Original Article: Fault Locating in Distributed Generation Network Based on the Use of Phasor Measurement Unit in Oil and Gas Industry

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ABSTRACT

Power system protection is a major and essential element in exploiting the power system. Generally, two approaches for security system can be represented, which are identification and separation of the fault from the system and the fault location in order to solve the problem. The distribution system as a subset of power system requires protection measures. Today, with the expanding utilization of the distributed generation in the distribution system, its structure has been changed. The existence of distributed generation, which is called DGs, poses a major challenge to the protection coordination system and fault location in the distribution system. In this paper, a new method was provided for fault location in the distribution system with the distributed generation. The proposed method used the data obtained from the phasor measurement units, which were installed in the distributed generation terminal, to determine the fault location rate and then determine the exact fault location using substitution theorem. The suggested method was tested on a distribution system sample; the simulation results of which indicated its proper functioning. In order to simulate the understudied system, digsilent, a powerful software, was used and the fault location program was written in the form of MATLAB software.

Introduction

Wide area measurement systems that are equipped with PMUs, are used to detect the fault in the power systems. High speed and accuracy of the PMUs and the simultaneous ability of the phasor from the high-voltage substations lead to their superiority over SCADA. In the first step, input signals to the PMU are passed through an Anti-Aliasing Analog Filter. In the second step, analog output signals are sampled from the anti-aliasing filter. New PMUs possess the rate graph. In the third step, decaying DC offset from the signals is removed using the digital mimic circuit. In the final step, the main component and the phase component of the input signals are extracted using Discrete Fourier Transformation [1-7].

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One of the most important problems in distribution systems is the long-term power failure. Providing solutions to reduce their time is essential. The method used to resolve faults in distribution companies is a shortcut method that is based on trial and error method. In this method, according to the information that the subscribers provide to the accident center, the operators in term of feeder arrangement and the protection plan of that area, identify the fault and then by performing sequential maneuvers in that area of the system try to identify the fault location and isolate the fault. Due to long-term power failure, in order to determine the fault distance in the conventional way, the resulting losses are imposed on both consumers and distribution companies [8]. Given the increased cost of transmission and distribution, the interest and essential investment in renewable energy technologies, which is the need of distribution companies to access these resources, and the development of the attached Microgrids to the main distribution feeder, the rapid growth of the DG connection to the main distribution feeders is provided. Distribution systems will be dependent on DGs in the near future not only to improve the peak traffic but also to provide continuous supply. Moreover, their influence is likely to be voluntarily, and the network may not have sufficient control over the number and the location of DGs. The presence of the distributed generation disrupts the coordination of relay protection and results in difficulty of the fault location [9].

In the present study, the proposed method for fault location in a distribution system with distributed generation is presented in details and finally a supplementary method is suggested to reduce the computational processes and improve the performance of the method. In the applied method, it is assumed that phasor measurement units are installed in the generators' terminal and the information regarding the current and voltage of a three-phase generator is measured simultaneously. In addition, the loads in the network are considered as the constant current loads. With this assumption, loads on the impedance matrix of the network would not be entered.

Phasor measurement units

Smart grids are a new concept in the 21st century that aims to apply modern telecommunications and computer technologies in the electricity industry [10-11]. The main focus in this concept is on the distribution system and the end consumer: advanced measurement in the distribution system, two-way communication between the consumer and the electricity company, increasing the penetration of distributed generation in the distribution system, micro-grids, etc. It has been considered in smart networks [12]. Meanwhile, less attention has been paid to the intelligent transmission network. Concepts such as adaptive relay [13] and self-healing networks [14] and [15] are among the few that have been proposed in this regard. The purpose of a self-healing network is to automatically detect errors and intelligently rearrange the network to minimize damage to the network. Island dynamics in emergencies, design of intelligent special protection plans, and use of global measurements to stabilize the system are some of the applications for intelligent transmission networks that require intelligent fault detection.

