ANN based Optimized Battery Energy Storage System Size and Loss Analysis for Distributed Energy Storage Location in PV-Microgrid

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***Abstract*— This paper proposes a method to determine the optimum Battery Energy Storage System (BESS) size, considering how the location of BESS affects the micro-grid and analysis of power loss for the consideration of different locations of BESS. The possibility of installing an optimum BESS as the distributed BESS at different locations is proposed. Artificial neural network (ANN) was established to evaluate the optimum size of BESS based on frequency and voltage regulation. To investigate and improve system performance, a BESS installation is considered as the distributed BESS at different locations. Then, power compensation to local loads is analyzed to obtain the improvement for entire system performance. Results show that the proposed ANN can achieve the very good performance in predicting the optimum size of BESS compared to the measured targets. In terms of BESS location, the optimum BESS size located at local loads shows better performance than the optimum BESS size located at a main substation.**

***Index Terms*—ANN, Battery energy storage system, Frequency and voltage control, Micro-grid, Optimization.**

I. INTRODUCTION

After the great east Japan earthquake and Tsunami in March 2011, the Fukushima Daiichi nuclear station raised the safety concerns which led to the shutdown of all of Japan's nuclear power plants by May 2012. Since that time, micro/smart grids developed in Japan have been focused on resilience. The concept of micro-grid which consists of a localized grouping of DGs, local loads and energy storage system interconnected by transmission line and communication was introduced [1]. Micro-grids can operate both in grid-connected mode and stand-alone mode. In the grid-connected mode, participants can achieve the economic benefits by participating in the electrical markets. In case of stand-alone mode (i.e., problems in the utility grid), micro-grids are able to maintenance the grid assets without de-electrifying the network downstream which occurred in Canada [2]. Isolated micro-grids can also help electrifying areas which have no grid access. This is an important contribution of micro-grids because the electrification is an essential condition for attaining a sustainable economic development. However, as the output characteristics of DGs in a micro-grid are quite different from the conventional energy sources and the output of DGs cannot predict, a micro-grid should be capable of handling unexpected fluctuation and maintaining system reliability. Thus, storage elements are essential components of a micro-grid so as to maintain stability, to simplify integration of renewable energies and enhance power quality [3].

Battery Energy Storage System (BESS) can be applied in several features of power system as one key issue for sustainable energy in various nations mostly in Japan, America and Europe. Advantages of BESS include improvement of the system frequency especially when BESS is used for system frequency control. In the circumstance of small disturbance, BESS is discharging when the system frequency is lower than 50 or 60 Hz. On the other hand, BESS is charging when the system frequency is higher than 50 or 60 Hz. In the circumstance of large disturbance, BESS is able to improve the performance of the system frequency control by integrating BESS with under frequency load shedding scheme, or under/over frequency generation trip. With these different utilities, BESS can offer a good solution to power system. It can be summarized that BESS is a quick and flexible component for power system [4, 5].

The optimal size and location of BESS is an important aspect to maximize the benefits of BESS in the micro-grid. The inappropriate size and location of BESS can cause low or over frequency and voltage to the micro-grid system. It can also cause inefficient system in terms of BESS role for power compensation and increased losses in the system. Hence, it is essential to consider an appropriate size and location of BESS to the micro-grid in order to improve system performance, power quality and reliability [6]. In fact, BESS should be connected at a bus which BESS can provide the best reduction in losses without any violation to the frequency and voltage of the micro-grid. Several optimization techniques for optimum size of BESS are proposed in the literature [7, 8]. However, there is no clearly suggestion for choosing the optimal location of BESS in a micro-grid system [9]. Thus, the main purpose of this paper is to determine the optimal size of BESS and identify where BESS can be located in the micro-grid. Because of non-linear relationship constrains in this proposed method such as frequency and voltage of the microgrid, power capacity of BESS and system power losses, Artificial Neural Network (ANN) seems to be the most suitable for such modeling method. ANN has been proven to be a successful type of Artificial Intelligence (AI) in many applications [12], [13].

