Location of phase to ground and phase to phase faults in a power distribution system

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1. Introduction

In the last years fault location on power distribution systems is receiving especial attention due to the importance of a fast actuation to clear the fault causes and the resulting increase in the quality of the power supply. More specifically this papers focus on a frequent kind of fault, voltage sags. They can be produced by many causes and they are responsible of the shortness of electronic devices life, undesired reset of industrial production lines among other many harmful effects. Moreover the causes that produce voltage sags can later produce interruptions if they are not located and cleared.

At [1] different fault location techniques were analysed an at [2] the method proposed in [3] was successfully implemented and tested with simulations.

Key words: fault location, phase to ground faults, phase to phase faults, power distribution system

2. Description of the previous work

The study presented on this paper is possible due to the work done in [2]. A brief explanation of the work done will be pointed as follows.

An actual power distribution network was modelled using the information provided by the power supplier company "Endesa Distribución Eléctrica SLU". The system has a radial topology and it was simplified in order to reduce the simulation time and the execution time to compute the fault location method. The Matlab/Simulink toolbox SimPowerSystems was used as simulation engine. Two fault location techniques were implemented in Matlab and a graphical user interface was developed. The application allows to work with waveforms obtained through simulations or waveforms obtained through digital fault recorders, as the ones recorded on the substation by the power supplier with the Merlin Gerin Circuit Monitor 4000 digital fault recorder. An example of an actual fault produced on the power distribution system and recorded on the mentioned digital fault recorder is shown in figure 1.

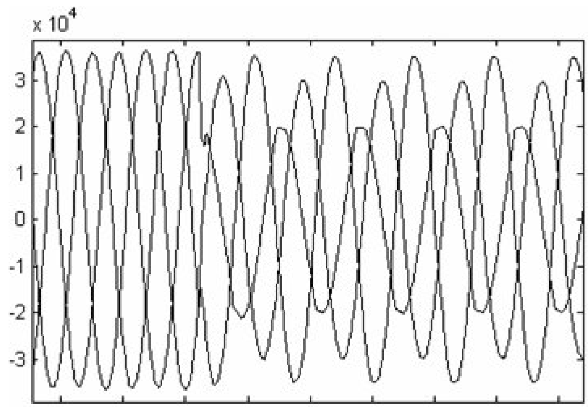

Fig 1. Actual fault recorded by a digital fault recorder

3. Power distribution system

The power distribution system used to do the tests through simulations, is an actual distribution system. It has an high degree of heterogeneity as a result of the existence of different kind of conductors with different impedance, both overhead and cable lines and lines with different length. There is also heterogeneity in the loads: five transformers feed industrial consumers and eighteen feed household consumers.

One end of the distribution power system is on a MV substation. A 40 MVA apparent power transformer feed several distribution power systems. Until now we have assumed the voltage and current waveforms at one end of the feeder to be known but, as figure 2 shows, the digital fault recorder is at substation level. As we want the method to function with real recorded faults we have taken into account the influence of the other present power distribution systems. This is done by simplifying every system to an equivalent load consolidated at the 25 kV bus bar just after the digital fault recorder.

