POWER QUALITY IMPROVEMENT IN DISTRIBUTION SYSTEMS BY MEANS OF OPTIMIZATION OF THE PROTECTION AND CONTROL SYSTEM

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1. INTRODUCTION

The present scenario in which Electric Distribution Companies supply their service in Argentina, is within a regulatory framework that has led utilities to implement new technological solutions in medium voltage distribution. Such solutions are strongly oriented towards the improvement of customer service, reflected by quality indexes. The present paper is focused on the technical solution adopted by EDEMSA (Empresa Distribuidora de Electricidad de Mendoza S.A), which has incorporated a massive number of state-of-the-art reclosers (270 in the last two years), teleoperated from a unique control center and whose operation is coordinated by means of circuit breakers, fuses and reclosers at the output of Transformer Stations.

A comparison of quality factors, expressed in frequency of power outages and average outage times (FMIK and TTIK) which were taken before and after the equipment implementation, will be offered here. An evaluation of results obtained in that period and investment recovery through the reduction of penalties from power outages, is also presented.

2. POWER QUALITY. MARKET DEMANDS

The quality of the electricity supply service offered to customers is EDEMSA’s main objective and central axis guiding most investments and the implementation of new technology in the medium voltage network. No doubt, this is a common objective for all Electric Distribution Companies that have been privatized in Argentina in the last few years, whose supply is regulated through their respective franchise contracts.

The internal need to improve power quality in order to avoid penalties applied by the State Regulating Institution, has been enhanced by an increased customer demand for quality and response from distribution companies since they were privatized.

As a consequence, EDEMSA has set as its main technical management objective the improvement of service by keeping power outages as short as possible and by delimiting them to the smallest possible area. In order to reach this objective it was necessary to carry out a Protection and Control Engineering study encompassing selectivity studies on the distribution network protection devices and an analysis of the optimum location for said equipment while limiting the affected powers in case of permanent faults. The FMIK parameter (Mean frequency of power outage per installed kVA) and TTIK (Total Time of power outage per installed kVA) which determine service quality indexes to be considered by the State Regulatory Institution, depend directly on the power interrupted at the moment of a fault.

The following formula is applied to calculate FMIK and TTIK values:

Where:

$KVA_{fs}$: Amount of rated kVA out of service in each of the “n” power outages undergone by the feeder.

$FMIK = \frac{\sum_{i=1}^{n} KVA_{fs}}{KVA_{inst}}$  \hspace{1cm} (1)

$TTIK = \frac{\sum_{i=1}^{n} KVA_{fs} \times T_{fs}}{KVA_{inst}}$  \hspace{1cm} (2)

$KVA_{inst}$: Amount of rated installed kVA in the feeder.

$T_{fs}$: Duration of power outage

Limits per semester on these indicators for MV feeders are as follows:

<table>
<thead>
<tr>
<th></th>
<th>URBAN</th>
<th>RURAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMIK</td>
<td>2.5</td>
<td>5.0</td>
</tr>
<tr>
<td>TTIK</td>
<td>2.0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

As indicated in each case, it is obvious that the variables that participate in the calculation of these parameters are the interrupted power in each opening and the duration of each power outage.

It was therefore necessary to reduce the interrupted power in each fault opening by means of the incorporation, in the first place, of a recloser at 50% of each feeder’s power and another one at the linking points with neighbouring feeders.

Moreover, to improve power outage times and conduct restorations from remote locations, the solution chosen was teleoperate each one of the pieces of equipment. A quick restoration of service at the 50% power of the “healthy” feeder by means of operations carried out in real time from the unique center of operations must be carried out.

Taking into consideration the kind of faults in the network the best possible clearing schedule and its coordination were determined in order to reach maximum selectivity.

3. FAULT TIMES IN AERIAL DISTRIBUTION SYSTEMS
In general, MV distribution networks have a radial structure and because of their characteristics they have a set of in-series protection elements that must be regulated so that they meet the objectives for which they were designed [1], namely:

- **SELECTIVITY**: It should activate only the circuit breakers in the faulted segment to isolate the troubled segment but not other segments.
- **SPEED**: The system must isolate the fault as quickly as possible.
- **RELIABILITY**: It is the system capability to perform its function adequately. In other words, it must only act at the right times and not when it is not necessary.

