Optimal placement of energy storage system in hybrid AC/DC microgrid to enhance stability

Pagidela Yamuna, N. Visali
Department of Electrical and Electronics Engineering, JNTUA College of Engineering, Ananthapuramu, India

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ABSTRACT

Nowadays, growing interest in sustainable energy solutions, hybrid AC/DC microgrids are becoming more and more recognized as a reliable and efficient option. In order to improve the stability of such microgrids advanced solutions for ESS placement are required due to the unpredictable nature of renewable energy sources and the complexity of load needs. The precision needed to maximize microgrid stability in the face of these obstacles is lacking. In this paper, an artificial neural networks (ANN)-based framework for the strategic allocation and sizing of ESS is proposed. This study uses ANN and the process is to determine the best locations and capacities for energy storage systems (ESS) to minimize system losses while accounting for variations in renewable generating and demand profiles. Simulation is carried on IEEE 12 bus system for studying the usefulness of the proposed method and stability is determined. The power flow datasets generated through simulation are utilized to train the ANN in order to determine the most appropriate placements for ESS. Furthermore, a series of simulations were performed to examine the impact of ESS characteristics on the performance of system loss under various circumstances.

Corresponding Author:

Pagidela Yamuna
Department of Electrical and Electronics Engineering, JNTUA College of Engineering
Ananthapuramu, India
Email: yamuna.pagidela@gmail.com

1. INTRODUCTION

Recently, renewable energy systems (RES) offer a greener technology that can meet the increasing needs of isolated and networked communities for electricity [1]-[3]. As a potential replacement for conventional energy systems in the future, MGs have drawn a lot of interest from the scientific community in recent years. A potential technological solution for integrating variable renewable energy systems into the conventional grid is the use of microgrids (MGs) [4]. These days, MG is being used in various applications, particularly in the creation of controllers and electronic energy converters, thanks to the advent of new digital technologies [5] like micro-processed systems and advancements in power electronics.

One of the most crucial areas of this research is the optimal placement of energy storage systems (ESS) in the hybrid AC/DC microgrid in order to address these issues. Carefully locating and scaling ESS can lower system losses [6] and improve the overall performance of the microgrid, especially in scenarios where a significant proportion of renewable energy sources are used. In literature survey, several studies have been conducted to address the challenges associated with the operation and control of hybrid AC/DC microgrids, optimal coordination, and energy management system. Researchers have proposed various techniques for power flow management, voltage regulation, and optimal energy management in these microgrids. i.e., a dual-storage, grid-tied microgrid can have its operation schedule by Mousa *et.al* [7], and facility sizing optimized by Murugan *et al.* [8], also authors such as Sattarpour and Tousi [9] study aims to determine the optimal battery energy system (BES) sizing and placement in the context of stochastic renewable power generation by in order to reduce total investment and operating costs by Zhang *et al.* [10] while taking energy savings provided by CVR into consideration and meeting system operational limits by Muzzammel *et al.* study [11], Han and Zhang [12].

Iria *et al.* [13] proposed structure, the scenario tree method addresses the existing ambiguities in the distribution network's load demand and distributed generation (DG). Alzahrani *et al.* [14] looked at the effect of ESS utilization on energy generating costs in networks over a specific amount of time. Nevertheless, the adoption of non-dispatchable DGs such as photovoltaic (PV) plants has been hindered by irregularities in the timing of energy supply and demand in distribution networks, as stated by Das *et al.* [15]. On an IEEE 33 bus system, the methodology outlined by previous authors [16]-[20] has been validated and tested. In an attempt to reduce waste and increase utility profitability, battery energy storage systems (BESSs) are now being considered for power systems that include solar power systems. In solar farms, authors [21]-[25] has proposed that BESSs are usually mounted on buses to allow for the quick storage of extra solar power and to reduce transmission line losses.

While a number of elements of hybrid AC/DC microgrids have been studied in the past [26], [27], little attention has been paid to where ESS should be placed in order to maximize these microgrids' stability and reliability. However, adding renewable energy sources, like solar photovoltaics, into the system creates variability and intermittency in the generation profile, which can cause instability problems and higher system losses in the past. In order to minimize system losses and take into account variations in renewable generation and demand profiles, an optimization problem is constructed to identify the optimal locations and capacities for ESS.