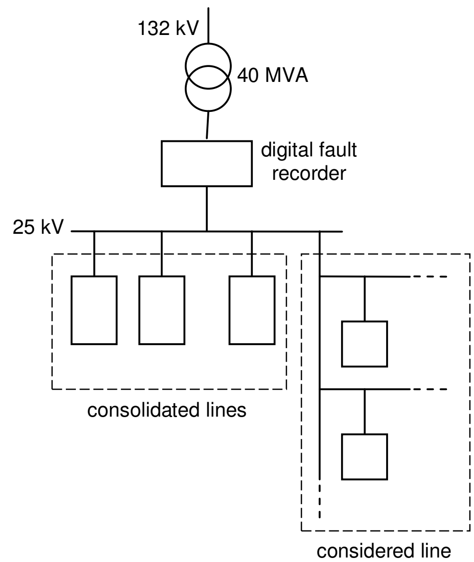

Fig. 2. Scheme of the power distribution system

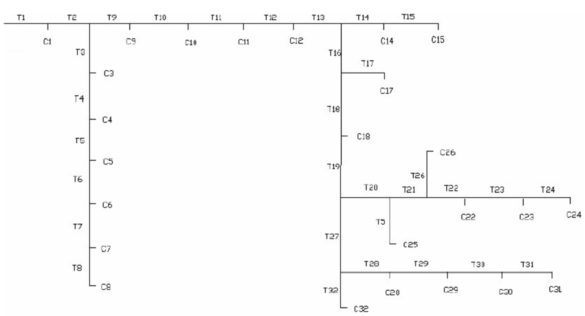

Fig. 3. Scheme of the considered line

4. Modelling of the lines

All the necessary parameters to build the model of the line are known: topology (see figure 3), section lengths, section unitary impedances, transformer nominal powers for household consumer and contract powers for industrial consumers. Also we had line terminal current measurements in intervals of one hour along a day (see figure 4). This is a necessary information to adjust the model as much as possible. As will be shown in the conclusions the loads are a factor that have a significant influence on the fault location.

Comparing the connected load of the considered line (this is the sum of the apparent power of the transformers plus the total contract load for industrial consumers) with the values of actual power (obtained through the currents) along a day, we observed that the last values were significantly lower. This lead to think that the transformers don't work at full load, they are overdimensioned in order to deal with load peaks and future growth of the energy demand. To adjust these loads we have applied two correction factors, one for household loads and another for industrial loads. The last ones are supposed to be similar to the contract power.

The model used to obtain the results presented in [2], assumed there was a digital fault recorder at the line terminal. Though these devices are expensive (also voltage and current measurement transformers are needed) usually they are only present downstream the power transformer. A load to model the influence of the other lines has been connected just after the measurement point. Its power has been calculated using the mean value of the sum of the power supplied for the lines between 8:00 and 19:00. In this interval the energy demand is similar. To locate faults produced outside this interval another model with the correct power has to be used.

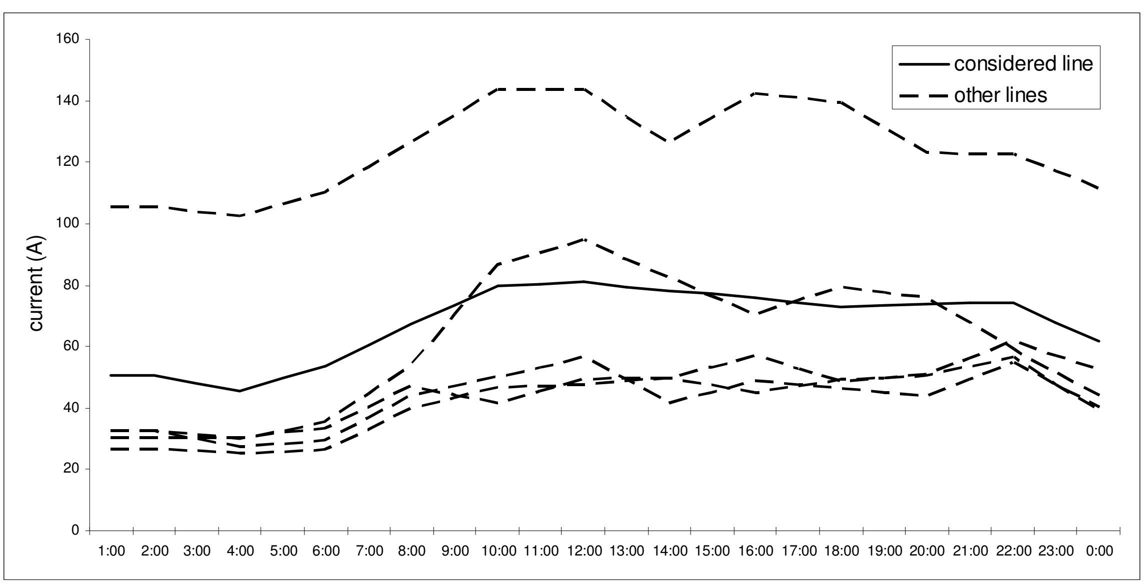

Fig. 4. Current of all the lines along a day

Not only the loads but also the voltages have been adjusted in order to have the same values at the measurement point.

