The ANN Design Based On PMU Readings For Fault Location Detection

AzriyenniAzhariZakri, M RoisKhumaini, Herman Syaibi, Wenny DwiTristiyanti

Abstract: A fault diagnosis of an electric power transmission systems is sensitive to power outages and this has led to the introduction of several recycling techniques to find faults in transmission lines. The system-based measurement known as the Phasor Measurement Unit (PMU) is designed to monitor large systems over a large area as well as to regulate related applications. Therefore, this research was conducted to improve the PMU and Wide Area Protection (WAP) IEEE 9-bus and 14-bus systems. PMU is used to convert voltage and current waves into phasors, magnitude, and angles of energy and current to protect the fault site from a three-phase short circuit. All lines of the IEEE 9-bus and 14-bus systems are simulated with distance variations of 10%, 30%, 50%, 70%, and 90% and the results serve as a contribution to infer fault points in the system. In addition, an analysis of the PMU and Artificial Neural Networks (ANN) for inaccuracy, RMSE, MAE, and MSE values was also analyzed from three-phase faults on each networks of IEEE 9-bus & 14-bus tests, respectively. The simulation is validated through variations in the ANN data input consisting of current and voltage.

Index Terms: ANN, fault diagnosis, PMU, WAP.

1. Introduction

The transmission system is an integral part of the electrical supply consisting of a transmission line and an energy distribution system. However, the presence of a fault in the system has the ability to disrupt the capacity of the source, thereby leading to subsequent losses for users. Therefore, there is need to increase in the processes involved in fault identification in the transmission line to improve electricity supply to users. This led to the use of a quantity technique connected to a significant zone to supervise the scheme implemented in large topographical regions. This process involves using a Wide Area Protection (WAP) to oversee, secure, and combine the meanings of the phasor measurements [1][2]. The Measurement Phasor Unit (PMU) is the electrical power system with synchronously rationalized and instantaneous dimension procedures [3][4]. It is a similar portion of computing phasor rate, which donates the current and voltage principles to the headquarters [5]. R. A. Reyes & J. L. Guardado investigated PMU and demonstrated the use of consuming software to supervise the scheme below the usual and frequently occurring fault. Reflection is approved out on the public of the power system precisely. Moreover, the PMU was observed to be produced in the phasors of current and voltage with the system working continuously [6]. B. Malikarjuna et al. also researched the use of PMU on electrical power systems in India and it was discovered to have improved effectiveness, consistency, and observation. Therefore, the use of Simulated Annealing (SA) to increase the application of the model requires 25% of the total amount of buses in the energy scheme [7].

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Mohammed Mahdi, V. M recommended forecasting the constancy of power system consumption information on PMU. This involves accepting the opinion of the system immediately after the fault occurs after which there is a breakdown to use voltage information in the forecasting system constancy specified to be covered or insecure. The purpose of this recommendation is to operate a smart system known as Artificial Neural Networks (ANN) in predicting the permanency of the order [8]. Saeed A et al. also recycled the Wavelet Packet Transform (WPT) process by applying WAP prepared through PMU on electrical power systems. This object emphasizes on transmission system fault, especially High Impedance Faults (HIF) characterized by elevated occurrences. The three bus scheme on the power system, such as New England, is a route on replicated disruptions in unique situations, for example, the original approach used for the condition and the kind of fault [9]. Jac W Lee provided a scheme to estimate fault areas using PMU and traveling wave concept. The study was conducted to formulate an estimation system for the disturbance area with an estimated fault location based on traveling wave theory on the 119-bus power transmission system at 765-kV and 5-bus at 765-kV in South Korea [10]. Moreover, Fengqun Z et al. also developed WAP and integration protection on Smart Grid to protect and control electric power over large areas and substations and also to use interconnection channels between large areas for future use [1]. This research is a continuation of a study that has been discussed [5] by applying the PMU as a phasor measurement of current and voltage values a for a 9-bus system. In addition, the study was improved by applying the previous concept to the IEEE 14 bus system, with the data results of these tests validated based on the ANN technique. This research was conducted to develop IEEE 9-bus and 14-bus systems based on WAP to identify faults in the electrical power system using MATLAB/Simulink software. The PMU observations on the network were investigated to determine the state of the short circuit. In addition, the WAP used to monitor the interference on the 14-bus network was also tested, while the system applied in conducting the test was validated using ANN with the back propagation algorithm.

