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FUZZY LOGIC TECHNIQUE FOR HIGH IMPEDANCE FAULT DETECTION IN DISTRIBUTION FEEDER

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ABSTRACT

The distribution feeder faults need to be detected and isolated in a reliable Maintenance and operation of a distribution type electrical power system, calls for a safe, reliable and efficient fault detection systems. As the number of techniques available to detect faults do not address the above concerns in to-to, especially in the case of a High Impedance Faults. Keeping in view of aforesaid situation, a new approach based on Fuzzy Logic (FL) and wavelet transform is presented here for HIF detection. With the measured fault currents and normal current as the base, the standard deviations of the wavelet coefficients are used to gather data which act as inputs to the Fuzzy Logic model for the detection of High Impedance Faults on any given distribution feeder. A realistically developed HIF model using a typical IEEE 13 Radial Distribution System was used to determine the performance of the technique for different types of HIF such as Capacitor switching , Linear faults , transients etc. The method was found to be robust, fast and accurate.

Key Words: High-Impedance Fault Detection, Wavelet Transforms, Fuzzy Logic, Electrical Distribution System, No Fault.

I. INTRODUCTION

An electrical power system deals with number of sub stations, which are of different kinds, interconnected by number of tie line systems, supplying to various loads. Electrical power distribution systems are responsible for maintaining the uninterrupted the power supply to the geographical dispersed residential, commercial and Industrial consumers such that the power received is safe, reliable and is economical, But electric power systems are daily exposed to service interruption due to fault which causes reduction in power quality. To overcome such problems conventional protection schemes have been used Conventional protective schemes, were able to detect Low Impedance Faults, as the governing parameter Current was very easily distinguishable vis-à-vis the normal current. However the same methods fail when applied to High Impedance Faults as the discriminating parameter i.e current yield very small value which is near about the range of a healthy system.

Initially the detection of HIF involved the straight measurement of primary electrical quantities/parameters, i.e. three phase voltages and currents and by analyzing in the their variations or by analyzing their harmonic components. The various methods developed which employed the various combinations of above said parameters [2-4]. But the results are ambiguous because of the similarity of information between frequency domain data produced by high impedance faults and other transient events occur on electrical power system, which leads to mal operation of protection system. This poses even further difficulty when HIF and Transient faults are to be discriminated.

The method of signal processing can be applied to develop algorithms for all combinations of the current signals frequency and time domain and this highly improves the HIFs detection capacity in electrical distribution feeder systems. Instead of analyzing time domain and frequency domain information, the hybrid analysis of low frequencies and high frequencies can be achieved by the de-composition of the measured current signal by using WT [9]. The wavelet transform based methods were for analysis the measured signal in after extracting features, the HIF should be distinguished from normal operating conditions [10],Unique Combined Wave transform and FL application to HIF detection, with reasonable cost to utilities. Regarding the implementation, a WT would perform the proposed FL and the harmonics calculation.

In this paper, firstly the signal is decomposed using WT. In the next stage, the wavelet output is used to find appropriate features for fault detection. In order to consider the more realistic case, a combined model of the HIF is used. In the Fault detection stage an FL intelligent method for is presented. This technique is verified with the aid of MAT LAB/SIMULINK. The mainly objective of this work, by combing WT and FL, is to propose a scheme which can detect normal switching operation and HIF. The interface of WT and FL was evaluated for effective combination

II. HIGH IMPEDANCE FAULT DETECTING METHODOLOGY

The proposed methodology to detect HIFs and LIFs, as well as to discriminate them from normal transient switching operations, is performed in two stages:

The first stage the current signals of the feeders, using WT, is analyzed to obtain the relevant data signals. In the second stage, the properly trained FL is used as a classifier processing, to classify the state of each feeder. Fig. 1. Gives the structure of the application of WT and FL This different stages of the working of the methodology are given in the block diagram schematic. Although some methods that use similar approaches may be affected by topology changes in the distribution network, this methodology is specially designed to be applied in the rural distribution systems whose topology is almost invariable. These kinds of distribution systems are very typical in several countries.

HIF currents are generated by using simplified two-diode model. The model consists of two DC sources V1 and V2. It also consists of two variable resistances R1 and R2 represents the fault resistance. In this model if phase voltage is more than V1 the fault current flows towards the ground. If the phase voltage is less than V2 then the fault current flows in reverse direction. Two diode HIF model implemented here is shown in fig. 2 varying the resistances R1 and R2 generate the waveforms. Capacitive switching transients shows high frequency current in its waveform and its magnitude depends on size and distance from the monitoring point. Capacitor banks for power factor improvement are generally installed in distribution system. These capacitors are switched into the system in accordance to load. Generally these capacitors are permanently connected in the substation and some of them are connected back to back so that they can operate whenever it is required.

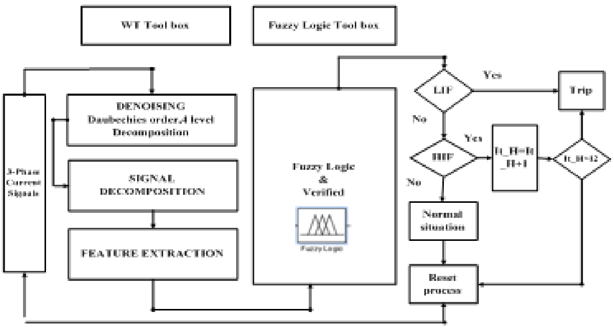

Fig. 1.Schematic diagram of the methodology

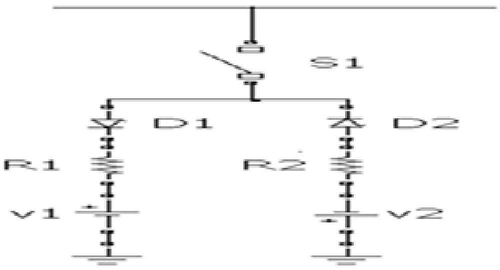

Fig.2.HIF model

2.1 Wavelet Transform

In the process of HIF detection, the signal data is to be analyzed to find adequate information that can be useful for the fault detection, as it may not clearly appear in the original time signal. The application of WT can be segregated as :

(a) De-noising process of the current signals.

