ACCELERATED PROTECTION (AP) SCHEME IN OVERHEAD DISTRIBUTION NETWORKS

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ABSTRACT

It is a new philosophy of protection in distribution networks, whose objective is to reduce, in an unconventional way, the sum of the operating times (exposure) of the protection equipment (reclosers and circuit breakers) on the short-circuit currents, while throughout the automatic reclosing cycle, maintaining the coordination of the protection system. From the protection point of view, this philosophy can be applied mainly in feeders that contain a large number of protection devices in series, which results in long operating times and exposure to fault currents, especially in devices further upstream in the feeders, with using conventional protection philosophies. Pilots of this new philosophy were applied, which presented satisfactory and even surprising results (in cases of broken cables), thus, resulting in a roll-out process of this philosophy in about 400 other devices protection in the utility grid, presenting good scalability due to possibility of its application in all models of IEDs of reclosers and circuit breakers of the utility that are found on the market. This scheme was elaborated and managed through the project called Urban Futurability, which consists of an R&D project performed at Enel-SP.

INTRODUCTION

With the large amount of new protection equipment (reclosers, automatic switches, etc) installed along the feeders, it resulted in the improvement of the SAIDI/SAIFI indicators, as it divided them into blocks of loads optimizing maneuvers (automatic or not), however, they caused new problems and unknowns of how to keep all this equipment selective or coordinated from a protection point of view.

Such unknowns arose, as the conventional protection (CP) methods of calculating parameters obtain chronological selectivity of curves with inverse time (between protection equipment – reclosers, fuses, etc) generate long operating times under fault current (fault exposure), especially when adding up all these operations in an automatic reclosing cycle (ANSI 79), mainly in equipment further upstream in a feeder. This, even tightening the minimum selectivity time to 0.2s between equipment, which is already risky in view of the practices of most other utilities, which use a minimum selectivity time equal to greater than 0.3s.

The Figure 1 shows a typical urban feeder from Enel-SP, with its main protection equipment (circuit breaker, reclosers and automatic switches) represented by red (equipment Normally Closed) and green (equipment Normally Open) squares, in addition to automatic switches working with automatic sectionalizer (green or red circles). It is worth remembering that before the execution of these investment plans, typically in an urban feeder, there was only overcurrent protection, the circuit breaker (allocated in the substation) and fuses in branches:

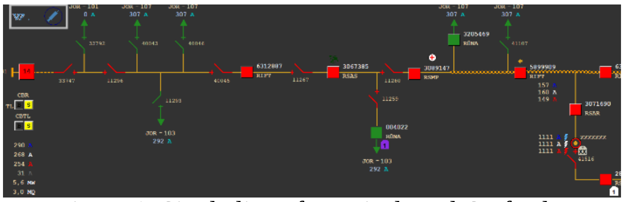


Figure 1: Single line of a typical Enel-SP feeder

Thus, although there are investment opportunities and desires (in view of the tariff review) for the division of load blocks, there is no more “space” in the coordinated protection system when using the Conventional Protection (CP) philosophy, especially in feeders of medium and short lengths with concentrated loads (urban locations).

Therefore, there was an unavoidable and urgent need to develop a new protection philosophy which results in the reduction of the total time of operation of the overcurrent functions, during a complete cycle from reclosing to tripping and blocking. This, for each protection equipment installed along the feeders, simply, locally, with good scalability and without the need for additional infrastructure, such as tele-protection.

This work is the result of the ANEEL Urban Futurability R&D project of ENEL Distribuição São Paulo, which aims to digitize the electrical network, both overhead and underground, incorporating the most modern techniques and network automation trends into the system, providing the concept of living-lab in the area with the highest electrical density of its concession.

DEVELOPMENT

The philosophy called Accelerated Protection (AP) was designed to reduce the times that consisted of the return of instantaneous trip (or fast curve) in the last trips of a reclose cycle (79) under a fault, after the first two trips (1st operation - Instantaneous conjugated with timed (slow curve) and 2nd op. - Timed (slow curve) Thus, in the Conventional Protection (CP) scheme uses the reclose cycle with operation sequence ITTT (1st Instantaneous; 2nd Timed; 3rd Timed; 4th Timed), and the proposal (AP) is ITFF (1st Instant; 2nd Timed; 3rd Fast; 4th Fast), according to table 1 below:

Table 1: Settings of Overcurrent Functions Over a Function Cycle 79

Trip Sequence	Conventional Protection	Accelerated Protection
1st	50/50N or 51/51N Slow Curve	50/50N or 51/51N Slow Curve
2nd	51/51N Slow Curve	51/51N Slow Curve
3rd	51/51N Slow Curve	51/51N Fast Curve
4th	51/51N Slow Curve	51/51N Fast Curve

The idea is that if the fault remains after the second timed trip (inverse-time slow curve), it means that the fault is not beyond some device just downstream, since such curves are dimensioned to obtain selectivity with all downstream devices. Thus, according to reference (1) as long as it is verified that the other device is not involved in the occurrence, then in the next following reclosing of the same cycle 79, there is no need to wait for the respective times of such slow curves to act for a fault which is located in the stretches of its main protection coverage zone.

