ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

Ground Fault Location in Distribution System Using MATLAB

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ABSTRACT: Identifying ground fault location is one of the major issue in power distribution system. Periodic identification/sensing and isolation of faulted distribution line greatly prevent propagation of fault, many economic losses, and any devastating impact on people's life. Basically this paper deals with the periodical identification/sensing and isolation of fault lines using already available systems with minor changes. As With the advancement of smart metering technology, ground fault location can be easily identified using the negative sequence analyzing feature of smart meter. In this paper we also discuss about the relationship between the negative sequence voltage measured from a location and distance of fault from that location briefly. In addition to the above said advantage, indispensable presence of Peterson coil in compensated distribution system, results in a comparatively lower range of fault current. So the isolation of them becomes cost effective even with the use of simple contactor. Hence this method is found superior when considering cost and performance factor.

KEYWORD*S*: negative sequence voltage, smart meter, ground fault location, distribution system, MATLAB, sequence analyser.

I.INTRODUCTION

Electric power distribution system is the final stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers. Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage ranging between 2 kV and 35 kV with the use of transformers. Primary distribution lines carry this medium voltage power to distribution transformers located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage of household appliances and typically feed several customers through secondary distribution lines at this voltage. Commercial and residential customers are connected to the secondary distribution lines through service drops. At electrical substations, the voltage is stepped down to lower values for distribution, for example, around a city. "Medium" voltage, lower than 33 kV, is used for distribution. Near each customer's premises, a final transformer is used to reduce the transmission voltage to the level used by the customer's lighting and power equipment. Conductors for distribution may be carried on overhead pole lines, or in densely populated areas, buried underground. Urban and suburban distribution is done with three-phase systems to serve all residential, commercial, and industrial loads.

In [1], distribution in rural areas may be only single-phase if it is not economical to install three-phase power for relatively few and small customers.In an electric power system, a fault is any abnormal electric current. For example, a short circuit is a fault in which current bypasses the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault" or "earth fault", current flows into the earth. The prospective short circuit current of a predictable fault can be calculated for most situations. Fault location in distribution and transmission system can be detected by various methods. Some previously used methods are impedance based approaches, traveling wave method and the wide area synchronized method .Firstly, One-ended impedance methods of fault location are a standard feature in most numerical relays. One-ended impedance methods use a simple algorithm, and communication channels and remote data are not required (except when a channel is required to bring the fault location estimate to an operator). In [2] and [3], Takagi method requires pre-fault and fault data. It improves upon the simple reactance method by reducing the effect of load flow and minimizing the effect of fault resistance. Two-ended methods can be more accurate but require data from both terminals. Data must be captured from both ends before an algorithm can be applied. Modified

Takagi method is used to correct the difference in source angle .In [4]-[6], they perform well for low impedance ground fault, but affected by system variation. Due to assumption of lossless distribution lines, they may end up with low fault location accuracy. A sequential component method for fault detection and classification can be used for manual fault analysis as in [7].The only drawback is that, it require massive calculation and it is also a time consuming process.

Secondly, travelling wave method is used to provide high accuracy [8]-[12]. Because fault waveforms travel at the speed of light, or very nearly, this application imposes the most stringent requirements of all those listed. In [10]-[12], most faults generate a waveform containing a significant amount of high-frequency energy. This can be caused by the primary event initiating the fault, such as a lightning strike or tree hit and the resulting arc; or it can be caused by a break in the line due, for example, to snow, ice, and/or wind loading. This high-frequency energy can often be detected with excellent resolution in the time domain. This event 'signature' propagates down the transmission line at nearly the speed of light. Therefore, the 'signature' will be received at the ends of the line at times equal to the time of the fault event, plus the propagation delay along the line. If the arrival times at both ends of the line can be measured, then the location of the fault can be estimated. Thirdly, wide area method is used with the help of modern intelligent electronic devices. An electromagnetic time reversal (EMTR) method is discussed in [13]. In this method experimental test are performed to prove the accuracy of fault location within few meter length by using sensor.

