MINISTRY OF EDUCATION AND TRAINING
DA NANG UNIVERSITY

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A STUDY OF INTELLIGENT METHODS
FOR FAULT CLASSIFICATION AND
FAULT LOCATION ON THE TRANSMISSION LINE

SPECIALIZATION: POWER SYSTEM & NETWORK
CODE: 62.52.50.05

PHD. THESIS IN BRIEF

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The thesis is available at:
1. The National Library.
2. The Information Resources Center, University of Danang.
INTRODUCTION

1. THE REASON FOR CHOOSING THE THESIS
   Fault location methods on EVN’s transmission line, which is based on the experimental operation and relay protection (using measurement data at one overhead line). Therefore, it meets many difficulties in locating faults, increasing time electric losts, economics damages. Thus, the thesis “a study of intelligent methods for fault classification and fault location on the transmission line” has scientific meaning and application in managing electrical operations.

2. THE CONTENT AND PURPOSES OF THE RESEARCH
   The content and purposes of the research such as:
   - Systematizing methods, the researches published in the fault classification and location area on the grid’s power transmission.
   - Researching effects of main factors on the performance and calculating distance to fault of relay protection.
   - Assessing fault location methods of relay manufacturers, which are for the diagram of transmission lines using current, voltage data measurement at one, two or three ended of the transmission line.
   - The research uses intelligent methods in order to classify and locate transmission line’s faults.

3. RESEARCH METHODS
   The thesis combines two methods: theory research and experimental research.

4. THE OBJECTIVE AND SCOPE OF RESEARCH
Fault location methods of numerical relay protection from manufacturers like ABB, SIEMENS, AREVA, SEL.Inc, TOSHIBA, etc. applied popularly on the high-voltage transmission grid, which has voltage level from 110 kV to 220 kV. The research uses intelligent methods like Fuzzy, Wavelet, ANN, and ANFIS that is for classifying and locating faults.

5. THE MEANING OF SCIENCE AND PRACTICE OF THE THESIS

5.1 The meaning of science:

During the process, analyzing and assessing the fault location methods of numerical relay are the foundation to develop methods of solving fault location’s problems with higher level of accuracy.

The thesis concreted methods of analysis positive, negative and zero component sequence of the relationship angle and magnitude ratio between the currents, which are applied on building Fuzzy laws for fault classification. Base on that, testing for transmission line’s diagram 220kV A Vuong – Hoakhanh.

With this model 220kV, the author builds classification methods base on Discrete Wave Transform (DWT) analysis of transient signals (Ia, Ib, Ic and Io), which combines with algorithm comparing between current value and fault threshold levels.

Besides, the author researches fault classification using ANN (automatic determining an optimal number of hidden layer neuron) or ANFIS (with 4 inputs and 1 output) for 10 kinds of faults (AN, BN, CN, AB, BC, AC, ABG, BCN, ACN, ABN, ABC).

In addition, the fault from the previous year and updated statistics on Power Transmission Company and Grid Company, which is the foundation to test and expand applications of ANN, ANFIS calculating the similar future fault location in the power system.
5.2 The practice:

a) Designing and managing electrical consultation processes: The thesis contributes on quick solving a big amount of work, which is in fault classification and location at the request of the Power Sector. Besides, the thesis supplies the knowledge supporting for operation, increasing the effectiveness of relay’s utilization.

b) Orienting Power sector’s investment: The thesis’s result for the fault location techniques (in 110 kV and 220 kV transmission line) is the foundation towards building the fault solving process for various types of transmission line in Viet Nam.

6. COMPOSITION OF THE THESIS

Outside of the Introduction, appendix, this thesis consists of five chapters.

