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Analysis of Faults in Power Distribution Systems With Distributed Generation

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Abstract. The paper studies the location of single-phase faults abstract in power distribution systems with distributed generation by means of impedance-based methods. These methods are based on the measurement of voltages and currents and in one measurement point and distributed generation cause errors in the estimated location.

The paper shows the influence of parameters such as the magnitude of distributed generation, the fault impedance and the relative position of the fault location and the distributed generation in the estimated location.

Key words

Power Quality Monitoring, Fault Location, Power Distribution, Distributed Generation.

1. Introduction

Today worldwide distributed generation (DG) takes a very important role in the operation of distribution electric power systems [1]. However, the existence of distributed generation may have impacts on different topics such as fault protection, coordination schemes or fault location [2-5].

If there is a short-circuit in the system, the presence of one or more distributed generators can affect the monitoring of voltages and currents at the substation. The main supply generation will not have to inject as much power to the line because of the DG and, therefore, voltages and currents at the substation will be different from the ones that would be measured without DG. This fact may have consequences if these magnitudes that are used to locate where the fault has occurred (Fig. 1 and 2).

In this paper, the behaviour of the most significant parameters in power distribution systems, such as voltages, currents and apparent impedances at the substations, is studied depending on the values of fault resistance, the power supplied by DG and the relative location of DG and the fault. Different analysis are performed by varying the locations of the DG and the fault, in order to analyze the influence of DG together with the position where the fault has occurred

In addition, the sensitivity of impedance-based fault location methods, such as the presented in [6], is analysed taking into account the effect of DG.

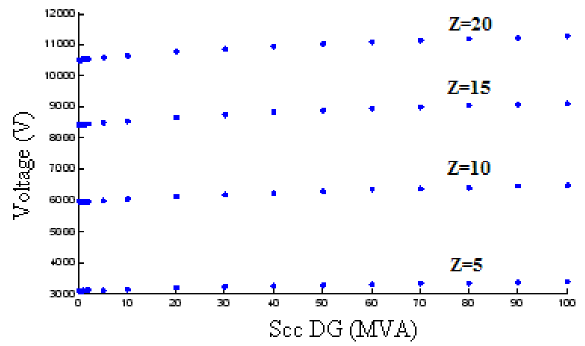

Fig. 1. Voltage variation depending on the value of DG and fault resistance (in ohms), measured at substation.

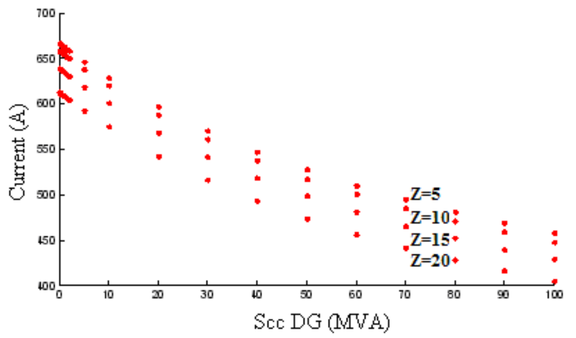

Fig. 2. Current variation depending on the value of DG and fault resistance (in ohms), measured at substation.

2. Simulation Model

It has been developed an application in Matlab/Simulink that can obtain the electrical and topological data from a database, and that allows to simulate faults in those lines. The application is based on [7] and allows to modify all the parameters, such as the type of fault, the fault resistance, the location of the fault, and the location and parameters of DG buses.

Nominal voltage of distribution systems is 25 kV, and the secondary of the transformer is grounded by an equivalent reactance of 25 ohms. Voltages and currents at the secondary of the substation are monitored. The model for each section of line will be a RL circuit and finally MT and BT consumptions are included. Figure 3 shows an example of an automatically generated line using the application with data from a real line.

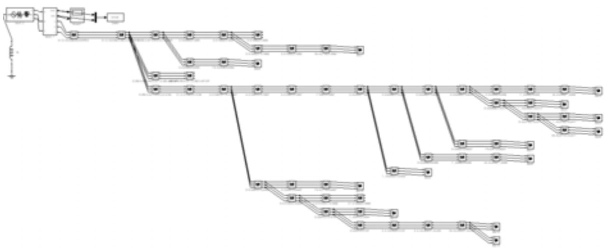

Fig. 3. Power distribution system generated by the Matlab/Simulink application.

