Challenges of Storage in Large Power Systems

Desafíos del Almacenamiento en Grandes Sistemas de Potencia

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Keywords

Power system planning; voltage stability; energy storage; voltage control; BEES.

Abstract

Fossil fuel-based electric generation is a major contributor to air pollution in the world. In this regard, storage is viable, especially if it is combined with solar energy and wind generation. Storage also represents a significant challenge for the traditional criteria for planning the power system, which is generated with hydro and non-renewable generation as it is in Central America. This article reviews topics such as loadability, frequency regulation, control, stability, economic issues, reliability, harmonics, and power quality and resilience applied to power systems using storage. It presents a ETAP simulation to analyze voltage profiles considering storage for the El Salvador Power System (ESPS). The result significantly contributes to enhancing the voltage profiles and voltage regulation after failure. Opportunities also arise when storage is considered potential ancillary service providers that can help to stabilize the grid under a faulty situation or mitigate the power generation variability of non-traditional renewable power sources such as wind and solar energy in Central America Power System. The present paper provides an overview of the significant challenges of storage to large power systems.

Palabras clave

Planificación del sistema de potencia; estabilidad de tensión; almacenamiento de energía; control de tensión, BEES.

Resumen

La generación eléctrica basada en combustibles fósiles contribuye a la contaminación del aire en el mundo. En este sentido, el almacenamiento proporciona una posibilidad de reducir las emisiones especialmente si se combina con la energía solar y la generación eólica. El almacenamiento también representa un gran desafío para los criterios tradicionales de planificación del sistema eléctrico, que se genera con generación hidroeléctrica y no renovable como es el caso de Centroamérica. Este artículo revisa la literatura sobre la cargabilidad, regulación y control de frecuencia, estabilidad, aspectos económicos, confiabilidad, armónicos, calidad y resiliencia de la energía aplicada a los sistemas de energía. Presenta una simulación usando ETAP para analizar perfiles de tensión considerando el almacenamiento para el Sistema Eléctrico de El Salvador (ESPS). El resultado muestra una contribución significativa para mejorar los perfiles de tensión y la regulación posterior a una falla. También se identifican oportunidades para el almacenamiento se considera como posibles proveedores de servicios auxiliares que pueden ayudar a estabilizar la red en situaciones de falla o mitigar la variabilidad de generación de energía de fuentes de energía renovables no tradicionales como la energía eólica y solar en el Sistema Eléctrico de Centroamérica. El presente documento proporciona una descripción general de los principales desafíos del almacenamiento para los grandes sistemas de energía.

Introduction

Mass utilization of storage serves as an excellent opportunity to reduce air pollution. However, it also represents a challenge to increase the penetration of renewable generation like wind, PV, and marine energy sources. Storage can use electric vehicle batteries in two conditions: vehicle or batteries to grid (x2G) or grid to vehicle or batteries (G2x). The first condition can provide the stored electric power to the power grid, and the second condition consumes electric energy from the grid. If storage interaction to the grid is intelligently managed, it could alleviate the intrinsic power generation variability of non-traditional renewable energy sources, which are substituting more expensive and pollutant power plants. For instance, if batteries are fully charged, they could supply active and reactive power in case of disturbances, and therefore, opportunities arise to enhance voltage, unbalance compensation, frequency regulation, and stability, among others. Several authors have analyzed the impact of EVs on the medium voltage power grid.

Take, for instance, the work of [1-3], where different aspects of the interaction of EV with the distribution grid are analyzed. The analysis in power system transmission is an opportunity to study electric vehicles EVs' interaction with other elements as intermittent and non-intermittent generation and storage. Similarly, long storage can use in Battery Energy Storage System (BESS), and investigation must focus on transmission and distribution planning to analyze the impact on the power grid. In addition, there are issues like resilience services, renewable generation penetration, deferring infrastructure additions, and increasing infrastructure utilization in ancillary services [17].

Nowadays, economic issues are considered to make decisions and give the most use of the transmission and distribution grid. Incorporating storage can support the stability as proposed by Du et al. [25] or enhance the intermittency generation as Gaunt analyzes in [22], whatever case it is necessary to consider the cost-benefit analysis [18]. Is it possible to increase the renewable generation penetration as wind, marine, and PV in combination with storage to delay the grid investment maintaining low cost, the operation and reliability conditions in a resilience power grid?