2 Methodology

There are three principal concepts in computing a widespread space and they include information achievement, transmission, and management. The process has been discovered to be achievable using dimension scheme, statement scheme, and vitality managing of separate instructions [11]. The level of the widespread space established on the PMU was expressed as the scheme to calculate the extension of the power system to other zones with high accuracy and also to serve as an improvement to the conservative supervising measurement scheme. The results obtained were secondary to the growth constancy of the program below ordinary and disruption situations. However, significant studies on widespread space have focused on expending coordinated capacities [12]. Supervising schemes have also been reported to be actual, quick, and precise in improving the current power scheme while PMU was reported to be effective in the power system to assemble the experiments [13].

2.1 PMU

PMU is a concept used to construct electrical control schemes requited to ensure repeated efficiency of phasor measurement gear. It is a portion containing both current and voltage phasors connected to the bus and the outcome is assumed to have made the model a desirable tool in the electric system. Figure 1 shows the PMU scheme has a central processing unit and the facility used a digital indication on a supercomputer with 50/60Hz AC voltage and current influencing at a rate of 48 examples per-cycle or 2400/2880 samples per second. Meanwhile, analog AC waves were experimented casually by A/D converter for the apiece phase and the asynchronous period for all the schemes was provided. Moreover, the colonies of the GPS were expended as contributions to capture the oscillator and waves since all programs were experimented with single-microsecond accuracy. A digital indication exemption performance was used to compute phasors of voltage and current for every bus [1][14]. The fault diagnosis was conducted using PMU production and this involved scheming the pure reactance, the impedance was occupied by orientation to one incurable to likening the restrained route impedance (Z_{1L}), besides the impedance intended after a fault happens ($V_{s.}$ / I_s), to decide the fault location. This shows the importance of the fault resistance is nil. Furthermore, the computation was precisely contracted and the reactance contingent on the direction was found to be identical to the I_f in other to determine the location of the fault [15][16].

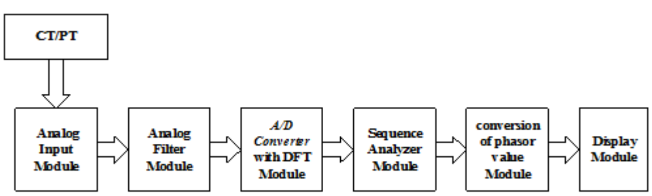


Fig. *1. Scheme of PMU*

2.2 ANN

The Artificial Neural Networks are large parallel distributed processors with a tendency to store experiential knowledge and make it ready for use. They consist of a collection of arranged nerve cells called layers and each neuron in a particular segment is connected with others based on weight. The determination of the values of these weights provides the correct output value called learning. This, therefore means nerve cells are informationprocessing units used as the basis for ANN operations [8][17][18]

Back propagation Algorithm (BA) is recyclable to explain the problems in the investigation to conclude on the area of fault in an electrical power system and to construct the right choice through assumed input patterns in the examination. BA is a single typical example of feed-forward spending managed to train created to ensure error improvement and the procedures involve two steps which are feed-forward and feed-backward. Moreover, Figure 2 shows each neuron performs the task of triggering such that every neuron in the input used the character and those in the hidden layer consumed the nonlinear triggering role and the constant triggering features expended unoriginal and repetitive growth. This shows the production of all the neurons involved the use of similar straight triggering functions and they were observed to have followed the procedure of BA to increase the weights of the neural networks. This means the hidden layer was consuming a linear triggering function while the BA was able to explain the difficulty since the configuration of straight features is accurate [19][20].

