Electric fault location methods implemented on an electric distribution network

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Abstract. This paper compares two electric fault location techniques, [1]&[2]. Using prefault and fault data (voltages and currents) and a model of the network, the algorithms can give an approximation of the actual fault location. They were chosen because the final aim is to implement them on a real distribution network, where we have registered faults with the prefault and fault information, and where the parameters of the network are known. Both techniques were implemented on simple lines and tested through simulations. The results obtained, showed that Ratan Das algorithm was giving better approximations to the actual fault. On a second step the algorithms were implemented on a real distribution network. The results also showed that Ratan Das algorithm give better results and is less sensible to fault impedance, a parameter that in the majority of cases is unknown. An application with a graphical user interface has been created to execute the methods, but also to execute the necessary previous steps: obtain the phasors of the fault, either through a simulation or loading actual registered faults, graphical representation of waveforms and phasors... In conclusion, the Saha method is easy to implement but an evaluation of the fault resistance is needed, and this let the method to be more sensible at uncertainties.

Key words

fault location, two-phase faults, electric distribution network

1. Introduction

Traditionally fault location techniques have been developed for transmission electric lines due to the importance they have in the electric system and the impact that would have faults on these kinds of lines. More recently distribution lines have been taken more into account in order to improve the quality of power supply and to avoid the big penalties imposed by electric commissions.

The aim of the work presented on this paper is to compare two electric fault location methods, those proposed by Saha and Ratan Das. A common feature of these methods is that their inputs are the voltages and currents at the line terminal before and during the fault, and also the model of the network (topology, conductors, loads…). Before deciding which techniques we should use, a brief state of the art was made and presented in [3]. Due to a working agreement with the electric distribution enterprise "Endesa Distribución" we wanted to apply the fault detection technique in a real distribution network exploited by them. The mentioned network has a metering device at the header, which detects voltage sags and is capable of acquiring data in prefault and fault conditions. Moreover, the model of the network is known. For all these reasons, when the state of the art was made we paid attention on methods that work in the same conditions that we would.

2. Description and modelling of the electric distribution network

The origin of the modelled distribution network is in a 132/25 kV substation. It is one of different networks hanging from a 40 MVA transformer and is formed by 297 lines.

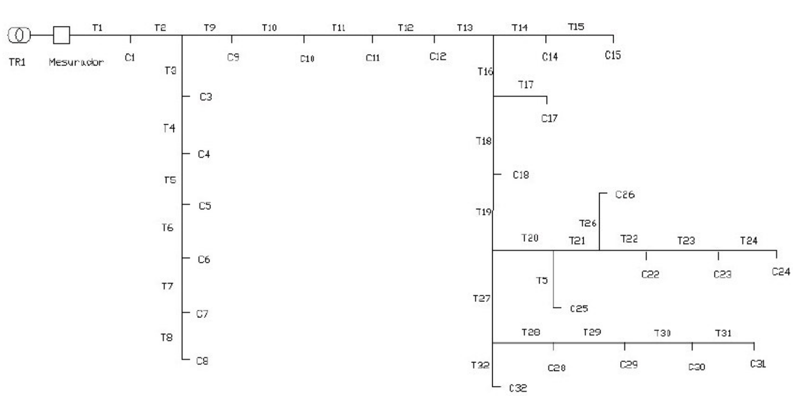


Fig. 1. Scheme of the described electric distribution network once simplified

Some of the lines are subterranean, other aerial. But the majority of them are short connections that are used to join the real lines with the transformers (they lack of length and impedance) and thus they should not be included in the model. In order to simplify more the model, consecutive real lines with the same unitary impedance have been considered as a line of the model with the resulting parameters equal to the sum of the parameters of each real line. This simplification leads to a model that requires less computing time to obtain the results.

Once simplified, the network consists on 32 lines that constitute eight different branches. The branches are all the possible roads from the header of the network to the extreme nodes. A scheme of the network is shown in figure 1.

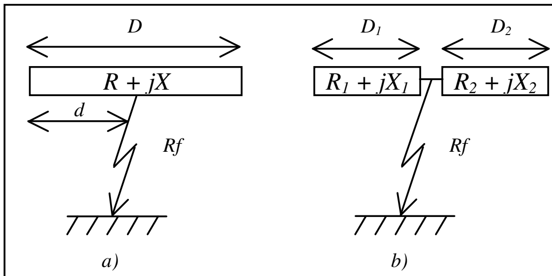
Loads are placed throughout the network. They are connected between lines and can feed small or industrial consumers. In both cases a voltage transformer is present between the MV and the LV network. Specifically, there are 18 transformer to small consumers and 5 to industrial consumers. The transformer nominal power, in the first case, and the hired power in the second case, have been used as apparent power of the loads in the model.

