LAST GENERATION RECLOSERS FOR MV OVERHEAD LINES AT EDP DISTRIBUIÇÃO – RESULTS AND CONCLUSIONS

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ABSTRACT

Recent investments on distribution automation (supported on telecontrol and voltage-time automatic function) contributed to considerable improvement of the quality of service for electric distribution in Portugal. Presently, 3.500 automated distribution devices are installed on the 60.000 km of overhead medium voltage (MV) lines. These are broadly categorized in two types: OCR1, load break switches with actuators and telecommunications that provide dispatchers remote operation and monitoring capability; OCR2, devices with fault interrupting capability, designed to operate automatically based on voltage sensors and timers. The OCR2 also has telecommunication capabilities like the OCR1.

This paper provides a description of the OCR3 pilot project, presenting an overview on the implementation, the pilot network and its architecture, examples of the behaviour of the OCR3 in real situations occurred on EDP Distribuição MV network, results and conclusions.

INTRODUCTION

EDP Distribuição developed a study of a new switch for the MV network, termed OCR3, with the main purpose of facilitating the operations in the electrical network and reducing the impact of faults. This device may be used for two distinct configurations: as a Recloser or as a Sectionalizer. It is equipped with last generation relays, up and downstream voltage sensors and current transformers.

In order to mitigate the risk associated with the introduction of this new device in the grid, EDP carried out a pilot project in order to evaluate its behaviour as a key component of the smart grid.

OBJECTIVES

The objectives of this pilot project, whose approach was presented in CIRED in 2011 [4], were to evaluate the robustness of the new automation concept (considering the protection settings, network automation functions and communications), the quality of the manufacturers involved and finally its effect on the MV network operational indices (TIEMT – Time of Interruption). The new focus of EDP on MAIFI reduction also deserved special attention.

IMPLEMENTATION

After a period of manufacturer qualification, including a complete set of FAT and SAT, a total of twenty OCR3 from two different suppliers and 180 FCI (Fault Current Indicators) were installed in a pilot network, between 2012 and 2013. These FCI provide a visual signaling for field crews at or near the site without telecommunication capabilities, for cost reasons [4]. The pilot network involves 5 primary substations in the centre of Portugal (Cantanhede, Tocha, Vila Robim, Alfarelos and Taveiro) and 16 MV feeders (500 km), as represented in the following figure.

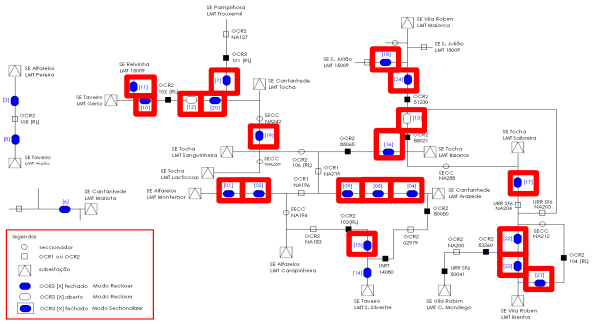

Figure 1. Single line diagram of the pilot network. The 20 OCR3 are represented with red rectangles.

The application of such devices on the MV network impacts on the current protection and reclosing practices of EDP. It is necessary to ensure that the protections at the primary substation and the OCR3 (when working as reclosers) are coordinated. In practice, this is a challenge regarding the number of OCR3 working in series as reclosers in the same feeder. For this project, it was decided not to install more than three consecutive OCR3, parametrised as reclosers.

TELECOMUNICATIONS

To support the TCP/IP based protocol IEC 870-5-104 (light profile), EDP Distribuição used one of the three available GPRS public operators. All OCR3 sites were validated through site surveys signal coverage measures, ensuring a good connectivity to the GPRS network (only signals lower than -84 dBm were accepted). To obtain a higher degree of availability and security we used a private APN only available to EDP SIM cards. Furthermore, EDP Distribuição deployed a dual optical fibre connection between the core network of the public operator and our SCADA network, guaranteeing a higher availability for this pilot project.

CASE STUDIES

Case Study I

The present case shows an example of a selective extinction of a transient phase-phase fault, resulted from the correct operation of OCR3 (#04) on a MV feeder – "Cantanhede – Arazede".

