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Rough Sets and Genetic Algorithm for Power Cable Joints Fault Diagnosis

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***Abstract*—The influence factors of cable junction accidents was determined by accidents analysis. The research methods to utilize rough set theory to extract effective information from cable junction accident data in history was discussed in this paper. Cable junction accident decision table attribute reduction algorithm and cable junction accident decision table based on genetic algorithm were obtained. The results show that the model is scientific and reasonable, and the algorithm is efficient and feasible.**

Keywords-rough set; cable jonit; genetic algorithm; fault diagnosis

I. INTRODUCTION

With the rapid development of economy and city construction, renovation of city power grid deepening distribution using overhead line and pole equipment, has been unable to meet the requirements of city residents and beautiful environment. The requirements of quality of the power supply is more and more high and dependence on power is more and more strong. Therefore, the development of city distribution network change rapidly, has formed a complicated structure, which with numerous equipment and meet the requirements of the huge system of people's livelihood. In the city power grid 10kV power distribution cable operation is very important. Some researchers proposed a new partial discharge (PD) pattern recognition of power cable joints using the extension method with fractal feature enhancement [1,2]. Through statistical analysis of various fault types and fault causes, put forward to prevent the 10kV power cable fault protection measures of city power grid power supply quality requirements.". [3-5]

Rough set theory can remove the redundant information in keeping the original classification ability unchanged.[6-8] Genetic algorithm is an adaptive search algorithm for global optimization and the formation in simulation of biological genetic and evolutionary processes in the natural environment.[9,10] This paper analyses the influence factors of electric power cable joint, the decision table is established to reflect the relationship between the type of power cable joint breakdown and the causes of joint fault. The rule of removal redundant decision table has been provided, which using attribute reduction method combining rough set theory and genetic algorithm, providing a scientific basis for preventing power cable fault.

II. FAILURE ANALYSIS OF CABLE JOINT BREAKOUT

Cable joint faults happen under certain conditions, error installation, metal burrs and improper storage are the main factors of cable joint faults.

A. Conductor Connection Problems

Problems mainly include electric field distortion by burr from the conductor crimp, fever result in untreated connect tube internal oxide layer, large contact resistance caused by lack of contact surface pressure.

B. Insulation, Semi-Conductive Layer, Sheath Problems

Some problems include partial discharge after installation caused by cable stripping and cutting scratches, insulation shielding is not fully cleaned, semi conductive residues in the main insulation after joint installation, the electric stress concentration at the cut in semi conductive layer. The oxide layer, between the ground wire and the shielding layer, is easy to be produced owing to the binding method of sheath.

C. Faults between the Conductor and the inner Shielding Layer

The quality of insulation grease used between conductor and the inner shielding layer is not good, leading to the air gap cannot be drafted effectively in this area. The middle point of cold shrink tube cannot coincide middle line of metal tube result in lack of insulation.

D. Inappropriate Storage

The storage period is too long, so that the silicone rubber loses part of elasticity, cannot guarantee the interfacial pressure, and is easy to exist air gap.

E. Environmental Problems of Cable Operation

The problems of cable operation environment include water seepage and improper arrangement. The main reason is improper method of arranging cable to break the cable outer sheath. Once cable outer broken protective layer is flooded, the water will be immersed in the cable sheath, penetration in the middle joint internal. In the long operation period, the middle connector, expansion and contraction of XLPE cable insulation material, or contact scratches leaving on the insulation by unstandardized construction process, causing the air gap between silicon rubber sleeve and the cable insulation layer and water immersion, which is the main reason of intermediate joint failure. In addition to the poor cable line arrangement and operation conditions, the cable cannot be well cooled to enhance cable operation failure rate.

F. Hazards Caused by Improper Cable Laying

In the installation process, semi conductive layer in the corner may bind due to mechanical torsion effect. The curvature of cable decrease and easy to form a charge accumulation tip, and insulation surface was extended by elongation result from stress distorting effect, moreover, if some partial discharges exist there, it will result in electrical tree submicroscopic cracks caused by the surface bending stress to produce the, or new crack and new electric branches caused by partial discharge corrosion, leading to reduced levels of insulation.

