QUALITY OF SUPPLY DRIVEN INVESTMENT PLANNING AND REGULATORY SUPPORT USING REPRESENTATIVE NETWORKS

Alexandre PAIS DA SILVA
EDP-Distribuição – Portugal
alexandremiguel.silva@edp.pt

José RIBEIRO DA SILVA
EDP-Distribuição – Portugal
jose.ribeirodasilva@edp.pt

Nina CLEMENTE
EDP-Distribuição – Portugal
nina.clemente@edp.pt

Lina AFONSO
EDP-Distribuição – Portugal
Lina.afonso@edp.pt

Carlos ALBERTO SANTOS
EDP-Distribuição – Portugal
carlosalberto.santos@edp.pt

ABSTRACT

The regulation of electricity distribution network monopolies has been shifting from asset-based to performance-based regulation and therefore is becoming more dependent on the quality of customer service: EDP Distribuição (EDPD) is exposed to a quality of supply incentive mechanism which is adjusted on a yearly basis. This regulatory framework has the potential to create opportunities that may generate value for both business and customers provided adequate information supports the setting of performance targets and of the financial incentives.

Following significant performance improvements that have been attained in recent years, EDP-Distribuição has identified the need for further, technically more demanding quality of supply planning. The conventional rationale for planning quality of supply driven investment has been challenged and novel approaches have been developed accordingly.

EDP-Distribuição has been implementing a quality of supply representative network (RN) based approach to analyse its MV networks. This enabled to appreciate and explain the differences in performance across urban, semi-urban and rural networks. EDP-Distribuição is addressing the need to quantify the impact that historical design and operation practices, different topology and population characteristics may have on network performance. This is perceived as an important contribution towards understanding the costs associated with setting adequate quality of supply performance targets.

INTRODUCTION

EDPD is a company of EDP-Energias de Portugal. It operates the majority of the distribution system in continental Portugal (high, medium and low voltages) connecting over 6.6 million customers.

Due to the intrinsically monopolistic nature of the distribution business, the revenue recovered by EDPD is closely regulated by ERSE (Portuguese energy services regulator) in order to protect the customers and deliver economic efficiency.

ERSE has maintained on behalf of the customer's interests a quality of supply regulation based on the monitoring of both individual and overall standards of performance. Failure to comply with the former entitles customers to receive compensation payments from EDPD. Failure to comply with the latter may require EDPD to plan, submit and seek approval for specific investment programs to address difficulties.

Performance Based Regulation (PBR)

In addition to the quality of supply regulation aspects already mentioned, the performance of distribution systems is now becoming customer driven. This means that the logic of weighting the investment on the network against the loss of kWhs not supplied has been changed. This leads to the need to include an assessment of the customer's worth of supply and the benefit they derive by system investment.

This is the underlying concept of what is called performance-based regulation. Limited aspects of this form of regulation have been introduced in Portugal through the quality of supply incentive mechanism. This was set up to strengthen the incentives with respect to delivering the quality of output. As this mechanism is based on financial penalties and rewards, the overall distribution revenue is a function not only of the operating and capital costs incurred by the network owner in providing the service, but also of the quality of customer service [1].

The parameters of the quality of supply incentive mechanism enforced by ERSE are reviewed on a yearly basis. Currently, it determines that the maximum reward or penalty incurred by EDPD is 5M€ annually (Fig.1) with reference to the performance observed two years before. A reference value of energy not distributed (END) was set up as a percentage of the total annual distributed energy and has been decreased every year. This reference value represents the underlying assumption of the quality of supply TIEPI (Tempo de Interrupção Equivalente da Potência Instalada) target with no costs for the customer. A dead band (flat area of the chart depicted in Fig.1) around this target has been set to account for data imprecision [3]. The mechanism has been set to value the non-distributed kWh at 1.5€.

