[ENE02] Artificial neural network based arcing fault detection algorithm for underground distribution cable

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Introduction

Arcing fault occurs in underground distribution cable due to electrical and water treeing in XLPE insulation and inadequate splices assembly. These faults can cause considerable damage to the equipments if they are not detected and isolated promptly.

An arc is a luminous discharge of electricity flowing between two electrodes through an insulating medium. The electrical discharge of an arc can involve temperatures of up to or exceed 35,000^{o}F (Koch, B. and Christophe, P. 1993).

Depending upon the environment of the installation, moisture, small metal particles and pollution can easily penetrate into a failed insulation creating an electrically conductive path between an energized conductor and other parts of the system which are at different electrical potentials. A conductive path created in this way often has a high resistance that will not immediately cause a bolted short circuit between two different potential levels of a system (Crnko, T. and Dyrnes, S. 2001). Hence, fault currents, until a bolted short circuit is established, will be limited and often cannot be detected by overcurrent protective devices connected upstream from the location of the fault. Such a fault would first persist as an arcing, not drawing enough current to be detected by standard overcurrent protections, and creating a fire hazard.

In the case of overhead line the gas generated through arcing is dispersed rapidly. But in the case of underground cable the generated gas could travel along cable duct and could result in explosion at manhole location, which is dangerous to personnel.

Arcing fault does not occur frequently on underground distribution cable but it can draw a large amount of electrical energy from the system. This energy is dissipated into the environment in various forms through the following mechanisms, namely melting and evaporation of the electrode material, noise produced by powerful ac arcs, jets of very high temperature vapours and ionised gases, temperature and pressure rises in a limited volume of a closed manhole and thermal degradation of nearby organic materials.

Materials and methods

Modelling of underground distribution systems

To study the characterization of arcing fault in underground distribution cable, a simple underground distribution system has been modelled and simulated using Power System Computer Aided Design / ElectroMagnetic Transients for Direct Current (PSCAD/EMTDC) program. The data obtained from simulation based on this system are used for neural network training and testing purposes. Figure 1 depicts the circuit diagram of simple underground distribution system.

This system includes typical distribution components, which consists of system source, distribution transformer, underground cables and loads. An arc model has been used to study the characterization of arcing fault.

To evaluate the performance of the detection algorithm, two practical TNB distribution systems will be used in this study. The first system is 11 kV underground distribution system in Taman Rinting, Masai, Johor (PPU Taman Rinting 11 kV) and the second system is 6.6 kV underground distribution system in Pasir Gudang, Johor (PMU PGIE 6.6 kV). The schematic diagrams of both systems are illustrated in Figure 2 and 3, respectively. Both systems consist of system source, transformers, underground cables and loads.

