An Assessment Method for Secondary Equipment Condition of 750kV Substations Based on Rough Set and Fuzzy Petri Net

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Abstract. As the secondary equipment of 750kV substations have the characteristics like dual protection configuration, a large amount of alarm information and the weak real-time performance on maintenance, an assessment method of substation with redundant protection configuration based on rough sets (RS) and fuzzy Petri net (FPN) is proposed. In this method, the secondary equipment is divided into three regions according to the voltage grade characteristics and each region is divided according to the characteristics of device type. Afterwards, the assessment decision table based on rough set is constructed by using the self-detected information about protection devices and measurement and control devices. Based on this, the assessment model based on fuzzy Petri nets is established and the initial information of the model is determined. Through the use of fuzzy reasoning, a certain assessment result is obtained. Results show that the proposed method reduces the complexity of solving secondary equipment condition, and improve the ability of classification and identification and the efficiency of assessment.

Introduction

The 750kV grid from Hami to Lanzhou is an important delivery channel of wind and solar power in Gansu and Xinjiang, the 750kV substations are considered as the hub of the 750kV grid, in which the safety and reliability of secondary equipment operation state is of great significance to ensure its stable. This grid uses dual protection configuration and two protective devices are in parallel operation and redundant, in which the 750kV substations include 750kV, 330kV and 66kV secondary equipment. Once a fault occurs, a large number of alarm information is sent to control center. So it is very necessary for an operator to detect the operation state of secondary equipment quickly and accurately. Hence, it is very important to study assessment system of secondary equipment.

For this, the various assessment methods are proposed by foreign and domestic scholars. Thereby, the unascertained mathematics theory [1] was adopted to determine the weight values of assessment indicators. The impact of the experts’ subjectivity on the results of index weight was effectively reduced by constructing the unascertained rational numbers. In [2-3], aiming at the easily occurred incompatibility which leads to erroneous assessment, a transformer
operational state assessment hierarchy index system was established, and the corresponding model on the basis of the extension theory was proposed. A model based on the fault tree analysis and the effectiveness assessment [4] was established. For analyzing the reliability of the secondary system quantitatively, the reliability index of sub-module and whole system has been established. A method calculated the failure probability [5] of secondary equipment was proposed. Based on the assessment condition, with the equivalent running time as the intermediate variable, the results of assessment was associated with the failure statistics, and the failure probability curve was fitted by inverting the correlation coefficient. While in [6] an effective assessment policy and typical mathematical model was proposed aiming at the need and lack in application of relaying protection device state assessment, in which analyses the relevant secondary equipment and its operation characteristics. Afterforward, the condition monitoring and assessment of secondary equipments was researched, and the architecture and functionality deployment of intelligent operation and maintenance systems [7-8] was proposed according to the technical features of intelligent substation.

The secondary equipment of these references have the characteristics like single net, single protection configuration, the incomplete assessment information and the weak real-time performance. Based on this, a method based on rough set and fuzzy Petri net is proposed to assess the condition of secondary equipment. In this method, the secondary equipment are divided according to the voltage grade characteristics, the assessment decision tables based on rough set are constructed, and the evaluation model based on fuzzy Petri nets is established.

