An overview to fault location methods in distribution system based on single end measures of voltage and current

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Abstract

The problem of fault location has been studied deeply for transmission lines due its importance in the power system. Nowadays the problem of fault location on distribution systems is receiving special attention mainly because of the power quality regulations. This paper presents some of the most relevant methods for fault location in radial power systems. Additionally here is presented an hybrid fault location algorithm which takes advantage of both, the algorithmic and the knowledge based methods. The obtained results from fault location methods help utilities in both network operation and network planning.

Keywords

Algorithmic based methods, knowledge based methods, fault location.

1. Introduction

Fault location has been of considerable interest for researchers over long time. These approaches have been mainly focused on locating faults in transmission lines because of its importance and due to the time required to physically check long lines is much larger than in distribution lines. However, nowadays fault location in distribution systems has started receiving attention as many utilities are operating in a deregulated environment and competing to increase the availability of power supply.

The methods proposed for fault location in transmission lines are not easily applicable to distribution systems because these use measures from two terminal lines, the non-homogeneity, presence of laterals and load taps on distribution lines. Fault location techniques in distribution systems can be classified in four categories [9]: the classical approaches that use fundamental voltages and currents, techniques based in travelling wave theory, approaches based on topological methods and those knowledge-based approaches. This paper presents a review of the classical techniques and knowledge based approaches and also proposes an hybrid approach based on both.

The information given in [10] has been used as it describes radial lines systems and how to calculate fault currents.

In this paper, fault location approaches in distribution systems, which use the fundamental voltages and currents, are presented. In the numeral 2, a method based on a distribution management system is described. The method proposed by Ratan Das is presented in numeral 3, while the proposed by Mourari Saha is described in 4. One method which uses the superimposed components is analysed in 5. The approach developed by Damir Novosel is presented in 6 and the hybrid approach proposed by the author of this paper, is presented in 7. Finally some conclusions are given.

2. Distribution Management System approach

A fault location approach based on the idea of the integration of network information and distribution automation in a Distribution Management System (DMS) is presented in [2]. The principle of fault location is very simple, finding the similarity of calculated and measured fault current.

The database of network information system includes the data needed for fault current analysis of the distribution network. The network modelling and fault current calculation method are also part of DMS and together with real time topology information it provides the basis for fault location. The measured fault current can be obtained from microprocessor-based relays, which are quite common nowadays. As a result, the algorithm finds one or several possible faulted line sections based on distance.

The DMS provides the environment for further processing, because the distance based fault location result is not explicit. The information of possible fault detectors and also the terrain and weather conditions can be taken into account. An important part of fault location is the user interface of the DMS, which provides geographic view to the network and fault location results. In addition to the fault location module, it provides a whole concept of fault management, including for example restoration and fault reporting.

3. Method of Ratan Das

The approach proposed in [1] uses voltages and currents measured at a line terminal before and during the fault.

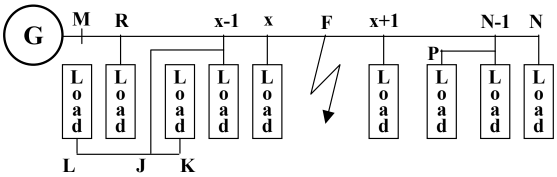

Fig. 1: Single line diagram of a radial line experiencing a fault at ***F***

The location technique could provide multiple estimates if the line has 'laterals'. This fault location technique consists of six steps:

1. Apparent faulted section: A preliminary estimate of the location of the fault is made using voltages and currents, identifying a probable fault location (node ***F***). Line parameters, the type of fault and phasors of the sequence voltages and currents are used to obtain this estimate.
2. Equivalent radial system: All laterals between initial node and the apparent location of the fault ***F*** are ignored and the loads on a lateral are considered to be present at the node to which the lateral is connected.
3. Load modelling: The effects of the loads are considered by compensating for their currents. Static response type models are used for all loads up to node just before of the node ***F***, and also for a consolidated load at the remote end.
4. Voltages and currents at the fault and remote end: Estimate the fault sequence voltages and currents at node ***F***, by assuming that all loads beyond ***F*** are consolidated into a single load at the remote end node.
5. Estimating the location of the fault: The distance to the fault node ***F*** from the previous expressed as a fraction of the distance between previous and next nodes is estimated from the voltage-current relationships at the fault and the resistive nature of the fault impedance.
6. Converting multiple estimates to single estimate: The fault location technique could provide multiple estimates if the line has 'laterals'. The number of estimates, for a fault, depends on the system configuration and the location of the fault. Software-based fault indicators, like those commercially available, are developed for this purpose. They detect downstream faults irrespective of their location. Information from the fault indicators is combined with multiple estimates, to arrive at a single estimate for the location of a fault.

