A Voltage Sag Source Locating Method with Multiple Screening Criterions Considering Voltage Measurement Errors

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***Abstract*—Voltage sag location is basis for voltage sag analysis and control. Based on the optimum allocation of voltage sag monitors, this paper proposes a voltage sag source locating method with multiple screening criterions considering the measurement error. Using the off-line database and collected monitor data, the fault located lines are screened out first, and then the fault located segment on the possible faulty lines is screened with Newton interpolation approach. At last, the fault is located via cost function. The simulation of IEEE39 bus model verifies the effectiveness and feasibility of the method. Considering the measurement error improves the accuracy of the locating result; progressively screening out the fault location improves the calculation efficiency and weakens the effect of the mistaken fault point.**

Keywords—voltage sag, fault location, measurement errors, screening method

I. INTRODUCTION

The voltage sag event is defined as the power quality problem when rms value of the AC voltage drops under 0.9 p.u and above 0.1 P.U lasting from 0.5 cycle to 1 minutes. Among the various cause of voltage sag, ine fault accounts for over 80% , and this kind voltage sag is easy to spread widely in power grid thus affect sensitive customers[1,2].

Accurate fault locating is the basis for analyzing, evaluating and regulating voltage sag. The research on voltage sag locating method mostly worked on judging whether the fault is on upstream or downstream of the monitoring device [3-4]. The existing methods for accurate fault locating cannot avoid iterating all the lines in network [5-6]. Thus the lack of effective screening approach leads to a large calculation burden. Moreover, existing methods seldom considers measurement error, which may leads to false results [7-8].

To solve the problem of large calculation burden and inaccurate result of the existing methods, the method proposed in this paper based on the optimum monitor allocation, considering the measurement error of the monitor device, gradually screen out the possible fault location, thus the efficiency is higher and the accuracy of the results is improved.

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II. PROCESS OF THE LOCATION METHOD

The procedure of the proposed fault locating method is as follows:

1) Determine the optimum monitor allocation. The goal of optimum allocation is that voltage sag happened anywhere in the grid could be observed and the number of monitor points is minimum .On the basis of traditional MRA method, the binary gravitational search algorithm (BGSA) is used to solve the problem [9]. Based on the Mamdani fuzzy inference model, the optimum allocation is finally obtained.

2) Establish an off-line database for each monitor. In the off-line state, assume faults happened at each node in the grid, and the corresponding voltage sags monitored by monitor devices are calculated through fault analysis theory, and the obtained three-phase voltage information of the monitors is recorded in the database.

3) According to the monitored three-phase voltage information, the lowest phase voltage among the three phases is extracted at each monitoring point, because the phase with the lowest voltage amplitude can best reflect the influence of the sag location. So if using the lowest phase voltage to solve the fault location, the result is more accurate.

4) Screen out possible fault located lines. For the minimum voltage amplitude at each monitoring point, a ±5% measurement error is considered, so the monitored data becomes an interval $\left[95\%V_m\ 105\%V_m\right]$. For the line i-j, when the monitored interval intersects with $\left[V_{c\_i}\ V_{c\_j}\right]$, is the voltage sag at the monitor point when fault is at node i and is the voltage sag at the monitor point when fault is at node j. That is to say when $\left[95\%V_m\ 105\%V_m\right]\cap\left[V_{c\_i}\ V_{c\_j}\right]\neq\varnothing$ is satisfied, the line is a possible fault located line.

5) Screen possible faulty sections on the extracted possible fault located lines. On each possible fault located line, the voltage at the monitoring point is calculated by assuming virtual fault points with a certain step along the line, and a fault distance function is derived based on these virtual fault points. Finally, according to the actual monitored voltage sag amplitude interval $\left[95\%V_m\ 105\%V_m\right]$

the fault distance is calculated and the possible fault segments are ordered.