2. OPTIMAL PLACEMENT OF BATTERY ENERGY STORAGE SYSTEM USING ANN

The proposed three-phase archetype is explained in detail in this section. The MATLAB/Simulink environment's equivalent Simscape library was used for modeling it. The objective is to give the scientific community a tool and a deeper comprehension of the dynamics of MG and all of its constituent parts, as well as their collective capabilities.

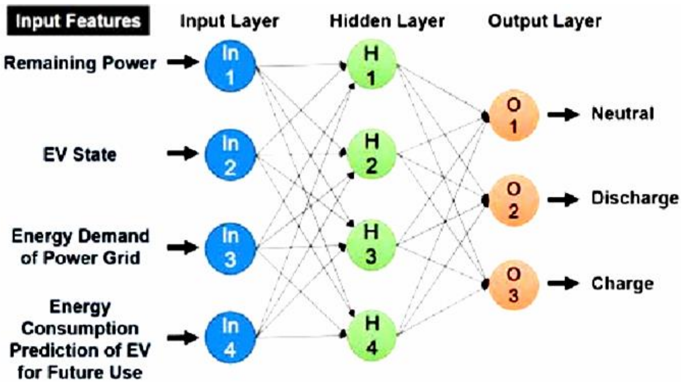


Figure 1. Energy storage system with NN

The proposed objective function prioritized 12 buses in total, excluding the real slack bus that was already connected to an ESS as depicted in Figure 1. Figures 2 and 3 presents a suggested model. The defined objective function indicated that bus-8 was the ideal location for a new ESS installation, and that 0.186437 MW was the ideal ESS size. However, bus-1 was the least suitable location for a new ESS installation. The biggest difference between bus-1 and bus-8 was that bus 8's SP_{ESS} value was significantly larger than bus 1's. There is no significant difference in the SP_{ESS} values between both positions. This indicates that the reaction to changes in all loads was not significantly different; nonetheless, bus 1 needs an ESS with an unreasonably high capacity in order to operate in the voltage management system (VMS) for a single load change.

The proposed potential location is continuously subjected to hourly BESS sizing optimization. The following are the procedures:

a. Simulink is used to represent the artificial neural networks or ANN distribution network and BESS.
b. An initialized IEEE 12 bus system indicating potential BESS locations is in place.
c. Stored are the recommended BESS allocations in power flow to be used.

d. Using the recommended locations from step (c), the BESS sizing optimization process is started during the first hour of the time period.
e. Buses are initialized to represent potential BESS sizing.
f. The ramp rate for net load is monitored and kept within the ramp.
g. The Loads h offer the suggested locations and sizing for the power flow, which is run in Simulink.
h. The data obtained from the power flow is then used to evaluate the performance using the objective function, or ObjF.
i. New parameters and optimal bus locations for BESS size have been revised.
j. Up until the allotted number of iterations was reached, repeat the optimization procedure from steps (f) to (i).
k. Stored is the recommended ideal sizing along with the matching BESS locations found in step (c). Repeated steps (e) through (j).
l. Updates are made to parameters and the bus location positions for BESS. Until the allotted maximum number of iterations is reached, the optimization procedure from steps (c) through (l) is repeated.

