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# IDENTIFYING TYPES OF SIMULTANEOUS FAULT IN TRANSMISSION LINE USING DISCRETE WAVELET TRANSFORM AND FUZZY LOGIC ALGORITHM

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Abstract. *In the literature for fault classification, several decision algorithms have different solutions and techniques. These research works have been rarely mentioned about simultaneous faults in transmission systems. This paper presents the decision algorithm for identifying types of simultaneous fault along the transmission line. Decision algorithms based on discrete wavelet transform (DWT) and fuzzy logic are investigated. The analysis of fault signals is performed using DWT. The DWT is used in order to detect the high frequency components. The coefficient details (phase A, B, C and zero sequence of post-fault current signals) of DWT at the first peak time that positive sequence current can detect fault, are performed as an input for the fuzzy logic. The result shows that the accuracy of the proposed algorithm is highly satisfactory.*
**Keywords:** Wavelet transform, Fuzzy logic, Simultaneous fault, Transmission line

1. **Introduction.** The development of the algorithm for detecting the faults on the transmission lines has been progressed, especially in recent years. These several decision algorithms have different solutions and techniques [1-18]. Although these algorithms can give precise results in fault analysis, the effects of simultaneous faults have not been yet taken into account. Simultaneous faults are the situation that two or more faults occur at the same time, but at different locations. Such a fault can lead to the malfunction of the protective relays. It is necessary that the protection system must function precisely during simultaneous faults, and it is very advantageous if the simultaneous faults are taken into account in the decision algorithm of the relays. In previous research works [1,19], in order to classify characteristics of single fault and simultaneous faults in electrical transmission system, the variation of maximum coefficients from the first scale of discrete wavelet transform (DWT) extracted from high frequency components at the duration of 1/4 cycle of phase A, B, C and zero sequence of post-fault current signals is used as an indicator of a fault occurrence. However, when this algorithm is employed in simultaneous fault classification, it gives an unacceptable precision in classifying the fault types. This shows the failure of the decision algorithm when dealing with simultaneous fault cases. When carefully investigating, it is found that the error in simultaneous fault classification is caused by an effect of the zero sequence current from the other fault that occurs at the other side of the system. In order to overcome this problem, a new algorithm has been developed. The coefficients detail (phase A, B, C and zero sequence of post-fault current signals) of DWT at the first peak time that positive sequence current can detect fault, is

performed as comparison indicator. The new decision algorithm can give more satisfactory results in simultaneous fault cases. Even though the new algorithm can overcome the drawback of the previous one in classifying simultaneous faults, the overall accuracy indicates that the algorithm requires the further improvement.

Back-propagation neural network (BPNN) is a kind of neural networks, which is widely applied today owing to its effectiveness to solve almost all types of problems. In previous research works [20], in order to classify fault types in electrical transmission system, the variation of maximum coefficients from the first scale of discrete wavelet transform (DWT) extracted from high frequency components at the duration of 1/4 cycle of phase A, B, C and zero sequence of post-fault current signals can be used as an input for the training process of an artificial neural network in a decision algorithm. In addition, BPNN is also compared with Radial basis function (RBF) neural network. Even if the application of BPNN algorithm can give more satisfactory results, in practice, BPNN is partly limited by the slow training performance. This drawback of BPNN must be improved; otherwise the other artificial intelligence should be developed instead.

Therefore, this paper presents a development of decision algorithm used in the protective relays in order to identify types of simultaneous fault along the transmission systems. A decision algorithm based on DWT and fuzzy logic is an alternative or improvement to the existing protective relaying functions. It is interesting to investigate an appropriate fuzzy logic if the fault types on the transmission line can be identified using DWT and fuzzy logic for being included in newly-developed protection systems. The fault signals are simulated using PACAD/EMTDC. The current waveforms obtained from the simulation are next extracted using the DWT. The validity of the proposed algorithm is tested with various fault inception angles, fault locations, and faulty phases. In addition, the construction of the decision algorithm is detailed and implemented with various case studies based on Thailand electricity transmission systems.

2. **Power System Simulation Using EMTP.** The PSCAD/EMTDC is employed to simulate fault signals at a sampling rate of 200 kHz (The sampling time used in PSCAD/EMTDC is 5 $\mu$sec). The system under investigations is a part of Thailand electricity transmission network systems as illustrated in Figure 1. To avoid complexity, the fault resistance is assumed to be 10 $\Omega$. Fault patterns in the simulations are performed with various changes in system parameters as follows:

- Fault types are single line to ground, double lines to ground, line to line, three-phase fault and three-phase to ground fault (AG, ABG, AB, ABC, ABCG);
- For the single fault, fault locations are from 10% to 90% (each step = 10%) of the transmission line length measured from the TTK bus;
- For the simultaneous faults, the location of F1 on the transmission line is designated at 10% and 50% of the transmission line length measured from the TTK bus;
- For the simultaneous faults, the location of F2 on the transmission line is designated at 50% and 90% of the transmission line length measured from the TTK bus;
- Fault inception angles on the phase A voltage waveform are varied from 0° to 150° with a step of 30°.