In this section, first, how the phasor measurement devices work as the cornerstone of the global measuring system is discussed. Then, examples of the use of these devices in network accident detection are discussed. Detection of transmission line exit from the network, detection of output/load exit from the system, and detection of low-frequency fluctuations in the system are examples of the application of the global measurement system in the detection and detection of accidents. Attempts have also been made to detect errors using phasor measurement units using a global measurement system. In this paper, new methods for error location in the distribution network using phasor measurements are presented. This new method uses the voltages and currents measured by the PMUs installed in the source terminal to determine the source, area, line, and location of the fault. Therefore, due to the use of this algorithm from the data measured by the modeling PMUs of the phasor measurement device, it is necessary and in this article, PMU modeling is discussed.

Many substations today are equipped with intelligent electronic tools that can collect large amounts of data and process them to take the necessary steps. These intelligent electronic devices include digital protection relay, digital fault recorder, breaker monitor, power quality monitor, remote terminal unit, and phasor measurement unit.

The simultaneous phasor system, which is very suitable for the realization of the global measurement system, includes many phasor measurement devices that are installed in the substations, one phasor data concentrator in each substation, and one phasor data concentrator in the control center. The task of the CCPDC will be to distribute data for various applications, including displaying system status, recording system status history, and control and protection applications. Also, network accident autopsy is another application of this system so that the network operator can reproduce the captured data and analyze the data.

The phasor measurement device can be any device that has the ability to produce simultaneous phasors by the IEEE C37.118-2005 standard. These devices can include phasor measurement units. Digital fault recorders and traditional relays capable of such simultaneous measurement are also included in phasor measurement devices [16] and [17].

PDC is used to collect simultaneous phasors, phasor measurement devices and data processing to send to the control center. Usually, a PDC is installed in each post to send the phased data from the PMUs simultaneously to the control center in the form of a data packet. Without PDC, the control center would have to manage many PMUs across the network. PDCs can also process data for a specific post at the post level [18]. Traditionally, RTUs have been tasked with collecting data in the telecommunications system and collecting data, which is the most important infrastructure for monitoring and operating the power system. The data collected through SCADA is called exploitation data because it is constantly circulating. On the other hand, data from other intelligent electronic devices, such as DPRs and DFRs, which collect data only when there is a disturbance in the system, is called non-exploitable data. This non-exploitable data plays an important role in error analysis and alarm processing. In [19] it is stated that the oscillator device records the waveform and other information (date and time) if its amplitude is different from the nominal value.

A phasor measurement unit is any device that uses digital signal processors to measure alternating current, voltage, and current waves at a power frequency (50 or 60 Hz). AC analog waveforms are digitized by analog-to-digital converters in each phase, providing a phase-lock oscillator and a high-speed simultaneous sampling GPS reference. This function is not necessarily the sole function of a device, for example, many digital relays function as PMUs, but their main function is to act as a relay rather than a PMU.

Voltage and current phases collected at very fast rates of up to 120 phases per second [20] by PMUs have not yet been fully utilized and many of their potentials remain unknown. In this study, the application of a global measurement system equipped with PMUs in error detection in power systems is investigated. The very high speed and accuracy of PMUs and the ability to simultaneously collect phasors from high pressure substations make it superior to SCADA. Specifically in the field of power system error detection, the two advantages of the extensive measurement system over the SCADA are:

1- Accuracy of PMU measurements, which makes it possible to measure and record changes in quantities with a frequency of 50 Hz with very high accuracy. This feature of the extensive measurement system with PMUs provides new information that differs from the traditional SCADA system, which measures only steady-state values.

2- Using a synchronizing signal using GPS makes it possible to have simultaneous phased displays (with an error of less than one microsecond) in addition to the size of voltage and current quantities in different parts of the system [21].

Measurement, protection, and control systems based on digital computers have become common in power posts. These systems use sampled data to calculate various quantities such as current and voltage phases. Phasors are used in many protection and data collection applications and using a common time reference we can display all of these quantities across the power system in phases. This is done by synchronizing signal processing at different network locations. Figure (1) shows an example of a phasor measuring device in a substation. Simultaneously measured sets obtained from simultaneous phases provide a platform for tracking the dynamics of phenomena in the power system to improve the control, operation, protection, and monitoring of the power system.

