A PARTIAL RELATIONSHIP BETWEEN COSTS AND QUALITY AS A BASIS FOR SETTING REGULATION PARAMETERS OF SUPPLY CONTINUITY

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ABSTRACT

The relationship between the costs of measures affecting the quality of power distribution (or more precisely, the supply continuity) and the expected SAIFI and SAIDI indices is at the core of a number of decision issues in the field of distribution networks. This task in its completeness is extremely extensive. However, if we narrow the view only to selected measures and a set of selected feeders, the problem can be solved more easily. Due to these important initial assumptions, we deliberately talk about "a partial relationship between costs and quality".

This paper presents a general methodology for the calculation of the partial relationship between costs and quality based on Monte Carlo simulation. The advantage of the selected approach is that we obtain a complete statistical distribution of the resulting SAIFI and SAIDI indices, which can then be used (as opposed to averages) for the calculation of the quality factor and quantification of associated probabilities and risks.

INTRODUCTION

Power supply continuity is a part of the regulatory mechanisms in a number of countries [1]. Each country selects its own approach to setting the regulation parameters of supply continuity, which is influenced by the overall regulation framework, by the characteristics of distribution networks, the currently attained levels of supply continuity and other factors. The regulation of supply continuity also develops in each country over time in an individual manner [2].

It was the year 2005 that can already be considered as the beginning of quality regulation in the Czech Republic. This was when new customer standards entered into force. These standards are associated with penalties payable on demand to customers if the set limits are not kept. Since 2013, the quality factor (the so-called Q component) has been a part of the regulatory formula. This has created a direct economic link between the *SAIFI* and *SAIDI* indices and the cost of distribution. At the same time the question of the relationship (or dependence) between investment and operating costs and supply continuity indices rose to prominence.

A complete answer to this question is an extremely difficult task - especially due to its scope and amount of non-linearities. It is known, for instance, that the benefit of a certain type of measures in the distribution network varies greatly depending on specific conditions, such as the implementation site (the selected feeder, or even the selected section or the switch). The estimates based on unit costs and unit benefits are very rough and inaccurate.

This paper describes a methodology that does not insist on complete answers to the above question. The methodology is openly and deliberately limited to some selected feeders and selected measures, but it also gives very good results with predictive capability, based on real data (the actual network feeders). For this reason, it can well be used as a basis for making decisions with serious economic consequences.

THE QUALITY FACTOR AND ITS EVALUATION IN CONNECTION WITH MEASURES TO IMPROVE THE SUPPLY CONTINUITY

The quality factor (the so-called Q component) is an added part of the regulatory formula, specifically the formula for calculating the adjusted allowed revenues for distribution network operator. It consists of two components - a quality factor taking into account the number of interruptions of power supply, and a quality factor taking into account the duration of the interruptions. In fact, it is a component which is a function of *SAIFI*, and a component which is a function of *SAIDI*. Both indices are system-wide values calculated i) from the unplanned interruptions caused by failures originating in the distribution operator's supply system under normal weather conditions, and ii) from the planned interruptions. Unplanned interruptions caused by failures in adverse weather conditions are not included, neither are interruptions resulting from interventions of a third party, nor several other categories.

The actual calculation of both components takes place according to a nonlinear function depicted in general terms in fig. 1. This function includes:

- a dead band, in which the value of the quality factor component is zero,
- proportional bands, in which the value of the quality factor component varies linearly according to the value of the supply continuity index,
- bands of maximum bonus and of maximum penalty, in which the quality factor component reaches the limit value and is no longer dependent on the value of the index.

