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The performance comparison of artificial intelligence based distance relays for the protection of transmission lines

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ABSTRACT

The safe and reliable generation and transmission of electricity is the desirable factor for utilities which arises the need of protection equipment such as relays in the power systems. According to recent studies, the conventional relays are not able to provide the required protection to the power systems, resulting in the emergence of various artificial intelligence (AI) techniques such as (i) artificial neural network (ANN); (ii) adaptive neuro fuzzy interface system (ANFIS); and (iii) fuzzy logic based relays for the protection. This work presents the protection scheme for transmission lines using various AI based distance relays along with performance comparison of these relays with a conventional numerical distance relay (NL). The comparison analysis has been performed by generating a test model in the MATLAB/Simulink environment and comparing "response time" against the same fault occurence for all relays. The comparison analysis found that AI based relays outperformed than conventional relay in terms of response time and accuracy level against the faults.

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1. INTRODUCTION

Protection is an essential feature of the power systems and for that reason various protection equipment are being used in order to ensure secure and safe operation of the power system. Relays are the devices which are extensively used to provide protection in the power systems and they play a vital role in the fault detection and isolation. Normally, a relay is an electromechanical device and its switching operation is combination of both electronic and mechanical components. Unfortunately, this electromechanical combination in the relay leads to the time delay between an action taken and the response of relay, which may be called as the "response time" of relay. Response time has a crucial importance in the parameters of a relay and a minimum response time is usually desired from the protection equipment for an effective protection. There are various type of relays but distance protection relay is extensively used in the power networks and transmission lines for providing safety and protection. This relay detects the fault by change in the line impedance due to fault occurrence. Whenever a fault occurs, the distance relay decreases the line impedance and thus the relay detects the fault by comparing this change in impedance with a predefined threshold value of impedanc. So, as soon as the impedance change occurs in a transmission line, the distance protection relay responds to fault condition and takes action according to the change in the set-point(s) [1], [2]. There are three types of distance protection relays based on their working principle namely reactance type, impedance type and mho type. Reactance and impedance type are non-directional relays but mho type is directional. The above mentioned three types of relays are used in various types of transmission lines depending on the situation and conditions of the environment [3]. Apart from the benefits of the distance protection relays, there are many other challenges as well which are associated with the effective implementation of the distance relays. For instance, the signals of current and voltage from the distance relay may contain some DC component and harmonics in addition to the fundamental frequency. These associated issues with the distance relays make them unsuitable for effective protection of the power systems. That's why for the purpose of phasor extraction, various methods such as discrete fourier transform [3], symmetrical components [4], kalman filtering [5] and orthogonal expansion [6] can be used. In addition to that, another technique to measure positive sequence incremental impedance has also been presented in the previous works as well [7]. This implies that conventional electromechanical distance protection relays may generate long "response time", which is not desirable for the effective protection of the power systems. Whereas, in case of advanced protection relays, other methods such as differential equations and mathematical operation are used to calculate the impedance, which are obviously more accurate and fast methods. Overall, this can be deduced from the above discussion that the distance protection relays have various categories of mis operations and even solution to these mis operations cannot eliminate the associated challenges completely [8]-[11]. Consequently, it can be concluded that conventional methods of distance protection relays have some limitations in the optimum operation of relay and thus fail to provide better protection.

Keeping in view the issues associated with the conventional distance relays, the protection technology of the power systems is adapting artificial intelligence (neural networks, fuzzy logic) for the relays to enhance the protection levels of the relays. Artificial intelligence (AI) provides good solution for the power system protection in terms of the selection and the decision taking for the distance relaying. Among the various AI protection techniques, it has been observed that fuzzy logic control in relays provides very fast and accurate performance because there is no need to solve mathematical equations in fuzzy based system [12], [13] as required in the other techniques. However, there is another type of AI protection technique, named as ANFIS relaying, in which fuzzy logic is used to define the linear operating regions and the fuzzy logic controller is implemented in neuro fuzzy network. This technique has advantage over the fuzzy logic controller because simple fuzzy logic controller does not provide training of the system which in fact helps in the effective detection of faults. Thus, it might be said that AI based distance relays are designed with trained data set for specific output and usually provide very accurate results.