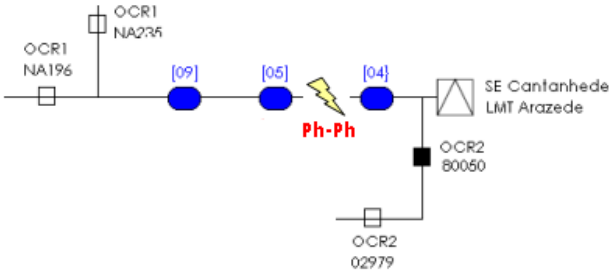

Figure 2. MV feeder "Cantanhede – Arazede" – Single-line diagram.

In this topology, the protection system coordination was tested, considering the maximum number of 3 OCR3´s installed in a series configuration.

Some particular notes about phase-overcurrent protection (50) coordination:

- Definite-time operational characteristics;
- Protection operation time: [0,1; 1] sec.;
- Minimum coordination time-step: 0,2 sec.;
- No coordination assumed for short-circuit faults above 2 kA.

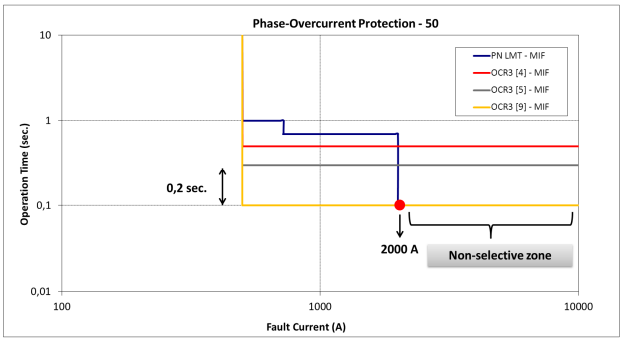

Figure 3. Phase-overcurrent protection – Operational characteristics.

Through the chronological events analysis, it was confirmed that the fault-clearance time did not compromise OCR3 selective operation.

18-10-2013 13:01:42.395	TCMT CANTANHEDE	OCR3 N00001 CNT	AUTORECLOSURE CYCLE	START
18-10-2013 13:01:42.410	TCMT CANTANHEDE	OCR3 N00001 CNT	I> INST +	PICKUP
18-10-2013 **13:01:42.910**	TCMT CANTANHEDE	OCR3 N00001 CNT	I> TEMP +	TRIP
18-10-2013 13:01:42.955	TCMT CANTANHEDE	OCR3 N00001 CNT	I> TEMP +	NORMAL
18-10-2013 **13:01:42.955**	TCMT CANTANHEDE	OCR3 N00001 CNT	OCR3	OPEN
18-10-2013 13:01:43.128	SE CANTANHEDE	P223 ARAZEDE	I> INST	PICKUP
18-10-2013 13:01:43.138	SE CANTANHEDE	P223 ARAZEDE	I>> INST	PICKUP
18-10-2013 13:01:43.140	SE CANTANHEDE	P223 ARAZEDE	AUTORECLOSURE	START
18-10-2013 13:01:43.143	SE CANTANHEDE	P223 ARAZEDE	AUTORECLOSURE CYCLE 1	START
18-10-2013 13:01:43.188	TCMT CANTANHEDE	OCR3 N00001 CNT	I> INST +	NORMAL
18-10-2013 13:01:43.315	TCMT CANTANHEDE	OCR3 N00001 CNT	OCR3	CLOSED
18-10-2013 13:02:43.317	TCMT CANTANHEDE	OCR3 N00001 CNT	AUTORECLOSURE CYCLE	END
18-10-2013 13:01:43.698	SE CANTANHEDE	P223 ARAZEDE	I>> INST	NORMAL
18-10-2013 13:01:43.699	SE CANTANHEDE	P223 ARAZEDE	AUTORECLOSURE FUNCTION	SUSPENDED
18-10-2013 13:01:43.701	SE CANTANHEDE	P223 ARAZEDE	I> INST	NORMAL
18-10-2013 13:01:43.704	SE CANTANHEDE	P223 ARAZEDE	AUTORECLOSURE FUNCTION	NORMAL
18-10-2013 13:01:43.704	SE CANTANHEDE	P223 ARAZEDE	AUTORECLOSURE CYCLE 1	END
18-10-2013 13:01:43.705	SE CANTANHEDE	P223 ARAZEDE	AUTORECLOSURE	END
18-10-2013 13:01:44.058	SE CANTANHEDE	P223 ARAZEDE	I> INST	PICKUP
18-10-2013 13:01:44.079	SE CANTANHEDE	P223 ARAZEDE	I> INST	NORMAL

Figure 4. SCADA chronological events recording.