4. Method of Mourari Saha

The algorithm proposed by Saha in [7] uses the fundamental frequency voltages and currents measured at a line terminal before and during the fault. Current can also be measured at the supplying transformer if only one centralized type of fault recorder is installed at the substation. A distance to fault is estimated based on the topology principle. The proposed method is devoted for estimating the location of faults on radial MV system, which can include many intermediate load taps. In the method non-homogeneity of the feeder section is also taken into account. The calculation of fault-location consists of two steps. First, the fault-loop impedance is calculated by utilising the measured voltages and currents obtained before and during the fault. Second, the impedance along the feeder is calculated by assuming the faults at each successive section. By comparing the measured impedance with the calculated feeder impedance, an indication of the fault-location can be obtained. Based on the measured fault-loop impedance and the cable parameters it is possible to estimate the distance to a fault.

Different algorithms are considered depending on the type of fault and on the fact of having the measurements on the faulty feeder or in the substation.

To estimate a phase-phase fault loop impedance, the next formula is proposed:

$$Z_k = \frac{V_{pp}}{I_{pp} - (1 - k_{zk})\dfrac{V_{pp}}{Z_{pre}}} \qquad (1)$$

being V_{pp} and I_{pp} the phase to phase fault-loop voltage and current, Z_{pre} the impedance in prefault conditions and k_{zk} the relation between the power in the faulty line and the power in all the lines, in prefault conditions.

In phase-ground fault, the fault-loop impedance is obtained as follows:

$$Z_k = \frac{Z_g Z_{pre}}{Z_{pre} - Z_g(1-k_{zk})(1-\frac{V_o}{V_{ph}})} \qquad (2)$$

where: $$Z_g = \frac{V_{ph}}{I_{ph} + k_{kn} I_{kn}} \qquad (3)$$

$$V_o = (V_A + V_B + V_C)/3 \qquad (4)$$

Z_{pre} is the impedance in prefault condition seen from the substation, k_{zk} is the relation between the power in the faulty line and the power in all the lines, in pre-fault conditions and V_{ph} the voltage of the faulty phase.

On the next step, the cable parameters of the distribution network are needed. The equivalent fault-loop impedance seen from one node to the fault point should be calculated at the successive nodes. It is possible to determine the fault distance due to the fact that fault-loop impedance decreases when the observation and the fault points are nearer. When a successive reactance assumes a negative value, the fault point is reached and the procedure stops.

5. The method of superimposed components

This technique estimates the location of faults in radial distribution lines with several load taps [8]. The performance of the algorithm has been examined for networks with remote infeeds, as it is very common to find private generators connected in the distribution lines.

The method does single-ended fault location for overhead distribution systems. The superimposed voltage (difference between post-fault and pre-fault voltage) is calculated. This voltage is then injected at the assumed fault point to check currents in the other phases. When the fault point is correct the sound phase injected currents at the actual fault point attain a near zero value.

In a plain feeder, with no load taps, the total voltage $[V_f]$ at the assumed fault point is related to the measured total voltages and currents by

$$\begin{bmatrix} V_{fa}(\beta) \\ V_{fb}(\beta) \\ V_{fc}(\beta) \end{bmatrix} = \beta \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} \begin{bmatrix} I_{Sa} \\ I_{Sb} \\ I_{Sc} \end{bmatrix} + \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \qquad (5)$$

where β is the assumed fault position, Z_s and Z_m are the line self and mutual impedances/unit length and V_S and I_S are the mesured total voltages and currents.

The superimposed voltages in the assumed fault position can be obteined as follows

$$\lfloor V'_{fa,b,c}(\beta) \rfloor = \lfloor V_{fa,b,c}(\beta) \rfloor - \lfloor V_{fa,b,c(ss)}(\beta) \rfloor \qquad (6)$$

and the superimposed voltages and currents at the measuring point are given by

$$\lfloor V'_{Sa,b,c} \rfloor = \lfloor V_{Sa,b,c} \rfloor - \lfloor V_{Sa,b,c(ss)} \rfloor \qquad (7)$$

$$\lfloor I'_{Sa,b,c} \rfloor = \lfloor I_{Sa,b,c} \rfloor - \lfloor I_{Sa,b,c(ss)} \rfloor \qquad (8)$$

Also is possible to calculate the superimposed currents at the end of the line (9)

$$\begin{bmatrix} I'_{Ra} \\ I'_{Rb} \\ I'_{Rc} \end{bmatrix} = \left[(L-\beta) \begin{bmatrix} Z_s & Z_m & Z_m \\ Z_m & Z_s & Z_m \\ Z_m & Z_m & Z_s \end{bmatrix} + [Z_{SR}] \right]^{-1} \begin{bmatrix} V'_{fa} \\ V'_{fb} \\ V'_{fc} \end{bmatrix}$$

where L is the total length of the line, $[Z_{SR}]$ is the matrix representing the remote source.