III. ROUGH SET THEORY KNOWLEDGE

A. Definition 1

A decision table is a system, which called

$$S = (Univ, Att, Val, f) \tag{1}$$

where:
Univ is a finite set of states, called the universe.
Att, which means Con ∪ Dec, is the set of attributes; Con is the set of Conditions attributes and Dec is the set of decisions attributes.

$$Val = \bigcup_{a \in ATT} Val_a \tag{2}$$

Val is the set of values of an attribute a∈Att.
f means Univ × Att~Val, is a total function, called the decision function, such that f(x,a)∈Vala for every x∈Univ and a∈Att.

B. Definition 2

We define R is a family of equivalence relation, r∈R, if ind (R) =ind (R-{r}), r is said to be unnecessary; otherwise r is called necessary. If each of r is necessary, R is said to be independent. We assume Q∈P, if Q is independent, and the ind (Q) =ind (P), then Q is called a reduction of P.

C. Definition 3

Decision attribute D on the condition of attribute of C positive region:

$$pos_c(D) = \bigcup_{x \in \frac{U}{d}} c(X) \tag{3}$$

D. Definition 4

Dependence of decision attributes on condition attributes C is defined as

$$\gamma_c(d) = \frac{|pos_c(d)|}{|U|} \tag{4}$$

where |U| means the base of U.

IV. CABLE JOINT ACCIDENT ANALYSIS BASED ON ROUGH SET AND GENETIC ALGORITHM

A. Determination of Accident Information Table

The annual cable joint accidents are taken as the universe, the influencing factors of cable joint accidents as the condition attribute set, the cable junction accident type as the decision attribute set. There are nine factors selected as condition attributes, such as pressure tube burr, insufficient pressure, air gap between the pressure tube and insulation, insulation cut wound, semi-conductor residual, middle point distance between cold shrink tube and press metal tube, outer semi conductive layer transition, storage period, moist operation environment, representing by C1, C2 to C10 respectively. Through the data preprocessing of the original cable joint accidents, including the data denoising, discretization and normalization, the cable joint accidents decision table is established (Table 1).

For instance, C1 is equal 0 means none burr existed, if then record 1. C2 means pressure on metal connecting tube, 0 indicates sufficient and 1 insufficient. C3 means air gap between the pressure tube and insulation, 0 shows no air gap and 1 shows air gap exists. C4 means insulation cut wound, 0 shows no cut wound and 1 shows cut wound. C5 indicates semi-conductor residual, 0 shows no residual and 1 shows residual. C6 expresses middle point distance between cold shrink tube and press metal tube, 0 shows no distance and 1 shows distance. C7 expresses outer semi conductive layer transition, 0 means chamfer and 1 means step. C8 means storage period, 0 means less than six months and 1 indicates more than six months. C9 means moist operation environment,0 means dry and 1 represents moist. C10 indicates current overload, 0 means normal while 1 means overload. The ten factors considered here are the main causes of cable joint accidents, while other minor factors are ignored.

B. Attribute Reduction Algorithm

Because attribute reduction problem belongs to NP complete problem, this paper proposes a genetic algorithm

to reduce redundant attribute attributes to simplify the decision table.

TABLE I. CABLE JOINT ACCIDENT DECISION

U	C										D
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*	*C10*	
1	0	1	1	0	0	0	0	0	0	1	1
2	0	0	1	1	0	0	0	0	0	0	1
3	0	0	0	0	0	0	0	0	1	0	1
4	1	1	0	1	0	0	0	0	0	0	1
5	1	0	0	0	0	0	0	0	1	0	1
6	0	1	0	0	0	0	0	0	1	1	2
7	0	0	0	0	0	0	0	1	0	1	2
8	0	0	0	0	1	0	0	0	0	0	1
9	0	0	1	1	1	0	1	0	0	0	0
10	0	0	1	0	1	1	1	0	0	0	1
11	0	0	1	1	1	1	0	0	0	0	0
12	0	0	1	1	1	1	1	0	0	0	1
13	0	0	1	0	1	1	1	0	0	0	0
14	0	0	1	1	1	1	1	0	0	0	1
15	0	1	1	0	1	0	0	0	1	0	1
16	0	0	1	0	0	0	0	0	1	0	0
17	0	0	0	0	0	0	0	0	0	1	2
18	1	0	0	0	1	1	0	0	0	0	1
19	0	1	1	0	1	0	1	0	0	1	1
20	0	0	1	0	0	0	0	0	1	0	0
21	0	1	1	0	0	1	0	0	1	0	1
22	0	1	1	1	1	0	0	1	0	1	2
23	0	1	1	1	0	0	0	0	1	0	1
24	0	0	1	0	1	0	1	0	0	0	1
25	0	1	0	0	0	0	0	1	0	0	1