In this proposed work, in order to improve and examine the protection level of transmission lines, various AI based distance relays have been investigated because they have shown tremendous improvements in the performance of many systems in recent years [14]-[16]. Moreover, in this paper a performance comparison has been performed between conventional distance relay (NL), fuzzy logic based distance relay (FLR), ANFIS and artificial neural network (ANN) feed forward based distance relays in order to check their response time towards faults and levels of accuracy. For the said purpose, a simulation model for the protection is generated in MATLAB/Simulink environment and comparison is performed between all four types of relays based on the response time and accuracy to the same fault level.

2. METHOD

In order to perform the analysis and comparison of various relays, a simulation model of the transmission line is generated in MATLAB/Simulink as shown in Figure 1(a). The network model for the simulation has adjacent transmission lines of 240 kV and the relay to be tested is located at bus 1. The comparison has been performed by placing the various relays at the position of relay at bus 1 in the model and then evaluating the system against the same fault for each relay. The model has been distributed in 3 zones as shown in the figure. The test relay operates by obtained voltage and current values from current and voltage transormers (CT and PT) on bus 1, which are passed through 2nd order anti-aliasing low pass filter before applying to relay as described in the Figure 1(b). The details of the AI based relays simulated in the provided simulation model are given as:

2.1. Fuzzy logic based distance relay

The first relay to be used in the simulation model is the FLR. For the fuzzy interface system in FLR, a Mamdani interface is chosen because it provides simplified controller designing. The basic feedback control scheme has been used for the implementation of the fuzzy logic controller because in this scheme the threshold impedance is monitored and compared continuously with the output impedance unless difference reduces drastically, as provided in [17]:

$$(Z + 1) = Z_{th} - Z \mid (Z_{th} - Z) > 0 \quad (1)$$

$$(Z + 1) = Z_{th} - Z \mid (Z_{th} - Z) = 0 \quad (2)$$

Where Z is the obtained impedance and Z_{th} is the threshold value of impedance.

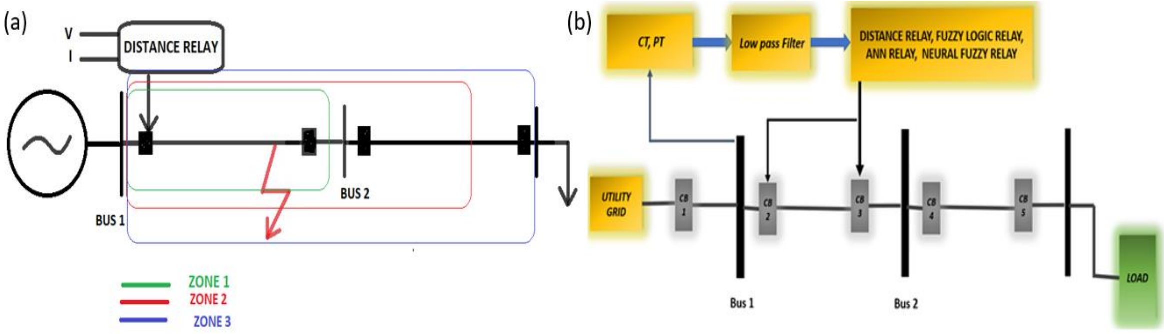
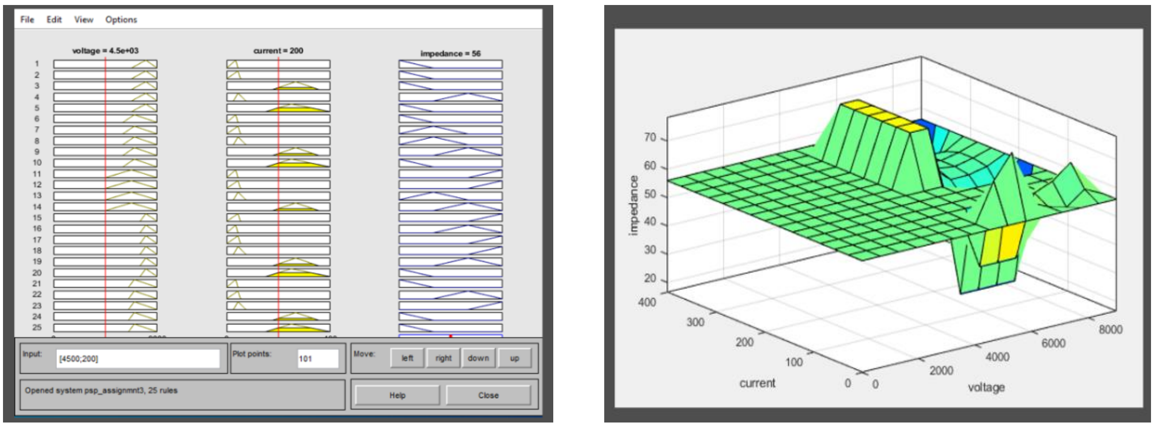