III. SCREENIGN POSSIBLE FAULT LOCATED LINES

A. Principle of the approach

As shown in Fig. 1, the fault occurs at p percent of line i-j (0≤p≤100%), and the fault point is denoted as f. Then, the impedance from the monitoring point m to the fault point can be obtained $Z_{mf} = Z_{mi} + \left(Z_{mj} - Z_{mi}\right) p$, where Z_{mi} and Z_{mj} is the impedance from the monitoring point m to the line point i and j. Z_{mf} can be interpreted as $\Delta V_m = Z_{mf} \cdot I_{fault}$ From the above relationship, $Z_{mf} \in \left[Z_{mi}, Z_{mj}\right]$ can be obtained, so under the assumption that the fault current is the same, $V_m \in \left[V_{mi}, V_{mj}\right]$ can be obtained, wh*ere* V_m is the *actual* monitored voltage sag amplitude, and V_{mi} , V_{mj} is the theoretical voltage at the monitoring point when the fault occurs at line end point i and end point j. That is to say, if the fault point is located on line i-j, then the monitored voltage drop value is between the theoretical values of the voltage sag at monitor point caused by the fault at both ends of the line.

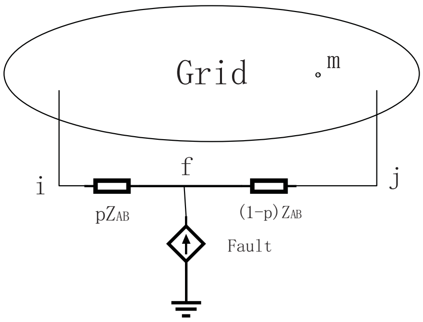


Fig. 1 Fault on line i-j

B. Process of the approach

Based on the monitor allocation scheme, the voltage data of each monitor is used to screen possible faulty lines. Procedure for screening possible faulty lines is shown in Fig. 2. Steps for screening possible faulty lines are as follows:

1. Consider the measurement error of ±5% to V_m and form voltage interval $[95\%V_m \ 105\%V_m]$.

2. For every node in the grid, suppose there is a fault, and calculate the voltage sag at monitor point according to the node impedance matrix. Then compare the calculated voltage to the monitored data. For example, the voltage sag at monitor point caused by fault at node i and node j are denoted as V_{c_i} and V_{c_j} , if it satisfies $[95\%V_m \ 105\%V_m] \cap [V_{c\_i} \ V_{c\_j}] \neq \varnothing$, line i-j is extracted into the possible faulty line set. After examining all the lines, a set of possible faulty line set for the monitoring point n was build.

3. Further narrow this set down according to the data at the n+1th monitor by doing the same steps. 4. Until the screening procedure by data at the last monitor, the final set is decided.

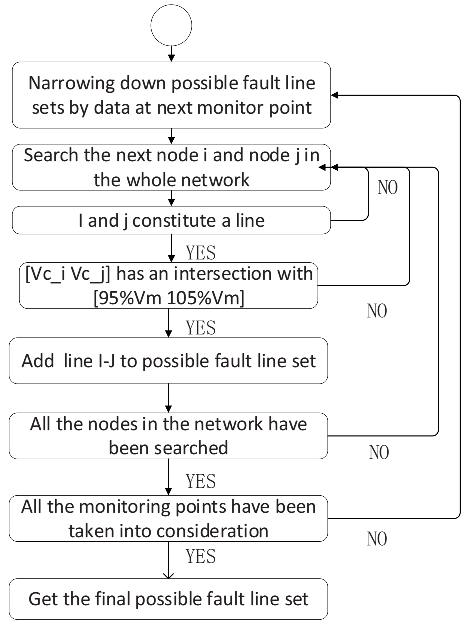


Fig. 2 Screening process for possible fault lines

The screening method firstly reduces the computational burden, because when performing line screening procedure via the monitoring information at the (n+1)th monitor point, it is not necessary examining all the lines in the grid, but only possible faulty lines that have been extracted via data at the nth monitoring point. Secondly, this method considers the measurement error and optimizes the monitored voltage amplitude data as the voltage amplitude interval. Thus, the screening results of this method are more accurate, the actual fault located line will not be excluded due to the existence of monitoring errors, and the extracted faulty lines for different monitors will not conflict with each other.

