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OPTIMAL PLACEMENT OF EV CHARGING STATIONS IN THE DISTRIBUTION NETWORK USING OPTIMIZATION TECHNIQUES

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Abstract: The rapid growth of electric vehicles (EVs) has brought about the imperative an increase in EVCI (Electric Vehicle Charging Infrastructure) to meet the surging demand. Within this context, our project confronts the critical challenge of strategically situating EV Charging Stations (EVCS) within a distributed power network with the dual objectives of minimizing voltage losses and associated costs. To accomplish this, we implemented a two-step methodology. First and foremost, we harnessed the Forward- Backward Sweep method to comprehensively assess voltage loss across the network. This initial phase yielded a granular understanding of the voltage profile, enabling us to pinpoint areas of concern and prioritize their mitigation. Subsequently, we devised a cost function, considering diverse factors such as installation and operational expenses, to quantify the economic ramifications of deploying EVCS at distinct locations within the network. Consequently, we applied an Arithmetic optimization algorithm to identify the best position for EVCS, a placement that simultaneously minimizes voltage loss while optimizing costs. By iteratively fine-tuning the positioning of charging stations, we unearthed solutions that strike an equilibrium between network performance and financial prudence. The results of our project serve as compelling evidence that through the systematic application of optimization techniques, it is feasible to the lion's share advantageous places where EV Charging Stations are located in a distributed network. By better utilizing the infrastructure for charging electric vehicles, this not only strengthens the distribution system's dependability and efficiency but also promotes the adoption of electric vehicles on a sustainable basis. Our findings offer invaluable insights to utility companies, policymakers, and stakeholders engaged in the planning and expansion of EVCI networks, promoting an economically and technically astute approach.

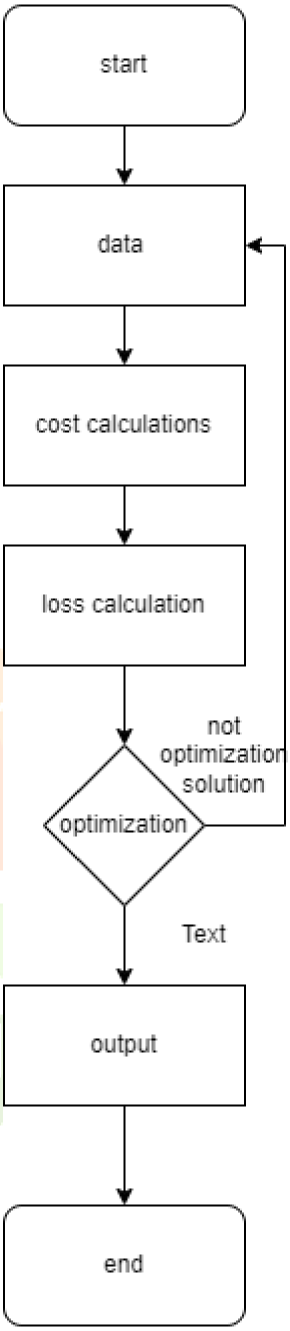
***Keywords* – EV charging station, distributed network data, power loss, installation cost, loss analysis, operational cost.**

I. INTRODUCTION

Electric Vehicles (EVs) have emerged as a revolutionary and environmentally conscious solution in the field of sustainable transportation. Their appeal extends beyond their sleek designs and advanced technology; it's deeply rooted in their potential to transform our daily commutes while addressing critical environmental concerns. This shift towards EVs represents a significant step in reducing the ecological footprint of the transportation sector. In this discussion, we will delve into the multifaceted aspects of Electric Vehicles, their advantages over traditional fossil fuel-powered vehicles, and the pivotal role played by Electric Vehicle Charging Stations (EVCS) in this transformative journey. The swift embrace of Electric Vehicles (EVs) carries both potential advantages and daunting hurdles. On one hand, it holds the promise of substantial environmental gains, yet on the other, it poses substantial challenges to the stability of electrical distribution systems. The remarkable surge in power demand stemming from EV charging translates into elevated power losses and substantial modifications to the voltage distribution within the electrical grid. Consequently, a meticulous strategy is imperative when deploying Electric Vehicle Charging Stations (EVCS) to uphold the power quality of the distribution network. Any concession made in maintaining power quality could yield adverse repercussions for the overall efficiency and reliability of the system. The rapid electric vehicle adoption presents a paradoxical situation. While it holds the promise of significant environmental benefits, it simultaneously presents formidable challenges to the stability of electrical distribution systems. The exponential surge in power demand for charging EVs results in heightened power losses and substantial alterations in the voltage profile within the electrical grid. Hence, the stability and dependability of the distribution network are contingent upon the prudent positioning of high-speed charging Electric Vehicle (EV) stations. Within this intricate puzzle, the strategic placement of charging infrastructure takes on a central role. It demands a delicate equilibrium between maximizing coverage within the traffic network and minimizing losses and voltage fluctuations within the electric distribution system. This strategic deployment not only exerts a significant influence on the behavior of EV users but also serves as a magnet for investments from charging station operators. It emerges as a linchpin in expediting the widespread embrace of EVs and molding smart, sustainable urban environments. We handle the varied character of the problem in search of the best locations for Electric Vehicle Charging Stations (EVCS). First and foremost, we aim to maximize coverage to ensure that a substantial portion of the transportation network is adequately served by charging infrastructure. At the same time, we try to reduce losses in order to lessen how much EV charging affects the distribution network's overall effectiveness. As part of our efforts to preserve the stability and dependability of the electrical grid, we also work to minimize node voltage variations. By merging insights from both transportation and distribution networks, our methodology offers a comprehensive view of the EVCS siting challenge. This holistic approach enables us to tackle not just the accessibility and convenience of charging stations for EV users but also the profound influence on the electrical grid's operational integrity. Utilizing this forward-thinking framework, we can make well-informed choices that account for the intricate synergy of variables, ultimately fostering the strategic and streamlined positioning of EV charging infrastructure. This endeavor proves pivotal for the sustainable and intelligent advancement of our urban environments.

