HIGH IMPEDANCE FAULT LOCATION – CASE STUDY WITH DEVELOPED MODELS FROM FIELD EXPERIMENTS

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ABSTRACT

This paper presents a high impedance fault (HIF) detection and location method in distribution systems. The detection method is based on the discrete wavelet transform (DWT). On the other hand, the estimation of the HIF location is carried out by using an artificial neural network (ANN). The inputs of the ANN are both fundamental and harmonic components obtained from three phase voltages and currents during the HIF by using the Fourier algorithm. The ANN was trained and the performance of the proposed HIF location was evaluated by using a HIF modeled with two series time-varying resistances controlled by the Transient Analysis of Control Systems (TACS) of the Alternative Transient Program (ATP). Actual data obtained from several staged HIFs in different soil types on Energisa utility (a Brazilian distribution system) were used to adjust the HIF model.

INTRODUCTION

High impedance faults in distribution lines are short-circuits that cannot be easily detected, located and cleared by conventional protective devices due to their low fault current magnitudes. This kind of fault occurs when an energized conductor of the primary network falls in a surface with high resistive value, as well as trees or sand. When a HIF happens, energized conductors may fall within reach of personnel and, as the arcing often accompanies these faults, it further poses a fire hazard [1].

A reliable HIF diagnosis is essential to avoid dangerous consequences for both people and power system equipment. In order to reach success in these purposes, a method should be developed and evaluated with actual and simulated data, in which are necessary an accurate system modelling, and a HIF model which represents typical characteristics observed in actual HIFs, such as: buildup, shoulder, nonlinearity, and asymmetry.

Recently, several works have been done for fault diagnosis in distribution systems. Some of them are based on conventional methods [2] and latest techniques involve the use of ANNs [3, 4]. The ANNs present high capacity for learning and generalization, besides velocity and robustness in the diagnosis. A brief review of the fault location techniques can be found in [5].

In order to adjust the HIF model with a typical HIF on Energisa utility, a Brazilian distribution system, as well as develop and evaluate the proposed HIF detection and location method, several HIF experiments were staged, taking into account dry and wet contact surfaces: grass, crushed stone, sand, pavement, and local soil. The current and voltage waveforms in each stage were captured by digital fault recorders (DFRs) at both HIF location and far from 1 and 11 km. The HIF simulations were carried out on ATP [6] by using the power system model of the Energisa utility where the HIFs were staged.

The HIF detection and location method composes the ANFAI, software for HIF diagnosis, which is running in some Energisa substations. When a HIF is detected and located, a message is sent to power system operation. The main purpose of this paper is deal with the HIF location method. However, the main steps of the ANFAI building: the experiments, the HIF modeling, the HIF database construction [7] and the HIF detection will also be addressed.

The HIF locator is based on ANN where the input database was built with the post-fault current with its harmonics (phasor estimation for amplitude and phase). The *Neural Network Toolbox* from MATLAB® was used for ANN construction and knowledge. Good results were obtained at HIF location evaluation.

FIELD EXPERIMENTS SUMMARY

In order to collect HIF data to assist the development of HIF modeling and database building, staged fault tests were performed on a distribution feeder at Energisa, in Boa Vista town. Fig. 1 depicts the structure built for the tests, whose main features were:

- HIF tests were done on seven different kinds of contact surfaces: grass, crushed stone, pavement, asphalt, sand, tree, and local soil. Fig. 2 depicts a staged HIF on dry grass.
- A two-meter transition pole was placed between the common pole and the fault point, where the potential

and current transformers were installed;

- A 13.8 kV conductor coming from the common pole was connected to the transition pole and to an insulating rod;
- An insulating scaffold was placed in order to enable security for the responsible technician;
- Isolation and signalizing of the testing area;
- A 15360 Hz sampling frequency DFR was installed at the fault point and configured in order to enable the measurement, recording, and viewing of the events to be generated in the tests;
- Other DFRs were installed far 1 and 11 km from the fault point.

Fig. 1 – Structure to stage HIF.

Fig. 2 – Staged HIF on dry grass.

HIF MODELING

A HIF presents typical characteristics, described as follows [8]:

Buildup: Fault current grows to its maximum value in about tens of cycles.

Shoulder: Buildup is ceased for a few cycles.

Nonlinearity: The voltage-current characteristic curve of HIF is nonlinear.

Asymmetry: Fault current has different waveforms for positive and negative half cycle.