Usually electric lines are modelled with the serial impedance and the parallel admittance. As the lines are short, the parallel part can be omitted (assuming that there are no current leakages). Then, the only modelling parameters are resistance and reactance.

The complexity of an electric model depend on the number of nodes because, during the simulation, the voltages and current at all nodes have to be computed. To induce a fault, a point of the line has to be connected to the ground through a small resistance (fault resistance). To be able to simulate a fault in any point of any line, it is necessary to model every line with two blocks, the first will have the distance equal to the distance from the beginning of the line to the fault and the second will have a distance equal to the total length of the line minus the fault distance. In figure 2a, a line with a fault at a certain distance is shown and in figure 2b, the method used to simulate a fault in that point is displayed. The unitary resistance and reactance will be necessary to compute the parameters of the new blocks.

3. Implemented algorithms

The algorithms proposed by Saha and Ratan Das were chosen. The first appeared to be easier to implement, and the second was more complex but the author stated that his method had better results than other existing methods. Both techniques use single end measures and additional information of the network (topology, length, resistance, reactance, transformers...). The results obtained in this comparison, will be very useful for taking decisions in the future implementation on the real distribution network.



where,

D: length of the line
d: fault distance
D_1: equivalent distance
D_2: equivalent distance
Rf: fault resistance
R_1: equivalent resistance
R_2: equivalent resistance
R_1: equivalent reactance
R_2: equivalent reactance

Fig. 2. a) Line with fault, b) Modelling of the line

The Saha algorithm consists on, using data from the metering point, computing the fault loop impedance. Starting with this impedance, the fault loop impedance as seen from the next node to the fault point has to be computed on an iterative way. Also information of the line impedance and loads has to be used. When the value obtained is negative, the fault is reached and the procedure stops. Then assuming a fault resistance value, an approximation of the fault location is obtained. For radial networks, all the branches have to be explored.

On the other hand, Ratan Das algorithm 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 voltages and currents at all nodes are computed
- all the fault 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.

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.

The above-explained algorithms have been implemented on Matlab scripts.

4. Software application

The model has been created with a toolbox of Matlab/Simulink called SimPowerSystems. It is a collection of blocks that allow the modelling of different elements, that usually are present on power systems. It uses the Simulink as simulation engine.

The results of the simulations are the waveforms of the three phases at the header of the line, the same information that provide fault registers obtained in real faults. At least two cycles of the waveform should be in prefault conditions.

The next step is to find the voltage and current phasors, in prefault and in fault conditions. These phasors are found taking the fundamental frequency by using the fast Fourier transform. With the phasors and the model of the network, now the algorithms can be computed.

To be able to do all the necessary actions automatically and easily, a Matlab graphical user interface has been created. The interface allows:

- see a scheme of the network
- choose the fault conditions before a fault is simulated: faulty line, the distance between the previous node and the fault, and the fault resistance
- simulate a fault
- import a register that contain the waveform of a real fault
- see the waveforms and its phasors and the consumed power before and after the fault
- compute Saha method
- compute Ratan Das method
- see the results of both methods