The application will allow to display waveforms of voltage and current, impedances, and make new graphics of the performance of the system, representing the state of fault and DG.

4. Fault location algorithm

An estimation of the location of the fault can be made, considering that the fault impedance is completely resistive, by comparing the apparent reactance computed by using the faulted phase voltage and current (RMS values calculated in one cycle) measured at substation, and the modified reactance of the line between the substation and the location of the fault [6]. For single-phase-to-ground faults, the modified reactance of a line between nodes *m* and *r* can be calculated as

$$X_{mr}^{m} = X_{1mr} + \frac{X_{0mr} - X_{1mr}}{3} \qquad (1)$$

where, X_{0mr} and X_{1mr} are the zero and positive sequence reactance of the line, respectively.

5. Simulation Tests

Two cases have been considered to analyse the influence of DG in the location of faults:

a) Short line with DG at the beginning of the line and a single-phase-to-ground fault located at the end of the line.
b) Long line with DG at the ending of the line and a single-phase-to-ground fault located at the beginning of the line.

A.. Short line (DG at the beginning, fault at the end)

The power distribution line data a topology is chosen from a real database according to the following considerations: it has one DG point whose nominal power is about a 10% of the substation nominal power and it is a few-branched line, since this simplifies the analysis in case of fault. Table I shows the real data of the test line.

Table I. Data of test line 1

Substation	S1
Transformer	TR3
Line	L1
S_N (MVA)	45
Length (km)	22.51
Levels	18
DG	DG1
S_N DG (MVA)	6
Max. length feeder (km)	4.452

1) Simulation of the line: Figure 4 shows the voltages and currents at the substation obtained from the simulation of test line 1.

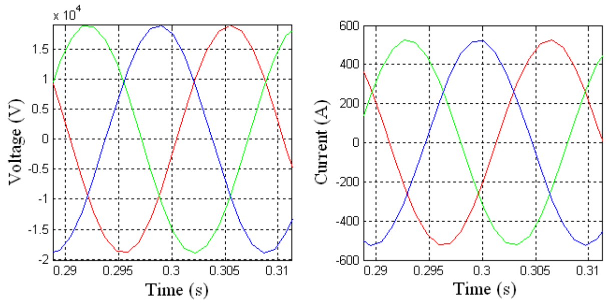

Fig. 4. Voltages and currents at substation of test line 1.

2) Simulation of the line during the fault: The fault is located in a section located between 3.224 km and 3.226 km from the substation. The fault is single-phase-to-ground with a fault impedance equal to 0 Ω (Figure 5).

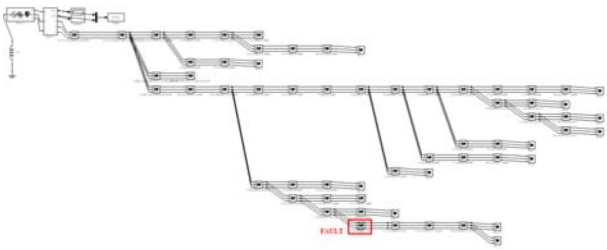

Fig. 5. Location of the fault in the test line 1 (red section).

Figure 6 shows the voltages and currents that result from the simulation of the fault, which are used to locate the fault based on the methodology explained in Section 4.

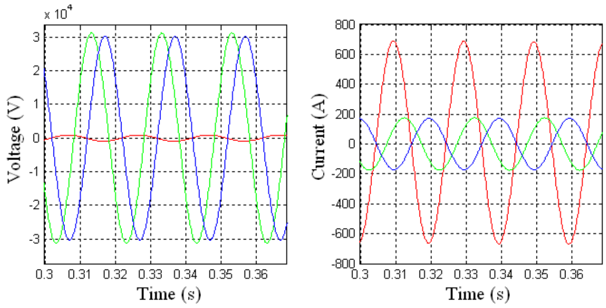

Fig. 6. Voltages and currents during the fault at substation.

