전기품질 모니터링 시스템에서의 사고거리계산 알고리즘

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A Modified Fault Distance Calculation in the Power Quality Monitoring System

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Abstract - This paper proposes a new fault distance calculation method in the power quality (PQ) monitoring system. The proposed method calculates the fault impedance and the fault distance based on the measurement data of the PQ monitors and the information of the topology of the distribution systems. By using the iterative calculation method, the proposed method can find more exact location of the PQ events than the exisitng methods. The proposed method is applied to the IEEE 34 bus test feeders by using the PSCAD/EMTDC™.

1. INTRODUCTION

Power quality (PQ) has become a significant issue for both power suppliers and customers. In the past, the frequency and duration of power outages are only a matter of concern. However, those reliability issues are not sufficient in the current power systems because the loads grow more sensitive to the power quality. Moreover, the deregulation of the electric power business will increase the significance of the power quality to both the utilities and the customers in the power system market [1].

Therefore, the measurement and diagnosis of the power quality is the most important issues to manage and improve the power quality. This paper based on the power quality management system that consists of several power quality monitors (PQM) and the power quality diagnosis system [2]. The PQMs are installed in the distribution lines for measuring of the line voltage and current. The determination of the location of the PQM installation in the distribution system is also a critical problem for accurate diagnosis of the power quality events [3]. The PQ diagnosis system gathers the measurement data from the PQMs through data communication. Then, it identifies the location and type of the PQ events. Reference [3] presented the topological locating method of PQ event source in the PQ diagnosis system.

This paper proposes a modified fault distance calculation method that can improve the accuracy of the fault location. The proposed method has two stages to determine the fault location. In the first stage, it locates the initial fault locating by solving the equivalent circuit equations. In the second stage, the iterative calculation improves the accuracy of the fault location. The algorithm of modified method is presented in Section II. Section III explains the simulation results of the proposed method in the IEEE 34 bus test feeder.

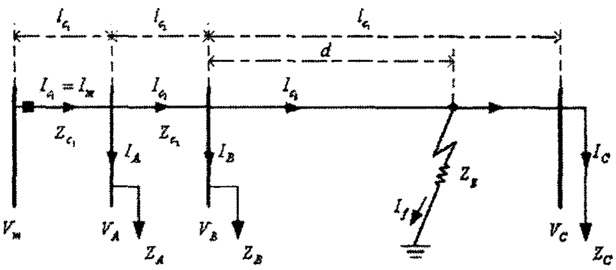
2. FAULT DISTANCE CALCULATION

2.1 INITIAL FAULT DISTANCE CALCULATION

If a line-to-ground fault occurs in the distribution feeders, the PQ supervisor needs to know the fault location to get rid of the cause. To find the exact fault location, the PQ management system collects the measurement data of the PQMs that are scattered in the distribution systems. First of all, the PQ diagnosis system finds the closest PQM position in the distribution system from the fault location by using the topological fault location method [3]. Then, the fault distance calculation method that is dealt with in this paper is needed for finding more accurate fault location.

Fig. 1 shows the equivalent circuit of the local distribution system under the PQM that is the closest to the fault position in case of a line-to-ground fault. The circuit of Fig. 1 is showed one-line diagram of three phase distribution feeder line.

In Fig. 1, V_m and I_m mean the voltages and the currents measured by the PQM that is the closest to the fault. $Z_{c_1}, Z_{c_2}, Z_{c_3}$ mean the line impedances and $l_{c_1}, l_{c_2}, l_{c_3}$ are corresponding distance between each buses. Z_A, Z_B, Z_C are the equivalent load impedances of each bus. d is the fault distance upon a fault occurrence with the fault impedance, Z_g.



<Fig. 1> Equivalent circuit to calculate fault distance

To find the initial fault location, let us suppose two facts as follows. First, we can assume that almost all the current flows directly through to the fault location during faults [1]. Then, the lateral currents such as I_A, I_B and I_C can be neglected. Therefore, the initial fault current I_f^0 is equal to I_m that is measured at the monitor. Second, the fault impedance Z_g is generally assumed as the resistive impedance R_g. Under these assumptions, the following equation can be obtained as (1).