Fault signals generated by PSCAD/EMTDC are employed as input for the wavelet toolbox of MATLAB to analyse the high frequency transient components. The Clark's transformation matrix is employed to calculate the positive sequence and zero sequence of currents. The mother wavelet daubechies4 (db4) [22-25] is employed to decompose high frequency components from signals. An example of single fault current signals is shown in Figure 2(a) and Figure 2(b). There is a fault occurring at the length of 10% measured from the bus TTK as depicted in Figure 1. Meanwhile, an example of simultaneous fault

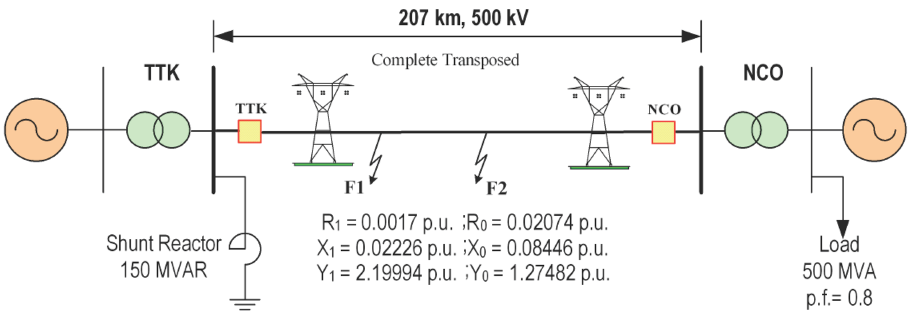
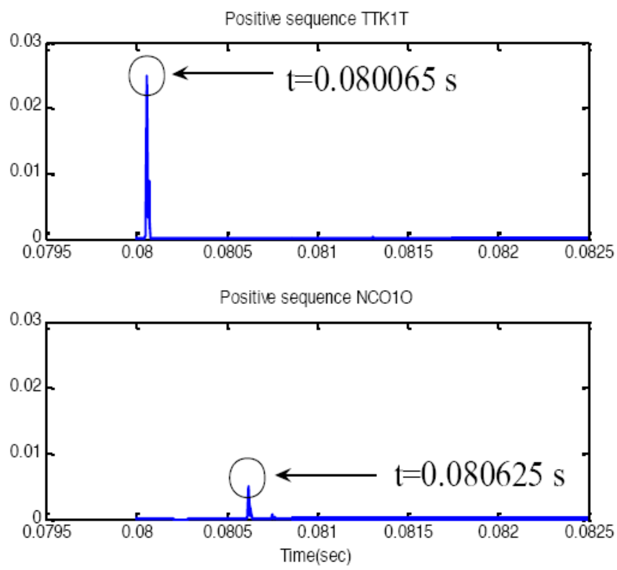
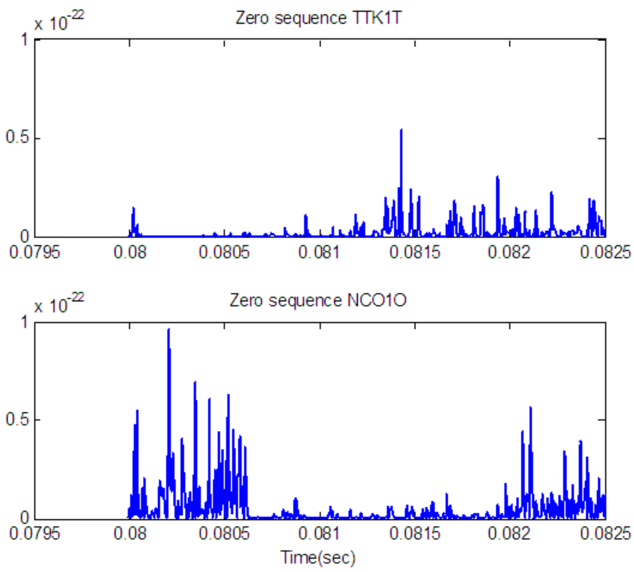



FIGURE 1. The system used in simulations studies for double circuit structure (system 1) [21,22]

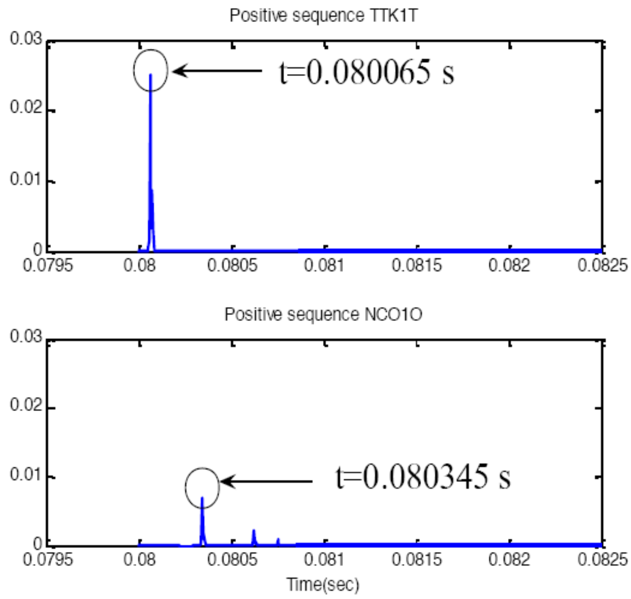



(a) Positive sequence current

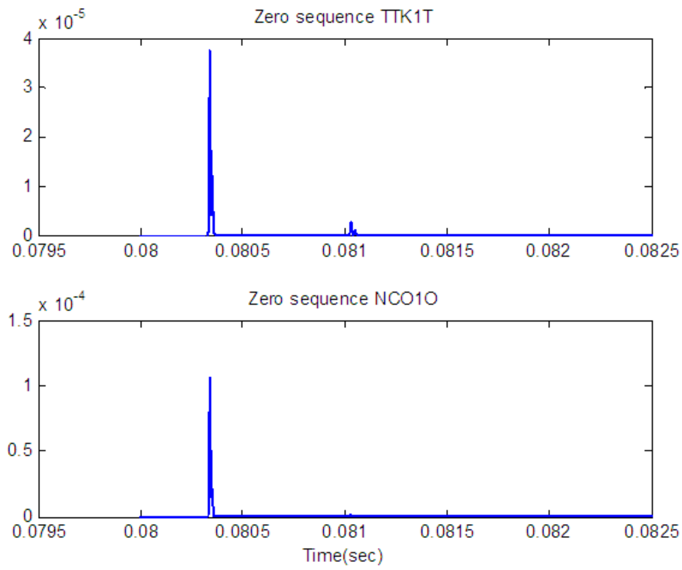



(b) Zero sequence current

FIGURE 2. DWT of single fault current signals for line B to line C fault (BC)




(a) Positive sequence current




(b) Zero sequence current

FIGURE 3. DWT of simultaneous fault current signals for line B to line C fault (BC) at F1, and phase A to ground fault (AG) at F2

current signals which occur between the length of 10% and the length of 50% measured from the bus TTK is illustrated in Figure 3(a) and Figure 3(b).