**CHAPTER 1**

OVERVIEW STUDY ON FAULT CLASSIFICATION AND LOCATION

1.1 INTRODUCTION

1.2 OVERVIEW OF THE RESEARCH

1.2.1. The technique based on power management

1.2.2 The technique based on fundamental frequency signals, mainly on impedance measurement.

1.2.3 The technique based on high frequency components of signals generated by faults.

1.2.4 The technique based on intelligent systems

1.2.5 The technique based on hybrid method

1.3 CONCLUSION

Chapter 1 generally introduced about fault location and classification methods on the transmission line. In which, intelligent
methods utilize on classifying and locating faults with high accuracy, which continuous develop by scientists on the world. In Vietnam, there are some fault detecting researches, but it is still new, especially intelligent methods applied on this area is rare. Therefore, the necessary is continuous developing these researches to find solutions of accurate and quick fault detection on the transmission line; suitable with conditions of real transmission lines; overcome factors affecting on outputs. It is the thesis’s content.

CHAPTER 2
THE EFFECT OF MAIN FACTORS ON THE PERFORMANCE AND IDENTIFY OF RELAY PROTECTION

2.1 INTRODUCTION

2.2 THE EFFECT OF HARMONIC ON RELAY PROTECTION IN POWER SYSTEM

2.2.1 Harmonic on power system

Harmonics has always existed in electrical power systems. It induced by these nonlinear loads are a potential risk.

<table>
<thead>
<tr>
<th>Harmonics</th>
<th>A (%)</th>
<th>B (%)</th>
<th>C (%)</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>THD</td>
<td>70.4</td>
<td>45.1</td>
<td>51.3</td>
<td>143.3</td>
</tr>
<tr>
<td>H2</td>
<td>45.1</td>
<td>32.0</td>
<td>29.6</td>
<td>1.7</td>
</tr>
<tr>
<td>H3</td>
<td>31.3</td>
<td>13.8</td>
<td>14.3</td>
<td>2.8</td>
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<tr>
<td>H6</td>
<td>18.0</td>
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<td>9.8</td>
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</tr>
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<td>H9</td>
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</tr>
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<tr>
<td>H13</td>
<td>3.0</td>
<td>1.6</td>
<td>3.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Figure 2.1a: numerical values of a set of harmonics at transformer T1 in substation 110kV Dong Ha.

2.2.2 Effect of harmonic on protection relay

2.2.3 Review and evaluation

Figure 2.1b: Connection of Analyzer to 3 phase distribution system
The testing effect of harmonic on electro-mechanical, static and numerical protection relay were performed by Fluke 434 (figure 2.1) and the total harmonic distortion of the nonlinear-load current (THDi) are adjusted by CMC 256. In this study, electromechanical relay (EIOCR, ITOCR) designs for sinusoidal current, operates faulty in non-sinusoidal current. How ever, the static relay and numerical relay have measurement function and harmonic restraint function that helps the relay can perform right protection function in the distortion of the current.

2.3 THE EFFECT OF FAULT RESISTANCE ON THE PERFORMANCE OF DISTANCE RELAY PROTECTION

2.3.1 Fault resistance of a transmission line that fed from one end

2.3.2 Fault resistance of a transmission line that fed from double end

2.3.3 Overcome limitations of fault resistance on the performance of relay’s characteristic

2.3.4 Review and evaluation

The effect of fault resistance ($R_F$) on the mho characteristic in case of phase–earth fault was more than in case of phase – phase fault. The effect of $R_F$ on the mho characteristic decreased when the fault is more nearer to the relay location.
To overcome the under reach due to the effects of resistance faults (may make relays response slowly), relays use some typical methods like moving angular of mho characteristic impedance or using quadrilateral characteristic style (Figure 2.2).

2.4 THE EFFECT OF CT, VT ERROR ON THE MEASUREMENT OF RELAY PROTECTION

2.4.1 CT, VT error

2.4.2 Improving accuracy of CT, VT

Non Conventional Instrument Transformer (NCIT) does not use traditional iron core, it may improve output errors by using different sensor technologies as optical and Rogowski coils. MU (Merging Unit) places between NCIT and protection IEDs. This equipment can receive the sampled value from NCIT, and output data to protection IEDs in accordance with IEC 61850 with a high speed data processing (Figure 2.3).