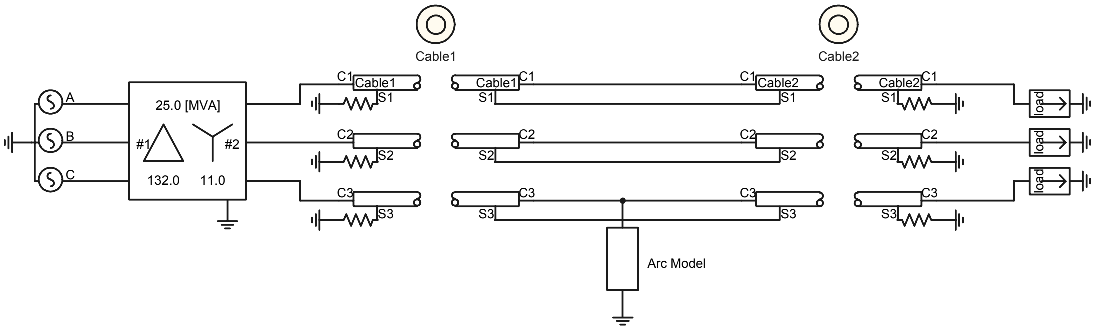

FIGURE 1 Circuit diagram of simple underground distribution system

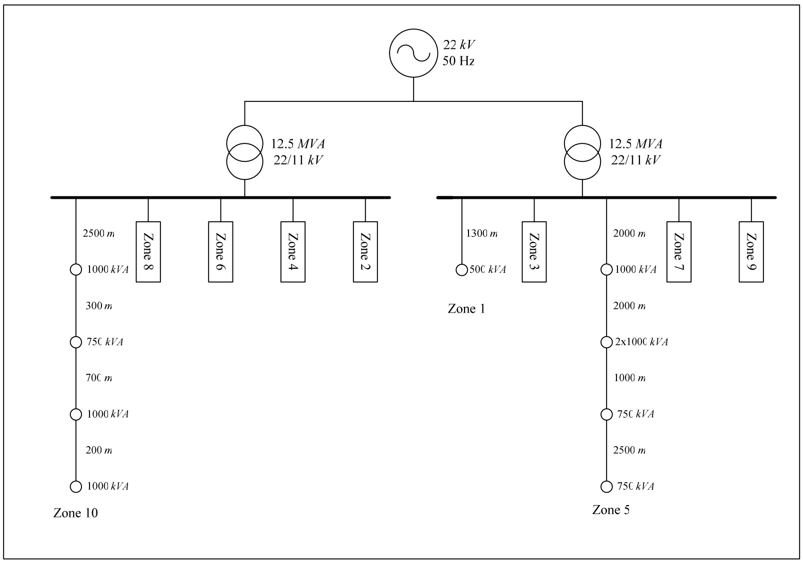

FIGURE 2 Schematic diagram of 11kV underground distribution system in Taman Rinting, Masai, Johor

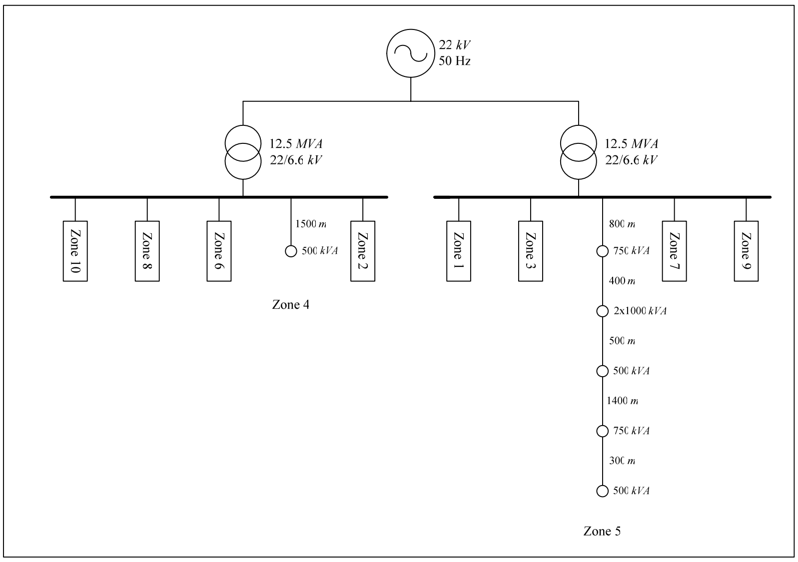

FIGURE 3 Schematic diagram of 6.6kV underground distribution system in Pasir Gudang, Johor

Due to the PSCAD/EMTDC program educational edition's limitation of 200 electrical nodes, the modelling of underground cables is focused on 3 zones in PPU Taman Rinting 11 kV system and 2 zones in PMU PGIE 6.6 kV system. The other 7 zones in

PPU Taman Rinting 11 kV system and 8 zones in PMU PGIE 6.6 kV system are represented by fixed loads.

Extensive simulations have been performed using PSCAD/EMTDC program for different values of arc fault resistance and fault locations. The phase current signals were collected and stored in out (*.out) format for later analysis on the data in Matrix Laboratory (Matlab) software package.

The arc model

An arc model developed based on (Emanuel, A. E. *et al.*, 1990) is used to examine the diverse and complex characteristics of arcing fault, as shown in Figure 4. The arc model is embraced with nonlinear arc fault resistance R, two DC voltage sources V_P and V_N, connected in anti-parallel by means of two diodes D_1 and D_2. S is a conventional time-controlled switch which connects the cable to the fault path. Z_{in} is connected to cable conductor meanwhile Z_{out} is connected to ground. A random number generator is used to generate random values of arc fault resistance in order to get different arcing faults current magnitudes. The current flows through V_P only during positive half cycle and V_N only during negative half cycle.