This paper deals with ground or earth fault location in a compensated distribution network by using negative sequence analyser. Here the fault section is located based on the negative sequence voltage on the lower side of the transformers. The simulation result provides an accurate fault location based on fault distance.

II. ALGORITHM OVERVIEW

The distribution segment continues to carry electricity from the point where transmission leaves off, that is, at the 66/33kv level. The standard voltages on the distribution side are therefore 66kv, 33kv, 22kv, 11kv and 400/230 volts, beside 6.6 kv, 3.3 kv and 2.2 kv. Depending upon the quantum of power and the distance involved, lines of appropriate voltages are laid. The main distribution equipment comprises HT and LT lines, transformers, substations, switchgears, capacitors, conductors and meters. HT lines supply electricity to industrial consumers while LT lines carry it to residential and commercial consumers. Here we are taking a 10kv compensated distribution system for fault elimination and it brings the permanent fault current down to a very low value for proper switching operation. Since the development of smart metering units and other IEDs, they have been commonly utilized in the distribution systems. Accompanied with the circuit breakers/contactors, the faulted sections can be located and isolated from the system without interrupting the normal operation of the rest healthy system.

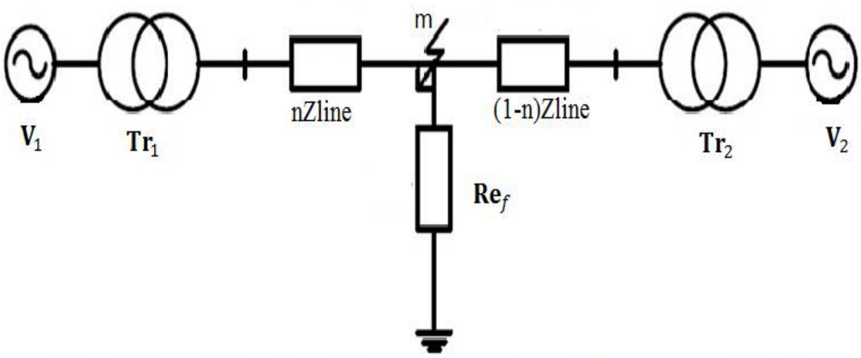

Fig. 1 (a) Configuration of two ends system before a ground fault

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

Although the ground fault in a compensated system offers little fault current, it will create imbalanced phase voltages and by monitoring the increasing of the negative sequence voltages the fault can be detected and located. For a clear demonstration, a simple two-end equivalent distribution system is used as shown in Fig.1.

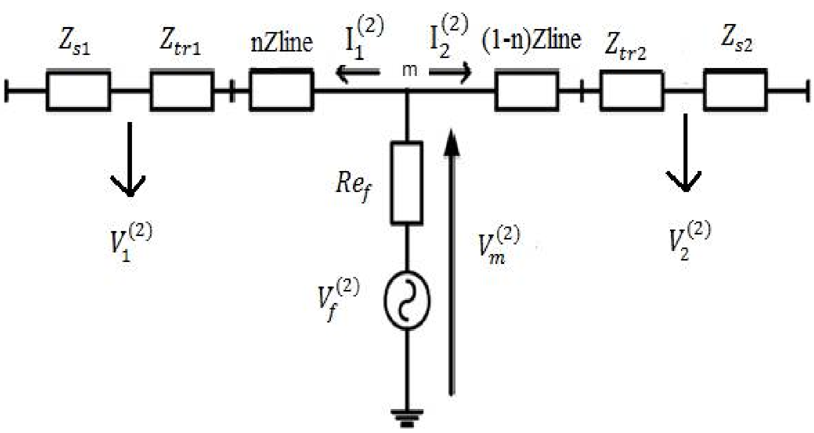

Fig. 1 (b) The faulted negative-sequence component

In Fig. 1(a), a ground fault is imposed on the distribution line with a distance “n” to the terminal 1. The ground fault itself can be regarded as a negative voltage source due to the short circuit transient as shown in Fig. 1(b). The negative sequence voltage will drop along distribution cables/ lines and transformers where Zline , Ztr and Zs denote the negative sequence line, transformer and source/load impedance separately. The absolute value of the negative sequence current $I_1^{(2)}$ and $I_2^{(2)}$ varies with the fault resistance. However, with known supply/load impedance and total cable impedance, for a fixed fault point, the ratio of negative current ($I_1^{(2)}/\ I_2^{(2)}$) is fixed.