Hình 2.3: IEC 61850 testing

2.4.3 Review and evaluation

The development of NCIT steeply perform at in digital substations, which offers many advantages over the conventional instrumental transformers, such as immune to electromagnetic noise, rationalization of electrical insulation, and extension of dynamic
ranges and frequency bands of the measured signals, therefore to achieve higher performance, higher compactness and higher reliability of instrument transformers. So that NCIT is recommended to applying in combination with IED such as digital relays, digital measurement system or digital device measurement of electric quality, which intend to collect current data, voltage accurately for different purposes.

2.5 THE EFFECT OF LINE PARAMETER ON THE PERFORMANCE OF RELAY PROTECTION

2.5.1 Line impedances

2.5.2 Calculating impedances and the k-factor

2.5.2.1 Line parameter measurement with electronic machines

2.5.2.2 Line parameter measurement with CPC 100 and CP CU1

![Figure 2.4: Line Impedance Measurement](image)

2.5.2.3 Line parameter measurement using synchronized method

2.5.3 Review and evaluation

With the CPC 100 and the CP CU1 (Figure 2.4), the impedance of power lines can be measured accurately and cost saving. Actual measurement of the fault-loop impedance is the best way to ensure that the distance relay and direction relay settings are correct, preventing unexpected effects of them and increase accuracy of fault location.
2.6 CONCLUSION

Based on the analysis of the factors of harmonic, fault resistance, CT, VT error and line parameter to show that the demands with relay protection is reliable, selective, and quick removal fault feasible only if current and voltage value collected accurately, the relay’s functions and parameters set correctly. The consideration of these factors contributes to the collection of believe information, meet the accuracy of fault detection algorithms.

CHAPTER 3
FAULT LOCATION ALGORITHMS ANALYSIS FOR NUMERICAL RELAY

3.1 INTRODUCTION

3.2 ANALYSES OF EVENT RECORD FUNCTION OF NUMERICAL RELAY WITH THE USE OF SOFTWARE

Fault recorded information is integrated in digital relays. Thus, fault-analyzing softwares are used to monitor operations, report, and identify causes of faults (Figure 3.1)

Figure 3.1: The read and store fault record model

3.3 ANALYSES OF SINGLE ENDED FAULT LOCATION
3.3.1 The algorithms of SEL and GE
3.3.2 The algorithm of TOSHIBA
3.3.3 the algorithm of SIEMENS
3.3.4 The algorithm of ABB
3.3.5 The algorithm of AREVA
3.3.6 Review and evaluation

The singled end fault location methods using current, voltage data at one terminal, which have advantages of being suitable with conditions of networks and technology of protection in countries. However, the formula is build on the homogenous power system, so the method has disadvantages of reducing level of accuracy: the mix influence of the load current and fault resistance, the value may be high at ground faults; the accuracy of line’s parameters set on relays; measurement errors…

3.4 ANALYSES OF TWO ENDED FAULT LOCATION
3.4.1 The algorithm of TOSHIBA
3.4.2 The algorithm of SEL
3.4.3 Review and evaluation

The fault location method using two terminal line, which uses postitive and negative sequence quantities. It can improve upon the accuracy of single ended methods. The limitation of this method is expensive devices, because the signal needs to collected synchronously, using a big mount of send and receive data (if there is GPS system). Therefore, it has not used popularly in Vietnam.

3.5 FAULT LOCATION ALGORITHMS ANALYSIS FOR THREE TERMINAL TRANSMISSION LINES
3.5.1 The algorithm using unsynchronized sampling of SEL
3.5.2 The algorithm using synchronized sampling of TOSHIBA
3.5.3 The algorithm using expanded Clarke transformation of GE
3.5.4 Review and evaluation
Base on the result of analyzing the fault location method of SEL, TOSHIBA, and GE relays, which is used for the three terminal transmission line. It shows that the result of distance to the fault point calculate with real time is not affected by factors, including mutual coupling lines. In which, accurate of SEL is the biggest error, and TOSHIBA is smallest error. In another way, these methods always remain errors, so it needs deeper researches to improve calculations’ accuracy.

