NAME : Paulo Sergio Pereira Junior
COUNTRY : Brazil
REGISTRATION NUMBER : DLG5073
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***Question 2.03 What are the experiences to fault identification and location and how to design the scheme to meet the practical application requirement?***

The interconnected power systems are day by day requiring faster and precise identification of faults to ensure its stability. Due to this need, more efficient location and protection algorithms are needed so that the impact of the fault is mitigated as quickly as possible. Among the various methods in the literature, algorithms based on traveling waves stand out for their high accuracy.

Due the importance of this function to the power system, it is important to evaluate the performance of protection equipment when in real fault conditions, especially when considering the economic impact caused by interruptions in the system. To meet the test conditions, a new methodology was developed: a system composed of software and hardware capable of accurate modeling all the electrical system components, including the transmission lines, and later reproducing the very high frequency waveforms along with the fundamental frequency at secondary levels, thus contemplating all the necessary requirements for evaluating the device under test.

The PS Simul software (developed in Brazil since 2009) was created with the main purpose of allowing the user to model complex power, control systems and to simulate electromagnetic and electromechanical transients, working with a very friendly interface, with a series of resources that facilitate the obtaining and evaluation of results, data entry, visualization, among others. In addition to carrying out the simulations, the software allows the reproduction / acquisition of the signals by the test set.

In order to calculate faithful signals, PS Simul has in addition to the traditional lumped models like PI and RL, four different models with distributed parameters capable to reproduce traveling waves: Loss-less, Bergeron, Frequency Dependent Phase and Frequency Dependent Mode. The Frequency Dependent (Phase) model is numerically robust and more accurate than any other commercially available line/cable model, and thus, is the preferred model to use.

As mentioned before, the simulated signal is separated in two: the low frequency being generated by a conventional test set and the high frequency being reproduced by special amplifiers capable of responding to a wide frequency spectrum (DC - MHz). Synchronization is responsible for ensuring that there are no signal slips and the result of the combined waveforms is shown in an oscilloscope capture below (Figure 1).

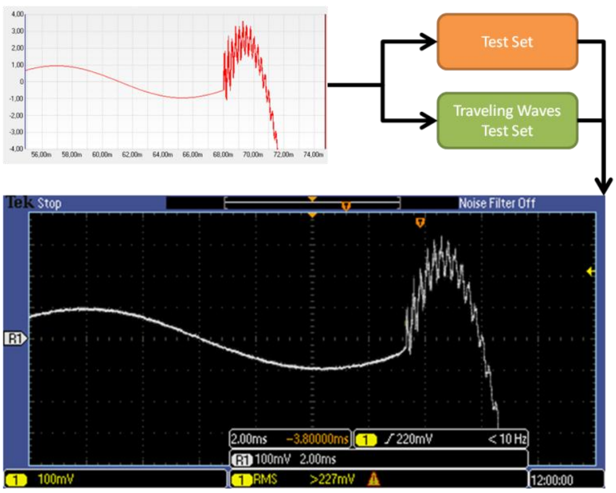

Figure 1 - Calculated signal at PS Simul x Oscilloscope capture

If the test must be carried out on site or it is not possible to use only one test set, the PS Simul software has a feature called Remote Generation, which allows a user to control several test set simultaneously regardless of the geographic distance between them, either through a local network or through the cloud. This allows all results to be centralized in a single location, maximizing gains in skilled labor, analysis of results and agility in testing.

The results shown below ilustrate a Brazilian basic power system submitted to a total of 57 test scenarios repeating 3 times each, totalizing 171 tests, where several internal fault conditions were simulated, with variation of the fault type, incidence angle and location. The same tests were performed on three commercial devices models from two different manufacturers, including digital registers, fault locator IEDs and time-domain protection IEDs. All the 513 tests were performed with real waveforms, in order to verify the devices behavior in terms of fault location.

To exemplify voltages and currents calculated by PS Simul and injected into the IEDs, the signals obtained in the case of an A-G fault in 35% of a transmission line, with an incidence angle of 30º, are shown in Figure 2.

