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AN OVERVIEW ON DIFFERENT METHODS OF FAULT LOCATION IN UNDERGROUND CABLE SYSTEM

A. A. Bhole[1], **A. M. Paikrao**[2]

[1, 2]Electrical Department, Govt. College of Engineering, Aurangabad, MH, INDIA

ABSTRACT

Finding and designing new methods for determining type and exact location of faults in power system has been a major subject for power system protection. One of the main capabilities that can improve the efficiency of new protection relays in power systems is exact fault location. In this paper various approaches used for determiningfault location in underground cable systems and the factors that affects the fault location are discussed.

Keywords: Fault Location, Neural Networks, Underground Cable System, Wavelet Transform.

1. INTRODUCTION

The main function of the electrical transmission and distribution systems is to transport electrical energy from the generation unit to the customers. Generally, when fault occurs on transmission lines, detecting fault is necessary for power system in order to clear fault before it increases the damage to the power system. Although the underground cable system provides higher reliability than the overhead line system, it is hard to seek out the fault location. The demand for reliable service has led to the development of technique of locating faults. During the course of recent years, the development of the fault diagnosis has been progressed with the applications of signal processing techniques and results in transient based techniques. It has been found that the wavelet transform is capable of investigating the transient signals generated in power system.

In recent years, there have been many activities in usingfault generated travelling wave methods for fault location andprotection. The travelling wave current-based fault locationscheme in which the distance to fault is determined by thetime differences measured at the sending end between anincident wave and the corresponding wave reflected from thefault have been developed for permanent faults in undergroundlow voltage distribution networks. However, due to the limitation of the bandwidth of theconventional CT (up to a few GHz) and VT (up to 50 kHz),the accuracy of fault location provided by such a scheme is notsatisfactory for a power cable [1]. Also there have been many activities in using power frequency (low frequency) for faultlocation and protection. However, in such techniques which arebased on power frequency signals, some useful informationassociated with high frequencies in transient condition ismissed. In association with wavelet transform the artificial intelligence can also be used in locating faults on power cable by means of neural networks [2]. Although this method is complex yet speed for fault location is increased.

2. IDENTIFICATION OF FAULTLOCATION METHODS

The approach used by utilities for fault location depends onthe types of installations. Underground distribution circuitroutes are less defined than underground transmission circuitsand affect the application of fault location methods. Thedetails required to locate the fault vary with the types ofinstallations.

Several techniques were determined from literature searches, fault location equipment-manufacturers. Each of these aresummarized in the following sections, where the general procedure and some theory for the approach to each method is described. Generalizeddescriptions of the two categories of fault location methods areprovided in the following two paragraphs.

2.1 Terminal Methods

Terminal fault location methods aretechniques which are performed from one or both ends of thecable circuit. In general, these methods are most useful in pre-locatingthe cable fault.

2.2 Tracer Methods

Cable fault location with tracertechniques requires “walking the route” to locate an audible orelectromagnetic signal. These methods are most useful forpinpointing the fault location after the approximate location hasbeen determined.

3. FAULT LOCATION METHODS

3.1 Bridge Techniques

Bridge techniques require a resistive bridge todetermine the location of the fault. In the past, bridges were useful forlocating cable faults although the accuracy of common nulldetectors (galvanometer or other means) was poor. With theadvent of digital multi-meters and other devices that may beaccurate to 4-5 digits, several utilities are revisiting the use ofbridges for cable fault location. A generic bridge is shown inFigure 1.

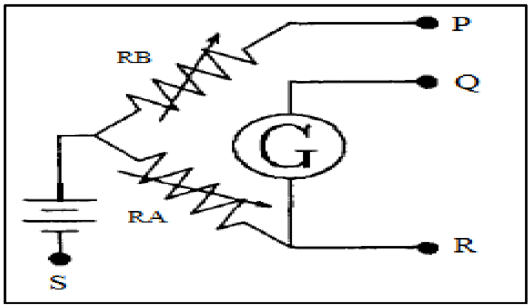

Figure. 1: Typical electrical bridge with terminals P, *Q,* R, and S.

In the bridge, RA and RB arevariable resistors that areadjusted until the galvanometer,*G,* indicates a null.Under this condition, thebridge is balanced.Several fault locationmethods employ the use of abridge. Each of the bridgemethods found during researchfor the EPRI fault locationexpert system is described inthe remainder of this section.