(b) Signal decomposition and (c) Feature extraction

The use of the Wavelet Toolbox from MATLAB which provides useful functions and an extraordinary computing environment for the implementation of the WT in an efficient way in a computer. This implementation can be done either by command line functions or by graphical interactive tools. The DWT instead of the continuous wavelet transform (CWT) is considered for application in order to reduce the vast amount of computational work and data the latter would require.

2.1.1 Denoising Process

De-noising process the de-noising process is applied to eliminate the existing distortion in the current signals, which may have been produced by several events: switching operations and other feeder events. The idea of DWT preprocessing is to convert the three-phase current signals into one dimension hard threshold de-noising stage. For this purpose, a Daubechie’s order 4(db2), level 4 wavelet decomposition is applied to the registered currents. The heuristic Steins unbiased estimate principle gives the threshold rule. The decomposition level and basis function have been selected after a thorough analysis of different levels and many types of basic functions. The objective is to find the optimum de-noising for the signals in every simulated case of each feeder of the distribution power system described in Section 3.

2.1.2 Signal Decomposition

Signal decomposition the information from the time-domain signals registered under normal or fault situations, is usually not enough to detect the HIFs. Therefore, the DWT is applied to transform the de-noised time signals to time-frequency domain signals, where the different characteristics of each current signal may appear more clearly, by the large coefficients in different frequencies.

This process is known as Decomposition process, in which the Daubechie’s basis of order four (db4), in seven decomposition levels, has been applied.. The features from all these frequencies are used to give discrimination.

When analyzing the characteristics of current signals by the use of DWT, the following parameters must be specified:

i. Sampling frequency
ii. Window length
iii. Levels of decomposition
iv. Wavelet basis type

Usually, a low sampling rate leads to the reduction of the computation process. However, in some cases, such as in fault situation and switching operations, the sampling rate needs to be high so as to capture the characteristic information of the signal. After testing many possibilities, among 128, 256 and 512 samples per cycle, a sampling frequency of 512 samples per cycle (sampling rate of 2.56 kHz) taken in the analysis The sampling frequency, along with the selected Wavelet basis function also influences the window length and on the decomposition level number. In this methodology, the implementation of the DWT is based on the Multi Resolution Analysis (MRA) theory, which requires filtering and down sampling. This decomposition level (number of stages) is inversely related to the frequency components of any level.

Consequently, the higher decomposition level, the lower frequency components are considered. The role of wavelet functions is very important in implementation therefore, selecting an appropriate mother Wavelet to extract the useful information quickly and efficiently is crucial to increase the performance of any particular application. The Wavelet basis selection usually depends on the type of application or the similarity between the basis function and the signal to be analyzed.

2.1.3 Feature Extraction

The feature extraction is to reduce the amount of information, either from original waveform or from its transformation format in the distinct waveform parameter, having the significant information which represents the fundamental characteristics of the problem in the feature extraction process of this work. The multilayer FL has the input data vector, for each frequency band extracted using the coefficients standard deviation.

This feature has been selected after tests and comparisons between the performance of neural networks (generalization, simplicity, efficiency and convergence speed) and other features like energy and RMS of each frequency bands (signals and coefficients).The STD of the output signal is the square root of the data vector variance, as it is shown in (1). This feature provides information about the level of variation of the signal frequency distribution.

$$STD = \sqrt{\left(\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{i=1}^{n}x_i\right)^2\right)} \qquad (1)$$

where “x” is the data vector and “n” the number of elements in that data vector.

2.2 Fuzzy Logic

Fuzzy system is a non liner - mapping between inputs and outputs. The great advantage of the fuzzy logic system, is that it is customer friendly, using the syntax understandable by any costumer, in the form of IF – THEN Logic. In this simple format, the customer’s experience can be utilized to develop the algorithm. Whereas the FIS system is Fixed Membership dependant.

Fuzzy inferencing method is basically an inferencing process for a given input so as to provide an output using knowledge base / rule base which consist of number of rules. This system helps the fuzzy controller to understand different parameters and to make the rules in accordance to it. Fuzzy system is capable of handling imprecise data during processing and thus can locate fault more accurately than differential protection methods. Some of the steps of the fuzzy logic are:

2.2.1 Fuzzification

It is a process of transforming a classical set into fuzzy set or it is a process of translating an uncertain event into fuzzy set by assigning a Fuzzification: It is a process of transforming a classical set into fuzzy set or it is a process of translating an uncertain event into fuzzy set or transforming a scalar value into a fuzzy value. The various methods adopted are Singleton, Gaussian and Trapezoidal or Triangular Fuzzifiers.

