# CHOOSING OF THE OPTIMUM TYPE OF THE MV MUNICIPAL DISTRIBUTION NETWORK WHEN RESPECTING THE CUSTOMER'S STANDARDS OF ELECTRICITY SUPPLY CONTINUITY

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## *ABSTRACT*

*This paper deals with choosing an optimum type of the MV municipal cable distribution network with including the costs of penalty payments into the criterial function. The analysis was performed for a real area of the centre of a large town. Three network types were considered: a network with switching stations, a station-to-station network and a network with reserve cable. The networks were completed with telecontrolled switching elements for securing a comparable switching capability. The situations of building the given network in green fields and of refurbishing the existing two-stage network onto another one of the above-mentioned types were evaluated as variants.*

## INTRODUCTION

The present-day situation in the field of electric energy gives cause to a continuously growing pressure to reduce costs. Distribution companies are also subjected to this pressure and they thus try to reduce operational as well as investment costs of distribution networks operated by them. Consequently, the distribution companies become also interested in choosing the optimum type of the distribution network in a certain locality. This problem arises both when planning new networks (e. g. in case of a more extensive construction of new networks in suburban parts of towns) and when planning the refurbishment of the existing networks (e. g. in case of refurbishing older networks in town centres). A natural tendency prevailing in such considerations (due to pressure to costs reduction) is the building of simplified networks.
Due to the increasing interest of consumers in the electricity supply continuity and to a successive implementation of standards for the electricity supply continuity and to increasing their stringency by energy regulatory offices, it is necessary to evaluate the reliability of variants being considered in financial terms and to include this evaluation into decision making processes.
The transformation of reliability indices into monetary presentation may be carried out based on:

- the estimate of electricity probably not supplied and of the price for it,
- the function of damages,
- penalty payments paid for breaching the standards of supply continuity (see [2], [3]).

The above-mentioned three approaches to assessing the costs of electricity supply interruptions represent three different methods giving, in general, different results.
The assessment of the costs of supply interruptions by means of the electricity not supplied follows from the estimate of the electricity which will not be supplied probably (based on mean values only) and it is necessary to determine the price of it which means a heavy obstacle when really credible data should be acquired.
The assessment of the costs of supply interruptions by means of the function of damages incurred provides credible data in the case that this function can be constructed for each consumer. Due to the difficulty if not impossibility of constructing such "individual" functions of damages we must again resort to certain simplifications. As when using the electricity not supplied, the costs of supply interruptions also represent fictive amounts in most cases.
At present, the costs of penalty payments for not meeting the customer's standards of the electricity supply continuity represent real costs the paying of which may be imposed to distribution companies. Even with regard to expanding activities of energy regulatory offices, we consider these costs as the most appropriate way of expressing the reliability of the supply of electricity to customers (especially to small consumers) in financial terms and, therefore, this method was used in this paper for evaluating the costs of three network types: The first of them – a network with switching stations is the network type actually operated in the examined locality (in centre of a large town). The matter concerns the locality with about 58 thousand of supply points supplied by 413 MV/LV distribution transformer stations dislocated in the area of 4 km$^2$. A station-to-station network and a network with reserve cable are the other network types considered from which the optimum type is being chosen. Individual types of networks will be described in more detail in the next chapter.

## NETWORK TYPES HAVING BEEN ANALYSED

The network with switching stations (NSS) has a two-stage structure as illustrated in Fig. 1. Supply network feeders with cross section 240 mm$^2$ arranged in string 2-1-1 lead from the 110/22 kV transformer station (TR) and they are connected into neighbouring TRs (less frequently into the same TR). Supply feeders supply the switching stations from which distribution feeders with cross section 120 mm$^2$ usually

arranged as semi-loops (individual feeders are operated radially) are going out. Distribution transformer stations are connected to these distribution feeders. This network type resulted from the historical development in the examined locality. In spite of a more complicated structure it has many operational advantages.
In the station-to-station network – S-SN (see Fig. 2) – cable lines lead from one TR into another one. The isolator in the middle of the line, disconnected under normal operation, splits the line into two feeders providing a back-up supply for one to another. Each feeder is loaded by 50% under normal operational conditions.
In the network with reserve cable – NRC (see Fig. 3) – groups of feeders lead from TR and they are connected into a switching station together with a back-up (reserve) cable. The feeders are loaded by 100%. In failure state the load of the failed feeder is taken over by the reserve cable.

