DETECTION OF HIGH IMPEDANCE FAULTS IN MEDIUM VOLTAGE DISTRIBUTION NETWORKS USING DISCRETE WAVELET TRANSFORM

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ABSTRACT

Detection and identification of high impedance faults in power networks are still a major challenge for protection engineers. In these cases, the fault current is so low that conventional protection devices are unable to detect it. A modeling study is developed to simulate the performance of the high impedance fault using MATLAB/Simulink program. Regarding the detection process, this paper uses the discrete wavelet transform as a powerful signal-processing tool. After performing five decompositions for the three phase current signals, we have extracted the detail, the wavelet output, to construct a detection criterion. The moving window approach is the technique used to obtain this criterion. Then, we have developed an algorithm for the detection issue. Two other algorithms are presented for the determination of faulted phase and feeder.

INTRODUCTION

Detection of high impedance faults (HIFs) in power distribution networks is a long-standing problem to electric utilities. HIF is defined as unwanted electrical contact between an energized conductor and a high impedance surface such as an asphalt road, sand, grass or a tree. This fault has a small current ranging from a few mA to 75A [1]. As the high impedance at the point of fault limits the fault currents, they are unlikely to be visible to the conventional protection devices [1].

Consequently, various solutions for detecting HIF have been the objective of the researchers over the years. However, most of these approaches are difficult in implementation. The features of the HIF are extracted and investigated using fuzzy logic [2], genetic algorithm [3], and Kalman filtering [4]. Another effective tools utilized to detect HIFs is the expert systems as in [5]. Many researchers have used artificial neural network to significantly improve the fault detection as in [6]. In addition, wavelet transform (WT) is used for localizing the fault features as in [7].

MODELING AND SIMULATION OF HIF

An accurate simulation of the HIF is essential to help develop a truthful detection technique. In 2007, a HIF due to a leaning tree in a medium voltage (MV) network was modeled [8]. As shown in Fig.1, the fault is represented as two parts: an arc model, and a high resistance. This model is adopted in this paper.

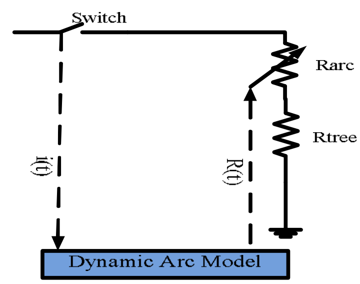

Fig. 1 Used HIF model

To simulate the arcing resistance, an arc model should also be adopted. Kizilcay model is a well-trusted one in calculating the fault arc in the air [9]. It is given by:

$$dg/dt=1/\tau(G-g) \qquad (1)$$

$$G=|i|/V_{arc} \qquad (2)$$

Where G is the stationary arc conductance, |i| is the absolute value of the arc current, V_{arc} is the stationary arc voltage, g is the time varying arc conductance, t is the time, and τ is the arc time constant which can be stated as in (3).

$$\tau = A \,.\, e^{Bg} \qquad (3)$$

Where A and B are constant parameters which represent compromised experimental values for positive and negative half cycles. However, the proper parameters for the positive half cycle do not provide a good agreement in the characteristics during the negative half cycle. The equations' parameters are set so as to match the results of experimental arc current performed in [8]. However, the latter resistance found in the HIF model (R_{tree}) is a linear resistor representing the fault path resistance through high impedance object, which is a tree in our application.

Fig.2 illustrates the developed Simulink program used for simulating HIF. As shown, the resistance representing the arc is of variable type whose value is obtained from 'getting R from I 'subsystem block which represents the Kizilcay arc model. This subsystem is presented in Fig.3.

After simulating the whole HIF model performance, the resulted voltage and current waveforms at the fault point are drawn in Fig.4. We notice that the voltage waveform does not show a noticeable fault contribution. On the other hand, inspecting the current waveform, we notice that the waveform is rich in distortions especially during extinction/ reignition periods. Therefore, the HIF is a very complex phenomenon and exhibits very highly nonlinear behaviour.