2.2.2 Knowledge and Rule Base

In this stage a knowledge data base is built which forms the rules for the control operations. These are in the form of IF-THEN-ELSE format. For example

2.2.3 Inference Engine

These are the types of the method with the rule base so as to obtain the fuzzy values. There are basically two types of methods which we are using in this:

i. Mamdani method
ii. Sugeno method

Mamdani Method: It is a graphical technique of inference. It is a simple rule system which comprises of two hypotheses and one conclusion. This method is the most common, easy to understand and hence in use in most of the cases. Mamdani's logic gets its basics from the Lofti's Zadeh's 1973 paper. In this paper Lofti suggested fuzzy method or algorithm for decision making of complex systems. Mamdani using the method suggested by Lofti and using the linguistic control rules given by plant operators tried to control a steam engine and thus framed a rule base, now known as Mamdani's rule base. Advantages of Mamdani Method:

a) It is intuitive.
b) It can be implemented in most of the problems.
c) It can easily be understood by humans as it contains language rules.

Sugeno Method: In this method, a linear combination of inputs results in a fuzzy inference rule. The output is a weighted linear combination of the consequents. It is suited to mathematical analysis.

2.2.4 Defuzzification

It is the reverse process of fuzzification. In defuzzification we convert the fuzzy set or fuzzy value into real set or real scalar. There are five methods for defuzzification:

i. Centroid method
ii. Bisector method
iii. Middle of Maximum
iv. Smallest of Maximum
v. Largest of Maximum

The most commonly used method among all is the centroid method. In this stage the fuzzy output variables is converted to a crisp value based on a Defuzzification rule. In fuzzy logic, these parameters are found in the fuzzification and defuzzification routines and it can be trained. Membership and their associated degrees are based on IF-THEN rules [7].

Fig. 2 represents the Implementation of WT, as a block diagram. The inputs are obtained by pre-processing primary and secondary current signals [8].

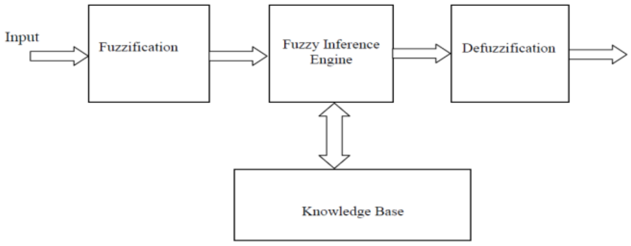

Fig 3 Shows the Fuzzy Inference System

2.2.5 Fuzzy Logic Verification

When the training process is finished, the optimal network configurations obtained are verified with the MAT LAB software tool, in reference to their generalization ability under untrained situations. The comparison between the network outputs and its corresponding targets over the test dataset, by means of (2)

$$\%Error = \frac{t\arg et\ output - calculated\ output}{t\arg et\ output} X100 \quad (2)$$

Taking as an example the dataset of feeder number one (Section3), the solutions matrix obtained from (2) shows the percentage comparison between the outputs and targets of testing cases, using the previously mentioned FL architecture.

This matrix (3) is organized such that the first column corresponds to the percentage output error (three outputs) under normal situations, while the second and the third columns correspond to the percentage output error of LIF and HIF cases, respectively.

$$\%Error = \begin{bmatrix} 0.0030 & 0.0003 & 0.0003 \\ 0.0000 & 0.0000 & 0.0001 \\ 0.0015 & 0.0001 & 0.0006 \end{bmatrix} \quad (3)$$

2.2.6 Fuzzy Logic Tree Stage

Decision Tree stage once the training and testing processes have been concluded, the resulting networks are ready to operate. The FL outputs vary from ‘0’ to ‘1’. Therefore, to reach the desired results of either ‘1’ or ‘0’, the outputs are processed with a ‘round’ function, in order to round the output data vector to the nearest integer value. Finally, the outputs of the proposed method give the state (healthy or faulty) of a distribution feeder, when all stages of the method are followed. If the method gives indication of LIF or HIF in12 consecutive iterations, the outputs of the method may be used to take an appropriate control action. Nevertheless, when a feeder is under a normal situation, the method turns back to take a new data window after 200 samples and then every step of this detection methodology is repeated again. The designed FL in MATLAB/ SIMULINK is shown in Fig. 3 and a typical two layer ANN model is designed as in Fig. 4.