Intermittence: some cycles that the energized wire interrupts the contact with the soil. The arcing fault can be reduced hardly and restored back.

Fig. 3 depicts an actual oscillographic record regarding an HIF on dry sand in which some of the above characteristic can be observed.

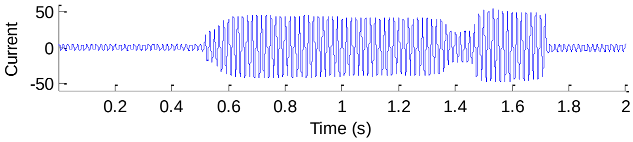

Fig. 3 – Actual current on phase A with HIF on dry sand.

In order to choose a HIF model, the characteristics of the HIF must be represented adequately. The adopted model was proposed by [8], which simulates all HIF characteristics by employing two time-varying resistances controlled by TACS in ATP. In this model, the first resistance (R_1) represents the characteristics of nonlinearity and asymmetry (it has the same characteristics at every cycle of the signal), while the second resistance (R_2) represents the characteristics of buildup and shoulder (it only has influence at the beginning of the signal). In order to obtain R_1 and R_2 behavior, 32 points for the V-I characteristic (obtained from voltage and current waveforms) for one cycle in the steady-state were considered.

If the faulted branch voltage is in $v_n \leq v(t) < v_{n+1}$, the corresponding current is obtained by:

$$i(t) = i_n + \frac{i_{n+1} - i_n}{v_{n+1} - v_n} \cdot (v(t) - v_n) \tag{1}$$

The resistance R_1 will be estimated by Law of Ohm using *v(t)* and *i(t)*. The resistance R_2 is calculated considering only the maximum absolute value of voltage and current because the buildup and shoulder characteristics. The steps to compute R_1 and R_2 are as follows:

1. Obtain the total resistance $R(\tau)$ by dividing $v(\tau)$ by $i(\tau)$;
2. Obtain $R_2(\tau)$ by subtracting $R_1(\tau)$ from $R(\tau)$;
3. Obtain R_2 applying the method of least squares.

DATABASE BUILDING

System Modeling

The proposed method was developed in order to be used in a real 13.8 kV distribution feeder of Energisa. To make the modeling, the utility provided data about the chosen feeder, such as: the power of transformers, the wire and poles characteristics, the distances between line sections, and the loads. The feeder is illustrated in the Fig. 4.

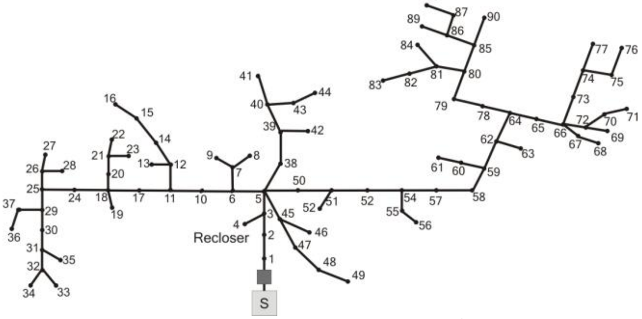

Fig. 4 – The modeled distribution feeder.

In order to model the system, some considerations were necessary. For instance, the distribution feeder was modeled and simulated by using the ATP. The skin adopted was 0.33 and the ground resistivity 350 Ω.m. A constant impedance load model has been adopted with a power factor of 0.955, a distributed parameters model has been used to all line sections composed by 4 AWG wires. The loads were concentrated into 90 bus.

Database Building

A variety of situations were considered to form a set of 1260 different test cases, 252 for each contact surface used in the experiments. The simulation variables chosen are summarized in the Table I. HIF between one phase and ground were simulated [7].

TABLE I – Simulation Variables

Simulation variables	Test set
Load condition (%)	25, 50, 75, 100
Fault location (Bus)	10, 23, 30, 44, 49, 56, 63, 68, 90
Inception angle (°)	0, 30, 60, 90, 120, 150, 180
Contact surface	Crushed stone, grass, local soil, pavement, and sand

ANFAI

The ANFAI is a software for HIF diagnosis which is running in some Energisa substations. A typical HIF is not cleared by conventional protection system and is not detected by triggering methods of usual DFRs. Therefore, the ANFAI triggers a DFR automatically and evaluate the respective oscillographic record. When a HIF is detected and located, a message and the record with HIF are sent to the power system operation.