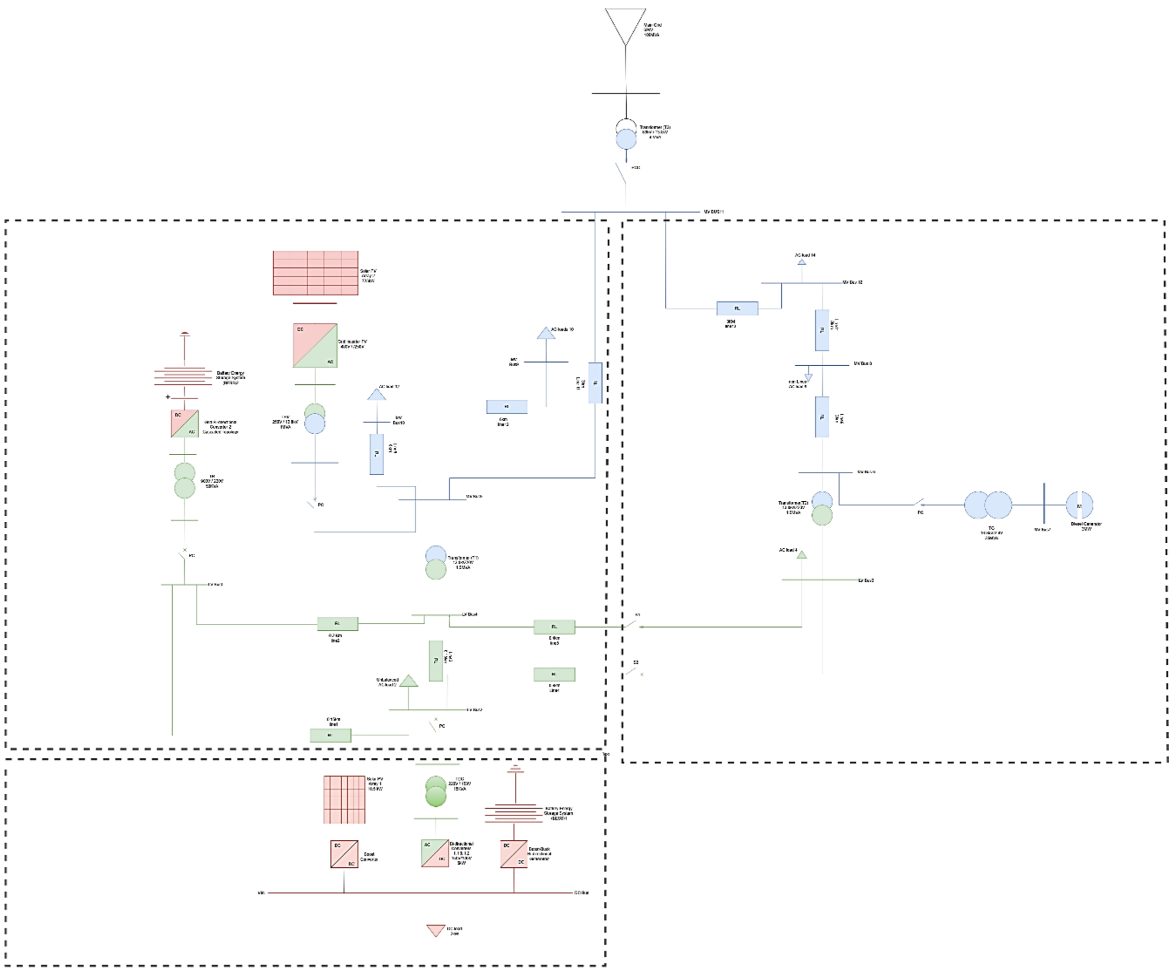


Figure 2. Proposed method

The DC microgrids (DCMG) bus functions in two opposing scenarios: a max demand state and a minimal demand scenario. The PV1 system may pathway the maximum power point (MPPT) in the first working mode (max demand). As a result, the ACMG serves as an energy storage device with a specific capacity. When the PV-1 system is operating in the second mode, or lowest amount demand, no power is generated. As a result, power flow from the ACMG#2 to the DCMG is controlled by the bidirectional AC/DC VSC connection, which enables energy storage and supplies the load in the BESS#1 for DC system.