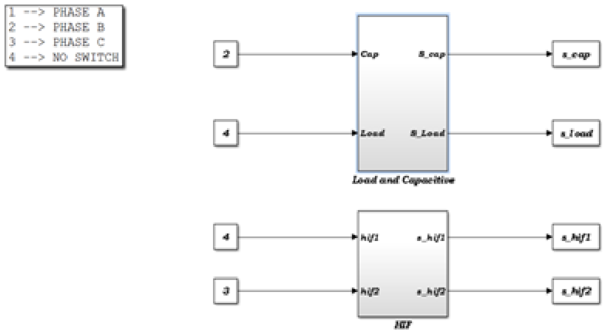

Fig. 4 Simulation diagram for HIF, Load, Capacitor Switching

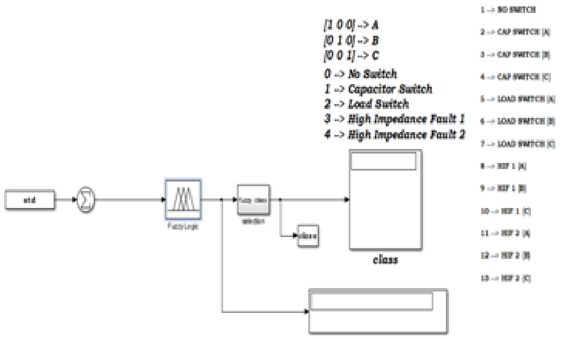

Fig. 5 Simulation diagram for Structure of Fuzzy Logic

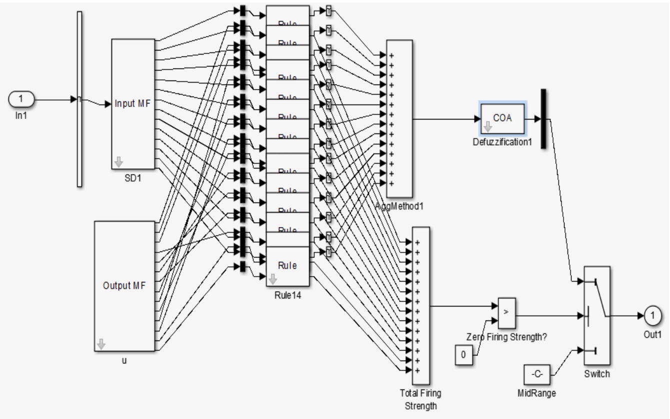

Fig.6 The architecture of the Fuzzy Logic

III. THE DISTRIBUTION TEST FEEDER

The data for the feeders being voluminous only the data for the 13 node feeder will be given in this paper.

(a)Data of Line parameters:

The solution comprises of:

a) listing of per mile / phase impedance and admittance matrices. With a value of 100 ohm – meter and 2.3 for resistivity and relative permittivity respectively

b) Radial Flow is summarized for the total system input / total load / total loss and three phase shunt capacitors.

c) Vole profile: the per unit vales of Magnitude and phase at every node

d) Voltage regulator data provides a summary of final tap Settings

e) Radial Power Flow : Nodal data comprising of line flow (A) , Phase (deg) Line power loss (kW) for each phase and total phase

The IEEE 13 Node Test feeder is an interesting small test feeder

1. A short / heavily loaded 4.16kV feeder
2. Wye Connected single phase voltage regulators
3. Over head and underground lines
4. Shunt capacitor banks
5. In-line transformer
6. Spot and Distributed Unbalanced loads

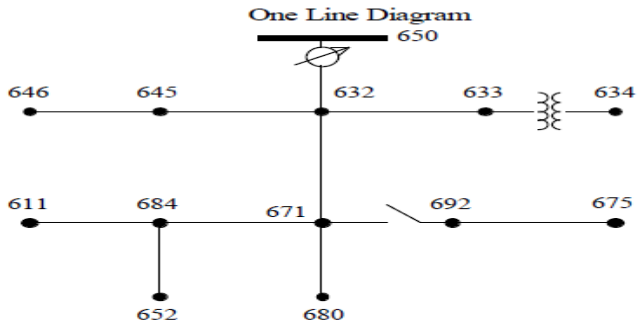

Fig.7 IEEE 13 Node Test Feeder

IV. SIMULATION AND RESULTS

The verification of the methodology developed is done on all the test cases. As an example, the following circuit Situations developed in this section:

It is well known that fault testing on real Distribution systems is difficult because of technical and economical reasons, also the test data usually suffer from certain limitations. That is why a real IEE 13 bus Test Feeder, under different conditions, has been accurately modelled and simulated with MATLAB/SIMULINK as given in fig.8 / Fig.

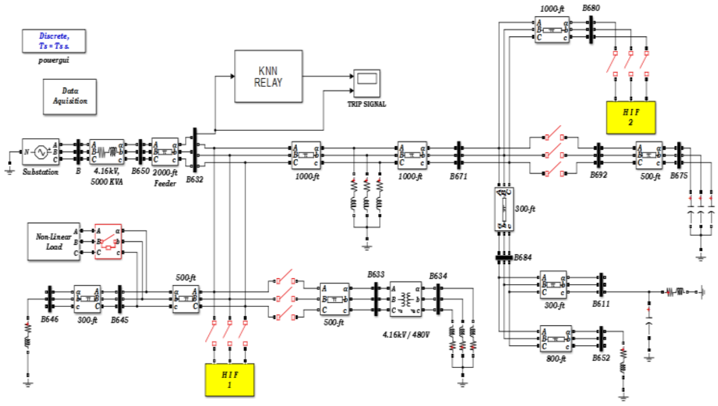

Fig. 8 Configuration of Distribution feeder

Finally, the DT is tested using following cases.

High impedance fault1: High Impedance Fault 1 created at feeder bus 632 in phase A, phase B and phase C with a fault resistance of 100 Ω.Fig. 8 shows the current signal produced by High Impedance Fault 1applied in feeder 632.

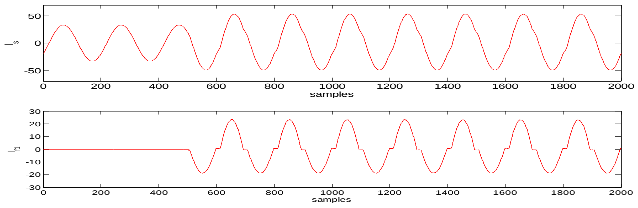

Fig. 9 High Impedance Fault1distorted current on phase- A

After the denoising process, Fig. 10, 11 and 12shows the behavior of the decomposed signals of the faulty phase currents under a HIF1 situation. The dominant Wavelet levels (high amplitude) are D1 and D4, which represent the sub-harmonic frequency component. The high transient frequencies appear during the arc period which is seen in the Wavelet levels D2 to D4.