3.6 CONCLUSION

Fault location methods using data measurement at two or three terminal line, which are only performed under conditions of completing information management in order to serve measuring the data at the center control.

Fault location methods using data measurement at one terminal line, which are applied popularly on substation in Vietnam. However, they almost concentrate on solving faults in each local line. It has errors bigger than other method, so the value of fault location is different from the actual position. The next chapter presents fault classification and location methods built on intelligent system, which use current, voltage data on relays and actual fault position in order to solve problem effectively.

CHAPTER 4
INTELLIGENT TECHNIQUES FOR TRANSMISSION LINE FAULT CLASSIFICATION

4.1 INTRODUCTION

4.2 CLASSIFICATION OF FAULTS ON POWER TRANSMISSION LINES USING FUZZY LOGIC

4.2.1 Fuzzy logic algorithm for fault classification
Step 1: Fuzzify inputs
Step 2: Apply fuzzy operator
Step 3: Apply implication method
Step 4: Aggregate and defuzzify of all outputs

4.2.2 Simulation and results

The single-line diagram of the simulated system is a 220kV Transmission Line A Vuong – Hoa Khanh. The results obtained from the analysis are clearly presented in appendix 4.1.
4.2.3 Review and evaluation

In order to distinguish every fault type instead of using current phase quantities, the thesis only uses 4 coefficients $\alpha$, $\beta$, $R_{21}$, $R_{02}$ at one end of transmission line. The Fuzzy logic supply results rapidly and effectively.

4.3 FAULT CLASSIFICATION OF POWER TRANSMISSION LINES USING WAVELET TRANSFORM

4.3.1 Discrete wavelet transform (DWT)

Figure 4.2: The process of DWT

4.3.2 Fault detection algorithm

The figure 4.4 shows the algorithm for detecting the transmission line faults using DWT.

4.3.3 Simulation study and results

The results obtained from the analysis on 220kV Transmission Line A Vuong – Hoa Khanh are clearly presented in figure 4.3.

Figure 4.3a: DWT output for AN fault at distance 1 km, $R_F=1\ \Omega$, fault time 0.02s.

Figure 4.3b: DWT output for AC fault at distance 49km, $R_F=80\Omega$, fault time 0.03s.
4.3.4 Review and evaluation

The thesis researches fault detection and classification of short-circuit by using discrete wavelet transform. Each case corresponds to the problem on the transmission grid, three-phase current signal $I_a$, $I_b$, $I_c$, and $I_0$, which is used to analyze db5. In which, detail signals in analyzing level 1 were found, that is the most appropriate to detect faults (faults time). Besides, base on the signal’s differency; comparing current value for each phase from details and appropriate 1 sampling cycle current signal (1024); comparing with threshold value ($\varepsilon_1$), the tow phase current ratio ($\varepsilon_2$), the ratio of neutral current and current phase ($\varepsilon_3$), in order to classify faults. The algorithm
does not depend on fault time, distance and resistor. The simulate result points out that the method is very effective in fault classification.

**4.4 FAULT CLASSIFICATION IN TRANSMISSION LINES USING ANN**

**4.4.1 Steps in designing an ANN for fault classification**

Eight steps in designing ANN forecasting model:

*Step 1:* Variable selection

*Step 2:* Data collection

*Step 3:* Data preprocessing

*Step 4:* Training, testing sets

*Step 5:* Neural network paradigms

*Step 6:* Evaluation criteria

*Step 7:* ANN training

*Step 8:* Implementation ANN

**Figure 4.5:** Designing an ANN for fault classification

**Figure 4.6:** Architectures of ANN for fault classification using 4 neuron input, 5 hidden neuron and 4 neuron output
4.4.2 Power system under study

![Power system under study](image)