II. FLOW DIAGRAM OF THE PROPOSED DC-DC CONVERTER MODEL

Fig. 1: Flow diagram of the proposed interleaved dc-dc converter



The detailed schematic representation of the optimization technique EV charging station represented in Figure 1 [8]. The proposed converter, which has two individual conventional converters stacked in parallel, receives a DC power source. By dividing the current across the two switches, this parallel arrangement significantly reduces current strains. A PID algorithm controls the feedback loop before the planned converter output is transmitted to the load being controlled [3]. The Ziegler-Nichols tuning technique is implemented by the PID controller, which uses the DC power source as its input. By implementing the PID controller, the number of harmonics and disturbances is minimal. The output that has less voltage ripple is then delivered to the load after being fed back into the converters.

III. PROPOSED METHODOLOGY

First of all, we need to gather data about real power, reactive power, and voltage magnitude from the buses. The installation of EV charging stations within the distribution network may cause voltage fluctuations, higher peak demand, harmonic power quality difficulties, and overloaded transformers in addition to deteriorating the operating characteristics of the distribution network, such as voltage stability and reliability.

The main goal is to determine the ideal location for EV charging stations based on bus losses, quick or slow charging stations, and those variables. To facilitate the effective integration of Electric Vehicle (EV) charging infrastructure into the distribution network while ensuring grid reliability and minimizing operational costs. So we need to find the cost of operation and installation for the placement of EV charging stations and losses of every bus. And to decide where the best EV charging stations should be placed inside the distribution network to balance EV user accessibility with minimal infrastructure and grid impact. From that data, we need to choose the minimum losses and total cost and we need to iterate several times until an optimized solution is found.

A. *OBJECTIVE FUNCTIONS*

a. *LOSSES*

The objective to find real and reactive power loss occurring in the network. So, finding the power loss

$$P_{n+1} = P_n - P_{(loss,n)} - P_{Ln+1}$$
$$Q_{n+1} = Q_n - Q_{(loss,n)} - Q_{Ln+1}$$

P_n => Real power flow out of bus
Q_n => Reactive power flow out of bus
P_{Ln+1} => Power loss at n+1 bus
Q_{Ln+1} => Reactive power loss at n+1 bus

The real and reactive power loss between n and n+1 bus,

$$P_{loss}(n, n+1) = R_n \frac{P_n^2 + Q_n^2}{V_n^2}$$

$$Q_{loss}(n, n+1) = X_n \frac{P_n^2 + Q_n^2}{V_k^2}$$

$P_{loss}\,(n, n+1)$ is real power loss between n and (n+1) buses
$Q_{loss}\,(n, n+1)$ is reactive power loss between n and (n+1) buses So, the total power loss will be

Assumption:
Initial voltage is 1p.u

$$P_{loss}\,(n, n+1) = \sum_{n=1}^{t} P_{loss}\,(n, n+1)$$

$$Q_{loss}\,(n, n+1) = \sum_{n=1}^{t} Q_{loss}\,(n, n+1)$$

Initial power
loss both real and reactive are zero.

b. *.FORWARD BACKWARD SWEEP METHOD:*

The Forward-Backward Sweep Load Flow Analysis is a vital technique for solving power flow problems in radial distribution networks. It operates in two main phases. First, the forward sweep starts at the source and progresses towards the loads, computing currents and voltages at each node while adhering to Kirchhoff's Current Law. Subsequently, the backward sweep starts at the loads and shifts backward to the source, calculating voltages and currents and applying Kirchhoff's Voltage Law. This iterative process continues until the values converge. Throughout the analysis, factors like line impedance, various load characteristics, and distributed generation sources are considered. Accurate load modeling, encompassing constant power, current, or impedance, plays a pivotal role. Ultimately, this method is indispensable for distribution system engineers, as it enables the efficient and reliable assessment of voltage profiles, power losses, and line currents in radial distribution networks.