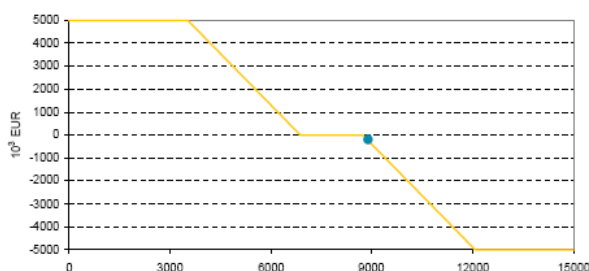Incentive curve (2006) ● END – 2006 (MWh)
Fig.1 – Quality of supply incentive scheme for 2006 [2]

TIEPI is a system reliability index that measures the severity of interruptions in terms of the amount of time that the curtailed installed rated power (MV/LV distribution substations) is out of supply in relation to the whole network installed power:

$$TIEPI = \frac{\sum_{j=1}^{k}\sum_{i=1}^{NI_j} DI_{ij} \times PI_j}{\sum_{j=1}^{k} PI_j}$$

DI_{ij} - duration of the interruption I of the MV load point j
PI_j – Installed rated power of the load point j
k – total number of MV load points
NI_j – number of interruptions of load point j originated upstream

This index is used to monitor the quality of supply of MV networks which have the greatest influence on the annual outage costs as experience shows. SAIFI and SAIDI indices are also closely monitored in these networks but have had no impact on the quality of supply mechanism so far.

EDP-Distribuição quality of supply track record

Quality of supply has long been a major priority for EDPD. Fig.2 gives an overview of the performance improvements achieved in the past years. It should be pointed out that the incentive mechanism currently in place began to influence the company's revenue in 2005 based on targets and quality of supply data from 2003 which did not consider previous investment efforts.

The data in Fig.2 has been compiled by geographical areas. "Zona A" refers to predominantly urban areas (over 25000 inhabitants) and district capitals. "Zona B" refers to areas with more than 2500 and less than 25000 inhabitants. "Zona C" covers the remaining territory.

Previous investment programmes that progressively targeted the most problematic parts of the network have considerably increased the level of automation and remote control of HV and MV systems. These programs have also addressed the construction of new infrastructure and the refurbishment of existing assets.
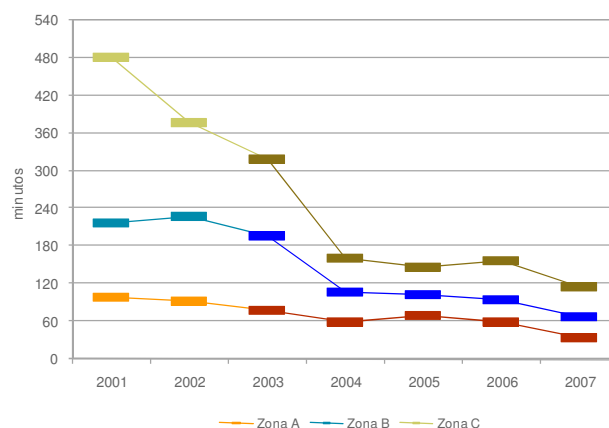

Fig 2 – Annual TIEPI performance (2001-2007)

Given that a significant proportion of the potential gains have already been attained and that the regulatory targets are becoming even more demanding, EDP-Distribuição has identified the need for further and technically more demanding quality of supply planning. .

Quality of supply investment planning using Representative Networks

The enormous diversity of topologies, customer densities and protection levels of MV feeders in a real distribution system has been a major obstacle for the strategic planning activity. It would be easier to plan a distribution system if the circuits were identical or if they could be grouped by similar characteristics and studied accordingly. Previous research [4][5] has defined Representative networks (RN) as typical feeders: each RN is supposed to be the best fit to a specific group of real feeders. Building on these concepts, a RN based planning approach and performance comparison framework was proposed and validated [6] [7].

The work described in this paper goes one step further towards the implementation of a reference network based approach that enables an effective reliability driven network planning and a network performance comparison framework to be established that adequately supports PBR.