**Figure 4.7: Power system model simulated in MATLAB Simulink software**

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Fault time [s]</th>
<th>Fault location [km]</th>
<th>Fault resistance [Ω]</th>
<th>ANN’s output</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>0.06</td>
<td>3</td>
<td>3</td>
<td>1 0 0 0 1</td>
</tr>
<tr>
<td>BN</td>
<td>6</td>
<td>8</td>
<td>13</td>
<td>0 1 0 1 1</td>
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<tr>
<td>CN</td>
<td>11</td>
<td>20</td>
<td>0</td>
<td>1 1 0 0 0</td>
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<tr>
<td>AB</td>
<td>0.07</td>
<td>15</td>
<td>27</td>
<td>0 1 1 1 0</td>
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<td>BC</td>
<td>22</td>
<td>34</td>
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<td>43</td>
<td>1</td>
<td>1 1 0 1 1</td>
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<tr>
<td>ABN</td>
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<td>40</td>
<td>50</td>
<td>0 1 1 1 1</td>
</tr>
<tr>
<td>BCN</td>
<td>44</td>
<td>17</td>
<td>1</td>
<td>0 1 1 1 0</td>
</tr>
<tr>
<td>ABC</td>
<td>0.09</td>
<td>50</td>
<td>1</td>
<td>1 1 1 1 0</td>
</tr>
</tbody>
</table>

Table 4.1: The results for fault classification

4.4.3 Review and evaluation

ANN’s fault classification is the algorithm of sample detections. The thesis develops the algorithm of determining automatically hidden layer neurons for ANN, which allows learning data noise after trained in order to classify transmission lines’ fault types. ANN outputs results stably, accurately and ontime.

4.5 FAULT CLASSIFICATION IN TRANSMISSION LINES USING ANFIS

4.5.1 Steps in designing an ANFIS for fault classification

*Step 1:* performance similar steps 1 to 4 in section 4.4.1.
**Step 2:** design ANFIS.

**Step 3:** train ANFIS.

![Figure 4.8a. Structure of ANFIS for fault classification](image1)

![Figure 4.8b. Membership function of input variables for fault classification](image2)

### 4.5.2 Power system under study

Power system under study is similar to section 4.4.2.

#### Table 4.2: The results for fault classification

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Fault time [s]</th>
<th>Fault location [km]</th>
<th>Fault resistance [Ω]</th>
<th>ANFIS’s output</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>0,06</td>
<td>3</td>
<td>3</td>
<td>1,0</td>
</tr>
<tr>
<td>BN</td>
<td></td>
<td>6</td>
<td>8</td>
<td>2,0</td>
</tr>
<tr>
<td>CN</td>
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<td>22</td>
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<td>6,0</td>
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<td>ABC</td>
<td>0,09</td>
<td>50</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

### 4.5.3 Review and evaluation

The thesis develops the ANFIS network structure using 4 inputs, 1 output in fault classification. The result shows that ANFIS is suitable with transmission lines, meets time demands and errors for each application.
4.6 CONCLUSION

This chapter was designed to evaluate the applicability of intelligent techniques including FL, WT, ANN and ANFIS for fault classification estimation in overhead transmission line. It would be interesting to compare these techniques with each others. According to the results, the results produced by WT show a good level of accuracy.

CHAPTER 5

FAULT LOCATION ON OVERHEAD TRANSMISSION LINE USING ANN, ANFIS

5.1 INTRODUCTION

5.2 FAULT LOCATION ON OVERHEAD TRANSMISSION LINE USING ANN

5.2.1 Proposed ANN based fault locator

The 110kV, 50km transmission line in figure 4.7 uses architectures of ANN based fault locator modules to show in Table 5.1.

Table 5.1: Architectures of ANN based fault locators

<table>
<thead>
<tr>
<th>S. No</th>
<th>Type of network</th>
<th>Number of neurons</th>
<th>MSE</th>
<th>No. of epoch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Input layer</td>
<td>Hidden layer</td>
<td>Output layer</td>
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<tr>
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<td>AN</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>BN</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
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<td>CN</td>
<td>6</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
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<td>6</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
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<td>ACN</td>
<td>6</td>
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<tr>
<td>10</td>
<td>ABC</td>
<td>6</td>
<td>35</td>
<td>16</td>
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</tbody>
</table>

5.2.2 Test results of ANN based fault locator

The trained ANN based Fault detector and locator modules were then extensively tested by using independent data sets consisting of
fault scenarios never used previously in training. Fault type, fault location and fault time were changed to investigate the effects of these factors on the performance of the proposed algorithm. The results obtained are explained in more detail in appendix 5.1.