$$\frac{V_m}{I_f^0} = Z_{c_1} + Z_{c_2} + dz_{c_3} + Z_g$$

$$\begin{aligned} \text{where, } \; & V_m = V_M(\cos\theta_v + j\sin\theta_v) \\ & I_m = I_M(\cos\theta_i + j\sin\theta_i) \\ & I_f^0 = I_m \\ & Z_{c_1} = l_{c_1} z_{c_1} = l_{c_1}(r_{c_1} + jx_{c_1}) = R_{c_1} + jX_{c_1} \\ & Z_{c_2} = l_{c_2} z_{c_2} = l_{c_2}(r_{c_2} + jx_{c_2}) = R_{c_2} + jX_{c_2} \\ & Z_{c_3} = l_{c_3} z_{c_3} = l_{c_3}(r_{c_3} + jx_{c_3}) = R_{c_3} + jX_{c_3} \\ & Z_g \approx R_g \end{aligned} \tag{1}$$

In the equation (1), z_{c_1}, z_{c_2} and z_{c_3} are the line impedance per unit length of each line impedance Z_{c_1}, Z_{c_2} and Z_{c_3}. By separating real and imaginary part of (1), the initial fault distance d^0 and the initial fault impedance R_g^0 can be obtained as the equation (4) and (5).

* Separating real & imaginary part :

$$\text{Real part : } \frac{V_M}{I_M}\cos(\theta_v - \theta_i) = R_{c_1} + R_{c_2} + d^0 r_{c_3} + R_g^0 \tag{2}$$

$$\text{Imag. part : } \frac{V_M}{I_M}\sin(\theta_v - \theta_i) = X_{c_1} + X_{c_2} + d^0 x_{c_3} \tag{3}$$

$$d^0 = \frac{V_M \sin(\theta_v - \theta_i)}{I_M x_{c_3}} - \frac{X_{c_1} + X_{c_2}}{x_{c_3}} \tag{4}$$

$$R_g^0 = \frac{V_M}{I_M}\cos(\theta_v - \theta_i) - R_{c_1} - R_{c_2} - d^0 r_{c_3} \tag{5}$$

2.2 ITERATIVE FAULT DISTANCE CALCULATION

The values of the initial fault distance and impedance that are obtained as (4) and (5) have so many errors that are due to our assumptions. By assumptions, the initial fault current is equal to all the current that is flowed through the monitor. To find the more exact solutions, the fault current needs to be updated by considering lateral currents-I_A, I_B and I_C-that are neglected to determine the initial fault current I_f^0. Therefore, the fault current I_f^n, where the superscript indicates the iteration number, can be updated by the current division of parallel circuit analysis as followed equations (6).

$$I_f^n = \frac{Y_g^{n-1}}{Y_A+Y_B+Y_C+Y_g^{n-1}} I_f^{n-1} \tag{6}$$

where, $I_f^n = I_{fM}^n(\cos\theta_{I_f^n} + j\sin\theta_{I_f^n})$

$I_f^0 = I_m, \quad n=1,2,3,\cdots$

$Y_g^{n-1} = 1/R_g^{n-1}$

Y_A, Y_B and Y_C are the admittance of each load. I_f^n that is obtained by equation (6), is the updated fault current of n iteration. I_{fM}^n and $\theta_{I_f^n}$ are the magnitude and phase of I_f^n. The n-th iterative equation can be got to rewrite the equation (1) using the updated fault current, I_f^n.

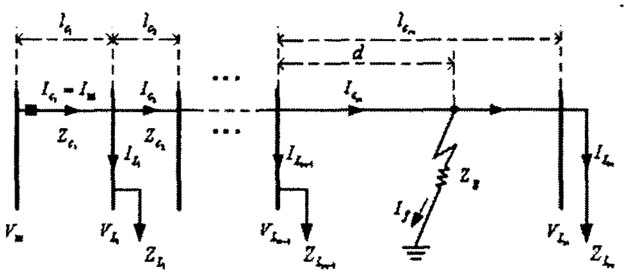
$$\frac{V_m}{I_f^n} = Z_{c_1} + Z_{c_2} + d^n z_{c_3} + Z_g \tag{7}$$

The n-th fault distance and impedance that is computed using separating real & imaginary part like section 2.1.

$$d^n = \frac{V_M \sin(\theta_v - \theta_{I_f^n})}{I_{fM}^n \cdot x_{c_3}} - \frac{X_{c_1}+X_{c_2}}{x_{c_3}} \tag{8}$$

$$R_g^n = \frac{V_M}{I_{fM}^n}\cos(\theta_v - \theta_{I_f^n}) - R_{c_1} - R_{c_2} - d^n r_{c_3} \tag{9}$$

These equation can be generalized to equation (10). Iteration stops when the changes in $\Delta d = d^n - d^{n-1}$ or $\Delta R_g = R_g^n - R_g^{n-1}$ becomes a very small value that is defined the mismatch.