Case Study II

In the present case, a successful operation of the automatic back-feed restoration functionality is presented, performed by OCR3 (#13) installed in a normally open point.

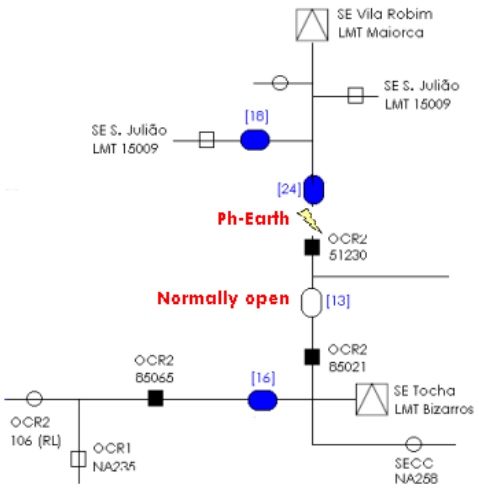

Figure 5. MV feeders "Vila Robim – Maiorca" vs. "Tocha – Bizarros" – Single-line diagram.

Previous to the operation of the automatic back-feed restoration functionality, it was verified a selective extinction of a permanent phase-earth fault, resulted from

the correct operation of OCR3 (#24) (conductor on the ground located between this OCR3 and OCR2 (#51230)).

Some particular notes about earth-fault protection coordination (50N, 51N(s), 67N):

- Definite-time vs. inverse-time operational characteristic (Note: implemented only at the substation);
- Protection operation time: [0,1; 0,7] sec. (definite-time);
- Minimum coordination time-step: 0,2 sec.;
- No coordination for resistive earth-faults (Note: due to technological limitations of OCR3´s).

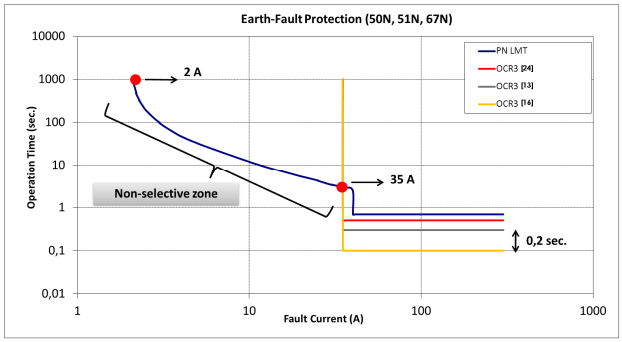

Figure 6. Earth-fault protection – Operational characteristics.

This case will be described on 3 stages, due to the higher number of devices and functionalities involved.

Stage 1: fault extinction after 3 selective autoreclosure cycles performed by OCR3 (#24):

05-07-2013 07:45:15.353	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	I> INST +	PICKUP
05-07-2013 07:45:15.889	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	I> INST +	NORMAL
05-07-2013 07:45:15.889	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	I> TEMP +	TRIP
05-07-2013 07:45:15.889	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	OPEN
05-07-2013 07:45:15.889	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE CYCLE	START
05-07-2013 07:45:16.249	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	I> TEMP +	NORMAL
05-07-2013 07:45:16.249	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	CLOSED
05-07-2013 07:45:16.249	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE CYCLE	END
05-07-2013 07:45:16.284	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> INST +	PICKUP
05-07-2013 07:45:16.819	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io TEMP	TRIP
05-07-2013 07:45:16.819	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> INST +	NORMAL
05-07-2013 07:45:16.819	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> TEMP +	TRIP
05-07-2013 07:45:16.819	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	OPEN
05-07-2013 07:45:16.819	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE CYCLE	START
05-07-2013 07:45:31.880	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io TEMP	NORMAL
05-07-2013 07:45:31.880	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> TEMP +	NORMAL
05-07-2013 07:45:31.880	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	CLOSED
05-07-2013 07:45:31.880	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE CYCLE	END
05-07-2013 07:45:31.910	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> INST +	PICKUP
05-07-2013 07:45:32.445	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io TEMP	TRIP
05-07-2013 07:45:32.446	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> INST +	NORMAL
05-07-2013 07:45:32.446	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> TEMP +	TRIP
05-07-2013 07:45:32.446	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	OPEN
05-07-2013 07:45:32.446	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE CYCLE	START
05-07-2013 07:46:02.509	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io TEMP	NORMAL
05-07-2013 07:46:02.509	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> TEMP +	NORMAL
05-07-2013 07:46:02.509	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	CLOSED
05-07-2013 07:46:02.509	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE CYCLE	END
05-07-2013 07:46:02.539	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> INST +	PICKUP
05-07-2013 07:46:03.074	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io TEMP	TRIP
05-07-2013 07:46:03.076	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	AUTORECLOSURE FUNCTION	BLOCKED
05-07-2013 07:46:03.076	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> INST +	NORMAL
05-07-2013 07:46:03.076	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	Io> TEMP +	TRIP
05-07-2013 07:46:03.076	TCMT FIGUEIRA DA FOZ	OCR3 N00006 FIG	OCR3	OPEN

