Energy storage system for increasing electric-power stability

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ABSTRACT

At present, energy storage systems are being generalized due to the necessity of providing stable and good-quality electrical service in all homes. Solutions are given to Ecuador's electrical power system using distributed generation facilities with different renewable energy sources. However, some of those facilities in the Province of Manabí are located relatively far from the power consumption areas, causing an energy deficit in some electrical feeders when demand increases. The objective of the present study is to analyze the functioning of an electrical feeder when energy storage systems and photovoltaic systems are connected as a hybrid system. Two different software, CYME, and ArcGIS, were used to analyze the electrical power system in the province object of study and to design the simulation that showed better functioning of the electrical feeder when energy storage systems are connected than with connection to photovoltaic systems.

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1. INTRODUCTION

Nowadays, electrical energy is such a necessary factor for society that trying to find a solution to keep and increase stability in the electrical service has become a priority for entities related to that field [1], [2]. Energy store systems have improved the scope of the electrical service by using different kinds of technology for energy storage, solving problems occurring in the electrical service, and enhancing its stability. Nevertheless, more research works must be done concerning the behavior of energy storage systems when connected to electrical power systems because of its various advantages, like reduction of voltage peaks, energy disposal at any time, a decrease of greenhouse gases, better integration of renewable energy sources (RES), among others [3]-[5]. The function of a device for energy storage is to capture energy at a particular moment and to store it until its use is necessary [6]. According to [7], energy storage systems constitute special devices that store and generate energy through a chemical process to release the energy in the form of electrical current.

The way of getting electrical power stability when introducing distributed generation (DG) with RES is one of the essential themes that require further research work since systems using RES need special devices for energy storage, in correspondence to the characteristics of the place they will be located [8]-[10]. When storing the exceeding energy, the energy storage systems (ESS) can supply energy to the electrical network whenever necessary, giving, therefore, the possibility of satisfying the energy demand at every moment, even in case of sudden break-down in any electrical station or network, without causing a black-out [11]-[15].

Wu *et al.* [16] have concluded that ESS provides the required reliability, availability, and quality of electrical service. The objective and characteristics of a microgrid must be considered when selecting the corresponding ESS. According to [17], the generation of electrical energy using RES is expected to increase; however, once this technology reaches a certain level of penetration, it will be impossible for the electrical network to handle the variability and intermittency of the generation without ESS. Other kinds of disruptive events will also affect the electrical network, like extreme natural phenomena [18].

DG is significantly increasing in Latin America; in 2019-2020, a total power capacity of 4.4 GW was installed in the region. During the first ten months of 2022, the power capacity reached almost 67% in Brazil, with a DG of 14 GW, an amount which will become thrice by 2030, according to Americas Market Intelligence (AMI). The power capacity grew 28% in Chile up to mid-2022 [19], [20]. Due to DG's quick growth, finding alternatives for stability and quality of the electrical service has become a priority, mainly in zones with difficulties fulfilling the established norms to guarantee adequate energy supply [20], [21]. To solve those problems, the RES and ESS, located as microgrids, can play decisive roles [22], [23].

In Colombia, a transitory energetic process has been conducted, considering the cost policy of carbon neutrality [24]. Furthermore, renewable energy sources (RES) such as solar and wind power are foreseen to be fundamental for developing energy programs, where energy storage systems (ESS) like batteries or pumped hydro must be included to improve energy quality and reduce greenhouse gases [25]. In Ecuador, different studies about ESS have been carried out to supply energy at a specific period using optimum power flows [26]. Also, the advantage of the ESS for operating and planning the electrical power system has been the object of several research works [27].

Researchers have been actively working on improving electric power stability in specific parishes of the Manabí Province, Ecuador. Their focus has been on the practical application of photovoltaic systems to enhance the electric service in many houses located in rural zones, which are often far from the main energy generation or distribution systems [28]-[30]. The results of their work have outlined practical strategies, providing valuable insights into improving the service and introducing new forms of generation, such as microgrids or accumulation systems, to ensure a stable electricity supply. According to the previous analysis, the present study's objective is to compare the results of the electrical feeder behavior in the Chone Canton Province of Manabí. This province was chosen as the study area because of its importance in the region when ESS is implemented, and photovoltaic systems are used as DG systems through microgrids.