Figure 1. The complete figure of simulation model as developed in MATLAB (a) the simulation model of transmission line along with zones details and location of the testing relay and (b) the complete diagram of simulation model with the testing relay

The relay control has been designed according to the operational determinants in our protection network i.e.; current, voltage, and impedance. The controlling current parameter is the over-current of FLR as safety action will be taken depending on the occurrence of overcurrent due to the fault. On the other hand, the control parameters of voltage for this FLR will be either under-voltage or over-voltage. The very first step for implementing the fuzzy logic scheme is the fuzzification which involves converting crisp or traditional parameters into fuzzy parameters, acceptable for fuzzy operations and processing. In this work, triangular membership functions are used for FLR due to their simplicity, low-memory space requirement and ease of adjusting control output functions. The fuzzy rules have been developed in such a way that, when current is very high and voltage is low the relay is open while on the other hand when current is low and voltage is high the relay should close. Whereas, there can also be intermediate operating conditions for these relays and the fuzzy rules should be designed while taking into account such situations. For the FLR controller, the internal operations have been shown in the Figure 2(a) and these operations are based on the developed fuzzy rules. In the Figure 2(b) the three-dimensional view of the relay operations have been explained with three dimensional image. Defuzzification is the last step of fuzzy logic-based controller and the defuzzification converts a fuzzy quantity into a precise quantity. The centroid method (center of the area) has been used in this work for the said purpose. These output values act as the actuating signal for the operation of relay.



(a) (b)

Figure 2. Fuzzy logic based control in relay (a) the performance diagram of the fuzzy logic controller with internal operations and (b) three-dimensional view of the fuzzy logic based relay operations

2.2. Adaptive neuro fuzzy interface system

The next AI based relay selected for the performance comparison is adaptive neuro fuzzy interface system (ANFIS). ANFIS is a multilayer method that uses neural network learning algorithm and fuzzy logic reasoning. The ability of the fuzzy logic system to unify values with the neural network capability to adopt numerical value, has made ANFIS good in performance for modeling and updating the systems [18]-[24]. The ANFIS has five layers for operations discussed. In the first step of fuzzification, the node of functions having membership degree which include compatible fuzzy are set by using membership functions as provided here [25]:

$$O_{i,1} = \mu_{A_i}(x) \text{ for i=1,2} \tag{3}$$

$$O_{i,1} = \mu_{B_{i-2}}(y) \text{ for i=3,4} \tag{4}$$

Where x, y are crisp inputs to the node and A_i , B_i

$$\mu_{Ai} = \begin{cases} 1 - \frac{a_{i1}-u}{a_{i2}} \; if \; a_{i1} - a_{i2} \leq u \leq a_{i1} \\ 1 - \frac{u-a_{i1}}{a_{i3}} \; if \; a_{i1} \leq u \leq a_{i1} + a_{i3} \\ 0 \; otherwise \end{cases} \tag{5}$$

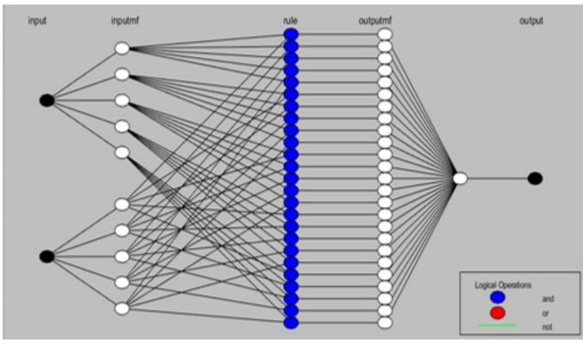
$$\mu_{Bi} = \begin{cases} 1 - \frac{b_{i1}-v}{b_{i2}} \; if \; b_{i1} - b_{i2} \leq v \leq b_{i1} \\ 1 - \frac{v-b_{i1}}{b_{i3}} \; if \; b_{i1} \leq v \leq b_{i1} + b_{i3} \\ 0 \; otherwise \end{cases} \tag{6}$$