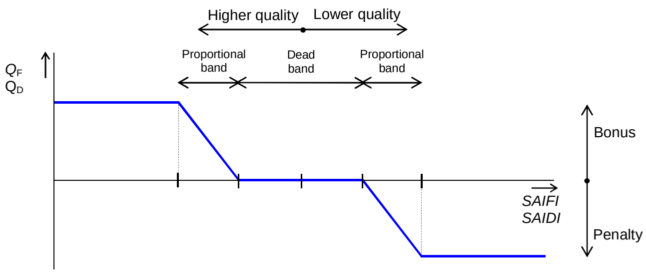


Fig. 1: An illustration for the quality factor components calculation

The shape of the function for the calculation with *SAIFI* is the same as that with *SAIDI*, but the parameters of these functions are different. For each distribution system operator, there are two functions, whose resulting values are added together. Generally, the components of the quality factor can acquire different values (within the given limits). Theoretically, there is a possibility of the situation when one component reaches a maximum bonus, while the second one a maximum penalty, with the resulting value of the quality factor being nil, because the legislation in the Czech Republic established that the maximum values for both components are equal.

However, an evaluation of the quality factor with regard to the measures considered to improve the supply continuity indices has some drawbacks.

The first is the existence of the dead band. One measure at a single network feeder (e.g. a single investment project) has rarely enough strength to overcome the dead band and lead to a bonus (the initial state would have to be very close to the lower boundary of the dead band). In most cases, therefore, a combination of several measures is needed for the transition to the bonus band.

The second challenge is the fact that the indices of supply continuity entering into the calculation are essentially random variables. Their values observed in individual years may therefore be different without any changes actually taking place in the network itself. Changes of indices predicted by simulations also have a random character. Consequently, the quality factor is a random variable too.

Furthermore, due to the nonlinearity of the functions according to which the calculation is carried out, it is impossible to calculate only with average values of supply continuity indices. The calculation must be based on their complete distributions. This is the same situation as when evaluating the fulfilment of customer standards.

A PARTIAL RELATIONSHIP BETWEEN COSTS AND QUALITY - BASIC IDEAS

The relationship between costs and quality, more exactly supply continuity indices, assumes an estimate of benefits of various options with gradually increasing costs to reduce the *SAIFI* and *SAIDI* indices. Simulation tools are generally used to make predictions of this type. However, it is impossible to obtain a "global" relationship, i.e. a relationship covering the whole distribution network and all possible measures. This would be an extremely large optimization problem requiring a lot of input data and time (the number of combinations of measures would be enormous). A more practical solution is to admit a limitation to a "partial" relationship, covering only a selected part of the network (e.g. selected feeders) and selected measures. If the most appropriate sections and measures are selected (in terms of the expected improvements in the supply continuity indices), even a "partial" relationship is representative enough to be used in regulation. Ultimately, the experience with reliability analyses of distribution networks clearly shows a non-homogeneity of failures - which means that only a small part of the network dominantly contributes to supply interruptions to customers. On the other hand, one should bear in mind that this relationship is only "partial", and the acquired curve cannot be extrapolated (the relationship is nonlinear and the effect of the best measures is greater in comparison with the others, whose benefit gradually decreases).

The partial relationship between costs and quality is always a pair of relationships: i) *SAIFI* vs. costs and ii) *SAIDI* vs. costs. The pair of expected values - *SAIFI* and *SAIDI* - always correspond with the given costs, and they cannot be separated from each other.

MEASURES TO IMPROVE SUPPLY CONTINUITY AND THEIR SIMULATION

For each distribution network it is possible to design an array of measure types, from which an improvement in one or both supply continuity indices can reasonably be expected. These types of measures differ between cable and overhead networks. Due to the dominant share of events in the MV network on system-wide supply continuity indices, it is appropriate to concentrate the selection of measures included in the calculation of the partial relationship only on measures implemented at this voltage level.

It is essential for the calculation that only such measures should be included where the benefits can be predicted (quantified) and the related costs determined.

The measures can be divided into those affecting the unplanned interruptions and those affecting the planned interruptions. In the following text, however, we shall only focus on measures affecting the unplanned interruptions.

These measures in MV overhead networks can include:

- deploying remote-controlled section switches,
- deploying reclosers,
- cabling selected sections of overhead lines.

The measures in MV cable network can include:

- the remote control of distribution transformer stations,
- equipping distribution transformer stations with short-circuit current indicators,
- installing the shunting technology in HV/MV substations.