3. **Fault Behavior of Coefficient Detail.** As a mention, these research works have never been mentioned about simultaneous faults in transmission systems. Therefore, it is necessary to understand fault behavior of fault signals before doing decision algorithm of the relays. After applying the DWT, the coefficients of the signals obtained from the DWT are squared for a more explicit comparison. From Figure 2(a) and Figure 3(a), when considering the positive sequence, it can be seen that the coefficient obtained from DWT at TTK side has similar value in case of single fault and simultaneous faults. In addition, coefficient obtained from DWT at TTK side has value more than coefficient at NCO side

due to fault occurring near TTK side at 10% of the transmission line length measured from the bus TTK. However, at the other side of the system (NCO side in Figure 1), it is noted that the simultaneous faults are detected faster than the single fault with the higher amplitude. Meanwhile, when investigating the zero sequence fault currents shown in Figure 2(b) and Figure 3(b), it is found that, in case of the single fault, the coefficient amplitude of the zero sequence current is very low, and can be treated as zero due to the fact that the fault type is the line to line fault.

4. **Decision Algorithm.** The decision algorithm, therefore, are constructed based on the fuzzy logic toolboxes in MATLAB. Before the decision algorithm process, a structure of the fuzzy logic consists of 4 inputs and 1 output as illustrated in Figure 4. The output variables of the fuzzy logic are designated as values range from 1 to 10, corresponding to various types of faults as shown in Figure 5.

The coefficients detail (phase A, B, C and zero sequence of post-fault current signals) of DWT at the first peak time that positive sequence current can detect fault, is performed as input variables for proposed division algorithm as shown in Equations (1)-(3).

$$I^L_{P1,\max(post)} = \frac{I^L_{A(FP_{post})}}{I^L_{Z(FP_{post})}} \tag{1}$$

$$I^L_{P2,\max(post)} = \frac{I^L_{B(FP_{post})}}{I^L_{Z(FP_{post})}} \tag{2}$$

$$I^L_{P3,\max(post)} = \frac{I^L_{C(FP_{post})}}{I^L_{Z(FP_{post})}} \tag{3}$$

where
L is the scale of wavelet transform that can detect fault;
$I^L_{A(FP_{post})}$ is coefficient at first peak time that can detect fault of phase A for post-fault current;
$I^L_{B(FP_{post})}$ is coefficient at first peak time that can detect fault of phase B for post-fault current;
$I^L_{C(FP_{post})}$ is coefficient at first peak time that can detect fault of phase C for post-fault current;
$I^L_{Z(FP_{post})}$ is coefficient at first peak time that can detect fault of zero sequence for post-fault current;
$I^L_{P1,\max}, \ldots, I^L_{P4,\max}$ are input variables of the fuzzy logic.

When the proposed division algorithm is performed, coefficient of DWT at the first peak time that positive sequence current can detect fault, is detected as shown in Table 1, then, is divided and employed in the division algorithm. The results obtained from the proposed division algorithm are also shown in Figure 6.

Table 1. Coefficient detail (cD1) obtained from the proposed algorithm at 1/4 cycles

| Bus | Data | the variations of first scale that can detect fault | | | |
|---|---|---|---|---|---|
| | | $I_A$ | $I_B$ | $I_C$ | $I_Z$ |
| TTK | Coefficient | 8.69E-09 | 8.58E-09 | 2.70E-02 | 8.98E-03 |
| | Time (ms) | 40.065 | 40.065 | 40.065 | 40.065 |
| NCO | Coefficient | 9.34E-03 | 2.27E-02 | 8.78E-06 | 8.73E-04 |
| | Time (ms) | 40.065 | 40.065 | 40.065 | 40.065 |

