Available online at www.iseec2012.com

I-SEEC 2012

Proceeding - Science and Engineering (2013) 203–209

Proceeding
Science and Engineering

www.iseec2012.com

Science and Engineering Symposium
4th International Science, Social Science, Engineering and Energy Conference 2012

Assessment of Fault Location in Power Distribution Networks Using Path Classification Technique

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Abstract

This paper presents a method for fault location in radial distribution by simplified path classification technique. A constrained parameter is the square root of the sum of squares for error of measurement and simulation voltage or current. The complex system is divided into a single path to calculate the fault distance and fault resistance. The path minimum sum of squares different of voltage or current was identified the fault location. The minimum percentage error of fault distant when evaluated the proposed method with 20 bus radial distribution system equal to -0.45 and faults can locate accurately in all cases.

Keywords: Fault location, fault analysis, fault assessment, path classification technique, radial distribution system

1. Introduction

The continuity of power supply to consumers is very important for electric distribution system operation. The transient circumstance called fault is the cause of protection devices are activated and will result in a power outage. The consequence situation is the lack of connection between power supply and consumers. The major problem in the power outage was due to some electrical fault is the optimum method of fault location and restore the system to normal operation within the shortest possible time. Although there are many researches proposed to locate faults in power distribution systems, however, these methods are not satisfied to radial distribution ([1]-[2]). The research involved locating faults on distribution systems only might be face with the budget problem of the installation of additional equipment into the system. These are supervisory control and data acquisition (SCADA) system, sensor status of breakers and relays measuring the parameters of the input string, sensor signals, current and voltage at bus, etc. ([3]-[4]). This paper focuses on the method of fault location by analyzing the voltage and current at the substation using path classification technique. The input data of computation only need the real time value of current and voltage and electrical parameters of network. The complex system is divided into a single path to calculate the fault distance and fault resistance. The path minimum sum of squares

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different of voltage or current was identified the fault location. To evaluate the performance of proposed method, the simulation results of 20-bus radial distribution system are shown and summarized.

Nomenclature

$\bar{\mathbf{i}}_{abc,s}^{(k)}$	sending end current of feeder connect bus *k*-*m*-*n*
$\bar{\mathbf{i}}_{abc,r}^{(k)}$	receiving end current of feeder connect bus *k*-*m*-*n*
$\bar{\mathbf{i}}_{abc,d}^{(m)}$	load current of bus *m*
$\bar{\mathbf{z}}_{abc}^{(k,m)}$	impedance matrix of feeder connect bus *k*-*m*
$\bar{\mathbf{z}}_{abc}^{(m,n)}$	impedance matrix of feeder connect bus *m*-*n*
N	system bus number
p, q, u	phase *a b* or *c*
$\bar{v}_{pn}$	phase-*u* voltage at substation
$\bar{i}_p$	phase-*p* current at substation
$\bar{i}_{pp}$	phase *p* current of feeder
$\bar{i}_{qq}$	phase *p* current of feeder
$\bar{i}_{uu}$	phase *p* current of feeder
$\bar{i}_{ps}$	phase-*p* current of equivalent impedance at sending end
$\bar{z}_{ps}$	equivalent impedance of phase-*p* at sending end
$\bar{v}_t$	$\bar{z}_{pp}\bar{i}_{pp} + \bar{z}_{pq}\bar{i}_{qq} + \bar{z}_{pu}\bar{i}_{uu}$
r_f	fault resistance
$\bar{z}_{pp}$	self-impedance of phase *p* of feeder
$\bar{z}_{pq}$	mutual-impedance of phase *p* and *q*, $p \neq q$
$\bar{z}_{pu}$	mutual-impedance of phase *p* and *u*, $p \neq u$
$\bar{i}_f$	fault current
d	fault distant from substation
$\bar{v}_t$	$(\bar{z}_{aa} - \bar{z}_{ba})\bar{i}_{aa} + (\bar{z}_{ab} - \bar{z}_{bb})\bar{i}_{bb} + (\bar{z}_{ac} - \bar{z}_{bc})\bar{i}_{cc}$
$rsse_v$	root-mean square of voltage different
$rsse_i$	root-mean square of current different

v_{act}	actual voltage at substation
i_{act}	actual current at substation
v_{sim}	simulated voltage at substation
i_{sim}	simulated current at substation
k	sampling index
n	sampling points

