MORGAT for testing MV and EHV protective relays

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Abstract—**The development of new protective relays for electrical systems makes it necessary to update equipment testing devices. New digital relays operate faster and cover an increasingly broad frequency spectrum. Their acceptance and routine tests, the analysis of operating incidents and even the study of new principles require a tool that can generate transient currents and voltages accurately over a large bandwidth.**
Therefore, since 1985, Electricité de France (EDF) has used MORGAT, a simulator that allows tests of the EHV transmission protective relay. Since 1992, MORGAT allows tests of the MV protective relay. In view of the complexity of the transient modelling, it could appear that the integration of this code in the environment of a protection-unit test laboratory presented major difficulties. Nothing of the kind, since the original design integrates the automated management of the test data bases, the man-machine graphical interface, the plotting and the post-processing of the simulation results, which now allows an operator used to former analogue test benches to use MORGAT without any difficulty.
This paper present the new developments that now enable to test MV relays, and brings a feedback on how tests are performed. Finally, we introduce the computation of the apparent impedance in MORGAT.

Keywords—**Power System simulation, Real Time Digital TNA, Test of equipment, feedback experience.**

The development of protections for electrical systems makes it necessary to update equipment testing devices. New digital relays operate faster and cover an increasingly broad frequency spectrum. Their acceptance and routine tests, the analysis of operating incidents and even the study of new principles require a tool that can accurately generate transient currents and voltages over a large bandwidth.

Electricité de France (EDF) therefore developed the MORGAT program [2], [3]. Since 1985, it allows tests of the EHV transmission protective relay. Since 1992, it allows tests of the MV protective relay. In view of the complexity of the transient modelling, it could appear that the integration of this code in the environment of a protection-unit test laboratory presented insurmountable problems. Nothing of the kind, since the original design integrates the automated management of the test data bases, the man-machine graphical interface, the plotting and the post-processing of the simulation results, which now allows an operator used to former analogue test benches to use MORGAT without any difficulty.
The upgrade of new models (intermittent fault, voltage generator with a non-linear frequency, a non- linear amplitude, and a superposition of harmonics) allows MV and EHV transmission protective relay tests to more more convenient.

The object of this paper is to present new models included in the MORGAT sofware which offer the possibility to test both MV and EHV protective relays.

The first section presents two examples of new models, the second one explains how tests are organised, the third section introduces both the apparent impedance calculation and the real time tests.

I. New Models

A. *The intermittent fault*

Accurate simulation of rapid transients, as well as established non linear transients, is altogether indispensable in spite of their short duration or their generally localised effect on the power system to reproduce complex phenomena which can appear in certain network configurations and lead either to appreciable damage to equipment or even subsequent to the operation of protection systems, to cause a series of failures affecting extended parts of the electric system.
In fact, those phenomena can be modelled with the simulation of different faults or different switch drivings. The first model of fault was a simple fault but it is also necessary to have self extinguishing fault). When the fault appears the first time, it cannot be de-energised, and the second time, we assume that the arc is sufficiently stretched and it is de-energised when the current across it passes though zero. In fact, that sort of fault is a three phase element which may appear at different times on each phase. Thus, it can affect any number of phases simultaneously or one after the other. It can occur several time, repetitively the same fault with the same characteristics (post

sparking resistance (1,2), break voltage(1,2) and the time between 1 and 2 (cf figure 1 and 2)).