In this paper, the main purpose is to evaluate the optimum BESS size, considering how the location of BESS affects the micro-grid, and identify where BESS can be located in the micro-grid. System losses are investigated and analyzed for different BESS locations in order to study and investigate the effect of BESS locations in terms of reduced loss and localized power compensation in the micro-grid. The location of BESS is changed from a main substation to a local substation/load. Four different cases of BESS locations were considered for improved performance based on power compensation from BESS to localized load with minimized active and reactive power loss. The rest of the paper is organized as follows: Section II presents a brief description of the micro-grid system; Section III illustrates the ANN based BESS size optimization; Section IV analyses the micro-grid performance by changing locations of BESS; Section V displays the simulation results and analysis; Section VI accomplishes the work.

II. System Configuration

A. Micro-grid Structure

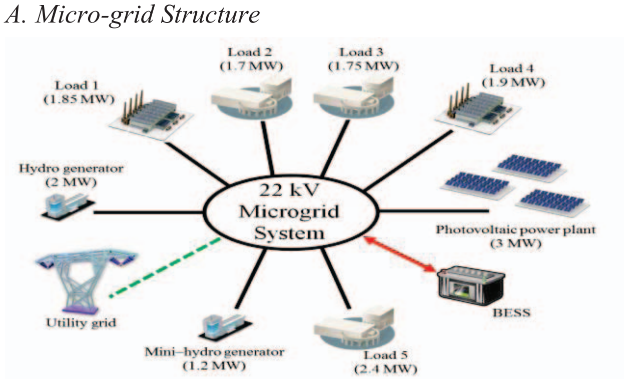

Figure. 1. The study micro-grid

The typical micro-grid structure, which considered in this study, is consists of four major power sources; the 1.2 MW mini-hydro generator, 2 MW hydro generator, 3 MW solar photovoltaic sources and BESS as shown in Figure 1. Each DG unit has its own local controller to handle the relevant electrical variables. This system also consists of group of feeders which could be part of the distribution design. The load 1 and 4 are the critical load with peak power of 1.85 MW and 1.9 MW respectively. The load 2, 3 and 5 are the non-critical load with peak power of 1.7 MW, 1.75 MW and 2.4 MW respectively.

B. Battery Energy Storage System (BESS)

Renewable energy sources are depending on weather conditions. Thus, BESS is used to store surplus electrical energy to maintain the system frequency, voltage and supply the power to loads in case of low solar ration or wind speed in a micro-grid. Moreover, BESS can smooth out the fluctuation of wind/solar and enhance the load availability. For future BESS information, along with most BESS models demonstrated in various researches [7-9].

The structure of BESS consists of power converters, battery cells and control parts which are shown in Figure 2.

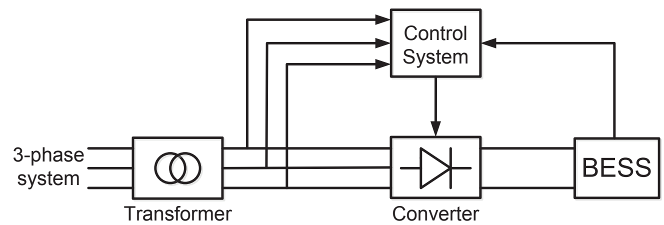

Figure. 2. A structure of BESS [7]

In this study, when the power generated by the micro-grid system is greater than the load demand, the surplus power can be stored in BESS for future uses. On the other hand, when there is any deficiency in the power generation of the micro-grid, the stored power can be used to supply the load. Thus, this will improve the system performance and reliability.

C. Solar Photovoltaic Generation

The power output of solar photovoltaic (PV) is uncertain as it is mostly affected by the environmental factors, namely the environmental random changes will inevitably lead to constantly changing of output power of PV [10, 11]. In order to illustrate PV characteristics in operating condition, the influence of solar radiation and atmosphere temperature are designed. The temperature effect is denoted by a temperature coefficient of T_{co} (1/c°). The efficiency of the inverter is multiplied by the DC output converting DC to AC output as in (1).

$$P_{PV} = n_{PV} P_{rate\ PV} \left(G / G_0\right)\left(1 - T_{co}\left(T_A - 25^{\circ}\right)\right) \eta_{inv}\eta_{rel} \quad (1)$$

where n_{PV} is PV modules number, $P_{rate\ PV}$ is the PV array rated power (W), G is the global insolation on the PV array (W/m^2), G_0 is the standard amount of insolation rating the capacity of PV modules (W/m^2), T_A is the ambient temperature, T_{CO} is the temperature coefficient of the maximum power of PV, η_{rel} is the relative efficiency of the PV modules, η_{inv} is the efficiency of the inverter.

