Comparison of Impedance and Traveling wave Methods of Fault Location Using Real Faults

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Abstract – Market deregulation has changed the way transmission utilities manage their lines as they are not paid by the amount of transmitted power, but by the availability of their lines. The reason for that is the concept of free energy market (generation prices), that need the transmission system to be always available for large energy block transfers of the cheapest generator in the system. In this new model, the transmission utilities are penalized for the time a line is off service to the system after a permanent fault. The time needed for restoring the line to the system is mostly lost in locating the real point of the fault. This paper show how this time can be significantly reduced by using traveling wave.

1 - INTRODUCTION

This paper present the traveling wave fault location technology and also the first results of a demonstration system installed in the transmission and generating utility Furnas Centrais Elétricas in a 248.6 km (155 mi), 500kV transmission line, that is series compensated. The results obtained from this system are compared to the ones obtained considering one and two side impedance fault location algorithms.

The transmission line where the system was installed is the Circuit 2 of Samambaia-Serra da Mesa, that is in red in the next figure.

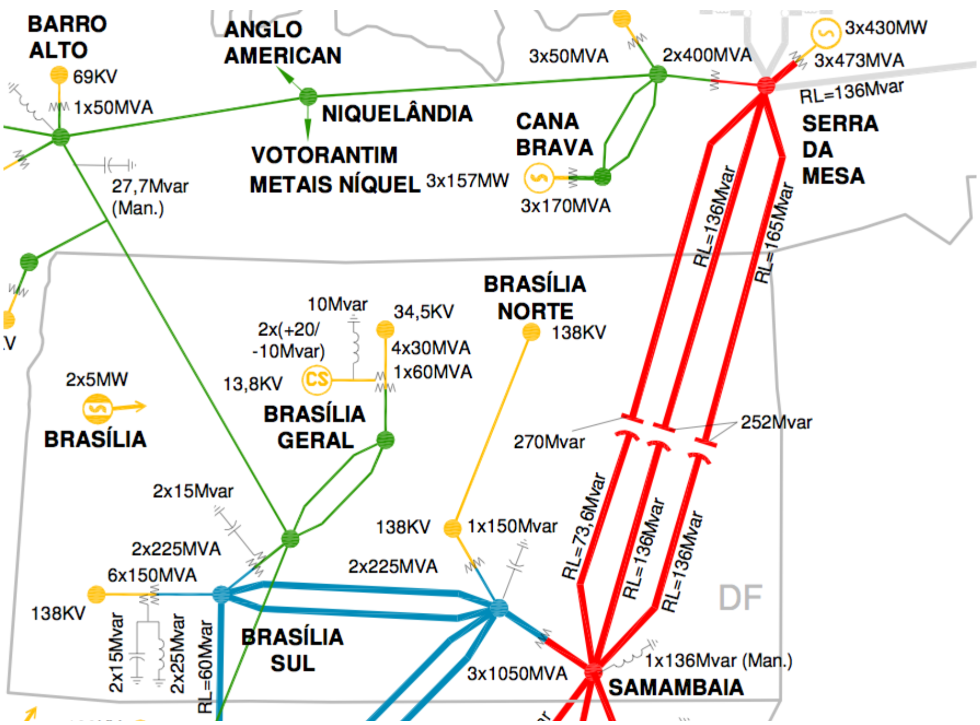

Figure 1 – Transmission line Serra da Mesa-Samambaia

This system was installed as a technology demonstration in Furnas as there was no previous experience with this technology at that transmission utility and the utility is penalized for the time the transmission lines are not available to the Brazilian electric network system.

This transmission line was selected because it has a high number of protection actuations per year, is a long line and is series compensated, making it very difficult for traditional impedance methods to precisely locate a fault on this line.

It also has a particularity that it is in the same region of a bird called “Curicaca” that is regularly found standing on the towers.

The bird’s stream is the major cause of faults on this line when it happens and they are standing over insulators. Although most of the times they are not permanent faults, but with successful reclosing, they become permanent in some point in the future due to small cracks in the insulator after and arc passed true it.