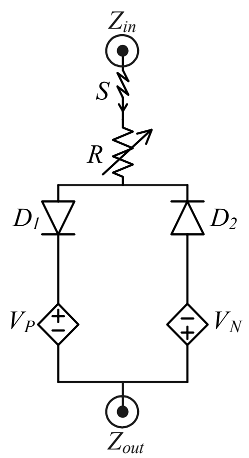

FIGURE 4 The arc model

Network architecture

A fully connected three-layer (input, hidden and output) feed-forward neural network have been used to discriminate arcing fault currents from normal load currents. Figure 5 depicts the pattern recognition network architecture. The input layer of the network is composed of 52 neurons. The first 50 neurons are phase current inputs between the range of value 1 to value -1, which represent the instantaneous values of the sampled phase current per cycle, starting at the current zero crossing of the positive half cycle. The last two neurons are inputs consist of two ratios. The first ratio is the DC component to the fundamental frequency (I_{dc}/I_1) of the phase current per cycle; meanwhile the second ratio is the second harmonic to the fundamental frequency (I_2/I_1) of the phase current per cycle.

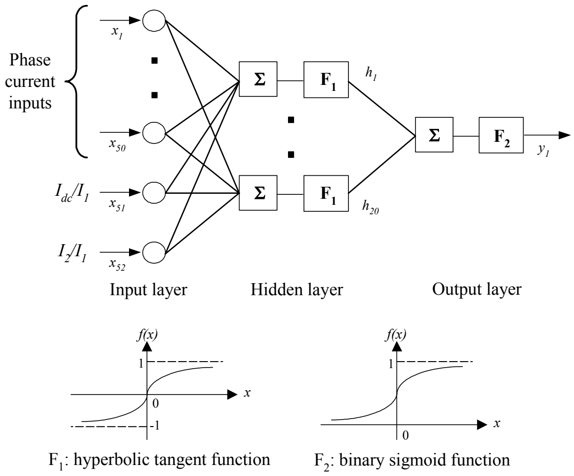

FIGURE 5 Pattern recognition network architecture

The hidden layer of the both networks is composed of 20 hidden neurons. In this layer, hyperbolic tangent function is used as the activation function with a range of –1 and 1. The output layer of both networks has one neuron. The target output of the network is '1' for arcing faults and '0' for normal load conditions. As a result, binary sigmoid function is used as the activation function in this layer.

Training patterns

The neural network is trained by a set of phase current patterns of arcing faults and normal load conditions gathered from simulation results based on the simple underground distribution system in Figure 1. Figure 6 and Figure 7 illustrate some of the phase current patterns that were used to train the network. The arcing fault currents in Figure 7 are characterized by unsymmetrical half cycles due to harmonic contents.

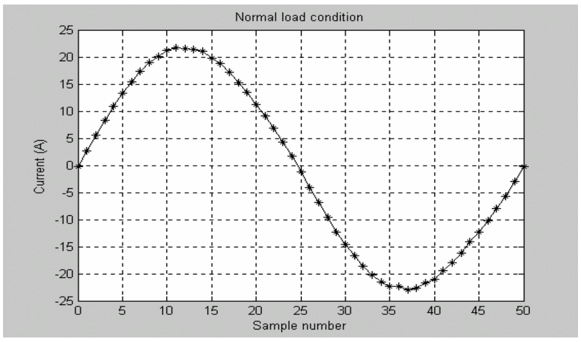

FIGURE 6 Normal load current training pattern

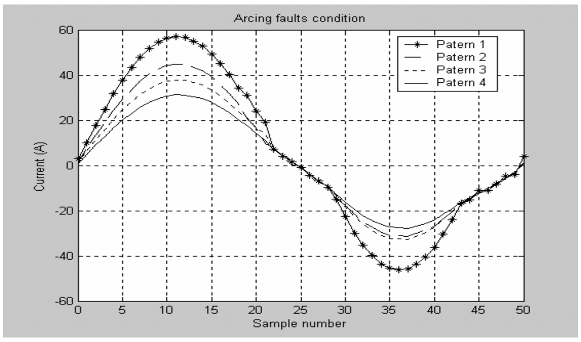

FIGURE 7 Arcing faults current training patterns

The neural network training can be made more efficient if certain pre-processing steps are performed on the network inputs and target outputs. As a result, the training patterns are sampled at the rate of 50 samples per cycle and then normalised between the range of value 1 to value –1, while maintaining the target outputs remained unchanged.

The neural network was trained with the backpropagation algorithm. The Matlab ANN Toolbox was selected for the implementation of backpropagation due to its simplicity and flexibility.

