Use of Symmetrical Components in the Study of Electrical Disturbances in Distribution Systems with Charging Allocation for Electric Vehicles and Battery Banks

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Abstract— This paper presents a study of electric power distribution systems, which include battery banks and electric vehicle charging. Emphasis is placed to detect and distinguish voltage disturbances, conductor breaks, and other events that commonly occur in distribution systems. The research uses free license software ATPDraw™ to accurately model distribution systems and replicate voltage characteristics. The study investigates the ideal location of electric vehicle chargers, battery banks and electrical voltage meters in distribution systems. For this purpose, the General Algebraic Modeling System (GAMS) will be used, which provides high-level mathematical optimization capabilities to improve the observability of the system. The study will focus on possible mitigation to the problems these factors can cause in the power distribution system and explore strategies to minimize their negative effects. The discoveries will help improve the system performance, stability, and reliability of power distribution systems and support the integration of electric vehicles and energy storage.

Keywords— Electrical Distribution System, Electric Vehicle Charging, Allocation of battery banks, Symmetrical Components, Detection and Classification of Voltage Disturbances, ATPDraw™.

I. Introduction

Battery bank (BB) allocation is a strategy for distributing energy storage systems in strategic locations that aims to optimize power supply, balance electrical load, and increase system reliability [1]. These BBs consist of sets of batteries that can store energy for later use. The strategic allocation of these banks brings benefits such as balancing the load during peak demand, storing intermittent renewable energy, and efficiently integrating renewable sources into the energy mix [2]. Therefore, the study of BB allocation is of utmost importance to ensure stable and reliable energy supply, especially with the increasing share of renewable energy sources in electricity generation [3].

The study of optimal allocation of Electric Vehicle (EV) charging is of significant scientific importance due to the potential impacts that this charging can have on electrical distribution systems (DSs) [4]. With the increasing adoption of EVs, the demand for electrical energy also grows, which can result in overload on DSs. By investigating the optimal charging allocation, it is possible to prevent issues such as voltage drops, transformer and cable overloads, and minimize the occurrence of disturbances and system failures. Furthermore, a careful study can also identify charging strategies that help balance the load demand and optimize energy usage, resulting in a more efficient and sustainable system [5]. Therefore, research in this area contributes to the advancement of electrical science, enabling the development of solutions that ensure a smooth and efficient integration of EVs into the electrical distribution system.

It is important to note that this paper is part of a large research project. Thus, it is material based on an original and as yet unresolved scientific hypothesis, validated by modeling and simulations using three freely licensed programs: GAMS [6], ATPDraw™ [7], and Octave [8]. So far, this research project and the papers published in it have shown that the identification and detection of conductor breaks (CBs) and various other types of faults that occur in the DS is an area of constant research due to the current demand for electricity and the increasing expansion of the DSs, as well as the constant changes in this scenario [9].

II. Related work

In this section their are the main publications that the research project has achieved so far, as well as the main publications that support the research on EV charger allocation and BB allocation in DSs.

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a. Detection and distinction of faults in DSs

Through the study presented by [10], its importance in the area of detecting and discriminating conductor breaks in DSs could be observed before the high impedance fault occurs. In [11, 12, 13, 14], the authors explained how to simulate and model an electric power distribution system using the license-free software ATPDraw™, which was considered as the first step of this research project.

It is shown how Negative Sequence Voltage (NSV) can be a tool to detect and discriminate CBs in DSs in [15]. Also using NSV, a comprehensive study was presented in [16], including programming in the software GAMS, to identify the best locations of voltage (and current) meters in DSs with different topologies. This study was presented in paper form in [17]. In this sense, in [18] he used another symmetrical component: the Positive Sequence Voltage.

In the following subsections are the main works that support the construction of methodological philosophy for the continuation of this research project, which includes studies on the allocation of EVs chargers and the allocation of BBs.

b. Allocation of Battery Bank

The paper [1] presents a comprehensive study on the integration of energy storage systems (ESS) with economic technologies and its impact on system reliability. The authors address the challenges posed by intermittent and variable Renewable Energy Sources (RES) and emphasize the role of ESS in mitigating power fluctuations and ensuring voltage stability. The study includes a discussion about ESS technologies and applications. Overall, the study highlights the potential benefits of coordinating ESS with economic technologies to enhance the reliability of the DS in the face of the intermittent nature of renewable energy resources. However, the authors report that the intermittent and variable nature of these resources has made it difficult to maintain a balance between supply and demand.

In [3], were conducted an experimental analysis on the use of supercapacitor banks as ESS in microgrids. They compared the performance of a microgrid with conventional ESS to a hybrid system incorporating supercapacitors. The study involved designing, developing and testing a supercapacitor within an existing RES-based microgrid. Results demonstrated that microgrid with supercapacitor ESS exhibited more consistent dynamic behavior and flexible power management, improved voltage stability, longer battery life, and protection against power spikes. However, achieving these benefits relies on the microgrid control system's ability to optimize the operation of each ESS component. The availability of additional degrees of freedom in the ESS allows for tailored control strategies for specific elements.