Where $\{a_i, b_i, c_i\}$ are the parameters set for membership function in premise part of fuzzy. After that, there is "if-then" rule that changes shape of membership functions (voltage, current and impedance) and the membership function can be of any shape such as triangular, gaussian and trapezoidal. The membership function for ANFIS in our case is of triangular shape. The ANFIS model has been presented in the Figure 3(a), where each input has been distributed into five triangular fuzzy members while 25 rules have been generated with MATLAB neuro fuzzy toolbox. In the figure, the blue dots are depicting the "AND" functions and these functions correspond to a certain neuron. The Figure 3(b) represents the internal operations of the ANFIS controller based on the developed operational rule. Whereas, the Figure 3(c) is showing the ANFIS rules as developed by neuro fuzzy system and there is a specific impedance value for each value of the voltage and current.

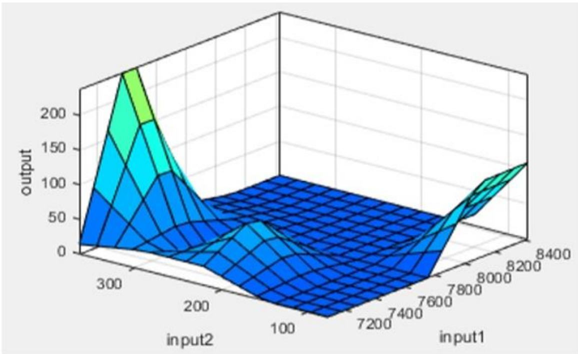
2.3. Artificial neural network feed forward based relay

The third AI based relay selected for the comparison purpose is ANN feed forward relay. In this technique, the ANN is neural system which resembles with the biological brain. It has three layers composed of input layer, hidden layer and output layer. The input given to the system is in the form of commands, database and different codes. In the hidden layer, processing is done using iteration called epoch and during each epoch the evaluation of each process is performed. Figure 4(a) shows the structure of ANN feed forward implementation inside the relay and the Figure 4(b) provides the image of detailed neural network for the distance relay. In this network, there are two inputs of the current and voltage and output value is impedance which has been obtained by corresponding value of current and voltage available at the input. The whole system is trained in order to detect faults and the performance function of ANN is mean square error (MSE). For this work, in order to train the network 2500 sample were taken and the corresponding figure shows that there is less chance of error because of small error value in the proposed scheme.

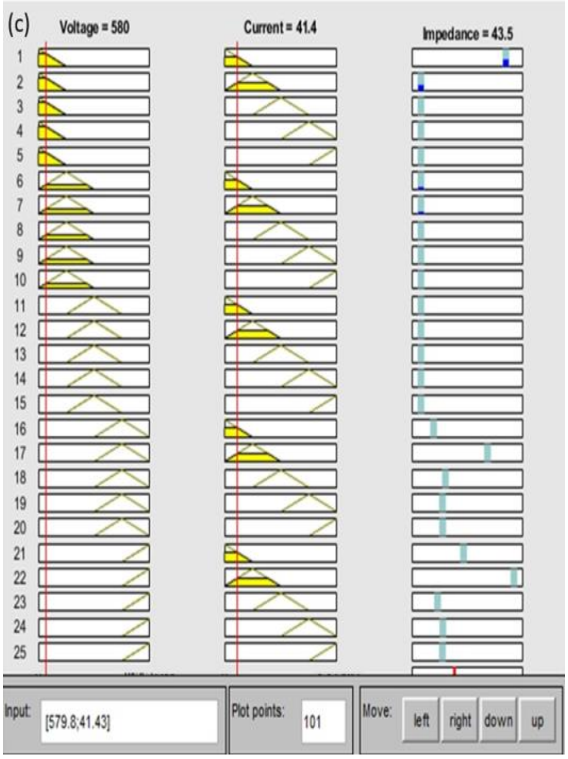
The testing, target and training of the data has been provided in the Figure 5. The regression plot of the ANN feed forward relay as shown in Figure 5(a) presents the training of given data with target output while the Figure 5(b) presents the validation of given input data with target value. Figure 5(c) shows the testing of given data with target output and Figure 5(d) depicts the overall comparison of input given data with target output value. In the Figure 5, the dot circle represents data and solid line represents fit line. If the data is above the line then it is accurate and if the data is below line than there is error. It is evident from the figure that most of data is trained in an accurate way.