Due to the branched nature of power distribution lines, three different sections are obtained as possible locations of the fault are, two located at 3.447 km from the substation and one at 3.228 km. The three estimated locations can be seen in Figure 7 .

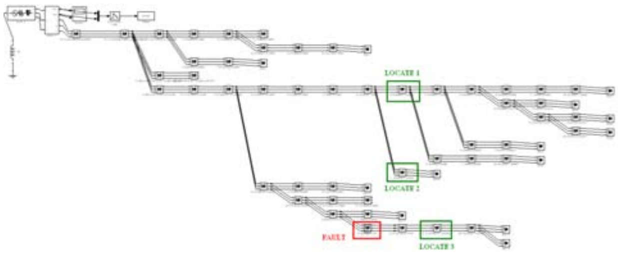

Fig. 7. Fault location results (green sections).

The section located at 3.228 km from the substation is the most accurate result. The error in the estimation is calculated as

$$error\ (\%) = \frac{\text{estimated location} - \text{actual location}}{\text{lenght of distribution feeder}} \cdot 100 \quad (3)$$

For the previous case, the fault distance estimate error is equal to 0.07%.

3) Simulation of the line with DG during the fault: in order to introduce DG in the model, the DG-unit is located at 2.18 km from the substation. For modelling, the short-circuit power of the DG-unit in this point is obtained considering that the nominal power of the actual DG-unit in the line is about a 13.33% of the substation nominal power ($S_{N,substation}$ = 45 MVA, $S_{N,DG}$ = 6 MVA). As the substation has a short-circuit between 236 MVA and 230 MVA (mean value, 233 MVA), a short-circuit power of 31 MVA is selected for the DG-unit. Figure 8 shows the locations of the fault and the DG-unit.

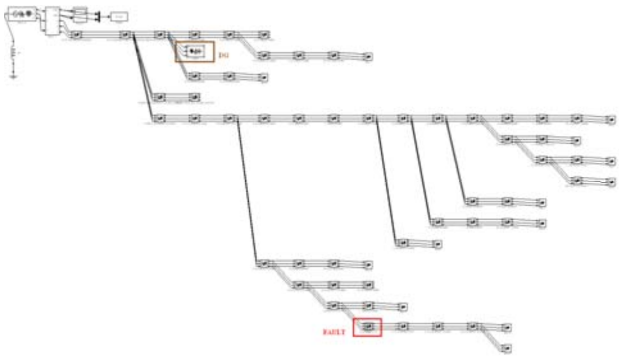

Fig. 8. Model line with the location of the fault (red) and DG-unit (brown).

In Figure 9, voltages and currents at substation during the fault are shown. There is a decrease in the values of currents due to the fact that part of the power required is supplied by the DG-unit.

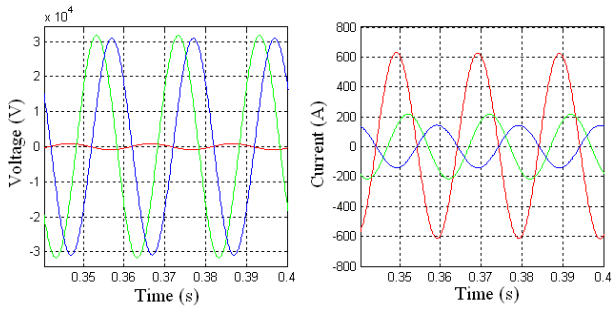

Fig. 9. Voltages and currents during the fault at substation (with DG-unit)

In this case, the estimated locations are found at 2.984 km and 3.228 km from the substation (Figure 10), and the most accurate location has not varied respect to the case without DG (error = 0.07%).