The calculation methodology for all overcurrent functions (50/50N 51/51N) is similar to the conventional method for obtaining selectivity between devices, as typical examples outlined in reference (2). It is worth mentioning that the fast curves used in the last trips (phase and neutral) are equal in dial and time values between the devices.

For this philosophy, each device also uses the timed negative sequence overcurrent function (Function 46), with the objective of faster tripping for two-phase faults (the most critical type of short circuit for cable oscillations in sections upstream of the fault, due to the characteristics and resultant of magnetic forces for this type of current). The calculation methodology adopted to obtain the trigger parameters and curves was according to the reference (3) described in the bibliography of this work.

Examples of operation

Figures 2 to 4 show some examples of operation or performance in two protection devices in series with this AP philosophy proposed and implemented in both.

Example 1: Fault beyond downstream device R2

Device trip sequence per reclosing cycle:
R1: 1st op. 50/51; 2nd op. 51; 3rd e 4th op. Fast Curve

R2: 1st op. 50/51; 2nd op. 51; 3rd e 4th op. Fast Curve

Figure 2: Single-line and parameterization in R1 and R2 of Example 1.

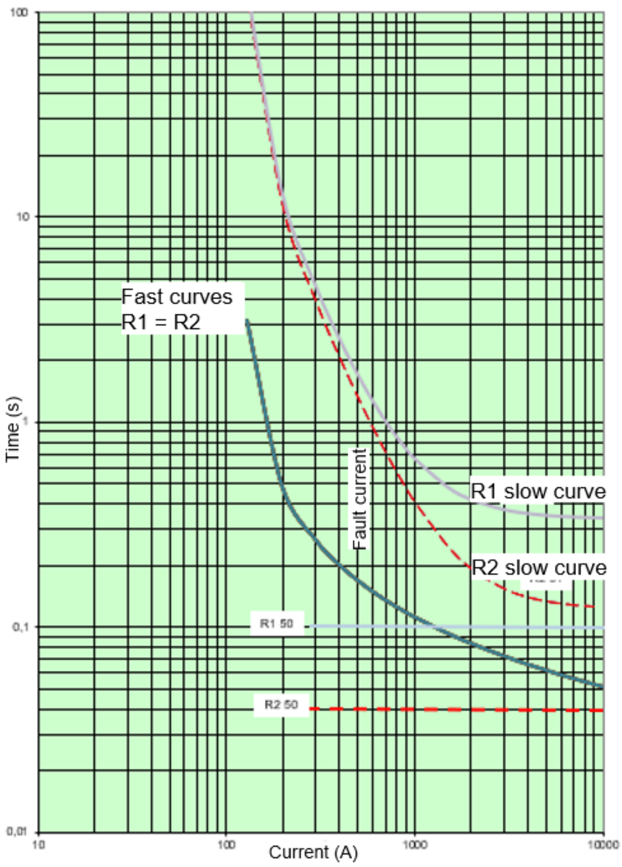


Figure 3: Protection Coordinogram of Example 1.

Cycle operation (Scc = 600A)

1st R2 - trips by 50 and recloses
R1 – doesn't trip and advances to 2nd op. (ZSC)

2nd R2 – trips by 51 in 0,95sec and recloses
R1 – doesn't trip, due its 51 function is selective w/ 51 (R2

3rd R2 – trips by Fast curve in 0,15sec and recloses
R1 – doesn't trip, due its 51 function is selective w/ Fast-cu

4th R2 – trips by Fast curve in 0,15sec and goes to lockout
R1 – doesn't trip, due its 51 function is selective w/ Fast-cu

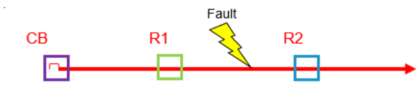
Sum of total time for trip (throughout the sequence) under fa

Conventional Protection = 2,85s Accelerated Protection = 1

Decrease of 56% of the total time.

Figure 4: Description of the sequence of trip operations and reclosing function of Example 1.

Example 2: Fault just beyond device R1



Device trip sequence per reclosing cycle:
CB: 1st op. 50/51; 2nd op. 51; 3rd e 4th op. Fast Curve

R1: 1st op. 50/51; 2nd op. 51; 3rd e 4th op. Fast Curve

Figure 5: Single-line and parameterization in CB and R1 for Example 2.