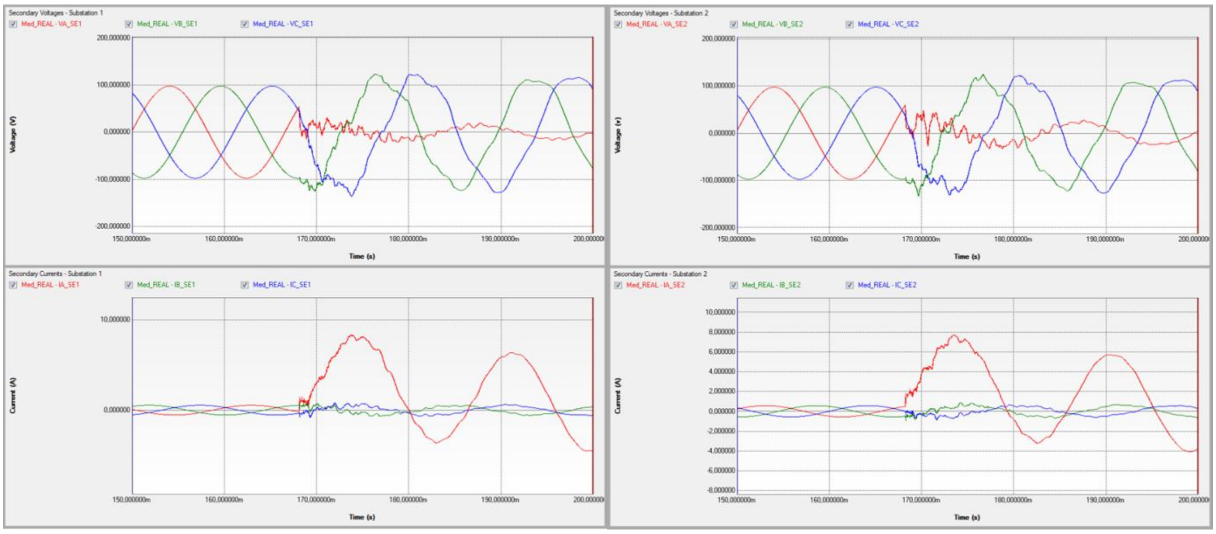

Figure 2 - Voltages and Currents – A-G fault at 35%

The graphs presented illustrate for each fault type (A-G – Figure 3, BC-G – Figure 4 and ABC – Figure 5) and theoretical fault location (5% to 95% - Step 5%) in the transmission line, a fault location error in meters. Each point on the graphs corresponds to the average error of three tests performed at same conditions. It is important to note that the repetition of each point is also intended to verify the IED repeatability.

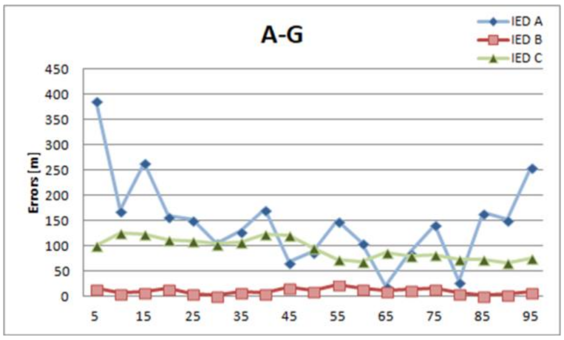


Figure 3 - Errors A-G fault

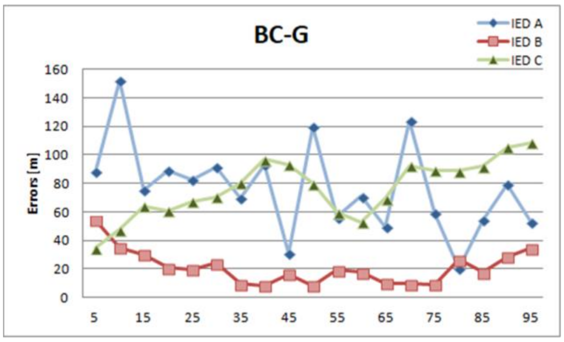


Figure 4 - Errors BC-G fault

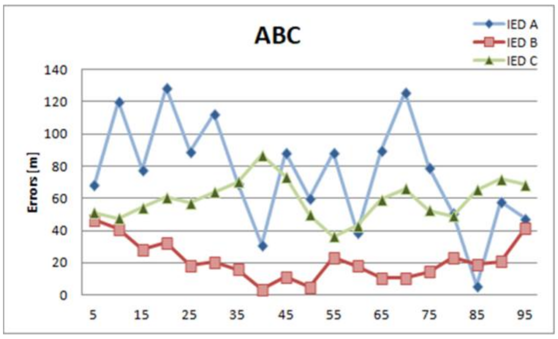

Figure 5 - Errors ABC fault

As expected, the location errors were too small, less than 0.4% of the line length for all devices. Most errors were less than 0.15% (150m in this case), which is smaller than one tower span. The fault location errors by the traditional method of calculation, through the measured impedance, were also cataloged. It was verified that these errors can reach the order of kilometers while the method based on traveling waves finds values in the order of meters. Figure 6 demonstrates the behavior of errors by impedance location method compared with errors by application of real TW waveform for A-G fault at IED B.

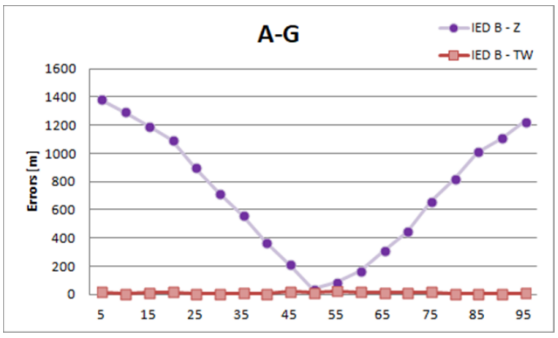

Figure 6 - Errors: Real TW x Impedance – A-G

The tests presented with the new methodology showed how important is to test the IED in conditions close to real ones, as this will be the scenario found by the IED on site. For this reason, the use of PS Simul was extremely important, as it has reliable models of electrical system components, resulting in realistic waveforms. In order to carry out the tests, it is not enough to obtain realistic signals, it is also necessary to have hardware capable of reproducing them. In this regard, the CE-TW1 proved to be a very powerful tool, due to its capacity to generate voltages and currents at the secondary level in megahertz.