Behavior of the protection system of Extra High Voltage lines in faults with resistance to ground

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***Abstract*- This article presents a study about the behavior of the EHV (Extra High Voltage) lines protection system installed in UTE. Our aim is to be able to detect errors on the distance algorithms of the protection equipment in order to consider them in the setting calculation stage. Usually this error is considered like a fixed percentage of the longitude of the line without taking in account neither the algorithm of the relay nor the characteristics of the electric system.**

At the same time we developed a set of programs using MATLAB® and its SIMULINK® library for studying phase to ground faults in a transmission line and the algorithms of the distance protection relays. When we could not get the algorithm we used voltage and current values which were obtained in the simulation for testing a real distance protection relay.

I. NOMENCLATURE

UTE - Administración Nacional de Usinas y Trasmisiones Eléctricas, Uruguay.

EHV- Extra High Voltage.

II. INTRODUCTION

When a phase to ground fault with resistance is produced in a line with bilateral feeding, the impedance seen by the relay can differ a lot from the impedance of the section from the line to the fault. This can cause a difference in the resistance as well as in the reactance that must be compensated by the relay calculus when estimating the distance to the fault. It is important to know this compensation for determining the settings of the distance relay zone so not to overestimate or underestimate the error of the algorithm. This was the main reason for our work.

III. DEVELOPMENT

In order to determine the behavior of distance relay's algorithms the first thing we did was to simulate a transmission line with bilateral feeding, where values of voltage and current seen by the relay during the fault are obtained. The protection system of lines of the EHV of UTE is mostly made up of distance relays from two different generations and manufac[1]turers: the first are of solid-state type and correspond to the PDTS 1453D model of ENERTEC Schlumberger [2], while the latter are microprocessor based relays of ABB, REL531 model [4]. According to the information brought up by the manufacturer about the relay algorithm we proceeded in different ways as it will be considered later.

A. *Simulation of the fault*

We used a simple model of the power system for the simulation of faults to ground in an EHV line. This model is made up by a distributed parameters line with two generators in both independent extremes (Fig 1), this was implemented in Simulink of Matlab®.

Real EHV lines were modeled. In order to do so we had to set the power system model in Simulink® with a short-circuit and power-flow program that is used nowadays in UTE and which has already modeled the whole Uruguayan electric system. The approximated Thevenin equivalent impedances were found with the short-circuit program, there we took off the line and we obtained the equivalents in the extremes. The values of the Thevenin sources, modules and phase angles were adjusted in such a way that the pre-fault voltages and currents would become similar between the results of the short-circuit program and the regime values of our Simulink® model.

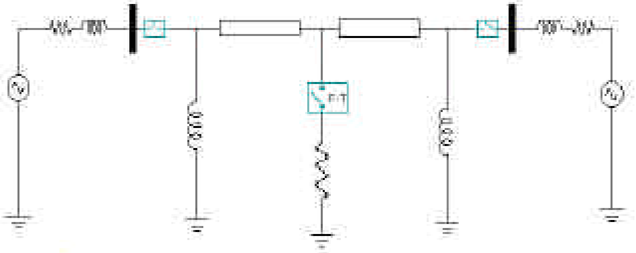

Fig. 1. Power system model used for the simulation in Simulink Matlab®.

Although the model considers two independent sources for simulating the feeding in both extremes (which is not correct for a meshed net) the comparison among the results we got allowed us to take this model like an acceptable one for our aims. The type of fault simulated was a phase to ground with constant resistance during the transient. Several simulations were made: varying the resistance of each fault, varying the location of it in the line and the previous conditions of charge, in order to obtain the currents and voltages of polarization of each relay and therefore determine the behavior of the protection system in the line investigated. To be able to perform these simulations we developed a set of applications in the GUI Modelred program (a software tool developed using Matlab 5.2). In the graphic user interface it is possible to

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This work belongs to the Final Project corresponding to the career of Electric Engineering, and it was directed by Jorge Alonso. It came to be because of the state made by the Protection Department of UTE about their necessity of having a more profound knowledge concerning the behavior of the Protection system for the EHV power system.

enter in a direct form all the parameters of the different components of the modeled power system as well as to obtain the currents and instantaneous voltages during each fault, moreover, it allows us to store the results in COMTRADE format. Fig. 2 shows the user's interface, where it is possible to appreciate some of the parameters and results obtained (voltages and currents).