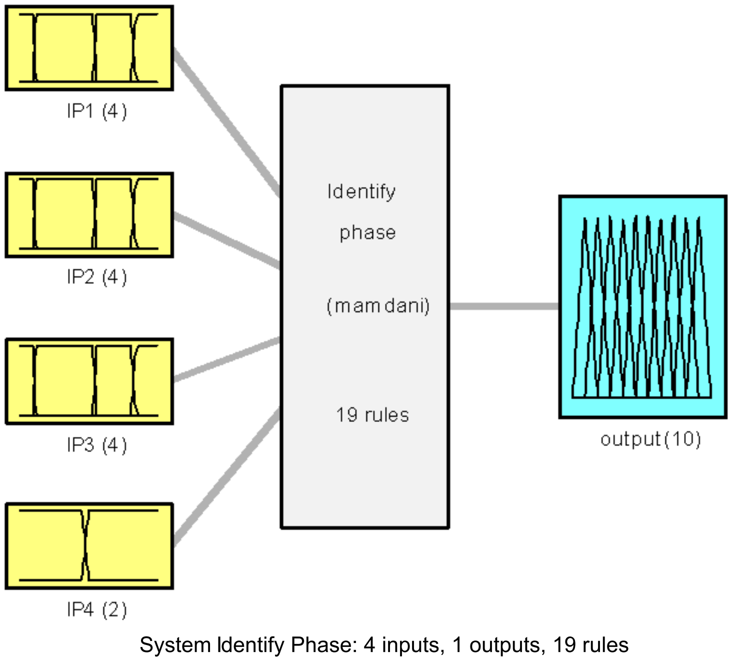



FIGURE 4. Structure of fuzzy logic for classifying the occurred fault

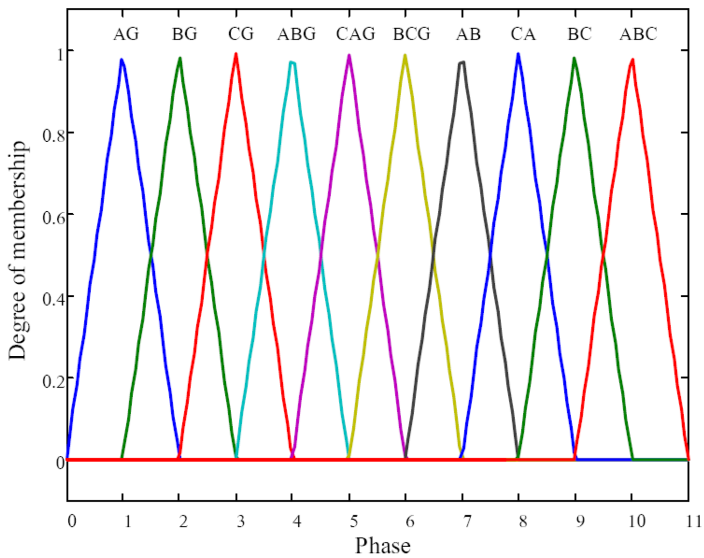



FIGURE 5. Membership functions of output type variable for classifying the fault types

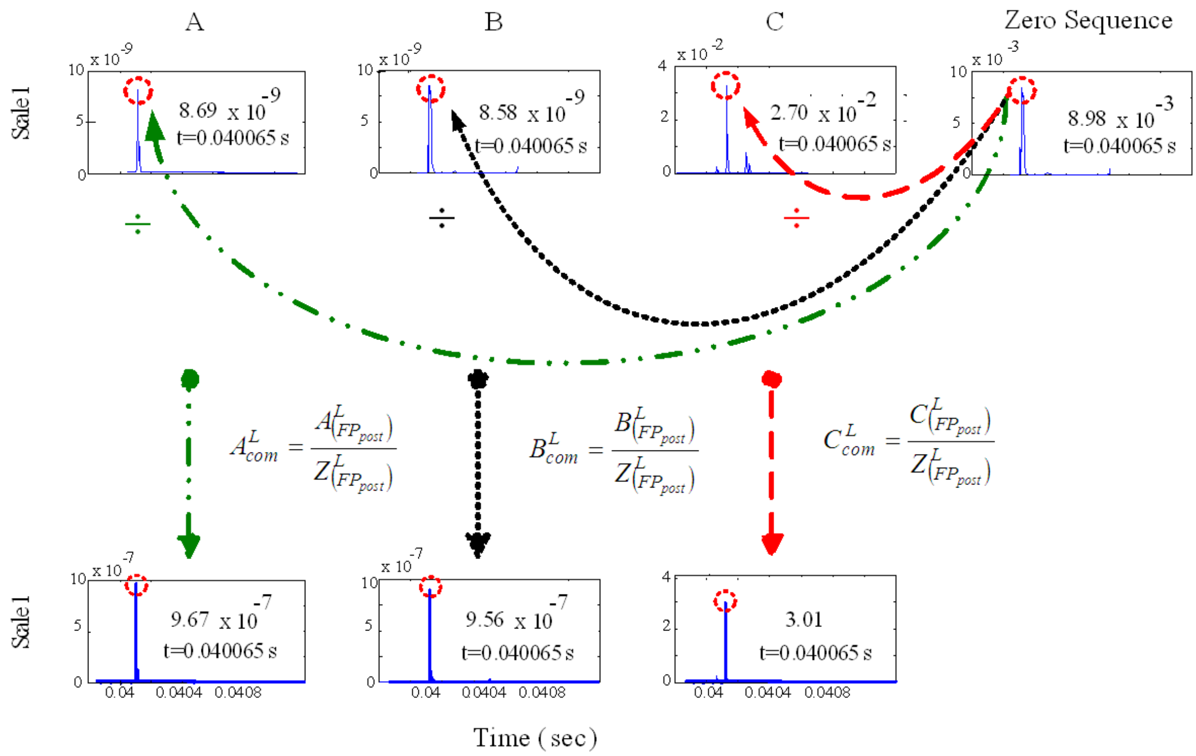
In addition, if the result obtained from division is more than 1 then it is supposed to be 100 as shown in Equations (4) and (5).

$$\text{if } \left(I^L_{P1,\max(post)}, \ldots, I^L_{P3,\max(post)}\right) \geq 1$$