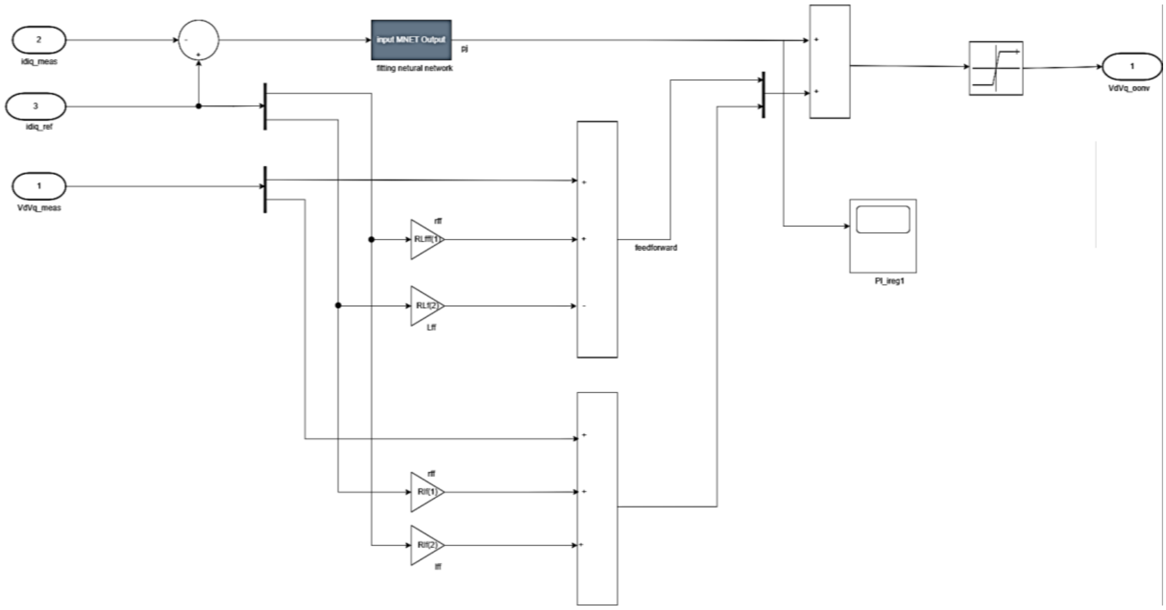


Figure 3. Proposed ANN

3. RESULTS AND DISCUSSION

The provided consequences are examined in this section, along with the establishment of measurements for the power's efficiency and quality factors. Two analysis scenarios are defined in order to calculate metrics that enable the definition of a base case for upcoming optimization and recompense investigations. An inverter converts 480 VDC to 250 VAC for the second solar PV array linked to AC 13.9 kV. Transformer connects MG primary distribution to AC inverter. The converter is a three-level PWM-controlled IGBT bridge. Concurrent closed-loop control uses 1983 Hz PWM carrier frequency.

For the recently installed ESS, the optimal size and installation location were determined by the suggested method. Voltage stability at the site of the ESS installation was verified when each load connected to the microgrid was progressively increased and then decreased. The voltage stability with the ESS sized ideally was compared to the situations where the ESS was installed at the lower priority location and the case when the ESS was positioned at the ideal placement, all in accordance with the defined objective function. the priorities for each placement were compiled in order to install a new ESS in the microgrid. Because of this significant difference between the two situations, a realistic study for reactive power compensation in the future may be built. Considering the minimum demand scenario, the position and capacity of compensating devices must be determined. The compensatory strategy's reactive insertion may cause overvoltage in the system. Approximately 25% of the daily total demand is the minimal demand of the anticipated system. When determining the overall reactive power of the system, the analogous link between the active power demands was taken into account as shown in Tables 1 and 2.

Table 1. Maximum demand load flow outcome

Bus *i*	Type	P_g (kW)	Q_g (kVAr)	P_l (kW)	Q_l (kVAr)	Ptransf (kW)	Q_{transf} (kVAr)	V (pu)	δ (°)
LV 1	BESS 2	43.66	30.45	-	-	-	-	0.935	-29.75
LV 2	TransferBus	-	-	64.72	40.11	62.6	43.86	0.925	-31.19
LV 3	TransferBus	-	-	-	-	120.66	84.61	0.949	-31.4
LV 4	TransferBus	-	-	-	-	34.73	58.77	0.953	-31.29
MV 5	TransferBus	-	-	-	-	780	1095	0.964	-30.32
MV 6	TransferBus	-	-	-	-	554.6	356.2	0.969	-30.71
MV 7	Diesel	690	450	0	0	-	-	0.973	-60.83
MV 8	Non-linearLoad	-	-	327.3	38.23	-	-	0.964	-30.66
MV 9	-	0	0	572.4	427.2	-	-	0.939	-29.79
MV 10	-	-	-	586.2	439.8	-	-	0.949	-30.09
MV 11	SlackBus	1810.2	1665	0	0	-	-	0.973	-30.65
MV 12	TransferBus	-	-	119.61	89.7	226.02	397.2	0.968	-30.57
DC	DC Bus	-	-	-	-	8	0	0.931	0