Figure 7. SCADA chronological events recording.

Stage 2: operation of voltage-time automation function by OCR2 (#51230), after definite trip of OCR3 (#24):

05-07-2013 07:45:15.216	ARCL - AVEIRO	OCR2 N01229 FIG	AC VOLTAGE	FAILURE
05-07-2013 07:45:18.056	ARCL - AVEIRO	OCR2 N01229 FIG	OCR2	OPEN
05-07-2013 07:45:31.176	ARCL - AVEIRO	OCR2 N01229 FIG	AC VOLTAGE	NORMAL
05-07-2013 07:48:55.669	ARCL - AVEIRO	OCR2 N01229 FIG	VOLTAGE-TIME AUT.	OUT OF SERVICE

Figure 8. SCADA chronological events recording.

Stage 3: operation of automatic back-feed restoration function by OCR3 (#13), after OCR2 (#51230) opening, restoring the service to the loads between both:

05-07-2013 07:45:16.036	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	AUTORECLOSURE CYCLE	START
05-07-2013 07:45:22.237	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	AC VOLTAGE	FAILURE
05-07-2013 07:45:57.019	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	AUTOMATIC CLOSE	START
05-07-2013 07:45:57.019	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	OCR3 CN	CLOSED
05-07-2013 07:45:57.019	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	AUT. BACK-FEED RESTORATION	OUT OF SERVICE
05-07-2013 07:45:57.019	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	AUTORECLOSURE CYCLE	END
05-07-2013 07:46:02.245	TCMT FIGUEIRA DA FOZ	OCR3 N00011 FIG	AC VOLTAGE	NORMAL

Figure 9. SCADA chronological events recording.

Of course that, if the fault was located between OCR2 (#51230) and OCR3 (#13), there would be an unsuccessful attempt to restore the service automatically by OCR3 (#13), transferring the fault to a healthy feeder.

RESULTS

SCADA Key Performance Indicators

The performance of the OCR3 was evaluated based on three key performance indicators:

- **Availability.** Ratio between the time during which the communications channel is active (thus providing telecontrol) and the time elapsed, in a given time frame (24 hours).
- **Control Efficiency.** Ratio of controls issued from SCADA in which the expected result was obtained, and the total controls issued, in a given time frame (24 hours).
- **Operability.** Ratio between the number of devices functioning correctly, and available for the control centre, and the total number of installed devices, at a given moment (snapshot).

The following figures display the results of these indicators during the evaluation period.

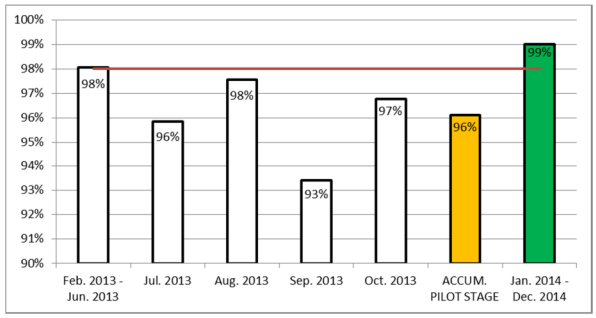

Figure 10. Availability of the 20 OCR3's installed in this pilot project.