III. OPTIMUM SIZE OF BESS BASED ANN

Artificial Neural Network (ANN) models are used worldwide in various research areas such as engineering, classification and medicine. In the multilayer perceptron structure, this structure is established in a layered feed-forward network and it consists of an input layer, one or more hidden layers and output layer. The weight total of the input data and chosen bias are passed through a transfer function to obtain the output data. The number of hidden layers can be changed based on the problem data in the training process [12, 13]. In this paper, the multilayer perceptron (MLP) neural network consists of three-layers of neurons which demonstrates that only one hidden layer is contained and one type of activation function (i.e. hyperbolic tangent transfer function) is used in the hidden layer. Based on the measured values of output frequency and voltage in the stand-alone micro-grid, this paper can evaluate the optimal size of BESS to supply the micro-grid when the micro-grid is isolated from the utility grid. As a nonlinear modelling method, the MLP neural network has nonlinearity quality and it can guarantee the accuracy of fitting. There are two inputs with the one output in this study as shown in Figure 3.

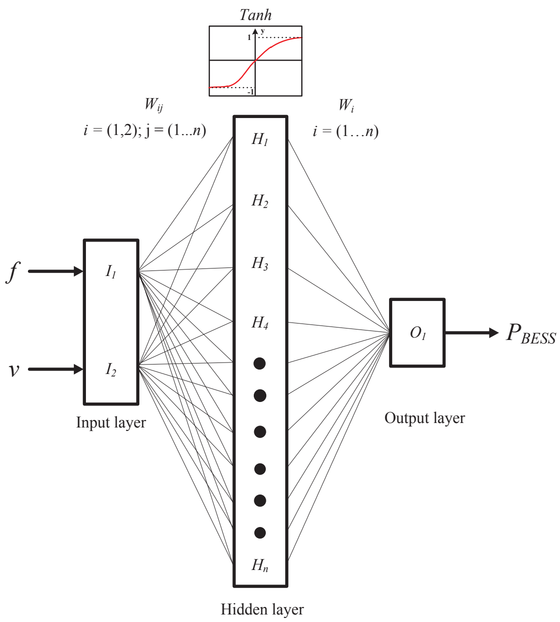

Figure. 3. The ANN model for BESS size estimation

where f is the frequency of the micro-grid (Hz.) while v is the voltage of the micro-grid (pu.). P_{BESS} means the power capacity of BESS (MW).

The activation transfer function is used to convert the activate level of a neuron to an output value. The output value of the network is created by transforming a weight total of input based on a transfer function. The hyperbolic tangent (*Tanh*) activation transfer function is activated between the input layer and the output layer as follow:

$$y_i = f_{Tanh}(x_i) = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}} \tag{2}$$

The output of the hidden layer can be shown as:

$$\begin{bmatrix} g_1 \\ g_2 \\ \bullet \\ \bullet \\ g_i \end{bmatrix} = f_{Tanh}\left(\begin{bmatrix} W_{11}^{(1)} & W_{21}^{(1)} \\ W_{12}^{(1)} & W_{22}^{(1)} \\ \bullet & \bullet \\ \bullet & \bullet \\ W_{1j}^{(1)} & W_{2j}^{(1)} \end{bmatrix} \cdot \begin{bmatrix} f \\ v \end{bmatrix} \right) \tag{3}$$

From (3), it can be simplified as:

$$g(f,v) = f_{Tanh}\left(W^{(1)}(f,v)^{T}\right) \tag{4}$$

The output of the neural network can be expressed as:

$$P_{BESS}(f,v) = f_{Tanh}\left(W^{(2)} g(f,v)\right) \tag{5}$$

Lastly, the proposed ANN model can be designed as:

$$P_{BESS}(f,v) = f_{Tanh}\left(W^{(2)} f_{Tanh}\left(W^{(1)}(f,v)^{T}\right)\right) \tag{6}$$

Based on Table I, the parameter details for the proposed ANN are shown and used in the training and the testing database.