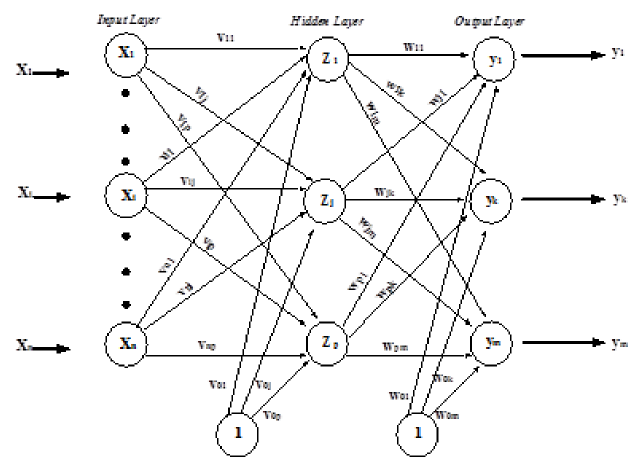


Fig. 2*. Design back propagation neural network*

The procedure of a Typical BA [17][19]:

Step 1. Preparation of weights.

Step 2. There are no specific measures to decide the significance of ending this procedure.

Step 3. Every neuron input $(x_i, i = 1, \ldots, n)$ produced an indication, x_i, and later has direct importance on the rate of all these neurons.

Step 4. Every hidden neuron has an input in the formula produced by magnifying the importance of every indication through the weight on the link joined to the hidden layer as shown in the following equation.

$$z_{in_j} = v_{0j+} \sum_{i=1}^{n} x_i v_{ij} \qquad (1)$$

Meanwhile, the triggering role used in calculating the production indication is shown as follows.

$$z_j = f\left(z_{in_j}\right) = \frac{1}{1+e^{-z\_in_j}} \qquad (2)$$

Step 5. Every neuron production $(y_k, k = 1, \ldots, m)$ was assumed to be contributing to the formula of the hypothetical importance of creating all the hidden layers in weight on the link related to the production layer as shown in the following relationship.

$$y_{in_k} = w_{0k} + \sum_{j=1}^{p} z_j w_{jk} \qquad (3)$$

The triggering role was made on the routine to estimate the production indication as follows:

$$y_k = f(y_{in_k}) = \frac{1}{1+e^{-y\_in_k}} \quad (4)$$

BA of Inaccuracy:

Step 6. Compute the production element of inaccuracy in every production layer through $(y_k, k = 1, \ldots, m)$

$$\partial_k = (t_k - y_k)\, f'(y_{in_k}) = (t_k - y_k) y_k (1 - y_k) \quad (5)$$

Where ∂_k is the inaccuracy elements expended in the fluctuating weight layer.

The estimate of an activity weight modification (jt) expended was advanced to modify the weight w_{jk} rate observed $\alpha\,(z_j = j = 1, \ldots, p)$ to present the hidden layer bias to the production layer;

$$\Delta w_{0k} = \alpha\, \partial_k \quad (6)$$

Step 7. Estimate the hidden layer constructed on the inherent error element $z_j = j = 1, \ldots, p$ and the expected ∂ input is

$$\partial_{net_j} = \sum_{k=1}^{m} \partial_k w_{jk} \quad (7)$$

The element ∂ is a hidden layer as follows:

$$\partial\_j = \partial\_(in\_j)\, f\^{\prime}\, (z\_(in\_j)) = \partial\_in\_j\, z\_j\, (1 - z\_j) \quad (8)$$

Compute the weight modification v_{ij} as follows:

$$\Delta V_{ij} = \alpha\, \partial_j X_i \,, j = 1,2, \ldots, n \quad (9)$$

This was expanded later to modify the weight at $j = 1,2, \ldots, p$ while $i = 1,2, \ldots, n$.

Furthermore, a hidden layer was applied to renew the weights through the following contribution layer

$$\Delta V_{0j} = \alpha\, \partial_j \quad (10)$$

Renewed Weight and Bias:

Step 8. All neuron output $(y_k, k = 1, \ldots, m)$ modernizes the weights apart from the bias $(j = 1, \ldots, p)$;

$$w_{jk}(new) = w_{jk}(old) + \Delta w_{jk} \quad (11)$$

Every neuron has hidden; $(z_j, j = 1, \ldots, p)$ to modernize the hidden layer preference $(i = 1, \ldots, n)$;

$$v\_ij\,(new) = V\_ij\,(old) + \Delta v\_ij \quad (12)$$

Step 9. Testing the importance of strong minded to the left.

This development subsequently made it possible to expend the network overhead for the test procedure. In this circumstance, the feed forward events were consumed to ensure the significant production of energy from the grid.