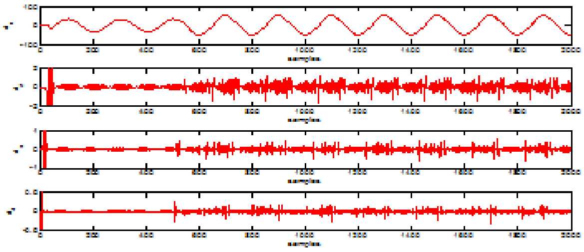

Fig. 10 Wavelet Transform of phase-A current signal of Distribution feeder during HIF1 Transients

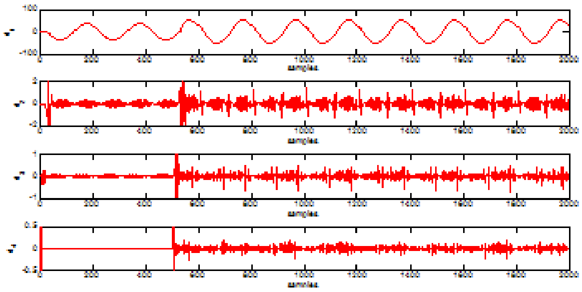

Fig.11 Wavelet Transform of phase-B current signal of Distribution

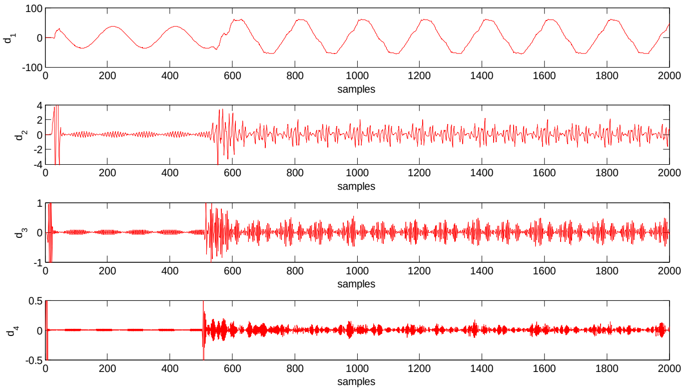

Fig.12 Wavelet Transform of phase-C current signal of Distribution feeder during HIF1 Transients

Applying the STD of each decomposition level, the numerical values of patterns can be realized from the analyzed signal. Applying these data matrix as the input to the selected FL, This methodology gives the exact output corresponding to each HIF situation, and it is not confused by the transients caused by LIFs and normal switching events. It can be concluded that feeder 632 is under HIF1.

High Impedance Fault 2 created at feeder bus 680 in phase A, phase B and phase C respectively with a fault resistance of 100 Ω. Fig. 13 shows the current signal produced by High Impedance Fault 2applied in feeder 680.

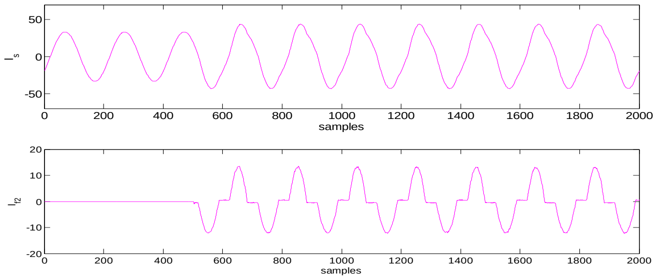

Fig.13High Impedance Fault 2distorted current on phase A.

After the de-noising process, Fig. 14, 15 and 16 shows the behavior of the decomposed signals of the faulty phase currents under a HIF1 situation. The dominant Wavelet levels (high amplitude) are D1 and D4, which represent the sub-harmonic frequency component. The high transient frequencies appear during the arc period which is seen in the Wavelet levels D2 to D4.

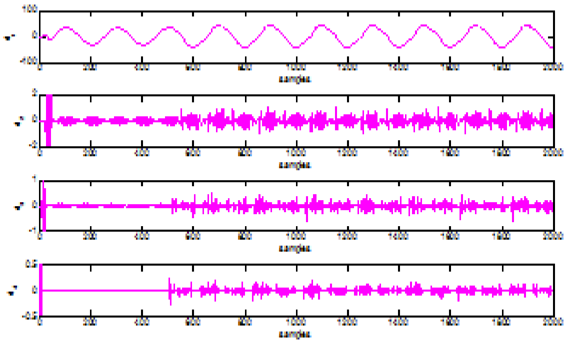

Fig.14 Wavelet Transform of phase-A current signal of Distribution Feeder during HIF2 Transients

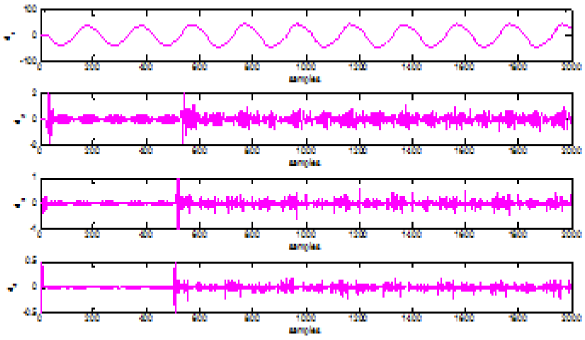

Fig.15 Wavelet Transform of phase-B current signal of Distribution Feeder during HIF2 Transients

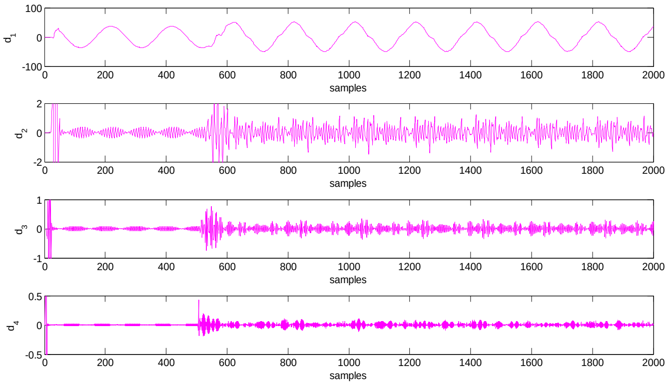

Fig.16 Wavelet Transform of phase-C current signal of Distribution Feeder during HIF2 Transients

Applying the STD of each decomposition level, the numerical values of patterns can be obtained from the analyzed signal. Applying these data matrix as the input to the selected DT, This methodology gives the exact output corresponding to each HIF situation, and it is not confused by the transients caused by LIFs and normal switching events. It can be concluded that feeder 632 is under HIF2.