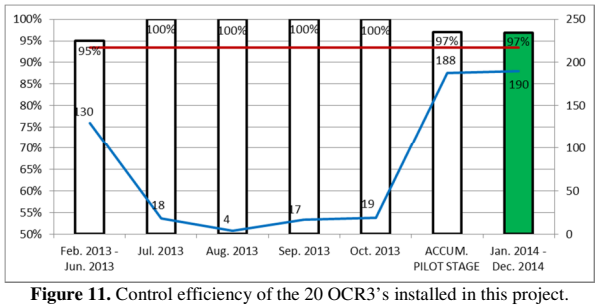

Figure 11. Control efficiency of the 20 OCR3's installed in this pilot project.

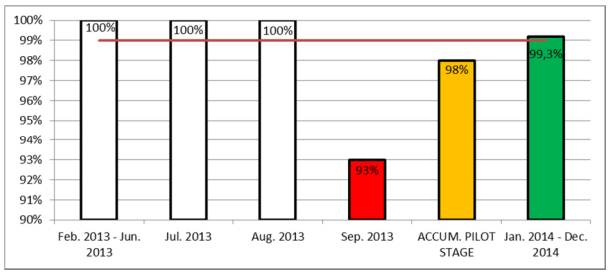

Figure 12. Operability of the 20 OCR3's installed in the scope of this project.

The worse indicators during the pilot stage were mainly related with the youth of these devices. It was possible to verify an improvement on all the three aforementioned indicators during 2014.

Taking this into account, it is possible to conclude that the performance of the OCR3, regarding communications and telecontrol, is in line with the history of EDP Distribuição for similar devices.

Protections and Automatic Functionalities Key Performance Indicators

Concerning the performance of the protections and automation functionalities, the following three key performance indicators were evaluated:

- Selective actuations of the protection functions;
- Coordination of reclosing cycles between primary substations and OCR3;
- Successful actuation of the automatic back-feed restoration (ABR) functionality.

The following figures show the results obtained between February and December of 2013.

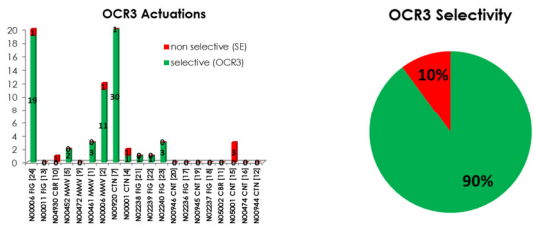

Figure 13. Results: Selectivity of the 20 OCR3's installed in the scope of the pilot project.

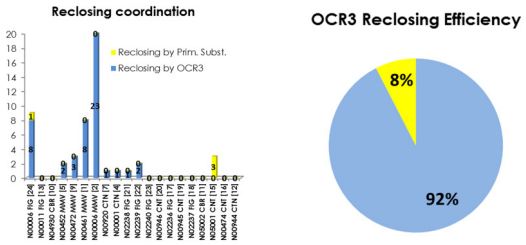

Figure 14. Results: Coordination of reclosing cycles between primary substations and the 20 OCR3 installed in the scope of the pilot project.

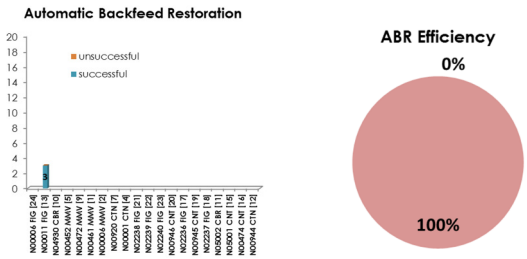

Figure 15. Results: Successful actuation of the ABR feature.

It was possible to conclude that, in most cases, the protections of the OCR3 performed selectively. In fact, the non-selective actuations took place in situations where the fault current was over 2kA (conceptually assumed discoordination), upon the occurrence of live-line works and in situations where fast reclosing at the primary substation occurred. In MV networks with OCR3s installed, the fast reclosing functionality at the primary substation should be inhibited or associated with the trip of the protections (not pick-up, as currently project specifications). It was also possible to verify a failure on the correct identification of the directionality of an OCR3 provided by one of the suppliers, in a ground fault situation. This happened because the ground directionality of this supplier's device uses the homopolar voltage measurement as its polarization unit, which brings challenges regarding the computation of the operational angle settable.

