FINEP PROJECT OF BREAKTHROUGH INNOVATION: VIRTUAL ENERGY STORAGE APPLIED IN E-MICROMOBILITY CONSIDERING BATTERY SWAP TECHNOLOGY

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ABSTRACT

This paper presents the perspectives of battery swap stations (BSS) to form virtual energy storage systems (VSS) considering electric micromobility (e-micromobility). A description of VSS and BSS characteristics describes the advantages and potential for these concepts. Then, the models required in decision-making are discussed. Finally, information about Brazilian real implementation is presented.

Keywords: Battery swap stations, e-micromobility, virtual energy storage systems, energy management, energy flexibility.

INTRODUCTION

Sustainable transportation has become critical, with electric mobility and micromobility offering alternatives to pollutant transportation. However, this increases recharging infrastructure, impacting distribution systems. Moreover, technologies such as battery swap with hybrid inverters can help reduce waiting times and inject energy into the grid [1, 2]. The strategic coordination of BSS can harness idle capacity to provide energy flexibility, forming a Virtual Energy Storage System (VSS) [3]. This VSS approach contributes to supporting distribution systems, reducing investments in reinforces, and forming new business models based on energy transactions [4]. Nevertheless, real implementation requires time. Furthermore, this paper presents a discussion of the potential of VSS formed by BSS considering the new challenge in mobility and sustainability. Then, a Brazilian project related to this theme is presented, describing its characteristics and opportunity.

MATERIALS AND METHODS

a) VSS and BSS Characteristics:

VSS consists of the coordinated use of several energy storage systems (ESS), increasing its nominal capacity and allowing the energy transactions between different types of agents as prosumers, consumers, and network operators [4]. Given the ESS charge and discharge, VSS offers flexibility for energy injection/absorption, allowing to reduce imbalance in the grid [5]. Also, it can avoid curtailments for excess PV generation by charging actions and reduce peak demand by discharging operations [6]. The VSS concept integrated with BSS is presented in Figure 1.

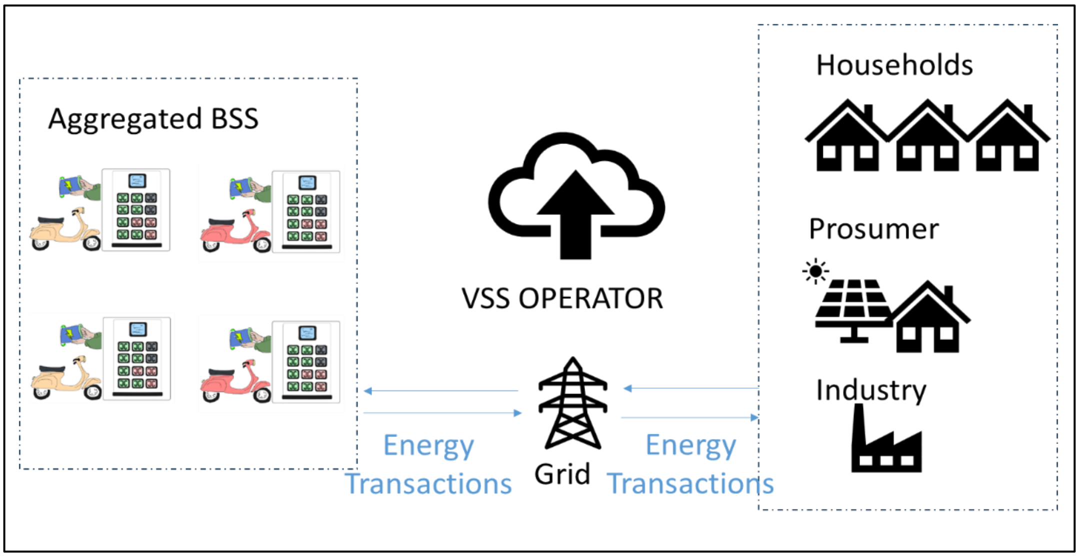

Figure 1. VSS concept.

In a BSS, there are fully charged batteries concentrated in slots in a station, and the user changes its empty battery instead of using chargers. This process reduces waiting time and allows control from the management systems to exchange energy with the network [7]. BSS infrastructure requires the correct communication between the user, the distribution system operator, and the local management system. This communication allows the adequate charging time for the users and the correct use of the energy presented in the depleted batteries that must attend both swap demand and grid needs [8].

RESULTS AND DISCUSSION

b) VSS Operation and integration with BSS

VSS's correct operation depends on economic and technical decisions. The participation of multiple agents implies the need for adequate negotiation schemes to set fairness in competition. Game theory is normally applied to determine the dispatch of the resources between the participants, considering the formation or not of coalitions [4, 9]. Technical management of VSS is usually handled by a multi-level approach [3, 4, 9]. Since ESS can be installed in several locations, strategies for managing central and local objectives are required to maximize advantages for all parties involved. This problem has normally two forms of solution. First, using Mixed Linear Integer Programming (MILP) models that require linear approximation but less computational burden [3, 4, 10]. Second, machine learning (ML) approaches that require a significant collection of data but can consider nonlinear variables and more complex equations with a more holistic response [3, 9]. Hybrid approaches that consider both MILP and ML algorithms can be an alternative.