IV. SCREENING POSSIBLE FAULT LOCATED SEGMENT

As shown in Fig. 1, suppose a fault occurring at f on the line i-j. The distance from f to the endpoint i is p (0≤p≤100%) and the distance to the endpoint j is 1-p. The voltage sag amplitude at the monitoring point is a function of the distance p, denoted as $V_m = F(p)$. Therefore, by setting virtual fault points on the extracted possible faulty lines, and using the corresponding monitoring voltages, it is possible to fitting the function F, and then finding the fault position with the actual monitored voltage.

This paper uses Newton interpolation method to directly solve the fault location. As shown in Fig. 3, take n+1 points (including two endpoints) with even steps on the line i-j, and set the faults at n+1 points respectively. Record the distance from each point to i as $[y_0, y_1, \cdots, y_n]$, and calculate the corresponding n+1 voltage sag amplitudes at the monitoring points according to the network topology, denoted as $[x_0, x_1, \cdots, x_n]$. The actual monitored voltage sag amplitude V_m is recorded as x. According to the definition of Newton interpolation, the function f(x) is defined on [a b], here a=0 and b=1. For n nodes (x_i, y_i), $f(x_i) = y_i$. is satisfied. Then for x∈[a b], the corresponding y can be obtained, here y is the distance of the real fault point from the endpoint i. Considering the monitor measurement error, the amplitude of the monitored voltage sag is a vector $x=[95\%V_m, \ldots, 105\%V_m]$, so the y solved by the Newton interpolation method is also a vector, which is the extracted faulty segment. The monitor information at each monitor point is processed as above, and the intersection of the obtained segments is the fault segment finally selected.

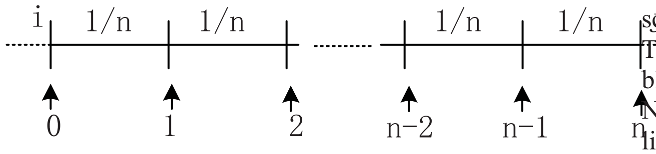


Fig. 3 Set virtual fault points on line i-j

Screening fault segments by Newton interpolation does not require the construction of a function model, thus eliminating errors that may result from improper model. At the same time, compared to solving the fault location using function-fitting methods, the process is simpler, because it does not require solving the coefficients of the function, instead it directly performs the interpolation calculation. Moreover, because the method considers the monitoring error, the section on the line is screened instead of the specific fault point, thus avoiding dismissing the correct position, and the result is more comprehensive and accurate.

V. SIMULATION ANALYSIS

Verification of the proposed fault locating method is performed via the IEEE 39-bus model. IEEE 39-bus system model is shown in Fig. 4. The system includes 10 power supplies, 12 transformers and 39 buses. After optimum monitor allocation, four monitor points are placed in the system at nodes 15, 17, 25, and 30 respectively. A single-phase line to ground fault is set at 78% on the bus linked node 3 and node 2. The voltage amplitudes of the deepest sag phase for four monitoring points are: monitor at node 15: 0.10098pu; monitor at node 17: 0.08843pu; monitor at node 25: 0.05539pu; monitor at node 30: 0.06559pu. Considering 5% monitor error, monitor data from 4 monitor points produces 4 monitor intervals. An off-line database is established for the four monitor points. The database includes the deepest sag phase voltage at the four monitor points when single-phase line to ground faults are successively set at each node in the grid and the data size is 39*4=156.