$$I_1^{(2)} = \frac{V_m^{(2)}}{nZline+Z_{tr1}+Z_{s1}} \tag{1}$$

$$I_2^{(2)} = \frac{V_m^{(2)}}{(1-n)Zline+Z_{tr2}+Z_{s2}} \tag{2}$$

Due to the fact that the measured negative sequence current is small value during a fault for a compensated system (especially with a fault resistance), the voltages at the low voltage side of MV/LV transformers are used

$$I_1^{(2)} = \frac{V_{s1}^{(2)}}{Z_{s1}} \tag{3a}$$

$$I_2^{(2)} = \frac{V_{s2}^{(2)}}{Z_{s2}} \tag{3b}$$

Applying (3a, 3b) into (1) and (2), the distance can be estimated as:

$$n = \frac{Zline+Zsum2-ABZsum1}{ABZline+Zline} \tag{4}$$

where,

$$Zsum1 = Z_{s1} + Z_{tr1} \tag{5}$$

$$Zsum2 = Z_{s2} + Z_{tr2} \tag{6}$$

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$$A = \frac{V_1^{(2)}}{V_2^{(2)}}$$

$$B = \frac{Z_{s2}}{Z_{s1}}$$

When distribution system compared with load impedance, the system supply impedance is much smaller and its variation can be ignored. The pre-fault load impedance can be monitored by the smaller meter (V/I) and updated to the centre controller and this load impedance information (assuming load remains the same during the update interval) can be used for fault location. The fault distance can be calculated by equation (4).

However, for a practical distribution network with quite a lot of loads and the embedded generation branches, fault location using equation (4) can be complicated and involving massive calculations. Equation (5) & (6) represent the Zsum1and Zsum 2 respectively. The measurement error and signal delay can be enlarged during this procedure and lead to wrong fault location results. According to equations (1), (2) and (3a, 3b), the fault distance can be represented by the negative sequence voltages recorded by the smart meters ($V_1^{(2)}$ and $V_2^{(2)}$) and for different fault positions the ratio of them varies.

$$\frac{V_1^{(2)}}{V_2^{(2)}} = \frac{((1-n)\text{Zline}+\text{Zsum2})Z_{S1}}{(n\text{Zline}+\text{Zsum1})Z_{S2}} \qquad (7)$$

From equation (7) the ratio of the negative sequence voltage, seen from each measurement end, has an inverse proportion to the fault distance assuming that the impedances (load/supply) at the terminals are the same. If the terminal impedance varies, an index which equals to the reverse ratio of the variation will be used to multiply with the voltage and the estimation errors will be reduced. The faulted section can simply be selected from the comparison of the measured voltages as shown in Fig. 2