TABLE I. MULTILAYER PERCEPTRON ANN PARAMETERS

Parameters	**ANN**
Goal (MSE)	0.00001
Inputs	2
Output	1
Hidden layer	1
Training data	90
Testing data	30
Hidden layer neurons	10
Output layer neurons	1
Transfer function	Hyperbolic Tangent

IV. MICROGRID ANALYSIS FOR DIFFERENT BESS LOCATIONS BASED ON LOSSES

The case studies are analysed and implemented for four cases with different BESS locations to consider how the BESS location affects the micro-grid and evaluate where BESS can be located in the micro-grid based on losses.

From Figure 4, BESS is located at the main substation/bus 4 which demonstrates the case 1.

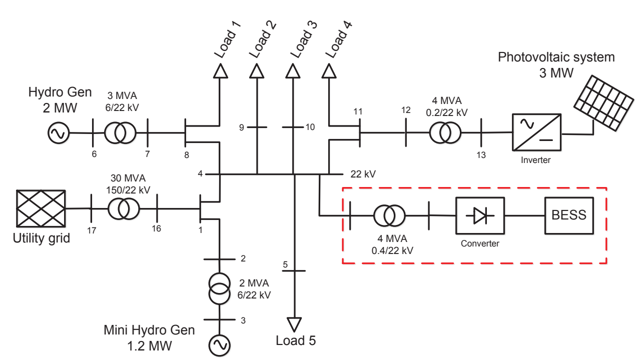

Figure. 4. The BESS installation at a main substation

For the case 2, BESS is separated into two parts. The first part is located at the local substation/load1 (i.e., bus 8) and another part is located at the main substation (i.e., bus 4) as shown in Figure 5.

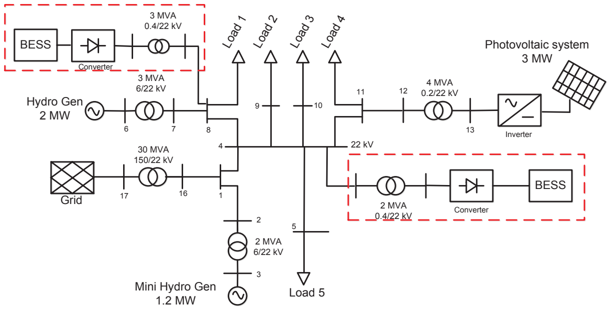

Figure. 5. The BESS installations at a main and local substation

In the case 3, BESS is separated into two parts. The first part is located at the local substation/load 1 (i.e., bus 8) and another part is located at the local substation/load 5 (i.e., bus 5) as depicted in Figure 6.

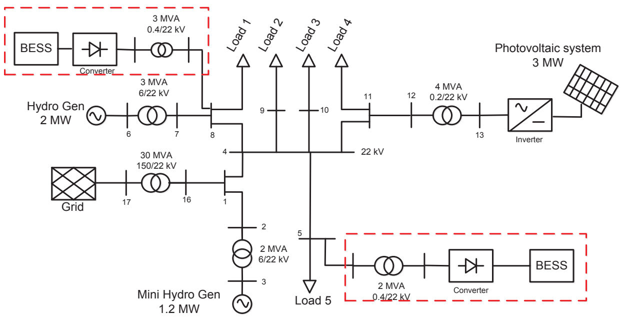

Figure. 6. The BESS installations at local substations

Based on the case 4, BESS is separated into two parts. The first part is located at the local substation/load 4 (i.e., bus 11) and another part is located at the local substation/load 5 (i.e., bus 5) as shown in Figure 7.

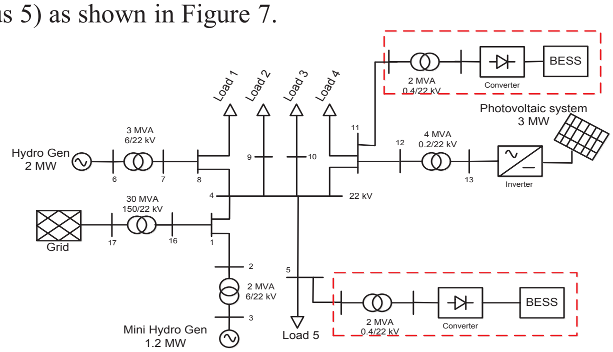

Figure .7. The BESS installations at local substations

V. Simulation Results and Analysis

This section demonstrates the comparison results of the optimal size of BESS based ANN with different case studies of locations in the micro-grid.