Capacitor switching: capacitor switching created at feeder bus 675inphase A, phase B and phase C with 100 kVAr and 0.05Sec. to 0.5 Sec. of inception time.Fig. 15 shows the current signal produced by capacitor switchingapplied in feeder 675.

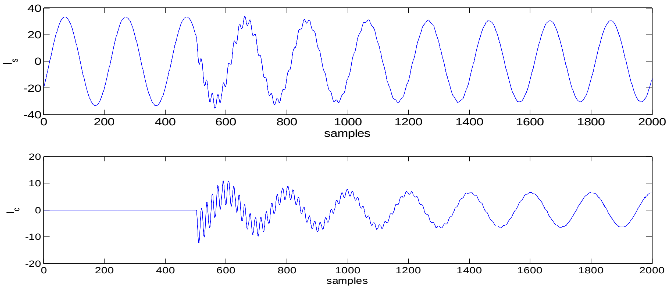

Fig.17capacitor switching distorted current on phase- A

The process starts by a de-noising process and the application of WT to the current signals. Then, the STD from all frequency levels are calculated and used as the inputs to the trained FL. Finally, the state of a feeder is calculated according to the outputs of the neural network.

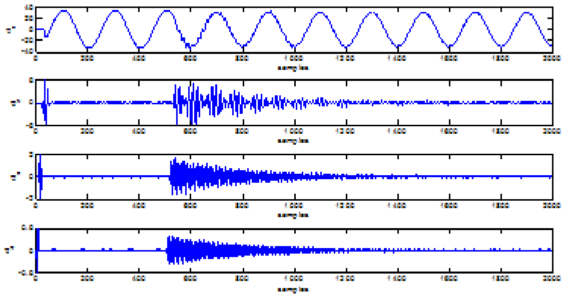

Fig.18 Wavelet Transform of phase-A current signal of Distribution Feeder during capacitor switching

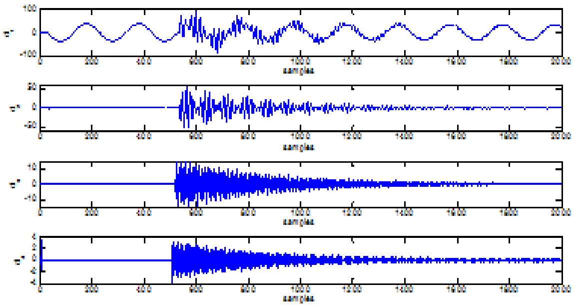

Fig.19 Wavelet Transform of phase-B current signal of Distribution Feeder during capacitor switching

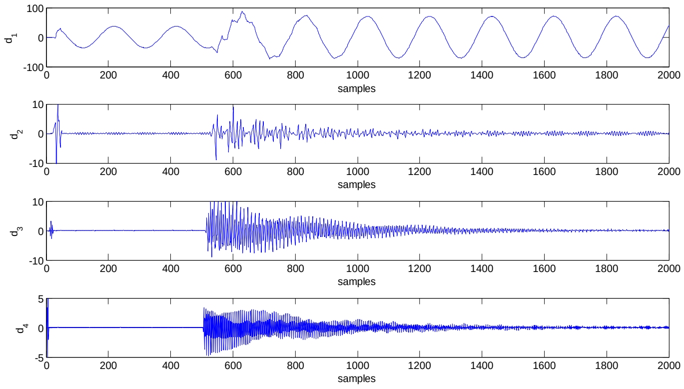

Fig. 20 Wavelet Transform of phase-C current signal of Distribution feeder during capacitor switching

The complete performance of the proposed technique has been tested by its application to data under different conditions. The test set was formed by patterns from different situations compared to the training patterns. There is a large spikes in d1 to d4 coefficient in signal waveform as shown in fig.18,19 and 20. It is clearly observed for capacitor switching.

Load switching:load switching created in between feeder bus 632 and 671inphase A,phase B and phase C with 160 kw and 0.05Sec.to 0.5 Sec. Of inception time.Fig.21 shows the current signal produced by capacitor switching applied in between feeder bus 632 and 671.

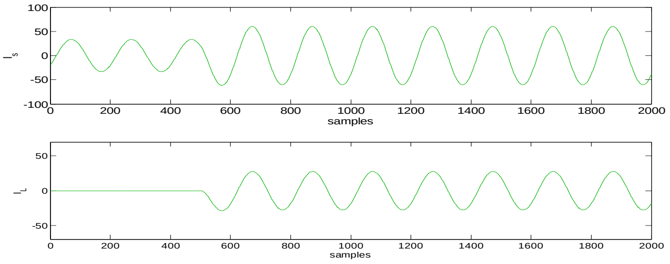

Fig.21 Load switching distorted current on phase A

The process starts by a de-noising process and the application of DWT to the current signals. Then, the STD from all frequency levels are calculated and used as the inputs to the trained FL. Finally, the state of a feeder is calculated according to the outputs of the neural network.