2.3 Power System Transmission

The IEEE 9-bus & 14-bus tests were developed to demonstrate the operations of PMU. This involves the use of a widespread zone amount technique through a triple-phase short circuit model at the fault expanse opinion of 10%, 30%, 50%, 70%, and 90% [20][21]. The link-in-link of the systems demonstrated in the MATLAB/Simulink is presented in Figure 3 and the information obtained from the triple-phase short circuit models was used as input to identify the location of the fault in the transmission system. Moreover, the electric power system recycled in the report was the link scheme of the IEEE 230 kV 14-bus test. The program involved triple generators, triple transformers, six transmission channels, and triple loads [5][22].

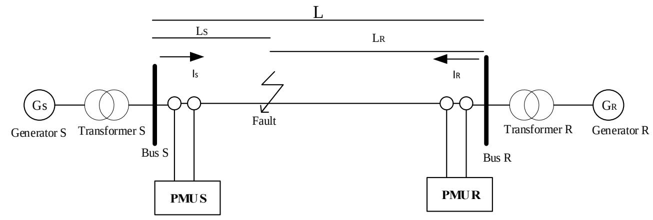


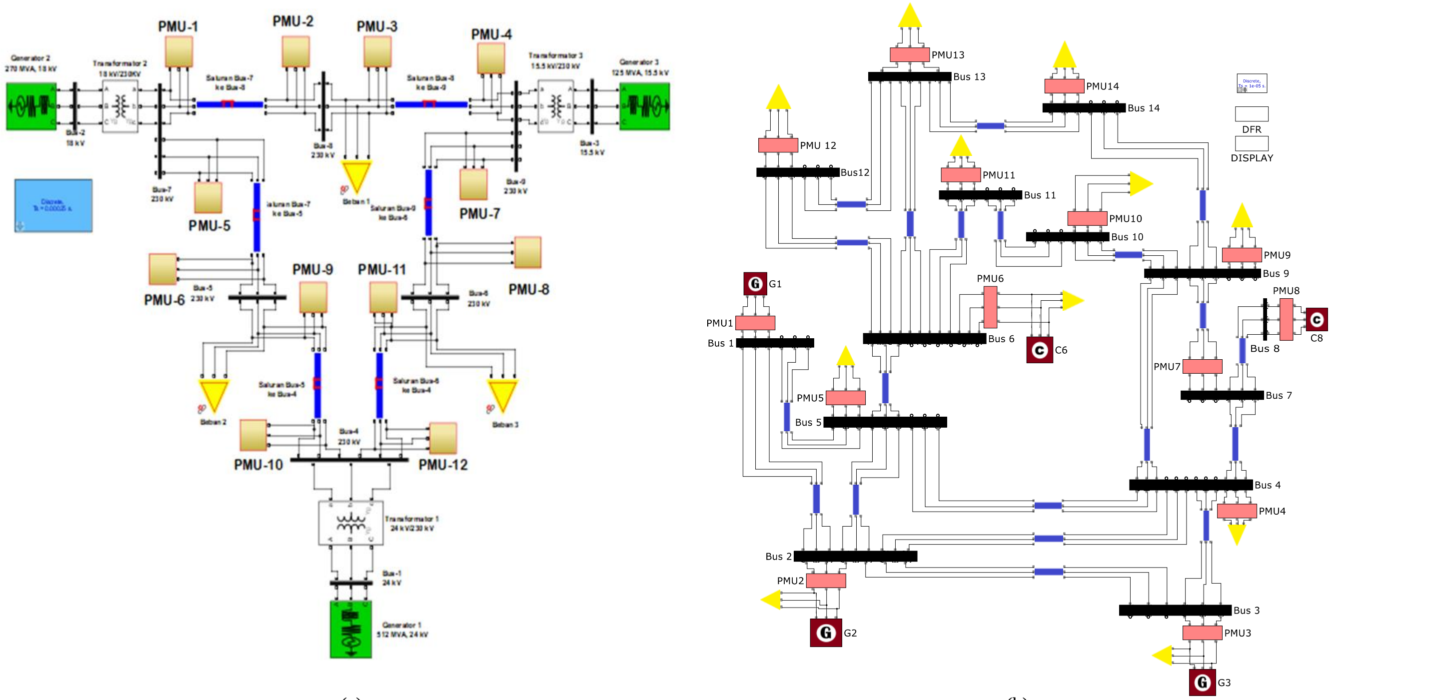
***Fig. 3**. Demonstration of PMU*

Figure 4 shows the PMU combines the measure of supervising, defense, and controller schemes, and also have the possibility of being affected by a widespread part scheme. It also harmonizes the voltage and measures the current in different categories of fault in an electrical power scheme. However, the actuality was checked to defend the power energy in the scheme [14]. This study constructed an IEEE 9-bus & 14-bus tests to demonstrate the PMU. In this typical, an excellent zone dimension technique is useful for the PMU through the successful implementation of a triple-phase short circuit virtual reality at a fault space target of 10%, 30%, 50%, 70%, and 90%.Root Mean Square Error (RMSE) was used with the Mean Absolute Error (MAE) to estimate the typical inaccuracy in the model. The RMSE is a quadratic clearing instruction to determine the scale of the ordinary inaccuracy by modifying the usual square root of the real rate to produce a forecasted price while MAE is usually used significantly for typical fault forecasts. However, the Mean Square Error (MSE) is usually used to predict every failure. The sample experiment involves the complete modification of the real and analytical rates and a similar weight was observed in the differentiation of every information. The RMSE and then, the MAE equivalences of an aggregate of information were used to obtain inequality as shown in equations (13), (14), and (15) [23].