(a)

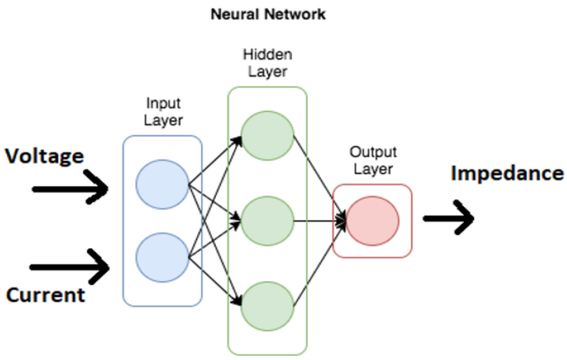


(b)

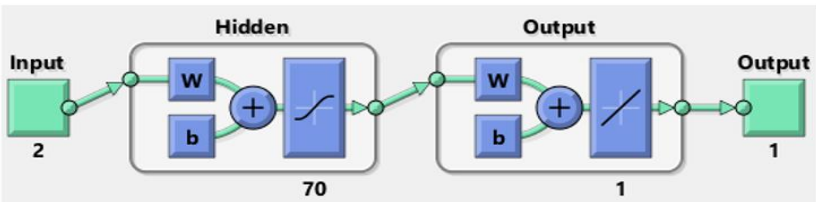


(c)

Figure 3. Adaptive neuro fuzzy interface system (ANFIS) implementation for relay control (a) the planned structure model of the ANFIS control in distance relay, (b) the three-dimensional view of the ANFIS relay operations and (c) the relation between current and voltage for specific zone protection



(a)



(b)

Figure 4. ANN feed forward implantation model for relay control (a) the implementation model of the ANN feed forward inside the distance relay and (b) the detailed image of the neural network of the distance relay

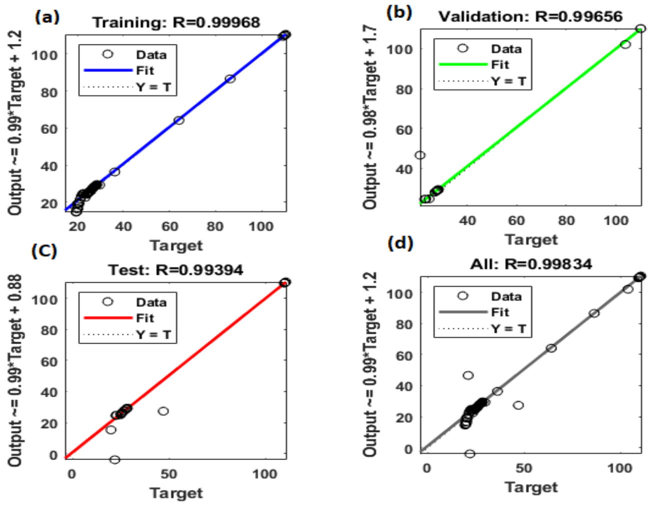


Figure 5. Regression plot of ANN feed forward relay (a) training of given data with target output, (b) the validation of given input data with target value, (c) the testing of given data with target output, and (d) the overall comparison of input given data with target output value

3. RESULTS AND DISCUSSION

In order to compare the performance of the above mentioned relays, the simulation has been performed in MATLAB/Simulink for the provided simulation model in the Figure 1. The comparison is performed for the same type of symmetrical fault and for the same location in the network (as shown in Figure 1) while keeping the loading conditions constant. The working algorithm for the fault detection using AI technology for distance relaying has been provided in the Figure 6. This is evident from the algorithm that fault is detected by the change in the impedance and then various AI methods are subjected accordingly for the generation of trip signals.