All these measures can be modelled by means of the Monte Carlo simulation of reliability and its evaluation. For a correct evaluation, the simulation needs to generate all the necessary data at the beginning - the numbers of failures and the durations that could be needed. This ensures a comparability of results for the individual measures and their combinations. Quantifying the benefits of a particular measure only takes place as part of the evaluation of the simulation and takes into account the topology of individual feeders, including the deployment of protection, states of the switches and possibilities of power backup.

The exact extent of simulated values depends on the measures selected [3-5]. Especially the cabling of some overhead lines sections and "shunting" in cable networks lead to the need of dividing the simulation of the numbers of failures into "layers" according to the specific causes of failures. A simulation of the impact of telemetry and tele-mechanization, on the other hand, puts higher demands primarily on the simulation of the durations, which should reflect the most important moments of the process of successive restoration of power supply to customers after a failure. Regardless of the selected measures, it is appropriate to work on real data when setting the distributions of the simulated quantities. What is most significant is the non-homogeneity of failure rates of individual line sections. As the entire calculation of partial relationship is based on specific real feeders, it is advisable to use the records of failures at those feeders during a sufficiently long period (e.g. 10 years), and whenever possible, localize the failures directly in feeder sections.

Operational experience with some types of measures can show a certain "unreliability" of the particular technology (unreliability of measurements, assessment of the situation, communication, etc.). This is another aspect that can be appropriately incorporated in the simulation and its evaluation.

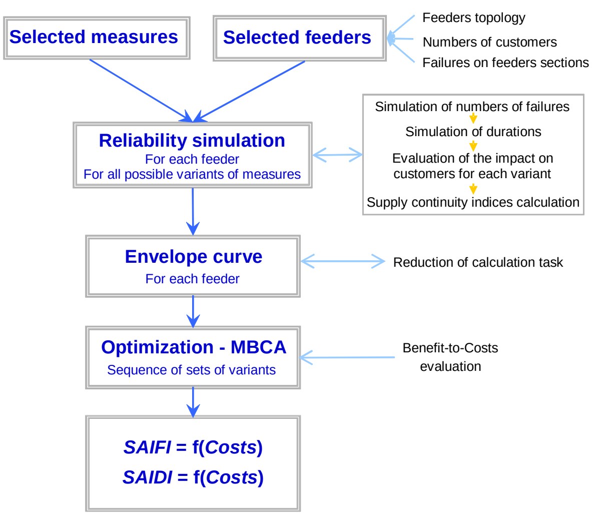


Fig. 2: A framework procedure for establishing a partial relationship

CALCULATION OF PARTIAL RELATIONSHIP BETWEEN COSTS AND QUALITY

Calculating a partial relationship between costs and quality consists of the following main steps (see Fig. 2):

- Selection of measures
- Selection of feeders and processing their topologies (reliability schemes)
- Simulation of reliability for each feeder and all variants of measures
- Creating an enveloping curve for each feeder
- Calculating a partial relationship using the MBCA method
- Evaluation (economic assessment of the specified time scenarios)

The first three steps have already been mentioned in general terms in the previous section. They are performed separately for each selected feeder, as well as the creation of the so-called envelop curve. Its purpose is to reduce the number of options to work with further on. Multiple variants may in fact occur with the same costs in one feeder, but with a different location of the measure (e.g. the placement of a given number of remote control elements on a feeder, etc.). Then each of the variants usually offers a different reduction of supply continuity indices. In this situation, the envelope curve encompasses only those variants that offer the greatest reduction in the selected index (the criteria expressing the benefits in MBCA) for individual costs. Thanks to this reduction, it is possible to use quite a large set of initial options for each feeder.