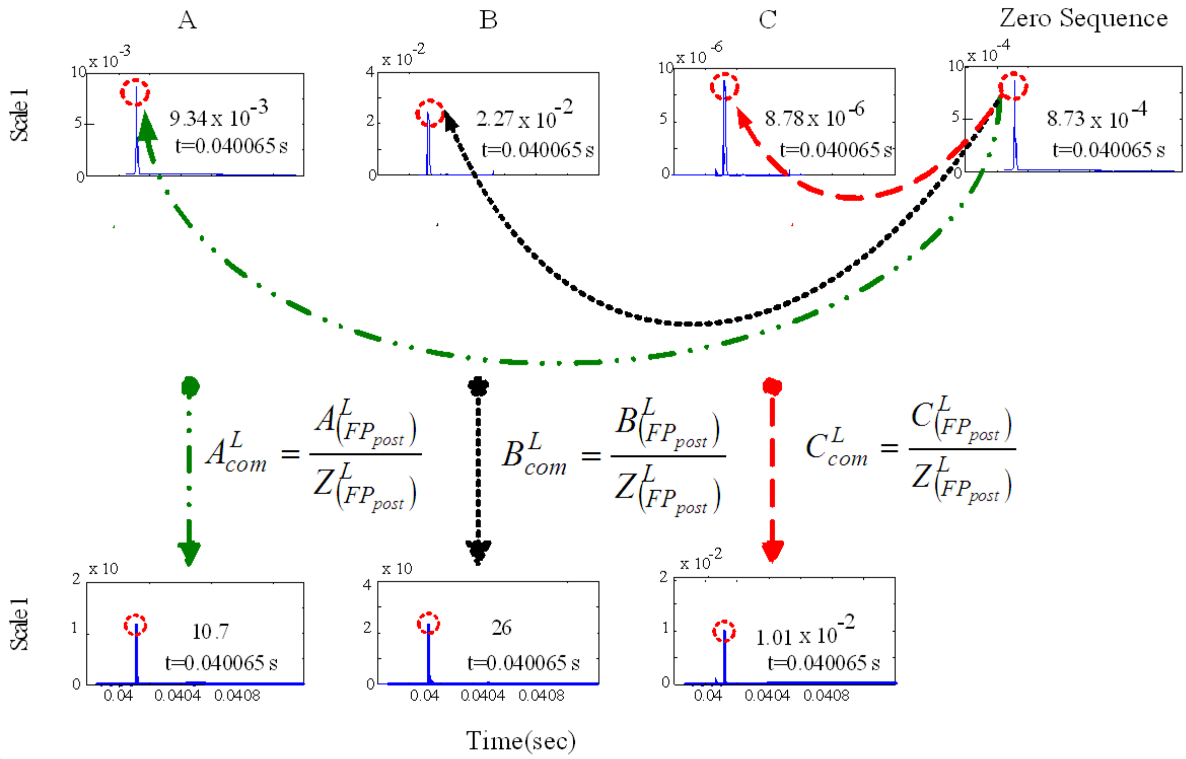
$$\text{then } \left(I^L_{P1,\max}, \ldots, I^L_{P3,\max}\right) = 100 \tag{4}$$

$$\text{else } \left(I^L_{P1,\max}, \ldots, I^L_{P3,\max}\right) = \left(I^L_{P1,\max(post)}, \ldots, I^L_{P3,\max(post)}\right) \tag{5}$$

end




(a) TTK bus




(b) NCO bus

FIGURE 6. Result of maximum ratio used as input variables from the division algorithm proposed in this paper

For detecting the zero sequence current with a fault condition, we follow the below algorithm.

$$\text{If } \left(Z^L_{\max(post)} \geq 5 \times Z^L_{\max(pre)}\right) \text{ or } \left(Z^L_{chk} \geq 0.00005\right)$$

$$\text{then } I^L_{P4,\max(post)} = 1 \tag{6}$$

$$\text{else } I^L_{P4,\max(post)} = 0 \tag{7}$$

$$\text{end}$$

where

$Z^L_{chk} = \frac{Z^L_{\max(post)}}{Z^L_{\max(pre)}}$ is indicator used in detecting the ground fault;

$Z^L_{\max(post)}$ is maximum coefficient from Wavelet transform of zero sequence current at the time of 1/4 cycles after detecting faults;

$Z^L_{\max(pre)}$ is maximum coefficient from Wavelet transform of zero sequence current at the time of 1/4 cycles before the inception of faults.

Membership functions for input variable are defined as zero, low, medium, and high as shown in Figure 7 and Table 2. Case study results presented in Table 1 and Figure 6 are obtained from the phase C to ground fault (CG) taking place at the position of F1 when the phase A and phase B to ground fault (ABG) is at the position of F2, and two types of faults occurring at the same time. From Table 3 and Figure 8, it is shown that the results obtained from the decision algorithm proposed in this paper, are obtained by applying the rules listed in Table 2.