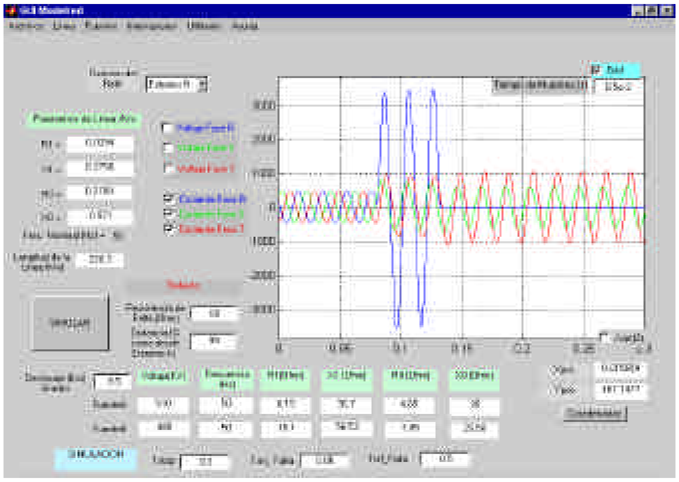

Fig. 2. User Interface of the application GUI Modelred.

The output of the GUI Modelred application are several files with the currents and voltages seen in both extremes. This allows us to separate the part of the net simulation and the protection system, and by doing so the data of currents and voltages are now easy to obtain either by this or any other application, or by using data obtained in registers installed in the electric net. It also allows the obtained files to be used in different simulations of the protection system or even to test a real relay.

B. Relay PDTS

After simulating the power system we tried to determine the behavior of the algorithm of the relay when facing resistive faults to ground with previous current. We particularly studied the possible over or under-reach that can appear in this kind of faults. To do so we did not take into account the characteristic in resistive direction (Fig. 3). In addition, only the behavior of the first and the second zone were studied. From this relay model we obtained abundant information about the algorithm being used and the way in which it is implemented. For the successful fulfillment of the analysis of this algorithm we followed two ways, the analytical and the dynamic simulation.

The analytic way, from the equations described in the relay manual, in which one can only work with phasors and not with instantaneous values. The electric power circuit was resolved analytically in order to obtain the currents and voltages that the relay sees during a phase to ground fault with a Rf resistance varying from 0 to 100 ohm. Afterwards these magnitudes were entered in the relay equations for determining if the relay trips in the first or second zone.

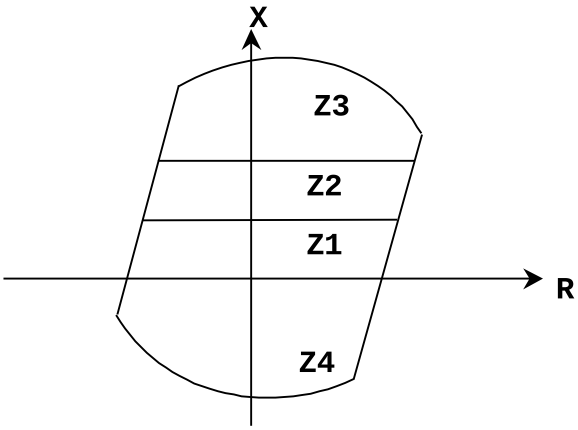

Fig. 3. PDTS distance relay operating principles (Static characteristic).

The algorithm used by the relay is the following: take the instantaneous voltage of phase A, for instance: **va**, is compared with the voltage **wa** in the passage of current $\mathbf{i_0}$ through 0, where: $\mathbf{wa = y\,[\,r\,(ia\text{-}i_0) + l\,(ia'\text{-}i_0') + l_0\,i_0'\,]}$, with **r, l** y $\mathbf{l_0}$ the parameters of the line and **y** the setting of the relay. Where **ia** and $\mathbf{i_0}$ are phase A and zero sequence currents, **ia'** and $\mathbf{i_0'}$ are the time derivatives.

The passage from $\mathbf{i_0}$ through 0 deletes the influence of the fault resistance, we take as an hypothesis that the current in the fault has the same phase than $\mathbf{i_0}$ seen by the relay, this applies if the factors of distribution of the zero sequence current have the same argument, which happens approximately in EHV nets.

If the **va** voltage is bigger than **wa** in the passage of $\mathbf{i_0}$ from the negative semi-cycle to the positive one, then the fault is placed out from the setting zone and vice versa.