In practice, it is often difficult to satisfy in an optimum manner the three above-mentioned requirements since sometimes satisfying a requirement might cause problems to meet the rest of them.

### 3.1. Temporary and permanent faults

Most faults in aerial distribution systems are temporary (between 70% and 80%). Besides there are permanent faults, of which at least a third has been initially temporary, that is, they have decreased after a few cycles to a few seconds.

A TEMPORARY fault is one whose cause is transitory in nature. If the arc produced by the fault current can be quickly cleared before it becomes a permanent fault, the circuit can be immediately re-energized and service restored to the whole system. Temporary faults can be classified in:

- **SELF-CLEARING FAULTS**: These faults disappear spontaneously in a short time and do not cause the activation of protection relays.
- **FUGITIVE OR PASSING FAULTS**: They are faults that need a brief opening of the circuit breaker to disappear. They can be cleared by means of a quick reclosing.
- **SEMIPERMANENT FAULTS**: They need a long opening of the circuit breaker to disappear. They can be eliminated by means of a slow reclosing.
- **A PERMANENT fault occurs due to the fault’s cause itself or because of its own arc. When there is a permanent fault, the line must be de-energized.**

Maximum service reliability is achieved when the distribution system is designed and operated to minimize the effects of any temporary fault that might happen. Given the high percentage of temporary faults, two basic rules for distribution protection must be observed.

1- All faults should be given the “possibility” of being temporary faults by allowing a reclosing operation to isolate said fault.

2- In answer to the low percentage of faults that become permanent after a certain number of reclosings, the protection device must only remove from service only the smallest portion of the system in order to isolate the faulted segment.

### 3.2. Service experiences

Information published by EDF [2,3] for medium voltage networks and based on a sample size of 20,000 faults, have allowed the elaboration of statistics that group faults according to their nature.

**Fig. 1: Fault Type Statistics (source: EDF)**

Besides, 65 to 75% of temporary faults are single-phase. Conclusions about the most common causes and characteristics of faults in Mendoza can be drawn from power outage distribution and their causes in the EDEMSA system (year 2000 statistics). See Fig. 2.

### 4. SOLUTIONS IMPLEMENTED TO OPTIMIZE SYSTEM AVAILABILITY.

The implementation of two groups of curves (fast and slow) for the reclosing signal in relays and reclosers was thought as a way of clearing all faults that might happen in the system, while affecting the smallest possible distribution portion in each fault.

In the instance of transitory faults both, in the trunk and in branch lines, one or two quick reclosings can isolate them without causing power failures in the feeder [4].

In the case of permanent faults in branch lines, the slow curve of relays or reclosers enables the branch fuse to act, thus causing a power failure only in the affected branch and in the smallest possible portion of the feeder.

**Fig. 2: Distribution of power failure causes in the EDEMSA system**
In order to achieve an implementation plan for all overhead feeders of the company in the short term, the following basic principles have been adopted:

4.1. Fuse Standardization

Drop-out fuses used for the protection of line derivation branches have been standardized to three sizes. Sizes used are 80T (usually for starting at the beginning of the feeder); 30T (for mid-power starting) and 20K (for end-of line starting).

As a principle in the application, only branches having more than three substations connected to their route are to be protected with fuses. The starting of branches with fewer than three substations were by-passed.

Fuses on the feeder trunk were eliminated to allow the free action of reclosers in case of any feeder faults.

Fuse coordination at line derivations was calculated according to the shortcircuit and not to the overload (as it used to be), to let them act selectively with station reclosers and reclosers.

An identification plan for field operation apparatus was implemented according to a unique code and indicating the size and kind of fuse utilized.

This way, there is a reduction of stock material in store rooms and reposition mistakes by maintenance shift personnel are minimized.

4.2. Recloser implementation

A massive implementation of relays with reclosers to protect all air-type feeders was carried out. This configuration can isolate transitory faults in the first feeder half without causing permanent openings in the head circuit breaker [6].

4.3. Reclosers

In the last two years, 270 telecontrolled/teleoperated reclosers were installed and commissioned.

This equipment was used at 50% power of each distributor to protect the last feeder segment and at least at one limit point with other feeders placed upstream from the protection recloser. The latter linking equipment allows a quick restoration of the final 50% of feeder when facing a permanent fall in the first half, by means of their remote operation.