Figure 2 – Curicaca bird standing on a tower structure

Furnas has a total of 46 substations with a transformation capacity of 101.651 MVA, 19278 km of transmission lines from 138kV to 750kV and a DC link of ±600kV and also 11 power plants.

2 – TRAVELING WAVE FAULT LOCATOR

The system is composed of 2 equipments, one on each line end and is connected to the potential transformers, and both equipped with a GPS to time tag the exact moment the wave form of the traveling wave reach each side of the line.

This principle uses only the information of the cable length of the line (*l*) and the propagation speed of the traveling wave (*k*) and the time difference between the times of arrival of the traveling waves of each side ($t_a - t_b$).

The equation that is used to calculate the position of the fault is therefore:

$$d = \frac{l + kc(t_a - t_b)}{2} \qquad (1)$$

When comparing to impedance methods, the first difference that can be seen is the absence of information of line parameters related to the nominal frequency of 60Hz or 50Hz.

In fact, the first thing that is done in fault locators based on the traveling wave method, is to filter the nominal frequency content by applying a high pass filter in order to completely eliminate it.

It's important to state de difference between line length and cable length, because usually the information about length of the line is composed by the geographical distance between all the line towers, which is good for impedance methods as they inform the distance proportional to the impedance of the line.

But as the principle of traveling actually measure the cable length as considered in the equation, we have to take account the cable length that is due the temperature of the cable and also the cable from the potential transformer till the fault locator.

The figure 3 shows the line length that is normally used, composed by the sum of the distances between all the towers of a transmission line.

Usually not even the connection between the last structure and the bus bar is considered as this makes not a big difference in the over all line length and causes no problem for distance protective relays that are designed to work by zones and not by the exactly distance to the fault.

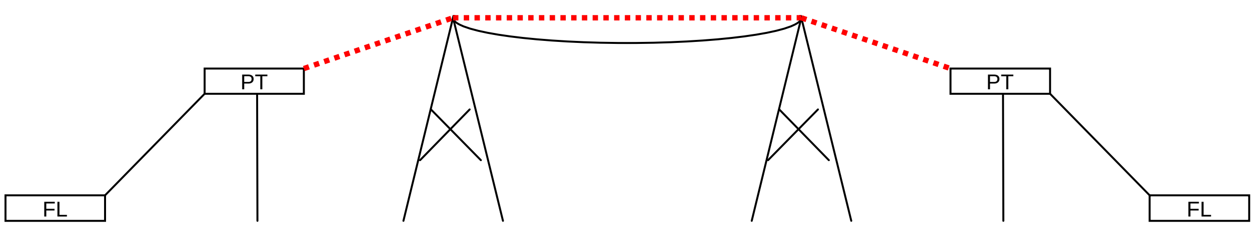

Figure 3: Cable length for impedance methods

On the other hand, traveling wave fault locators are expected to present results with errors in the order of a few hundred meters or less.

In this case, we do have to consider all the cable length that is connected between the two fault locators, including the cable from the potential transformer till the terminals of the fault locator.

It has been found distances of cable of 500 m or more just from the PT to the fault locator device installed in the cabinet, and if we are talking of a device with a precision of a few hundred meters, this will for sure make a huge difference in the final result.

So, the correct distance informed to the traveling wave fault locating device is the sum of the cable length and the cables inside the substation as shown in figure 4.

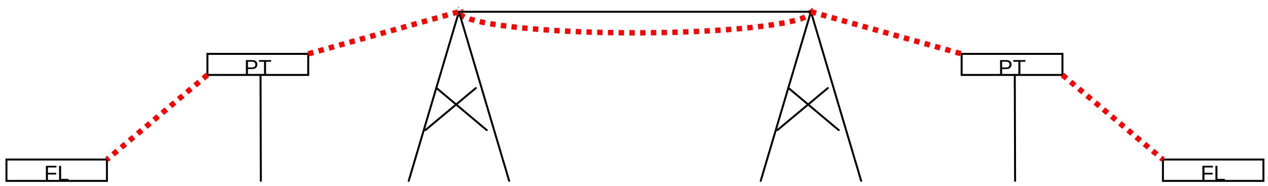

Figure 4: Cable length for traveling wave methods

If we return to the equation (1), other important information that has to be informed to the algorithm is the propagation speed of the traveling wave.

