NAME : Paulo Junior	GROUP REF. : B5
COUNTRY : Brazil	PREF. SUBJECT : PS2
REGISTRATION NUMBER : 11569	QUESTION N° : 2.09

The application of Travelling Waves for fault location and protection functions is advancing significantly. What are the main difficulties in testing these applications?

In testing applications of TW for fault location and protection functions, the simulated signal is splitted in two spectrums: 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).

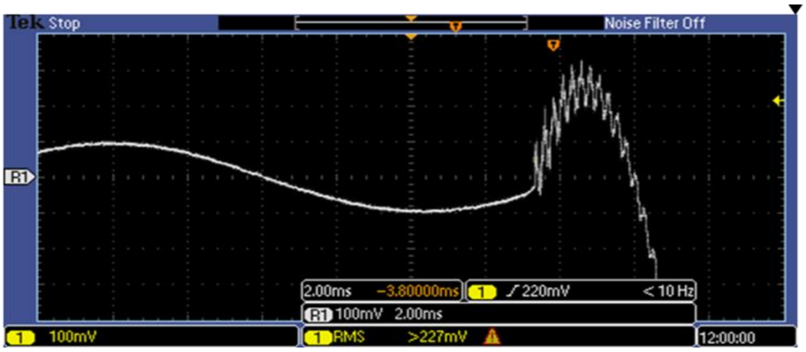

Figure 1 - High frequency in oscilloscope capture

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 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.

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.

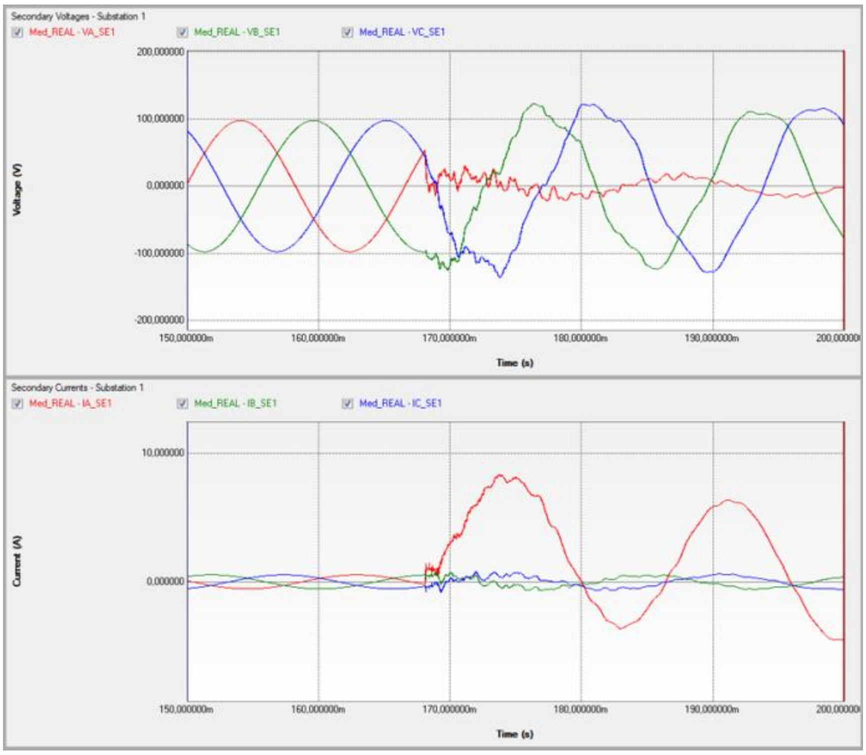

Figure 2 - Voltages and Currents – A-G fault at 35%

For information purposes, details are presented for the case of a BC-G fault in 45% of the transmission line. The voltages and currents simulated and later reproduced by the tests set, in addition to the records of IED protection actuations in this case, are shown in Figure 3.