The present paper analyses the main challenges and opportunities of storage integration in the power system and shows the benefits of its use. Section 2 makes a review of the central literature. Later, the main techniques used for improving the power system's conditions are presented. Section 4 and 5 analyze a case study of El Salvador power grid and discussion. Finally, the main challenges of storage integrating with large power systems are listed.

Literature Review

Loadability refers to the transformer and transmission line capability under operating conditions. Mass storage integration in G2x or x2G conditions or loads can affect loadability in large power systems. Nevertheless, storage can reduce loadability if collocated in distributed generation and not in concentrated generation. Storage can be the way to reduce transmission congestion and increase capacities and behavior voltage regulation [17,23]. To determine the limits of the power system element, a suitable and accurate load model for electric vehicles batteries of storage is required. For instance, hybrid vehicles have been modeled as loads of constant power demand, constant current demand, and constant impedance demand [4]. The load model of EV is essential when analyzing large power system, given that constant current demand (I) yield instabilities. At the same time, constant power demand may permit higher penetration in the power system [9].

The huge loadability can produce problems in frequency behavior, stability, voltage regulation. For this reason, the biggest challenge is to establish a model with adequate precision because it requires real analysis in the power grid. Intermittent generation, EVs penetration could establish the need for maximum regulation of generators. Additionally, distributed grid requires Automatic Generation Controller to improve frequency regulation considering intermittent and non-intermittent generation [5,8]. Control schemes to improve the stability with EV penetration due to the various loading and unloading cycles [6] have been a solution in small grids. Nonetheless, Automatic Voltage Regulator (AVR) and Governors could supply voltage and frequency regulation if their setting responds adequately in large power systems for short and mid-term disturbances. On the other hand, Qazi proposes a power system frequency regulation using hybrid storage [20] as a supercapacitor. However, nowadays, considering the EVs to enhance the grid conditions is not possible due to the economic implications, as indicated by Sharma in [21] when analyzing BEES to provide support services.

The impact of EVs' batteries on distribution networks has been studied in x2G condition [1]; the emphasis has been on developing and establishing a mathematical model for evaluating voltage stability. Traditionally, faults are modeled to analyze transient and voltage stability with defined penetration [6]. Eigenvalue analysis has been calculated in oscillatory conditions [7]. Transient voltage stability of micro and isolated networks has been analyzed with criteria of equal areas.

Notwithstanding, sizable EVs' batteries penetration must study in real conditions (transmission grids) to a large power system because control and regulation and loadability combination is primordial, especially if the power system has intermittent generation. Therefore, EVs integration has been considered into power system and the technical operation is analyzed in [8] where some benefits and impacts are discussed.

The administration of energy is an interesting option to manage EVs' charging. This topic presents high opportunities if the management of storage and EVs [8] could be quantified and establish energy sales rates. Finally, the way must focus on using storage in reliability and resilience enhancement [17] and allow a lot of renewable energy penetration [19,24] to support power systems.

Gómez et al. [27] propose the integration of storage in Central American Power Grid to take advantage of generation exceeds. Storage is a real opportunity to reduce the Fossil fuel-based electric generation of the region. The Central American generation is mainly based on hydro generation (39.6%), and the non-Renewable generation is 33.96%, which can potentially be replaced with storage. The other 25% of the power mix is wind, solar and geothermal energies [26]. Therefore, there is an opportunity to use the storage to improve the power system's conditions, stability, and security if the management is suitable and appropriate. In this way, the biggest hydropower plants can contribute to the power regulation to permit a considerable penetration of wind and solar energy combined with storage.

Techniques to enhance power system conditions

Nowadays, technology is producing faster chargers, which has an essential impact on loadability. Stability conditions can be affected if the relationship between demand and generation is broken. Similarly, discharge's use state (x2G conditions) could improve the power stability if planned appropriately.