2. Equivalent Circuit of Single Path

Fault location process initiate by division of the complex distribution network into single paths as shown in Fig 1(a). The equivalent circuit of single path is shown in Fig 1(b). The loads of buses are transformed to the sending end and the receiving end of the feeder as shown in Fig 2. The transform equation of load impedance is,

$$\bar{i}_{abc,s}^{(k)} = \left(\bar{z}_{abc}^{(k,m)} + \bar{z}_{abc}^{(m,n)}\right)^{-1} \bar{z}_{abc}^{(m,n)} \bar{i}_{abc,d}^{(m)} \tag{1}$$

$$\bar{i}_{abc,r}^{(n)} = -\left(\bar{z}_{abc}^{(k,m)} + \bar{z}_{abc}^{(m,n)}\right)^{-1} \bar{z}_{abc}^{(k,m)} \bar{i}_{abc,d}^{(m)} \tag{2}$$

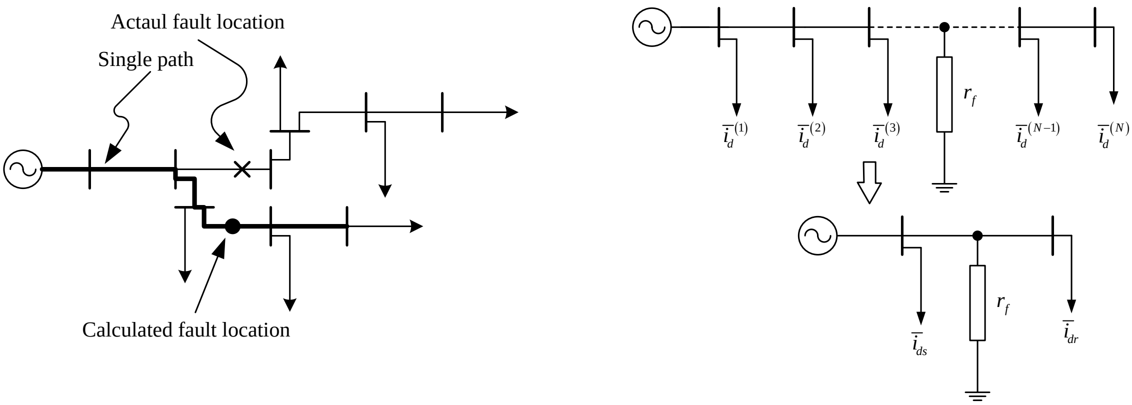

Fig. 1. (a) Single path of network; (b) Single path equivalent circuit

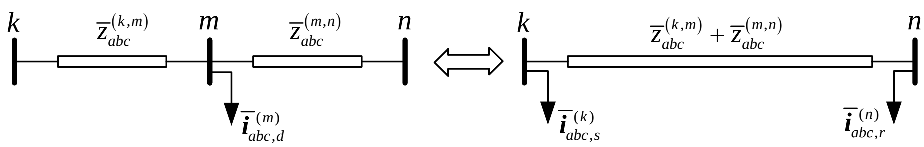

Fig. 2. Load transfer

For the *N* bus system, load transfer process start at bus *N-2 N-1* and *N* respectively. Complex power of load at nus *N-1* is transferred to bus *N-2* with the new value calculates by *(1)* and transferred to bus *N* with the new value calculates by *(2)*. This process is continuing progressive until the equivalent circuit of single path is the same as right hand side of Fig 2.