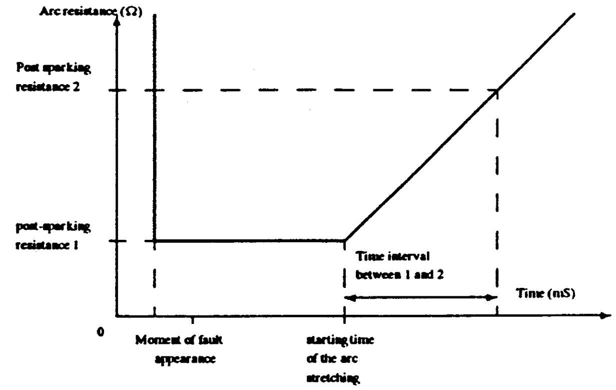


Figure 1. Variation in arc resistance with time

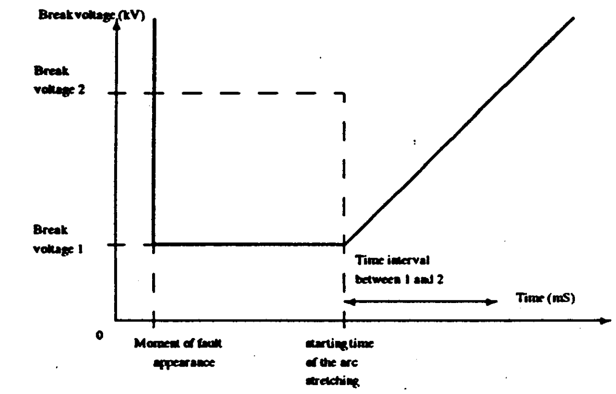


Figure 2. Break voltage variation with time

B. *The modulated voltage generator*

Instead of coupling a block diagram simulator to the MORGAT software to drive a voltage generator, which could lead to a complex simulator, it is easier to develop a model where the amplitude and the frequency will be modulated : this allows us now a lot of different test benches. The equations of the new models are the following :

$$E(t)=A(t)\cos(\omega(t)t+\Phi)+\Gamma(t-\tau_i)A_i\sum_{i=1}^{5}\cos(\omega_i t+\Phi-\tau_i)$$

- $A(t)$: instantaneous amplitude of the fondamental
- $\Gamma(t-\tau_i)$: step function ($\Gamma(t-\tau_i)=0$ if $t<\tau_i$, $\Gamma(t-\tau_i)=1$ if $t\geq\tau_i$)
- τ_i : harmonic delay i

This model can generate a non-linear frequency variation. In figure 3 : first a double of the frequency at 200 ms during 100 ms, second a steady state of 200 ms, third a decrease of the frequency at 500 ms during 100 ms and then to finish another steady state of 200 ms.

With that model, it is also possible to have a non linear amplitude variation. In figure 4 : first a double of the amplitude at 200 ms during 100 ms, second a steady state of 200 ms, third a decrease of the amplitude at 500 ms during 100 ms and then to finish another steady state of 200 ms.

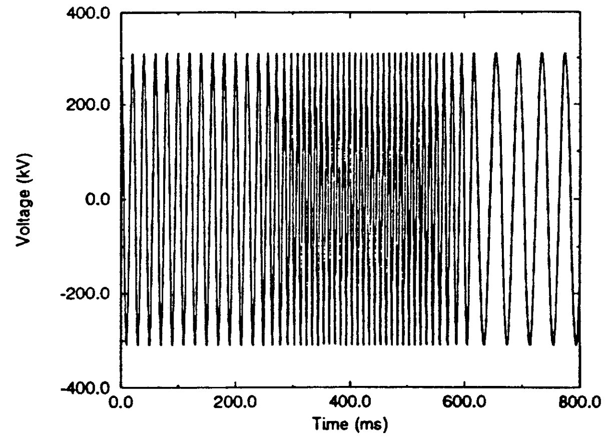


Figure 3. Scheme of a frequency modulation

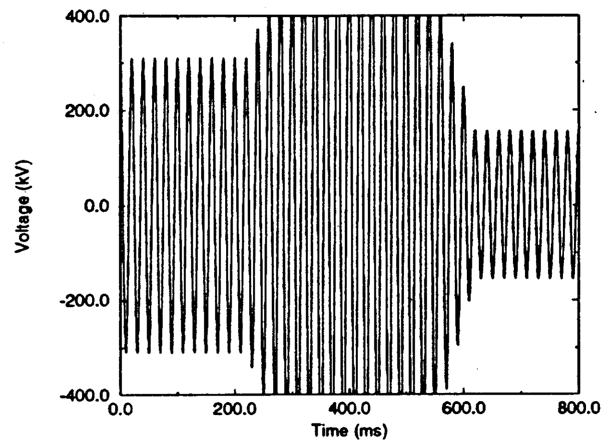


Figure 4. Scheme of an amplitude modulation

It is also possible to add five different harmonics to the fundamental, cf figure 5. In that figure, harmonics of range 3, 5, 7, 9 and 11 have been added.