An overview of techniques for optimizing economical and reliable green microgrids is shown in [19]. The authors highlight the importance of considering economic aspects and evaluating reliability in renewable energy microgrid development. The paper discusses techniques for sizing renewable energy systems to enhance efficiency, reliability, grid resilience, and cost reduction. Its goal is to promote renewable energy deployment and create clean, affordable, and highly reliable microgrids. The authors also stress the need to consider the economics of renewable energy technologies and evaluate the reliability of microgrids due to the unpredictability of renewable energy sources.

This study [2]evaluates the economic feasibility of hybrid distributed generation systems (DG) with battery storage in light of proposed regulatory changes in the Brazilian energy compensation system. The authors emphasize the complementarity of wind and solar sources and the potential benefits of ESS in DG. Stochastic analyzes were performed considering different variables and three types of hybrid systems. The results indicate a high probability of economic viability, but highlight the need for incentives and regulatory frameworks to support battery integration and recognize the benefits of using a ESS in DG. However, the authors have highlighted an economic impasse in the implementation of the project presented in the study.

c. Allocation of electric vehicle chargers

The author of the paper [4] examines the impact of Electric Vehicles (EVs) on the stability of the low-voltage grid. The increasing number of EVs poses challenges to the distribution grid, including power outages, voltage fluctuations, and thermal stress. To address these issues, the paper suggests smart load management and demand-side management as alternatives to grid reinforcement. Five case studies, including one for the city of Palmas, are analyzed to explore different scenarios. However, the article does not delve into the role of smart grids in facilitating the complete transition from combustion cars to EVs.

In [20], the author analyzes the replacement of vehicles with internal combustion engines by electric or hybrid vehicles, considering their advantages and disadvantages, as well as the challenges faced by the country. Based on the analysis of economic and operational characteristics and the current political situation, it is concluded that large-scale growth of EV fleets in Brazil is not yet feasible. However, hybrid EVs are more advanced and viable today. However, the author does not say what needs to be done for a full transition to electric cars.

In their study [5], the authors propose a strategy to optimize the placement of EV charging stations and EV battery swap stations within a radial distribution system. They assess the impact of these stations on voltage profiles, active power losses, and system operating costs using different load models. Additionally, they explore the integration of renewable distributed generation systems, such as photovoltaic and wind turbines, utilizing a student-inspired chaotic optimization algorithm. The results demonstrate the feasibility of determining suitable sizes and locations for these renewable energy sources in the RDS, which can enhance the efficiency and reliability of the EV industry and distribution system.

III. METHODOLOGY

The methodology is based on the use of the recognized Alternative Transients Program software through the ATPDraw™ interface [7]. ATPDraw™ is a open-source software that is widely used in the scientific community to model electrical power DSs and case studies will be modeled using the 5-bus system [17], IEEE 34 node test feeder [21], the 33-bus test system [16], and the real DS from Palmas/TO [22]. It is worth noting that these systems are already modeled in ATPDraw™, as the following voltage disturbances were also performed through the MODELS routine [23]: Swell, sag, harmonic, outage, swell and sag with harmonic and events such as: Lateral Branch Switching, Lumped Load Switching, Distributed Load Switching, Capacitor Switching. This software has robust capabilities to accurately simulate and replicate the main voltage characteristics of BBs, EVs charging, CB and various disturbances commonly found in DSs.

The implementation of an algorithm based on the analysis of the symmetrical voltage components at each cycle (γ) adds significant value to the methodology. By using an algorithm through the Octave software [8], this algorithm has already proven to be able to effectively detect and distinguish the conductors break from other events, increasing the accuracy and reliability of the analysis. Finally, the methodology includes the General Algebraic Modeling System (GAMS) [6] software to optimize the placement of the meters in the DS This allows the identification of the most appropriate locations, minimizing the number of meters required and thus generating savings for the electric utilities.

IV. Conclusions

Therefore, the chosen methodology, which combines ATPDraw™, Octave, and GAMS, provides a robust and effective framework for studying power DSs. It enables accurate modeling of multiple components, fault detection and distinction, and meter placement optimization. The use of these tools ensures the reliability and effectiveness of research and leads to valuable insights and advances in the field of electrical engineering, a fundamental mission of the academic community.

a. Future Work

Considering the results of the research project so far, some suggestions can be highlighted to deepen this study, such as:

- Carrying out tests with other models of DSs with different configurations and topology;
- Carrying out the insertion of EVs charging points;
- Carrying out the insertion of BBs;
- Conducting a three-phase detection study to identify in which phase the disturbance is occurring.

As can see, the methodology used in this research project is not limited to a simple and easy problem to solve. Therefore, it is important to extend the study in all directions to make a great contribution to society.

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