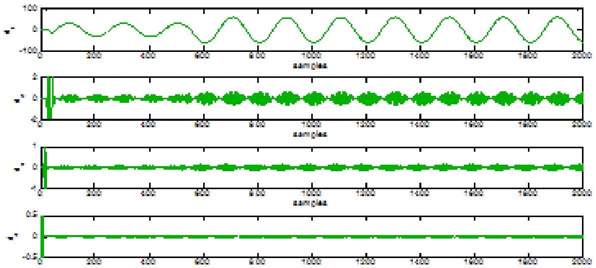

Fig.22 Wavelet Transform of phase-A current signal of Distribution Feeder during load switching

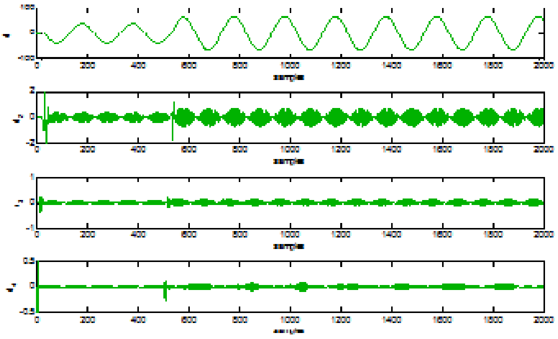

Fig.23 Wavelet Transform of phase-B current signal of Distribution feeder during load switching

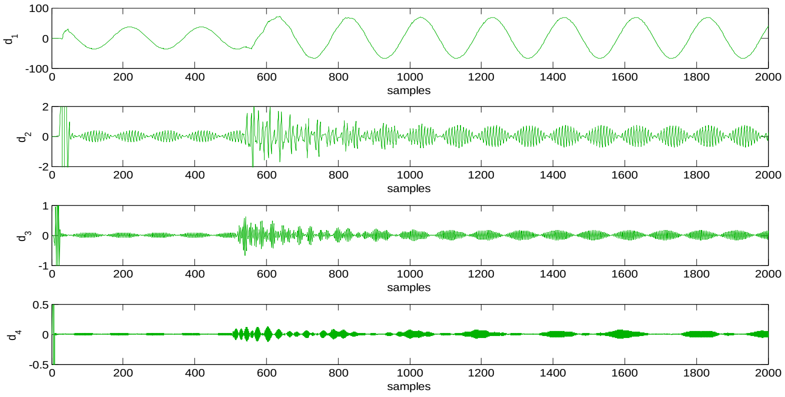

Fig.24Wavelet Transform of phase-C current signal of Distribution feeder during load switching

The complete performance of the proposed technique has beentested by its application to data under different conditions. The test set was formed by patterns from different situations compared to the training patterns. There is a large spikes in d1 to d4 coefficient in signal waveform as shown in fig.26, 27 and 28. It is clearly observed for load switching.

Non Linear LoadSwitching: Non-linear load switching created at feeder bus 645inphase A,phase B and phase C with 0.5kVAr and 0.05Sec.to 0.5 Sec. of inception timeFig. 23 shows the current signal produced by the nonlinear load applied in feeder 645.

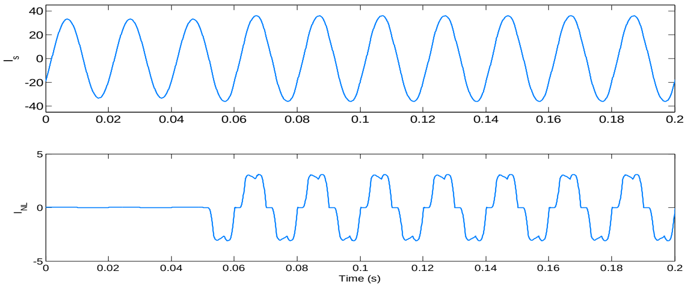

Fig.25Nonlinear load distorted currenton phase A.

The process starts by a de-noising process and the application of DWT to the current signals. Then, the STD from all frequency levels are calculated and used as the inputs to the trained FL. Finally, the state of a feeder is calculated according to the outputs of the neural network.

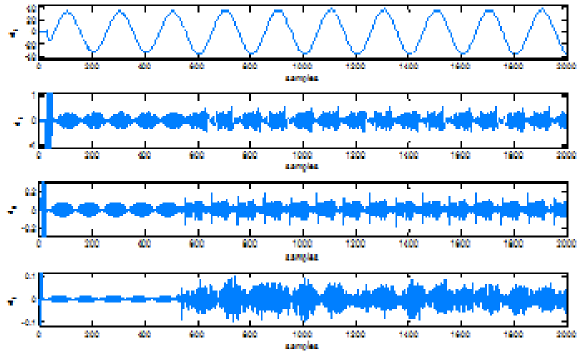

Fig.26Wavelet Transform of phase-A current signal of Distribution feeder during Non-linear load switching

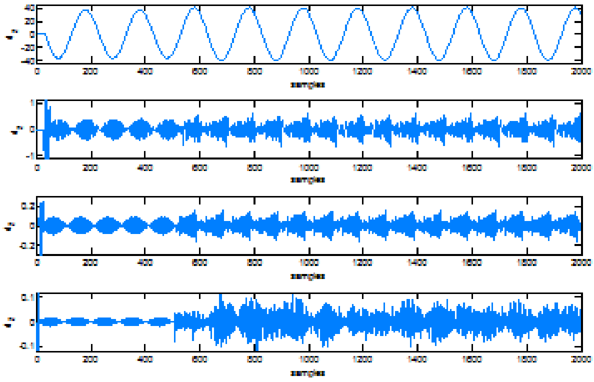

Fig.27 Wavelet Transform of phase-B current signal of Distribution feeder during Non-linear load switching