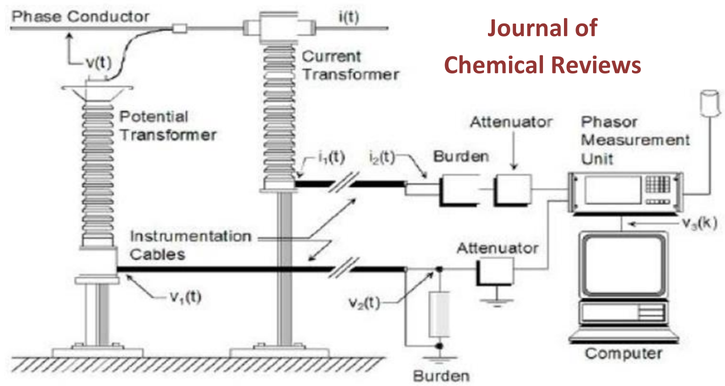

Figure 1. Phasor measurement unit

Simulation of the Understudies System

In this paper, the simulation results of the applied method in [9] and the proposed method were evaluated. The digsilent software was used to simulate the distribution system and the simulation results were used by the program written in MATLAB to locate the fault. The method explained in [9] is called FLDA (Fault Location Detection Algorithm) and its modified suggested method is called MFLDA (Modified Fault Location Detection Algorithm). In order to evaluate the proposed method, the selected system must have an enough number of buses and branches [22-25]. For this aim, a 20-bus distribution system was applied [26]. Then for increasing the size of the system, two new branches, which totally had 18 buses, were added. Figure (2) shows a single line-diagram of the network that was simulated in digsilent software.

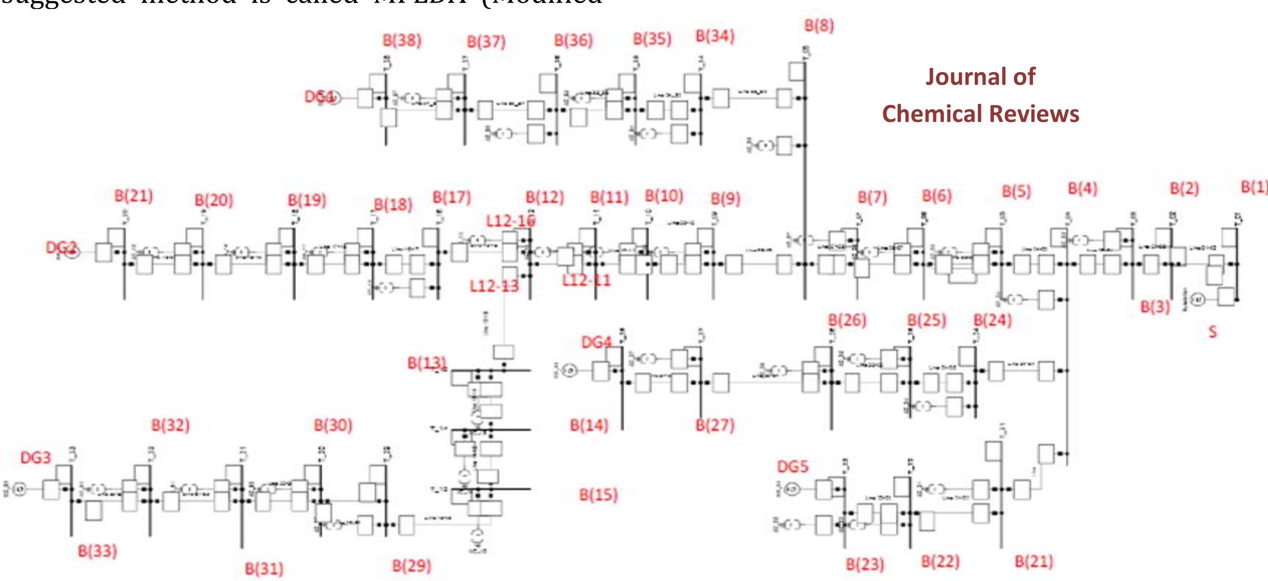

Figure 2. The simulated distribution system in digsilent software

This network was consisted of 5 DGs and a synchronous generator was used to model the upstream network. The system loads were modeled as the constant current and the generator-bus voltage and the current were continuously recorded. In addition, it was assumed that a phasor measurement unit was installed on B (12) which recorded B (12) voltage and L12-11, L12-16, and L12-13 currents continuously. So, the network is divided into three main areas:

$Area_1$ = {12, 16, 17, 18, 19, 20}
$Area_2$ = {13, 14, 15, 29, 30, 32, 32, 33}
$Area_3$ = {1,2,3,4,5,6,7,8,9,10,11,21,22,23,24,25,26,27,28,34,35,36,37,38}

The data of the studied network lines is presented in Table (1). The purpose of simulation in digsilent is obtaining the voltage and current measurements during the fault.

Table 1. The Number of Lines of the Studied Network

Line	from	To	Line	from	to
1	1	2	20	30	**31**
2	2	3	21	21	**22**
3	3	4	22	22	**23**
4	4	5	23	16	**17**
5	4	24	24	17	**18**
6	5	6	25	18	**19**
7	6	7	26	19	**20**
8	7	8	27	34	**35**
9	8	9	28	35	**36**
10	8	34	29	36	**37**
11	9	10	30	37	**38**
12	10	11	31	4	**21**
13	11	12	32	24	**25**
14	12	13	33	25	**26**
15	12	16	34	26	**27**
16	13	14	35	27	**28**
17	14	15	36	31	**32**
18	15	29	37	32	**33**
19	29	30			

Results of the Fault Location by MFLDA Method

In this section, in order to evaluate the performance of the proposed MFLDA method in fault location, several lines were selected and different faults with different resistance were placed on them, then the accuracy of the MFLDA method was evaluated. Note that, the amount of

X for dividing the line was 100 and the sampling frequency for phasor measurement units was considered 5 KHz. It should be mentioned that it was assumed that a short circuit accrued in t=1 and was cleared after 5 cycles.

Short circuit on line 23 at 50% point

As the first case, line 23 was selected and a short circuit single phase-to-ground with a resistance of about 10 ohms in the middle of the line was considered. The measured current by installed measurement unit in DG2 terminal with the output current from mimic filter is shown in figure (3). According to this figure, during the short circuit, the current increased suddenly and the output current of mimic filter did not have a DC component [27-29].

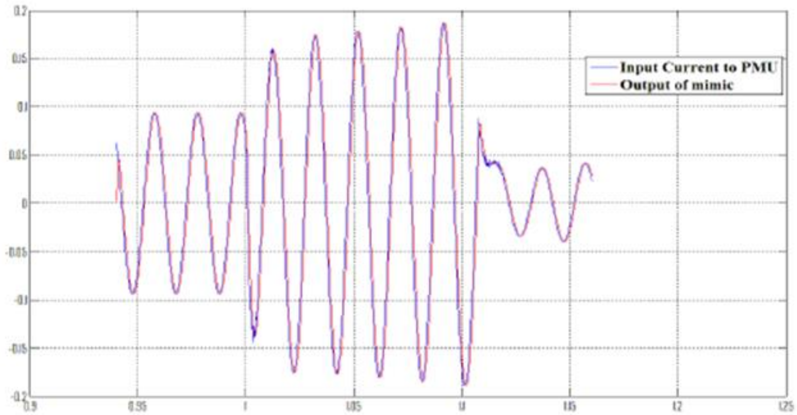

Figure 3. Measured current at the terminal DG2

By implementing the fault location algorithm, in the first step, Area1 was determined as the fault area from the fault current direction and Thevenin model was obtained for the non fault area. By calculating the fault index, the amount of the fault index for B (16) and B (17) was obtained to be 0.562 and 0.573, respectively that are both minimum values. Therefore, to determine the exact location of the fault, the line between these buses was evaluated. Figure (4) shows the amount of the fault index in the different line points. According to this graph, the minimum value of the fault index occurred exactly in the middle of the line; therefore, MFLDA determined the middle of the line as the fault point and the fault locating was minimal.