Power system condition and operation improvement

Storage can support the power stability in the discharge state, and for example, Figure 1 shows the power contribution of discharge conditions according to the battery's type. Depending on the disturbance, discharge time could improve the stability if power systems' planners make good decisions in its use, e.g., strategic installations in diverse points of power system because the disturbance should be studied and valued previously. Thus, active power support in emergency conditions. Another issue to consider after disturbance is the resilience of the power system.

In a small-signal stability problem, it is necessary to identify factors that influence it and the adjustment of AVR, Power System Stabilizer (PSS), and power system controls to increase the damping torque of generators. Local or global oscillations yield the situations mentioned above. Nevertheless, some changes of generation and load can be compensated for storage station because Li-ion batteries can discharge in a few minutes, and storage can supply active power in small disturbances. Therefore, storage can be an essential option to reduce disturbances in the power grid transient stability.

Before the loss of generation, large load, line transmission, power batteries can maintain synchronism in several conditions. This disturbance can produce an angular separation between machines that can consider 2 to 3 seconds after disturbance and depending on time e.g. short, mid, or long term. At this time, storage will supply the power required in discharge condition. Li-ion and flows batteries can dovetail to requirement. Frequency stability can be affected by changes in unbalance of demand and generation. Contingency conditions as a lost generation, batteries can supply power in minutes while grid reconfigures and reestablish it after disturbance. In this case, it is necessary to have a fast mechanism to transfer power to the grid not to affect operating conditions.

On the other hand, if a high penetration (G2x conditions) occurs in the short term, the power system can be affected in frequency stability, especially in x2G conditions. Voltage stability should be studied since it is a local problem in charging conditions. EVs' loadability must review, and its management could involve reactive compensation. The main problems with using batteries are time and cycles of discharge and charge because it reduces the lifetime of the batteries based on previous facts. Cost opportunities linked to maintaining stability are elevated. Researchers have an exciting field to analyze and study these issues and establish economic compensations and remunerations to batteries' owners.

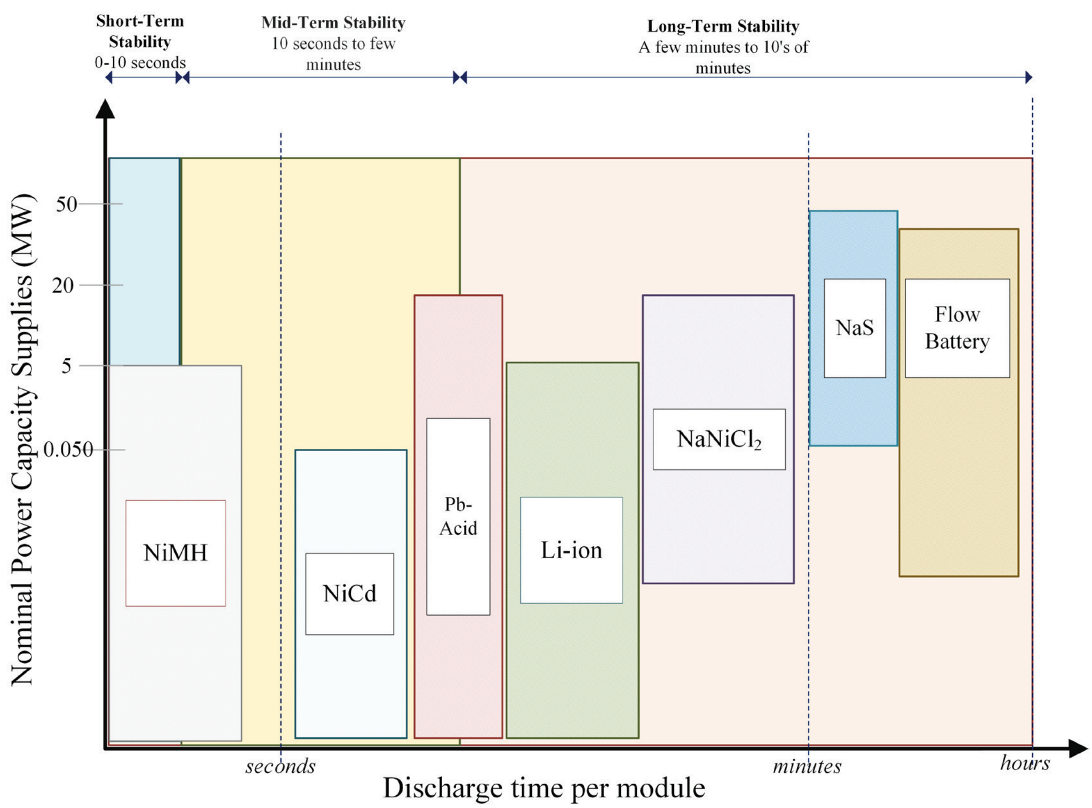

Figure 1. Different types of storages based on [20,13,16,15].