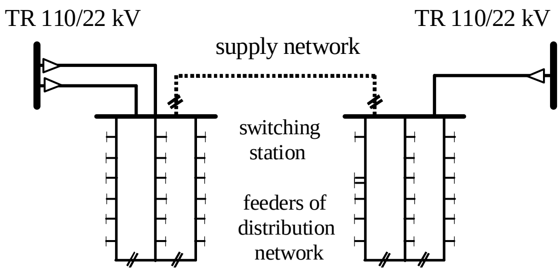


Fig. 1 Network with switching stations (NSS)

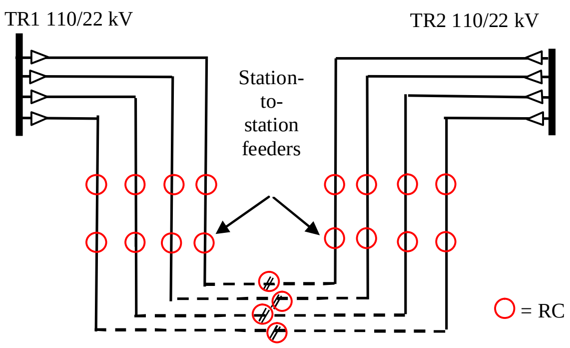


Fig. 2 Station-to-station network (S-SN)

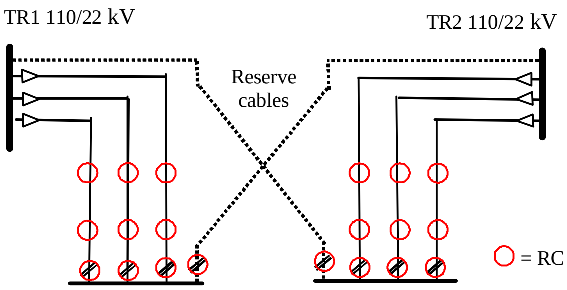


Fig. 3 Network with reserve cable (NRC)

## SECURING A COMPARABLE SWITCHING CAPABILITY OF THE NETWORKS

As the considered types of networks (NSS, S-SN and NRC) have to be used for supplying the centre of a large town where many important institutions, banks and commercial facilities are seated, it was required that switching capabilities comparable with the existing network with switching stations may be preserved even in other network variants.
The feeders of the NSS network most frequently include 6 up to 8 sections (7.1 in the average). Contrary to this, the S-SN network would have to comprise the feeders with 12 sections and the NRC network the feeders with 24 sections in the average for covering the given area.
For that reason we will consider the S-SN and NRC networks as completed with telecontrolled switching elements (RC) in distribution transformer stations (DTSs) in such a way that individual sections of the feeder may include 7 sections approximately.
Two possibilities are taken into consideration:

1. Refurbishment of the MV part of DTSs with fully equipping the station with telecontrolled isolators. The marking S-SN1 for the S-SN network and NRC 1 for the NRC network is then used for considering this possibility.
2. Refurbishment of the MV part of DTSs with fully equipping the station with telecontrolled circuit breakers. The marking S-SN2 for the S-SN network and NRC2 for the NRC network is then used for considering this possibility.

Investment costs of equipping one DTS for variants 1 and 2 are in the ratio of 2/3 approximately. The necessary supplementary equipment for DTSs is marked by rings in Fig. 2 and Fig. 3. In case of the S-SN1 and the S-SN2 network, three DTSs must be equipped with telecontrolled elements on each station-to-station line (i. e. on the couple of feeders). At the point of interconnection of ends of the feeders in the DTS with RC one switching apparatus will be open under normal operational state thus enabling the back-up supply. The remaining two DTSs with RC will be located in middle points of the feeders approximately (their switching apparatus will be closed). Two DTSs will be equipped with RC on each feeder of the NRC network. RC will be also installed in switching substations which secure the back-up switching-over of the feeder to a reserve cable.
With regard to obtaining a comparable manipulation capability of the networks under investigation, in case of NSS we consider an additional installing of telecontrolled isolators at the ends of the feeders.
As the NSS network already exists in the given locality, the matter would not concern building the network in green fields when refurbishing it onto another type. It may be assumed that the existing equipment of the network could be partly used (for about 85%). This solution will be marked as Alternative Mix while the solution with a completely new equipment will be marked as Alternative New. Due to this, the alternatives also differ by reliability. The Alternative New serves for getting a more general view.

## COSTS OF PENALTY PAYMENTS

In order to verify the assumption of a comparable reliability of the NSS, S-SN1, S-SN2, NRC1 and NRC2 networks we carried out an analysis of the sensitivity of the costs of penalty payments for a wilder spectrum of limits of a composed guaranteed standard of supply continuity connected with a jump-like penalization. At this standard, the exceeding of the limit of the annual number of supply interruptions $L_n$ and of the limit of the total annual duration of supply interruptions $L_t$ is evaluated in each supply point. The evaluation is carried out annually. A lump sum penalty is paid to consumers for whom at least one of the limits has been breached. The penalty payment per supply point was chosen in the height of 1000 CZK (approx. 33 €).

The reliability of the network is simulated by using a modified Monte Carlo method ([4], [5]). Its modification consists in a direct simulation of annual numbers of supply interruptions on individual sections of the feeders to which the corresponding durations of supply interruptions are generated additionally. The simulations are based on distributions of the simulated quantities following from real data of a MV cable distribution network for a ten-year period of observation.

Performed analysis revealed that the choice of the limit $L_n$ has a small influence when $L_t$ is lower than (90÷120) min.year$^{-1}$ approximately. However, at higher values of $L_t$ the choice of $L_n$ becomes significant. Under conditions existing in the network of the city the value $L_t$ > 120 min·year$^{-1}$ cannot be, of course, considered as a target limit.