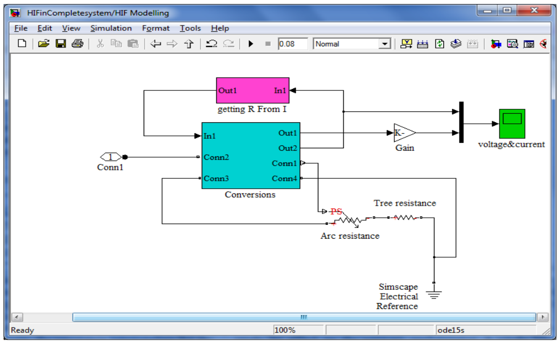

Fig. 2 Snapshot of Simulink showing HIF subsystem

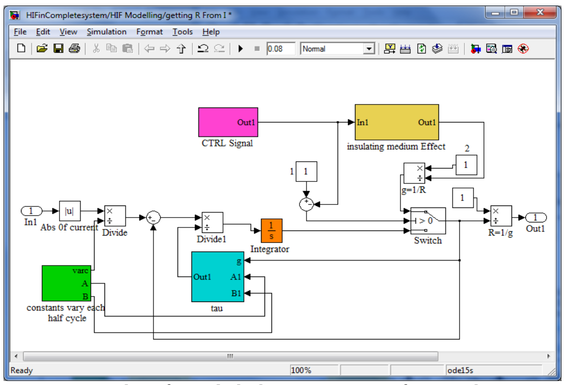

Fig. 3 Snapshot of Simulink showing 'getting R from I 'subsystem

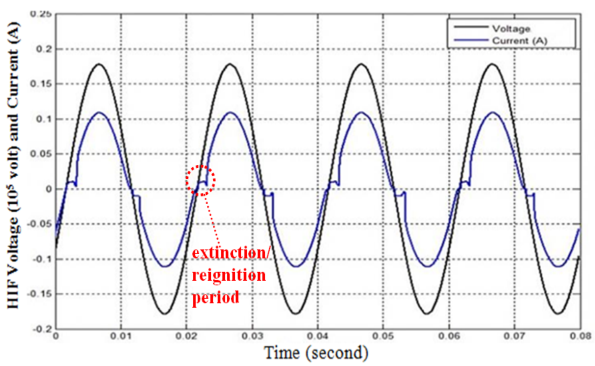

Fig. 4 Generated HIF voltage and current waveforms

Now, we need to add the HIF model to a simulation of a power network to study its effect on the network performance. A single line diagram of a part of a distribution network is selected as shown in Fig. 5. It is then developed using MATLAB/Simulink.

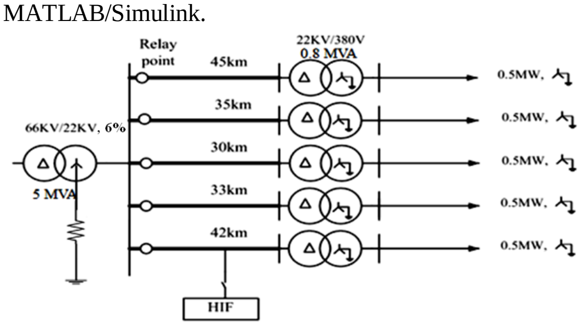

Fig. 5 Single line diagram of the used distribution network

Accordingly, three phase current waveforms at the start of the feeder under study (the fifth one) when the HIF due to leaning tree occurs at the end of phase A of the fifth feeder have been presented in Fig.6.

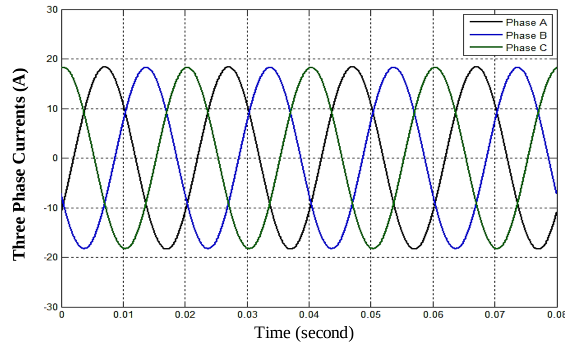

Fig. 6 Three phase currents at beginning of feeder 5

Due to the high impedance of this type of fault, the value of the fault current is so small in comparison with the value of the three phase currents at the feeder start. Therefore, HIF effect does not appear clearly on three phase current signals of fault cases presented in Fig.6.

DETECTION PROCEDURE

Hence, an alternative tool should be used to present a trustworthy fault identification based on features incorporated in signals. Thus, the discrete wavelet transform (DWT) is selected in our study. It offers windowing technique with variable-sized regions. A program is developed to extract the signal features of the feeder phase currents program with the help of wavelet toolbox incorporated into the MATLAB program. A wavelet debauchies 3 (db3) is used to analyze the three phase current signals at the feeder start.

Simulating the model is performed at a sampling frequency f = 1 MHz. Through comparative analysis, detail 5 (D5) is the best result which is capable of characterizing the amount of fault features found in the three phase currents.

