer Bus	Atwima-Hall Load Bus	0.798	60.423	61.479	50.933	52.069
Atwima-Hall Load Bus	Clinic Load Bus	0.103	2.281	2.309	1.912	1.947
Workshop Transformer Bus	Construction Load Bus	4.86	107.741	109.727	90.895	92.961
Workshop Transformer Bus	1" B Opoku-Ware Load Bus	0.552	23.747	22.14	18.196	17.814
A Opoku-Ware Load Bus	UBA Load Bus	0.11	1.709	1.581	1.299	1.267
Workshop Transformer Bus	Basic-Sch. Transformer Bus	3.74	36.842	29.212	23.596	21.872
Basic-Sch. Transformer Bus	Basic School Load Bus	0	0	0	0	0
Workshop Transformer Bus	ROB Transformer Bus	2.44	1176.537	759.985	648.048	288.411
ROB Transformer Bus	ROB Load Bus	0.113	0.017	0.025	0.01	0.002
ROB Transformer Bus	CBT Block Load Bus	1.3	0.191	0.27	0.104	0.024
CBT Block Load Bus	China Block Load Bus	0	0	0	0	0
ROB Transformer Bus	Auto. Transformer Bus	0.903	255.791	126.876	141.125	71.744
Auto. Transformer Bus	Autonomy-hall Load Bus	3.36	0.313	0.477	0.172	0.038
Auto. Transformer Bus	RG Bungalow Load Bus	0.244	31.734	0.035	17.545	0.003
Auto. Transformer Bus	Estate Bungalow Load Bus	1.58	2.125	3.125	1.172	39.78
Estate Bungalow Load Bus	Anest Load Bus	0.68	0.615	0.901	0.339	19.68
Anest Load Bus	Credit Union Load Bus	0.414	0.194	0.283	0.107	12.046
Credit Union Load Bus	Frank J Load Bus	1.19	0.245	0.357	0.135	40.893
Frank J Load Bus	B Opoku-Ware Load Bus	0.0681	0.006	0.009	0.003	5.186
B Opoku-Ware Load Bus	Tanoso Estate Load Bus	0.0059	0	0.001	0	19.517

Appendix III, Reactive Power Loss of Base Case, Case 1, Case 2, Case 3, and Case 4

From Bus	To Bus	Base Case	Case 1	Case 2	Case 3	Case 4
Source Bus 1	Workshop Transformer Bus	12.42	191937.081	89661.901	35183.271	51091.783
Workshop Transformer Bus	Admin Load Bus	95.08	-27504.465	111034.983	-166910.623	1442.332
Workshop Transformer Bus	Atwima-Hall Load Bus	1.15	82366.792	80094.629	135878.253	-21558.344
Atwima-Hall Load Bus	Clinic Load Bus	0.148	19880.812	28106.783	-22476.348	-17780.954
Workshop Transformer Bus	Construction Load Bus	6.98	62934.279	107709.844	-86636.087	-73686.003
Workshop Transformer Bus	1" B Opoku-Ware Load Bus	0.792	16372.478	28433.397	-21312.992	-15610.764
A Opoku-Ware Load Bus	UBA Load Bus	0.158	9534.849	15901.037	-14549.365	-11755.677
Workshop Transformer Bus	Basic-Sch. Transformer Bus	5.36	12703.455	22877.587	-20640.155	-14914.31
Basic-Sch. Transformer Bus	Basic School Load Bus	0	-3.413	-10.345	7.242	6.883
Workshop Transformer Bus	ROB Transformer Bus	2.09	43279.637	-113089.285	70751.497	64203.075
ROB Transformer Bus	ROB Load Bus	0.162	-16897.579	-14789.266	2707.415	-3985.285
ROB Transformer Bus	CBT Block Load Bus	1.86	-16586.094	-13740.957	3756.891	-4196.819
CBT Block Load Bus	China Block Load Bus	-0.0007	-12.09	-11.792	-0.359	-2.254
ROB Transformer Bus	Auto. Transformer Bus	0.772	-338637.413	-165157.64	27535.735	-109874.241
Auto. Transformer Bus	Autonomy-hall Load Bus	4.82	77880.98	27711.869	56877.848	-15250.857
Auto. Transformer Bus	RG Bungalow Load Bus	0.351	133824.272	1281.194	112908.872	-887.555
Auto. Transformer Bus	Estate Bungalow Load Bus	2.28	8774.284	11909.615	2991.916	-79271.275
Estate Bungalow Load Bus	Anest Load Bus	0.977	26281.297	22928.758	16037.416	95407.991
Anest Load Bus	Credit Union Load Bus	0.595	18863.419	18834.504	11006.565	-23335.027
Credit Union Load Bus	Frank J Load Bus	1.72	11356.164	11790.165	6545.065	-93396.639
Frank J Load Bus	B Opoku-Ware Load Bus	0.0977	4805.74	5370.711	2692.152	-1870.385
B Opoku-Ware Load Bus	Tanoso Estate Load Bus	0.0081	625.323	701.29	349.738	29937.629