PSEUDOCODE:

```
# Initialize variables total_losses = 0

# Forward Sweep
for each branch in the network:
    # Calculate forward power flow
    forward_power_flow = calculate_forward_power_flow(branch)

    # Accumulate losses
    losses = calculate_losses(forward_power_flow) total_losses += losses

# Backward Sweep
for each branch in the network (in reverse order):
    # Calculate backward power flow
    backward_power_flow = calculate_backward_power_flow(branch)

    # Accumulate losses
    losses = calculate_losses(backward_power_flow) total_losses += losses

# Total losses calculation
total_losses = total_losses / 2 # Divide by 2 since forward and backward sweeps count losses twice # At this

point, 'total_losses' contains the estimated losses in the distribution network
```

c. *COST FUNCTION:*

Optimization focuses on reducing the total expenditure, with particular emphasis on minimizing the comprehensive expenses. The installation cost encompasses the financial outlay linked to erecting charging stations, which comprises expenses related to land, construction, labor, and chargers. Meanwhile, the operational cost refers to the expenditure associated with supplying electric power to facilitate the charging service for electric vehicles (EVs).

The total cost function includes,

$$Cost = C_{installation} + C_{operation}$$

$$C_{installation} = f(N_{fastp}, N_{slowp})$$

$$= \sum N_{fastp} * C_{fast} + \sum N_{slowp} * C_{slow}$$

$$C_{operation} = f(N_{fastp}, N_{slowp})$$

$$= (\sum N_{fastp} * CP_{fast} + \sum N_{slowp} * CP_{slow}) * P_{electricity}$$

As indicated in the equations above, both installation and operational costs are solely contingent on the quantity of fast and slow charging stations, devoid of any influence from the charging station locations. This stems from the underlying assumption that the costs associated with land, construction, labor, chargers, and electricity remain uniform across all nodes within the entire network.

PSEUDOCODE:

```
Start
Declare variables

bus_data,line_data,cost_slowcharging,cost_fastcharging,pcost_slowcharging,pcost_fastcharging,no_of_faststation
,no_of_slowstat ion, power chestnut bus_data
Input line_data Operation_cost[33] Installation_cost[33] total_cost[33]


Function operational cost()
For i in 0:32
opertion_cost[i]=no_of_faststationpcost_fastcharging+  no_of_slowstationpcost_slowcharging*powercost

Function installation cost()
For j Jn 0:32
installation_cost[j]=no_of_faststationcost_fastcharging+  no_of_slowstationcost_slowcharging

Function total cost()
For k in 0:33 total_cost[k]=opertion_cost+installation_cost
```

B. *ALGORITHM*

Optimization plays a pervasive role across diverse domains, spanning from engineering design to economics, and extending from vacation scheduling to Internet routing. Given the perpetual constraints of limited funds, resources, and time, achieving the optimal utilization of these available resources stands as a matter of paramount importance. In the real world, most optimization challenges are inherently intricate, characterized by nonlinearity and multimodality, and they must contend with a multitude of complex constraints. Here we are using Arithmetic Optimization Algorithm (AOA) which is a meta-heuristic method where meta-heuristic refers to the strategies that guide the search process . To tackle these multifaceted optimization problems, a metaheuristic offers a valuable solution—an overarching algorithmic framework that is not tied to specific problems and offers a set of principles and strategies for crafting heuristic optimization algorithms. This innovative method leverages the statistical distribution characteristics of fundamental arithmetic operators commonly found in mathematics, namely Multiplication (M), Division (D), Subtraction (S), and Addition (A). AOA is rigorously formulated and implemented to excel in optimizing a diverse array of search spaces, making it a versatile tool in the domain of optimization.

To validate its effectiveness and applicability, AOA's performance is rigorously assessed across a comprehensive spectrum of challenges. This evaluation encompasses twenty-nine benchmark functions commonly used in optimization research, as well as numerous real-world engineering design problems that represent practical scenarios. The evaluation encompasses an in-depth analysis of AOA's performance, its convergence behaviour, and its computational complexity across various testing scenarios.

The experimental results clearly demonstrate the remarkable potential of AOA in addressing complex optimization problems. In fact, AOA outperforms eleven other widely recognized optimization algorithms, showcasing its capability to deliver highly promising solutions. This research not only introduces a novel metaheuristic approach in the form of AOA but also provides strong empirical evidence of its effectiveness through extensive testing and comparison with established algorithms.

- Collection of data of bus data (real power, reactive power ,type of the bus , voltage magnitude , voltage angle) and line data (resistance, reactance, rated current)
- The optimization aims to reduce overall costs as much as possible. The financial outlay necessary to build charging stations is known as the installation cost. The installation cost includes the costs of land, buildings, labor, and chargers. The cost of providing electric power to provide the service of charging EVs is included in the operation cost. For that problem we calculate the cost of installation and operation using
- $Cost = C_{installation} + C_{operation}$
- $C_{installation} = f(N_{fastp}, N_{slowp})$

- $C_{operation} = f(N_{fastp}, N_{slowp})$

$$= \sum N_{fastp} * C_{fast} + \sum N_{slowp} * C_{slow}$$

$$= (\sum N_{fastp} * CP_{fast} + \sum N_{slowp} * CP_{slow}) * P_{electricity}$$