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - y_i')^2} \quad (13)$$

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - y_i'| \quad (14)$$

$$\text{MSE} = \frac{|y_i - y_i'|^2}{N} \quad (15)$$



(a) (b)

***Fig. 4**. Model of MATLAB/Simulink (a) IEEE 9-bus test (b) IEEE 14-bus test*

3 Result and Analysis

The outcomes of the triple-phase short circuit fault model showed there was a connection at the IEEE 14-bus with the fault at 10%, 30%, 50%, 70%, and 90%. Moreover, the regeneration was used to determine the location of the triple-phase short circuit fault for every transmission connection during the diagnosis. Subsequently, the percentage inaccuracy was calculated using RMSE and MAE on every connection on the IEEE 9-bus & 14-bus systems at a space alternative strong minded. This was followed by the connection of the PMU to every bus to show the supervising consequences of the current and voltage phasor standards using MATLAB/Simulink. Furthermore, the ANN which was designed to have three network structures including voltage, current, and the combination of both was used to detect the location of faults and the percentage of the inaccuracies in the fault analysis are presented in Figure 5. The triple-phases short circuit fault was replicated on an electrical transmission system in the IEEE 14-bus test by varying the space at 10%, 30%, 50%, 70%, and 90%.Figure 6 shows the results from the ANN analysis which was conducted using new data as well as three structures with different previously trained inputs. The correct number of bus observations divided by the amount of test data showed there was accuracy in each bus with the input voltage observed to be at 95% while the current was 96% and the combination of both was found to be more than 93%. Moreover, the input voltage was found to be 100% accurate on buses 7, 8, and 14, input current on 3, 8, 9, 10, and 14 while the combination of both was found only with bus 14. This, therefore, means input current was accurate for most of the buses.