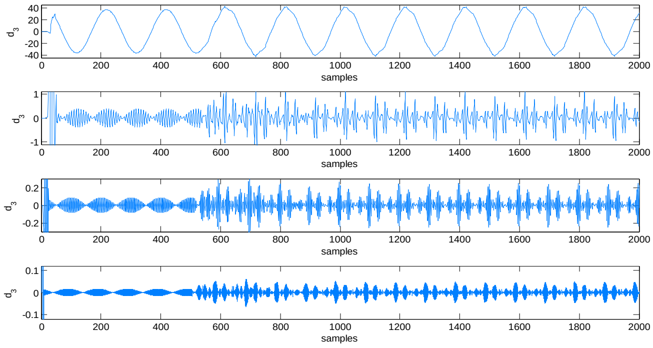

Fig.28 Wavelet Transform of phase-C current signal of Distribution Feeder during Non-linear load switching

The complete performance of the proposed technique has been tested by its application to data under different conditions. The test set was formed by patterns from different situations compared to the training patterns. There is a large spikes in d1 to d4 coefficient in signal waveform as shown in fig. 26, 27 and 28. It is clearly observed for Non-linear load switching.

Protection of distribution Feeder: The relay in distribution feeder is a sensor, which senses abnormal signals in the power system and trips the protective circuit. The inverse definite minimum time characteristics of over current and earth fault relay may be considered for developing Fuzzy Logic. There is a stabilized relationship between plug setting currents and operating time of relay.

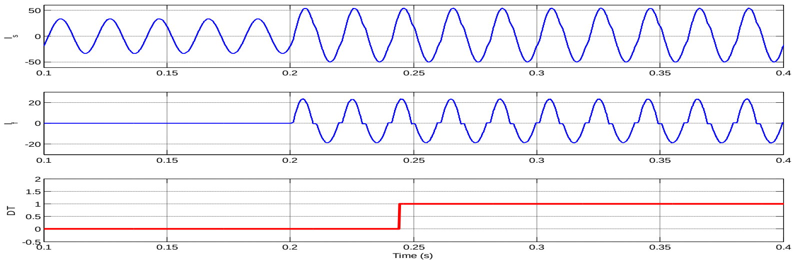

Fig.27 Fuzzy Logic based relay output Response

The training performance curve of Fuzzy Logic is shown in Fig.27.Simulation results show that, with the application of Fuzzy Logic and the unique way of choosing Fuzzy Logic inputs, the proposed differential relay operates properly under different conditions and the diagnosis is both accurate and fast.

V. CONCLUSIONS

The proposed new technique for HIF detection using Wavelet Transform and Fuzzy Logic.The simulation results of the developed HIF model, incorporated in MATLAB. Wavelet and Fuzzy Logic analysis for HIF, faults, load switching and capacitor switching and Non-Linear load are presented. To verify the performance, numerous cases have been analyzed. The results obtained have proved the correct operation (secure and reliable) of the developed method under various transient operation conditions in electrical distribution networks. This methodology gives the exact output corresponding to each HIF situation, and it is not confused by the transients caused by LIFs and normal switching events. After the test data has been fed into the Fuzzy Logic and the results obtained, it was noted that the efficiency of the neural network in terms of its ability to detect the occurrence of a fault is more than 78 percent.

REFERENCES

[1] High Impedance Fault Detection Technology, Mar. 1996, Report of PSRC Working_Group D15.[Online].Available:http://www.pespsrc.org/Reports/High Impedance Fault Detection Technology.

[2] C. L. Huang, H. Y. Chu, M. T. Chen, "Algorithm comparison for high impedance fault detection based on staged fault test, " IEEE Trans. Power Delivery, vol. 3, no.4, 1988, pp. 1427–1435.

[3] A. Girgis, W. Chang, E. B. Makram, "Analysis of high-impedance fault generated signals using a Kalman filtering approach," IEEE Trans. Power Delivery, vol. 5 no. 4, 1990, pp. 1714–1724.

[4] D. Russel1, R. P. Chinchali, "A digital signal processing algorithm for detecting arcing faults on power distribution feeders," IEEE Trans. Power Delivery, vol. 4, no. 1,1989, pp. 132–140.

[5] E. Emanuel, E. M. Gulachenski, "High impedance fault arcing on sandy soil in 15 kV distribution feeders: contribution to the evaluation of the low frequency spectrum," IEEE Trans. Power Delivery, vol. 5, no. 2, 1990, pp. 676–686.

[6] F. Sultan, G. W. Swift, D. J. Fediechuk, "Detection arcing downed wires using fault current flicker and half cycle asymmetry," IEEE Trans. Power Delivery, vol. 9, no. 1, 1998, pp. 461–470.

[7] D. Russell, R. P. Chinchali, C. J. Kim, "Behaviour of low frequency spectra during arcing fault and switching events," IEEE Trans. Power Delivery, vol. 3, no. 4, 1988, pp. 1485–1492.

[8] B.D. Russell, K. Mehta, R.P. Chinchali, "An arcing fault detection technique using low frequency current components-performance evaluation using recorded field data," IEEE Trans. Power Delivery, vol. 3, no. 4, 1988, pp. 1493–1500.

[9] Ibrahem Baqui, Inmaculada Zamora, Javier Mazón, Garikoitz Buigues High impedance fault detection methodology using wavelet transform and artificial neural networks‖ Electric Power Systems Research 81 (2011) 1325–33.

[10] Etemadi, A. H., & Sanaye-Pasand, M. (2008). High-impedance fault detection using multi-resolution signal decomposition and adaptive neural fuzzy inference system. Generation, Transmission & Distribution, vol. 2, no. 1, pp. 110-118.