It is seen that for low resistance the relay algorithm operates correctly. (Fig. 4). For high resistance in some cases we have wrong operations, although we must bare in mind that we are just modeling the reactive part of the characteristic of the relay. In order to get the total behavior we should also model

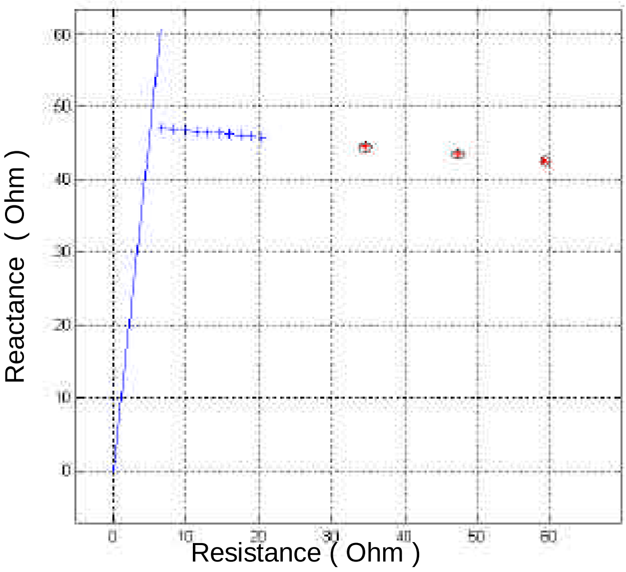

Fig. 4. Impedance seen in the fault, '+' does not operate, '**o**' shoots.

the resistive reach, which will limit the operation in the resistive axis.

The dynamic way. During the second stage we studied the dynamic behavior of the relay in the same power system used for the first analysis, but instead of using phasors we used instantaneous values. These values were obtained from the simulation of faults in the power system, just like it was explained before in *A*. The tool used was the Simulink Matlab with its power and digital library.

The relay operation principle was simulated based on the description from the manual (Fig. 5).

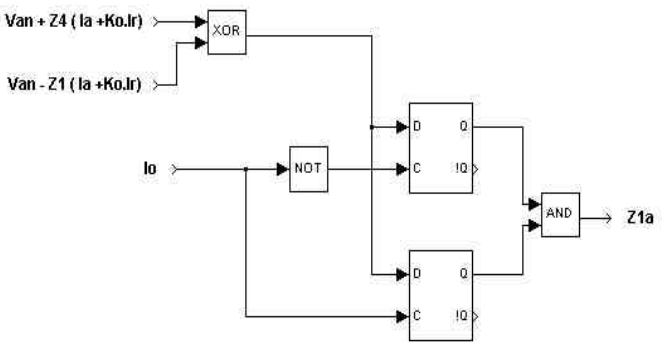

Fig. 5. Schematic model of the PDTS used in Simulink.

The relay works with squared waves, which are obtained from the analogous signals filtered. The filter generates a digital sign which value is "1" when the analogous sign of entrance is positive and "0" in the opposite case.

For the relay to recognize a fault in zone 1 the coming out of the flip-flops must be in logic level "1". In the case from the graphic, in Fig. 6, the relay recognizes the fault approximately about 30ms after the production of the fault in t = 80ms. In the same graphic we can appreciate the variation of the current and voltage in the phase A when the fault appears, in addition the binary signal of Trip is superimposed.

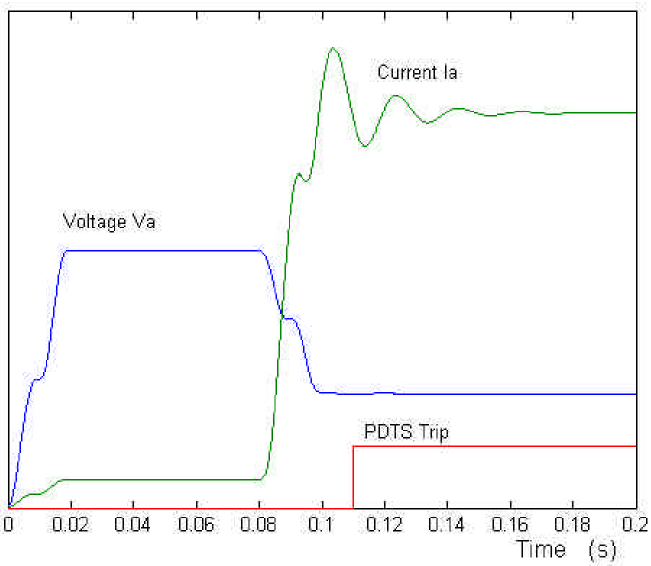

Fig. 6. PDTS trip, RMS current and voltage.

We evaluated the operation or no-operation of the relay when varying the resistance of fault and the previous current (importation and exportation). Moreover, we studied the validity of the following approximation, which was proposed by L. Mouton and M. Souillard [3].

What we did in this approximation was to correct the static characteristic of the relay with the angle that exists between the current of phase **Ia** and the one that circulates through the resistance of the fault **If**.