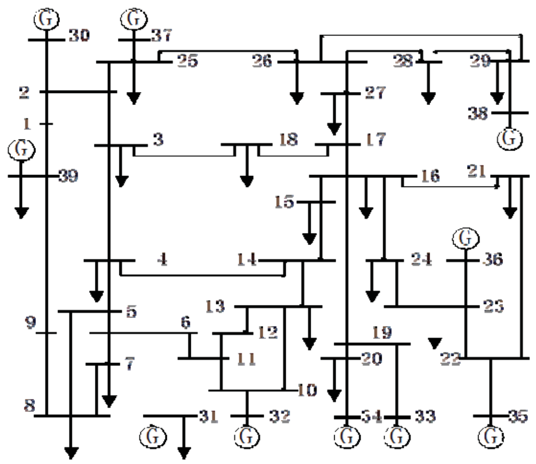
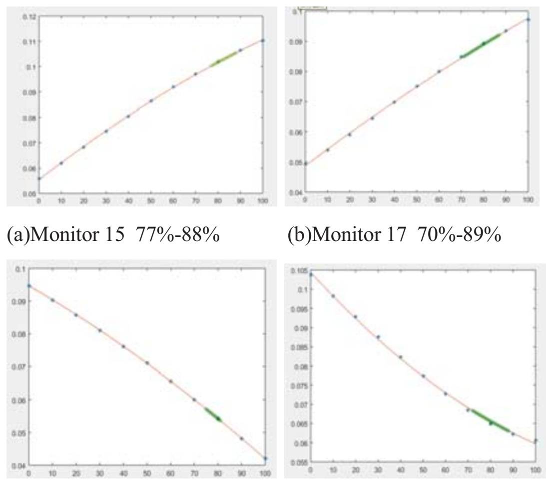


Fig. 4 IEEE 39 Buses Model

After the line-screening approach, bus 3-2 is selected as the possible faulty line. Afterwards, the fault segment screening approach has been executed. 10 nodes are set on the line to separate bus 3-2, and at each node, a single phase line to ground fault is set. The result of the screening is shown in Fig. 5 by distance as X-axis, and the voltage sag amplitude as Y-axis. (a)(b)(c)(d) indicates respectively the screening results via the information of four monitor points. The voltage sag triggered by virtual fault points is shown as blue circles. The red line represents the interpolation of the Newton interpolation method over the entire line. The green line indicates the result of the screening. According to the sag information at the monitoring point 15, 77%-88% of the line is screened as possible faulty segment. According to the sag information at the monitoring point 17, 70%-89% of the line is screened as the fault zone. According to the sag information at the monitoring point 25, 73%-81% of the line is screened as possible faulty segment. According to the sag information at the monitoring point 30, 71%-88% of the line is selected. The four fault segments are intersected, and the final selected fault segment is 77%-81% of the line. This segment contains the actual fault location and thus verifies the effectiveness of the screening algorithm.



(a)Monitor 15 77%-88% (b)Monitor 17 70%-89%

(c)Monitor 25 73%-81% (d) Monitor 30 71%-88%

Fig. 5 simulation result of possible fault section

In order to get precise fault location, cost function could be used to rank the possible fault locations on the segment. $J(p,z_f)=(\boldsymbol{V}_m-\boldsymbol{V}(p,z_f))^T(\boldsymbol{V}_m-\boldsymbol{V}(p,z_f))$ is taken as cost function, where $\boldsymbol{V}_m$ is the actual monitored data, and $\boldsymbol{V}(p,z_f)$ is the calculated voltage which depends on the distance p and fault resistance z_f. The result is shown in Fig.6. The minimum value of cost function is shown at 79.75% of the bus 3-2. The error is only 1.75%.

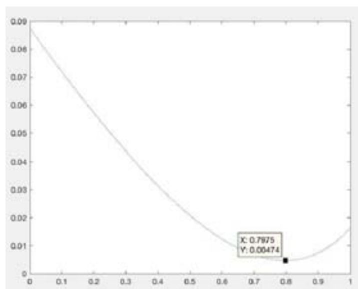


Fig. 6 simulation result of cost function

VI. CONCLUSION

1) This paper proposes a fault locating method with multiple screening criterions, which could significantly improve the calculation efficiency. When the grid has a large number of buses and monitors, the high calculation efficiency effect is more significant.

2) This paper considers the existence of voltage measurement error of the monitor device. The locating results are more comprehensive, convincing and accurate.

3) The fault segment screening method shown in this paper adopts Newton interpolation method. It does not need to determine the form of the function either the coefficient of the function. Compared with the traditional function fitting method, the calculation is more simplified and the result is more accurate.

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