Table 2. Minimum demand load flow outcome

Bus	Type	P_g (kW)	Q_g (kVAr)	P_l (kW)	Q_l (kVAr)	Ptransf (kW)	Q_{transf} (kVAr)	V (pu)	δ (°)
LV 1	BESS2	27.6	15.75	-	-	-	-	0.9567	-31.17
LV 2	TransferBus	-	-	21.1	13.09	25.47	14.43	0.967	-31.17
LV 3	TransferBus	-	-	-	-	50.3	25.74	0.979	-31.17
LV 4	TransferBus	-	-	-	-	51	26.79	0.983	-31.21
MV 5	TransferBus	-	-	-	-	471.2	346.1	0.980	-30.30
MV 6	TransferBus	-	-	-	-	89	84.4	0.98	-30.15
MV 7	Diesel	150.1	49	0	0	-	-	0.98	-60.19
MV 8	Non-linearLoad	-	-	110.2	0.69	-	-	0.98	-30.25
MV 9	-	0	0	183	135	-	-	0.97	-30.13
MV 10	-	-	-	184.8	138.6	-	-	0.98	-30.22
MV 11	SlackBus	91.8	74.1	0	0	-	-	0.99	-30.37
MV 12	TransferBus	-	-	372	279	21.84	84.6	0.98	-30.29
DC	DCBus	-	-	-	-	0.975	0	0.985	0

3.1. Voltage profile analysis

In Figure 4, the average system volume variance in the demand breakdown is less than 0.047 per unit at its highest importance. In contrast, the system's maximum voltage deviation (MVD) is 0.0692 (phases a, b, and c). Figure 4 shows that the voltage profile for all buses. The system's maximum divergence and volume computations show extremely low average and maximum deviations, confirming the operation's parameters.

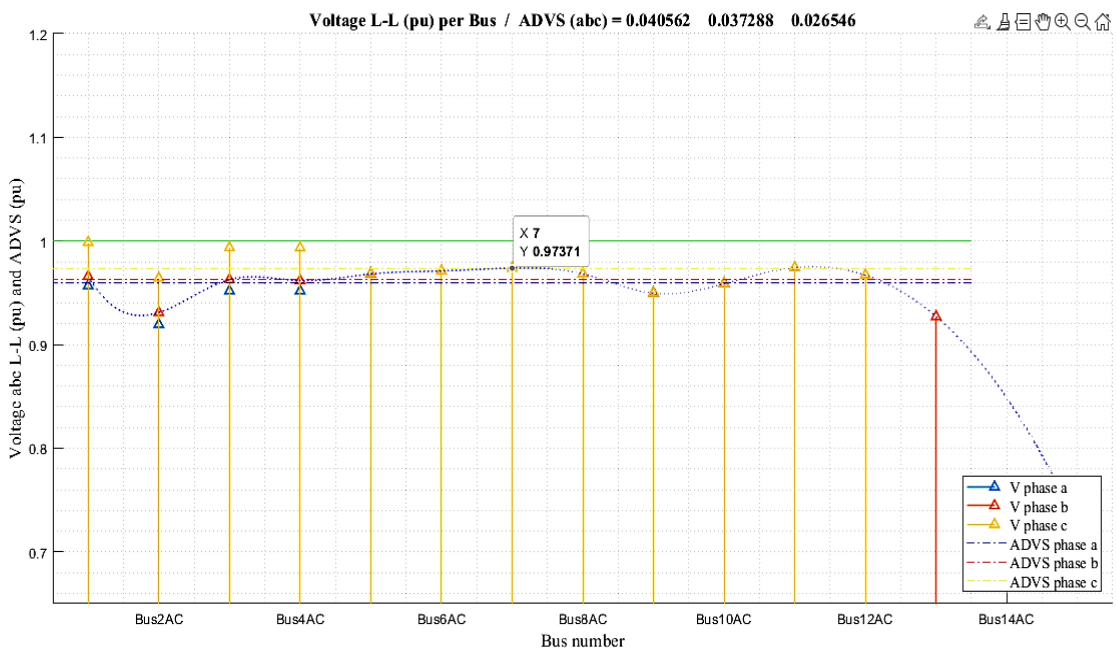


Figure 4. Analysis of voltage profile

3.2. Per-bus active power balance

Figures 5 and 6 show the proportion of the power in kVA produced and used in each bus in the framework, plus the kW power on the DC bus. With the exception of the diesel generator, which is linked at bus 7, the scenario also shows the contribution to dispersed generation. The connected grid uses bus 8 to supply the remaining amount of active power. The load powers linked to that bus or transferred are indicated by the positive graphical powers.