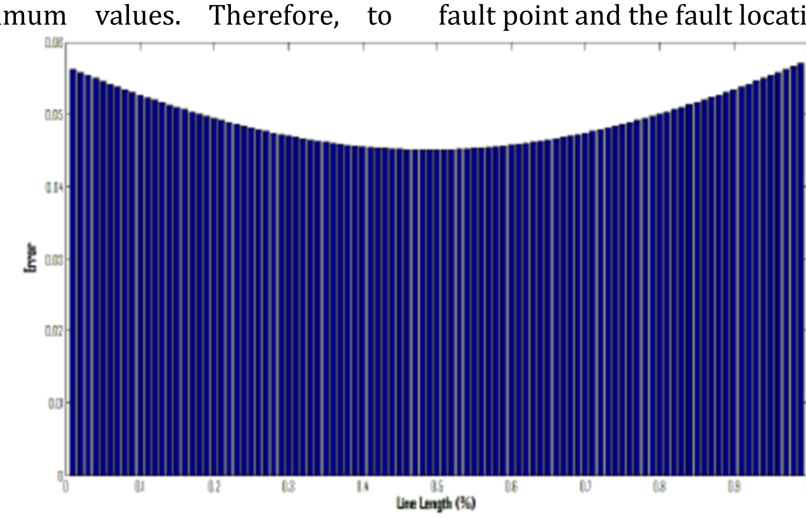

Figure 4. Fault index on the line 23

Short circuit on line 33 and at the 70% point from B (25)

In this section, it was assumed that a two-phase short circuit with 5 ohms of resistance occurred at 70% of the line 33. By implementing the MFLDA algorithm, and applying fault current direction on B (12), the third area was determined as the fault location area. By calculating the fault index on the buses of this area, the amount of the fault index for B(25) and B (26) were obtained to be 0.2125 and 0.1445, respectively that both are minimum values. Therefore, the fault location was on the line between these buses. Fault index on line 33 is shown in Figure (4). Considering the following figure, the value of the line index on line 33 was minimized at 30% distance of the B (26) (i.e., at 70% distance from the B (25)), therefore, the fault locating was minimal [30-35].

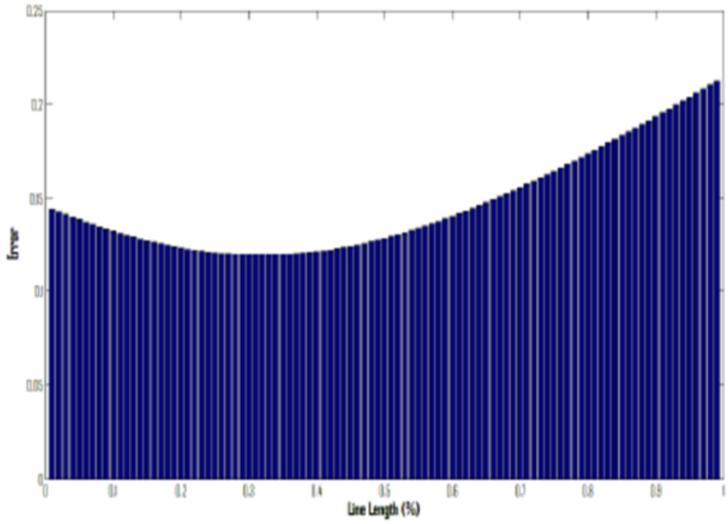

Figure 5. Fault location on line 23

Short circuit on line 20 at 60% point from the B (30)

In this section, it was assumed that a three-phase short-circuit with a zero-fault resistance at 60% of line from the B (30) occurred. By implementing the MFLDA algorithm and using the fault current direction in B (12), Area2 was defined as the fault area. By measuring the bus faults on the buses of the Area2, B (30) and B (31) having 0.1521 and 0.1262 index fault, respectively, were determined as buses in which the fault was occurred on the line between them. By evaluating the fault index on line 20, the index value at 42% from the B (31) (i.e., at 58% point from the B (30)) was minimal, as shown in Figure (6). Therefore, fault locating was performed on Line 20 with 2% error [36-39].