Table I shows one case of fault simulation (fault in 70% of line, exporting power), and the approximation to dynamic characteristic with zone 1 setting in 80% of the line. There we see the fault resistance, zone 1 trip, the fault impedance seen by the relay, the angle used to correct the static characteristic, and the limit of zone 1 in the reactance direction (X corrected).

In Fig. 7 is represented the impedance seen by the relay (a triangle if the relay has operated in Zone 1) and X corrected (a circle and a line). We can see that the relay tripped in all cases, although some of the fault impedances are over the limit proposed (X corrected).

TABLE I
FAULT F-T IN 70% OF LINE, EXPORTING POWER

Rf	Z1 Trip	Z seen (x + j y)		arg(If)-arg(Ia)	X corrected
0,01	Yes	4,8	42,7	-26,75	48,7
10	Yes	18,5	40,2	-25,5	42,2
20	Yes	30,2	37,9	-24,5	37,1
30	Yes	41,1	35,7	-23,7	32,7
50	Yes	58,9	32,0	-22,5	26,3
75	Yes	76,7	27,8	-20,9	21,2
100	Yes	90,6	24,3	-20,1	17,3
200	Yes	125,9	14,6	-18,3	8,6

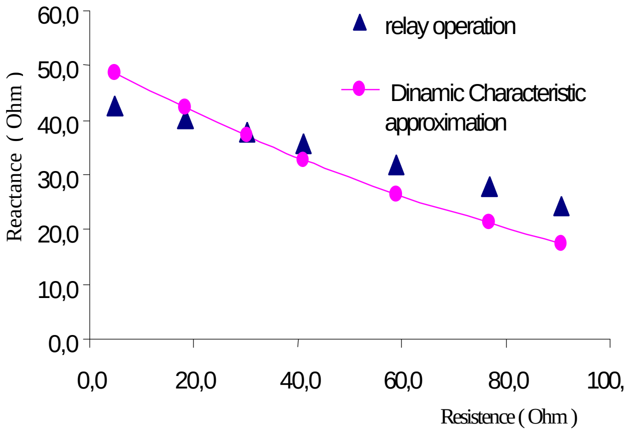

Fig. 7. Impedance fault seen by de relay and the approximated characteristic proposed by Mouton and Souillard.

We developed the application PDTS with the aim of evaluating the calculus characteristics of the impedance seen of the distance relay PDTS 1453D of ENERTEC Schlumberger. This is made up on one hand by the simulation file Simulink, and on the other hand by the graphic interface (Fig. 8), from which the data and adjustments for performing the simulation will be entered

Fig. 8. User's interface of the application PDTS.

This application needs, in order to perform their own simulations or calculus, the data of instantaneous voltages and currents during a fault. It is for this reason that before its usage it is necessary to run first a simulation in GUI Modelred.

As we saw above, the algorithm of the PDTS stays immune against the variations of the seen impedance caused by the resistance of fault and the previous current to the fault. This is proved for the rank of values of the interest resistance: 0 to 100 ohms approximately.

It is also observed that the correction used for the static characteristic of the relay proposed by L. Mouton and M. Souillard, can be used like a first approximation only for values of low Rf..

C. Relay REL531

Because the poor information available about the distance algorithm of the REL5XX relay of ABB we made some tests on a relay model REL531 for determining its characteristic of operation.

The working procedure was the following:

- We simulated different faults F+T in a line of 500kV and we obtained the currents and voltages seen by the relay. The tool used was Simulink of Matlab.
- With the obtained data in the previous stage we generated files within an IEEE Comtrade format.
- We set the relay according to the data of the line that was simulated.
- By using a test system we injected in the relay the voltages and currents contained in the Comtrade IEEE files.
- We analyzed the relay registers for determining the relay behavior.

The faults were simulated up to 75 % and 85 % of the line varying the resistance of fault and the extreme that exported power, while the relay was set up to 80 %. By doing this we were searching to determine how far the relay compensated the effect of the previous current when varying the fault resistance.

Table II is a summary of fault simulated. There we see the previous condition of power flow, the fault resistance, the fault impedance calculated in the moment of the fault following the formula ZV = Ua/ (Ia + Ko * 3Io), and zone 1 trip.

In Fig. 9 and Fig. 10 is represented the impedance seen by the relay (a cross if the relay operated in Zone 1 and a circle in the opposite case). We also used dashed lines for the interpolation of the impedance seen for faults up to 75 % and 85 % of the line.