4.4. Isolators/line breakers

Use of isolators/line breakers in startings where fuse coordination is impossible because of their available sizes. These isolators/line breakers work in coordination with reclosings of reclosers and relays.

5. QUALITY INDEX IMPROVEMENT STUDY

In the study of quality index improvement and penalty payment due to not-supply energy (NSE) for longer-than-three-minute power outages, the following fault distribution hypotheses were formulated:

- Faults uniformly distributed all over the feeder.
- 80% transitory faults and 20%permanent faults.
- 100% selectivity of the system.

5.1. Estimation of improvement in the NSE.

5.1.1. Initial Condition. In the scenario previous to the implementation of the telecontrol system, where there was only one protection point, without reclosing, on the line head, the circuit breaker opened in a permanent manner in 100% of feeder faults. Besides, resetting had to be performed locally.

In this case, the fine or penalty for NSE corresponds to the M1 value and can be equated to 100. In this case, the penalty to be paid was M1 = 100

5.1.2. Addition of recloser. If this relay is provided with an automatic device to make reclosings, or by a remote telecontrol action, the device will definitely open the circuit breaker with the total feeder power only for permanent faults, that is, 20% of the times. The remaining 80% corresponding to transitory faults is cleared by the action of the recloser. In that case, penalties for NSE are cut down to 80%. That was the situation before the initiation of the project. The target desired was reduce that value in at least 50%. Penalty to be paid:

\[ M_2 = 0.2 \times M_1 = 20 \]  

5.1.3. Adding a recloser at 50%. By placing of a telecontrolled recloser at 50% feeder power for permanent faults in the last section of the feeder, penalty for NSE have a 50% reduction. In the case of permanent faults in the first half, penalties are the same as in item 5.1.1. (M1). If a uniform fault distribution has been considered in the hypothesis, the penalty to be paid is 25% lower than M2.

Penalty to be paid:

\[ M_3 = 0.2 \times M_2 + 0.1 \times M_2/2 = 15 \]  

(The factor “2” affecting M2 means that the total number of faults is divided in two halves in each feeder portion)

5.1.4. Addition of a linking recloser. Placing a telecontrolled recloser in a limit point with other feeder, the NSE due to faults in the first section of the feeder is also reduced to a half. Since the last 50% power could be re-fed by means of remote operation from a neighbouring feeder.

Penalty to be paid:

\[ M_4 = 0.1 \times M_2/2 + 0.1 \times M_2/2 = 10 \]  

5.1.5. Fuse coordination in branches. In this case, new hypothesis are formulated for the calculation. Considering that 100% feeder faults are uniformly spread before and after the protection recloser. The hypothesis considered is that 20% of faults appear in the main feeder and 80% on the branches.
Considering a feeder with 4 branches, each of which have the same installed power:

NSE due to permanent faults is reduced to:

Feeder faults:  \[ M_{FT} = 0.2 \times 0.2 M_I = 0.04 M_I \] (6)
Branch faults:  \[ M_{FR} = 0.2 \times 0.8/n M_I = 0.04 M_I \] (7)
Where \( n \): Number of branches

Penalty:  \[ M_S = M_{FT} + M_{FR} = 0.08 M_I \] (8)

These were the premisses considered in the implementation of the project. Obviously, the coordination performance is not 100%, and fault distribution is not even in the MV network. However, global FMIK and TTIK indicators clearly reflected the improvements due to the implementation of the protection system improvement project.

### 6. ANALYSIS OF SYSTEM SELECTIVITY AND OPERATION

![Diagram of protection apparatus and their action](Attachment:Diagram.png)

**Fig. 3:** Position of protection apparatus and their action in case of faults

From the protection coordination point of view of a typical feeder, for different faults and location of protection apparatus like the one shown in Fig. 3, selectivity is accomplished as indicated in Table 1.