The ANFAI main blocks are the HIF detector and locator, which are properly described in the remain of this paper.

HIF DETECTOR

Beyond buildup, shoulder, nonlinearity, asymmetry, and intermittence, a typical current with HIF is composed by transients. Therefore, currents during HIFs are non-stationary in both time and frequency domains. As a consequence, these signals can be properly analyzed by using the DWT which is a well-known powerful tool to detect transients in power system disturbances [9].

The energy of the wavelet coefficients of the DWT has been used for detection of faults and power quality disturbances with transients, such as voltage sags and transients due to switching transients [10, 11]. This paper also proposes the analysis of the wavelet coefficient energies in order to detect the transients regarding the HIFs.

Fig. 5 depicts the wavelet coefficient energy of the phase A current shown in Fig. 3. The wavelet coefficient energies related to the steady-state normal system operation are due to electrical noises and present values almost constant. However, an increasing of energy occurs at each transient inception, such as the beginning of the HIF and in each arcing fault restoration. The wavelet coefficient energies present high values during the HIF. These energy features are used by proposed method to detect the HIF and estimate its duration.

After the detection of the transients in voltages and/or currents, the HIF is discriminated from other disturbances such as faults and power quality disturbances. The rules to identify the HIFs were obtained by the analysis of the actual HIFs in various types of soils. The main signature to distinguish HIF from other disturbances with transients is the duration of these transient.

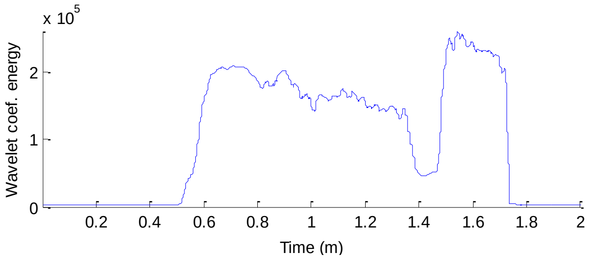

Fig. 5 – Wavelet coefficients Energy of a HIF current.

HIF LOCATOR

Among the existing architecture types for ANNs, the multi-layer perceptron network (MLP) was selected because of its simplicity and adequacy to solve properly the fault location problem. The resilient back propagation (RPROP) algorithm was used for ANN training [12]. In this case, the neuron weights are calculated by means of the partial derivative sign in each iteration, improving the learning process. The *Neural Network Toolbox* of MATLAB® was used for all ANN operations and development, followed by C++ implementation in the ANFAI.

According to [13], harmonics (mainly the third component) characterize strong indicators for HIF. Thus, the input database chosen for the selected ANN were the normalized phasor estimation magnitude regarding the fundamental and 2nd, 3rd, 5th, 7th and 9th harmonic components from the post-fault current after detection process. The difference between the phasor estimation angle for fundamental and 3rd harmonic components of the current and the fundamental voltage component were also used as input database. Fourier filters were used for phasor estimation [14]. The output is the normalized length of HIF location point.

In the pre-processing step, 80% of the database were chosen for ANN learning, in which 70% were used in training set and 30% were used in validation set. The remaining 20% of the database were designated for the methodology test. For training network, each input database variable was grouped in five samples, in a process known as windowing. Thus, the necessary number of inputs for the used ANN is 40 (8 variables for

5 cycles). The activation function for input layer was logarithmic. It was also chosen the hidden layer adoption, whose activation function was hyperbolic tangent.

With regarding the training process, a maximum of 30000 epochs was used to achieve the minimum root mean square (RMS) error. However, in the best result, the training process was stopped with 2878 epochs with an error of 0.0233. The architecture 40-50-1 presented the best result.

The test set was divided in files, in which all phasors were computed and submitted to the ANN. The most frequent location estimated by the ANN for each file is the normalized HIF location. In the substation, the location occurs when a HIF is first detected by the ANFAI software.

A success rate of 90.86% for the HIF location were obtained in the test set, providing the correct identification of the protection zone on which the HIF occurred.

CONCLUSION

The ANFAI software based on field experiments was presented for high impedance diagnosis. Currently, this software is installed in some Energisa substations.

A distinctive importance of the proposed method was the staged faults in a real distribution feeder, with a field tests build. The work was performed by both simulated and actual data.

A success rate of 90.86% in high impedance fault location was achieved. The obtained results for high impedance fault location based on artificial neural network attest the efficiency and effectiveness of the proposed method.

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