- And loss calculation for each bus using
- $P_{n+1} = P_n - P_{(loss,n)} - P_{Ln+1}$
- $Q_{n+1} = Q_n - Q_{(loss,n)} - Q_{Ln+1}$
- The real and reactive power loss between n and n+1 bus,

$$Ploss(n, n+1) = R_n \frac{P_n^2 + Q_n^2}{V_n^2}$$

$$Qloss(n, n+1) = X_n \frac{P_n^2 + Q_n^2}{V_k^2}$$

$Ploss\,(n, n+1)$ is real power loss between n and (n+1) buses

$Qloss\,(n, n+1)$ is reactive power loss between n and (n+1) buses

- the total power loss will be calculate using

$$Ploss\,(n, n+1) = \sum_{n=1}^{t} Ploss\,(n, n+1)$$

$$Qloss\,(n, n+1) = \sum_{n=1}^{t} Qloss\,(n, n+1)$$

- Then calculate total cos by adding installation cost and operational cost and losses cost
- And the system needs to give the suitable bus for placement of EV charging system and optimize the solution with the AOA algorithm

PSEUDOCODE:

```
Function operational cost()
For i in 0:32
opertion_cost[i]=no_of_faststationpcost_fastcharging+  no_of_slowstationpcost_slowcharging*powercost

Function installation cost()
For j Jn 0:32
installation_cost[j]=no_of_faststationcost_fastcharging+  no_of_slowstationcost_slowcharging

Function total cost()
For k in 0:33 total_cost[k]=opertion_cost+installation_cost


Function loss_calc() # Initialize variables total_losses = 0


# Forward Sweep
for each branch in the network:
# Calculate forward power flow
forward_power_flow = calculate_forward_power_flow(branch)

# Accumulate losses
losses = calculate_losses(forward_power_flow) total_losses += losses
```

```
# Backward Sweep
for each branch in the network (in reverse order):
# Calculate backward power flow
backward_power_flow = calculate_backward_power_flow(branch)

# Accumulate losses
losses = calculate_losses(backward_power_flow) total_losses += losses

# Total losses calculation
total_losses = total_losses / 2 # Divide by 2 since forward and backward sweeps count losses twice # At this

point, 'total_losses' contains the estimated losses in the distribution network

main()

bus_data,line_data,cost_slowcharging,cost_fastcharging,pcost_slowcharging,pcost_fastcharging,no_of_faststation
,no_of_slowstat  ion, power chestnut bus_data
Input line_data Operation_cost[33] Installation_cost[33] total_cost[33]

Function operational cost() Function installation cost() Function total cost() Function loss_calc()

If solution feasible:
update(bus_data) Else
Return Feasible solution found
```

IV.RESULTS AND DISCUSSION

The success of an electric bus project heavily relies on selecting the most suitable charging station locations. This pivotal decision directly impacts the operational efficiency, costs, and environmental impact of the project. In this section, we will delve into the results of our project, focusing on the process of choosing the optimal charging station locations while considering cost factors and minimizing energy losses.

Cost Analysis

Our project involved an exhaustive analysis of costs associated with various aspects of operating electric buses. Here are the key findings:

1. Charging Station Costs: After thorough research and evaluation, we identified the initial investment required to set up charging stations. This encompasses infrastructure development, equipment procurement, and installation expenses.
2. Electricity Costs: We conducted a comprehensive assessment of the ongoing electricity expenses incurred during bus charging.

Our analysis

factored in regional electricity rates, charging duration, and potential cost savings through the adoption of renewable energy sources.

Loss Analysis

Minimizing energy losses is critical for optimizing the efficiency of electric buses. Our loss analysis uncovered the following insights:

Conversion Losses: We quantified the conversion losses that occur during the transformation of electrical energy into a form suitable for the buses' motors. This allowed us to pinpoint areas where efficiency improvements can be made. Transmission Losses: By considering the transmission losses associated with energy transport from the charging station to the bus, we highlighted opportunities for reducing energy wastage. Charging and Discharging Losses: Our project meticulously examined the losses incurred during the charging and discharging processes of the buses' batteries. Identifying these losses was crucial in designing strategies to mitigate them.

Data-Driven Decision Making

One of the hallmarks of our project was the data-driven approach we adopted. To ensure the selection of optimal charging station locations, we gathered and analyzed a wealth of data, including:

1. Bus Specifications: We compiled detailed information about the buses, such as battery capacity, charging voltage, and charging speed. This data served as a foundation for our decision-making process.
2. Charging Infrastructure Data: Our team meticulously evaluated the available charging station options, assessing their locations, associated costs, and charging speeds. This allowed us to create a comprehensive database of potential charging sites.
3. Electricity Costs: We investigated local electricity rates and explored potential incentives or discounts for employing renewable energy sources. This knowledge was invaluable for projecting long-term operational costs.