3.3. Reactive power balance per bus

Figure 7, for the highest demand, respectively, illustrate the reactive power balance per bus, voltage profile per bus, and phase shift variation in the vol angle at the system buses. Both figures show a coherent relationship between the reactive injection and the rise in voltage profile at the bus, where the reactive power is balanced by the system's current production. It has good qualities and goes above 1 p.u. in some buses. When increasing the reactive injection to enhance the maximum demand scenario, this issue needs to be analyzed.

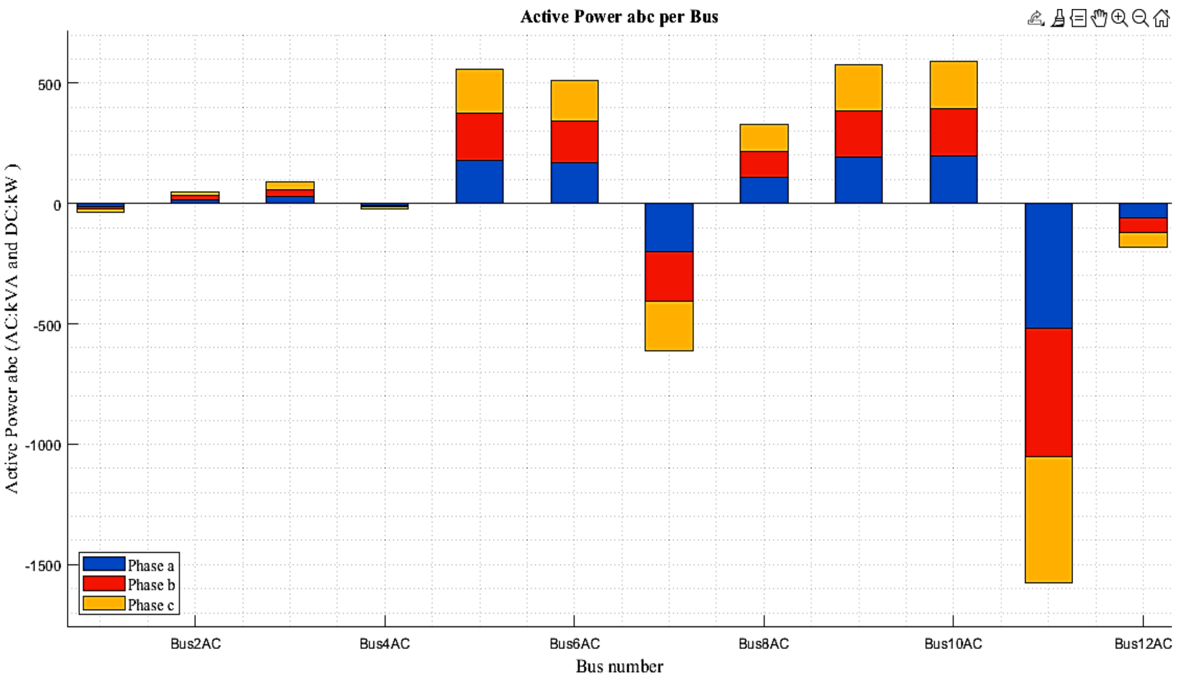