For overhead transmission lines this value is usually around 98% of the speed of light and for underground cables is more likely to be around 50% of the speed of light.

This value can be calculated based on the line parameters or measured using the fault locator itself. Although calculated values are close to the real value, a small difference can have a great impact on the precision, thus the recommended is to measure the propagation speed.

The measurement of the “real” propagation speed can be done by generating a traveling wave with the opening of a breaker or switching of a shunt reactor of the line for example.

Once the correct cable length of the transmission line is used in the equation, and as the exact position of the breaker or shunt reactor relative to the cable length should be known, is just a matter of adjusting the propagation speed in order to obtain the correct position of the device.

As for the time difference for the equation (1), this is obtained by capturing the waveforms from the traveling waves generated by discontinuity in power like faults or switching of breaker, shunt reactors or the protection of a series capacitor.

Each device works by capturing in a circular buffer with a sampling rate of 5 Mhz with acquisition points synchronized with the GPS system.

The bandwidth of the pass band filter of the fault locator is designed to capture signals from 1kHz to 1Mhz, thus eliminating completely the known voltage or current signals at nominal frequency.

The record that is captured at the sampling rate of 5Mhz is usually at a zero while the system is in normal condition and only present a value when there is an event in the system.

The next figures 5 and 6 are the captured records of a fault that occurred in 22/04/08 from both sides of the transmission line.

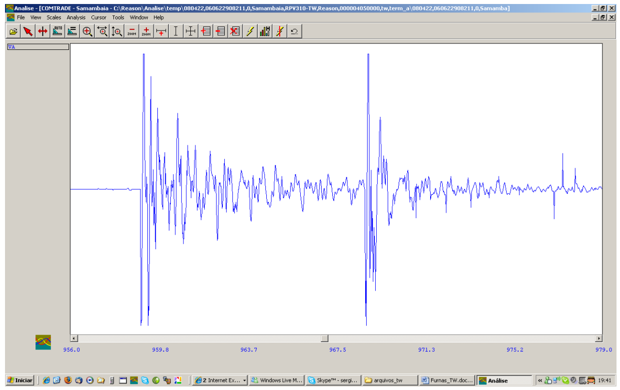

Figure 5: Traveling wave capture at the samambaia terminal

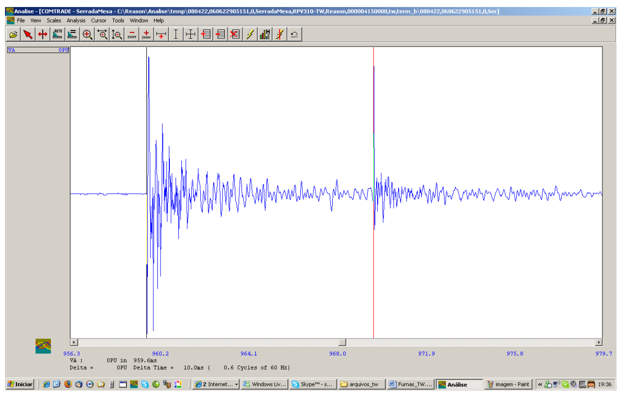

Figure 6: Traveling wave at the Serra da Mesa terminal

On both figures 5 and 6 it is possible to see that actually two traveling waves were captured spaced 10ms each other. This is due the activation of the gap from the series capacitor protection 10 ms after the beginning of the fault to avoid an over voltage in the series capacitor.