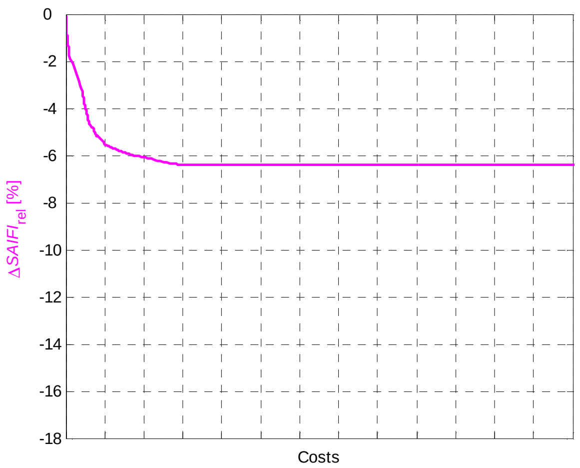
The envelope curves of all feeders are an input for the MBCA method (Marginal Benefit-to-Cost Analysis) [6], which is the next step of the whole procedure. The MBCA method represents an optimization procedure that can be used for forming the sequence of sets of variants (mutually not excluded) in which the costs and the benefits of individual sets steadily increase. The MBCA criterion is the ratio of "benefit-to-cost" - more precisely the ratio of the benefit increase to the costs increase. A benefit has the character of an expected value, which may be generally expressed in monetary or technical units. An evaluation of measures does not necessarily require the introduction of a financial equivalent of reliability (i.e. it doesn't require the choice of the way of converting supply interruptions into money). A benefit may include a change in *SAIDI*, a change in *SAIFI*, or a combination of both. The choice of the way of expressing the benefit is determined by the task being solved, not by the method itself.

The MBCA method is an iterative process which is repeated either until the maximum budget has been reached, or until all feeders have been processed, including all measures and variants. The MBCA general philosophy is to admit a more expensive alternative only if the benefit increase related to the costs increase is greater than for other measures and their variants. Every crown (€ or $) spent in each step must deliver the highest possible benefit. The MBCA method prevents an unjustified application of

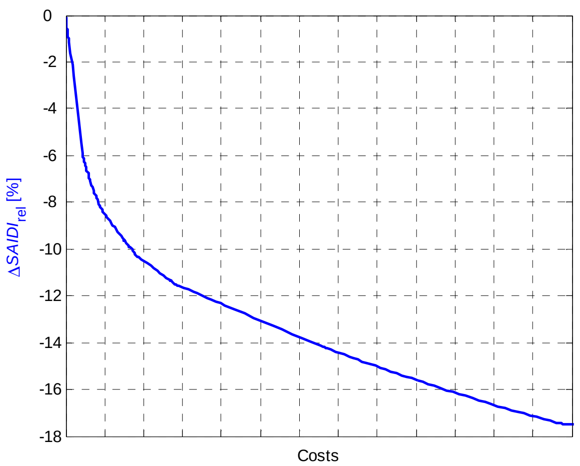
only the most expensive ("gold-plated") variants, which naturally have the highest benefit.
The MBCA method output represents the final step of the whole process and the required partial relationship between costs and quality - quality in terms of the mean change of system-wide supply continuity indices of *SAIFI* and *SAIDI*.

AN EXAMPLE OF PARTIAL RELATIONSHIP BETWEEN COSTS AND QUALITY

An example of partial relationship between costs and quality is shown in Fig. 3. There have been measures affecting unplanned and planned interruptions included in the calculation for the real part of the MV network. On the *y*-axis, the quality is expressed by the average relative changes of system-wide values of *SAIFI* and *SAIDI* indices in relation to the current state. The *x*-axis is the same in both graphs and contains comparative costs, which include investment and operational costs.



a) Change in *SAIFI* vs. costs



b) Change in *SAIDI* vs. costs

Fig. 3: An example of partial relationship between costs and quality

It is obvious that it is indeed a nonlinear dependence, which decreases significantly at the beginning and, after a part which declines less steeply, it continues in both indices to a near-saturation phase. The relative *SAIFI* change is smaller in almost all points of the relationship than the relative *SAIDI* change (except for the first few points). This corresponds with expectations, according to which the *SAIFI* index is harder to modify than *SAIDI*. *SAIDI* can be reduced by a higher amount of remote-controlled switching elements in the network, while a decrease in *SAIFI* requires much more costly measures (recloser installation, cabling overhead lines, etc.).