Figure 5. Analysis of power balance in maximum demand

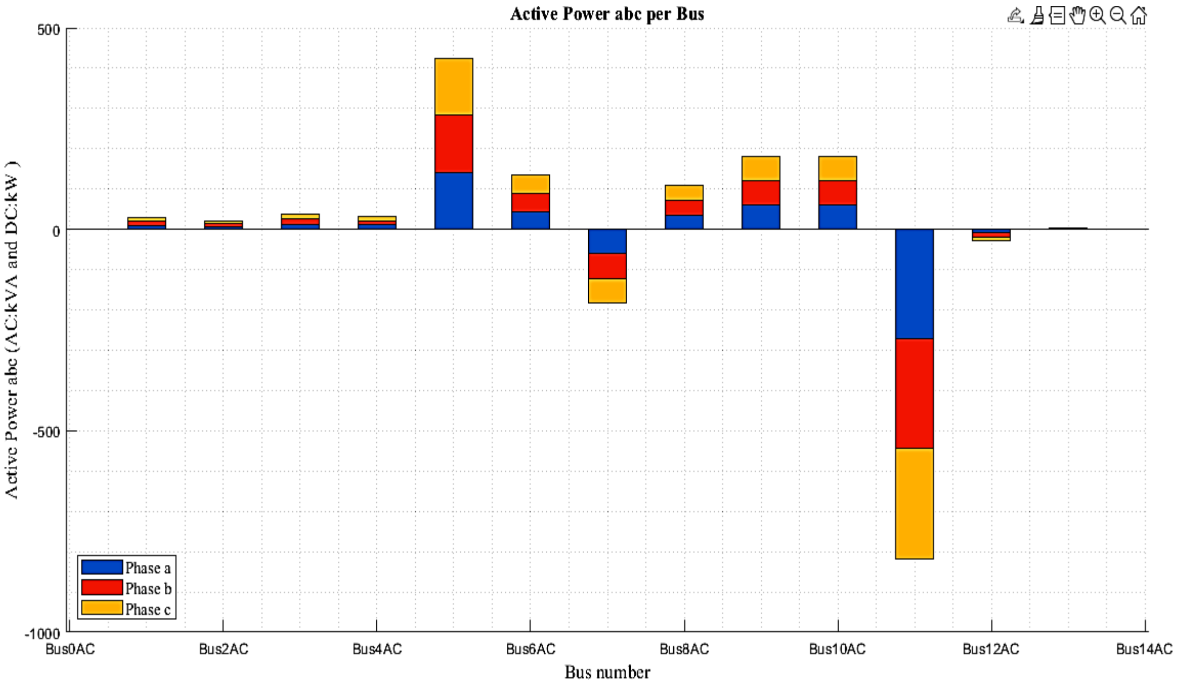
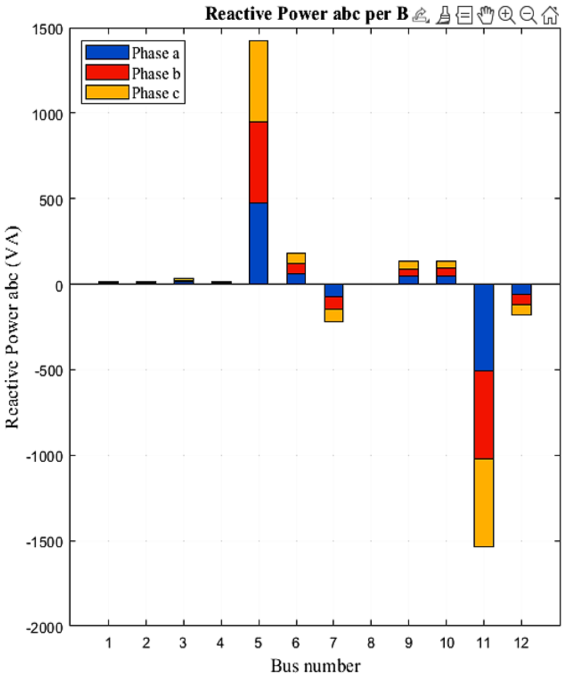


Figure 6. Analysis of power balance in minimum demand

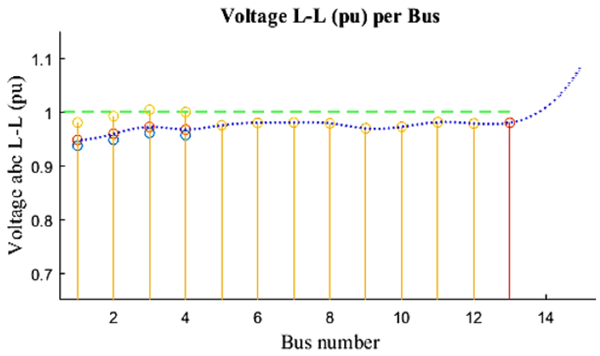
3.4. Power losses per bus

Figure 8 shows the losses per phase in each of the system's lines. According to both data, the low voltage grid's supply buses are located in the area with the highest loss levels. Even with its short path, line 8's phase a (the link between buses 4 and 5) has the highest level of phase losses, at over 9.9 kW. This outcome suggests that extremely imbalanced powers are transported down this connection.