Finally the superimposed fault path current is given by

$$\lfloor I'_{fa,b,c} \rfloor = \lfloor I'_{Sa,b,c} \rfloor + \lfloor I'_{Ra,b,c} \rfloor \qquad (10)$$

The assumed fault position β is moved to find the minimum value of the healthy-phase fault paths currents, and this point corresponds to the actual fault position.

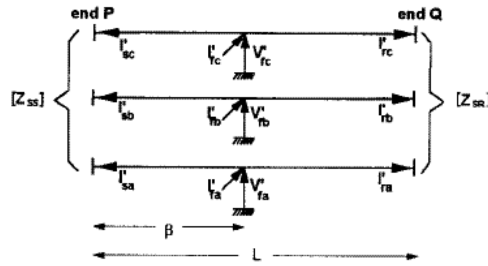

Fig. 2: Superimposed-component circuit

The computational process for a feeder with multiple taps is considerably more complex, however the same principle can be applied.

To represent the load, the primary impedance of the transformer is calculated, assuming a load factor p_f from about 0,8 to 0,95. It must be taken into account the type of the tap: single-phase or 3-phase. In the first case the impedance will be given by:

$$Z_L = \frac{|V_L|^2}{M} \angle \cos^{-1} p_f \qquad (11)$$

and on the second case:

$$Z_L = 3\frac{|V_L|^2}{M} \angle \cos^{-1} p_f \qquad (12)$$

being M the nominal transformer rating and V_L the voltage at the load point. With the above impedance relationships it can be set up a load matrix representing each load tap. Another impedance should be considered, these produced when a line section is terminated by a primary substation. It can be defined a source impedance matrix in terms of the symmetrical short circuit level and the ratio between zero-sequence impedance and first-sequence impedance.

To consider the variation of the load with time of day to determine the load impedance, the load level [L_{level}] must be calculated. It is the ratio between the active power fed to the feeder at the measuring point [P_{ss}] and the maximum total load [P_{Lmax}].

$$P_{ss} = \sqrt{3}|V_{Lss}||I_{Lss}|\cos\phi \qquad (13)$$

where V_{Lss} and I_{Lss} are the prefault line voltage and current

$$P_{L\max} = (M_1 + M_2 + ... + M_N)\cos\phi \qquad (14)$$

where N is the number of load taps and M is the nominal transformer rating

$$L_{level} = P_{ss} / P_{L\max} \qquad (15)$$

Impedance of a single phase load tap is given as

$$Z_L = \frac{|V_L|^2}{L_{level}M} \angle \cos^{-1} p_f \qquad (16)$$

To conclude, this method gives high accuracy for the majority of systems and fault conditions. It is robust to errors in the estimation of load taps.

6. Method of Novosel

Other method presented in [6] is based on the approach used to fault location in short transmission lines. This approach includes all loads and tapped lines, represented by a lumped-parameter impedance model placed behind the fault. This method is based on calculating both source and load impedances based on pre-fault and fault voltages and currents.

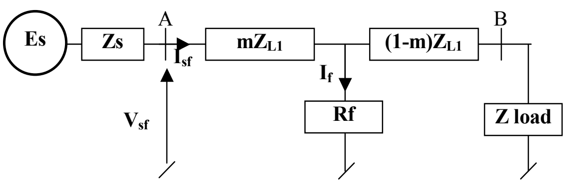

Fig. 2: Equivalent scheme of the distribution feeder

From the figure 2, the load impadance and the impedance behind the faul t locator are:

$$Z_{load} = \frac{V_{ps}}{I_{ps}} - Z_{L1} \qquad Z_s = \frac{\Delta V_s}{\Delta I_s} \qquad (17)$$

V_{ps} and V_{ps} are the prefault voltage and currante measured at the substation, while $\Delta V_s = V_{sf} - V_{ps}$ and $\Delta I_s = I_{sf} - I_{ps}$

In this method, the fault type is considering by including the adequate voltages and currents. In addition this method is not affected if the fault currents at the fault locator is not in phase with the current at the fault given a immunity to effects of load current and fault resistance. Compensation for tapped loads enables to provide accurate results, although, for heavily tapped feeders, the accuracy may degrade toward the end of the feeder.