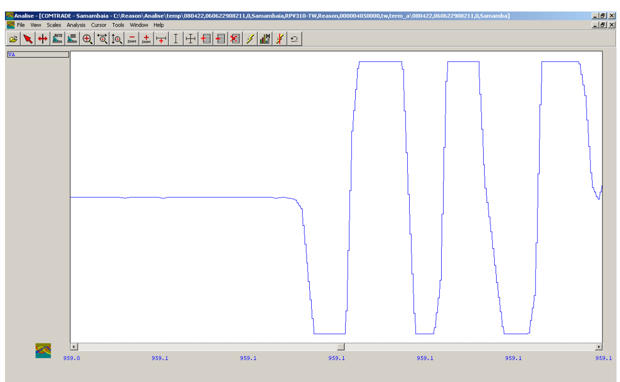

Figure 7: Detail of the waveform captured

Figure 7 shows a zoom of the waveform captured where is possible to see that the waveform of the traveling wave is smaller than the waveform of the fundamental wave. But, the most important information is the timestamp of the traveling wave arrives at the end of the line.

The figure 8 shows the standard fault recording from the moment of the fault, where is possible to see that the two discontinuities in the voltage occurred in less than one cycle.

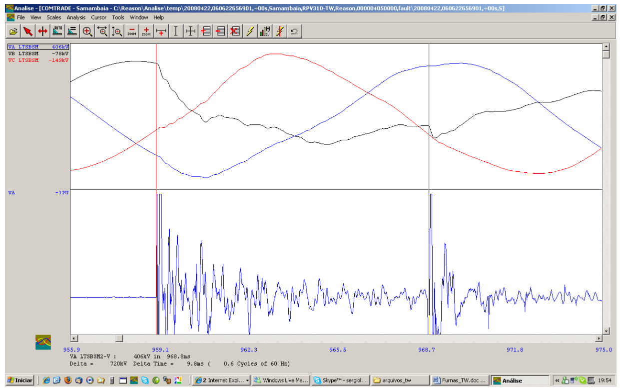

Figure 8: System voltage waveform and discontinuity

Another important point related to fault location device based on traveling waves is that they cannot be tested with standard test sets as usually the maximum frequency that they can reproduce is around 1000Hz, below the frequencies generated by traveling waves.

This means that the devices cannot be tested during commissioning using standard tests. The only way is to actually measure a traveling wave generated by equipment installed in a known position on the transmission line, like a breaker, switch or reactor for example.

3 – RESULTS

Impedance based fault location is the most known technology to used today to find the position of a fault in a transmission line.

There are two different methods that can be used to locate a fault based on impedance: one side algorithms and two side algorithms.

There are a number of papers in the literature that describe the disadvantages of one side fault location due the fact that part of the information, the contribution of the other side to the fault is, by different ways not considered in the equation in order to make possible the fault location using voltage and current information from just one side of the line.

Two side fault location on the other hand is less prone to errors as it actually uses all information available. Although this do not significantly improves the precision, it will make the solution much more stable that one side fault location, as the main reason to errors are PT, CT and line parameters errors.

But on both cases the precision is still a percentage of the line length, desired to be ±1% but actually around ±5% in most cases. For a transmission line as the one presented in this paper, with 248 km this represent almost 25 km that the line patrol personnel will have to see in order to find the fault.

The next table shows a comparison of algorithms of one side from the software of analysis of Reason Tecnologia, one and two sides algorithms from software of Furnas Centrais Elétricas and the traveling wave device for the first fault located with the traveling wave device installed at Furnas.

	Samambaia		Serra da Mesa	
	Km	Error	km	Error
Real position	41,9	-	206,6	-
TW device	42,3	0,2%	206,2	0,2%
One side impedance algorithm Reason	32,2	3,9%	183,7	9,2%
One side impedance algorithm Furnas	31,5	4,2%	188,9	7,1%
Two side impedance algorithm Furnas	30,4	4,7%	218,2	4,7%

Table 1: Comparison of different algorithms for same fault

It is important to notice that although the transmission line is series compensated and this causes sub synchronous frequencies during faults, the protection device of the series compensator capacitor actuated very fast and the phasor information used to locate the fault with impedance methods was obtained just from the waveform after the bypass of the series compensation.