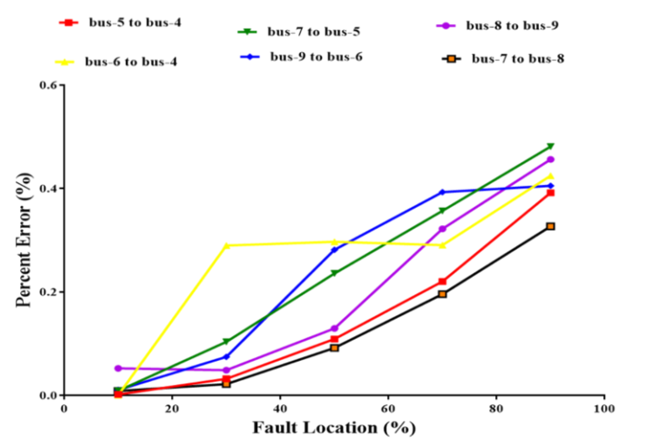


***Fig. 5**. A percentage scheming of the fault analysis of the 9-bus test*

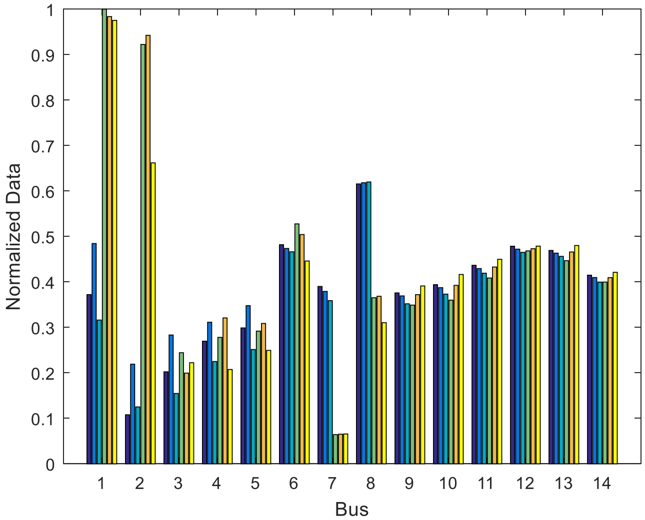


***Fig. 6**. Train data generalizations of ANN for 14-bus test*

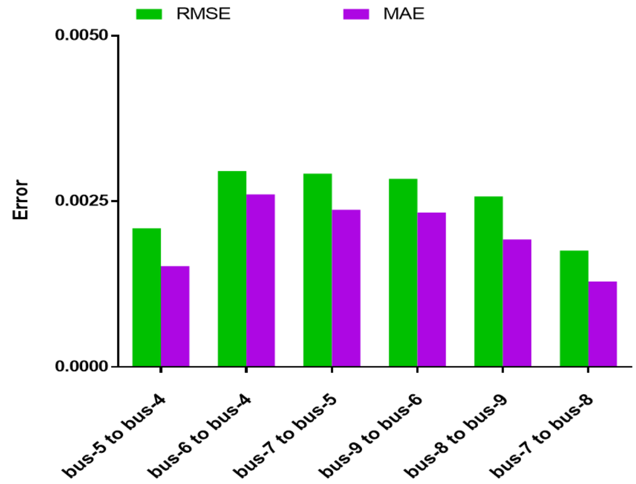


***Fig. 8**. Chart of RMSE & MAE*

Figure 7 shows the result of the overall efficiency of the ANN inputs with the voltage found to be 85%, current at 89%, and the combination of both at 78%. Accuracy of correct prediction of fault locations required the ANN to produce valid values at all points on all buses. Therefore, the test results showed appropriate outputs were found for the bus, however, the calculation would be declared invalid if one wrong value was obtained from the 14-bus system. Each type of input was tested 100 times and the input voltage was observed to have provided correct value for all buses of 85 trials, current for 89, and the combination of both for 78. Figure 8 shows the rate of the inaccuracy between the RMSE and MAE in separately transmission lines on the IEEE 9-bus test. The replication outcomes were used to track the triple-phase short circuit fault using the PMU and the inaccuracy rate between RMSE and MAE was found to be less substantial an acceptable by the nominal standards. This, therefore, means the model established for this system is first-rate.

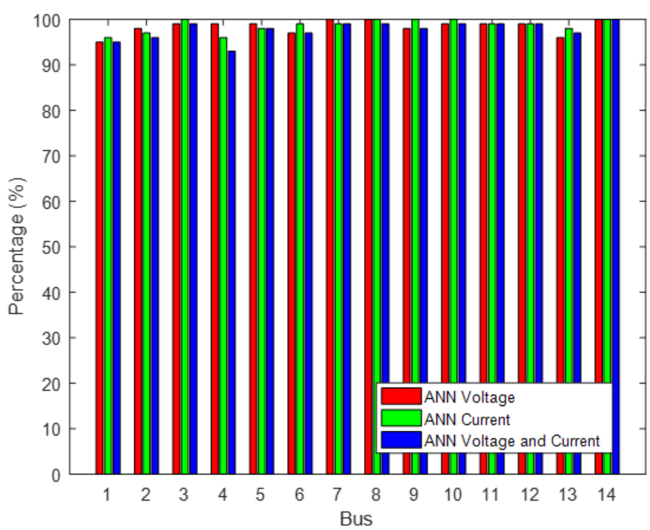


***Fig. 7**. The accuracy of ANN in each bus in the 14-bus test*

Figure 9 shows the ANN produced the best accuracy during the experiment with the MSE value of the input current observed to be lesser at 0.8778 compared to the voltage at 0.8897 and the combination of both at 0.8811. Moreover, the current was also observed to have the fastest time of 582.81 seconds compared to the voltage at 617.77 and the combination of 692.07. This shows the value for the combination was the longest because it has more input than other ANNs. This is in line with the fact that a greater number of data increases the weights on ANN and affects the training time.