Load-Generation conditions improvement

Renewable intermittent is gaining ground in power grids, and it is replacing in a significant way the non-renewable energy as shown in figure 2. Renewable non-intermittent energy is constant because projects are built, and large power generators enhance stability conditions, especially in hydro generation (salient pole rotor construction). Renewable intermittent energy could require storage (back-up state) if existing intermittent conditions. Storage (massive penetration and generation conditions) could maintain operating states in disturbances conditions.

To safeguard the power system is the most crucial priority because the operator must maintain the power operating equilibrium under contingency operating conditions. An investigation must analyze and simulate non-renewable, intermittent, and non-intermittent generation conditions, including load and generation conditions for storage penetration in the real power systems case. Shimizukawa propose storage to mitigation of intermittency in a generation [24], and Weihua research about control strategy with storage [23].

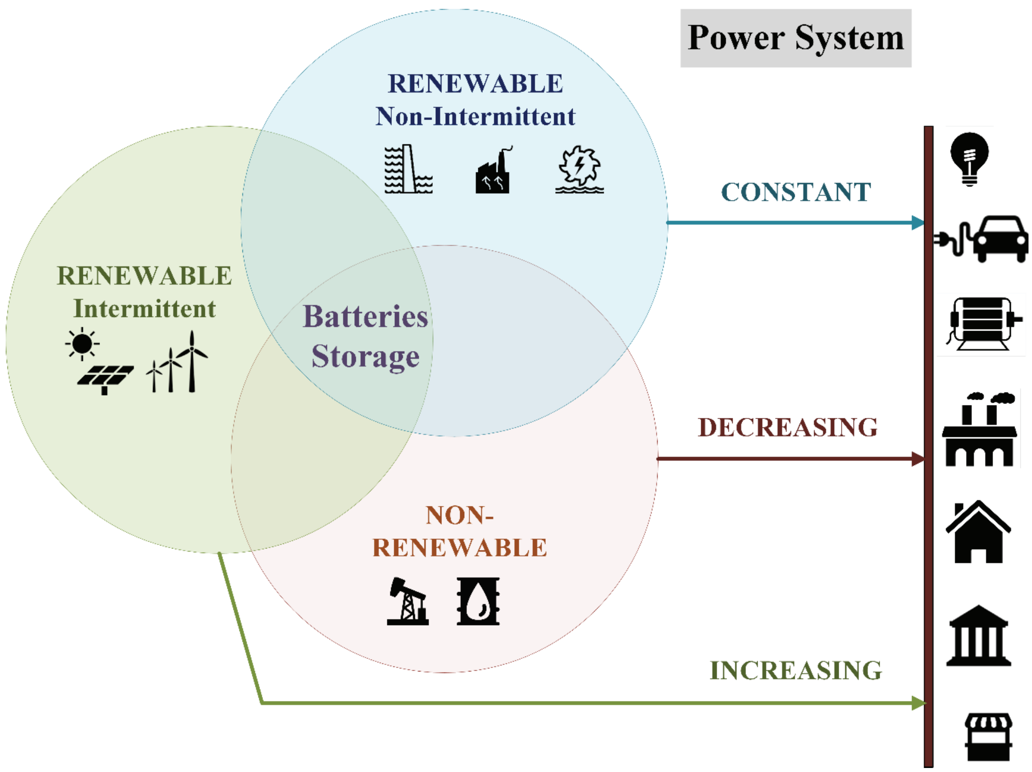

Figure 2. Future generation in power systems.