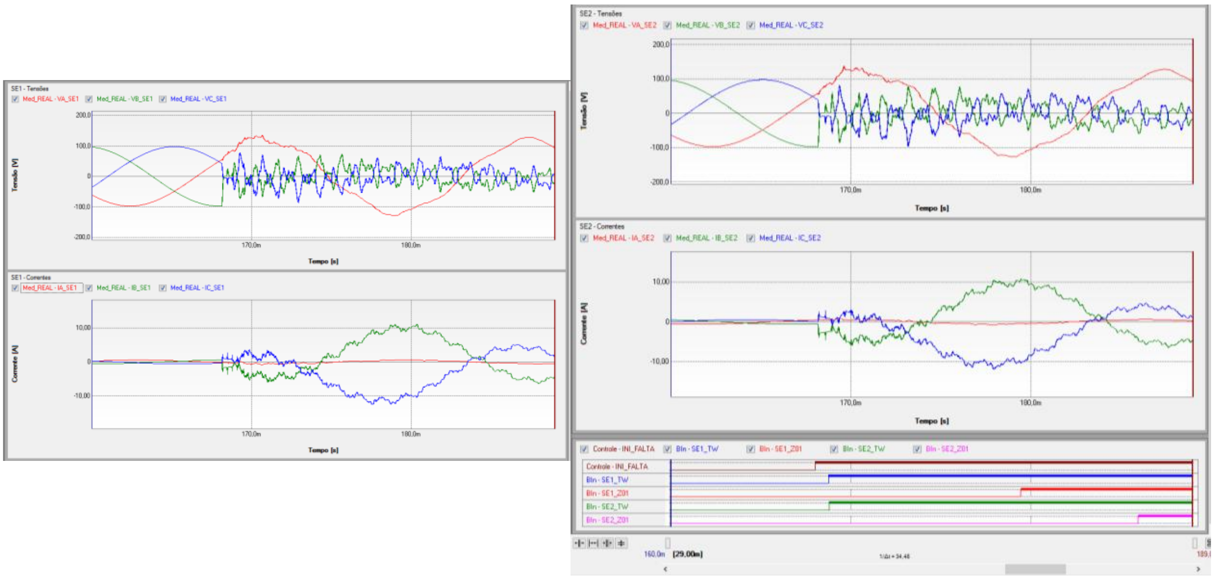

Figure 3 - Details: BC-G Fault in 45% of the Line

To meet the need of amplifiers with high frequency response, there are some models of universal test set: CE-6707, CE-6710, CE-7012 and CE-7024. The hardware capable of generating megahertz signals is the CE-TW1, which has 3 voltage channels with ±100Vpk and 3 current channels with ±7.5Apk. As the hardware works with a MHz digital-analogical converter, it is possible to generate any simulated signal that is within the working frequency range and the maximum secondary amplitude. Figure 4 illustrates in details CE-TW1.

FEATURE	CE-TW1
Simulation fidelity	Real waveform
Injection level	Secondary level
IED input test	Yes
Portability	Light weight
Test on site	Yes
COMTRADE with TW	Yes
Sensitivity test	Yes
Number of reflections	Several
Transmission line models for TW tests	Frequency-dependent line models (Mode / Phase)

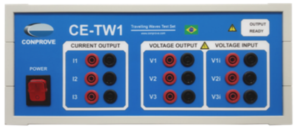

Figure 4 - CE-TW1 in details

Aiming to compare the actuation times of the protection function based on traveling waves with the traditional function 21, only the actuation times of zone 1 of the IEDs were evaluated. Only the actuations that occurred in up to 90% of the reach of zone 1 were considered, that is, 63% of the transmission line, because from this point, according to the manufacturer, the times can increase exponentially.

The graphics presented in Figure 5 illustrate, for each type of fault (A-G , BC-G, BC and ABC) and location of the fault (5% to 95% - Step of 5%) in the transmission line, the protections actuation times (based on traveling waves and based on impedance). Each point in the graphs corresponds to the average time of three tests performed under the same conditions. It is important to note that the repetition of each point also has the purpose of verifying the repeatability of the IED.

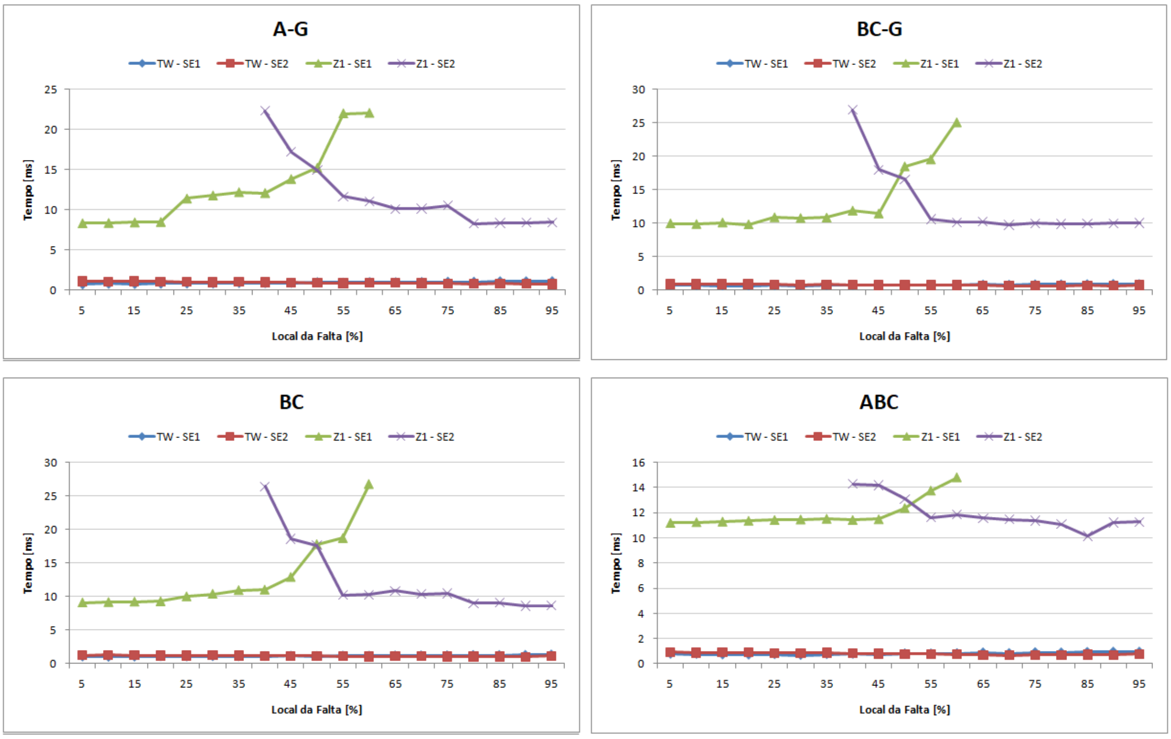

Figura 5 - Graphics for each type of fault

From the images, it is possible to verify that the actuation times of the traditional impedance protection function (21-Z1) vary with the fault location and are all greater than 8ms, while the protection function based on traveling waves works, mostly, with times below 1ms. Table 1 shows the minimum, average and maximum values of IEDs actuation times in the two substations for the protection functions based on TW and impedance.

Table 1 - Actuation times statistics

	SS1		SS2	
	TW	**21 (Z1)**	**TW**	**21 (Z1)**
Min [ms]	0,646	8,355	0,646	8,250
Aver [ms]	0,929	12,744	0,918	12,223
Max [ms]	1,341	26,757	1,306	27,035