Fault Detection Technique to pinpoint Incipient Fault for Underground Cables

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Abstract— If a fault occurs in an Underground cable, it is very difficult to track down the fault, as the conductors are concealed. The failure of cable does not occur instantly, it is developed slowly over a period of time, distinguished by series of single-phase sub-cycle incipient faults, accompanied by a high arc voltage. At the beginning the faults are self-clearer and incipient and they are unescorted by the operation of the overcurrent protective devices. If we overlook the incipient faults, they might provoke to a permanent fault. Hence an algorithm, incipient fault location algorithm is developed in a time-domain, to pinpoint the incipient fault in the underground cable. The algorithm estimates the distance to fault with respect to line impedance, by considering the arc voltage. The algorithm is simulated in MATLAB Simulink, it is evaluated by comparing with a base circuit, and for more accurate and error free identification of fault, ANN technique is used to process the result.

Keywords—Intermittent arcing, VSC, Artificial Neural Network (ANN), Fourier Transform (FT), Mean squared error (MSE).

I. INTRODUCTION

From decade, the use of underground cables in distribution network is practised worldwide. In recent years the high voltage line were developed, to reduce the sensitivity of the distribution network to the environmental influences. The underground cables are employed more and more, as they are unaffected by the weather conditions, heavy rain, snow, storm and ice as well as pollution. The cables are customarily laid in ground or in duct. For this reason, there is a remote possibility of, occurrence of faults in underground cables. If a fault occurs, it is very difficult to button-down, as the conductors are obscured. However, it is known that cable failure is a slow process, occurs over an interval of time. It is pecularised by series of single-phase sub-cycle incipient fault, accompanied by high arc voltage [1].The incipient faults are originally self-clearer faults, without operation of overcurrent protective devices. When these faults go undetected, they might lead to a permanent fault [2].

There are different methods and techniques available for diagnosing the incipient fault, however they fail either due to lack of capability to provide reasonable estimate, as it works only in phasor-domain and also suppresses the effect of arc volt. Hence a paper is presented by considering the advantage all three method, such as impedance based algorithm, sub-cycle fault detection method and arc voltage algorithm.

Impedance-based fault location method [1-4] are frequently used with voltage and current waveforms captured by the power quality monitor. It gives distance to fault in reference to line impedance. The algorithm predominantly works in the phasor-domain and hence, requires more than one cycle to provide reasonable location estimates [6]. Impedance based fault location method works well on the urban underground system as well as more suburban and rural systems.

To overcome the demerits of impedance based system, Sub-cycle ground fault location method presented in [8], [14], and [11] is used, which is an innovative method for detecting the sub-cycle incipient cable failure instigated by self-clearing faults. However the arc voltage at the location is neglected. It [7] is very important to consider the impact of arc voltage because high voltage magnitude electric arc is habitually associated with the incipient fault in the cable.

Arcing fault detection method presented in [15-17] is thrived in time domain, wavelet domain and frequency domain approach to determine sustained and intermittent arcing in underground distribution systems.

Given these requirements, the applicability of the impedance based method is limited. The Incipient fault detecting algorithm is developed to identify the incipient fault, this by amalgamating Impedance based fault location algorithm with the Arc voltage algorithm [13]. The objective of incipient fault detection algorithm is to establish a resilient yet feasible fault location algorithm which can identify single-phase sub-cycle incipient fault by taking into consideration of the arc voltage. This can be implemented in time-domain and frequency-domain, persuades fault distance in terms line impedance. To obtain error free result it is pre and post processed using ANN technique. This will pin down exact location of fault. In II fault location algorithm is derived and modelled. In III the fault detection algorithm is compared with a base circuit. IV gives pre- and post-processing of result, using ANN technique.