(a)



(b)



(c)

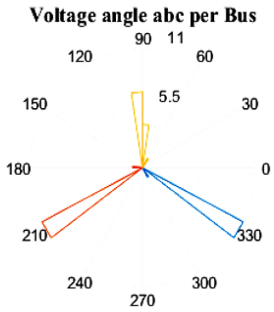


Figure 7. Analysis per bus and phase, in minimum demand scenario: (a) reactive power balance, (b) voltage profile, and (c) angular analysis

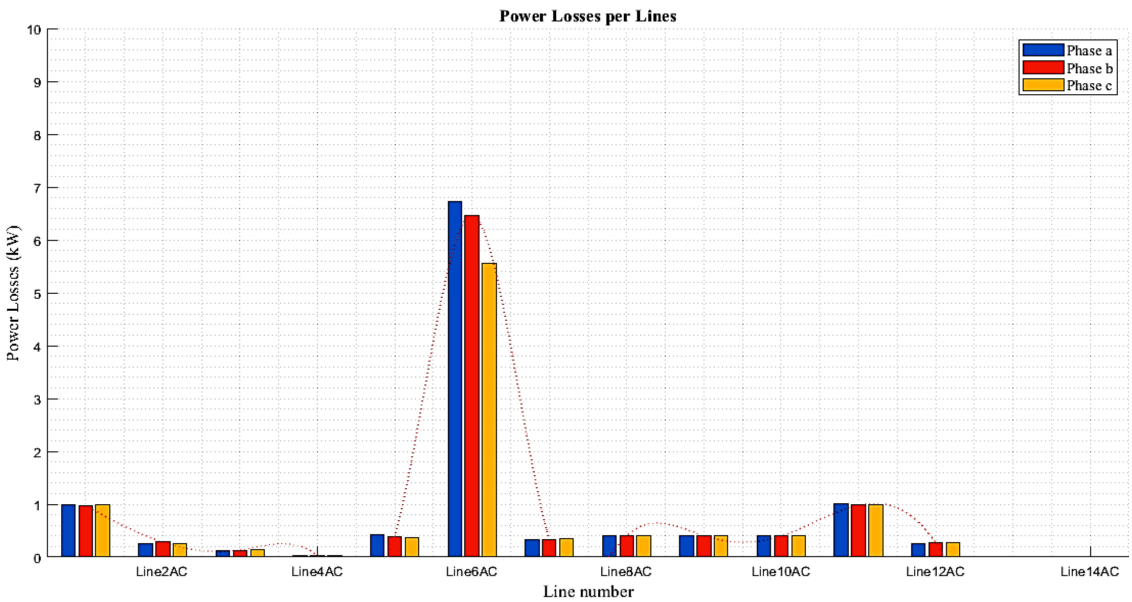


Figure 8. Analysis of power losses per line

4. CONCLUSION

This paper provides a scenario of an AC/DC-HMG point of reference based on the IEEE 12 bus. This AC/DC HMG standard includes a one-line schematic and the essential data for the 13.8-kV primary system and the 0.32-kV secondary system. The proposed research uses minimal and maximum electricity demands. A measurement module is on each bus. Simulations include power line losses. The individual discussion of the data from the study of the two scenarios computed in this suggested model has helped comprehend the challenges of each power quality and efficiency element. The suggested technique, which did not require pre-training on massive quantities of data and simultaneously calculated the optimal location and size for the ESS, might provide a solution with less processing when compared to existing methods. This study compared the power system operations results for all load fluctuations when the freshly installed ESS was positioned ideally and at a lesser priority, in accordance with the defined objective function. By placing the ESS in the optimal location, the voltage stability of the bus connecting to it and the other buses was ensured. By putting new ESSs in the optimal location, the root mean square error (RMSE) of voltage was reduced from 0.0683 without ESSs to 0.0413.

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BIOGRAPHIES OF AUTHORS

Pagidela Yamuna is a research scholar in Electrical and Electronic Engineering Department at the JNTUA College of Engineering Anantapuram. She received B.Tech. and M.Tech. degrees in Electrical and Electronic Engineering both from JNTUA University in 2013 and 2015 respectively. Her research interests include the field of distribution systems, microgrids, soft computing techniques. She can be contacted at email: yamuna.pagidela@gmail.com.

N. Visali is a professor in Electrical and Electronic Engineering Department at the JNTUA College of Engineering Anantapuram. She received B.Tech. degree in Electrical and Electronic Engineering, M.Tech. degree in P&ES from JNTUA University and Mangalore University in 1994 and 1998 respectively. She received a Ph.D. degree in Electrical and Electronic Engineering from JNTUA University in 2013. Her research interests include the field of power systems, distribution systems, microgrids, and power electronics. She can be contacted at email: nvisali.eee@jntua.ac.in.