Though, the principal use of that model is to represent the hunting of interconnected synchronous machines. Different frequency of hunting is possible. You can see in figure 6, a 1 Hz hunting and in figure 11 a 5 Hz hunting.

The continuation of the phase when the frequency is not constant imposes the model to be written in detail, that point proves it is not very easy to drive a generator by block diagram.

II. MV SIMULATION ON THE FRENCH SYSTEM

A. *A new protective relay on the French MV system*

The principal reason to upgrade MORGAT is to test new devices. For example, on the French MV system, we are changing our neutral grounding connection. The first reason is the development of the buried part of the combined overhead-underground networks which leads to an increase of the earth

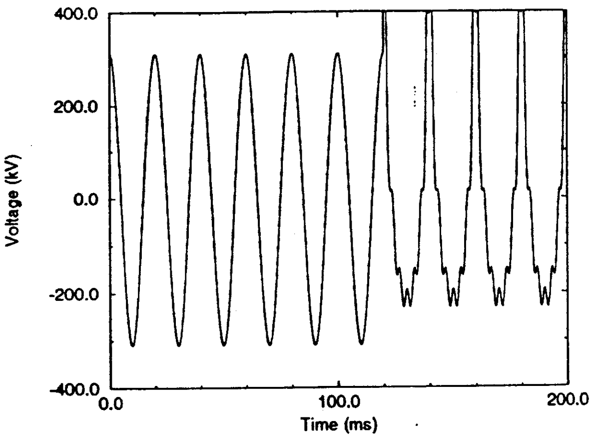


Figure 5. Scheme of an add of harmonics

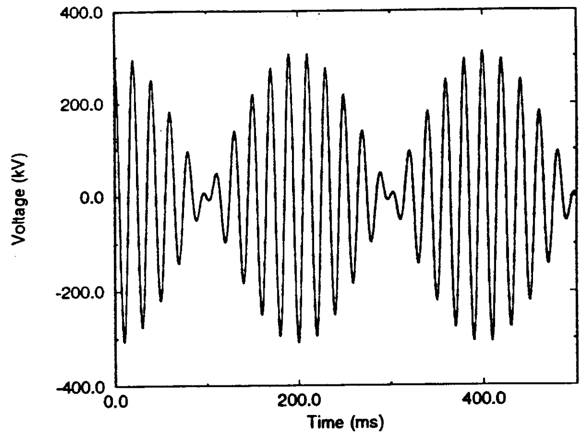


Figure 7. Scheme of a 5 Hz hunting

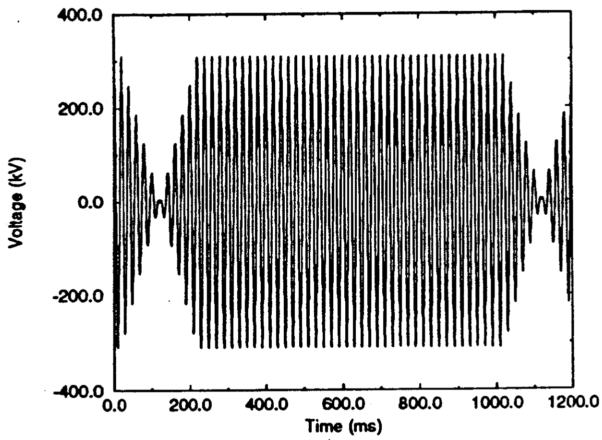


Figure 6. Scheme of a 1 Hz hunting

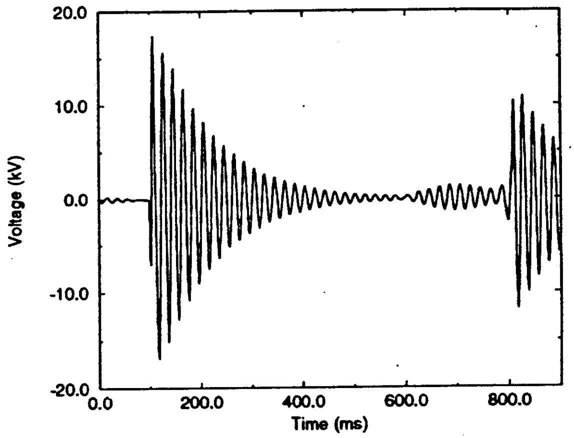


Figure 8. Zero sequence voltage observed during a restriking fault

fault current and the rise of overvoltages. The second reason is the development of new safety regulations and standards requiring electricity suppliers to reduce overvoltages. The adopted solution is the earthing of the neutral point by means of a compensating coil. The current in the compensating impedance cancels the effect of the currents generated by the MV network. In return, the compensation has modified the nature of the faults : most of them are now self-extinguishing and even restriking. On figures 8 and 9, you can see voltage and current during a restriking fault.

Even for permanent faults, the usual overcurrent criterion applied with networks earth by resistors is no longer valid. The faulty feeder does not necessarily have the highest residual current. For restriking faults (and of course for permanent 50 Hz faults) a new type of zero sequence wattmetric protection has been developed. The transient state correspond to the load of the zero sequence capacitors of the feeders and the coil inductance. There is a flow of positive energy into the sound feeders while the flow into the faulty feeder is negative.