1. Hillbom Loop
2. Murray Loop,
3. Murray Loop Two-End
4. Murray-Fisher Loop
5. Open &Closed Loop
6. Varley hop
7. Werren Overlap

These methods are valid for shorted and highimpedance(shunt) faults on shielded cables. In this method, the bridge is connected to thecable as shown in Figure 1. With $R_A$and R_B, known, thedistance to the fault can be found as follows:

$$X = \frac{R_A}{R_A+R_B+L_{UF}} L_F \ldots\ldots(1)$$

Where, X is distance to fault, L_{UF} and L_F is length of un-faulted cable and faulted cable.

3.2 Other Techniques

1. Capacitance Ratio
2. Charging Current
3. DC Charging Current
4. Halfway Approach
5. Insulation Resistance Ratio
6. Pulse Discharge Detection
7. Rudarhw Voltage
8. Radar with High Voltage Pulse
9. Standing Wave Differential
10. Voltage Drop Ratio

In these methods, 1, 2, 5 are valid for openconductor faults on shielded cables. Since the fault is open, itis possible to measure the capacitance, C of the cable sectionfrom one terminal to the fault and ratio this value to the capacitance, C of an un-faulted cable. The measurement is made from both ends.

Method 3 is valid for shortedand high-impedance (shunt) faults on shielded primarydistribution cables. This method provides a means to isolate a faulted feeder by using a d.c. source and volt-meter. Thevoltmeter is connected in series between the d.c. source andthe cable conductor. With the D.C. source applied to anhealthy cable, the volt-meter will initially show a potentialbetween the source and the cable, but will gradually go to zeroas the cable is charged. A faulted cable will never sustain a charge (continuously discharging through the fault), so thevolt-meter will show a continuous voltage, thereby indicatinga faulted cable.

While Method 4 is valid for all faulttypes. For extremely difficult faults, it may be necessary tosectionalize the cable and then test the individual sections untilthe fault is located. This is done by disconnecting the cablesat pad-mounted transformers, riser poles or other convenientpoints. In extreme cases (long circuits with limited access toterminals), it may be necessary to cut the cable and perform atest. This may damage the cable and prolong servicerestoration efforts.

Methods 5, 6, 7 employ the use of an impulse generator or capacitordischarge device (thumper) to cause a breakdown at the cablefault. A signal is sentdown the cable which produces reflections at the fault location.Where conventional radar does not sufficiently indicate thelocation of a cable fault, a capacitive discharge device mayenhance the radar trace. 9 and 10 are valid for alltypes of faults on shielded cables. A variable frequencyvoltage source is applied to the cable and adjusted until thefundamental harmonic is determined (input impedance isminimum), and the second (and subsequent) harmonic is found.

4. WAVELET TRANSFORM

Travelling wave approach is based on the correlation between fault location and some characteristic frequencies associated to fault-originated traveling-waves along the network. These characteristic frequencies can be identified by means of adequate signal analysis techniques applied to the voltage or current waveforms recorded at an observation point, typically located at the lower voltage terminals of the transformerfeeding the distribution network. In the case of WT, the analysing function, which is called wavelets, will adjust their time-widths to their frequency in such a way that higher frequency wavelets will be very narrow and lower frequency ones will be broader. This property of multi-resolution is particularly useful for analysing fault transients which localize high frequency components superposed on power frequency signals (Manago&Abur [4]). WT of sampled waveforms can be obtained by implementing the discrete WT which is given by:

$$DWT(f,m,n) = \frac{1}{\sqrt{{a_0}^m}} \sum_k f(k) h^* \left(\frac{n-k{a_0}^m}{{a_0}^m}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where, the parameters${a_0}^m$and k ${a_0}^m$ are the scaling and translation constant respectively, k and m being integer variables and h is the wavelet function which may not be real, as assumed in the above equation for simplicity. In a standard discrete WT (DWT), the coefficients are sampled from the continuous WT on a dyadic grid, $a_0=2$, yielding $a_0^0=1$, $a_0^{-1}=1/2$, etc. Actual implementation of the (DWT) involves successive pairs of high-pass and low-pass filters at each scaling stage of the WT. At each detail, there is a signal appearing at the filter output at the same sample rate as the input; thus, by using a sample rate F and scaling by two ($a_0=2$), Eq.(2) shows the association of each scale 2^m with a frequency band containing distinct components of signals.