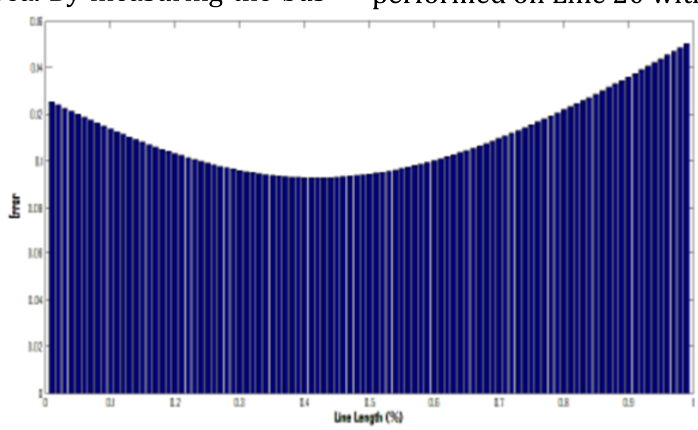

Figure 6. Fault index on line 20

Short circuit on line 5 at 5% point from the B (4)

In this section, it was assumed that a two-phase short circuit with 5 ohms resistance at 5% distance from B (4) occurred. By implementing the MFLDA algorithm and using fault current direction, Area3 was determined as the fault area [40-43]. By calculating the fault index on these areas of the buses, B (3) and B (4) were selected as the fault indexes having the value of 0.218 and 0.096, respectively. By calculating the fault index on the line between B (3) and B (4), i.e., B (3), it was observed that the minimal value of the index was 0.096 and was located on B (4), as shown in Figure (7). The next bus, which has fewer faults than other buses, is the B (24) with the fault index 0.224 [44-46]. Thus, it should be mentioned that the fault index value was checked between B (4) and B (24), i.e., line 5. The fault index value on line 5 was shown in Figure (8) and as it was observed, the fault index value at 4%-point line 5 from the B (4) was minimal and fault location was estimated at 4% of the length of the line. The fault index value at this point of the line was 0.094 and consequently fault locating was performed with a 1% error that is acceptable [47-50].