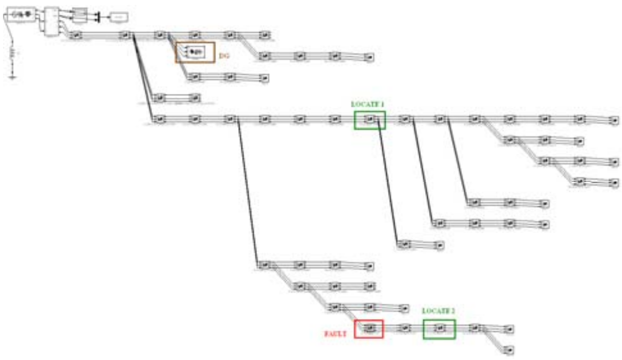

Fig. 10. Estimated fault locations (green sections).

The test was completed by analysing the estimated fault location for different values of short-circuit power in the DG-unit. Figure 11 shows the variation of the parameters that are use for location during the fault: voltage, current and the apparent reactance.

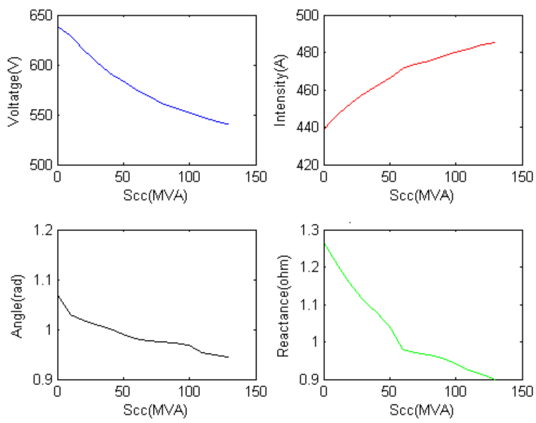

Fig. 11. Voltage, current, phase and apparent reactance during the fault.

As it can be expected, the bigger the capability of DG-unit, the bigger the error in the estimation (Table I). In this case, if the DG-unit size is around half the substation, the error in location is 10% approximately (Figure 12).

Table I. Fault distance estimate errors for different values of Scc in DG-unit.

S_{cc} (MVA)	Xap (Ω)	Distance (km)	Error (%)
1	1.261	3.228	0.07
10	1.208	3.228	0.07
20	1.157	3.228	0.07
30	1.114	3.228	0.07
40	1.077	3.228	0.07
50	1.040	3.228	0.07
60	0.980	3.228	0.07
70	0.970	3.115	-2.03
80	0.964	3.115	-2.03
90	0.957	3.115	-2.03
100	0.941	2.766	-8.43
110	0.926	2.766	-8.43
120	0.912	2.688	-9.86
130	0.900	2.472	-13.79

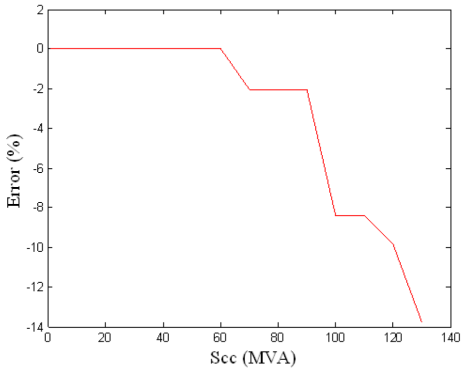

Fig.12. Fault distance estimate error for different values of DG-unit Scc.

It can be seen that for Scc lower than 60 MVA the error is below 0.07% and the error is not above 10% until Scc does not reach a level of 130 MVA.

The tests were performed also for a resistive fault with an impedance equal to 5 ohms (Table II)..

Table II. Fault distance estimate errors for different values of Scc in DG-unit and Z_{fault} = 5 ohms

S_{cc} (MVA)	Xap (Ω)	Distance (km)	Error (%)
50	1.070	3.228	0.07
90	0.977	2.776	-7.4
110	0.974	2.472	-13.8
130	0.910	2.176	-19.1

The results are quiet similar to those were obtained with Z_{fault} equal to 0 ohms, but bigger errors are reached with a lower Scc.

B. Long line (DG at the end, fault at the beginning)

The second group of simulation were performed considering a line with a longer length, which may present a wider variability in the results. Table III shows a summary of data of the chosen line.