II. INCIPIENT FAULT DETECTION ALGORITHM

A. CHARACTERISTICS OF:

i. SELF-CLEARER FAULTS OR INCIPIENT FAULTS:

The cable failure instigated by self- clearing faults that occur in the cable splices due to insulation breakdown [11], [14]. For e.g., when water accumulates in cable splice, it leads to insulation breakdown which is followed by an arc. Arcing causes rapid water evaporation and develops a high pressure inside the splice, this extinguishes the arc and also interrupts the fault within a quarter cycle is called a self-clearer fault. Self-clearing faults have their own characteristics: faults are self-cleared within a quarter cycle, they always occur near a voltage peak and their frequency of occurrences increases over period of time.

ii. arcing faults:

An arc is nothing but a self-sustained electrical discharge which is caused by the short circuits on the power system network. [15]The arc exhibits a low voltage drop and it is capable of withstanding large currents. The arc voltage will remain constant for a wide range of current and arc length. And hence, the arc resistance is non-linear function of voltage [9].

B. assumptions made for the algorithm:

The following assumptions are made to simplify the algorithm

1. [13], [16] the arc voltage is ideal square wave shape, this insinuates that, the voltage remains constant irrespective to the fault current.
2. The arc voltage are in phase with arc current [15].
3. The fault side capacitor in the model is considered as a lumped representation of distributed cable capacitance [17], [18].

C. DERIVATION FOR INCIPIENT FAULT DETECTION ALGORITHM

The derivation for this algorithm was presented in [9]. This [16] method is applicable to single line-to-ground fault and it estimates the arc magnitude in the affected phase and the reactance and resistance to the fault. Consider that a single line-to-ground fault has occurred on an underground cable. When seen from monitoring site, the cable can be represented by an equivalent model as shown in Fig. 1.

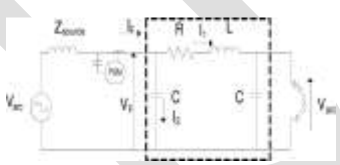

Fig. 1. Equivalent model of single-line-to-ground fault

To simplify the analysis it is assumed that the capacitor on the fault side of the model is shorted by the fault. Now the fault circuit consists of R, L and C only on the source side as in Fig 2.

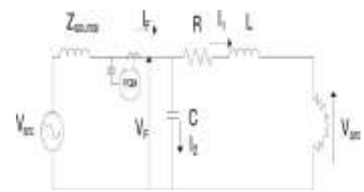

Fig. 2. Simplified model of cable during single line-to-ground fault

The fault side capacitor in the model is considered as a lumped representation of distributed cable capacitance. The assumption of essentially shorting the capacitor is justified, as during low resistance or bolted fault this capacitor immediately discharges into the fault with a RC time constant typically in the microsecond or even smaller range.

At the monitoring station, the faulted voltage v_F and currents i_1 and i_2 are represented in (1).

$$v_F = R.i_1 + L.\frac{di_1}{dt} + V_{arc,mag}.sign(i_1)$$

$$i_2 = C.\frac{dv_f}{dt}$$

$$i_1 = i_f \times i_2 \qquad (1)$$

These equations are represented in matrix form as shown in (2). $$[v_F] = \left[i_n - \frac{dv_F}{dt}\frac{di_n}{dt} - \frac{d^2v_F}{dt^2}\ sign(i_n)\right].\begin{bmatrix} R \\ -R.C \\ L \\ -L.C \\ V_{arc,mag} \end{bmatrix} \qquad (2)$$

Where,

v_F Faulted phase voltage

i_F Line current at the faulted phase

L Line inductance between the monitor and the fault

R Line resistance between the monitor and the fault

III. BASE CIRCUIT OR SIMPLE OHM'S LAW CIRCUIT

A model based on the concept of simple ohm's law is used to develop a base circuit. This model gives locates the fault very easily but the arc voltage characteristics are not considered. However this type of impedance based fault location algorithm cannot be used practically, as it does not give a reasonable fault estimate. Hence this model is considered only for the comparison purpose. The value of impedance obtained from this method is compared with incipient fault detection method. The model is developed in the MATLAB Simulink software.

a) Comparing incipient fault location circuit with Simple ohm's law circuit.