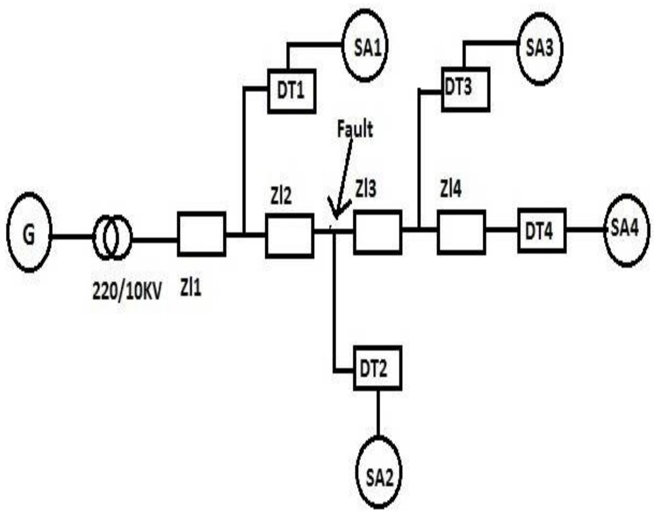

Fig.2 Configuration of distribution system with voltage measurements

A typical distribution system with four branches and their step-down transformers is represented in the equivalent impedance circuit and shown in Fig. 2. The main distribution line is separated into four equal sections and the four smart meters a placed at the low voltage (LV) ends of the distribution transformers (DT). For fault in the Fig. 2, the measured negative sequence voltage can be classified into three groups which are “SA1”, “SA2” and “SA3, SA4”. The SA2 which are closer to the fault has the largest voltage and the voltage from “M1” and “M3, M4, M5” can be comparable. During the fault location procedure, only the amplitude of the voltage recorded by the smart metering unit is required to achieve accurate fault locations.

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III.SIMULATION VERIFICATIONS AND RESULT

The proposed fault location scheme is further tested and demonstrated using Matlab simulation results. The schematic diagram of the tested distribution system is shown in Fig. 3.