2. MATERIALS AND METHOD

CYME software [31], [32] was used for different simulations related to the object of study of the present work. ESS systems were introduced to compare their results when incorporating photovoltaic systems as generation sources. The qualitative and quantitative methods were also used. Additionally, the bibliographical review was used to know the state of the art when introducing ESS to improve the energy quality in the electrical service through microgrids. ESS strengthens the electrical system when it fulfills all criteria that can affect its adequate functioning. Figure 1 shows the different criteria considered when evaluating the electrical service. Those criteria allow facing, in real-time, problems in the transmission line, not all predicted by statistical models, and solving any breakdown without causing a blackout.

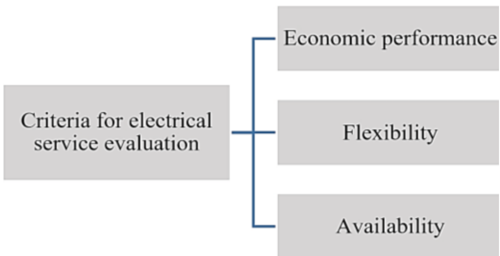


Figure 1. Criteria for electrical service evaluation [33]

Previous studies have evaluated the use of microgrids in the Manabi Province to improve the electrical supply quality in zones isolated from the transmission line [21], [22]. Results of some simulations done using CYME software [31], [32] showed that photovoltaic systems can be incorporated as DG to improve the electrical service quality in the mentioned province; furthermore, other research works have proposed including photovoltaic systems to decrease the energy demand during the morning period [33]-[36].

One of the limitations of the CYME software is that it requires accurate and detailed data on the network being modeled, such as equipment and load characteristics, which can be a challenge in poorly documented power grids. In our study, the grid operator provided the electrical data and parameters and the characteristics of the different equipment that make up the electrical system under study. In addition, CYME can have difficulties in simulating certain complex electrical phenomena, such as short-circuit dynamics in systems with a large amount of distributed generation. The analysis in our study considered the connection of the electrical feeder with the energy storage systems and the solar photovoltaic systems, so the CYME software presented no difficulties in the simulations carried out.

Finally, as CYME may need help integrating data from different formats or other software systems, which would complicate the workflow, ArcGIS software was used for geolocation and other geographic information data. In our paper, these two tools complement each other and create a synergy between electrical simulation and geospatial analysis.

In our study, to analyze the voltage stability in the transmission system, power flows were simulated by applying the Newton-Raphson method to determine the values of voltages, currents, and powers of the system [7], [9], [35]. To complement the study, the Newton-Raphson method was combined with the continuous power flow (CPF) method to obtain each system busbars' voltage stability curve. Finally, the mathematical model that allows the plotting of transmission line capacity curves is included to evaluate system collapse conditions due to the electrical power being transported or unacceptable voltage levels [35].

Considering the injection of power into a bus, for any i-th bus of the electrical power system (EPS), we have (1) and (2).

$$Pi = \sum_{j=1}^{n} Vi \; (G_{ij}\, Cos(\theta_{ij}) + B_{ij}\, Sin(\theta_{ij}))\, V \tag{1}$$

$$Qi = \sum_{j=1}^{n} Vi \; (G_{ij}\, Sin(\theta_{ij}) - B_{ij}\, Cos(\theta_{ij}))\, V \tag{2}$$

Where *P*: Active power of the load, W; *Q*: Reactive power of the load, kVAr; *G*: Electrical conductance of the line, S; *B*: Electrical susceptance, S; θ: phase angle.

The active and reactive power for any i-th bus of the electrical power system can be calculated using expressions (3) and (4). *G* refers to the generation parameter, and *D* refers to the electrical demand parameter. The (5) and (6) consider the variation parameter of the electric charge λ.

$$Pi = P_{Gi} - P_{Di} \tag{3}$$

$$Gi = Q_{Gi} - Q_{Di} \tag{4}$$

$$\Delta P = P^{specified} + \lambda P_D - P^{calculated} \tag{5}$$

$$\Delta Q = Q^{specified} + \lambda Q_D - Q^{calculated} \tag{6}$$

Substituting the above expressions into (5) and (6), the systems of equations becomes (7).

$$F(\theta, V, \lambda) = 0 \tag{7}$$

Where θ is the vector of voltage bus angles, V is the vector of bus voltage magnitudes, and λ is the load variation parameter.