B. The need of simulations

The observation of currents and voltages on figures 8 and 9 shows that it is not possible to do acceptance tests of these protections using only 50 Hz voltages and currents. Two ways are possible : to use records or to simulate the phenomenon. It is difficult to have records for a future device, so simulations are essential. For MV network protection tests, MORGAT is the center of our test facilities.

On figure 10, one can see that MORGAT is in relation with other devices :

- a data base where data are coming from MORGAT or from recording devices.
- the protection under test itself through DAC/ADC as shown on figure 11.
- Upstream MORGAT , works is done on MV networks to validate models in the frequency range of 0 to 1000 Hz [7].

After all, we are working on methods to help designers of protective relays from specification to acceptance tests.

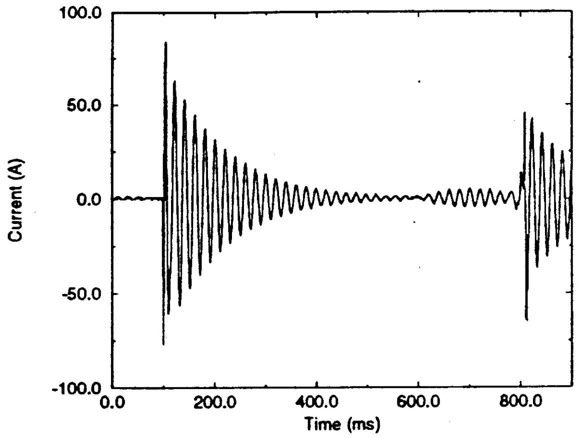


Figure 9. Residual current observed during a restriking fault

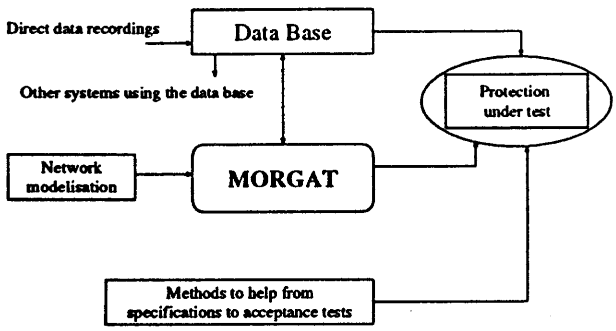


Figure 10. General organization of protection tests on MV networks

III. TESTING PROTECTIVE RELAY

Two ways are possible to test the protective relays (both are complementary) :

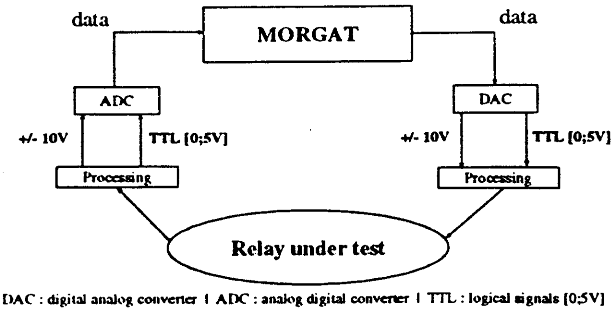
- a numerical off real time test if the characteristic is known
- the real time restitution and acquisition on the real equipment

The numerical test consists in the impedance calculation. MORGAT calculates the real and the imaginary parts of the impedance from the currents and the voltages at 50 Hz. Then the screen with the X(R) and the characteristic of the protective relay allows you to understand its dysfunction or its correct operation. Furthermore, it is possible to improve the static characteristic and to understand the dysfunction of a protective relay.