Mathematical Modelling for Optimization:

With the data in hand, we constructed a robust mathematical model. This model simulated various scenarios, each representing a combination of charging station locations, and quantified their associated costs and losses. By systematically exploring these scenarios, we were able to pinpoint the optimal combination of charging station locations that minimized overall expenses while satisfying project requirements.

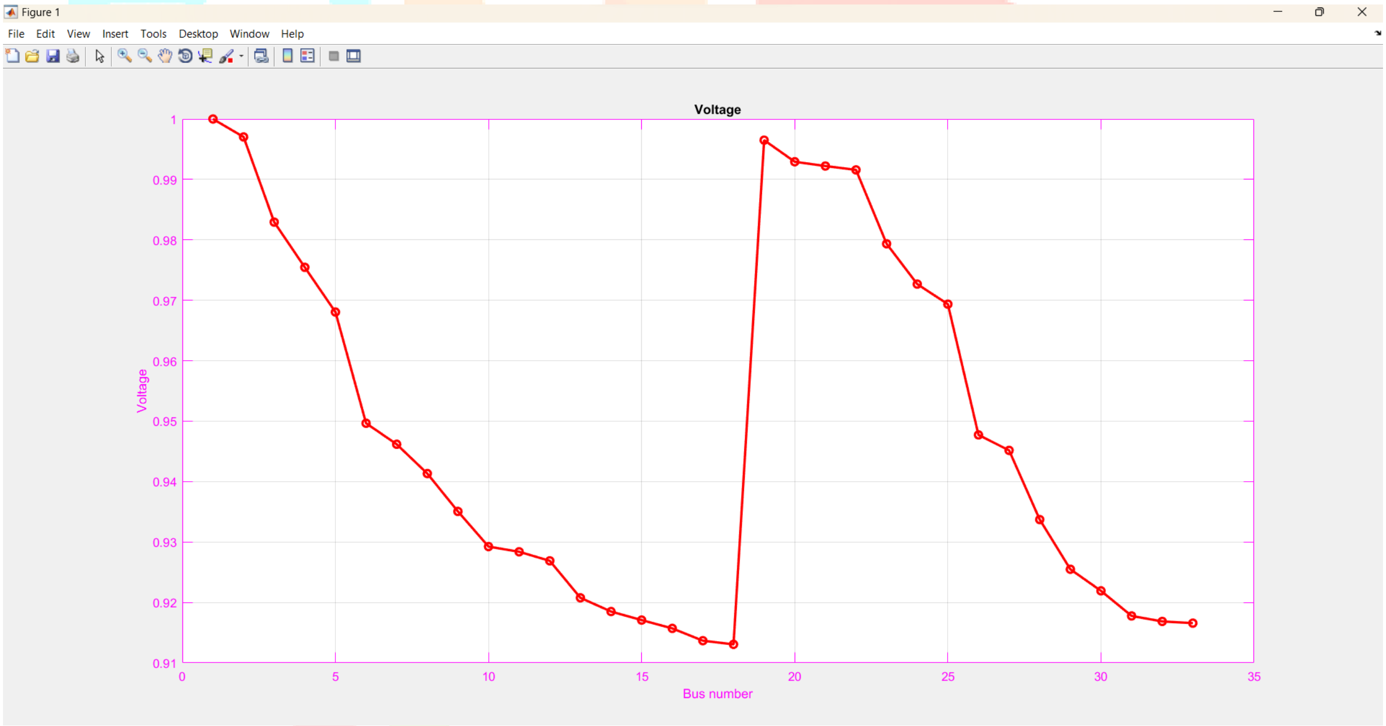