The automatic back-feed restoration feature was 100% effective. This functionality, together with the directionality capabilities for both ground-fault and phase-to-phase fault, provides the OCR3 with "self-healing" features, i.e. the faults are automatically eliminated and the network is automatically reconfigured, thus guaranteeing that the greatest possible number of clients are energized, with few human intervention (nevertheless on this solution there´s the possibility of an unsuccessful automatic close on-to a fault).

Quality of Service

The OCR3 performance, regarding its contribution for technical service quality improvement, was evaluated by monitoring the TIEMT and MAIFI indices in the pilot-zone, showing reductions around 21% and 58% regarding the TIEMT and MAIFI historical, respectively. In order to obtain an evaluation reference, the average TIEMT and MAIFI values were calculated from 2007 until 2011.

The operation of all the devices was monitored during a period of up to one year. During the pilot evaluation period 80 events were analyzed which validated the efficiency of the OCR3 selectivity, the reclosing and the network reconfiguration automation (when installed in a normally open point).

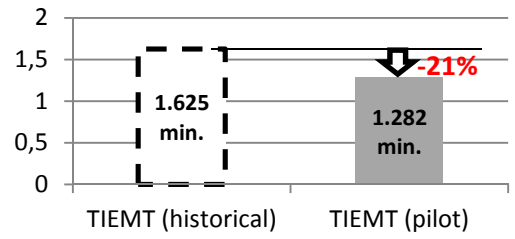

Figure 16. Comparison between the historical/pilot TIEMT.

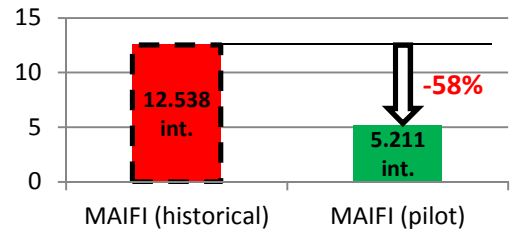

Figure 17. Comparison between the historical/pilot MAIFI.

The TIEMT showed an improvement of 21%, exceeding the initial expectations. Additionally, the OCR3 gave a strong contribution at MAIFI level, where an improvement of 58% was noted. Given the focus of EDP Distribuição on this index, it is possible to conclude that the OCR3 is an interesting equipment from a technical-economical point of view and qualifies itself as being capable of helping EDP on the pursuit of future goals in what concerns the technical service quality.

Manufacturers' Evaluation

The performance of the two reclosers manufacturers was evaluated based on several items: i) Delivery deadlines, ii) Deliverables, i.e. compliance with the specification and commitment to develop functionalities beyond the off-the-shelf product, iii) Quality of the provided documentation, iv) FAT results, v) Results of the visits to the manufacturing plants, vi) Failure of the equipment, i.e. total or partial loss of functionality of the devices deployed in the field, vii) Response in case of equipment failure, i.e. time of response, identification of the cause and the capability of recommending preventive actions.

The evaluation of each manufacturer should be carried out carefully, considering a contextualization of each case. For instance, one of the suppliers had a shorter delivery time when compared to the other, however one of them showed more availability to develop other functionalities beyond the ones offered by their off-the-shelf product. Additionally, the field performance of one of the types of devices used in this pilot was harmed by an engineering option (the inclusion of a protocol converter as part of the communications module), which caused problems "of youth".

CONCLUSIONS

Regarding the obtained results, it was concluded that:

- OCR3 contributes for the reduction of the TIEMT and MAIFI indices, having a positive impact in the quality of service;
- It enables the decentralization of protection functions;
- It is a valid solution for the MV network, in cohabitation with previous generations of MV switches.

From a manufacturer quality perspective, it could be concluded that the alternatives offered by two different suppliers showed an acceptable/good level of performance, although it became clear that solutions that imply communication protocol conversion via an additional device to the standard OCR3 control unit have greater vulnerability and thus lower reliability.

One of the next steps shall be the launching of an open market manufacturers qualification process, for OCR3 large scale acquisition.

EDP is presently exploring new possibilities offered by these devices, such as closed loop network operation.

ACKNOWLEDGEMENTS

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