**The Secondary Equipment Condition Assessment Method of 750kV Substations**

**The Division of Secondary Equipments**

For the complexity of the secondary equipments, it is divided into three regions X, Y and Z according to the voltage grade characteristics, like the part of 750kV, the part of 330kV, the part of 66kV. And the result divided is shown in Fig. 1. The region X is divided into five regions X1, X2, X3, X4 and X5 according to the characteristics of equipment type, and the result divided is shown in Fig. 2. Where, the region X1 consist of 11 circuit breaker auxiliary protection devices, 4 bus protection devices, 12 line protection devices and 12 remote trip protection devices. The region X2 consist of 11 circuit breaker measurement and control devices, 6 line measurement and control devices, and 3 public measurement and control devices. The region X3 consists of 3 electric energy metering devices. The region X4 consists of 6 DC power. The region X5 consists of 6 AC power. The region Y is divided into five regions Y1, Y2, Y3, Y4 and Y5 according to the characteristics of equipment type. And the results divided are shown in Fig. 3. Where, the region Y1 consist of 20 circuit breaker auxiliary protection devices, 4 bus protection devices, 22 line protection devices and 22 remote trip protection devices. The region Y2 consist of 20 circuit breaker measurement and control devices, 11 line measurement and control devices, and 2 public measurement and control devices. The region Y3 consists of 2 electric energy metering devices. The region Y4 consists of 4 DC power. The region Y5 consists of 4 AC power. The region Z is divided into five regions Z1, Z2, Z3, Z4 and Z5 according to the characteristics of equipment type. And the result divided is shown in Fig. 4. Where, the region Z1 consist of 6 circuit breaker auxiliary protection devices, 2 bus protection devices, 2 transformer protection devices, 2 home-load supply transformer protection devices, 1 backup power switchover unit protection devices, 3 reactor
protection devices and 1 capacitor protection device. The region Z2 consist of 1 capacitor measurement and control device, 1 reactor measurement and control device, 1 public measurement and control device, 1 transformer measurement and control device and 2 home-load supply transformer measurement and control devices. The region Z3 consists of 1 electric energy metering device. The region Z4 consists of 2 DC power. The region Z5 consists of 4 AC power.

Figure 1. The Division of 750kV Secondary Equipment.

Figure 2. The Division of Region X.

Figure 3. The Division of Region Y.

Figure 4. The Division of Region Z.

Knowledge Acquisition Based on RS. The equipment ID, equipment model, equipment name, equipment type is considered as condition attributes in decision table, while the assessment region is considered as decision attributes. The decision table about region X, Y, Z was established respectively. The decision table of region X consists of 4 condition attributes and 10 samples, the decision table of region Y consists of 4 condition attributes and 10 samples, and the decision table of region Z consists of 4 condition attributes and 15 samples. Due to the same principle to build decision tables of each region, we only lists the decision table of region X, as shown in Table 1. Where, “U” denotes universe, and “D” is decision attributes [9-11]. Equipment ID starting with "7" denotes 1, the ID starting with "3" denotes 2 and the ID starting with "6" denotes 3. Equipment model starting with "CSC/RCS" is 1, the model starting with "WMH/BP" is 2, the model starting with "WMH/BP" is 2, the model starting with "SGT" is 3, the model starting with "NDS" is 4 and the model starting with "other letters" is 5. Equipment name, called circuit breaker, denotes 1. The name, called line, denotes 2. The name called "bus" denotes 3. The name, called transformer, denotes 4. The name, called home-load supply transformer, denotes 5. The name, called reactor, denotes 6. The name, called Capacitor, denotes 7. The name, called station transformer, denotes 8. The name, called other name, denotes 9. Equipment type, contained protection, is 1. The type, contained measurement and control, is 2. The type, contained electric energy metering, is 3. The type, contained DC power, is 4. The type, contained AC power, is 5.

According to the characteristics of equipment type, each region is divided into the smaller region. The self-detected information of equipment is considered as condition attributes in decision table, while the suspicious secondary equipment is considered as decision attributes. The decision table about region X1, X2, X3, X4 and X5 was established respectively. Similarly, The decision table about region Y1, Y2, Y3, Y4 and Y5 was established, and the
decision table about region Z1, Z2, Z3, Z4 and Z5 was established respectively. Due to the same principle to build decision tables of the smaller region, we only lists the decision table of region X1, as shown in Table 2. It consists of 39 condition attributes and 39 samples. Where, A1, A2, ......, A11, respectively, denote the auxiliary protection devices of circuit breaker 7521, 7522, 7531, 7532, 7541, 7542, 7551, 7552 and 7552. BP11, BP12, BP21, BP22, respectively, are the first and second protective devices of the No. 1 and No.2 750kV bus. LP11, LP12, ......, LP62, respectively, are the first and second protective devices in Baidong No.1 line, Baiwu No.2 line, Baiwu No.1 line, Baihuang No.1 line, Baihuang No.2 line and Baijing No.1 line. LRP11, LRP12, ......, LRP62 BP11, BP12, BP21, BP22, respectively, are the first and second remote trip protective devices of in Baidong No.1 line, Baiwu No.2 line, Baiwu No.1 line, Baihuang No.1 line, Baihuang No.2 line and Baijing No.1 line.