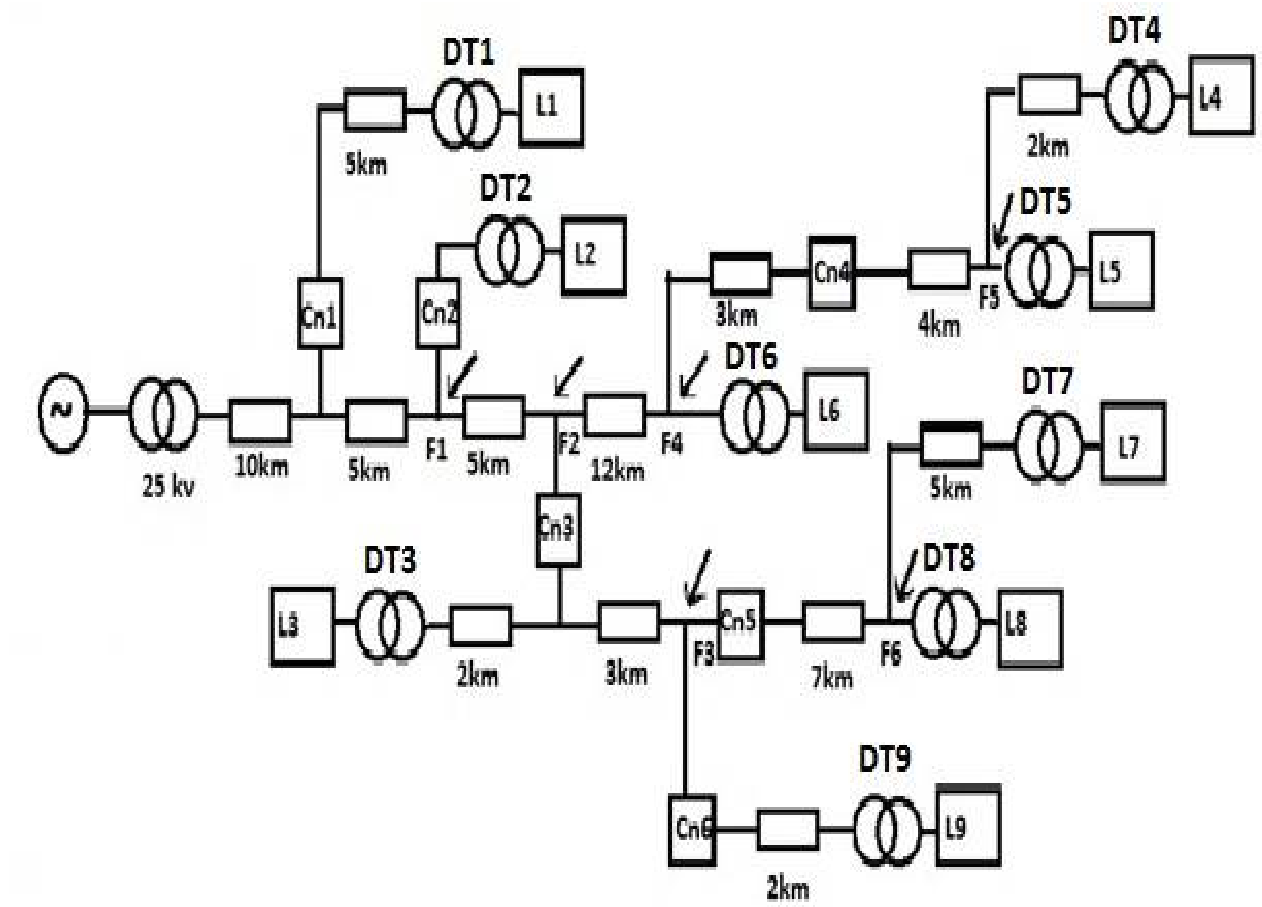

Fig .3 Schematic diagram of test system of distribution system

As shown in Fig.3, the distribution system contains different lengths of lines which connect multiple loads at the low voltage ends with the distribution transformers (DT).Negative sequence voltages are recorded at the nine labelled terminal. The system loads at all the terminals are all selected as 5KW. For the initial test, single phase to ground faults, with a 10Ω resistor, at 6 different locations are imposed in the system individually. Six contactors are installed in the system for fault isolation. For the fault F4, the measured three phase voltages from one of the terminals are shown in Fig .4. Fault is imposed in the system at 0.03s.the faulted voltage is derived using the post fault data minus the pre fault data. This system is simulated using MATLAB and all of the calculated negative sequence voltages from each terminal are shown in Fig .4.

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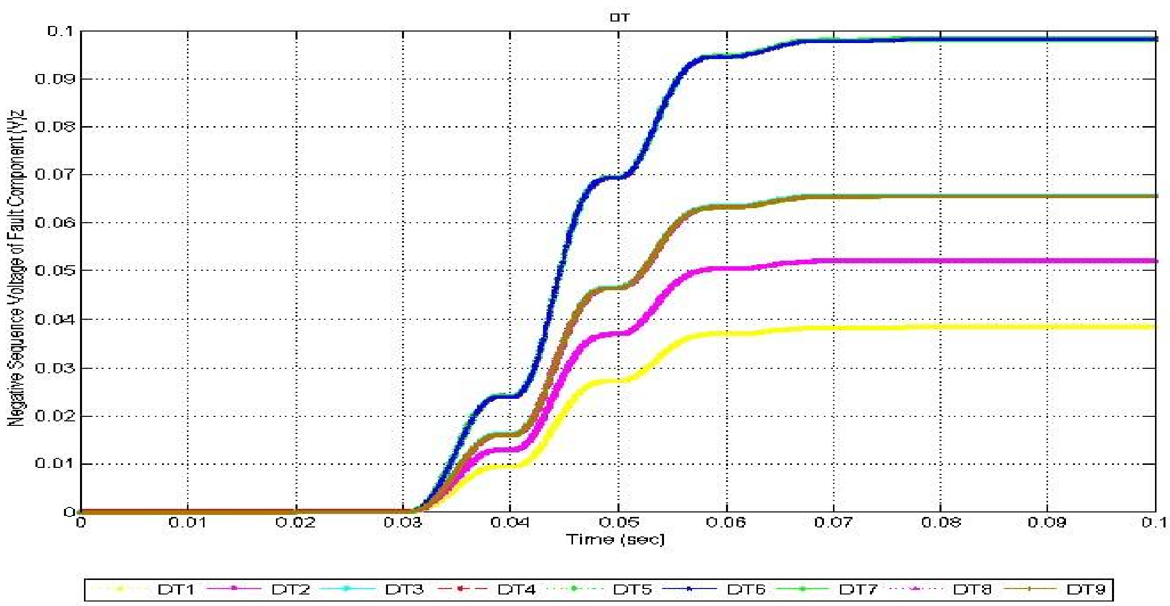

