Distribution System Faults Classification And Location Based On Wavelet Transform

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Abstract- **Electrical distribution system, which is the largest portion of networks, acts as a final power delivery path to the end users. Fault classification and location is very important in power system engineering in order to clear fault quickly and restore power supply as soon as possible with minimum interruption. Hence, ensuring its efficient and reliable operation is an extremely important and challenging task. With availability of inadequate system information and presence of high impedance faults, locating faults in a distribution system pose a major challenge to the utility operators. Most of the previous work on fault identification and location concentrated on estimating the status of circuit breakers and relays with aid of some algorithmic approaches. In this paper, a fault identification and location technique using wavelet multi-resolution approach for radial distribution systems are proposed. The current measurements at the substation, available in the distribution network have been utilized and the effectiveness of the proposed approach is demonstrated on 7-node three-phase test systems. Also in this work distribution systems model was developed and simulated using power system block set of MATLAB to obtain fault current waveforms. The waveforms were analyzed using the Discrete Wavelet Transform (DWT) toolbox by selecting suitable wavelet family to obtain the pre-fault, during-fault and post-fault coefficients for estimating the fault classification. It was estimated and achieved using Daubechies 'db5' discrete wavelet transform.**

Key Words-Distribution network, Fault identification, Multi-resolution analysis, Power system faults, and Wavelet transform.

I. INTRODUCTION

An important objective of all the power systems is to maintain a very high level of continuity of service, and when abnormal conditions occur, to minimize the outage times. It is practically impossible to avoid consequences of natural events, physical accidents, equipment failure or mis-operation which results in the loss of power, voltage dips on the power system.

Fault location and distance estimation is very important issue in power system engineering in order to clear fault quickly and restore power supply as soon as possible with minimum interruption. This is necessary for reliable operation of power equipment and satisfaction of customer. The following definitions related to this study are:

Fault: A fault is an unpermitted deviation of at least one characteristic property (feature) of the system from the acceptable, usual, standard condition.

Disturbance: undesired and uncontrollable interference acting on the system.

Fault detection: Finding if there is any fault in the system and also the time of the fault.

Fault Isolation: Determining the type and location of the fault.

Fault identification: Determining the magnitude and time-variant behavior of the fault.

Fault diagnosis: Fault diagnosis is determining which fault has occurred, in other words, determining the cause of the observed out-of-control status.

Monitoring: Observing and recording the progress of different variables in a process over a period of time.

Error: An error is the deviation of the measured value from the actual or true value.

Failure: A failure is a permanent interruption of a system's ability to perform a required function under specified operating conditions.

Malfunction: A malfunction is an intermittent irregularity in the fulfillment of a system‘s desired function.

Natural events can cause short circuits i.e. faults which can either be single phase to ground or phase to phase or phase to phase to ground or a three phase fault. Most faults in an electrical system occur with a network of overhead lines are single-phase to ground faults caused due to lightning induced transient high voltage and from falling trees. In the overhead lines, tree contact caused by wind is a major cause for faults. The appropriate percentages of occurrences various faults are listed below [1]:

Single line to ground fault – 70-80%

Line-Line to ground fault - 10-17%

Line-Line fault – 8-10%

Three phase – 2-3%

When faults occur in the power system, they usually provide significant changes in the system quantities like over-current, over or under-power, power factor, impedance, frequency and power or current direction. The most common and also the one used in this work is the over-current and so over-current protection is widely used.

Power system protection is the art of applying and setting up relays or fuses or both, to provide maximum sensitivity to faults and abnormal conditions and also to avoid false alarms during normal operating conditions. So it is desirable that a correct decision be made by the protective device as to whether the trouble is an abnormal condition or just a transient which the system can absorb and return to normal working condition. The protective relays are more of a preventive device which operates after a fault has occurred and it helps in minimizing the duration of trouble and limiting the damage, outage time and related problems. For the system to operate properly, it is necessary to isolate the trouble area quickly with a minimum number of system disturbances. Both failure to operate and incorrect operation can result in major system upsets involving increased equipment damage, increased personnel hazards and possibly long interruption of service.