3. RESULTS AND DISCUSSION

The load ability of the analyzed SEP is defined as the maximum power delivered to the transmission system's receiving terminal, expressed per unit of the surge impedance loading (SIL) of the line. The load ability of the SEP under analysis is defined as the maximum power delivered at the receiving terminal of the transmission system, expressed in units of SIL of the line. In other words, the load ability of the transmission line defines the power limit that can flow through the transmission line as a function of its length and other line parameters, such as resistance, reactance, thermal limit current, and operating voltage, among others [35], [36].

When analyzing the electrical feeder 2 of the Chone Canton, difficulties were observed that affected the poor quality of energy at different times. Using the geographic information system (GIS), it was possible to extract the elements of the electrical system involved, such as the substation, the sub-transmission lines, and the users. Figure 2 shows the location of the study area.

The Canton of Chone has 73.71% electricity coverage in dwellings, and 61.3% of its population resides in rural areas. The study area comprises 14 settlements and three parishes with a population of 67815 inhabitants and 16,971 dwellings, all connected to electrical feeder 2. Figure 3 shows the preliminary analysis carried out on feeder 2.

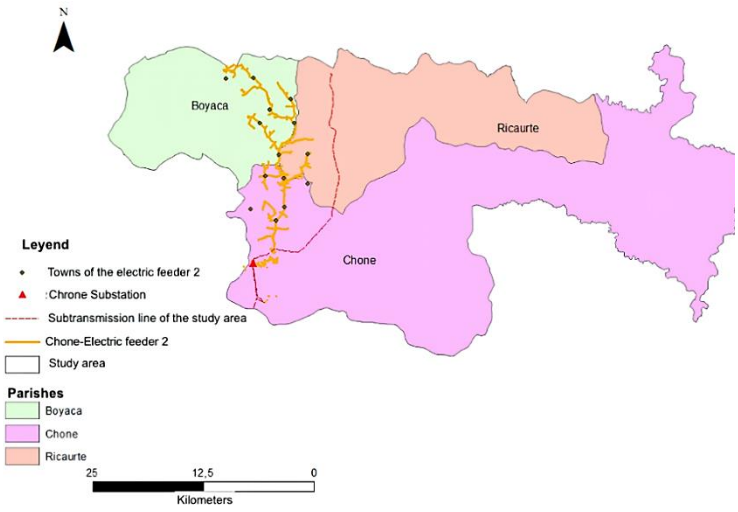


Figure 2. Location of the study area and the electrical feeder 2

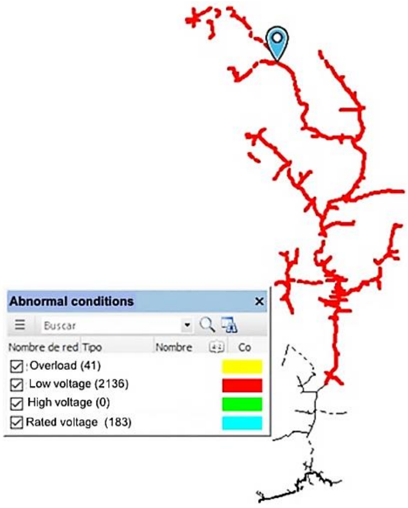


Figure 3. Current parameters of the electrical feeder 2

Bharati *et al.* [37] study the increase of dynamic loads and distributed energy resources (DER) in distribution networks that affect the performance of transmission systems using an unbalanced three-phase distribution network modeled in CYME with about 3000 nodes. Preview study [38], the power engineering software CYME is used together with a Python prototype to analyze the categories into which the existing phase identification methods are divided: hardware-based, real power-based, and voltage-based methods. To achieve the proposed objective, they evaluate the accuracy of six-phase identification algorithms based on power and voltage in four existing distribution systems.