5.2.3 Review and evaluation

The fault location technique basing on artificial neuron network is trained to detect faults and use 10 different ANN, which has errors in the range of 0.04% to 3.044%. Thus, all test results are correct with reasonable accuracy. However, each ANN needs training time from 40 to 50 minutes in order to find the optimal network.

5.3 FAULT LOCATION ON OVERHEAD TRANSMISSION LINE USING ANFIS

5.3.1 Proposed ANFIS based fault locator

The 110kV, 50km transmission line in figure 4.7 uses architectures of ANFIS based fault locator modules to show in Table 5.2.

<table>
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<tr>
<th>S.No</th>
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<td>Input mfs</td>
<td>Output layer</td>
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<tr>
<td>10</td>
<td>ABC</td>
<td>6</td>
<td>4</td>
<td>1</td>
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</tbody>
</table>

5.3.2 Test results of ANFIS based fault locator

The results obtained are explained in more detail in appendix 5.2.

5.3.3 Review and evaluation
To compare with ANN, ANFIS is a better choice as: quick training time; output errors in the range of \(0.042 \div 3.062\%\). Thus, the next thesis’s object is actual testing ANFIS design and application in order to locate fault on the transmission line.

### 5.4 FAULT LOCATION ASSESSMENT

![Figure 5.1: Application of ANFIS approach to fault classification and location on transmission line](image)

**5.4.1 The 110kV transmission line Dak Mil – Dak Nong**

#### 5.4.1.1 Verified model

![Figure 5.2: The 110kV transmission line Dak Mil – Dak Nong](image)

**5.4.1.2 Generation a suitable training data**

Matlab Simulink program is developed for generating training patterns with various fault type, fault resistance, fault location.

**Table 5.3: Parameter settings for generating training patterns**

<table>
<thead>
<tr>
<th>Case No</th>
<th>Parameters</th>
<th>Set value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fault type</td>
<td>AN, BN, CN, AB, BC, AC, ABN, BCN, ACN, ABC</td>
</tr>
<tr>
<td>2</td>
<td>Fault location [km]</td>
<td>1, 5, 10, 15, 20,25, 30, 35, 40, 45, 50, 55</td>
</tr>
<tr>
<td>3</td>
<td>Loading [MVA]</td>
<td>10, 30, 50, 70</td>
</tr>
<tr>
<td>4</td>
<td>Fault resistance (R_F) [Ω]</td>
<td>1, 3, 5, 7, 10</td>
</tr>
<tr>
<td>5</td>
<td>Time fault [s]</td>
<td>0.07, 0.075</td>
</tr>
</tbody>
</table>
Table 5.4: Structure of ANFIS for fault location

<table>
<thead>
<tr>
<th>No</th>
<th>Type anfis</th>
<th>Anfis information</th>
<th>RMSE</th>
<th>Epochs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inputs Numbers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input mfs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>AN</td>
<td>4 Ua, Ub, Uc, Ia</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3,01e-3</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>CN</td>
<td>4 Ua, Ub, Uc, Ic</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2,82e-3</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>ACN</td>
<td>5 Ua, Ub, Uc, Ia, Ic</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5,47e-4</td>
<td>30</td>
</tr>
</tbody>
</table>

5.4.1.3 Testing data

For this purpose, the ANFIS model for fault location and trainning data were described in Table 5.4. The thesis performs to compare the accuracy obtained of P543 of Central Grid Company with Anfis that based fault classifier and fault locator module for AN, CN and ACN fault at Dak Mil in 2013 which are provided in table 5.5.