Frequency band of scale $2^m = F/2^{m+2} \rightarrow F/2^{m+1}$……………………………………………..(3)

4.1Fault-Originated Traveling-Waves and Associated Characteristic Frequencies

Fault-originated traveling waves propagate along the network and reflect at line terminations, junctions between feeders and laterals, and the fault location. The relevant reflection coefficients depend on the line surge impedances, on the impedances of power components connected to the network terminations and on the fault impedance value.

The identification of characteristic frequencies *fp, I* associated with the fault location can be accomplished by using one the appropriate signal analysis technique, whose choice depends on the characteristics of the fault transient signals. These signals are composed by the superimposition of the stationary industrial frequency waveform (low frequency component of large duration) and the transient disturbance caused by the fault (high frequency component of short duration). The resulting signal is therefore characterized by a continuous spectrum due its time-variant properties [5]. The appropriate signal analysis technique should satisfy the two following requirements: (i) large temporal resolution at high frequencies and (ii) large frequency resolution at low frequencies. The use of time-frequency representations(TFRs) allows for the adjustment of the signal spectrum versus time [5]. A signal TFR links a one-dimensional time signal *x(t)*into a bi-dimensional function of time and frequency, $T_x(t,f)$. Typical examples of linear TFRs are the Short Time Fourier Transform (STFT) and the Wavelet Transform.

As known, STFT is a windowed Fourier transform in which the observation interval is divided into a given number of subintervals. For each subinterval, STFT is computed according to the following equation:

$$T_{STFT}(t,f) = \int_{-\infty}^{+\infty} x(\tau)w(t-\tau)e^{-j\omega\tau}d\tau \text{...}(4)$$

Where, $w(\tau)$ is the windowing function that defines the length of the subinterval. Similarly to the Fourier Transform, the main characteristic of the STFT is that the time-frequency resolution is constant and equal to the duration of each subinterval. Therefore, it is not the more appropriate tool for the analysis of fault signals. The wavelet transform, on the other hand, is a TFR which allows a good frequency resolution at low frequencies and a good time resolution at high frequencies [5]. In particular, it allows for the analysis of high frequency components very close to each other in time and low frequency components very close each other in frequency. These properties are indeed particularly suitable for the study of transient waveforms produced by faults.

Continuous Wavelet Transform (CWT) is also a useful tool of wavelet transform, The CWT of signal $x(t)$ is, as known, the integral of the product between $x(t)$ and the so-called daughter-wavelets, which are time translated and scale expanded/compressed versions of a finite energy function $\psi(t)$, called mother wavelet. This transform, which is equivalent to a scalar product, produces wavelet coefficients $C(a,b)$that represent the TFR bi-dimensional function of time and frequency $T_x(t,f)$. Coefficients $C(a,b)$ can be seen as "similarity indexes" between the signal and the so called daughter wavelet located at position b (time shifting factor) with positive scale a

$$c(a,b) = \int_{-\infty}^{+\infty} x(t)\frac{1}{\sqrt{a}}\psi^*\left(\frac{t-b}{a}\right)dt \text{..}(5)$$

where * denotes complex conjugation.
Equation (5) in frequency domain reads:

$$F\,(C(a,b)) \;= \sqrt{a}\Psi^*(a\;\cdot\omega\,)\,X\,(\omega\,) \text{..}(6)$$

Where, $F\,(C(a,b))$, $X(\omega)$ and $\Psi(\omega)$are the Fourier transforms of $C(a,b)$, $x(t)$ and $\psi(t)$ respectively.

If the centre frequency of the mother wavelet $\psi(t)$ is F_0, then the one of $\psi(at\;)$ is F_0/a. Therefore, different scales $a$allow the extraction of different frequencies. If the CWT backward transformation, *i.e.* the signal reconstruction, must be guaranteed, the choice of the number and spacing of scales a should comply with specific constraints. For our purposes, the signal reconstruction is not needed and therefore the CWT spectrum can use linear or logarithmic scales of any desired density. If needed, a high resolution spectrum can be generated for a narrow range of frequencies.