TABLE II

Previous condition	**Fault location (%)**	**R fault**	**Z seen (R,X)**		**Zone 1 Trip**
Exporting	85	1	7,42	51,46	NO
Exporting	85	10	24,54	47,22	NO
Exporting	85	100	109,50	22,71	NO
Exporting	75	1	6,36	45,43	Yes
Exporting	75	10	19,97	42,73	Yes
Exporting	75	100	96,22	24,34	Yes
Importing	85	1	7,55	52,64	NO
Importing	85	10	27,10	61,46	NO
Importing	85	100	-112,41	747,74	NO
Importing	75	1	6,42	46,25	Yes
Importing	75	10	21,22	52,52	NO
Importing	75	100	217,36	438,45	NO

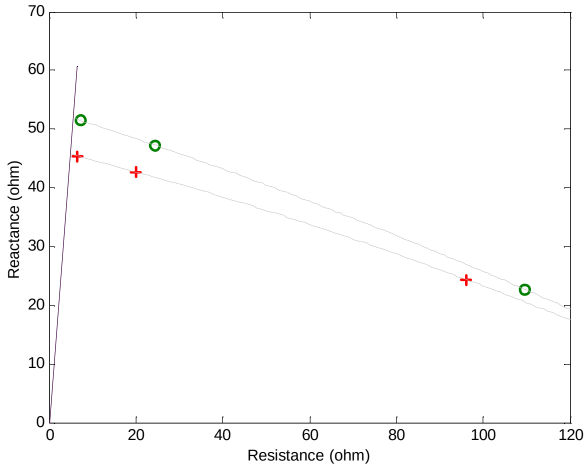

Fig. 9. Line exporting power.

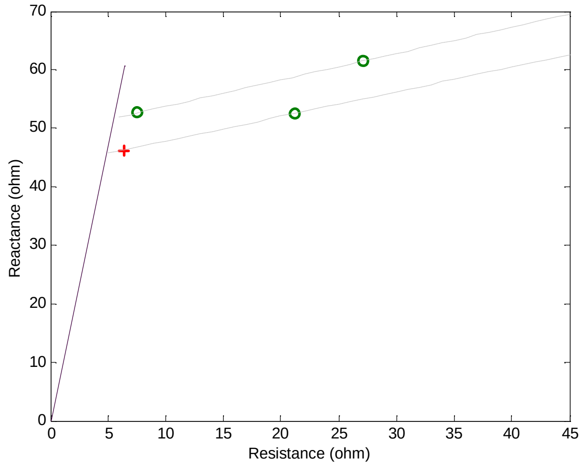

Fig. 10. Line importing power.

It is possible to see that whenever the relay is placed on the side of the exportation source of energy there are neither problems of under-reach nor problems of over-reach, because all the faults up to 85% stay out from zone 1, and all the faults up to 75% fall within zone 1. However, when we are in conditions for importation of energy the behavior of the relay is not that good any longer, it under-reaches for resistive faults. For the case of faults up to 75% with resistance of fault 10 and 100 Ω the relay sees them out of Zone 1, and for the faults up to 85% it behaves correctly.

With this research we determined that the relay algorithm only compensates the reactance when it exports energy, and not in the opposite case. As a result this is the model that will be used in future studies.

IV. CONCLUSIONS

The programs developed in Matlab are a tool for the study of the behavior of the protection system, and they allow us to anticipate to any possible miss functioning of the protections and therefore to correct them if possible. In these programs an operation of different distance relays is simulated, and in this way we can evaluate their behavior with different settings. This allows us to quantify the algorithm errors during different fault conditions in order to consider the error in the adjustment stage of the protections, or in an analysis of a real fault.

V. ACKNOWLEDGMENTS

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VII. BIOGRAPHIES

Fernando García was born in Montevideo, Uruguay, in 1973. He received his Electrical Engineer degree from the Universidad Mayor de la República Oriental del Uruguay, in 2001.

He joined the Administración Nacional de Usinas y Transmisiones Eléctricas (U.T.E.) in 1995 and worked in protection systems area since then. His main activity has been power system protection studies and projects.

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Jorge Alonso was born in Montevideo, Uruguay, in 1956. He received the Engineer and MSc. degrees all in Electrical Engineering from the Universidad Mayor de la República Oriental del Uruguay, in 1979 and 1998, respectively. Since 1980, he has been with the Institute of Electrical Engineering from the Universidad Mayor de la República Oriental del Uruguay, now as an Aggregate Professor.
Since 1979, he has been working for the Administración Nacional de Usinas y Transmisiones Eléctricas (U.T.E.), where he is currently a general manager of control and protection power transmission system section.
His main research and development activity has been on the simulation of numerical relays and the dynamic performance of electrical machines.

He is a member of the IEEE since 1987.