Table 1. X Decision of Assessment Region.

<table>
<thead>
<tr>
<th>U</th>
<th>Equipment ID</th>
<th>Equipment model</th>
<th>Equipment name</th>
<th>Equipment type</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>X1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>X2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>X3</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td>X4</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>5</td>
<td>X5</td>
</tr>
</tbody>
</table>

Table 2. X2 Decision Table of Suspicious Secondary Devices.

<table>
<thead>
<tr>
<th>U</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>...</th>
<th>LRP62</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>A1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>A2</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>...</td>
<td>0</td>
<td>A3</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>A4</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>A5</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>A6</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>LRP61</td>
</tr>
<tr>
<td>39</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>0</td>
<td>LRP62</td>
</tr>
</tbody>
</table>

Condition Assessment of Secondary Devices Based on Fuzzy Petri Net. For 750kV substation, the FPN Knowledge of suspicious secondary equipment can be defined as a seven-tuple \( S_{\text{FPN}} = (P, Q, I, O, M, W, \lambda) \). Where

1. \( P_i = \{p_{i1}, p_{i2}, \ldots, p_{in}\} \) is the fuzzy place, in which \( n \) is the number of place.
2. \( Q_i = \{q_{i1}, q_{i2}, \ldots, q_{in}\} \) is the fuzzy transition.
3. \( I: P \times Q \rightarrow \{0, 1\} \) is the input function.
4. \( O_i = \{q_{i1}, q_{i2}, \ldots, q_{in}\} \) is the output function.
5. \( M_i \) is the credibility of place.
6. \( W_i = \{w_{i1}, w_{i2}, \ldots, w_{in}\} \) is a weight matrix.
We analyses the self-detected information and history alarm information of secondary devices, extract and classify the important characteristic information. Its classified results consider as initial place of model based on fuzzy Petri net that is initial information. Subsequently, the condition assessment model of suspicious secondary equipment is established. For the first protection device of Baiwu No.1 line, the assessment model is established as shown in Fig. 5. In this model, P1, P2, ......, P9 denote the abnormality in memory, CPU, DSP, channel, power, procedure, setting, communication and logic verification.

Determine the Credibility of Initial Information. The initial information of the model which will be uploaded to the background monitor of substation automation system reflects intuitively the running state of secondary equipment, and a variety of different influence on the state of secondary equipment. In order to obtain more accurate assessment results, the initial information credibility of assessment model is determined according to maintenance guideline and assessment criteria [12, 13] of State Grid Corporation of China.

\[
H_i = \begin{cases} 
\frac{100 - A_i n_i}{100}, & (n_i \neq 0) \\
\frac{100 - A_i}{100}, & (n_i = 0) 
\end{cases}
\]  

(1)

Where, \( H_i \) is the credibility of the \( i \)th initial information. \( A_i \) is the corresponding deducting score parameter that is determined according to the state of the self-detected information. \( n_i \) denotes the number of alarms information occurred.

The Reasoning Process

(1) According to the information offered in case, search the decision table of assessment region and determine the suspicious region and secondary equipment.

(2) Determines the credibility of the initial information according to the information collected from background monitor.

(3) Calculate synthetic input credibility denoted by \( E \) in transition, where \( E \) is an \( l \)-dimensional row vector and \( l \) is the number of awaiting trigger transition. In this step, the fuzzy input of the same transition is equivalent to a unique weight fuzzy input according to its credibility and weight coefficient.