The simulation model system has been simulated every time for the same fault by replacing the relay only in order to perform a comparison. For the comparison purpose, the response time of each relay is recorded towards the same fault (line to ground) in order to find the fastest response relay against faults. The obtained results have been summarized in Table 1. It is clear from the comparison that the ANN feed forwards relay outperformed as compared to remaining three relays with the response time of 1.025s. Whereas, the simple conventional relay showed the longest response time and thus cannot provide good protection. On the other hand the other AI based relays (FLR and ANFIS) provide response time faster than numerical relay but slower than ANN feed forward relay. Furthermore, it can be deduced from above stated that ANN feed forward relays can provide fast and better safety in the system against the faults due to quick response and quick isolation of fault and ultimately providing better protection to the system.

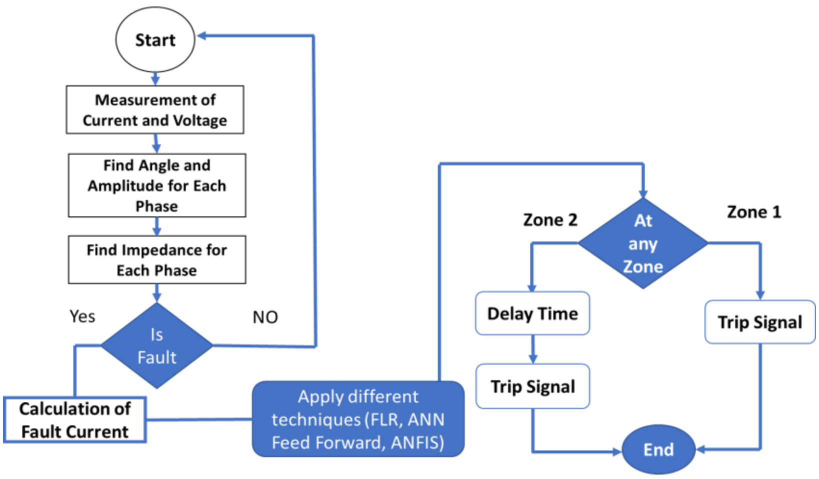


Figure 6. The working algorithm for the fault detection in the AI based distance relays

Table 1. The comparisons of response time for different relays

Relay type	Time (s)	Time (cycle)
Numerical relay (NL)	1.065	63.9
Fuzzy logic relay	1.055	63.3
ANFIS	1.03	61.8
ANN feed forward relay	1.025	61.5

The Figure 7(a) represents the comparison of the fault currents from the current sensors while the insert image presents the zoomed-in view of the current from different relays in order to get the better picture of the comparison. It shows that ANN based feed forward relay will operate quickly than other relays and current become zero after clearing fault faster. Whereas, in case of other relays the response is slow and current does not drop to zero as quickly as in the case of ANN feed forward relay. The Figure 7(b) presents the accuracy level of relays (ANN, ANFIS, FLR and NL) calculated in different zones of the network. It is found that accuracy level of ANN feed forward relays in zone 1 is 97 %, and ANFIS is 93 %, which is obviously higher that FLC and numerical relay that stand at 89% and 80% respectively as can be visulaized in the Figure 7(b). In zone 2 for different types of faults, the results showed accuracy level of 93.5 % for ANN feed forward, 89%, for ANFIS, 85% for FLC and 75 %. for NL in zone 3 the accuracy level stands at 87%, 83%, 83% and 70% for ANN, ANFIS, FLC and NL respectively.

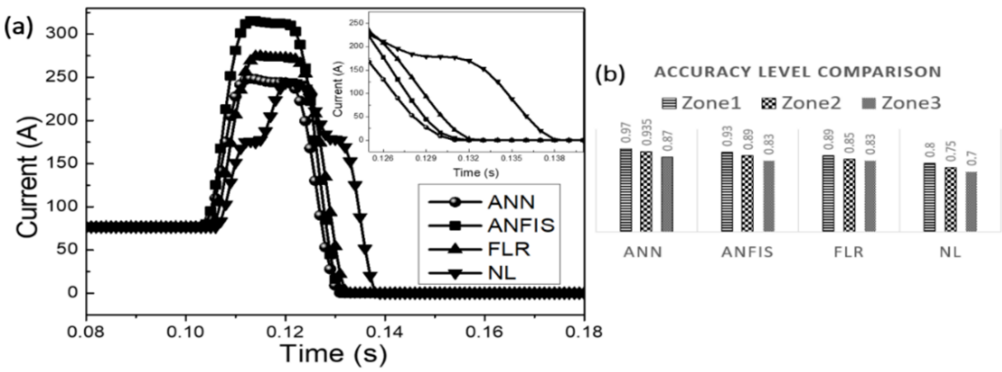


Figure 7. The comparitve study of different relays under fault occurrence (a) the comparison of the fault currents of different relays after tripping the circuit breaker (the insert image shows the zoomed view of the currents for a better comparison) and (b) the accuracy levels of various relays in different zones of the transmission line network