Arcing fault detection algorithm

To detect the presence of arcing faults in underground distribution cable, an arcing fault detection algorithm has been developed. Figure 8 shows the flowchart of the arcing fault detection algorithm. The algorithm processes the data as follows:

a) Input current signal

Phase current signals are loaded to the detector.

b) Data pre-processing

The neural network requires the input signals to suit the network input layer. Therefore each cycle of the phase current signals is sampled at the rate of 50 samples, starting at the current zero crossing of the positive half cycle. At the same time the two ratios, I_{dc}/I_1 and I_2/I_1 are calculated. Then the sampled signals are normalised between the range of value 1 to value –1.

c) Pattern recognition

The resulting input signals are passed cycle by cycle to the neural network for pattern recognition.

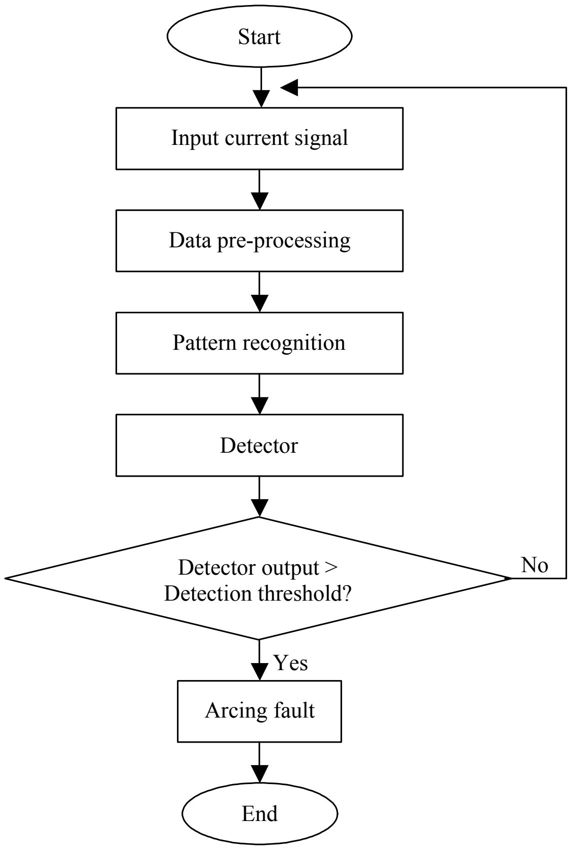

FIGURE 8 Flowchart of the arcing fault detection algorithm

d) Detector

The detection algorithm integrates the neural network scores to calculate the detector output.

$$output_{new} = output_{old} + \frac{\delta t}{\tau}\left(score_{new} - output_{old}\right) \quad (1)$$

where δt is the integration time step of one cycle and τ is the integration time constant of one second (Sultan A. F. *et al.*, 1994).

The output of detector is compared with a detection threshold to determine whether or not the disturbance is caused by an arcing fault. If the output of detector is more than a detection threshold, the process of detection would be completed. However, if this condition is not true, the process is then repeated.

Results and Discussion

Test with simulation database

To evaluate the dependability of the arcing fault detection algorithm, the algorithm is tested with four-second traces of normal load phase current corrupted by currents of phase-to-ground faults on different combination of arc fault resistances and locations. The test cases with different range of fault resistance and location, as tabulated in Table1 and Table 2, are obtained from the simulation results based on the PPU Taman Rinting 11 kV system and the PMU PGIE 6.6 kV system.

Figure 9 illustrates part of the test cases and detection results. It is clear that the detection results show a perfect performance in test cases 9 and 11. The neural network scores '0' for the first one second because the phase currents consist of normal load currents. After the one second, the phase currents consist of typical arcing fault currents; hence the network scores '1' within this period. The output of the fault detector indicates the probable presence of arcing fault is about 0.95, for duration of three seconds.

This is in contrast with test cases 23 and 28, the neural network shows relatively low scores in the detection results. This means that the neural network is unable to recognize all the arcing fault conditions. However, the outputs of the fault detector signify that the probable occurrences of arcing fault are about 0.9, during the period of three seconds.