5. Implemented algorithm

The implemented method, described in [3], is an algorithm based on single-end measures of voltage and currents and the full knowledge of the network is required (topology, loads, conductor parameters, etc). It consists on the following steps:

- fault loop reactance is compared with the accumulated reactance of the lines to determine the faulty line
- all the laterals are converted to an equivalent load
- all loads are modelled
- all the nodes beyond the faulty line are considered to be consolidated at the remote end
- all the prefault phasors of voltages and currents at all nodes are computed
- all the fault phasors of voltages and currents are computed
- an approximation of the distance between the beginning of the faulty line and the location of the fault is computed, using obtained values at the beginning of the faulty line, at the remote end and at the fault point. As all the branches have to be explored multiple estimates can be obtained.

This method can work with all fault types. We have implemented it to locate phase to ground and phase to phase faults which are, in this order, the most frequent kind of faults. An important feature of this algorithm is that it is not necessary to use the fault resistance to locate the fault. Fault resistance is in the majority of cases an unknown value, and indeed a source of uncertainties.

6. Fault location tests

To test the accuracy of the implemented method, faults have been simulated in different locations of the line. On table I, the obtained results for phase to ground faults with different values of fault resistance are shown. Moreover on figure 5 the error committed can be seen graphically.

Next, to be able to compare the accuracy for different kind of faults, phase to phase faults at the same location have been simulated and located with the algorithm. It has been done also for different values of fault resistance. The results are shown on table II and the error committed is displayed on figure 6.

Some aspects of the results shown on the tables should be commented. When the algorithm is run, several situations can happen:

- the algorithm determines correctly the faulty line and the location result is positive and lower than the length of the section
- the algorithm got a wrong faulty line but the location result is negative or higher than the length of the line showing that the faulty line is upstream or downstream. In this cases a correction can be done and a new location result computed.

TABLE I. – Results for phase to ground faults with different fault resistance values

section	distance (km)	length (km)	Rf=0.1	Rf=1	Rf=5	Rf=10
4	0.200	0.214	**0.200**	**0.200**	0.204	0.216
6	0.080	0.210	**0.080**	**0.080**	0.090	0.118
9	0.356	0.548	**0.356**	**0.357**	0.406	0.554
13	0.107	0.477	**0.107**	**0.107**	**0.110**	0.118
15	0.271	0.284	**0.271**	**0.271**	*0.271*	*0.271*
18	0.015	0.187	**0.015**	0.015	**0.023**	0.046
23	0.180	0.202	**0.180**	**0.18**	**0.185**	*0.202*
28	0.039	0.077	**0.039**	**0.039**	**0.040**	0.043
32	0.243	0.276	**0.243**	**0.243**	**0.267**	*0.344*