As the substation has a short-circuit between 253 MVA and 246 MVA (mean value, 249.5 MVA), a short-circuit power of 33.26 MVA is selected for the DG-unit.

Table III. Data of line test 2

Substation	S2
Transformer	TR2
Line	L2
S_N (MVA)	30
Length (km)	30.29
Levels	41
DG	DG2
S_N DG (MVA)	4
Max. length feeder (km)	13.391

1) Simulation of the line during the fault: In this case, the fault is located in a section at a distance between 3.501 km and 4.069 km from the substation and the fault impedance is equal to 5 ohms. Figure 14 shows the location of the fault (red section).

Figure 13 shows the voltages and currents that result from the simulation of the fault, which are used to locate the fault based on the methodology explained in Section 4.

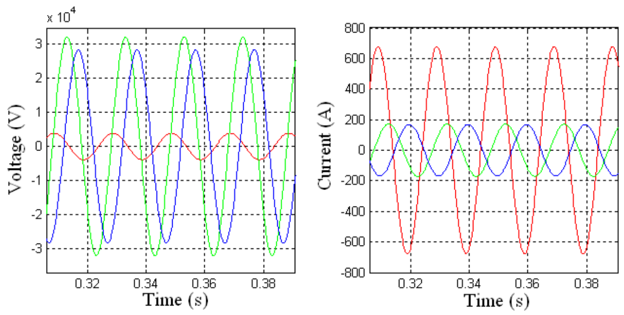

Fig. 13. Voltages and currents during the fault at substation.

The fault location algorithm commented in Section 4 allows to obtain two possible estimations at 4.937 km and 4.346 km from the monitored point.

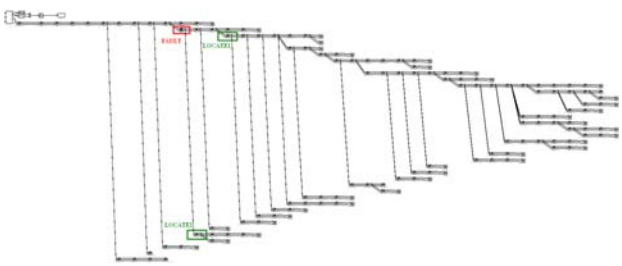

Fig. 14. Fault location results (green sections).

The fault distance estimate error for the most accurate solution is equal to:

$$error\ (\%) = \frac{4.346 - 4.062}{13.391} \cdot 100 = 2.6\% \qquad (4)$$

which is an error almost negligible.

2) Simulation of the line with DG during the fault: in order to introduce DG in the model, the DG-unit is located at 10.249 km from the monitored point. As it has been stated, for modelling, a short-circuit power of 33.26 MVA is selected for the DG-unit. Figure 12 shows the locations of the fault and the DG-unit.

In Figure 15, voltages and currents at substation during the fault are shown.

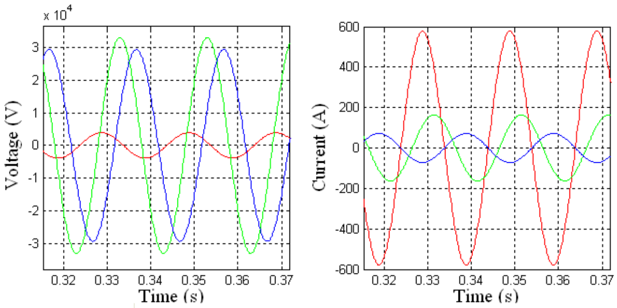

Fig. 15. Voltages and currents during the fault at substation (with DG-unit)

Applying the fault location algorithm, three estimations are obtained. The fault location estimates are located, one of them, at 4.069 km and, the other two, at 4.346 km from the substation. Figure 16 shows the location of the estimates (green sections)

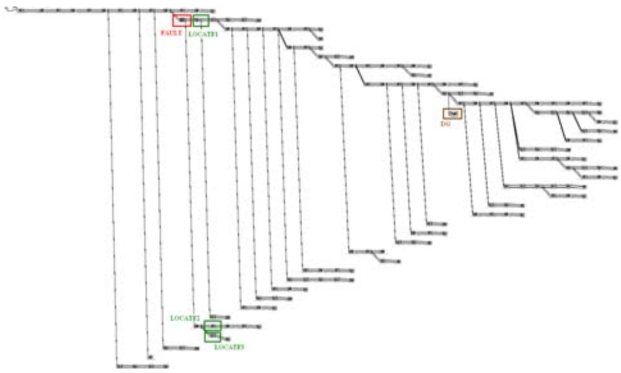

Fig. 16. Fault location results (green sections).