This paper builds on that knowledge base and covers a few key points:

- how the disaggregation of distribution networks can facilitate an efficient investment policy whilst relating to the regulatory framework in place;
- how EDPD tailored network development scenarios can be measured both in terms of expected performance gains and related costs;
- how EDPD can manage a portfolio of network development scenarios by comparing them and using them to establish its own reference networks, namely for each disaggregated group.

CASE STUDY

The present regulation does not propose any network based disaggregation in its quality of supply monitoring nor does it establish performance benchmarks for particular groups of feeders. It sets, however, standards of performance for three zone categories (A,B,C as described previously) which cover the whole country. Therefore, a first step to address the performance requirements in each zone was to disaggregate MV feeders on the basis of the predominant zone which they supplied. 3 groups of sample MV feeders (approximately 120 in total) were set up (urban, semi-urban and rural). The number of feeders to include in the analysis has no impact on its complexity given the methodology employed. Further disaggregation in each group may be exploited for the benefit of more refined planning studies where needed (for instance, differentiating between feeders with on-feeder remote control and without it).

An array of network development scenarios were simulated which enabled the measurement of the expected quality of supply benefits. This was used to establish correspondences between expected TIEPI, SAIDI and SAIFI gains which are both network and scenario specific and must be handled accordingly. Therefore, the results included in this section have been collated for methodological demonstration purposes and do not necessarily represent accurate values that apply to the whole distribution system.
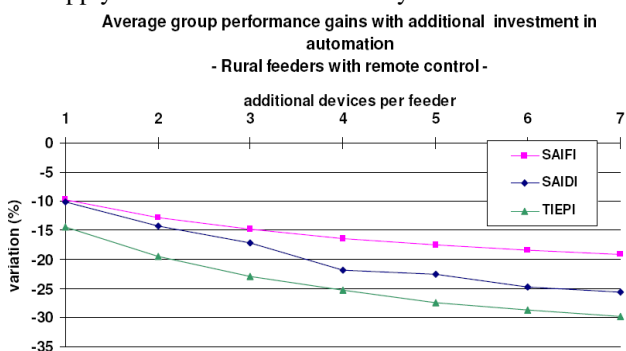

Fig.3 – Expected performance gains resulting from investment in automation in rural feeders with pre-existing remotely controlled switchgear

Results such as those depicted in Fig.3 allow the quantification of potential performance improvements that may be within reach in the group of feeders identified, provided sufficient investment in automation is carried out. Because TIEPI is directly related with the incentive mechanism, an implicit economic valuation of the SAIFI and SAIDI benefits derived may be obtained as well (there are currently no explicit incentive mechanisms concerning these indices).

It is also possible to acquire information regarding the local and company-wide impacts of network development scenarios. For instance, Table 1 displays sensitivity data concerning the variation of the average duration of repair operations once the network has been reconfigured to re-

supply as many customers as possible, following a fault.

Table 1: Average repair time sensitivity analysis

Feeder group	Repair time sensitivity analysis	
	group TIEPI (min)/h	national TIEPI (min) /h
Rural (no remote control)	28.7	3×10^{-3}
Rural (with remote control)	26.7	3.4×10^{-3}
Semi-urban	2.3	5.6×10^{-2}

The results shown in Table 1 take into account the topologies of the feeders in each group and, therefore, the average impact of the duration of repair operations whether these occur in underground or overhead networks. Semi-urban networks typically have more remotely controlled switching devices and switching capability given their relatively higher loads. This is why an hour of waiting time for the completion of repair operations has a lower impact in these networks (locally) and still produces a higher impact (more than 10 times higher) on company-wide performance. These results may help optimizing the location of repair response teams, emergency generators and spare gear.

Having built a portfolio of network development scenarios for each network group, the assessment of their relative benefits remains to be accomplished. Designing a reference network for each group requires scenarios to be measured, and the corresponding costs to be quantified and compared. Furthermore, designing an investment strategy demands that investment scenarios are either rejected or selected and subsequently prioritized.