Fig 6: Voltage

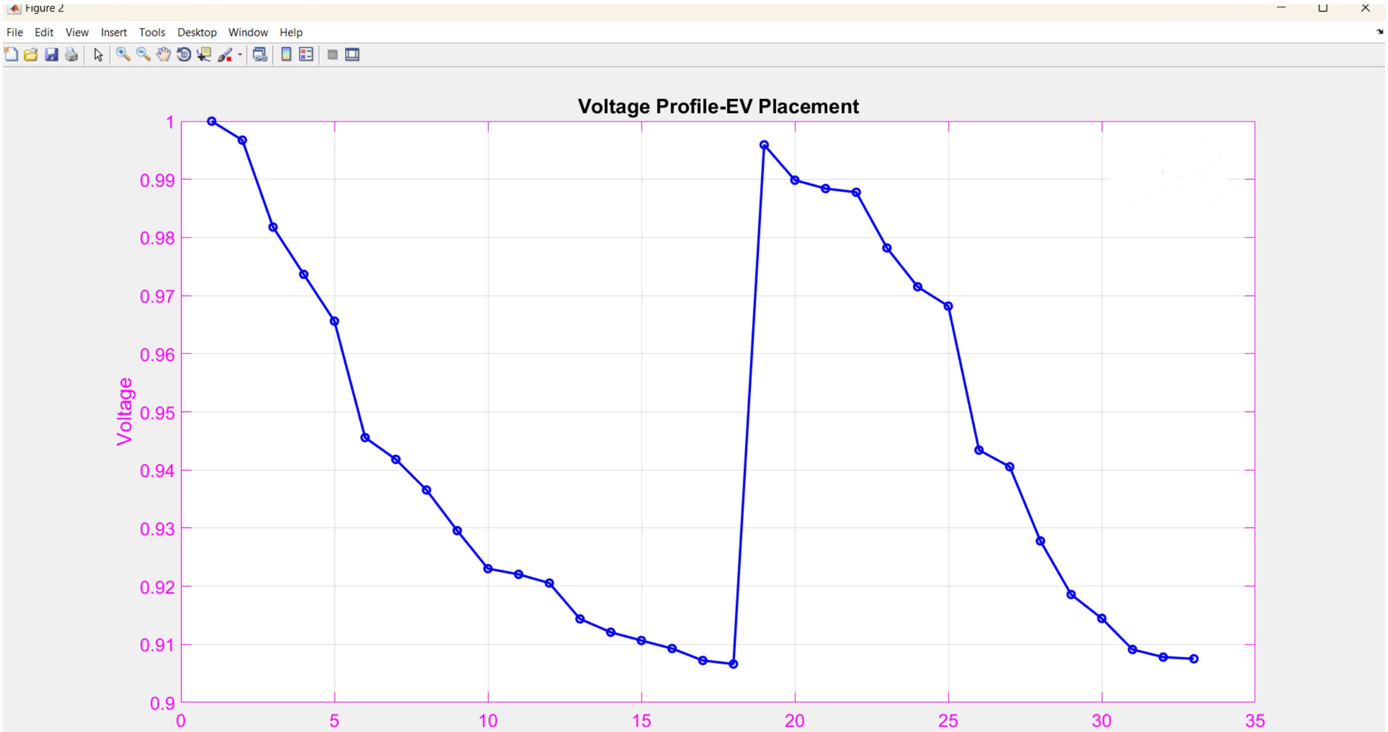


Fig 7: Voltage profile-Placement

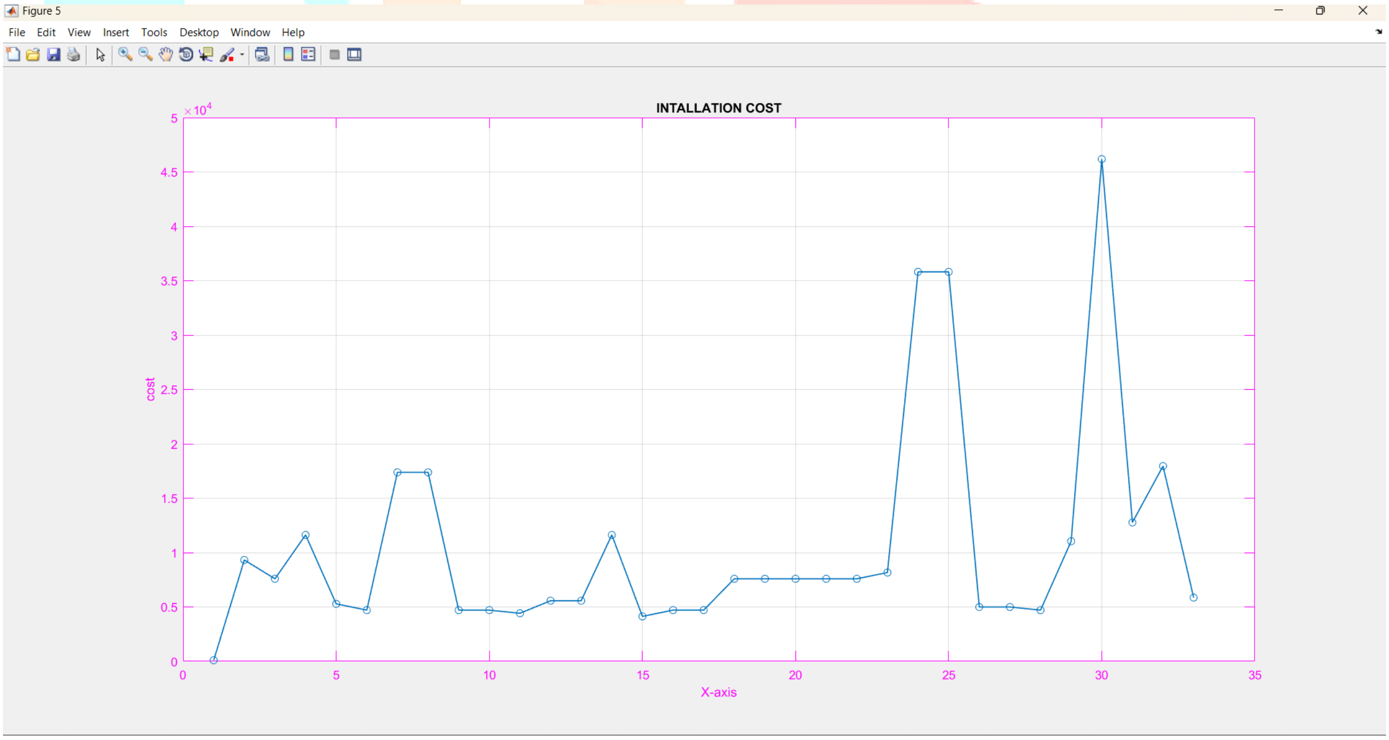


Fig 8: Operational cost

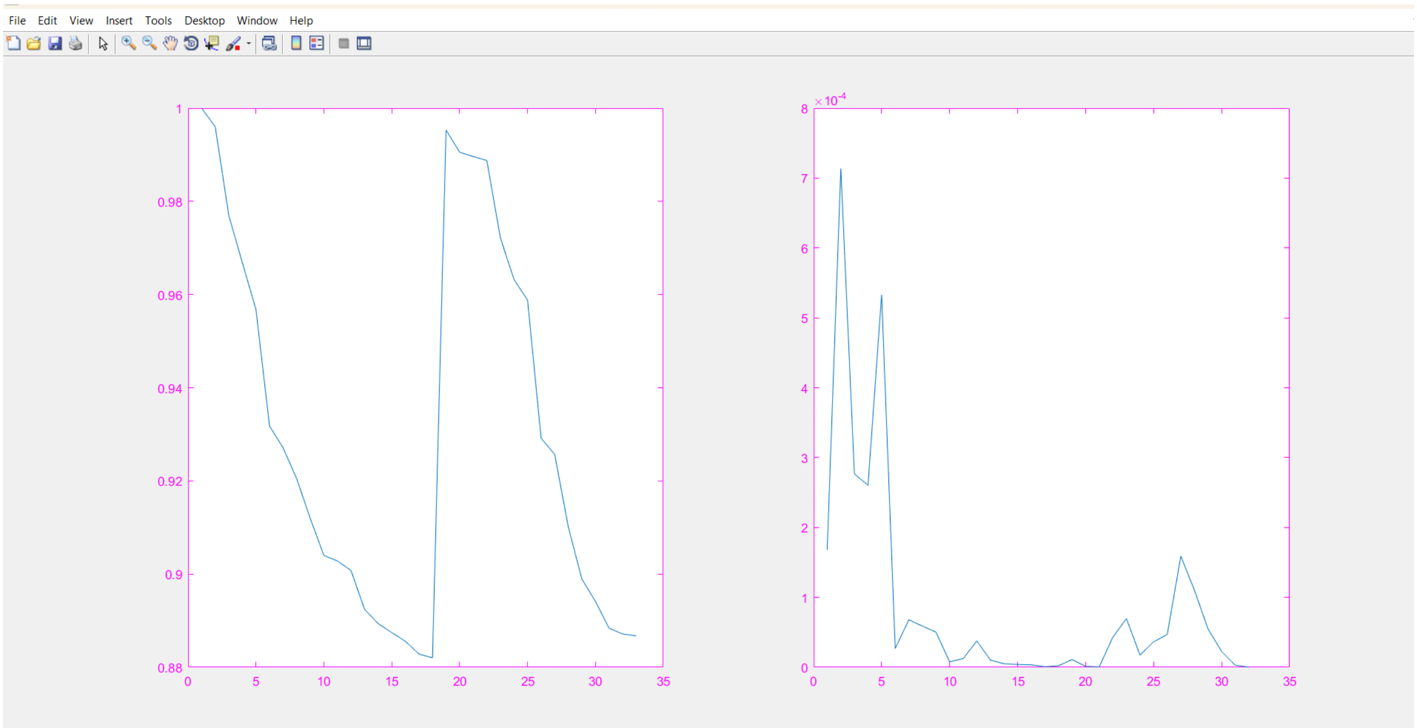
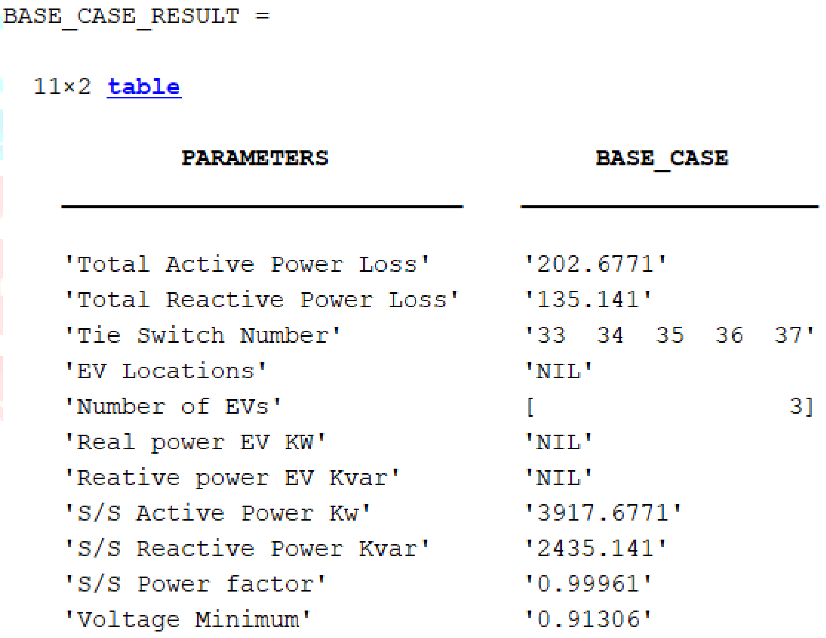