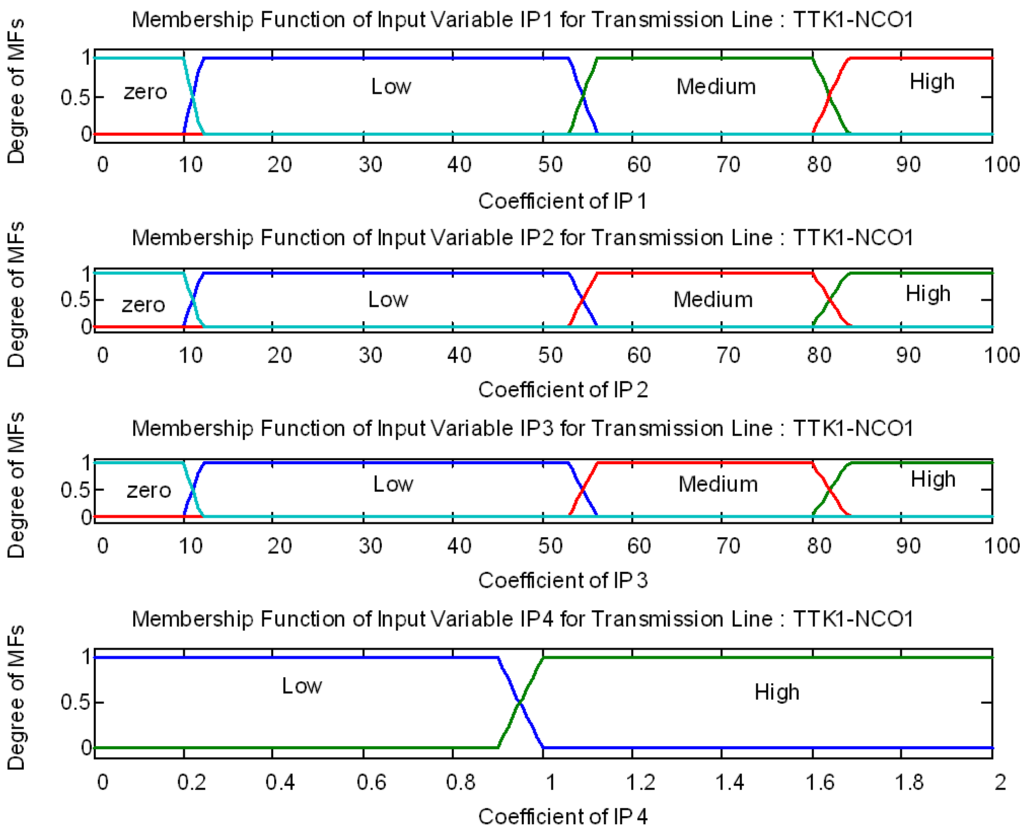


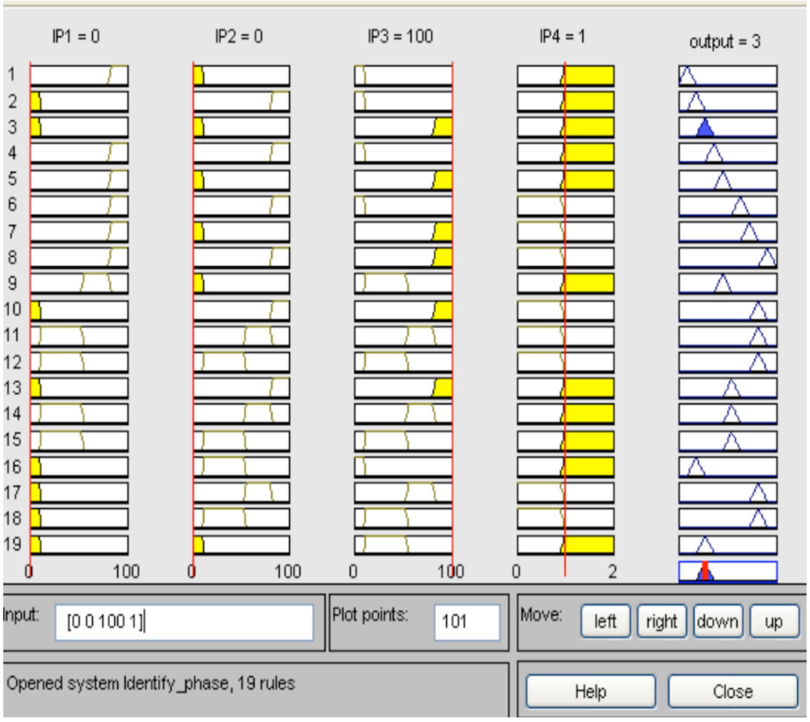

FIGURE 7. Membership Function of input variables of the fuzzy logic

Table 2. Rules of fuzzy logic

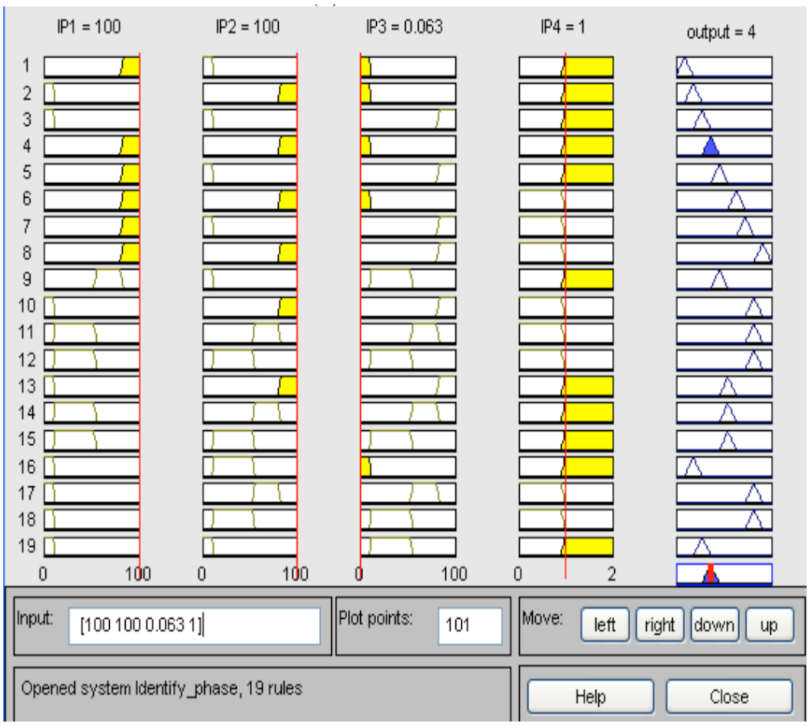
| Type of Fault | Rules of the module | Output |
|---|---|---|
| AG | If (IP1 is HIGH) and (IP2 is ZERO) and (IP3 is ZERO) and (IP4 is HIGH) THEN (Phase is AG) | 1 |
| BG | If (IP1 is ZERO) and (IP2 is HIGH) and (IP3 is ZERO) and (IP4 is HIGH) THEN (Phase is BG) | 2 |
| | If (IP1 is ZERO) and (IP2 is LOW) and (IP3 is ZERO) and (IP4 is HIGH) THEN (Phase is BG) | |
| CG | If (IP1 is ZERO) and (IP2 is ZERO) and (IP3 is HIGH) and (IP4 is HIGH) THEN (Phase is CG) | 3 |
| | If (IP1 is ZERO) and (IP2 is ZEROI) and (IP3 is LOW) and (IP4 is HIGH) THEN (Phase is CG) | |
| ABG | If (IP1 is HIGH) and (IP2 is HIGH) and (IP3 is ZERO) and (IP4 is HIGH) THEN (Phase is ABG) | 4 |
| CAG | If (IP1 is HIGH) and (IP2 is ZERO) and (IP3 is HIGH) and (IP4 is HIGH) THEN (Phase is CAG) | 5 |
| | If (IP1 is Medium) and (IP2 is ZERO) and (IP3 is LOW) and (IP4 is HIGH) THEN (Phase is CAG) | |
| BCG | If (IP1 is ZERO) and (IP2 is HIGH) and (IP3 is HIGH) and (IP4 is HIGH) THEN (Phase is BCG) | 6 |
| | If (IP1 is LOW) and (IP2 is Medium) and (IP3 is Medium) and (IP4 is HIGH) THEN (Phase is BCG) | |
| | If (IP1 is LOW) and (IP2 is LOW) and (IP3 is LOW) and (IP4 is HIGH) THEN (Phase is BCG) | |
| AB | If (IP1 is HIGH) and (IP2 is HIGH) and (IP3 is ZERO) and (IP4 is LOW) THEN (Phase is AB) | 7 |
| CA | If (IP1 is HIGH) and (IP2 is ZERO) and (IP3 is HIGH) and (IP4 is LOW) THEN (Phase is CA) | 8 |
| BC | If (IP1 is ZERO) and (IP2 is HIGH) and (IP3 is HIGH) and (IP4 is LOW) THEN (Phase is BC) | 9 |
| | If (IP1 is ZERO) and (IP2 is Medium) and (IP3 is Medium) and (IP4 is LOW) THEN (Phase is BC) | |
| | If (IP1 is ZERO) and (IP2 is LOW) and (IP3 is LOW) and (IP4 is LOW) THEN (Phase is BC) | |
| | If (IP1 is LOW) and (IP2 is Medium) and (IP3 is Medium) and (IP4 is LOW) THEN (Phase is BC) | |
| | If (IP1 is LOW) and (IP2 is LOW) and (IP3 is LOW) and (IP4 is LOW) THEN (Phase is BC) | |
| ABC | If (IP1 is HIGH) and (IP2 is HIGH) and (IP3 is HIGH) and (IP4 is ZERO) THEN (Phase is ABC) | 10 |
| ABCG | If (IP1 is HIGH) and (IP2 is HIGH) and (IP3 is HIGH) and (IP4 is ZERO) THEN (Phase is ABCG) | 10 |

Table 3. Result of fault type detection

| Bus | P1,max(post) | P2,max(post) | P3,max(post) | P4,max(post) | Output |
|---|---|---|---|---|---|
| TTK | 9.67E-07 | 9.56E-07 | 100 | 1 | 3.00 |
| NCO | 100 | 100 | 1.01E-02 | 1 | 4.00 |




(a) TTK bus