The method was tested on an EMTP model of a typical distribution tapped network and the test shows its good performance. However it is also notice that additional means are required to distinguish if the fault is on the tap or on the feeder.

7. Hybrid approach of algorithmic based method and knowledge based

There are other approaches in fault location but most of them use multiple devices as current/voltage sensors, fault recorders, and at least a good model of the system. The method proposed [3], [4] and [5], is based on classical approaches that use fundamental voltages and currents at line terminals and knowledge-based approaches. Specifically, this proposal is aimed at characterizing and extracting significant information from voltage sags (fig. 2) and the respective currents.

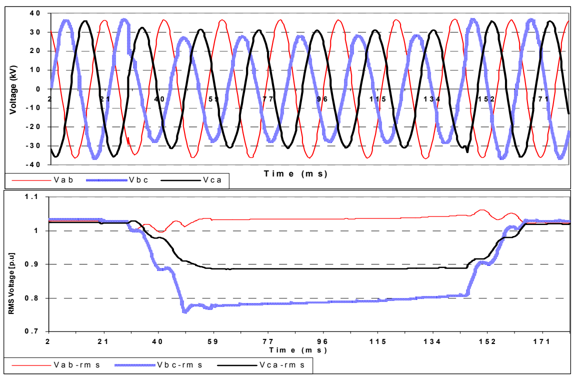

Fig. 3: Voltage sag to 75% and 108 ms duration

These information contain knowledge about the system performance as a consequence of the disturbance. The goal is to extract the meaningful information from the voltage measures and currents as it is presented in figure 3, to improve the diagnostic task.

This hybrid approach comprises the extraction of information from the recorded signals of voltage an current taken before and during the fault. Considering that most of the algorithmic methods use only state stable information from the fault, some techniques as neural nets, support vector machines and Bayesian classifiers are used to deal with the transient information. As a outputs of these knowledge based applications, there are information related to how to set the algorithmic methods, and also a set of possible fault locations (SLai).

On the other hand and having state stable data from the fault registers, and parameters as the mean fault resistance, it is possible to use an well known algorithmic method to locate the fault. Some these methods were presented before in this paper. As a result of the application of the algorithmic methods, a set of possible fault locations is obtained (SLalg).

Finally, and having the results of the two methods, it is necessary to make the intersection of the two possible fault sets obtained, in order to have the most possible fault location.

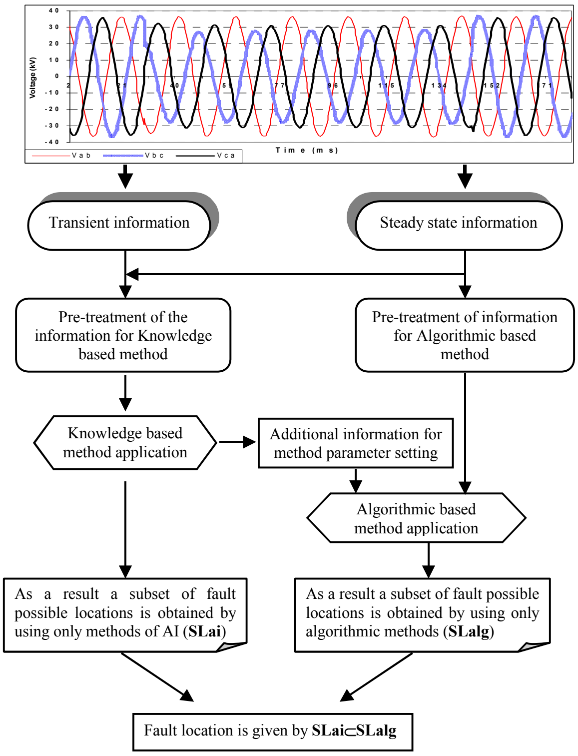

Fig 4: Hybrid based method for fault location in radial systems.

8. Conclusions

The fault location using the available voltage and current measurements implies a great amount of saved money to the distribution electrical utilities because there is not necessary a big investment in equipment.

The obtained results from fault location methods help utilities in both network operation and network planning. In operation, to maintain the continuity indexes due to the response improvement in the faulted system. In planning, for the design and assessment of sensitive equipment and for the design of better protection systems.

Acknowledgement

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