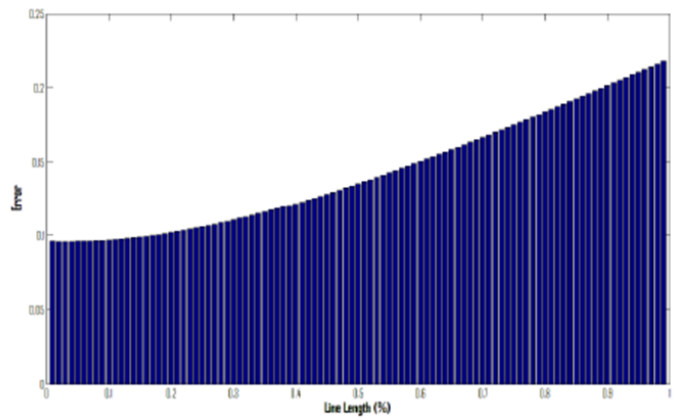

Figure 7. Fault index on Line 3

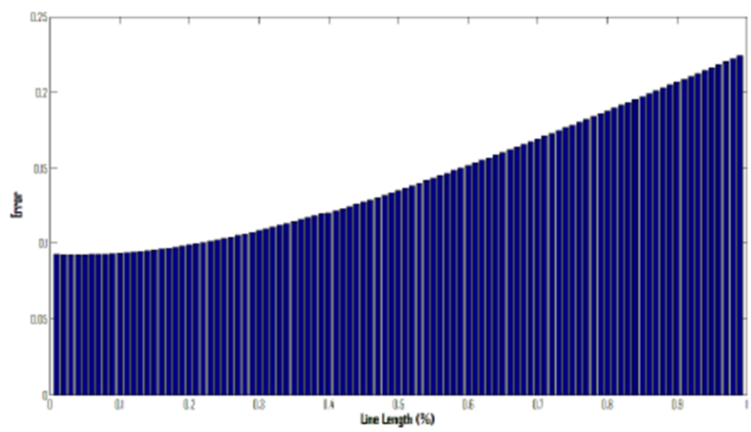

Figure 8. Fault index on line 5

Comparing the Results of FLDA and MFLDA Methods

In this section, the accuracy and speed of the fault location were compared using FLDA and MFLDA methods. To compare the speed of the computation, a Core i7 CPU with a frequency of 2.3 GHz and 4 GB of Ram was used. The results of the comparison of these methods for different lines are presented in table (2). In this table, “3ph” represents a three-phase fault, “LG” is a single phase-to-ground-fault, and “LL” indicates a two-phase fault [51-55].

Table 2. “3ph” represents a three-phase fault, “LG” is a single phase-to-ground-fault, and “LL” indicates a two-phase fault.

Line N.	Line Type	Fault Resistance (ohm)	Fault Distance (%)	FLDA		MFLDA	
				Fault (%)	Time (second)	Fault (%)	**Time (second)**
1	3ph	0	50	0	6.5	0	**5.8**
2	LL	5	30	1	6.6	2	**5.8**
3	LG	10	40	0	6.4	1	**5.6**
4	3ph	0	80	1	6.7	1	**5.7**
5	LL	5	5	1	6.9	2	**6.2**
6	LG	10	75	0	6.5	0	**5.6**
7	3ph	0	50	0	6.5	1	**5.7**
8	LL	5	85	2	6.7	2	**5.6**
9	LG	10	65	2	6.9	2	**5.9**
10	3ph	0	50	1	6.6	1	**5.8**
11	LL	5	20	0	6.4	0	**5.5**
12	LG	10	10	0	6.4	0	**5.6**
13	3ph	0	40	1	6.5	1	**5.7**
14	LL	5	10	1	6.7	2	**3.2**
15	LG	10	10	1	6.6	2	**2.9**
16	3ph	0	50	0	6.5	1	**3**
17	LL	5	70	1	6.4	1	**3.1**
18	LG	10	25	0	6.6	0	**3.1**
19	LG	10	30	0	6.7	0	**3.1**
20	3ph	0	60	1	6.6	2	**3.1**
21	LL	5	20	1	6.4	1	**5.8**
22	LG	10	70	1	6.5	2	**5.7**
23	LG	10	50	0	6.6	0	**2.8**
24	3ph	0	90	0	6.8	0	**2.9**
25	LL	5	40	0	6.5	1	**2.8**
26	LG	10	10	0	6.6	0	**2.7**

27	3ph	0	50	1	6.5	2	**5.8**
28	LL	5	80	0	6.6	1	**5.7**
29	LG	10	5	0	6.5	0	**5.8**
30	3ph	0	50	0	6.5	0	**5.7**
31	LL	5	95	1	6.8	2	**5.9**
32	LG	10	5	1	6.6	1	**5.6**
33	LL	5	70	0	6.7	0	**5.8**
34	3ph	0	50	0	6.6	0	**5.7**
35	LL	5	80	0	6.5	0	**5.7**
36	LG	10	60	0	6.7	0	**3.2**
37	LL	5	10	0	6.5	0	**3.1**

According to the results of Table (2), it was observed that the accuracy of the FLDA was slightly higher than MFLDA in some cases [56-60]. This is due to the application of the Thevenin model for the non-fault area in MFLDA method. This will be more tangible if the fault occurs in the area 1 or 2, because the speed of the MFLDA method will be more than double. The reason for the different speed in area 1 and 2 is that the number of the located buses in these areas is much lower than in area 3 [61-34].

Results

In this paper, a new method for fault location in a distribution system with distributed generation was presented based on using phasor measurements and improvement of the method. Fault location was tested on the three distribution systems with distributed generation by the proposed method and then the results of the fault location were compared with the obtained results in [65-67]. The comparison of the results indicated a higher speed of the proposed method, which was due to the reduction of the buses that the fault index must be investigated on them [68]. Moreover, it was due to applying Thevenin method for the non-fault area and simplification of the calculation of the impedance matrix of the network. However, fault location accuracy was slightly reduced.

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