Case of study

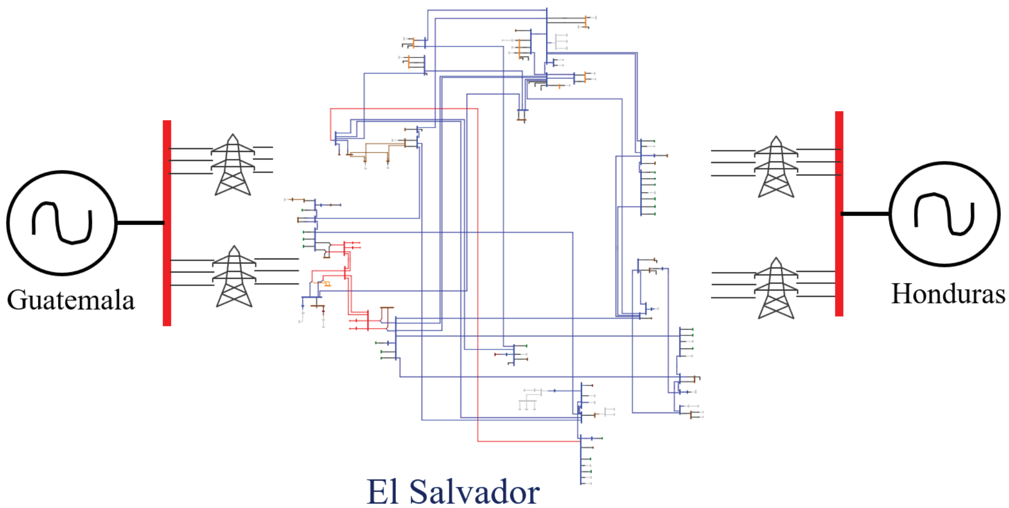

Figure 3. EPS simulated using ETAP.

The El Salvador Power System (ESPS) is inside Central America Electrical Market. México, Guatemala, Honduras, Nicaragua, Costa Rica, and Panama are also members, and the countries are joined with a 230 kV line transmission. The maximum demand for ESPS was 1,044 MW, and the generation was 5,672 GWh in 2019. Renewable generation represents 69.81%, whereas Hydro is 26.84%. Losses in the transmission and distribution grid are around 13.5%. Typical voltages are 230, 115, and 69 kV in transmission and 13.8, 23, 34.5, and 46 kV in the distribution grid. There are about 6315 MVA installed in power transformers, and they have the second electricity penetration with 96.7% in 6.48 million people [26].

ESPS has four international interconnections with Honduras and Guatemala in 230 kV. Figure 3 shows El Salvador Power System modeled using ETAP (Electrical Transient Analyzer Program). If it considerate the historical transactions (energy imports and exports) within the Electrical Market of Central America, El Salvador has imported about 8458.6 GWh from 2014 to 2019, as shown in table 1. On average, ESPS requires installing storage in 131 MW. This storage can be administrated so that the renewable generation supplies the energy to use. Guatemala will come out of the Central American Electric Market in 2031, and storage can be an alternative to maintain operation and reliability. Thus, this condition will be simulated to improve the voltage regulation in ESPS.

Table 1. Historical Transactions.

Year	Imp GWh	Exp GWh	Potential Storage MW
2014	618.8	238.0	43.47
2015	981.4	82.2	102.64
2016	1212.2	224.0	112.80
2017	1729.1	143.8	180.97
2018	1968.3	209.1	200.82
2019	1948.8	656.7	147.5

Based in [26].

Scenario Simulated and results

A study transient stability analysis was simulated in winter scenarios. CENCE-ICE provided the information. Winter conditions are rainy; therefore, plant dispatches, especially renewable generation, and power flow change significantly in the region. Nevertheless, ESPS requires non-renewables generation to supply the energy necessities o to import energy from Guatemala, Costa Rica, or Panama. A single-phase fault in the transmission line was simulated between the buses 27171-27371 (Cerrón Grande Power Plant - Nejapa Power Plant in 115 kV) using ETAP. Before fault, the transmission line carries 94.6 MW. Single-phase failures represent 80% of the events in transmission systems due to overvoltage of external or internal origin, insulation failures due to humidity and corrosion, mechanical failures such as ruptured conductors, and animals on the line. For this reason, this simulation corresponds to a current event in the normal operation in power systems.