Some authors have concluded that using RES plays a central role in electricity generation by increasing generation and their integration into the system [39]-[41]. Apart from the tremendous technological development with the use of new technology and artificial intelligence (AI) for energy transmission, generation, and distribution [42], [43]. Figure 4 shows one of the results obtained in electrical transmission lines from the Playa Prieta substation, which supplies energy to the Quebrada de Guillen in the Portoviejo Canton. It was observed that voltage and current levels improve when photovoltaic systems are included at different points on the electrical feeder.

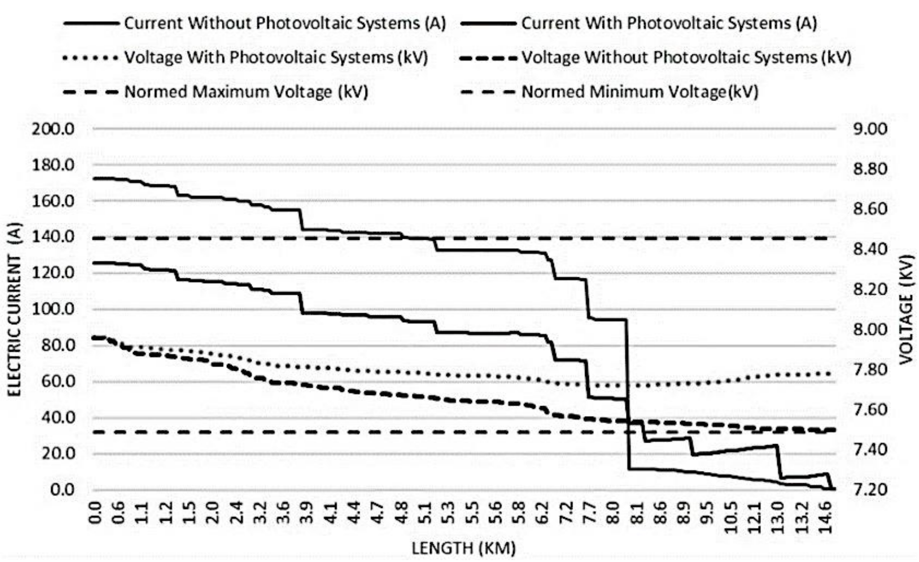


Figure 4. Voltage and current behavior with or without photovoltaic system

Results showed that photovoltaic systems used as DG can lead to electrical service stability when they are included at different points of the feeders that have had some difficulties. However, doing this is not economically possible for some entities because, apart from the cost of the system installation, the areas where they will be located are generally private. So, rent must be paid; consequently, those entities, as an alternative, prefer to value the ESS installation.

The CYME software was used to study the behavior of the electrical grid in feeder two at the Chone substation since good results had been obtained in previous studies with photovoltaic systems, as seen in Figure 5. It was observed that voltage behavior could be stabilized and maintained; simultaneously, the whole system stabilized, improving the voltage quality and allowing customers to receive a higher-quality service. The CYME software was also used to distribute ESS in feeder 2 of the Chone substation. That study aimed to improve voltage and current behavior by incorporating eight photovoltaic systems as DG at all lengths of feeder two and placing the ESS in 6 of the 8 points where the photovoltaic systems were located to be studied, as shown in Figure 6.