C. Chromosome Coding

A binary string of length L, which says the number of condition attributes, is used to represent each individual encoding. Each bit corresponds to a conditional attribute, for instance c1, c2, …, cl. If individual contains nth attribute, cn equals 1, otherwise, cn equals 0.

D. Fitness Function

$$\mathrm{F(r)} = \frac{l - l_r}{l} + \gamma_c(d) \tag{5}$$

Where:
lr means the number of gene equaling 1 in chromosome r.

E. Genetic Operator Design

Because attribute reduction problem belongs to NP complete problem, this paper proposes a genetic algorithm to reduce redundant attribute attributes to simplify the decision table.

F. Selection

To use the Roulette-wheel method.

G. Crossover

By using a crossover operator, part of the chromosomes of 2 individuals are exchanged at their intersections by using the crossover probability pc, and 2 new individuals are generated.

H. Mutation

The mutation operator pm is used to invert the binary character value of a certain allele randomly by using the uniform mutation operator.

I. Convergence

The calculation is terminated when iterative steps gets maximum generation Max Gen or $\gamma_{reduct(C)}(d) = \gamma C(d)$.

J. Algorithm Steps

The specific algorithm steps are as follows.

Input: Information System S = (Univ, Att, Val, f)

Output: All reduction of Information System S = (Univ, Att, Val, f)

Step 1 To calculate the decision attribute d on condition attribute γc(d).

Step 2 To make the set reduct (C) equals empty, remove the attribute one by one in ci ∈ C, if γC-{ci}(d) not equals to γC(d), reduct(C) equals to reduct(C) ∪ {ci}. However, if γC-{ci}(d) equals to γC(d), the calculation process is terminated, and C said reduction property of C, otherwise turn to Step3.

Step 3 Initial population consists of the number of pop size individuals represented binary string, which randomly generated by the |C| length (the number of condition attributes), the corresponding bits of randomly selected 0 or 1, and calculate the fitness of everyone in the initial population.

Step 4 To select individual and produce a new generation of groups according to the roulette method, crossover probability pc and mutation probability pm, maintaining the properties of the corresponding gene mutation does not occur.

Step 5 To calculate fitness of each individual group of new generation.

Step 6 On the basis of the optimal preservation strategy, best individual will be copied to the next generation groups, best individual is preserved according to the optimal preservation strategy.

Step 7 To determine whether the fitness of optimal individual continuous t generation will no longer increase, if the result is yes than the calculation is terminated and outputs of the best individual, otherwise to Step 4.

K. Analysis Decision Rule Generation

The redundant information are removed by attribute reduction, and the simplified information table and cable junction accident rules are obtained.

V. RESULTS AND DISCUSSION

Selecting p_c=0.7, p_m =0.01, Max Gen =100, the optimal solution is 0110101001, that is, C2, C3, C5, C7, C10 attribute reservation, then the reduced decision rules are shown in Table II.

TABLE II. DECISION RULES

C2	*C3*	*C5*	*C7*	*C10*	*D*
0	0	0	0	*	0
1	0	1	0	0	0
0	1	0	1	0	0
1	1	0	1	0	0
1	1	0	1	1	1
0	1	*	1	1	1
0	*	0	1	*	1
0	1	1	0	1	1
1	0	1	1	1	1
1	0	1	0	1	2

As can be seen from the decision rules, decision types of accidents are mainly pressure, air gap, semiconductor residual, transition and current overload 5 factors. And, if the accident occurred in the semiconductor residual, and air gap, is prone to general traffic accidents; if the accident occurred in the semiconductor residual and steps, current overload, easy occurrence of major accidents. If the cables were installed with semiconductor residual, serious current overload, is prone to accidents. Therefore, according to the rule of historical data extracted, for the establishment of cable junction accident analysis system to provide a scientific basis, can take different measures according to different the situation, effectively prevent the occurrence of cable junction accident.

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