Then, the moving window approach is adopted as a detection criterion. The absolute value of each D5 is summated over one cycle and then shifted by one sample as illustrated in (4).

$$S(k) = \sum_{n=k-N+1}^{k} |D5(n)| \qquad (4)$$

Where S(k) is the detector in discrete samples. N is the sampling points per a power frequency cycle; while n is used for carrying out a sliding window. As shown in the suggested flowchart in Fig.7, when S is greater than a threshold value S_{th} continuously for y_{th} samples, the HIF is present. Otherwise, it may be a normal transient event. Therefore, the value of S should stay above 0.1 (S_{th}=0.1) for more than y_{th} samples (equivalent to two successive cycles of power frequency) to give a correct tripping decision.

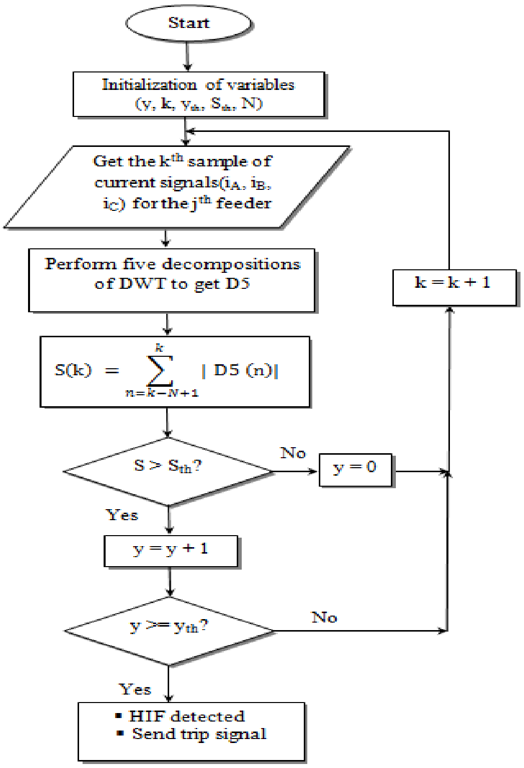

Fig. 7 Flow chart of fault detection technique

These values are chosen throughout extensive studies changing fault locations and loading conditions and one of these cases is presented in the next section. These set values are the same values reached by the researchers in [10].

The phase selectivity flow chart depicted in Fig. 8 is based on the fact that the detector S of the faulted phase has the largest value among others of healthy phases. Thus, the differences of the detector S of each phase (D_{ab}, D_{bc}, D_{ca}) are calculated. When any difference is positive, it is considered 1. Otherwise, it is considered zero. When the fault occurs in phase A, D_{ab} is positive while D_{ca} is negative whatever the status of D_{bc}.

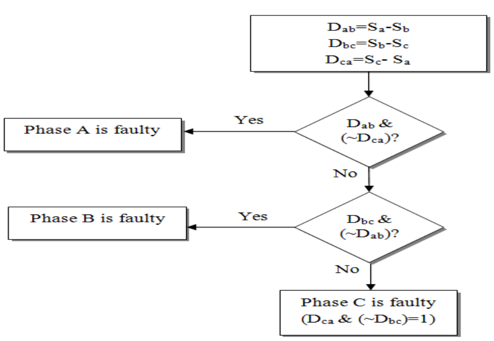

Fig. 8 Flow chart of phase selectivity

In the same manner, HIF in phases B and C can be identified [11]. Furthermore, the same idea can be applied for discriminate the faulted feeder as shown in Fig.9.

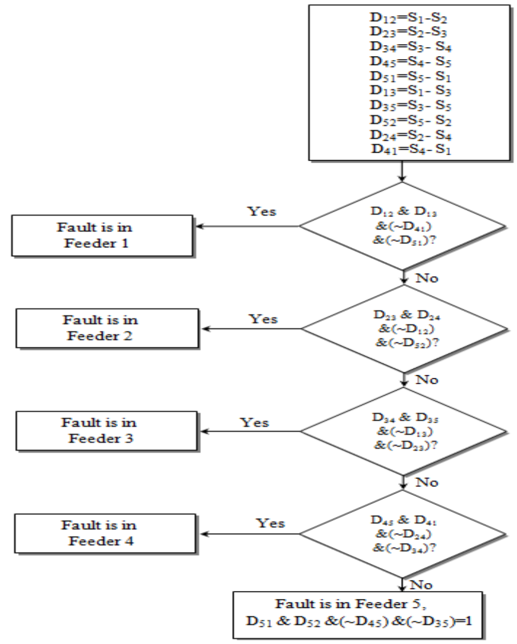

Fig. 9 Flow chart of feeder selectivity

RESULTS OF DETECTION PROCEDURES

Now, the outputs of D5 of the three phase currents of the faulted feeder are presented in Fig.10 followed by its computed detectors as shown in Fig.11.