Due to short circuit failure (0.2s), the scenario simulated consists of a trip-in-line transmission (0.9s), and two cases were analyzed: without and with storage. In the case without storage, buses of 230 and 115 kV maintain high voltage levels during analysis. Later, in some cases, the voltage does not stabilize, while ESPS with storage shows safety conditions of operation. In this case, storage is used to improve the voltage profiles via energy storage from five sources into ESPS total 100 MW power storage. Previously it was shown that around 131 MW is required in storage. Storage is based on Li-Ion commercial batteries with a voltage of 799.2 VDC/480 VAC and a capacity of 2226 Ah. An energy storage management can control the balance of power and power flows into the grid for disturbance conditions. The storage must be collocated strategically in the grid.

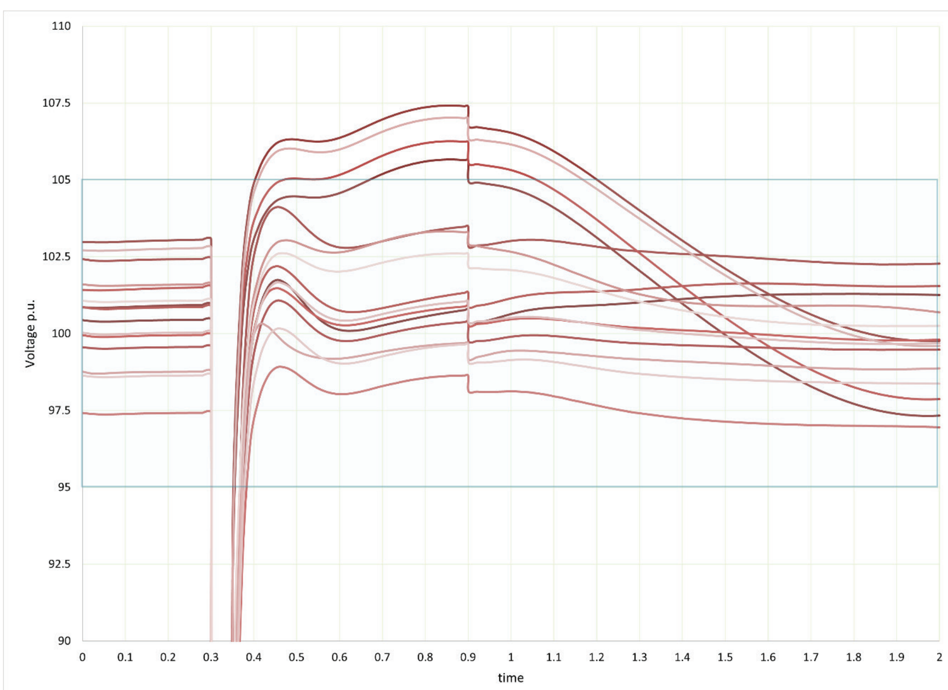

Figure 4. Failure simulated with storage.