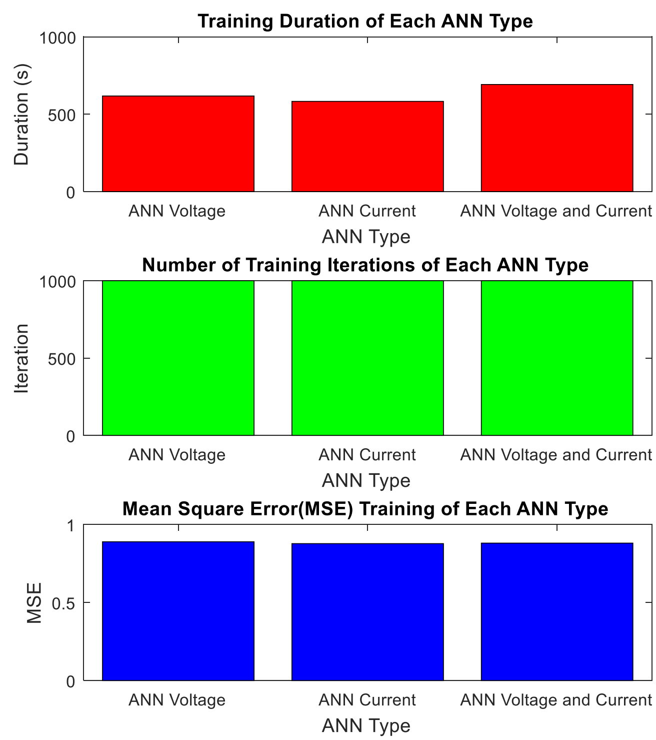


***Fig. 9**. Training for the three ANN structures*

4. Conclusion

Every line on the IEEE 9-bus test was simulated by varying the space at 10%, 30%, 50%, 70%, and, 90%. Moreover, the best substantial inaccuracy was obtained on the bus 9 to bus

6 through the fault location space of 90% of the 9-bus test identical to 0.72% with RMSE at 4.48*10-3 and MAE at 3.5*10-3 while a minimum inaccuracy on the bus-6 to bus-4 was discovered to be at the 10% fault location space due to the fact bus-8 was 4.03*10-4 %, RMSE 2.98*10-3, also MAE 2.6*10-3. The ANN design and analysis showed the PMU readings provided the voltage and current magnitude values were the same as the peak observed for those related to a sinusoidal wave with phase angles. The input effective for speeding up ANN for fault location detection was the data for current with a duration of training time of 582.81 seconds, the voltage at 617.77, and the combination at 692.07. Finally, the highest accuracy was found to be with currents at an efficiency of 89%, voltages with 85%, and the combination of both at 78%.