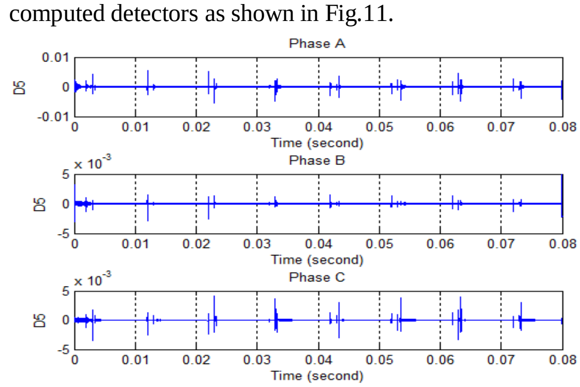

Fig. 10 Detail 5 of each phase of the fifth feeder

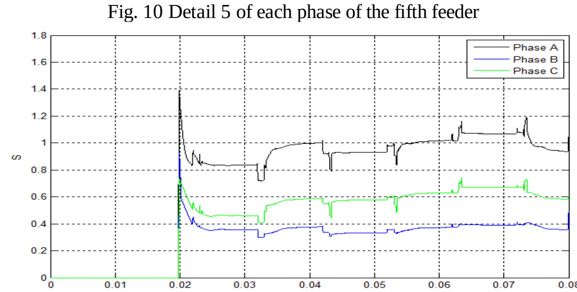

Fig. 11 S for the fifth feeder

From Fig.10, it is observable that the transients are present whenever arc reignition instants occur.

From Fig.11, we can observe that when fault occurs, the values of the detector S are greater than the threshold value of 0.1 for more than two consecutive cycles. Hence, the algorithm is capable of detecting the HIF event easily here.

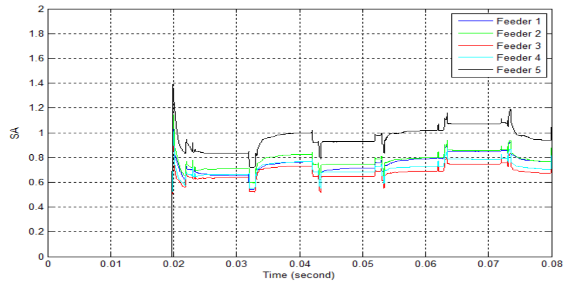

Fig. 12 S for the Phase A of all the feeders

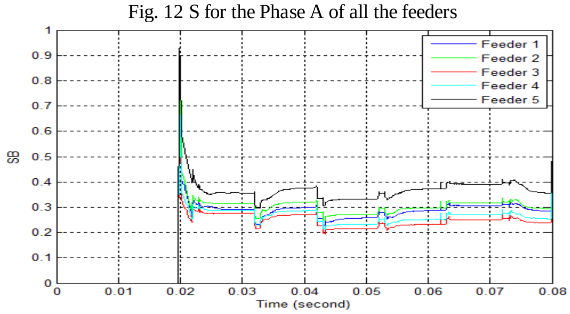

Fig. 13 S for the Phase B of all the feeders

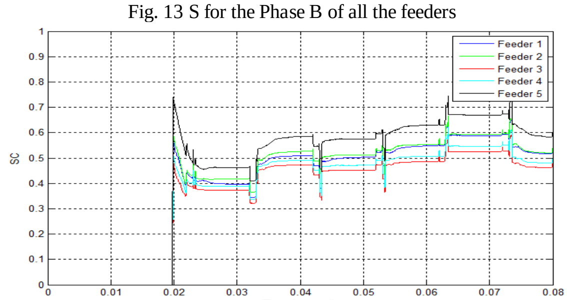

Fig. 14 S for the Phase C of all the feeders

It is also observable in Fig.11 that S for the faulted phase is about 1 that guarantees excessive safety when compared with the chosen threshold value. It is also obvious from Fig.11 that the value of S for phase A, the phase where the fault occurs in our study, is greater than those of phases B and C. Therefore, the difference D_{ab} is positive and D_{ca} is negative as illustrated in previous section. Hence, the phase selectivity algorithm can decide that phase A is the faulty.

In the same manner, using feeder selectivity algorithms, can easily determine that feeder five is where the fault occur due to superiority of S of phase A of the fifth feeder over the other feeders as shown in Fig.12. In addition, we can observe from Fig.13 and Fig.14 that the results of S for the two healthy phases for the faulty feeder are greater than the values of the same phases for the healthy feeders.

CONCLUSIONS

HIF detection is a disturbing problem for protection engineers. The developed algorithm is to extract the signal features of the feeder phase currents using DWT. Then, it uses the moving window approach to recognize if a HIF exists. Finally, if a HIF exists, the algorithms are capable of determining the phase and the feeder where the fault takes place to provide guaranteed selectivity. These algorithms when tested with data obtained from several computer simulations, produced impressive results in HIF detection.

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