In the Fig. 6, the incipient fault location circuit is connected to the base circuit using a summing block, the impedance comparison is done, in order to find out the error percent. From Fig. 7 shows the impedance for both the circuit.

IV. ARTIFICIAL NEURAL NETWORK

The artificial neural network is interconnected group of nodes, which is similar to the vast network of neurons in a brain. Each node represents an artificial neuron and the arrow represents a connection from the output of one neuron to the input of another.

The ANNs are a family of statistical learning algorithm inspired by biological neural networks and are used to appropriate or estimate functions that depend on the large number of inputs and generally unknowns. The neurons send message to each other, they are used for summing and non-linear mapping. The connections in ANN have numeric weights that can be tuned based on experience, making neural nets adaptive to inputs and it has capable of learning. The weights encode the knowledge [19-21].

i. Pre and Post processing using ANN technique

The processing is done to eliminate or filter out unwanted noise from the system, hence reducing the mean squared error.

1. *Mean Squared Error:* Average squared difference between the output and the target. Lower the value better the result.
2. *Regression R value:* measure of co-relation between output and target. An R value of 1 means close relation, 0 is random relation.

ii. Algorithm for fault location using ANN

Step 1: construct a power system with two bus system
Step 2: measuring the below parameters
1. Vs : sending end voltage
2. Is : sending end current
3. Vr : receiving end voltage
4. Ir : Receiving end current

Step 3: manipulate the equations and find the value of D
Step 4: display the estimated and manipulated location
Step 5: once the designing on two bus system is done, faults are applied to that system in the interval of 0.1s with ten fault locations. As we are applying the fault location, we know at which time and where the fault is applied. Vr is given as input and distance to the fault is the output.
Step 6: the two bus system is made run with the faults applied to the transmission line, say for 0.1 sec the first fault will be turned, at 0.2 the fault 2, like up to 1 sec, 10 faults can be enabled.
Step 7: measuring the fault distance in terms of variable D
Step 8: training the neural network for the stored parameters of Vr and D value.

V. SIMULATION AND RESULTS

a) *Modelling of Incipient Fault Location Algorithm*

The only access to the underground cables is through manholes. [10] The typical distance between two manholes is maximum of 500ft. At very street intersection manholes are located. Hence the job of algorithm is to predict cable fault location between two adjacent manholes. The algorithm is developed using MATLAB simulation. The Simulink model in Fig 3, is made to run, to pinpoint the fault location between two adjacent manholes.

The transition for fault is chosen between (0.25, 0.5), the algorithm is made to run, to verify whether the algorithm pin points the exact fault location or not.
It is seen from the Fig.4 that, the voltage remains constant irrespective of the current. It should be noted that, the magnitude of current increases between the transmission time (0.25, 0.5). Fig 5. Also depicts the non-linear property of resistance. Thus proving that, the incipient fault location algorithm provides accurate fault estimate.