An example is shown of such a case concerning the particular scenario of investing in automation schemes. The benefits are accounted for in euros, based on the economic signal provided by the incentive scheme. In this way it is possible to compare the merits of the scenario for groups of feeders of different characteristics.
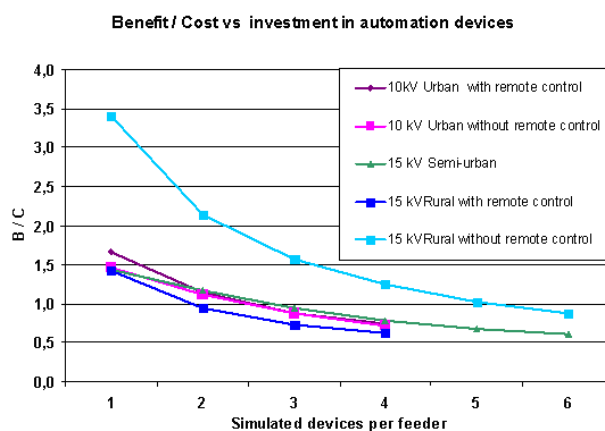

Fig. 4 – Investing in automation: typical B/C ratios obtained for various groups of feeders

The data depicted in Fig.4 helps to determine which scenarios may be of economic interest (B/C >1) when applied to the groups of feeders considered in the analysis. Load growth has been taken into account as far as it can be estimated. Investment costs were diluted over a 30 year period using a 10% interest rate. It is clear that under the present regulatory framework it is not cost-effective to improve the quality of supply of these urban feeders by investing in automation. Alternatively, this scenario seems to be of interest in the case of the rural networks analysed, particularly for those without remote control which represent a small proportion of MV feeders already.

Results such as these may also be compared on similar grounds with other network development scenarios which may be part of the portfolio: undergrounding overhead networks, refurbishing or re-enforcing existing networks, building more substations and shortening the average feeder length, etc.

Depending on the volume of investment involved these scenarios may be better characterized in order to facilitate their costing and consequently the definition of the global investment strategy to pursue.
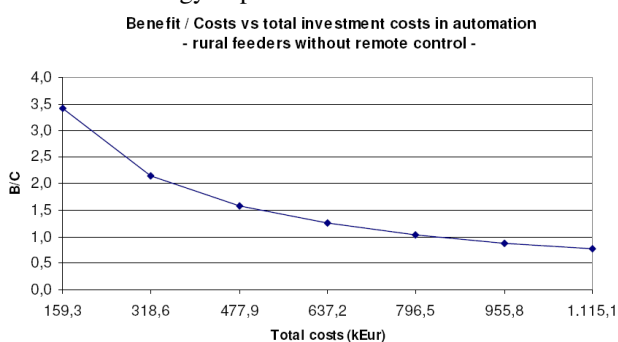

Fig. 5 – Investing in automation: rural feeders without remote control

Fig.5 relates B/C ratios with the volume of investment in this particular group of feeders, assuming a growing number of installed devices, on average, per feeder .

CONCLUSIONS

A RN based approach has been employed to design investment strategies by enabling the measurement (in terms of several quality of supply indices), the costing and the comparison of network development scenarios. These scenarios have been simulated for groups of real feeders taking into account their specific characteristics (lengths, failure rates, topologies, customer densities, etc). The making of these groups took into account the specific regulatory environment in which EDPD operates. This approach has also enabled the assessment of the strength of the incentive scheme currently in place by enabling the establishment of a direct link between quality of supply related investments and the corresponding benefits that may

be expected, both locally and at the company level. Within this context, this framework effectively supports the development of a reference network in a manageable manner, for particular groups of feeders. This facilitates the characterization of the optimum set of network development scenarios for each case. Simultaneously, this framework enables an efficient prioritization of investment scenarios at the company level.

The methodology can be employed to create or to specify benchmark networks. These are conceptually similar to reference networks and can be used to compare companies against a network of known performance. Benchmark networks may be the result of the average set of variables across companies, across distribution areas of similar characteristics or may be set by the regulator on the basis of some other process. The framework has the capability to compare the performances between companies whilst assessing the reasons for any differences.

ACKNOWLEDGMENTS

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