Fig. 4 Measured negative sequence voltage at the terminal during F4

As shown in the Table I, the maximum value of negative sequence voltage at any point, is calculated from the data obtained from the smart meters installed at different distribution transformers (DT's). Here the Fault is generated in F4 at 0.03sec and the samples are taken at an interval of 0.05sec. As per this theory, the smart meter bearing the highest value of negative sequence voltage is the smart meter that is very close to the fault location. This tabular calculation points the fault to be near DT6 which is in turn the closest DT to F4.

Table I Test result for all DT under fault F4

slno	TIME	DT1	DT2	DT3	DT4	DT5	DT6	DT7	DT8	DT9	MAX DT	FAULT @
1	0.000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
2	0.005	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
3	0.010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
4	0.015	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
5	0.020	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
6	0.025	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
7	0.030	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	Z
8	0.035	0.00491	0.00663	0.00836	0.01250	0.01250	0.01250	0.00835	0.00836	0.00836	0.01250	DT6
9	0.040	0.00949	0.01279	0.01608	0.02399	0.02399	0.02400	0.01608	0.01608	0.01608	0.02400	DT6
10	0.045	0.02062	0.02791	0.03520	0.05269	0.05269	0.05269	0.03519	0.03519	0.03519	0.05269	DT6
11	0.050	0.02727	0.03685	0.04642	0.06940	0.06940	0.06941	0.04642	0.04642	0.04642	0.06941	DT6
12	0.055	0.03444	0.04662	0.05881	0.08804	0.08805	0.08805	0.05880	0.05880	0.05880	0.08805	DT6
13	0.060	0.03704	0.05013	0.06321	0.09462	0.09463	0.09463	0.06321	0.06321	0.06321	0.09463	DT6
14	0.065	0.03788	0.05127	0.06467	0.09681	0.09682	0.09683	0.06466	0.06466	0.06466	0.09683	DT6
15	0.070	0.03831	0.05185	0.06540	0.09791	0.09791	0.09792	0.06539	0.06540	0.06540	0.09792	DT6
16	0.075	0.03836	0.05192	0.06549	0.09805	0.09805	0.09806	0.06548	0.06548	0.06549	0.09806	DT6
17	0.080	0.03841	0.05199	0.06558	0.09818	0.09818	0.09819	0.06557	0.06557	0.06558	0.09819	DT6
18	0.085	0.03841	0.05200	0.06558	0.09818	0.09819	0.09819	0.06557	0.06558	0.06558	0.09819	DT6
19	0.090	0.03842	0.05201	0.06559	0.09820	0.09820	0.09821	0.06559	0.06559	0.06559	0.09821	DT6
20	0.095	0.03842	0.05201	0.06559	0.09820	0.09820	0.09821	0.06558	0.06559	0.06559	0.09821	DT6
21	0.100	0.03842	0.05201	0.06559	0.09820	0.09820	0.09821	0.06559	0.06559	0.06559	0.09821	DT6

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

IV. CONCLUSIONS

Due to the small ground fault current in the compensated power distribution system , correct relay operation cannot be realized and the system normal operation will be influenced if the permanent fault is not located and removed . The developed method uses the relationship between the faulted negative sequence voltages and fault distance from the measurement unit, to locate the faulted sections once the wide-area low voltage end side data is collected. The proposed fault location detection method has been implemented in MATLAB environment for 25-kv distribution system with nine distribution transformers and the data is measured by using the low voltage side metering recorded data. Here the fault is located, by using the relationship between the faulted negative sequence voltage and fault distance from the measuring unit. This system is tested using multi-branch distribution system and the result shows good accuracy. It can be further improved by using low cost contactors, which protects the fault from spreading to the healthy system operation and this make it feasible for industrial implementation.

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