The fault detection and classification system which is discussed in this work is a part of the protective device. The five basic qualities of a protective relays [1] are

1. Reliability
2. Selectivity
3. Speed of operation
4. Simplicity
5. Economics

Various factors like availability of circuit breakers and fault indicators affect the protection system. The abnormalities, faults and intolerable conditions must provide a distinguishable difference between from the normal operating or tolerable conditions. In this works, voltage and current waveforms at both the sending and receiving end are used for detection and classification of the problem. Any significant changes in these quantities provide a means to detect abnormal conditions and hence employed for relay operation. So the important step is to first determine the quantity and the associated difference value that would separate the faulted and non-faulted waveforms. There could be two kinds of problems; a faulted waveform could be detected as a normal wave. This results in delivering the power exceeding the currents and frequency limits to the customers leading to equipment failures. The other error could arise if a normal waveform is detected as a faulted wave. In this case, a certain portion of the power system is unnecessarily isolated from the system.

In general, the first step in the power system relaying algorithms is the detection of fault and the next step is classification. This work uses a combination of Wavelet Transforms and multi-resolution detecting and classifying power system faults. The Objective of this work is to classify the faults according to the following parameters:

1. Fault type
2. Fault Location

The fault cases are classified as one of ten different types of faults viz. three Single line to ground faults, three Line to Line faults, three Line to Line to ground faults and a three phase fault. The fault location is an important parameter especially in high voltage power systems. The knowledge of fault location leads to high speed fault clearance as well as improved transient stability.

II. HISTORICAL REVIEW : FROM FOURIER ANALYSIS TO WAVELET ANALYSIS

The history of wavelets begins with the development of the traditional Fourier transform (FT) (Donald and Walden, 2000), which is widely applied in signal analysis and image processing. Fourier transform breaks down a signal into the sum of infinite series of sines and cosines of different frequencies, in another word; FT is a mathematical technique for transforming our view of the signal from time-based to frequency-based. Fourier transform is very effective in problems dealing with frequency location. However, time information is lost during the process of transforming to frequency domain. This means that although we might be able to determine all the frequencies present in a signal, we do not know when they are present. In the time series process data, the most important part of the signal is the transient characteristics: drift, trends, and abrupt changes, and FT is not suited to detect them.

In an effort to improve the performance of the FT, the short time Fourier transform (STFT) has been developed in signal analysis. STSF compromises between the time and frequency based views of a signal by examining a signal under a fixed time window. The drawback of STSF is that the time window is fixed and same for all the frequencies. Many signals require a more flexible approach; the window size is required to vary according to the frequency.

Wavelet analysis or wavelet transform is close in spirit to the Fourier transform, but has a significant advance. It applies a windowing technique with variable-sized regions, a shorter time interval is used to analyze the high frequency components of a signal and a longer one to analyze the low frequency components of the signal. Wavelet analysis is very effective for dealing with local aspects of a signal, like trends, breakdown points, and self similarity. Furthermore, wavelet analysis is capable of removing noise from signal and compress signal.

III. WAVELET TRANSFORM

Wavelet analysis is a relatively new signal processing tool and is applied recently by many researchers in power systems due to its strong capability of time and frequency domain analysis. The two areas with most applications are power quality analysis and power system protection.

The definition of continuous wavelet transform (CWT) for a given signal x(t)with respect to a mother wavelet (t) is:

$$CWT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\varphi\left(\frac{t-b}{a}\right) dt$$

Where a, is the scale factor and b is the translation factor.

For CWT, t, a, b are all continuous. Unlike Fourier transform, the wavelet transform requires selection of a mother wavelet for different applications. One of the most popular mother wavelets for power system transient analysis found in the literature is Daubechies's wavelet family. In the new scheme, the db5 wavelet is selected as the mother wavelet for detecting the short duration, fast decaying fault generated transient signals.

The application of wavelet transform in engineering areas usually requires discrete wavelet transform (DWT), which implies the discrete form of t, a, b eqn. The representation of DWT can be written as:

$$DWT(m,n) = \frac{1}{\sqrt{a_0}^{m}} \sum_{k} x(t)\varphi\left(\frac{k-nb_0 a_0^m}{a_0^m}\right)$$

Where original a and b parameters in eqn are changed to be the functions of integers m, n. k is an integer variable and it refers to a sample number in an input signal.