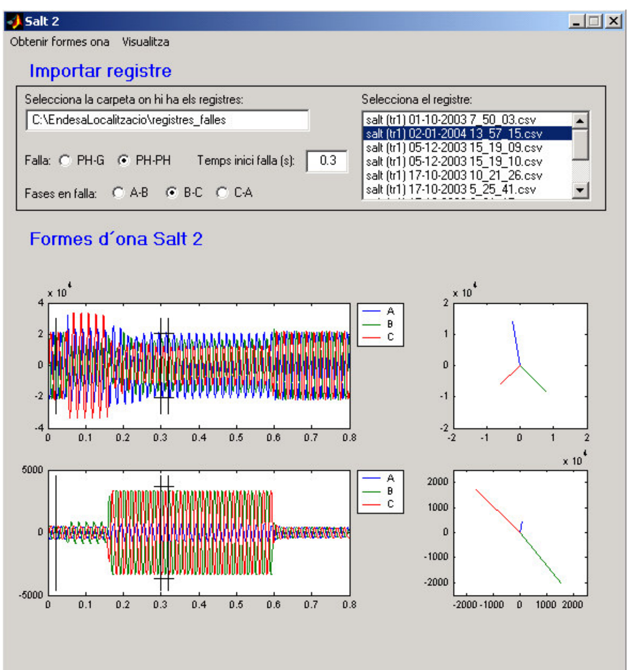


Fig. 3. Importing a register

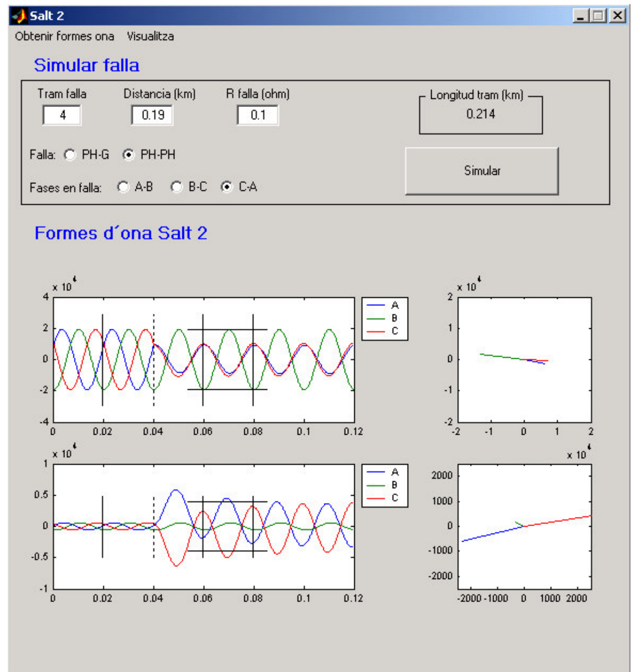


Fig. 4. After the simulation of a C to A fault

In figure 3, the application window to import fault registers is shown. The prefault and fault waveforms, and the fault phasors at the header are plotted. The fault cycle can be chosen in the top part of the window, and it is marked with a rectangle at the bottom part.

Other features are:

- before simulating a fault, when the desired faulty line is selected, the line length and a scheme of the situation of the line in the network are shown
- the waveforms and the fault phasors, are shown after a simulation is computed.
- when the two algorithms are computed, the results appear at the same window
- the results for each travelled branch are shown
- a pop-up window with a scheme specifying all the branches can be displayed

In figure 4, a two-phase fault (C to A), at a distance of 190 meter to the beginning of the fourth line, with a 0,1-ohm fault resistance, has been simulated. This line is 214 meters long.

5. Results

The obtained results are presented in tables I-IV. Faults have been simulated in twenty different locations, with different fault resistance impedance, and for both methods.

The units of line lengths and fault distances fields are kilometers. On the other hand, the error is in meters. Information of the simulated fault locations can be found on the left columns and on the right, the detected location

TABLE I. – Saha method results with a 0,1-ohm fault impedance

ACTUAL FAULT			SAHA			
line	length	distance	line	distance	error (m)	error (%)
2	0,952	0,7	**2**	**0,563**	-137	14,4
4	0,214	0,06	**4**	**0,131**	71	33,2
5	0,09	0,08	6/9	0,175/0,285		
6	0,21	0,1	**6**	**0,114**	14	6,7
7	0,105	0,05	8/10	0,205/0,111		
8	0,335	0,02	**8**	**0,147**	127	37,9
9	0,548	0,3	**9**	**0,245**	-55	10
11	0,385	0,19	**11**	**0,248**	58	15
14	0,433	0,2	**14**	**0,264**	64	14,8
16	2,384	1	**16**	**1,116**	116	4,9
19	0,571	0,2	22/29/32	2,077/2,746/0,852		
19	0,571	0,3	24	2,511		
20	0,162	0,1	-	-		
22	0,252	0,07	-	-		
24	0,512	0,32	-	-		
29	0,209	0,05	-	-		
31	0,287	0,21	-	-		
32	0,276	0,02	-	-		
32	0,276	0,19	-	-		
32	0,276	0,27	-	-		

TABLE II. – Ratan Das method results with a 0,1-ohm fault impedance

ACTUAL FAULT			RATAN DAS			
line	length	distance	line	distance	error (m)	error (%)
2	0,952	0,7	**2**	**0,721**	21	2,2
4	0,214	0,06	**4**	**0,095**	35	16,4
5	0,09	0,08	6/9	0,032/0,360		
6	0,21	0,1	**6**	**0,146**	46	21,9
7	0,105	0,05	**7**	**0,100**	50	47,6
8	0,335	0,02	**8**	**0,073**	53	15,8
9	0,548	0,3	**9**	**0,343**	43	7,8
11	0,385	0,19	**11**	**0,281**	91	23,6
14	0,433	0,2	**14**	**0,244**	44	10,2
16	2,384	1	**16**	**1,034**	34	1,4
19	0,571	0,2	**19**	**0,243**	43	7,5
19	0,571	0,3	**19**	**0,335**	35	6,1
20	0,162	0,1	19	0,610		
22	0,252	0,07	19	0,645		
24	0,512	0,32	20/28/32	0,909/0,330/0,311		
29	0,209	0,05	19	0,657		
31	0,287	0,21	19	0,746		
32	0,276	0,02	19	0,602		
32	0,276	0,19	19	0,740		
32	0,276	0,27	**32**	0,300	30	10,9