(b) NCO bus

FIGURE 8. Mamdani's rule and defuzzification module with COG method for classifying the fault types

From Figure 8, it can be seen that the index value at output TTK is 3 and that at NCO is 4. This means that the fault is classified as a phase C to ground fault, which occurs at the TTK and the phase A and phase B to ground fault (ABG) which occurs at the NCO bus.

Case studies are varied so that the decision algorithm capability can be verified. The system under consideration is shown in Figure 1. The total numbers of the case studies for single fault and simultaneous fault are 594 and 2178 sets, respectively. Various case studies are performed with various types of faults at each location on the transmission line including the variation of fault inception angles and locations at each transmission lines as shown in Table 4. Moreover, the results from the proposed algorithm are compared with the comparison of coefficients DWT which is the former decision algorithm in order to show the advantage of the proposed technique. From Table 4, it is shown that the average accuracy of fault classification from the decision algorithm proposed in this paper is highly satisfactory.

Table 4. Results of fault classification (case studies are 2762 cases)

| Average accuracy (%) | DWT and Fuzzy Logic | | DWT based on comparison of coefficients [22] | |
|---|---|---|---|---|
| | Single fault | Simultaneous fault | Single fault | Simultaneous fault |
| Single phase to ground (SLG) | 100% | 10% | 100% | 86.19% |
| Double-line to ground (DLG) | 100% | 99.33% | 100% | 95.62% |
| Line to line (LL) | 100% | 95.62% | 100% | 88.55% |
| Three-phase (3-P) | 100% | 99.07% | 99.07% | 98.48% |
| Average | 100% | 96.46% | 99.8% | 91.64% |

5. **Conclusions.** This paper proposed a technique using combination of DWT and fuzzy logic in order to identify simultaneous fault type on transmission line. Daubechies4 (db4) was selected as a mother wavelet. Positive sequence current signal was used in fault detection. The coefficients detail of DWT at the first peak time that positive sequence current can detect fault, was performed as an input pattern of fuzzy logic in a decision algorithm. The results show clearly that the accuracy of the combination of DWT and fuzzy logic algorithm is highly satisfactory as shown in Table 4. The further work will be the improvement of the algorithm when effects of other transmission line configurations or instance loop circuits are taken into account for the development of the practical protection system.