A very useful implementation of DWT, called multi-resolution analysis, is demonstrated in Fig. below. The original sampled signal x(n) is passed through a high pass filter h(n) and a low pass filter l(n). Then the outputs from both filters are decimated by 2to obtain the detail coefficients and the approximation coefficients at level 1 (D1 andA1). The approximation coefficients are then sent to the second stage to repeat the procedure. Finally, the signal is decomposed at the expected level.

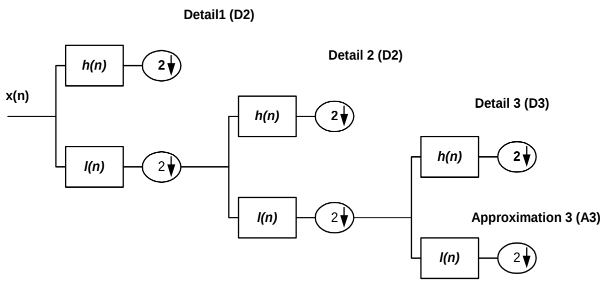


Fig.1. The idea of wavelet multi-resolution analysis

In the case shown in Fig., if the original sampling frequency is F, the signal information captured by D1 is between F/4 and F/2 of the frequency band. D2 captures the information between F/8 and F/4. D3 captures the information between F/16 and F/8, and A3retains the rest of the information of original signal between 0 and F/16. By such means, we can easily extract useful information from the original signal into different frequency bands and at the same time the information is matched to the related time period. An example, given in Fig., illustrates the procedure. The originalsignal is one cycle of a post-fault current signal, as shown in Fig. We use db5wavelet to make a 5 level decomposition. The reconstructed versions of each detail and the approximation are shown in Fig. The information of original signal is clearly represented at each frequency band. The original signal can be reconstructed by adding up those wavelet signals at the same sample point. The wavelet tool box in MATLAB provides a lot of useful techniques for wavelet analysis [8].

The wavelet transform contains a low pass filter (only obtaining low frequencies), which is denoted by l(n), and a high pass filter (only obtaining high frequencies), which is denoted by h(n). At each level, the original signal, s, passes through two both low and high pass filters and emerges as two signals, which is detail coefficients d_n, and approximation coefficients a_n. The terms "approximation" and "detail" are named by the fact that a_n. is the approximation of a_{n-1}corresponding to the "low frequencies" of a_{n-1}, whereas the detail d_n takes into account its "high frequencies". Wavelet coefficients at various frequencies reflect the signal variations at those frequencies and corresponding times. Clearly, at the k^{th} step of this partitioning procedure, the original signal, s, is expressed by Eq.

$$s = a_k + d_k + d_{k-1} + \ldots\ldots + d_1$$

With a_k. representing the smooth signals referring to the time scale 2^k and $d_n$is the detail of time series with the time scale located in the interval $[2^{k-1}, 2^k]$.

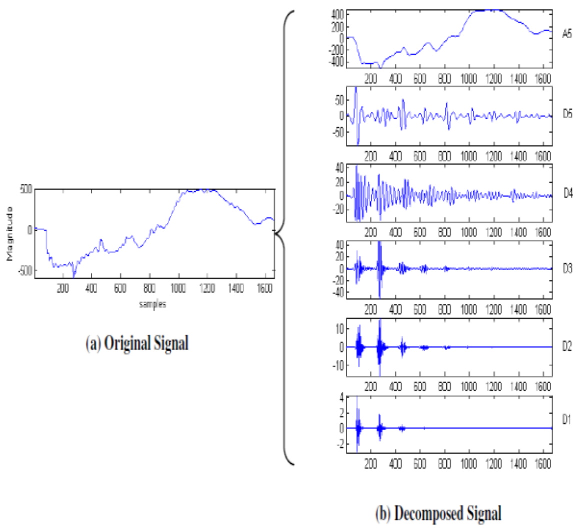


Fig.2. Wavelet multi-resolution analysis for a fault signal

IV. PROPOSED FAULT IDENTIFICATION SCHEME

Fault identification is to determine the process variables that are responsible for the fault and thus the information can be used to diagnose the fault. It will be helpful to focus on the subsystems where the fault occurred in a large plant. It not only helps to diagnose the fault more efficiently but also saves time and money.