A. Optimal BESS Size based Proposed ANN

In this paper, two inputs which are frequency and voltage of the micro-grid are fed to the proposed neural network. The output of the proposed ANN can be the predictive result of the optimal size of BESS for the stand-alone micro-grid.

After the inputs and targets for the training data are initiated, the next process is the separation of the data for training, validation and test. In this paper, 70 % samples of data are used for the training process, 15 % samples of data are used for validation and 15 % for test data.

From the training results, the correlation coefficient (R) for the activation transfer function is almost equal to 1 (i.e., 0.99992) which means that the target is equal to the output of the training data (See Figure 8). This reason indicates the strong correlation between the measured data and the proposed ANN output. Hence, this proposed ANN model is high accuracy.

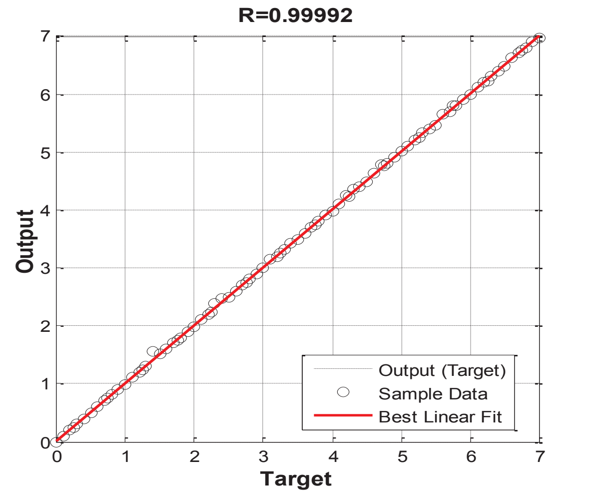

Figure. 8. A regression analysis between the network output and the corresponding target

From the testing results, it is seen that the proposed ANN with the hyperbolic tangent function is able to follow the pattern of BESS size based on frequency and voltage control of the micro-grid as shown in Figure 9. This figure demonstrates that the proposed ANN with the hyperbolic tangent function can accurately determine the optimal size of BESS for the stand-alone micro-grid. The outputs of the hyperbolic tangent function are only slightly different from the measured targets (i.e. simulation result).

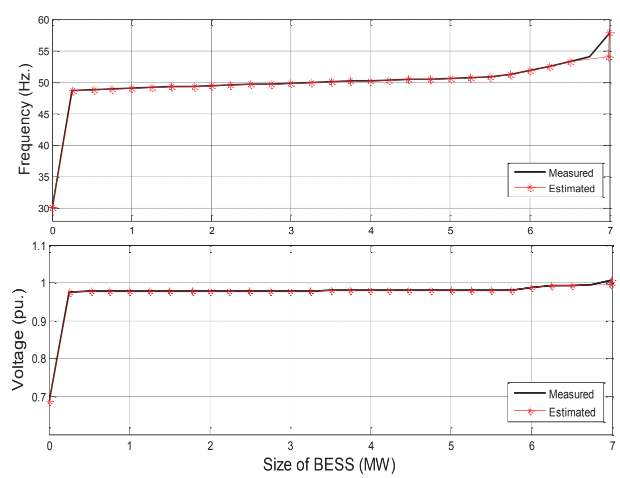

Figure. 9. A comparison between measured BESS size and predicted BESS size based on frequency and voltage control of the micro-grid

The mean square error (*MSE*) on forecasting performance shows the learning and generalization error of the normalized values of BESS size (See Table II). This value showed that the proposed ANN was able to accurately predict the optimum BESS size. MSE equation can be shown as:

$$MSE = \sqrt{\sum_{1}^{n}\left(T_i - O_i\right)^2} \qquad (7)$$

where T_i is the target vector, O_i is the output vector and n is the number of training data or data for each test in the testing data set.

TABLE II. MSE ERROR FOR BESS SIZE ESTIMATION

Performance predictor	MSE
BESS size (P_{BESS})	0.0000072

Finally, the optimal size of BESS is achieved by the proposed neural network model based on frequency and voltage control of the micro-grid as shown in Table III.