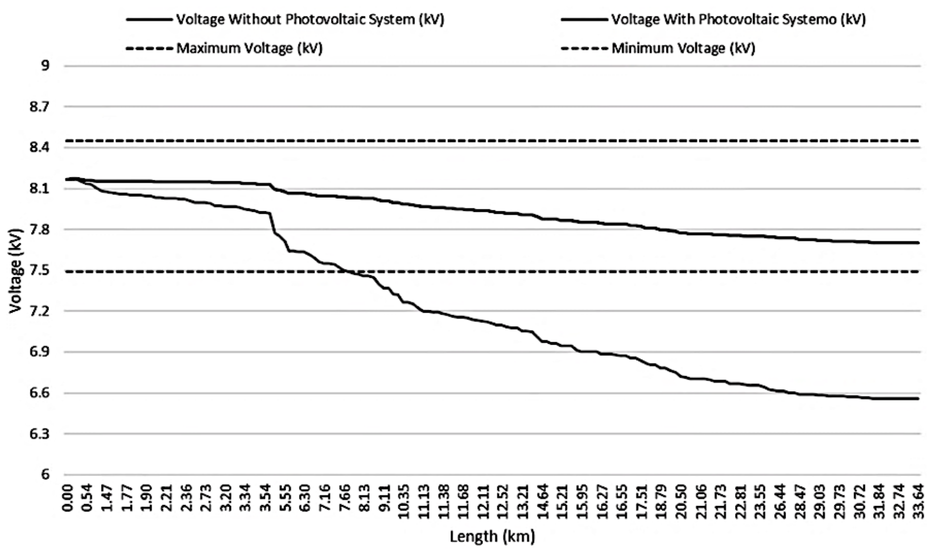


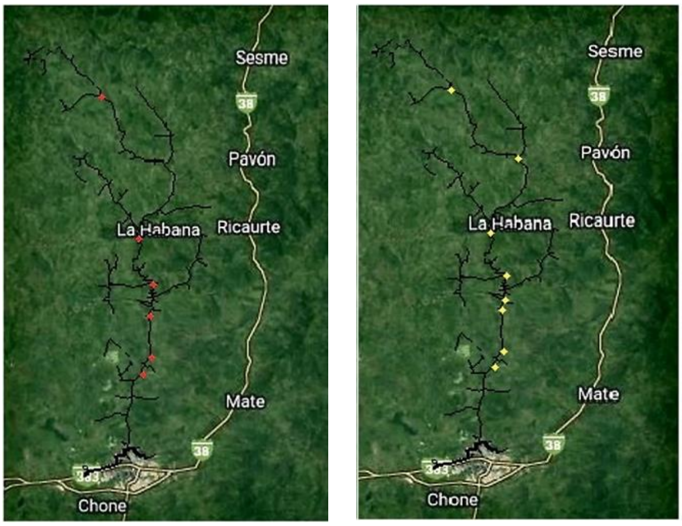
Figure 5. Voltage behavior in feeder two with and without photovoltaic system

Smaller available areas are needed for the installation of ESS than for photovoltaic systems. In the present study, 6 ESS were used instead of the eight photovoltaic systems required to improve the current and voltage behavior in feeder two of Chone, as shown in Figures 6(a) and 6(b). This means a significant economic saving for the energy distribution entity concerned with buying or renting the corresponding areas to install those systems. ESS is located at all lengths of feeder two in the following geographical coordinates: 601099, 9927936; 601597, 9929236; 601519, 9930923; 601725.92, 9932748.04; 600964, 9934974; 598923, and 9942540.

Each of the 6 ESS installed in feeder two of Chone has a storage battery capacity of 100 kWh, with a total of 600 kWh of stored energy, and substituting, in that way, the eight photovoltaic systems used to improve voltage level. Each photovoltaic system has a power capacity of 70 kWp, representing 560 kWp of DG at all feeder lengths. The currents were simulated with the 6 ESS installed in the 33 km long transmission line from the feeder to the farthest line point. Figure 7 shows the installation of an ESS in feeder two.

Figure 8 shows feeder two's nominal voltage and current behavior when the photovoltaic systems and ESS are included. The established maximum and minimum voltage levels for the DG system, which is ± 6%, are also shown in Figure 8 since those values can be stabilized with photovoltaic systems and ESS, whose corresponding graphs for voltage and current are very similar. As shown in Figure 8, when ESS with 100 kWh of storage capacity is included, the voltage behavior improves and reaches the values established in the operation of DG systems. In this way, it is possible to eliminate the poor quality of the power supplied to customers living in areas farther away from the feeder, demonstrating that ESS constitutes a real solution to power quality problems. In addition, the behavior of the electric current through the feeder shows that with both PV and ESS systems, current levels decrease compared to the system operating under current operating conditions, reaching a value of 123.76 A at the feeder's head.