<Fig. 2> Equivalent circuit of generalized distribution feeder

$$I_f^0 = I_m \tag{10}$$

$$d^n = \frac{V_M \sin(\theta_v - \theta_{I_f^n})}{I_{fM}^n \cdot x_{c_m}} - \frac{\sum_{k=1}^{m-1} X_{c_k}}{x_{c_m}}$$

$$R_g^n = \frac{V_M}{I_{fM}^n}\cos(\theta_v - \theta_{I_f^n}) - \sum_{k=1}^{m-1} R_{c_k} - d^n r_{c_3}$$

where,

$$Z_{c_k} = l_{c_k}(r_{c_k} + jx_{c_k}) = R_{c_k} + jX_{c_k}, \quad k=1,\cdots,m$$

$$I_f^n = \frac{1/R_g^{n-1}}{\sum_{k=1}^{m} 1/Z_{L_k} + 1/R_g^{n-1}} I_f^{n-1} = I_{fM}^n(\cos\theta_{I_f^n} + j\sin\theta_{I_f^n})$$

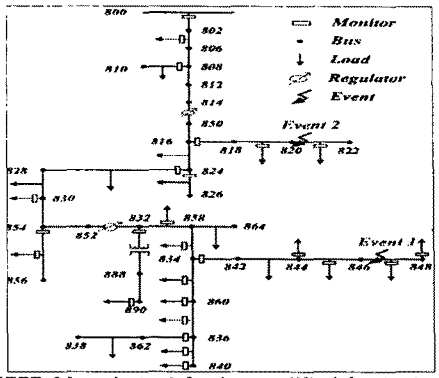
3. TEST SIMULATION

In this chapter, the algorithm of fault distance calculation is applied to the IEEE 34 node test feeder [4]. Fig. 3 shows the test system developed using PSCAD/EMTDC™.

2 events are assumed to happen in order to validate the fault distance calculation algorithm. The characteristics of each event are described in Table 1.

<Table 1> Event description

Event #.	Description	fault distance	fault resistance
1	3 line-to-ground fault at the between of Line 846 and 848	5,447 *ft.* from Line 834	15 Ω
2	1 line to ground fault at the Line 820	49,860 *ft.* from Line 816	10 Ω



<Fig. 3> IEEE 34 node test feeder modified for test simulation

Table 2 and 3 shows the results when the modified fault distance calculation is applied to the test system. The first step means the initial fault distance calculation and others mean the results of each iterative step when the mismatch, Δd is set as 0.1 ft

<Table 2> Estimated fault distance and impedance for event 1

Iteration #.	Event 1 (5,447 *ft*)					
	A		B		C	
	dist.(*ft*)	$R_g(\Omega)$	dist.(*ft*)	$R_g(\Omega)$	dist.(*ft*)	$R_g(\Omega)$
1	6,243.8	15.1	6,392.6	14.3	5,982.1	14.5
2	5.728.0	15.5	5,817.3	14.8	5,480.4	14.9
3	5,710.8	15.5	5,798.7	14.8	5,466.5	14.9
4	5,710.5	15.5	5,798.1	14.8	5,466.1	14.9

<Table 3> Estimated fault distance and impedance for event 2

Iteration #.	Event 2 (49,860 *ft*)	
	A	
	dist.(*ft*)	$R_g(\Omega)$
1	50,156	10
2	50,030	10
3	50,025	10

In case of Event 1, the error of phase B is 17.36% at first calculation. However the error becomes 6.45% after 4 iterations. Other cases are same that the errors are decreasing with increasing the iteration number.

4. CONCLUSION

This paper has presented a modified fault distance calculation method in power quality (PQ) monitoring system. The first stage consists of a fault distance calculation which searches through the information measured in PQ monitors to approximate the fault distances and impedances. Then the more exact fault distances and impedances are calculated by using iterative approach. This iterative approach makes the errors of the results of initial fault calculation to be smaller. The proposed algorithm can be applied to the diagnosis scheme of the PQ monitoring system, for determining the fault point and solving the problem upon a line-to-ground fault occurrence.

ACKNOWLEDGMENT

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