(4) Compare the equivalent fuzzy input credibility with the transition threshold, that is \( G = E \cap^O \lambda_i \), where \( G \) is an \( m \)-dimensional column vector. If the synthetic input credibility is
greater than the threshold, then \( g_i = 1 \). Otherwise \( g_i = 0, (i = 1, 2, \cdots, n_2) \). Where \( m \) is the number of triggered transition.

(5) Remove the input of synthetic input credibility which is less than the threshold and obtain \( H = E \odot G \), where \( H \) only contains synthetic input credibility of triggered transition.

(5) Calculate the credibility of fuzzy output denoted by \( M_i \), where \( M_i \) an \( m \)-dimensional column vector, \( m \) is the number of triggered transition.

(6) Perform iterative computation from step 2 to step 5 repeatedly.

(7) Obtain output results \( M_k \) until \( M_k = M_{(k-1)} \).

**Results and Discussion**

In this paper, the sample data comes from the 750kV EHV Baiyin substation of Gansu Electric Power Corporation. We select the 80 samples of Wubai No. 1 line protection device as an example, the equipment ID: 7093, the equipment model: RCS931. The sample data record the alarm number of the device.

<table>
<thead>
<tr>
<th>Samples</th>
<th>The credibility of initial information</th>
<th>The state credibility and state of suspicious secondary equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5, 0.3, 0.3, 0.3, 0.3, 0.3, 0.5, 0.73, 0.1</td>
<td>0.4085(Abnormal state)</td>
</tr>
<tr>
<td>2</td>
<td>0.5, 0.73, 0.5, 0.5, 0.5, 0.73, 0.73, 0.73, 0.73</td>
<td>0.5713(Attentional state)</td>
</tr>
<tr>
<td>3</td>
<td>0.5, 0.73, 0.73, 0.5, 0.5, 0.5, 0.3, 0.73, 0.73, 0.3</td>
<td>0.6587(Normal state)</td>
</tr>
<tr>
<td>4</td>
<td>0.73, 0.73, 0.5, 0.5, 0.3, 0.73, 0.5</td>
<td>0.5899(Attentional state)</td>
</tr>
<tr>
<td>5</td>
<td>0.5, 0.5, 0.3, 0.73, 0.73, 0.73, 0.73, 0.73</td>
<td>0.4958(Attentional state)</td>
</tr>
<tr>
<td>6</td>
<td>0.3, 0.73, 0.73, 0.73</td>
<td>0.5326(Attentional state)</td>
</tr>
</tbody>
</table>

1) According to the information in case, search decision table of region X, Y, Z and determine assessment region that is X, the division that is X1, and suspicious secondary equipment that is LP31. Compared with the references [5,14,15,16], we use division method that can accurately locate the assessment region, narrow down the scope of the assessment, reduce the decision table and decrease the scale and complexity of solution method, and improve the classification and recognition capacity of assessment knowledge.
2) According to the state of alarm information in the samples, applying formula 1 to calculate the credibility of assessment model Fig. 5, the corresponding initial information credibility of the sub-sample is shown in Table 3. If the importance degree of each place is same, the weight of input and output arcs in model is 1/h. Otherwise, the weight assumed as 0.8 and 0.2.

3) The state credibility of suspicious secondary equipment in sub-sample can be obtained through FPN reasoning as shown in Table 3.

Compared with the model [17], the assessment results of this paper is a value between 0 and 1, and can accurately describe the state information of secondary equipment. While the results based on Petri is a value that is 0 or 1, and can not accurately describe the state information.

Conclusion

1) In order to can accurately locate the assessment region, narrow down the scope of the assessment, reduce the decision table and decrease the scale and complexity of solution method, and improve the classification and recognition capacity of assessment knowledge. The secondary equipments are divided according to the voltage grade characteristics.

2) Calculate the initial information credibility of model by using fuzzy Petri nets. We can transfer the state of self-detected information into a problem solved the credibility, so that the assessment accuracy is improved.

3) The fusion idea that the changes a large sample data into a small data sample reduce the complexity of the assessment and improve the efficiency of the assessment.

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References