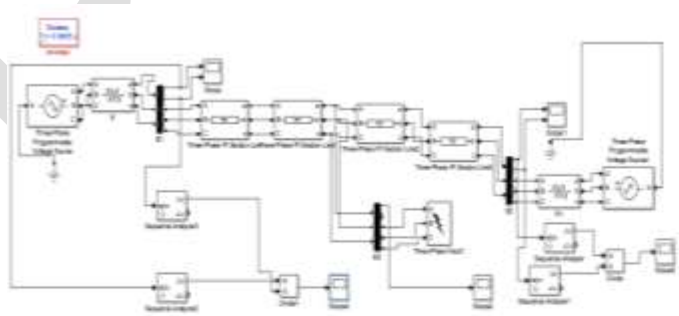

Fig. 3. Incipient fault location algorithm Simulink model

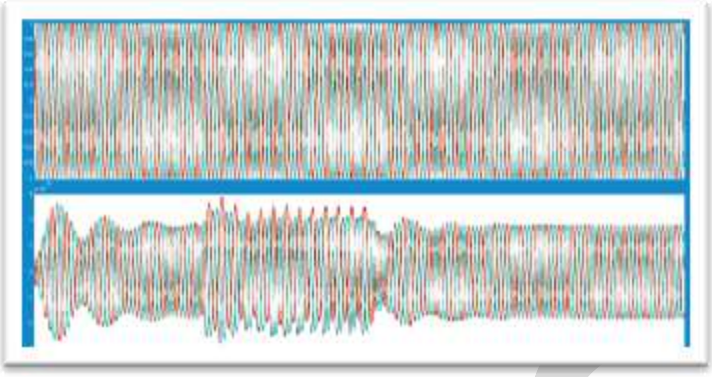

Fig. 4 Waveform showing receiving end voltage and current

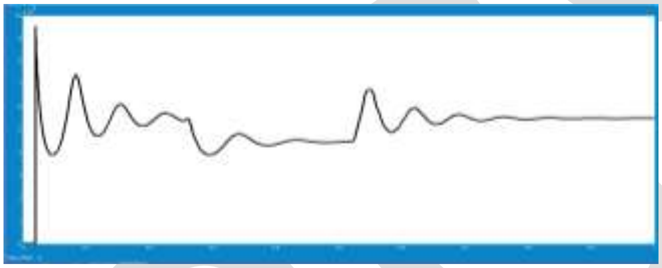

Fig. 5. Showing the receiving end side resistance

b) *Comparison circuit:*

In the Fig. 6, the incipient fault location circuit is connected to the base circuit using a comparator, the impedance comparison is done, to find out the error percent. The base circuit is similar to ideal fault locating circuit without any error. From Fig. 7, it can be inferred that, the absolute error percentage of 2.16% is been noted when compared with the ideal base circuit. The red dotted line shows the deviation of impedance in the incipient fault detection model, when compared to the base circuit.

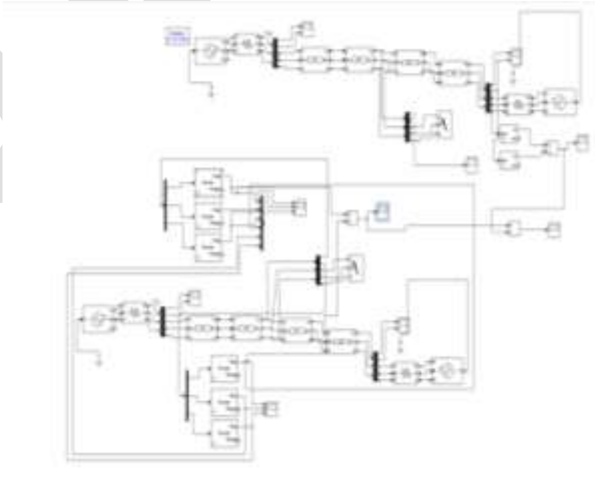

Fig 6. Simulink model of comparison circuit.

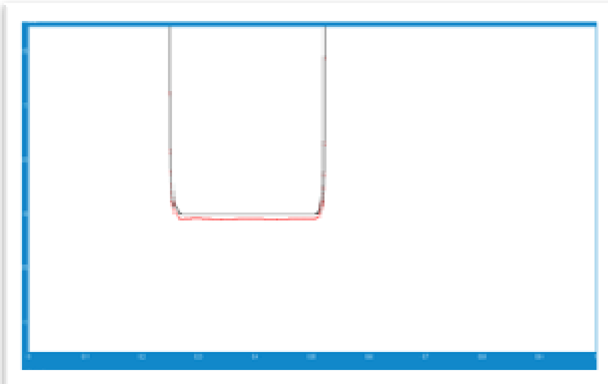

Fig. 7. Showing the difference in resistance

c) *Pre and Post processing using ANN:*

The Fig. 8, shows the diagram of the two bus system, which is having the set of fault created by the user. The receiving end voltage Vr will change according to the fault condition. The Vr is taken as input and the output is fixed as the distance is fixed in the fault creator. This distance is stored in the workspace as D variable. Hence the neurons should be trained by the receiving end voltage as input and D as output. The blue colour block is the trained neural network block. After running with the trained block at the single place of the fault application, will show the waveform as in Fig 9. MATLAB ANN toolbox NFT is used for the processing technique.