Although nothing can replace the real time restitution with the real equipment, MORGAT can restitute the currents, the voltages and logical values thanks to several DAC, filters and amplifiers. It is also possible to acquire analogic and logical values thanks to ADC from the real equipment.

A. Modelling of the apparent impedance

A fault appearance on the power system locally can be the cause of an impedance modification. That fault generally affects just a part of the system. Some relays are sensitive to an impedance modification. Each relay has its own template and its representation on a graphic allows the user to have a useful view of the different relay action areas.



DAC : digital analog converter I ADC : analog digital converter I TTL : logical signals [0;5V]

Figure 11. Configuration of a test protective relay

MORGAT is able to compute the apparent impedances of a line from couples of voltages and currents (Figure 12). It works on the fundamental components of each electrical value. The steady state frequency component is given by a Fourier transform.

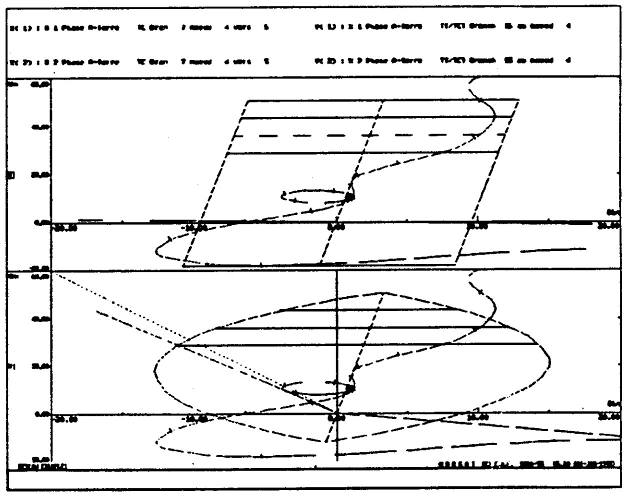


Figure 12. Scheme of an apparent impedances

The Figure 12 shows two curves representing the same apparent impedance with two different relay templates. First of all, we notice the appearance of the fault at about 10 ms. That is due to the half period of delay introduced by Fourier transformation. The first figure shows how the relay has a wrong action at time 67 ms which is not the case with the second one when the curve crosses another time the characteristic of the relay on the bottom left of the first figure. Furthermore, you can notice that the impedance curve is on the line impedance when the fault exists and that the fault appears at the third of the line.

B. How to test a real protective relay ?

Before beginning to test a real protective relay you must calibrate the whole loop. Our restitution chain allows restitution of 1 to 36 analogue quantities, with a band-width of [0 kHz ; 3 kHz] per channel. Digital to Analogue conversion takes place at a frequency of 10 kHz, with according the configuration a precision of 16 bits. It is also possible to allow a maximum of 64 logical outputs grouped by 16 bits. For the acquisition chain, it is possible to have a maximum of 64 logical inputs grouped by 16 bits. For the analogue quantities, you have 16 inputs with a 13 bits (including sign) resolution. First wiring of analogue channels, second calibration of the chains, third the real time test.

The analog outputs of the chain are connected to current or voltage amplifiers. If a simulated voltage is connected by error to a current amplifier, it could be damages. To avoid this kind of error, the software verifies each allocation by comparing the electric quantity type and the output amplifier one : if there is an incoherence between configuration file and wiring file, the creation procedure is automatically executed.

Calibration command allows to calculate amplitude variation and delays of voltage and current amplifies from restitution chain, and compensate after for the delay and gain drift of each amplifier. The calibration carries out two stages, the adjustment and the channel verification, which can be done, for example, before starting series of tests. If you have a restitution and an acquisition chain, the calibration is automatic. The delays and the gain variations are stored in a file and are used to correct signals automatically before their injection into each restitution channel.