3. Fault Distance Calculation

3.1. Short-to-ground fault

Short-to-ground fault can occur in 3 cases, single-phase short circuit to ground, two-phase short circuit to ground, and three-phase short circuit to ground. These faults are formulas to calculate the fault distance and fault resistance identical. With the case of short-to-ground fault more than one phase, consider any one phase only. When the subscript p represents phase a, b, or c is short-to-ground through the fault resistance, r_f . The current through the equivalent impedance on receiving end and feeder before fault location can be calculated from *(3)* and *(4)*, respectively.

$$\bar{i}_{ps} = \frac{1}{\bar{z}_{ps}} \bar{v}_{pn} \tag{3}$$

$$\bar{i}_{pp} = \bar{i}_p - \bar{i}_{ps} \tag{4}$$

Fault current is approximately equal to the feeder current which is expressed as,

$$\bar{i}_f = \bar{i}_{pp} \tag{5}$$

The result equation of KVL application for this case is

$$-\bar{v}_{pn} + d\bar{v}_t + r_f \bar{i}_f = 0 \tag{6}$$

The final result of *(6)* is distributed in terms of the real and imaginary part. The real part is equal to zero because fault impedance is resistance. On the new arrangement, the calculated fault distance equation is expressed as,

$$d = \frac{\bar{v}_{pn,r} - r_f \bar{i}_{f,r}}{\bar{v}_{t,r}} \tag{7}$$

Substitution d into *(6)* result the equation to calculate the fault resistance is expressed as,

$$r_f = \frac{\bar{v}_{pn,i}\bar{v}_{t,r} - \bar{v}_{pn,r}\bar{v}_{t,i}}{\bar{v}_{t,r}\bar{i}_{f,i} - \bar{v}_{t,i}\bar{i}_{f,r}} \tag{8}$$

The subscript i and r are imaginary part and real part respectively.

3.2. Phase-to-phase fault

The case of phase-to-phase fault will consider only the short-circuit of the two-phase approach only. Fault current flowing through the resistor is expressed as,

$$\bar{i}_f = \bar{i}_{pp} = -\bar{i}_{qq} \tag{9}$$

The result equation of KVL application for this case is

$$-\bar{v}_{pq} + d\bar{v}_t + r_f \bar{i}_f = 0 \tag{10}$$

By the inspection, *(10)* is similar to *(6)*, so the fault distance and fault resistance can be calculated from equation *(8)* and *(7)* respectively.

3.3. Three-phase fault

The three phase fault current is expressed as,

$$\begin{bmatrix} \bar{i}_{af} \\ \bar{i}_{bf} \\ \bar{i}_{cf} \end{bmatrix} = \begin{bmatrix} \bar{i}_{aa} \\ \bar{i}_{bb} \\ \bar{i}_{cc} \end{bmatrix} \tag{11}$$

The analysis equation to calculate the fault distance and fault resistance in this case, the second phase of the analysis can be considered a fault without considering the remaining phase. Consideration phase *a* and phase *b*, the KVL equation as follows.

$$-\bar{v}_{ab} + d\bar{v}_t + r_f \bar{i}_f = 0 \tag{12}$$

By the inspection, *(10)* is similar to *(6)*, so the fault distance and fault resistance can be calculated from equation *(8)* and *(7)* respectively.

4. Fault Location Algorithm

Electric distribution system consists of feeders which can be divided into single paths as described in section 2. The current and voltage at substation may be the response of any fault types. The section 3 described about the fault diagnosis which the single path is fault or un-fault. This part of work cannot specify the fault circumstance or fault location of path. The details of fault path and fault location are described as follow.

1. Determine the probability of fault of considered path by considering the calculated fault distance and check with the following conditions.

   a. If the calculated fault distance of any path is greater than the maximum length of the feeder length. Conclude that feeder is not a fault.

   b. If the calculated fault distance of any path is less than the maximum length of the feeder length. Such a path that it is possible to be existent fault.