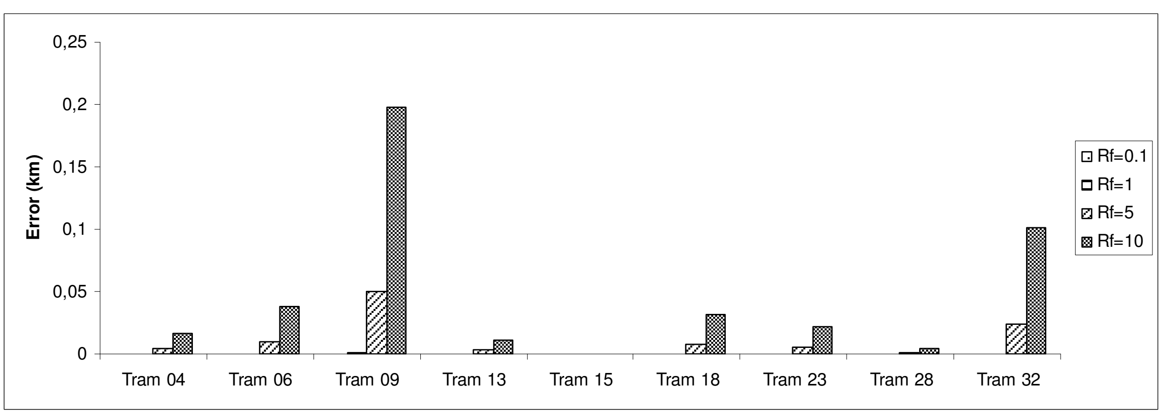

Fig. 5. Error committed for phase to ground faults

TABLE II. – Results for phase to phase faults with different fault resistance values

section	distance (km)	length (km)	Rf=0.1	Rf=1	Rf=5	Rf=10
4	0.200	0.214	**0.156**	**0.169**	0.199	0.203
6	0.080	0.210	**0.031**	**0.045**	**0.080**	0.090
9	0.356	0.548	**0.304**	**0.319**	**0.363**	0.401
13	0.107	0.477	**0.073**	**0.085**	**0.106**	**0.108**
15	0.271	0.284	**0.231**	**0.246**	**0.269**	0.270
18	0.015	0.187	*-0.046*	*-0.022*	0.014	**0.022**
23	0.180	0.202	0.104	0.135	**0.175**	**0.178**
28	0.039	0.077	0.014	0.024	**0.037**	**0.038**
32	0.243	0.276	**0.221**	**0.230**	**0.247**	**0.265**

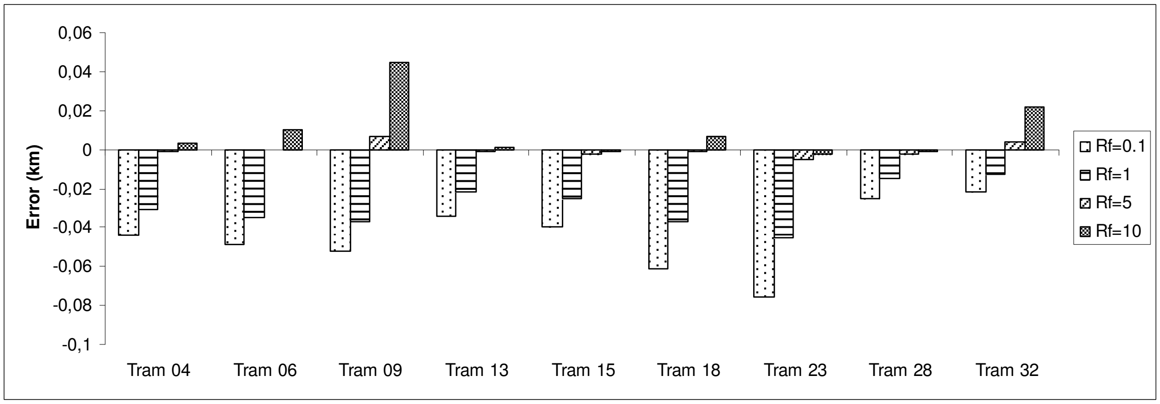

Fig. 6. Error committed for phase to ground faults

- the algorithm got a wrong faulty line and even using the location result the actual faulty line can not be determined. In this cases, in order to obtain a result, the faulty line has been corrected.

The results obtained as explained in the first case are displayed in the tables in **bold** and the ones obtained as the third case in *italic*. The rest correspond to the second case.

These above explained situations are possible because the algorithm compute the faulty line and the fault location among the nodes of that section on different steps.