TABLE III. OPTIMIAL PARAMETERS BASED ON ANN

P_{BESS} (MW)	f (Hz.)	v (pu.)
3.3520	50.000	0.979

B. Optimal BESS Location Selection

After the optimal size of BESS is achieved using the propose ANN, the simulation is done for four case scenarios based on BESS locations so as to consider how the BESS location affect the micro-grid and determine where BESS can be located. The simulation results are explained in the following:

The case 1; BESS with the capacity of 3.3520 MW/6.70 MWh is located at the main substation/bus4.

The case 2; BESS is separated into two parts. BESS with the capacity of 1.8520 MW/3.70 MWh is located at the main substation/bus 4 and another BESS with capacity of 1.50 MW/3.00 MWh is located at the local substation/load 1 (i.e, bus 8).

The case 3; BESS is separated into two parts. BESS with the capacity of 1.8520 MW/3.70 MWh is located at the local substation/load 5 (i.e., bus 5) and another BESS with capacity of 1.50 MW/3.00 MWh is located at the local substation/load 1 (i.e., bus 8).

The case 4; BESS is separated into two parts. BESS with the capacity of 1.8520 MW/3.70 MWh is located at the local substation/load 4 (i.e., bus 11) and another BESS with capacity of 1.50 MW/3.00 MWh is located at the local substation/load 5 (i.e., bus 5).

Figure 10 and 11 depict the system frequency and voltage of four scenarios incorporating optimal BESS respectively when the micro-grid is isolated from the utility grid at 10.0s. It is clearly seen that optimal BESS can improve a fast, smooth and secure system frequency and voltage for four case scenarios from the emergency situation to the normal state equilibrium. In case of no BESS, the system frequency and voltage dropped drastically because the power supply cannot meet the load demand.