<table>
<thead>
<tr>
<th>Fault</th>
<th>Description of Operation sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The relay (1) clears the fault and makes reclosings. If the fault is permanent after a predetermined number of reclosings the relay is blocked and the feeder remains open. It is remotely controlled on the recloser (2) (opening) and 6 (closing) and service is restored in the feeder healthy half.</td>
</tr>
<tr>
<td>b</td>
<td>The recloser (2) clears the fault and makes reclosings. If the fault is permanent after a pre-establish number of reconnections, the recloser is blocked and left open upstream said device.</td>
</tr>
<tr>
<td>c</td>
<td>The recloser (2) clears the fault and reconnects. If the fault is permanent, after a number of pre-established reclosings, sectionalizer (3) is open, thus removing from service only the section located upstream of it.</td>
</tr>
<tr>
<td>d</td>
<td>The relay (1) clears the fault before the fuse (5) works. Then a change of adjustment of (1) is made so that if the fault continues, (5) actuates and isolates the fault sector.</td>
</tr>
<tr>
<td>e</td>
<td>After the quick performances of the recloser (2), it must change to slow curves before reconnecting so that if fault persists the fuse (7) isolates only the small faulted segment.</td>
</tr>
</tbody>
</table>

**Table 1:** Analysis of selectivity and operation system

### 7. TELECONTROL OF RECLOSERS

In all cases, we consider for our analysis:

- A “protection” recloser in the first intervention point (generally at half the feeder power)
- A “linking” recloser at a limit point of the feeder, upstream the “protection”, so that the final 50% of the feeder can be fed from a neighbouring feeder in case of fault in the first half of the feeder.

Spread Spectrum Radio links were used for the telecommunications system, reporting to three concentrators located along the network. Said concentrators of communication report simultaneously to the operations center located in Mendoza, where all network operations are performed by remote control.

### 8. CONCLUSIONS OF THE APPLICATION.

#### 8.1. Reduction of frequency and power outage time.

The implementation of EDEMSA’s protection plan, according to the indicated guidelines, began in the second semester of year 2000 (Third semester of the franchise contract). Its results, reflected in terms of reduction of power outage frequency and duration and hence of energy not supplied to customers (NSE), can be seen in Fig. 4 and 5.

![Graph showing EVOLUTION FMIK](Attachment:Graph.png)

**Fig. 4:** Evolution of power outage frequency on the MV network.
The number of power outages due to system failure have remained constant in the period of time considered.

As can be seen from the figures, there has been a substantial improvement. In terms of FMIK there has been a reduction of 71% in relation to the initial stage of the franchise contract. Regarding the TTIK reduction, it is 68% in relation to the initial stage. In order to reduce that value even further, provisions have been made for the incorporation of shortcircuit indicators in MV feeders to simplify the work of maintenance shifts who must locate permanent faults on the network.

8.2. Recloser’s performance Statistics

In order to verify the correct performance of the implemented system, periodic checks of the reclosers installed in the network are carried out by means of an event collection.

Statistics show that on a sample of 876 events from different reclosers located on the network, percentages of fault clearance in each reclosing and the final clearance due to permanent fault are distributed according to Fig. 6.

8.3. Fuse performance

Finally, to verify the appropriate performance of selectivity in the implementation of calibrated fuses, comparative checks and statistics were conducted before and after such implementation.

Before starting the plan, most of fuse acting was due to “unknown” causes, in other words, maintenance shift personnel found no permanent fault and simply replaced the fuse. This situation happened due to the use of fuses in the sorting of branches calibrated to overload. In case their thermal performance curve were lower than the fast curve of upstream reclosers, fuses clear both, permanent and temporary faults.

With the use of coordinated gages with performance curves of the quick upstream recloser, the amount of fuse openings due to faults has been notably decreased, as well as the percentage of openings due to unknown causes. This is because fuses are now clearing only permanent faults, with the logical selectivity margin since they are devices whose performance curve depends on other factors, such as environment, fatigue of materials, heat accumulation, tube condition, etc.

<table>
<thead>
<tr>
<th></th>
<th>YEAR 2000 Without Coordination</th>
<th>YEAR 2001 With fuse Coordination</th>
<th>Percentage of reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>162</td>
<td>44</td>
<td>72.8%</td>
</tr>
<tr>
<td>Unknown</td>
<td>108</td>
<td>16</td>
<td>85.2%</td>
</tr>
<tr>
<td>% Unknown</td>
<td>66.7%</td>
<td>36.4%</td>
<td>45.5%</td>
</tr>
</tbody>
</table>

Tabla 2: Comparison of line fuse performances before and after standardization

Statistics shown in Table 2 compare conditions before and after the implementation of the plan. Such data correspond to the same observation period (months of October and November) for years 2000 and 2001.

9. REFERENCES