Table 5.5: The results compare the accuracy obtained of P543 with Anfis

<table>
<thead>
<tr>
<th>Fault time</th>
<th>Fault type</th>
<th>Actual fault location [km]</th>
<th>ANFIS Estimated fault location [km]</th>
<th>Error [%]</th>
<th>P543 Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17/05/2013</td>
<td>AN</td>
<td>44,64</td>
<td>46,27</td>
<td>2,74</td>
<td>0,43</td>
</tr>
<tr>
<td>06/06/2013</td>
<td>ACN</td>
<td>26,243</td>
<td>27,33</td>
<td>1,88</td>
<td>4,786</td>
</tr>
<tr>
<td>10/06/2013</td>
<td>CN</td>
<td>40,029</td>
<td>39,23</td>
<td>1,38</td>
<td>24,34</td>
</tr>
<tr>
<td>06/09/2013</td>
<td>AN</td>
<td>27,69</td>
<td>26,11</td>
<td><strong>2,82</strong></td>
<td>2,92</td>
</tr>
</tbody>
</table>

Reviews: The max error of ANFIS is 2.82% of the line length (smaller than P543).

5.4.2 The 220kV transmission line Hoa Khanh – Hue

Figure 5.3: Schematic diagram of 220kV transmission line Hoa Khanh – Hue
Table 5.6: Parameter settings for generating training patterns.

<table>
<thead>
<tr>
<th>Case No</th>
<th>Parameters</th>
<th>Set value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fault type</td>
<td>AN, BN, CN, AB, BC, AC, ABN, BCN, ACN, ABC</td>
</tr>
<tr>
<td>2</td>
<td>Fault location</td>
<td>1, 10, 20, 30, 40, 50, 60, 70, 80</td>
</tr>
<tr>
<td>3</td>
<td>Time fault [s]</td>
<td>0.075, 0.08</td>
</tr>
<tr>
<td>4</td>
<td>Fault resistance $R_f$ [Ω]</td>
<td>1, 5, 10, 20, 30</td>
</tr>
<tr>
<td>5</td>
<td>Loading [MVA]</td>
<td>1, 50, 100, 200</td>
</tr>
</tbody>
</table>

Table 5.7: Structure of Anfis for fault location

<table>
<thead>
<tr>
<th>No</th>
<th>Type anfis</th>
<th>Anfis information</th>
<th>RMSE</th>
<th>Epochs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Numbers</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>AN</td>
<td>4</td>
<td>Ua, Ub, Uc, Ia</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>BN</td>
<td>4</td>
<td>Ua, Ub, Uc, Ib</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>ABN</td>
<td>5</td>
<td>Ua, Ub, Uc, Ia, Ib</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>BCN</td>
<td>5</td>
<td>Ua, Ub, Uc, Ib, Ic</td>
<td>12</td>
</tr>
</tbody>
</table>

In this case, the ANFIS model for fault location and training data were described in Table 5.7, the thesis performs to compare the accuracy obtained of REL521 of transmission line 276 at 220kV Hoa Khanh Substation with Anfis that are provided in table 5.8.

Table 5.8: Results compare the accuracy obtained of REL521 with ANFIS

<table>
<thead>
<tr>
<th>Fault time</th>
<th>Fault type</th>
<th>Actual fault location [km]</th>
<th>ANFIS</th>
<th>P543</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Estimated fault location [km]</td>
<td>Error [%]</td>
</tr>
<tr>
<td>1/6/2009</td>
<td>ABN</td>
<td>29,36</td>
<td>29,46</td>
<td>0,36</td>
</tr>
<tr>
<td>16/10/2010</td>
<td>BN</td>
<td>27,4</td>
<td>22,95</td>
<td>1,38</td>
</tr>
<tr>
<td>2/8/2010</td>
<td>BN</td>
<td>35,9</td>
<td>36,08</td>
<td>0,03</td>
</tr>
<tr>
<td>12/8/2010</td>
<td>ABN</td>
<td>63,1</td>
<td>61,3</td>
<td>2,16</td>
</tr>
<tr>
<td>17/5/2011</td>
<td>BCN</td>
<td>25,4</td>
<td>27,55</td>
<td>1,38</td>
</tr>
<tr>
<td>20/5/2011</td>
<td>AN</td>
<td>81,8</td>
<td>83,22</td>
<td>0,02</td>
</tr>
<tr>
<td>19/8/2012</td>
<td>ABN</td>
<td>26,4</td>
<td>24,80</td>
<td>1,81</td>
</tr>
</tbody>
</table>