4. CONCLUSION

Overall, this paper presents the implementation of AI approaches in the distance relaying for the protection purposes along with the performance comparison of various AI based relays in the transmission lines model. In this work, within a single zone of network, protection comparison for a certain fault is performed between ANN feed forward, ANFIS, FLR and conventional distance relay. From the obtained results, it is evident that the ANFIS and ANN feed forward perform more accurately and fast as compared with FLR and conventional numerical relays under fault occurrence. However, the ANN based feed forward technique is found to be more faster than other AI based techniques for the protection purposes. It is also worth mentioning that, the AI based relays are better and faster than conventional numerical relays in terms of response time and accuracy of the faults detection.

REFERENCES

[1] C. Pang and M. Kezunovic, "Fast Distance Relay Scheme for Detecting Symmetrical Fault During Power Swing," *IEEE Transactions on Power Delivery*, vol. 25, no. 4, pp. 2205-2212, 2010, doi: 10.1109/TPWRD.2010.2050341.

[2] L. G. Lajoie, "A MHO distance relay device in EMTPWorks," *Electric Power Systems Research*, vol. 79, no. 3, pp. 484-491, 2009, doi: 10.1016/j.epsr.2008.09.010.

[3] P. G. McLaren and M. A. Redfern, "Fourier-series techniques applied to distance protection," *Proceedings of the Institution of Electrical Engineers*, 1975, vol. 122, no. 11, pp. 1301-1305. doi: 10.1049/piee.1975.0316.

[4] A. G. Phadke, T. Hlibka, M. Ibrahim, and M. G. Adamiak, "A Microprocessor-Based Symmetrical Component Distance Relay," *Proceedings of PICA*, 1979, pp. 40–60. doi: 10.1109/PICA.1979.720045.

[5] A. A. Girgis and E. B. Makram, "Application of adaptive Kalman filtering in fault classification, distance protection, and fault location using microprocessors," *IEEE Transactions on Power Systems*, vol. 3, no. 1, pp. 301-309, 1988, doi: 10.1109/59.43215.

[6] P. Kang, M. Farzad, S. Stricevic, P. Sadegh, and A. M. Finn, "Sensor fault diagnostics and prognostics using component model and time scale orthogonal expansions," *United States Patents*, 2007.

[7] P. G. McLaren, G. W. Swift, Z. Zhang, E. Dirks, R. P. Jayasinghe and I. Fernando, "A new directional element for numerical distance relays," *IEEE Transactions on Power Delivery*, vol. 10, no. 2, pp. 666-675, 1995, doi: 10.1109/61.400865.

[8] A. M. Abdullah and K. B. Purry, "Distance protection zone 3 misoperation during system wide cascading events: The problem and a survey of solutions," *Electric Power Systems Research*, vol. 154, pp. 151-159, 2018. doi:10.1016/j.epsr.2017.08.023.

[9] V. C. Nikolaidis, "Emergency Zone 3 Modification as a Local Response-Driven Protection Measure Against System Collapse," *IEEE Transactions on Power Delivery*, vol. 31, no. 5, pp. 2114-2122, 2016, doi: 10.1109/TPWRD.2016.2552644.

[10] X. Lin *et al.*, "Countermeasures on preventing backup protection mal-operation during load flow transferring," *International Journal of Electrical Power & Energy Systems*, vol. 79, pp. 27-33, 2016, doi: 10.1016/j.ijepes.2015.12.027.

[11] P. Gawande, P. Bedekar, M. Bagewadi and S. Dambhare, "An adaptive distance relay protection scheme for enhanced protection security," *IEEE 6th International Conference on Power Systems (ICPS)*, 2016, pp. 1-6, doi: 10.1109/ICPES.2016.7584119.

[12] M. Idrees *et al*., "Fuzzy Logic Based Calculation and Analysis of Health Index for Power Transformer Installed in Grid Stations," *International Symposium on Recent Advances in Electrical Engineering (RAEE)*, 2019, pp. 1-6, doi: 10.1109/RAEE.2019.8887016.