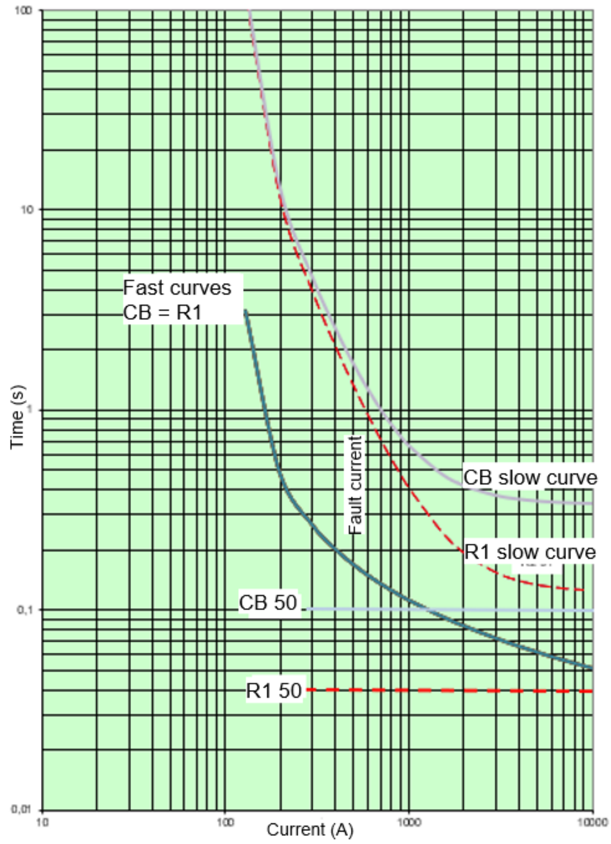


Figure 6: Protection Coordinogram of Example 2.

With these parameterizations and Coordinogram the operating cycle between CB and R1 will be similar to the devices described in example 1, which considering a Sci level of 1200A we will have the results and time gains (from the AP in relation to the CP) as illustrated in Figure 6.

Sum of total time for trip (throughout the sequence) under fault

Conventional Protection = 3,55s Accelerated Protection = 1,65s

Decrease of 53% of the total time.

Figure 7: Description of the sequence of trip operations and reclosing function of Example 2.

The proposed philosophy results in the sum of the times that the protection takes to trip and isolate a permanent short-circuit fault, with lower values compared to conventional philosophies. Table 2 shows a comparison of these protection trip times between the conventional protection philosophy (CP) and the proposal (AP) that aim to accelerate protection:

Table 2: Comparison of trip and lockout times between CP and AP schemes, as well as AP gain.

Fault (A)	**t(s) – (PC)**	**t(s) - (PA)**	**Δt (s)**	**Gain %**
180	64	33,22	30,78	48

300	15,6	8,34	7,26	47
600	2,85	1,25	1,60	56
1200	0,96	0,52	0,44	46
2500	0,51	0,33	0,18	35
3500	0,45	0,29	0,16	36

This philosophy results in shorter exposure times to short-circuit currents (Scc), reducing stress on network equipment as follows:
• Integrity of Cables, insulators, spacers and structures
• Broken cables
• Connections and jumpers
• Power transformers (SE)
• Physical oscillation of phase cables in long upstream spans (generator of new faults)

The AP Philosophy can be applied to any equipment that has a multifunction digital protection relay that is on the market. In this way, at Enel-SP, files and logics based on this AP philosophy were prepared and tested in the laboratory, for all relay models (of reclosers and circuit breakers) that were already installed in the feeders chosen as pilots, before the conception of this philosophy:

• Tavrida – RC05 Model
• Noja - RC10 Model
• Schneider – ADVC2 and 3 Model
• SEL 751 / 751-A Model
• Cooper - Form6 Model

In the laboratory, we tested the functionality with the equipment connected in series with their respective tanks (switches) on a platform that simulates the network with a voltage of 13.8kV, in order to verify the performance (time) of the openings of the set (relay - key) of the equipment which may vary between models, as well as whether the selectivity time of 0.2 (considered low) between the timed functions (51/51N/46) is satisfactory.

Subsequently, these logics were implemented in 10 feeders since Nov/20, where we can prove the theory, and collect the results that resulted in a Roll-out in more than 400 devices.

CONCLUSION

As previously mentioned, the proposed philosophy was implemented as a pilot in 10 distribution feeders of Enel-SP, comprising around 50 protection devices from different manufacturers.