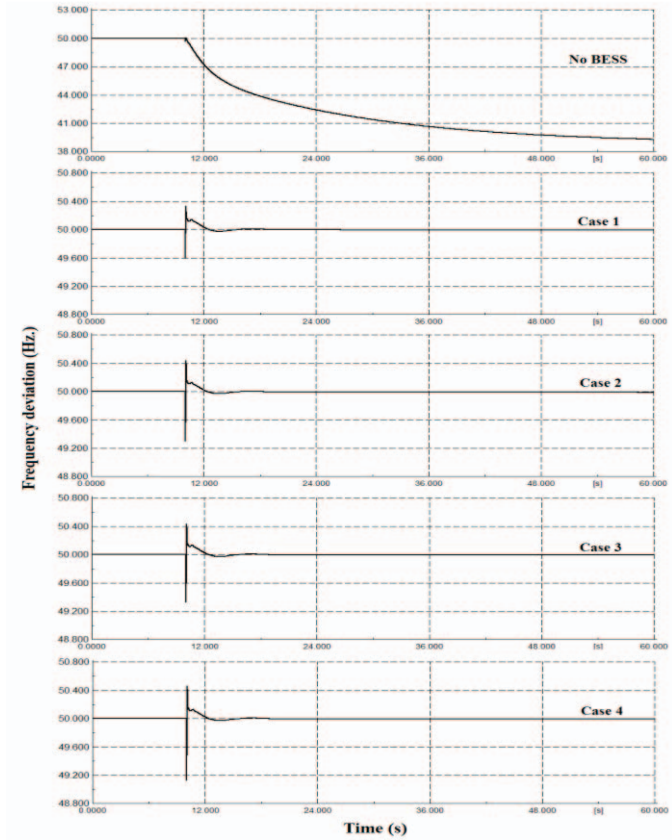

Figure. 11. Frequency deviations for different cases after islanding

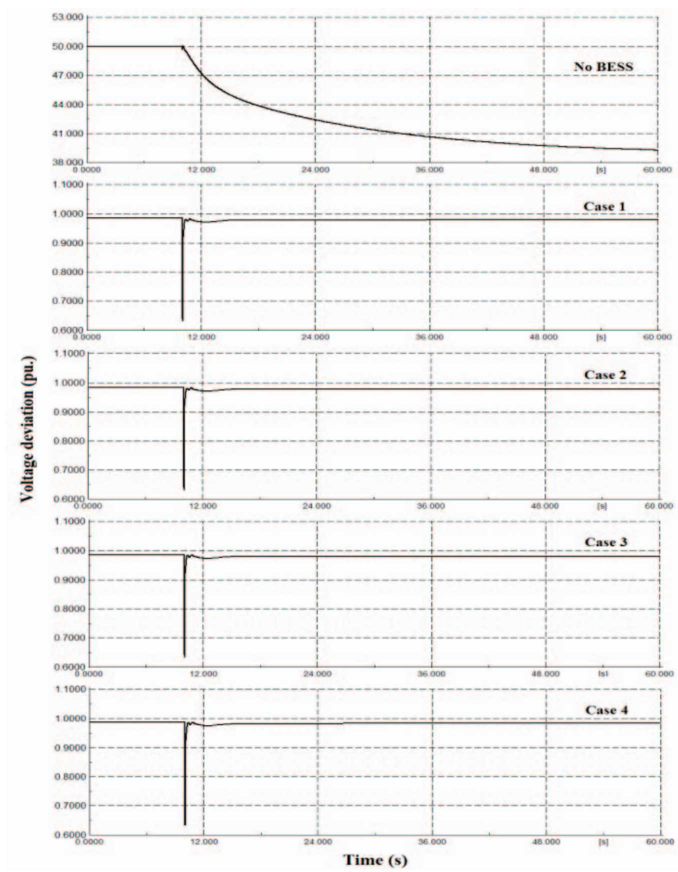

Figure. 12. Voltage deviations for different cases after islanding

In terms of power compensation, four cases with different BESS locations are investigated and analyzed. Based on Figure 13 and Table IV, it is obvious that BESS can help all power generations to supply the reactive powers. Moreover, BESS units which are located at the local substation/load (i.e., case 3 and 4) give better performance of power compensation than BESS units are located at the main substation (i.e., case 1 and 2) . However, the BESS location at the case 4 analyzed the best performance for the micro-grid. As the reactive power loss is minimum compared to other cases with battery and without battery. Considering power compensation, the power demand from different generating sources is maximally reduced under the case 4 for the same rating of the system as it also provides the best compensation. Thus, BESS units in the case 4 have been providing the most effective compensation and minimum loss in the comparison of all cases considered for the analysis of the power compensation from BESS in the micro-grid.

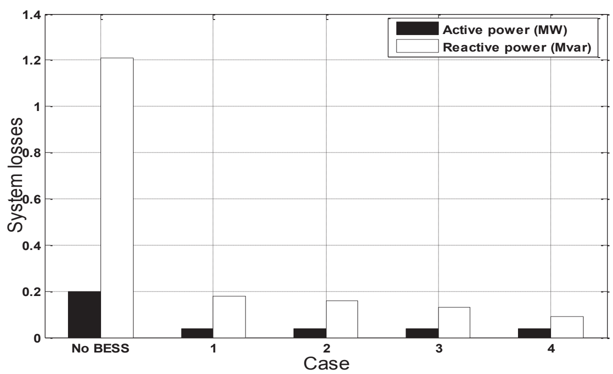

Figure. 13. A comparison of system losses for different BESS locations

TABLE IV. TOTAL SYSTEM LOSSES FOR DIFFERENT CASES BASED ON BESS LOCATIONS

Case	Active power (MW)	Reactive power (Mvar)
No BESS	0.20	1.21
1	0.04	0.18
2	0.04	0.16
3	0.04	0.13
4	0.04	0.09

VI. CONCLUSION

This paper deals with the optimum BESS size and investigation of locations for the micro-grid based on system losses. The proposed ANN with the hyperbolic tangent function has obtained the optimal size of BESS with a high accuracy. This is because the hyperbolic tangent neurons can have outputs over a large region of the input space. It can be concluded that the proposed ANN with the hyperbolic tangent activation function is appropriate for estimating the optimal size of BESS with only a minor change of BESS size compared to the target optimization. In order to improve the system performance by providing local compensation through BESS, four different scenarios of BESS locations are investigated effectively. The results obtained from each case are compared to determine the performance that gives the best effective power compensation for BESS location. Based on the results, the optimum BESS has shown a good performance in load frequency control and can be used for emergency control purposes. In terms of power compensation, the BESS units which are installed at bus 5 and 11 (i.e., case 4) have shown the capability of achieving the best performance based on distributed local compensation through BESS. This is because BESS units are located at local substations/loads which can support the power compensation to loads locally. It can be concluded that the micro-grid considered in this paper illustrating the best effective power compensation response for an optimized size of BESS when BESS is located at a local substation/load.

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