Another comment on the results is that, as the line has a radial topology, several results can be found. Only the correct result is displayed on the tables.

Also we have tested the algorithm when the loads are a 50% higher and lower of, what are supposed to be, the nominal conditions. This study will determine if it is important or not, to consider in which conditions the fault occur (during the week or the weekend, hour…).

We have done the load analysis simulating phase to ground faults with 0,1 fault resistance value. The results are displayed on table III and the error committed on figure 7.

All the units are in kilometres.

TABLE III. – Results for phase to ground faults with different load conditions

section	distance (km)	length (km)	S	S+50%	S-50%
4	0.200	0.214	**0.200**	**0.208**	**0.193**
6	0.080	0.210	**0.080**	**0.090**	**0.070**
9	0.356	0.548	**0.356**	**0.364**	**0.347**
13	0.107	0.477	**0.107**	**0.122**	**0.092**
15	0.271	0.284	**0.271**	*0.314*	**0.230**
18	0.015	0.187	**0.015**	**0.169**	*-0.130*
23	0.180	0.202	**0.180**	*1.332*	*-0.852*
28	0.039	0.077	**0.039**	*0.349*	*-0.241*
32	0.243	0.276	**0.243**	*0.564*	*-0.045*

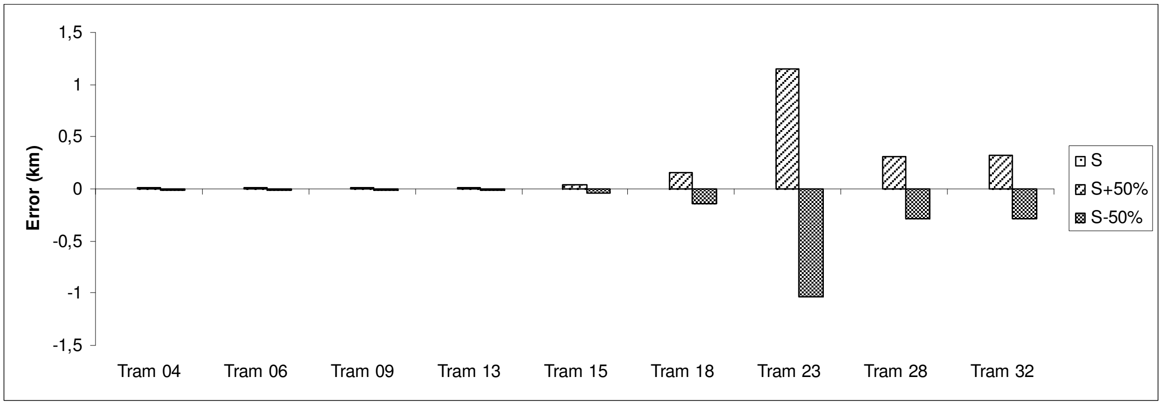

Fig. 7. Error committed for phase to ground faults with different load conditions

7. Conclusions

Analysing the results, it can be seen that for phase to ground faults the best results are achieved when the fault resistance value is small. When the value increases the algorithm doesn't determine correctly the faulty line, and the error committed is higher. The maximum error committed with this kind of fault is below 200 meters.

For phase to phase faults, the fault is located farer from the measurement point when the fault resistance increase. On the contrary of the previous case, when the fault resistance is lower the error is higher. Though, the maximum error committed with this kind of fault is less than in the previous case: below 80 meters.

With regard to the load influence, it can be seen that for faults occurred near the measurement point, variations on load conditions don't produce significant variations of the fault location (around 10 meters) but for faults occurred far from the measurement point the results get worse. The error committed with a variation of 50% of the load is above one kilometre. When the distance between the measurement point and the fault is high, there are a lot of loads between them and the current supplied for the transformer is distributed between the loads and the fault. When the fault is near the transformer the majority of the current that monitors the digital fault recorder is due to the fault.

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