2. Substitute the fault distance and fault resistance for each path with the possibility that there may be a fault into the simulation. Record the current and voltage at the substation for the phase fault. In the event of a system fault more than one phase, choose a phase transition between the normal state and fault state maximum. Calculate the square root of the sum of squared difference between the measured voltage or current at the substation and values are simulated by the fault location and the fault resistance by *(13)* and *(14)*

$$rsse_v = \sqrt{\sum_{k=1}^{n} \{v_{act}(k) - v_{sim}(k)\}^2} \tag{13}$$

$$rsse_i = \sqrt{\sum_{k=1}^{n} \{i_{act}(k) - i_{sim}(k)\}^2} \tag{14}$$

3. The path that evaluate the minimum of $rsse_v$ and $rsse_i$ will be concluded the fault circumstance. The fault distances is also calculated and specify the fault location.

5. Test Results

To evaluate the effectiveness of the method presented in this paper, the simulation was test on distribution systems with radial 20 bus, 22 kV 50 Hz as shown in Fig 3. The simulation situated a fault all 11 types each test 20 times with the different position fault resistances. The time interval of simulation is 0 - 0.04 s and the time step is 1 ms. The selected simulation results are shown in Table 1.

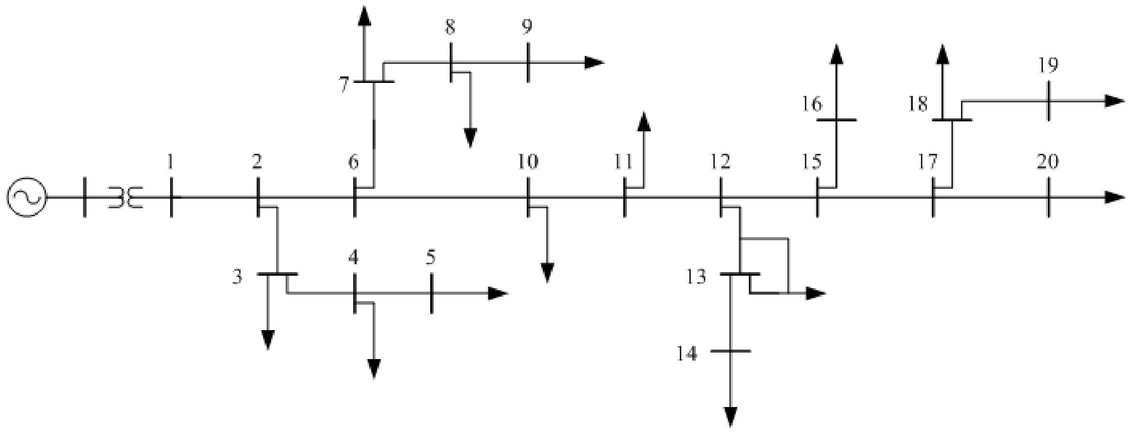

Fig. 3. The 20-bus test system

Table 1. Selected simulation results

No	Fault type	Fault distance (km)		%Error		$rsse_v$	$rsse_i$
		Actual	Simulation	m	(%)	kV	kA
1	A-G	4.96	4.93	30	0.61	0.424	0.413
2	AB	10.67	10.80	-130	-1.22	0.010	0.095
3	AB-G	5.99	5.80	190	3.17	0.017	0.123
4	ABC	11.05	11.10	-50	-0.45	0.016	0.130
5	ABC-G	7.63	7.71	-80	-1.05	0.412	0.501

6. Conclusion

The path classification technique is used to specify the faulted path and determine the fault location. The transient simulation results of a path which the most close to realistic fault conditions is concluded that the fault path. The fault location and fault distance calculation is determined from this specified path. The test results on 20-bus system were presented and also specify the fault location correct in all 11 cases.

Acknowledgements

This work was supported by Department of Electronics Engineering, Faculty of Technology, Udon Thani Rajabhat University.

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