Appendix IV, Voltage Profile of Base Case, Case 1, Case 2, Case 3, and Case 4

Bus Name	Bus ID	Base Case	Case 1	Case 2	Case 3	Case 4
Source Bus 1	1	0.002409639	0.00238554	0.00233735	0.002216867	0.00209639
Workshop Transformer Bus	2	0.004819277	0.00477108	0.0046747	0.004433735	0.00419277
Admin Load Bus	3	0.007228916	0.00715663	0.00701205	0.006650602	0.00667229
Atwima-Hall Load Bus	4	0.009638554	0.00954217	0.0093494	0.00886747	0.00889639
Clinic Load Bus	5	0.012048193	0.01192771	0.01168675	0.011084337	0.01048193
Construction Load Bus	6	0.014457831	0.01431325	0.0140241	0.013301205	0.01286747
A Opoku-Ware Load Bus	7	0.01686747	0.0166988	0.01636145	0.015518072	0.01501205
UBA Load Bus	8	0.019277108	0.01908434	0.0186988	0.01773494	0.01715663
Basic-Sch. Transformer Bus	9	0.021686747	0.02146988	0.02084096	0.019951807	0.01886747
Basic School Load Bus	10	0.024096386	0.02385542	0.02315663	0.022409639	0.02096386
ROB Transformer Bus	11	0.026506024	0.02624096	0.02547229	0.024650602	0.02306024
ROB Load Bus	12	0.028915663	0.02862651	0.02778795	0.026891566	0.02515663
CBT Block Load Bus	13	0.031325301	0.03101205	0.03010361	0.02913253	0.02725301
China Block Load Bus	14	0.03373494	0.03339759	0.03241928	0.031373494	0.0293494
Auto. Transformer Bus	15	0.036144578	0.03578313	0.03520482	0.033614458	0.03144578
Autonomy-hall Load Bus	16	0.038554217	0.03816867	0.03755181	0.035855422	0.03354217
RG Bungalow Load Bus	17	0.040963855	0.04055422	0.0398988	0.037686747	0.03563855
Estate Bungalow Load Bus	18	0.043373494	0.04293976	0.04224578	0.039903614	0.03773494
Anest Load Bus	19	0.045783133	0.0453253	0.04459277	0.042120482	0.04074699
Credit Union Load Bus	20	0.048192771	0.04771084	0.04693976	0.044337349	0.04289157
Frank J Load Bus	21	0.05060241	0.05009639	0.04908434	0.046655422	0.04503614
B Opoku-Ware Load Bus	22	0.053012048	0.05248193	0.05142169	0.048877108	0.04771084
Tanoso Estate Load Bus	23	0.055421687	0.05486747	0.05375904	0.051098795	0.05043373