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## REFERENCES

[1] P. Markming, S. Bunjongjit, A. Kunakorn, S. Jiriwibhakorn and M. Kando, Fault diagnosis in transmission lines using wavelet transform analysis, *IEEE/PES Transmission and Distribution Conference and Exhibition: Asia Pacific*, vol.3, pp.2246-2250, 2002.

[2] W. M. Line, C. D. Yang, J. H. Lin and M. T. Tsay, A fault classification method by RBF neural network with OLS learning procedure, *IEEE Transactions on Power Delivery*, vol.16, no.4, pp.473-477, 2001.

[3] R. N. Mahanty and P. B. Dutta Gupta, Comparison of fault classification methods based on wavelet analysis and ANN, *Electric Power Components and Systems*, vol.34, no.1, pp.47-60, 2006.

[4] K. M. Silva, B. A. Souza and N. S. D. Brito, Fault detection and classification in transmission lines based on wavelet transform and ANN, *IEEE Transactions on Power Delivery*, vol.21, no.4, pp.2058-2063, 2006.

[5] X. Dong, W. Kong and T. Cui, Fault classification and faulted-phase selection based on the initial current traveling wave, *IEEE Transactions on Power Delivery*, vol.24, no.2, pp.552-559, 2009.

[6] O. Mustapha, D. Lefebvre, M. Khalil, G. Hoblos and H. Chafouk, Fault detection algorithm using DCS method combined with filters bank derived from the wavelet transform, *International Journal of Innovative Computing, Information and Control*, vol.5, no.5, pp.1313-1328, 2009.

[7] F. B. Costa, B. A. Souza and N. S. D. Brito, Real-time detection of fault-induced transients in transmission lines, *Electronics Letters*, vol.46, no.1, pp.753-755, 2010.

[8] P. Jafarian and M. Sanaye-Pasand, A traveling-wave-based protection technique using wavelet/PCA analysis, *IEEE Transactions on Power Delivery*, vol.25, no.2, pp.588-599, 2010.

[9] Z. He, L. Fu, S. Lin and Z. Bo, Fault detection and classification in EHV transmission line based on wavelet singular entropy, *IEEE Transactions on Power Delivery*, vol.25, no.4, pp.2156-2163, 2010.

[10] J. Upendar, C. P. Gupta, G. K. Singh and G. Ramakrishna, PSO and ANN-based fault classification for protective relaying, *IET Generation, Transmission & Distribution*, vol.4, no.10, pp.1197-1212, 2010.

[11] N. Perera and A. D. Rajapakse, Recognition of fault transients using a probabilistic neural-network classifier, *IEEE Transactions on Power Delivery*, vol.26, no.1, pp.410-419, 2011.

[12] N. Zhang and M. Kezunovic, Transmission line boundary protection using wavelet transform and neural network, *IEEE Transactions on Power Delivery*, vol.22, no.2, pp.859-869, 2007.

[13] O. A. S. Youssef, Combined fuzzy-logic wavelet-based fault classification technique for power system relaying, *IEEE Transactions on Power Delivery*, vol.19, no.2, pp.582-589, 2004.

[14] T. Nguyen and Y. Liao, Transmission line fault type classification based on novel features and neuro-fuzzy system, *Electric Power Components and Systems*, vol.38, no.6, pp.695-709, 2010.

[15] S. R. Samantaray, Phase-space-based fault detection in distance relaying, *IEEE Transactions on Power Delivery*, vol.26, no.1, pp.33-41, 2011.

[16] Z. Xu, G. Xu, L. Ran, S. Yu and Q. X. Yang, A new fault-impedance algorithm for distance relaying on a transmission line, *IEEE Transactions on Power Delivery*, vol.25, no.3, pp.1384-1392, 2010.

[17] S. R. Samantaray and P. K. Dash, Transmission line distance relaying using machine intelligence technique, *IET Generation, Transmission & Distribution*, vol.2, no.1, pp.53-61, 2008.

[18] J. Upendar, C. P. Gupta and G. K. Singh, Fault classification scheme based on the adaptive resonance theory neural network for protection of transmission lines, *Electric Power Components and Systems*, vol.38, no.4, pp.424-444, 2010.

[19] A. Ngaopitakkul, W. Pongchaisrikul and A. Kunakorn, Analysis of characteristics of simultaneous faults in electrical power systems using wavelet transform, *Proc. of the 1st International Conference Sustainable Energy Technologies*, pp.249-252, 2008.

[20] P. Chiradeja and A. Ngaopitakkul, Identification of fault types for single circuit transmission line using discrete wavelet transform and artificial neural networks, *Proc. of International Conference on Electrical Engineering*, pp.1-4, 2009.

[21] *Switching and Transmission Line Diagram*, Electricity Generation Authorisation Thailand (EGAT).

[22] A. Ngaopitakkul, C. Apisit, C. Jettanasen and C. Pothisarn, Identification of simultaneous fault types in electrical power system using the comparisons technique of DWT coefficients, *ICIC Express Letters, Part B: Applications*, vol.2, no.2, pp.377-382, 2011.

[23] I. Daubechies, The wavelet transform, time-frequency localization and signal analysis, *IEEE Transactions of Information Theory*, pp.961-1005, 1990.

[24] N. S. D. Brito, B. A. Souza and F. A. C. Pires, Daubechies wavelets in quality of electrical power, *Proc. of the IEEE International Conference on Harmonics and Quality of Power*, pp.511-515, 1998.

[25] P. Chiradeja and C. Pothisarn, Identification of the fault location for three-terminal transmission lines using discrete wavelet transform, *Proc. of IEEE International Conference on Transmission and Distribution*, pp.1-4, 2009.