Then the real time test. Before executing the test, you must initialise the restitution part : the dates of various ratings defining the restitution time window, the analog channels allocations and gains, the events and allocation of logical bits. For the acquisition part, the acquisition time window, the gain of acquisition analogue channels and allocations, allocation of logical bits. Those definition parameters are automatically saved and they can be proposed to initialise the test.

IV. Conclusion

MORGAT improves the simulation of fast, non-linear and high frequency phenomena. It is also the heart of a test bench, used intensively during several years for the qualification tests of protection devices by the EDF as well as by major international protection device manufacturers and laboratories working in the electrical energy field.

The program is in full maturity, with a development policy driven by the needs of its many users. A major step in its evolution will be the emergence of a fully digital and real time Transient Network Analyser (Digital TNA) [6], currently being developed at EDF's R&D Division. This new DTNA, MURENE, is a full real time simulator running on a multi-purpose parallel computer. Its interaction with different equipment as grid relays, grid control systems, generator relays and controls, power system control equipment and equipment prototypes will allow to check, in real time, the behaviour of those equipments before their installation on the real system.

MORGAT is used since 1987 to qualify the relays installed on the French EHV system and since 1992 to test MV protective relays. It especially allowed to study fast relay performances used on the 400kV grid as part of the 1986 French protection plan. Both distance and line differential relays were tested.

The program is also very useful to do some investigation tests on relays when problems appear. Its flexibility allows to analyse the protection device behaviour during ferroresonance, transformer inrush current phenomena or evolutionary faults (from monophase to polyphase). These phenomena were very difficult to represent with an analogue simulator.

Finally, the new technology digital relays are very sensitive to electromagnetic transients. A tool as MORGAT, and tomorrow MURENE, is therefore particularly well suitable for these relay studies.

References

[1] H.W. Dommel, " Digital computer simulation of electromagnetic transients in single and multiphase networks ", *IEEE Trans. on Power Apparatus and Systems*, vol. PAS-88, no. 4, April 1969, pp. 388-399.

[2] P. Bornard, P. Erhard, and P. Fauquembergue, " MORGAT : a data processing program for testing transmission line protective relays ", IEEE/PES, vol. 3, no. 4, October 1988, pp. 1419-1426.

[3] M. Jerosolimski, P. Erhard, D. Descause and J.Y. Boussion, " Real-time simulation of electromagnetic transients for interactive testing of power system relays and control systems : general trend at EDF ", in *Proceedings of the IEEE/NTUA Athens Power Tech Conference*, September 1993, pp. 732-737.

[4] M. Kezunovic, M. Aganagic, V. Skendzic, J. Domaszewicz, J.K. Bladow, D. M. Hamai and S.M. McKenna, " Transients computation for relay testing in real-time ", *IEEE Trans. on Power Delivery*, vol. 9, no. 3, July 1994.

[5] R.P. Wierckx, W. Giesbrecht, R. Kuffel and X. Wang, " Validation of a fully digital real-time electromagnetical transients simulator for HVDC system and controls studies ", in *Proceedings of the IEEE/NTUA Athens Power Tech Conference*, vol. 2, September 1993, pp. 751-759.

[6] M.Jérosolimski, D.Descause, O.Devaux, O.Huet, L.Levacher, B.Meyer, " A Real Time Digital Transient Network Analyser for testing Equipment on a general purpose computer ", *ICDS'95, First International Conference on Digital Power System Simulators*, April 1995, pp. 3-8.

[7] I.Mocanu, M.Meunier, P.Lasbleiz, A.Giard, " Aggregated model of distribution network during transients ", *IPST'95*, September 1995.

Biography

Alain MONTMEAT was born in France in 1966. He received his engineering degree from the Institut National Polytechnique de Grenoble, Ecole Nationale Supérieur de Ingénieurs Electricien de Grenoble, in 1989. He is at the R&D division of Electricité de France, where he works on power system simulation. He is the project manager of MORGAT.

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Jean ROGUIN is presently in charge of relay and automation systems on the EDF power system at the Generation and Transmission Division of Electricit de France. He graduated from Ecole des Mines de Paris in 1978. He began working in 1979 in the R&D division in the field of overvoltages and insulation coordination.