After 12 months of implementation, the performance results were collected according to the table 3, where there were a total of 113 occurrences of faults in the zones/sections protected by the proposed philosophy, to certify the integrity of the selectivity between the device (due or undue outages) for defects beyond some other downstream. This is because all devices (even in series) work with the same fast curves (STI curve with the same time dial values) on the last recloses:

Table 3: Mapping of occurrences in the sections covered by the AP.

Fail	Success	Partial Success	Fail
Downstream Recloser	76	15	2
Downstream Fuse	84	0	0
Downstream Breaker	2	1	0
Total	162	15	2

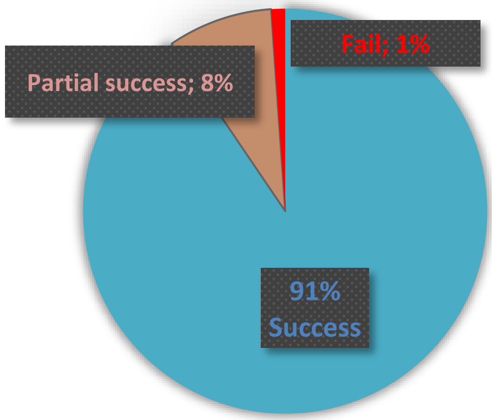


Figure 8: AP performance statistics.

Table 4: Description of items from figure 8.

Success	Only main device tripped
Partial Success	Main device isolated the fault, but upstream device tripped and reclosed
Fail	Upstream device also tripped and blocked

Table 5: Description of occurrences classified as Partial Success and Failure.

Fail	Causes	Quantity
Partial Success	Recloser with unplanned field adjustment	10
Partial Success	Breaker with unplanned field adjustment	1

Partial Success	Recloser function failure (79)	1
Partial Success	Fault beyond fuse whose field value was higher than planned	1
Fail	Electromechanical relay emulator function enabled on the upstream device, which resulted in selectivity time <0.2s	2

All these causes could be solved and corrected in the field to avoid new improper trips of the device.

Figures 9 shows the results regarding the performance of the devices parameterized with AP in relation to tripping/lockout or not for broken cables (High Impedance Fault - HIF) for the same pilot observation period, as well as a comparison, Figure 10 shows the devices that remained parameterized with CP and that are installed on the same feeders, but in different sections.

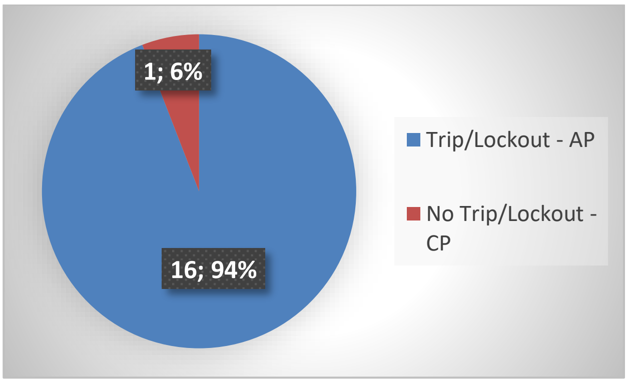


Figure 9: AP performance for HIF cases.

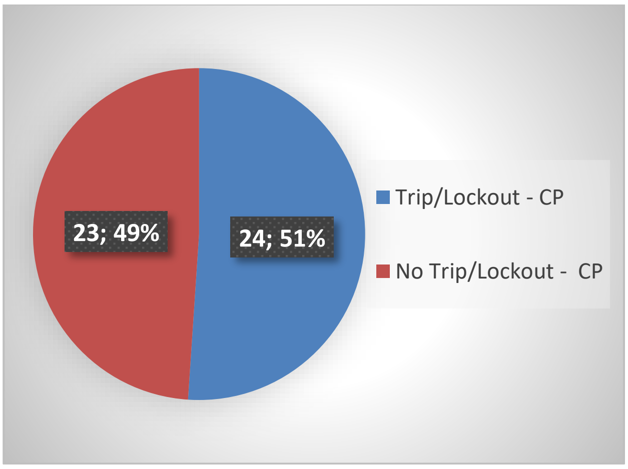


Figure 10: CP performance for HIF cases.

Comparing the data from Figures 9 and 10, we can observe that the AP scheme presented better efficiency than the CP in disconnecting (tripping) and isolating (lockout) occurrences with broken cables (HIF).

Therefore, based on the results presented, we conclude that the proposed philosophy entitled Accelerated Protection is a viable and applicable solution for any protection device equipped with a multi-function digital relay, since such device is usually found on the market. Therefore, it can be implemented in any overhead distribution feeder of any utility, which work with automatic reclosing, thus presenting a high potential for scalability.

It is noteworthy that this philosophy works with local logics in the device/IED, and there is no need for communication (tele-protection) between them.

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