TABLE 1 Test cases with different range of fault resistance obtained from PPU Taman Rinting 11 kV system

Test Case	Zone	Location (km)	Range of Fault Resistance (ohm)
9	1	0.5	300 – 800
10	5	0.5	200 – 900
11	5	1.0	200 – 1000
12	5	1.5	200 – 800
13	5	3.0	150 – 600
14	5	4.5	100 – 700
15	5	6.0	100 – 500
16	10	0.8	200 – 400
17	10	1.8	100 – 600
18	10	3.2	100 – 800
19	10	3.6	80 – 300

TABLE 2 Test cases with different range of fault resistance obtained from PMU PGIE 6.6 kV system

Test Case	Zone	Location (km)	Range of Fault Resistance (ohm)
20	4	0.5	100 – 200
21	4	0.9	90 – 250
22	4	1.2	110 – 270
23	5	0.4	120 – 300
24	5	1.0	80 – 350
25	5	1.4	150 – 400
26	5	2.0	100 – 380
27	5	2.2	70 – 170
28	5	2.4	85 – 234
29	5	2.6	130 – 330
30	5	2.8	60 – 150

Similarly in test cases 24 and 25, the neural network shows relatively low scores from 1 to 2 seconds. The arcing fault current patterns are very close to sinusoid within this period due to very high fault resistance. After 2 seconds, as the arc fault resistance is decreases, the fault currents become typical arcing fault with observable current spikes, which are easily detected by the neural network. For above two cases, the fault detector outputs show that the probable presences of arcing fault are about 0.9.

The detection results show satisfactory performance in all test cases where the output of the fault detector indicates the probable occurrence of arcing fault is above 0.85 for a period of time less than four seconds. For the detection threshold level, based on inspection of the fault detector output for all test cases shown

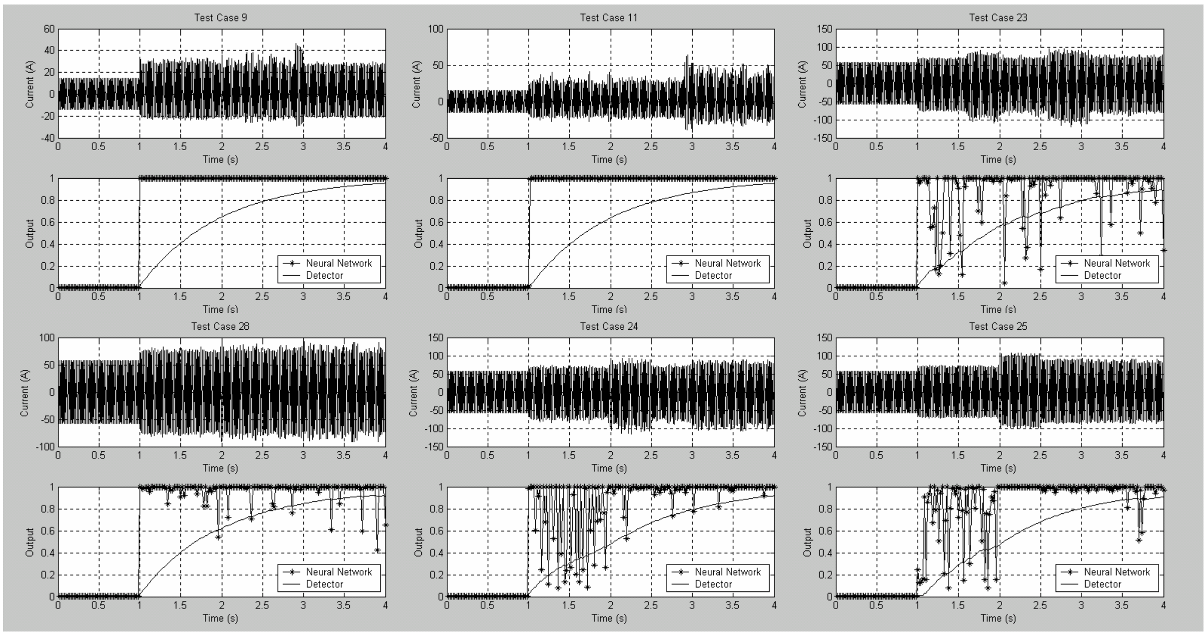

FIGURE 9 Test cases and detection results

in Figure 9, a detection threshold level of 0.85 is appropriate for a trip level setting.

The simulations database performed by PSCAD/EMTDC program was primarily designed to test the effectiveness of the proposed arcing fault detection algorithm. Therefore, the current patterns obtained from simulations are only representative of the types of patterns that could be generated by an arcing fault.

A more effective evaluation of the proposed arcing fault detection algorithm will require a lot more actual field data for reliability. In addition, the neural network need to be trained with more current patterns that include the patterns of nonlinear loads that mimic fault conditions would increase the network reliability.

Acknowledgements

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