Fig 9: Cost function, Losses

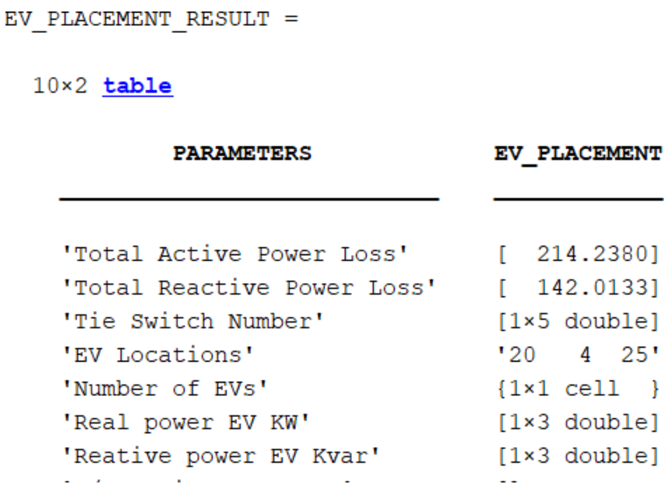


```
BASE_CASE_RESULT =

  11×2 table

          PARAMETERS                     BASE_CASE
    ____________________________    ____________________

    'Total Active Power Loss'       '202.6771'
    'Total Reactive Power Loss'     '135.141'
    'Tie Switch Number'             '33   34   35   36   37'
    'EV Locations'                  'NIL'
    'Number of EVs'                 [                  3]
    'Real power EV KW'              'NIL'
    'Reative power EV Kvar'         'NIL'
    'S/S Active Power Kw'           '3917.6771'
    'S/S Reactive Power Kvar'       '2435.141'
    'S/S Power factor'              '0.99961'
    'Voltage Minimum'               '0.91306'
```

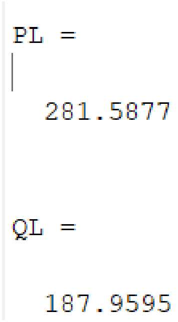


```
EV_PLACEMENT_RESULT =

  10×2 table

          PARAMETERS                EV_PLACEMENT
    ____________________________    _____________

    'Total Active Power Loss'       [  214.2380]
    'Total Reactive Power Loss'     [  142.0133]
    'Tie Switch Number'             [1×5 double]
    'EV Locations'                  '20    4   25'
    'Number of EVs'                 {1×1 cell   }
    'Real power EV KW'              [1×3 double]
    'Reative power EV Kvar'         [1×3 double]
```



```
PL =

  281.5877


QL =

  187.9595
```

V.CONCLUTION

The central focus of this research centred on addressing the critical issue of strategically situating electric vehicle (EV) charging stations within distribution networks. By combining the forward-backward sweep method for loss calculations with an arithmetic optimization algorithm aimed at cost-effective placement, this study not only laid the groundwork for a comprehensive approach to reducing power losses and optimizing expenses but also made a significant contribution to advancing sustainability and efficiency in the domain of EV charging infrastructure. One of the significant achievements of this investigation is the development of a holistic framework that harmonizes both the technical and economic dimensions of EV charging station placement. This equilibrium between technical effectiveness and economic viability represents a pivotal milestone in advocating for the widespread adoption of electric vehicles and the continuous progression of sustainable transportation solutions. By striking this balance, the research not only offers practical solutions to the challenges associated with EV infrastructure but also provides a blueprint for long-term sustainability and resilience in the face of the ever-changing energy landscape. Furthermore, the insights garnered from this study have broad-reaching implications that extend their value to various stakeholders. Utility companies, for example, can employ this research to optimize their distribution networks, reducing operational costs and thereby enhancing overall service reliability and customer satisfaction. Urban planners can utilize these findings to inform the development of EV-friendly urban environments, promoting cleaner air and reduced congestion. Policymakers, on the other hand, can draw upon the research's recommendations to craft regulations and incentives that further encourage the deployment of EV charging infrastructure, expediting the transition toward a more sustainable and environmentally friendly transportation ecosystem.

In essence, this study's holistic approach to strategically situate EV charging stations not only addresses a critical need in our swiftly evolving energy landscape but also presents a model for future research and development endeavors. By fostering a mutually beneficial relationship between technical innovation and economic feasibility, it paves the way for a future where electric vehicles seamlessly integrate into our daily lives, propelling us closer to a more sustainable and eco-conscious future. As the world grapples with the challenges of climate change and energy sustainability, this research serves as evidence of the potential of interdisciplinary collaboration and forward-thinking solutions, offering hope for a cleaner and greener tomorrow.

VI.ACKNOWLEDGEMENT

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