Also the small errors of Table 1 for impedance methods are the result of a “best choice“ of the instant to extract the phasors in order to lower the errors.

The next table resumes the results from the first faults that occurred in the transmission line after the traveling wave fault location device was installed.

Date	Indicated position (km)	Real position (km)
22/04/08	206.26	206.64
21/05/08	206.26	206.64
03/06/08	121.90	121.60
07/06/08	122.04	121.60
27/09/08	213.25	213.68
01/10/08	197.45	197.50
07/10/08	196.19	197.50
10/10/08	138.23	140.07
20/10/08	140.58	140.07
30/10/08	145.51	144.35
01/11/08	145.48	144.35
11/11/08	201.27	201.14
11/11/08	138.26	137.53

Table 2: Real and informed position for the first faults with known position

There were several faults were the line patrol personal only found the fault after the second fault on the same position because for the first actuation of each fault had a successful reclosing of the line and the line patrol was only sent to locate de fault after the second fault on the same position.

4 - CONCLUSIONS

This paper shows an actual comparison of different algorithms for fault location including traveling wave for a real fault on a transmission line.

There are already a reasonable amount of faults with a consistent precision, indicating a repeatability of results.

The line patrol was able to find a fault going right to the point indicated by the traveling wave device, reducing this way the total time needed to locate and fix the problem on the line.

The accuracy obtained with this method if far more precise than any impedance method and can be used in any transmission line, including lines with series compensation, parallel lines and even on DC lines with the same accuracy.

5 - REFERENCES

[1] nt0802-pt rev 3.2 - Traveling waves fault location – Technical note, Reason Tecnologia.

[2] nt0805-pt rev 1.1 – Experimental traveling wave line parameter determination – Technical note, Reason Tecnologia.

[3] “IEEE guide for determining fault location on AC transmission and distribution lines,” New York, jun. 2005.

[4] Fault location errors in transmission lines with one and two side algorithms, XII Eriac, 2007

Biography:

Sergio Luiz Zimath was born in Joinville, Brazil in December 23, 1971. Majored in Automation and Control Engineering in 1997 at the Federal University of Santa Catarina. Has worked for Reason Tecnologia since 1995. Responsible for several of Reason’s product development, such as RT1000 and RT2000 GPS clocks, as well for the RPIV Digital Fault Recorder, among others. Has worked in several research projects and published articles in national and international conferences.

Marco Antonio Fernandes Ramos was born in 1966 in Rio de Janeiro, Brazil. Graduated in Electric Engineering in 1992 at the Santa Ursula University, and Master of Sciences in Electric Engineering by the Catholic University of Rio de Janeiro in 2002. Since 1993 works in FURNAS Centrais Eletricas S.A. as Protection Engineer in the Protection and Analysis Division. Has participated on the development of the FURNAS´s Oscillography System, and today is responsible for the maintenance and operation of this system.

Jayme Evaristo da Silva Filho was Born in 1964 in Rio de Janeiro, Brazil. Graduated in Electric Engineering at the Rio de Janeiro State University in 1988. Worked between 1988 and 2000 at GE, from 2000 to 2003 at Alstom and 2003 to 2004 at ZIV. In 2004 joined Furnas where he works as a Protection Engineer in the Protection and Analysis Division.

Conrado Seibel was born in 1962 in Florianopolis, Brazil. After majoring in Electrical Engineering, he spent 6 years working for Mercedes Benz in Germany. After a brief spell in the United Kingdom for his Masters Degree, he returned to Brazil in 1992 and spent several years working with autonomous vehicles and in automation before joining Reason in 2002 as

Technical Director. He holds a PhD in Electrical Engineering from the Universidade Federal de Santa Catarina.