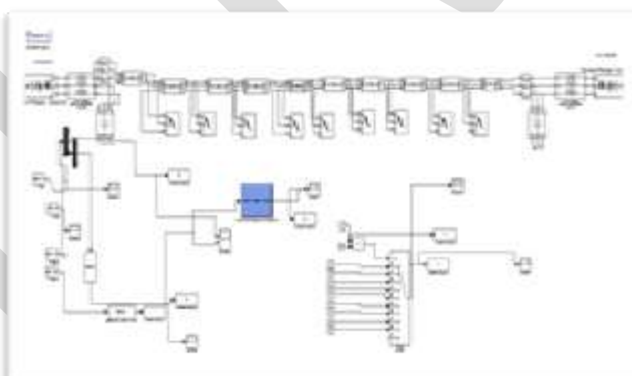

Fig. 8. Simulation of the two bus system of incipient fault location algorithm

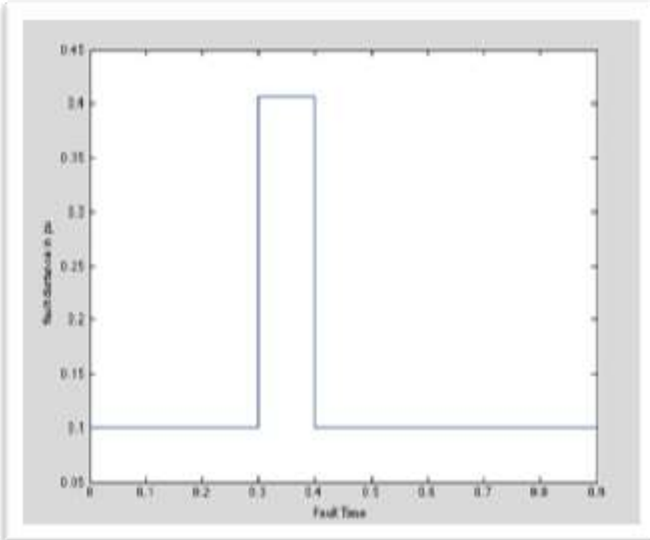

Fig. 9. Distance to fault location waveform

A table 1 shows the mean squared error and regression R value of trained neural network and table 2 shows the absolute error percentage of incipient fault location algorithm processing the result using ANN technique

TABLE 1 Trained Neural Network

Mean Squared Error	Regression R
1.767e-6	9.999e-1

TABLE 2 absolute error% of incipient fault location before and after processing

	Absolute error %
Incipient fault location before processing	2.16%
Incipient fault location after processing using ANN	0%

VI. CONCLUSION

Nowadays, electrical energy is being increasingly used. In order to maintain the reliability and security to an acceptable level, new technologies for protection and power control are needed. For distribution system, underground cables are very important part of transmission these days. Tracking down the fault in cable is very important task. However, the failure of cable does not occur instantly, it is developed slowly over a period of time, distinguished by series of single-phase sub-cycle incipient faults, accompanied by a high arc voltage. At the beginning the faults are self-clearer and incipient and they are unescorted by the operation of the overcurrent protective devices. If we overlook the incipient faults, they might provoke to a permanent fault

A resilient incipient fault location algorithm is developed in the time-domain, it utilizes data collected by PQ monitors to estimate the fault location in terms of the line impedance by taking into account the arc voltage which is associated with the incipient cable faults. This algorithm can be applied to any single line-to-ground fault. ANN technique is utilized to pre- and post-processes, to obtain accurate results. The efficiency of the proposed algorithm is proved by comparing with the base circuits. And after using ANN technique the error, by proper training, the error can be made zero. The proposed algorithm exactly pin-points the exact fault location in the underground cables.

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