TABLE III. – Saha method results with a 0,5-ohm fault impedance

ACTUAL FAULT			SAHA			
line	length	distance	line	distance	error (m)	error (%)
2	0,952	0,7	**2**	1,035	335	35,2
4	0,214	0,06	**4**	0,939	879	410,7
5	0,09	0,08	6/9	0,989/1,076		
6	0,21	0,1	**6**	0,894	794	378,1
7	0,105	0,05	8/10	1,015/1,113		
8	0,335	0,02	**8**	0,949	929	277,3
9	0,548	0,3	**9**	1,207	907	165,5
11	0,385	0,19	**11**	1,226	1036	269,1
14	0,433	0,2	**14**	**0,398**	198	45,7
16	2,384	1	**16**	**0,968**	-32	1,3
19	0,571	0,2	23/31/32	5,654/3,643/1,087		
19	0,571	0,3	24	3,223		
20	0,162	0,1	-	-		
22	0,252	0,07	-	-		
24	0,512	0,32	-	-		
29	0,209	0,05	-	-		
31	0,287	0,21	-	-		
32	0,276	0,02	-	-		
32	0,276	0,19	-	-		
32	0,276	0,27	-	-		

TABLE IV. – Ratan Das method results with a 0,5-ohm fault impedance

ACTUAL FAULT			RATAN DAS			
line	length	distance	line	distance	error (m)	error (%)
2	0,952	0,7	**2**	**0,717**	17	1,8
4	0,214	0,06	**4**	**0,094**	34	15,9
5	0,09	0,08	6/9	0,030/0,356		
6	0,21	0,1	**6**	**0,143**	43	20,5
7	0,105	0,05	**7**	**0,097**	47	44,8
8	0,335	0,02	**8**	**0,069**	49	14,6
9	0,548	0,3	**9**	**0,340**	40	7,3
11	0,385	0,19	**11**	**0,271**	81	21
14	0,433	0,2	**14**	**0,238**	38	8,8
16	2,384	1	**16**	**1,024**	24	1
19	0,571	0,2	**19**	**0,235**	35	6,1
19	0,571	0,3	**19**	**0,328**	28	4,9
20	0,162	0,1	19	0,605		
22	0,252	0,07	19	0,640		
24	0,512	0,32	20/28/32	0,894/0,324/0,306		
29	0,209	0,05	19	0,653		
31	0,287	0,21	19	0,742		
32	0,276	0,02	19	0,598		
32	0,276	0,19	19	0,735		
32	0,276	0,27	**32**	0,295	25	9,1

is shown. The cells of the line column are bolded when the line has been correctly detected. The cells of the distance to the previous node are bolded if the distance is lower than the total length of the line.

In the majority of cases, the techniques give multiple estimates. When one of these estimates is in the faulty line, only this one is shown in the tables. All the estimates are shown, when any of them are not in the faulty line. Sometimes the line estimate is correct but the distance is larger than the line length, indicating that the real fault is beyond that line. Only when the line is detected correctly the error committed by the algorithms can be calculated.

6. Conclusions

Being based on the results, some conclusions will be given next.

Saha method gives acceptable results when fault resistance is small and for faults not very far from the header. When faults are very far, simply it won't give any estimate. Moreover when the fault resistance is larger the results are worse.

Ratan Das method results are more accurate. The tests done show that the error is always fewer than hundred meters. When the fault is far from the header usually the fault is detected before the correct line and the fault distance is larger than the line length. This may happen because the estimate of the faulty line and the estimate of the exact location are computed on different steps. The fault resistance value doesn't change significantly the results.

Another important aspect is that Saha method uses fault resistance. This is a not problem with simulations because it is a known parameter, but in real electric systems it can vary depending on the nature of the fault.

Finally, and advantage of Saha method is that is easier to implement than Ratan Das method. The first method is able to give estimates only computing impedances, while the other method has to compute all the voltages, currents, equivalent impedances, and a lot of other parameters, before estimates are obtained.

7. Work in progress

We have access at registers created by a substation digital fault recorder. Therefore in future works we would be able to test these methods with real faults. Besides, a new fault detection method, based on knowledge, will be developed and, if the results obtained are satisfactory, implemented in the real network.

Acknowledgement

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