Reviews: Output of ANFIS for ABN fault is the highest error 2,16% of the line length. It can be clearly seen from the test results that the proposed method, which requires the same amount of
measured data, and has significantly outperformed the one-terminal method of REL521.

5.5 CONCLUSION

Three advantages of the algorithm proposed for fault location on actual transmission lines: First, it does not depend on the effect of the errors in CT and VT signals, fault resistance.... Second, the accuracy of the fault location does not rely on the accuracy of the algorithm type (REL 521 or P543). Third, ANFIS is easy to trained in personal computer and output result accurately.

The only disadvantage of the method is that the obtained accuracy depends on the current voltage data. Nevertheless, this issue can be solved by the current technology such as supervisory control and data acquisition (SCADA), wide area monitoring (WAM), and Automation Substation (TBA).

CONCLUSION AND RECOMMENDATION

The fault location techniques are applied to the power company in countries, and it is used for calculating the fault distance on the transmission line. By researching main factors affecting relay protection’s performance, and then analyzing, assessing fault location methods of famous manufacturers (SIEMEN, SEL, TOSHIBA, GE,…). The thesis purposes solutions to develop the fault classification and location appropriate with transmission line in Viet Nam. Moreover, it develops intelligent methods to quick responses, which are for HV transmission lines. Those are essential requirements for building actual models and algorithms.
New contributions of the thesis:
- The thesis clearly researches the effectiveness of main factors such as harmonic, fault resistance, CT, VT error and line parameters on the performance of relay protection. The research also proposes to use harmonic restraint function, the phase to earth distance protection with quadrilateral characteristic, phase to phase distance protection with mho characteristic, NCIT devices, the CPC 100 + CP CU1 measure line impedances and k-factors on overhead lines that help the relay can perform correctly protection function and improve the accuracy in the fault location.
- This thesis analyzes fault location algorithms based on different relays for overhead transmission line that acquired by the numerical relay at one terminal, or both the terminals or three-terminal transmission lines. Based on the literature reviews, the error of fault location methods were assessed. The research also propose to choose the most flexible and suitable method for power system in Viet Nam. It is the double end distance to fault location method using unsynchronized data measurements employed at each line end. In addition, this will flexible, suited to the actual conditions, infrastructure equipment for collection current, voltage data of the power system Viet Nam at moment and consider to the development of this in the next years.
- The thesis proposes an approach to the classification of transmission line fault by using FL, WT, ANN and ANFIS. The results obtained show that WT is suitable to choose current and voltage signals for trainning and testing ANN, ANFIS in fault location rapidly and correctly. This can appropriate with the collection data plan of EVN in the next time
Based on the above mentioned findings, a procedure for successful application of fault location based on ANFIS into the 110kV transmission line Dak Mil - Dak Nong and 220kV transmission line Hoa Khanh – Hue, which was proposed to test in the practice.

The thesis is the foundation to calculate fault locations, it contributes complement to the technique of fault locations effectively. The results obtained can be used for technical, man of science, Power Transmission Company, Grid Company to implement on other HV transmission line in Vietnam’s power system.

**Further research:**

Further research is recommended to extend this thesis in the following concerns:

- The research completes fault location algorithms using the COMTRADE file of fault data from all IEDs at central control.
- The research completes fault location algorithms on 500kV transmission line.
- Fault location using wavelet.

Besides, if there is a good condition and with the knowledge obtained in RLBV for years, it may be registrated subject for prototyping devices, which is for testing, applying classification and location methods.
PUBLICATIONS OF THE AUTHOR