However, 55.19 A is reached with photovoltaic systems and 51.89 A with ESS, with more than 50% reduction in both cases. Consequently, the supply capacity through conductors increases, allowing electric conductors of the minor cross-section to be used because the amount of electric current circulating through them is smaller. The reduction in current levels is due to the injection of active power at the different points of the feeder where the photovoltaic systems and ESS are installed, which leads to a change in the active power flow to other directions in the DG system so that the feeder is not injected with a significant amount of current.



(a) (b)

Figure 6. Geographical: (a) location of ESS and (b) photovoltaic system in feeder two of Chone

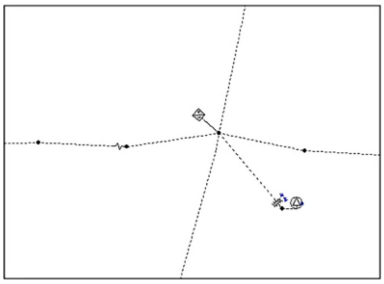


Figure 7. ESS installed in feeder 2

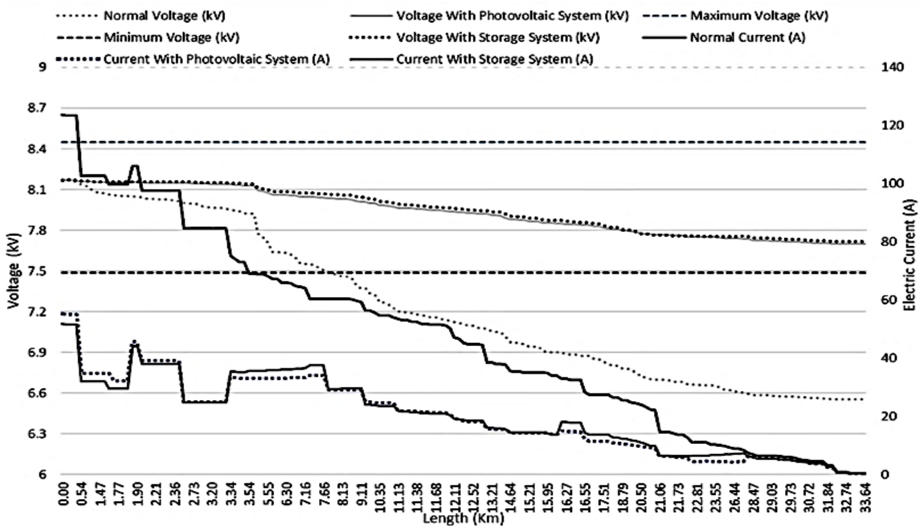


Figure 8. The behavior of nominal voltage and current with a photovoltaic system and ESS

4. CONCLUSION

Simulation in feeder two at Chone Canton, in Manabí Province, showed that with ESS, similar results are obtained than with photovoltaic systems, but occupying less space for its location since battery banks need less free space than the required by photovoltaic systems. Several ESS systems need to be installed at all feeder lengths, with only six systems with a supply capacity of 100 kW each. In comparison, eight photovoltaic systems of 70 kW are necessary for the voltage levels to be at the established ranges. ESS is more feasible to install than photovoltaic systems; only renting or buying the area for installation is necessary.

ESS is a natural solution to improve the quality and stability of the energy power supplied to customers, no matter how far they live from the electrical facilities. ESS also improves the voltage and current behavior, decreasing the current levels at all lengths of DG systems. Whenever the technology with photovoltaic systems or any other renewable energy source is not feasible, ESS can always be used.

The paper demonstrates that an ESS can store energy when demand is low and release it when demand is high, improving feeder stability and management. In addition, ESSs smooth the load, avoiding voltage peaks that can affect the feeder infrastructure, resulting in better operational performance. Finally, it is demonstrated that when combined with ESS, PV systems can operate more efficiently, mainly because batteries can manage the intermittency of solar generation. Therefore, a feeder combining storage systems can provide continuity of power supply, especially during high demand or unfavorable weather conditions.

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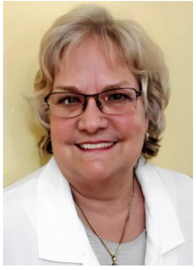

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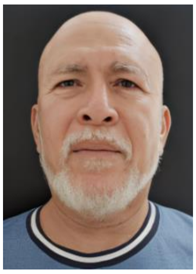

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