In this case, the location algorithm estimates a section line that is the same as the actual fault location, so the error is 0%.

The test were performed for different values of the short-circuti of power of the DG-unit. The results are presented in Table IV. All the errors in fault location are below 10%.

Table IV. Resultats de localització obinguts amb l'algorisme amb diferents potencies de cc del DG

S_{cc} (MVA)	Xap (Ω)	Distance (km)	Error (%)
1	1.680	4.346	2.6
10	1.560	4.346	2.6
20	1.458	4.346	2.6
30	1.370	0	0
40	1.296	0	0
50	1.254	3.501	-4.24
60	1.119	3.501	-4.24
70	1.147	3.501	-4.24
80	1.110	3.501	-4.24
90	1.077	3.501	-4.24
100	1.050	3.501	-4.24
110	1.024	2.935	-8.46
120	1.002	2.935	-8.46
130	0.982	2.935	-8.46
140	0.964	2.935	-8.46

Figure 17 shows the variation of the parameters that are use for location during the fault: voltage, current and the apparent reactance. From Figures 9 and 15, it can be noticed that in both cases the value of apparent reactance decreases as the size of the DG-unit increases, increasing the fault distance estimate error.

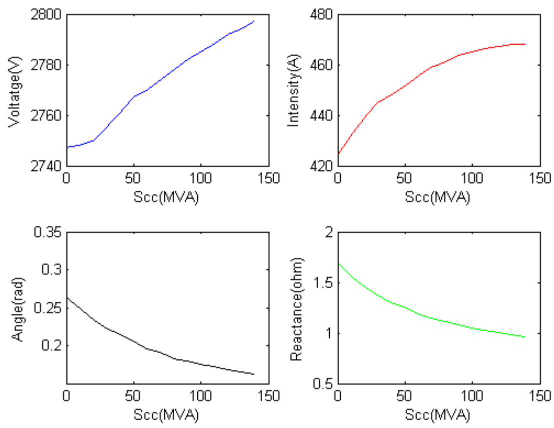

Fig. 17. Voltage, current, phase and apparent reactance during the fault.

Figure 18 the evolution of the error depending of the size of DG-unit. In this case, the existence of DG in the system increases the error in fault location but the error can be assumed due to the length of the feeder.

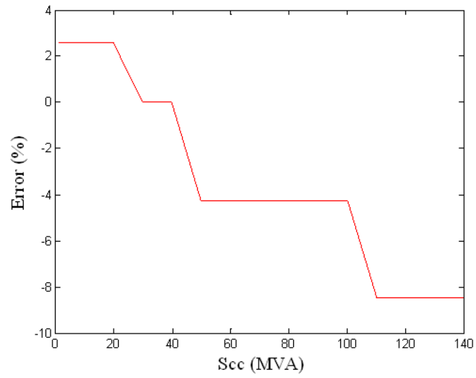

Fig. 18. Fault distance estimate error for different values of DG-unit Scc.

5. Conclusion

The paper analyzes the impact of distributed generation in the location of faults. From the tests performed, different impacts can exist depending on the relative position of the DG and the fault.

The presence of DG in a power distribution system gets to a decrease in the value of the apparent reactance seen from the main substation. Thus, the estimate locations calculated by using impedance-based fault location methodologies will be closer than the actual location of the fault, increasing the error.

A preliminary study of the sensitivity of fault location algorithm, for the case of single-phase-to-ground faults, has been studied for two particular cases, taking into account the impact of the size of DG in the system. Future work will consist in introduce more detailed models for the DG-units and quantify the goodness of the fault location methodologies.

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