VSS advantages have been proved in literature but focused more on residential batteries and demand or electric vehicle scheduling, disregarding BSS impact [3, 4, 9, 10]. Nevertheless, local application of BSS has proved potential for energy transactions, but coordination is still required [2]. Moreover, the BSS management is based on two levels. First level requires the scheduling of loads for optimization of the depleted batteries. This is handled by ML techniques or metaheuristics approaches to deal with the variability of load presented in the swapping requests [11]. Linear programming could also be applied but requires complex approximation to handle the nonlinear behavior of the BSS charging [11, 12]. In the second level, non-scheduled loads are handled with real-time control strategies, complementing the optimization of the first level with resilience [13]. It should be noted that BSS applications have been more focused on electric vehicles of large capacity (cars, trucks, and buses), but e-micromobility still requires more research. The research on BSS in e-micromobility is more focused on route optimization and allocation of capacity, disregarding energy transactions among the networks [7, 8]. Those approaches are based on Monte Carlo search for decision-making of the desired location [7, 8].

c) Brazilian Implementation:

The preceding data demonstrated the significance of integrating a practical scenario for VSS with BSS technology. Regarding this, we are currently working on a project in Brazil that considers each of the features to implement BSS in Rio de Janeiro City for e-micromobility. Cloud technology will be utilized to manage the virtualization of energy storage capacity. The project has the participation of Energy2Go, CIBiogas, and the Federal University of Santa Maria and has been founded by FINEP. EnergyG2o has previous experience working with BSS chargers.

An example applied for mobile applications is shown in Figure 2. The idea is to further extend this concept to mobility applications. Results are expected to be presented in future works.

Figure 2. Energy2go mobile charger.

CONCLUSION

The application of VSS with BSS in e-micromobility was discussed in this paper. The comprehensive data about VSS and BSS demonstrated the need for more e-micromobility studies. This lack of work highlights the significance of fresh initiatives tackling interdisciplinary topics like machine learning, metaheuristics, game theory, multi-level optimization, real-time control, Monte Carlo simulation, and e-micromobility, among others. Considering each of these factors will increase the viability of energy flexibility in distribution networks. Lastly, a project that is now in progress demonstrated the recent enthusiasm in Brazil for actual implementation and is expected to present results in future works.

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REFERENCES

[1] WANG, Ziqi; HOU, Sizu; GUO, Wei. Inventory management of battery swapping and charging stations considering uncertainty. International Journal of Electrical Power & Energy Systems, 2024, v. 155, p. 109528.

[2] ZENG, Bo; LUO, Yangfan; LIU, Yixian. Quantifying the contribution of EV battery swapping stations to the economic and reliability performance of future distribution system. International Journal of Electrical Power & Energy Systems, 2022.

[3] OSKOUEI, Morteza Zare; GHAREHPETIAN, Gevork B. Flexibility enhancement of multi-district DISCOs considering a trade-off between congestion and extractable reserve capacity from virtual energy storage systems. Applied Energy, 2024.

[4] ZHANG, Shixu et al. A review and outlook on cloud energy storage: An aggregated and shared utilizing method of energy storage system. Renewable and Sustainable Energy Reviews, 2023, p. 113606.

[5] AGHDAM, Farid Hamzeh et al. Optimal scheduling of multi-energy type virtual energy storage system in reconfigurable distribution networks for congestion management. Applied Energy, 2023, v. 333, p. 120569.

[6] GOLMOHAMADI, Hessam. Virtual storage plants in parking lots of electric vehicles providing local/global power system support. Journal of Energy Storage, v., 2021, 43, p. 103249.

[7] LIN, Min-Der et al. A multiobjective stochastic location-allocation model for scooter battery swapping stations. Sustainable Energy Technologies and Assessments, 2022, v. 52, p. 102079.

[8] ZHANG, Fan et al. Battery swapping demand simulation for electric micromobility vehicles considering multi-source information interaction and behavior decision. Journal of Cleaner Production, 2023, v. 414, p. 137525.

[9] LI, Xiangyu et al. Deep Reinforcement Learning Based Explainable Pricing Policy for Virtual Storage Rental Service. IEEE Transactions on Smart Grid, 2023.

[10] OH, Eunsung; SON, Sung-Yong. Dynamic virtual energy storage system operation strategy for smart energy communities. Applied Sciences, 2022.

[11] TAO, Yuechuan et al. Data-driven on-demand energy supplement planning for electric vehicles considering multi-charging/swapping services. Applied Energy, 2022, v. 311, p. 118632.

[12] GUELLER, Nickolas et al. Optimization of battery swapping stations with heterogeneity, charging degradation and PV-option. Journal of Energy Storage, 2023.

[13] KUMAR, Tushar et al. Charge scheduling framework with multiaggregator collaboration for direct charging and battery swapping station in a coupled distribution-transportation network. International Journal of Energy Research, 2022, v. 46, n. 8, p. 11139-11162.