For identification of fault type, several test cases for both 7-node systems are simulated. To generate a setof rule base for each of the cases considered, the MRA of the current signature obtained from main substation feeder are used to calculate the absolute values of fault levels. Experimentally, it is found that different types of faults generate different patterns of detail signals. Looking at the pattern of fault levels a set of rule base have been worked out to identify ten different types of faults (i.e. single phase to ground faults, line to line faults, double line to ground to faults and three-phase symmetrical fault). A simple rule base generated to identify the nature of fault on the distribution line in case of 7-node system is presented below:

Rule 1: Set the absolute values of fault levels for phases a, b and c, are Ka, Kb, and Kc. And assuming the fault values are K_1, K_2, K_3.

Rule 2: The notation for the system conditions are as: "1"denotes faulty conditions in particular phases, and "0" denotes no-faulty condition.

Rule 3: Use Comparator for compare the fault levels in the digital form "0" or "1"

Rule 4: If Ka >K_1then fault type is L-G.

Rule 5: If Ka >K_1,Kb >K_2 ,then fault type is LL-G.

Rule 6: If Ka >K_1,Kb >K_2 ,Kc>K_3,then fault type is LLL-G.

Rule 7: If Ka >K_1,Kb >K_2,and $|Ka| - |Kb| > \in$then faulttype is AB (i.e.LL), and similarly for other LL faults.

V. PROPOSED FAULT LOCATION ALGORITHM

The objective of the fault location algorithm is to identify the faulty section by comparing the sharp variation values of the detail signals in different phases. The method proposed for fault location assumes that the fault is identified using the method discussed in previous section. Prior knowledge of the type of fault is a requirement of the algorithm. The fault phenomena involve large disturbances in the system and the parameter selected for the fault location is summation of third level output of the wavelet transform. Hence, in the presence of the 'noisy data' found in the real time recordings, there will be only minor variations in the summation value of the third level output as the magnitude of disturbances created by faults are always large as compared to the noisy data. Also, noise consists of high frequency signals, whereas the third level output of the wavelet transforms contain signals only in the range of 60 - 200 Hz i.e. it includes second and third harmonic contents, which are predominant in case of faults. Therefore, the noise signals get filtered out from the third level output. This makes the fault location technique very effective. Variable calculated and used for fault location are:

$$T_{a,b,c} = \sum_{k=1}^{N} d_m(k)$$

VI. SIMULATION AND RESULTS

For identification and location of faulty section, several cases covering all the line sections (6 in case of 7-node system), different type of faults are studied. For each case, the summation of third level coefficients of MRA viz. $T_{a,b,c,}$ are determined. It is found that for each section, these values are different. However, $T_{a,b,c}$ values are find for different fault type (LG, LL, LLG or LLLG). The average value of $T_{a,b,c,}$ obtained for the 7-node systems are given in Tables I.

The effectiveness of the proposed algorithm is also tested for the fault cases in the line section or at buses for which the *a* , *b*and c coefficients are not determined for the rule generation. It is found that for both 7-node systems the method successfully locates the faulty section in all the cases except for a case when the fault occurs in the section (bus no. 3 and 4 in 7-node).

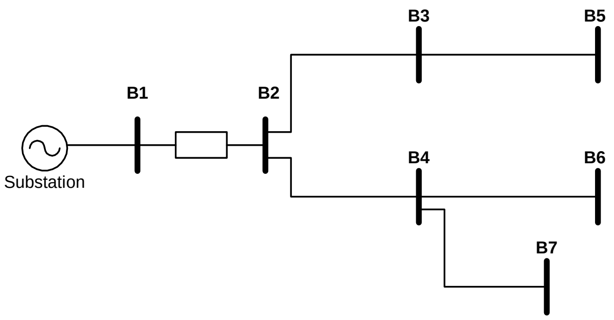
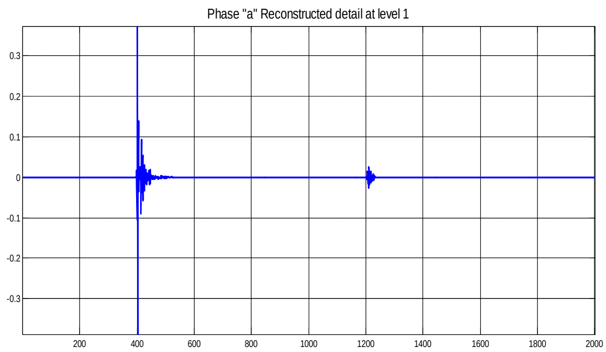