CONCLUSION

The procedure presented of the partial relationship calculation between the costs and the quality has been verified in a distribution network in the Czech Republic. The results show that the relationship between the distribution system operator's costs and supply continuity indices is a nonlinear relationship. Looking at this issue through unit costs and unit benefits, which must necessarily be only rough average estimates, would not be right, given the significant economic impact.
Based on our long experience with reliability analyses of distribution networks, with reliability simulations and related optimization tasks, we believe that a calculation of complete relationship is not necessary (it would be a calculation with all possible combinations of all possible measures throughout the whole network, which is not practically feasible). The *SAIFI* and *SAIDI* values have only a small number of dominant contributors, which are only a few "problematic" feeders (the feeders with frequent failures, with large numbers of customers and long durations of interruptions) [6]. These feeders are natural candidates to be included in the calculation, since the implementation of measures on them is the most effective. Likewise, it is possible to select such types of measures that promise significant benefits. Even with this limitation, the preparation of data for the calculation is a time-consuming act involving the creation of reliability schemes of all the feeders under consideration, as well as processing their failure data for a longer time period (including the assignment to the line sections).
On the other hand, one should always bear in mind the fact that this relationship is only "partial" and the result cannot be extrapolated without limits (the effect of the best measures is greater in comparison with other measures, whose effect gradually decreases).
The partial relationship itself between the costs and the quality is not a direct generator of the Q component parameters. However, it is a suitable basis for making decisions on their settings since it clearly shows the possibilities of the network and the related costs. For each point of the partial relationship it is possible to calculate the expected value of the quality factor. If taken together with the scenarios of further development, it is then possible to quantify the impacts on prices and define zones within

which the parameter setting can be recommended.
The nonlinearities contained in the Q component require the benefits of the measures in the area of unplanned interruptions to be obtained on the basis of the Monte Carlo simulation. Under each point in the partial relationship stand the full distributions of possible *SAIFI* and *SAIDI* values, which lead to a correct calculation of the quality factor and allow completing the results with the associated probabilities as well as quantifying the associated risks.

REFERENCES

[1] MOOG at al. *5th CEER benchmarking report on the quality of electricity supply 2011*. Council of European Energy Regulators CEER. Brussels, 2012.

[2] MOOG at al. *4th CEER benchmarking report on the quality of electricity supply 2008*. Council of European Energy Regulators CEER. Brussels, 2008.

[3] DĚTŘICH, V., SKALA, P., MATONOHA, K., ŠPAČEK, Z., GÖHLER, M., BLAŽEK, V. Modelling of Supply Interruptions in MV Cable Distribution Networks for a More Accurate Estimation of the Cost of Penalty Payments. In *IEEE Transaction on Power Systems*, vol. 21, No. 2, May 2006. ISSN 0885-8950.

[4] DĚTŘICH, V., MATONOHA, K., ŠPAČEK, Z. Choice of Appropriate Approach to Evaluating the Level of Reliability of Supplying Consumers from MV Distribution Networks . In *17th International Conference on Electricity Distribution CIRED*. Amsterdam, 2001.

[5] SKALA, P., DĚTŘICH, V., ŠPAČEK, Z., PAAR, M. Modelling of the Reliability of MV Lines and Its Utilization in Real Distribution Network. In *Reliability of Transmission and Distribution Networks Conference RTDN 2011*. London, 2011. ISBN 978-1-84919-557-7.

[6] BROWN, R.E. *Electric Power Distribution Reliability*. Second Edition. CRC Press. 2009. ISBN 978-0-8493-7567-5.

[7] SKALA, P., DĚTŘICH, V., BUCHOLCER, O., ŠPAČEK, Z. Value of Supply Interruptions and Its Impact on Optimal Solutions in Distribution Networks. In *2014 IEEE PES Transmission & Distribution Conference & Exposition*. Chicago, 2014. ISBN 978-1-4799-3655-7.