[13] M. R. Javed *et al*., "A Comparative Study of Maximum Power Point Tracking Techniques for Solar Systems," *22nd International Multitopic Conference (INMIC)*, 2019, pp. 1-6, doi: 10.1109/INMIC48123.2019.9022762.

[14] M. Fadaeenejad, A. M. Saberian, M. Fadaee, M. A. M. Radzi, H. Hizam, and M. Z. A. AbKadir, "The present and future of smart power grid in developing countries," *Renewable and Sustainable Energy Reviews*, vol. 29, pp. 828-834, 2014, doi:10.1016/j.rser.2013.08.072.

[15] R. M. S. Dawood, G. Pillai and M. Al-Greer, "Fuzzy Logic Based Scheme for Directional Earth Fault Detection and Classification," *53rd International Universities Power Engineering Conference (UPEC)*, 2018, pp. 1-6, doi: 10.1109/UPEC.2018.8542006.

[16] P. K. Dash, A. K. Pradhan and G. Panda, "A novel fuzzy neural network based distance relaying scheme," *IEEE Transactions on Power Delivery*, vol. 15, no. 3, pp. 902-907, 2000, doi: 10.1109/61.871350.

[17] A. K. Babarinde, P. A. Adewuyi, and A. A. Adekunle, "Design of Fuzzy Logic Based Relay for Distance Protection," *FUOYE Journal of Engineering and Technology*, vol. 2, no. 2, 2017. doi: 10.46792/fuoyejet.v2i2.104.

[18] Z. Alameer, M. A. Elaziz, A. A. Ewees, H. Ye, and Z. Jianhua, "Forecasting copper prices using hybrid adaptive neuro-fuzzy inference system and genetic algorithms," *Natural Resources Research*, vol. 28, no. 4, pp. 1385-1401, 2019. doi: 10.1007/s11053-019-09473-w.

[19] L. Tightiz, M. A. Nasab, H. Yang, and A. Addeh, "An intelligent system based on optimized ANFIS and association rules for power transformer fault diagnosis," *ISA Transaction.*, vol. 103, pp. 63-74, 2020, doi:10.1016/j.isatra.2020.03.022.

[20] W. R. A. Ibrahim and M. M. Morcos, "An adaptive fuzzy self-learning technique for prediction of abnormal operation of electrical systems," *IEEE Transactions on Power Delivery*, vol. 21, no. 4, pp. 1770-1777, 2006, doi: 10.1109/TPWRD.2006.881795.

[21] O. Noureldeen and I. Hamdan, "An efficient ANFIS crowbar protection for DFIG wind turbines during faults," *Nineteenth International Middle East Power Systems Conference (MEPCON)*, 2017, pp. 263-269, doi: 10.1109/MEPCON.2017.8301192.

[22] A. M. Salama, K. M. Abdel-Latif, M. M. Ismail, and S. M. Mousa, "A new hybrid protection algorithm for protection of power transformer based on discrete wavelet transform and ANFIS inference systems," *International Journal of Emerging Electric Power Systems*, vol. 19, no. 3, pp. 2017-0248, 2018. doi: 10.1515/ijeeps-2017-0248.

[23] D. Mlakić, H. R. Baghaee and S. Nikolovski, "A Novel ANFIS-Based Islanding Detection for Inverter-Interfaced Microgrids," *IEEE Transactions on Smart Grid*, vol. 10, no. 4, pp. 4411-4424, 2019, doi: 10.1109/TSG.2018.2859360.

[24] M. R. Javed, A. Waleed, U. S. Virk and S. Z. ul Hassan, "Comparison of the Adaptive Neural-Fuzzy Interface System (ANFIS) based Solar Maximum Power Point Tracking (MPPT) with other Solar MPPT Methods," *IEEE 23rd International Multitopic Conference (INMIC)*, 2020, pp. 1-5, doi: 10.1109/INMIC50486.2020.9318178.

[25] A. Azriyenni and M. W. Mustafa, "Application of ANFIS for Distance Relay Protection in Transmission Line," *International Journal of Electrical and Computer Engineering*, vol. 5, no. 6, pp. 1311-1318, 2015, doi: 10.11591/ijece.v5i6.pp1311-1318.

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