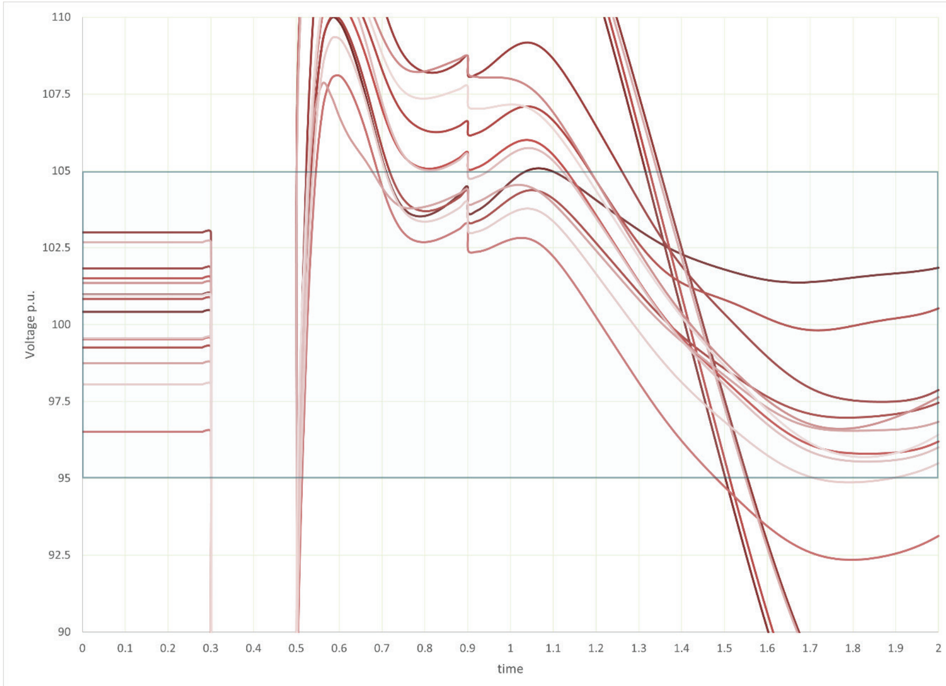

Figure 5. Failure simulated without storage.

Discussion

Figure 4 shows the ESPS modeled with five storage stations of 20 MW into the grid. The fault causes low voltage in most power system buses, as shown in figure 5. Some buses do not stabilize after 2 seconds, but the storage can enhance after disturbance. In both cases, voltage is elevated while a fault is present; however, storage contributes to voltage stability and regulation. The main problem is the vulnerability because when there is a huge generation of south (Panamá and Costa Rica) o North (Guatemala and México), and it produces an unbalanced condition of power, the disturbance can induce a blackout in the region, especially if it is not counted of high inertia in the generation.

The region has installed about 3129 MW in power plants larger than 100MW, contributing to power regulation of voltage or frequency. Nevertheless, problems associated with climate change have diminished generation capacities. High hydropower plants can integrate other renewable generation alternatives like wind, solar and marine generation using storage as a complement to minimize the variability of these sources.

Finally, as previously mentioned, Guatemala will come out of the Central American Electric Market. Therefore, the power planning of generation must focus on integrating non-traditional sources like wind, solar, and marine in combination with storage to reduce the impact of variability. This generation represented only 13 % in 2019. In addition, the growth must go hand in hand with transmission expansion to avoid voltage regulation and loadability problems.

Challenges

Storage brings new challenges and opportunities to power planning and operating; mainly, if its penetration is massive (x2G or G2x conditions). The main problems will affect power systems because power grids were not developed with actual necessities (especially in the transportation sector). Therefore, it is necessary to understand the behavior of load when it considers the effect of load in frequency and voltage. Depending on the model used in load, it could obtain different results. The storage model will be challenging to research because day-to-day technology expands in range applications in size and scale [17, 14].

High penetration modeling will be an opportunity to develop knowledge in EVs' penetration behavior and planning or operating transmission and distribution grids strategies to maintain reliability. Real cases must be analyzed, and investigation could simulate existing situations, e.g., in massive penetration conditions with renewable generation, to evaluate multiple responses in small-signal, frequency, voltage, and transient stability. Some frequency control strategies [10] can be an exciting option to improve instabilities and develop control strategies to understate the impact of disturbance in the power system.

EVs penetration could produce harmonic pollution, mainly in distribution grids [10,3]. Nevertheless, current research must pay attention to power transmission, and the investigation should consider the effect of solar and wind penetration with storage [22]. Operation cost must be considered [18,12] for establishing conditions to storage penetration on the power system. Issues such as massive power installations with high working voltage are necessary to integrate storage into the grid and establish a new business in topics, especially ancillary services. Their use could delay investment times if distributed integration can be identified in transmission and distribution planning. Opportunities to reduce electricity costs can be studied.

Conclusions

Storage penetration presents challenges and opportunities in power systems applications. Future research should continue to simulate conditions with storage penetration and propose suitable solutions in the future. If loadability is analyzed, stability and harmonics studies could be essential to understand the impact on the grid. The economy and the power market will be the most significant challenges to customers and power system operators. Further analysis must consider high demand conditions to establish penetration limits. Storage can improve the operation under instability conditions and disturbances, but this issue could be costly.

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