4.2Feature Extraction in Fault Location

In order to locate an ungrounded fault, three important parameters are employed;

1. Ratio of peak-peak voltage approximate to peak-peak current approximate at level five (a_ppv/a_ppi).
2. Sine of phase-shift between current andvoltage approximate at level 5 multiple by a_ppv/a_ppi, (sin(φi-φv).v/i).
3. Ratio of SD of voltage approximate to SDof current approximate at level 5 (SDv/SDi).

It should be mentioned that these three parameters are employed only forthe faulted phases in the case of a phase to phase fault, butonly phase-a is considered in the case of three-phase shortcircuit fault. In order to obtain more accurate results, thesignals are normalized according to Eq. (7)

$I_{normed} = (I - I_{min}) / (I_{max} - I_{min})$………………...(7)

5. FAULT LOCATION BASED ON ANNS

ANNs have emerged as a powerful pattern recognition technique and act on data by detecting some form of underlying organisation not explicitly given or even known by human experts and it possesses certain features which are not attainable by the conventional methods. In this respect, this paper describes a new method for fault location based on the ANNs technique. The successful development of ANNs approaches depends on the successful learning of the correct relationship or mapping between the input and output patterns by the ANNs [2]. In order to achieve this, practical issues surrounding the design, training and testing of an ANN such as the best network size, generalization versus memorisation, feature extraction, convergence of training process and scaling of signals have been addressed and examined.

In order to find the best topology for accurate fault location, an extensive series of studies have revealed that it is not satisfactory to merely employ a single ANN and attempt to train it with a large amount of data. A much better approach is to separate the problem into two parts: firstly to employ and train an ANN to classify the faults; secondly, to use separately ANNs (one for each type of fault and faulted phases) to accurately locate the actual fault position. Fig. (2) shows the fault location scheme based on ANNs.

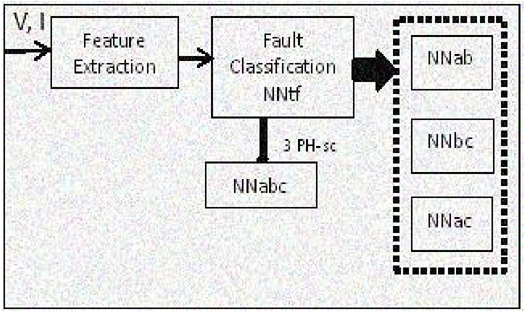

Figure 2. Schematic diagram of fault location by ANN

There are many types of ANNs but the most commonly used are the multi-layer feed-forward networks, as, a three-layer network (input, one hidden and output layers). Because of this, a fully connected three-layer feed-forward ANNs with Levenberg-Marquardt (LM) learning algorithm can be usedin the complete fault classification and fault location networks.

6. FACTORS AFFECTING ON FAULT LOCATION

6.1Effect of fault parameters

The inception angle significantly affects the fault transient voltage and current signals and it is vitally important to verify the effect of this parameter on the performance of the proposed technique. This feature is important since in practice, faults can occur at any point on wave i.e. the fault inception angle cannot be defined in advance[2].

6.2 Effect of remote source

It is well known that a remote in feed can adversely affect the accuracy of conventional fault locators.These small changes can be directly attributed to the fact that with a remote source, the current changes in the healthy phase in terms of magnitude and distortion.

6.3Effect of load taps

It is apparent that load tapssignificantly affect the fault transient waveforms. Therefore, it is vitally important to verify the effect of the load taps on the performance of the proposed techniques.This is a significant advantage since being different load taps at different location of DS is inevitable.

6.4 Effect of cable length

The cable length can vary considerably in the DS, it is vitally important to ascertain as to what extent the fault location accuracy is affected as a result of a change in the cable length.

6.5 Effect of External Faults

In any fault location technique, although a high accuracy for internal faults is ofprimary concern, nonetheless, it should also be stable underexternal faults.

7. CONCLUSION

In this paper, different methods of fault location in underground cable systems are discussed. For bridge technique accuracy level is poor, while accuracy level of wavelet transform is quite high compared to bridge technique but, it is still lower than artificial neural networks. By combining wavelet transform and neural networks the fault location accuracy increases and is found higher than other methods.

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