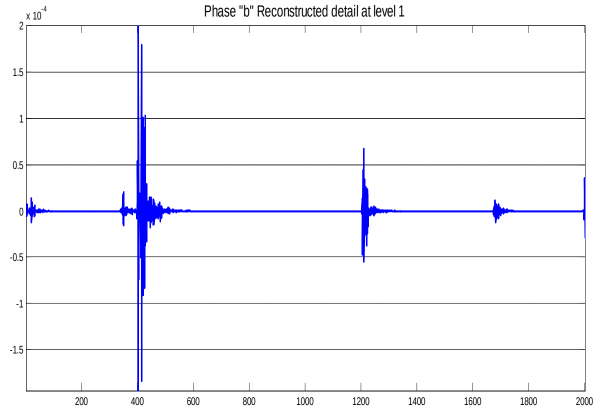
Fig. 3. Single line diagram of the 7-node distribution system

Table-I Fault identification and Localizations

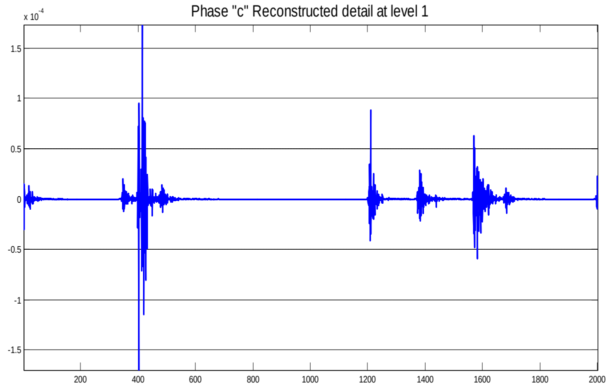
Bus No.	Fault Type	Distance from substation (in Km)
B-3	A-G (i.e LG)	9
B-4	A-G (i.e LG)	8



(a)



(b)



(c)

Fig. 4. Wavelet coefficients obtained from MRA of 3-phaes currents of LG ('AG fault) for (a) Phase A, (b) Phase B, and (c) for Phase C, respectively.

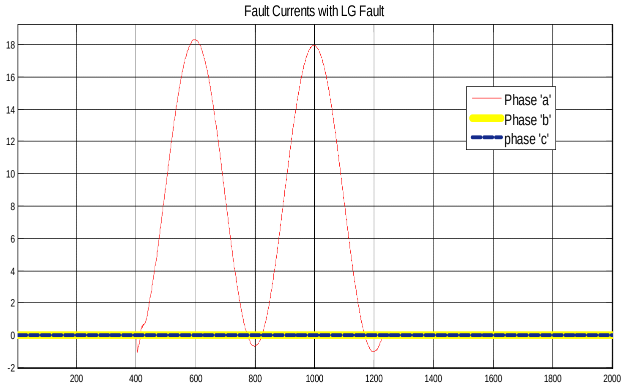


Fig. 5.The fault current value with LG (i.e. AG faults).

IV. CONCLUSIONS

In this paper, the wavelet Multi-Resolution Analysis(MRA) has been applied to identify and locate the fault in the radial distribution system and is tested on 7-nodedistribution systems. Wavelet Transform was used to extract distinctive features in the input signals. The MRA approach is found to be very effective in identifying various types of fault (LG, LL, LLG, and LLLG) and also in locating the faulty section. The method utilizes a set of quite simple rule base approach for identification of faults and only the average value of resolution of the substation current signal. Hence, the method is quite simple to adopt and extremely fast for the fault identification and location.

V. REFERENCES

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