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6 References

[1] F. Zhou, "Architecture Design for Integrated Wide Area Protection and Control Systems," J. Power Energy Eng., 2014.
[2] S. Talpur and T. T. Lie, "PMU based WAMC application in multi-modular HVDC based large scale solar system," 2017 IEEE Innov. Smart Grid Technol. - Asia Smart Grid Smart Community, ISGT-Asia 2017, pp. 1–3, 2018, doi: 10.1109/ISGT-Asia.2017.8378460.
[3] X. Zhao, H. Zhou, D. Shi, H. Zhao, C. Jing, and C. Jones, "On-line PMU-based transmission line parameter identification," CSEE J. Power Energy Syst., vol. 1, no. 2, pp. 68–74, 2015, doi: 10.17775/cseejpes.2015.00021.
[4] Z. Wu et al., "Optimal PMU Placement Considering Load Loss and Relaying in Distribution Networks," IEEE Access, vol. 6, pp. 33645–33653, 2018, doi: 10.1109/ACCESS.2018.2841891.
[5] A. A. Zakri, M. W. Mustafa, H. Syaibi, and I. Sofimieari, "Monitoring Fault Diagnosis Based on Phasor Measurement Unit at Wide Area Systems," IEEE Xplore, pp. 245–249, 2020, doi: 10.1109/cencon47160.2019.8974748.
[6] J. Reyes, R.A. and Guardado, "A PMU Model for Wide Area Protection in ATP / EMTP," Trans. Power Deliv., pp. 1–6, 2015.
[7] D. Mallikarjuna, B., Reddy, M.J.B. and Mohanta, "A Case Study on Optimal Phasor Measurement Unit Placement for Emerging Indian National Smart Grid," IEEE, pp. 1956–1960, 2016.
[8] V. Mohammed Mahdi, "Artificial Neural Network Based Algorithm for Early Prediction of Transient Stability Using Wide Area Measurements," IEEE, pp. 1–5, 2017.
[9] H. S. Saeed Asgharigoavr, "Development of PMU-based backup wide area protection for power systems considering HIF detection," Turkish J. Electr. Eng. Comput. Sci., 2017.
[10] J. W. Lee, "Fault area estimation using traveling wave for wide area Protection," 2016.
[11] M. Qiu, H. Su, M. Chen, and Z. Ming, "Balance of Security Strength and Energy for a PMU Monitoring System in Smart Grid," no. May, pp. 142–149, 2012.
[12] A. S. Dobackhshari, "Transmission Grid Fault Diagnosis by Wide Area Measurement System," IEEE, pp. 1–7, 2013.
[13] M. Shahraeini and M. H. Javidi, "Wide Area Measurement Systems," Adv. Top. Meas., pp. 304–321, 2012.
[14] A. Waqar, Z. Khurshid, J. Ahmad, M. Aamir, M. Yaqoob, and I. Alam, "Modeling and Simulation of Phasor Measurement Unit (PMU) for Early Fault Detection in Interconnected Two-Area Network," 2018 1st Int. Conf. Power, Energy Smart Grid, pp. 1–6, 2018.
[15] K. Zimmerman and David Costello, "Impedance-Based Fault Location Experience," SEL J. Reliab. Power, vol. 1, no. 1, pp. 1–27, 2005.
[16] H. Yin, "PMU data-based fault location techniques," IEEE, 2010.
[17] S. Ben Hessine, Moez Ben., Saber, Accurate Fault Clasifier and Locator for EHV Transmission Lines Based on Artificial Neural Networks. 2014.
[18] A. A. Zakri and S. Tua, "Recurrent Neural Networks to Identify Fault in Transmission Line," vol. 62, no. 03, pp. 733–742, 2020.
[19] A. Narwan, M. W. Mustafa, D. Y. Sukma, and M. E. Dame, "Backpropagation Neural Network Modeling for Fault Location in Transmission Line 150 kV," Indones. J. Electr. Eng. Informatics, vol. 2, no. 1, pp. 1–12, 2014, doi: 10.11591/ijeei.v2i1.92.
[20] M. Raoofat, A. Mahmoodian, and A. Abunasri, "Fault location in transmission lines using neural network and wavelet transform," 2015 Int. Congr. Electr. Ind. Autom. ICEIA 2015, pp. 1–6, 2015, doi: 10.1109/ICEIA.2015.7165837.
[21] A. A. Zakri, S. Darmawan, J. Usman, I. H. Rosma, and B. Ihsan, "Extract fault signal via DWT and penetration of SVM for fault classification at power system transmission," Proc. - 2018 2nd Int. Conf. Electr. Eng. Informatics Towar. Most Effic. W. Mak. Deal. with Futur. Electr. Power Syst. Big Data Anal. ICon EEI 2018, no. October, pp. 191–196, 2018, doi: 10.1109/ICon-EEI.2018.8784320.
[22] E. K. Sai Sowmya Nagam, "Artificial Neural Network Based Fault Locator for Three Phase Transmission Line with STATCOM," 2017.
[23] T. Chai and R. R. Draxler, "Root mean square error (RMSE) or mean absolute error (MAE)? Arguments against avoiding RMSE in the literature," Geosci. Model Dev., vol. 7, no. 3, pp. 1247–1250, Jun. 2014.