Tab. 1 The mean costs of penalty payments for chosen combinations of limits

| $L_n$ [year$^{-1}$] | $L_t$ [min. .year$^{-1}$] | $n_p$ [mil. CZK.year$^{-1}$] Síť NSS | S-SN1 | NRC1 | S-SN2 | NRC2 |
|---|---|---|---|---|---|---|
| Alternative New | | | | | | |
| 4 | 60 | 4.07 | 4.45 | 4.46 | 3.44 | 4.19 |
| | 90 | 2.20 | 2.44 | 2.60 | 1.82 | 2.24 |
| | 120 | 1.16 | 1.33 | 1.51 | 0.96 | 1.20 |
| Alternative Mix | | | | | | |
| 4 | 60 | 7.70 | 8.37 | 8.25 | 6.50 | 7.92 |
| | 90 | 4.39 | 4.89 | 5.25 | 3.62 | 4.51 |
| | 120 | 2.52 | 2.87 | 3.35 | 2.00 | 2.57 |

The choice of the limit $L_t \leq 60$ min.year$^{-1}$ does not result in substantial changes of the costs of penalty payments. However, the reduction of these costs becomes already evident when we choose higher values of $L_t$.

The mean costs of penalty payments for three chosen combinations of limits are summarized in Tab. 1.
It may thus be seen that – from the point of view of reliability – all five investigated networks represent roughly comparable variants and that the supplementary equipping the networks with telecontrolled elements brought us the required effect.
As the general evaluation consists, on principle, in comparing S-SN1, S-SN2, NCR1 and NCR2 networks with the NSS network, the differences of costs $n_p$ compared with NSS are then decisive. According to Table 1, these differences do not differ for the given combinations of limits significantly. It may thus be stated that the choice of any one from these three combinations of limits will have substantially the same impact on the result of the general evaluation of variants under consideration. Therefore, we will further operate with the costs of penalty payments for $L_n$ = 4 year$^{-1}$ and $L_t$ = 90 min.year$^{-1}$.

## TOTAL COSTS OF INVESTIGATED VARIANTS

So that the total annual costs $n$ of the examined network variants in both alternatives may be obtained, it is necessary to sum up the annual costs derived from investments $n_i$ (without RC) with the annual costs of equipping the network with telecontrolled elements RC $n_{RC}$ as well as with the annual costs of penalty payments for the chosen combination of limits $n_p$.
Individual components of the annual costs for variants of the Alternative NEW are shown in Fig. 4 and those for variants of the Alternative Mix in Fig. 5. The costs are expressed in percentage of the total annual costs of the NSS network.
Differences between the annual costs derived from investments (except for RC) do not exceed 10%.
In case of the Alternative New the annual costs of the S-SN1 network are lower by 3.2% than for NSS. In case of the S-SN2, NRC1 and NRC2 networks these costs are higher by 2.8%, 4.1% and 10.6% respectively. If the utilization of 85% of the existing cables is considered (i. e. Alternative Mix) the annual costs of S-SN1, S-SN2, NRC1 and NRC2 are higher than for the NSS network (by 2.1%, 7.1%, 9.1% and 16.1% respectively).

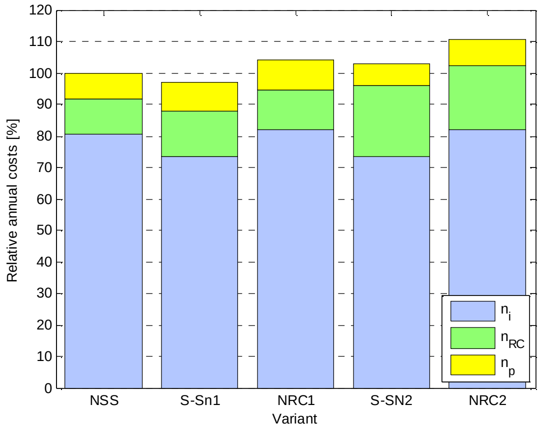


Fig. 4 Relative annual costs of the networks – Alternative New

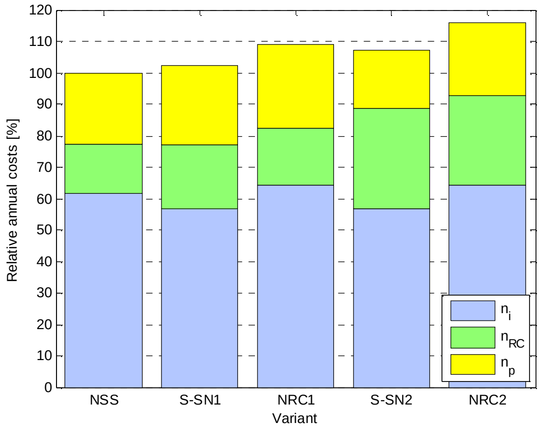


Fig. 5 Relative annual costs of the networks – Alternative Mix

## CONCLUSION

When choosing the optimum type of the network we must also respect the fact that the networks are designed for at least 20 to 30 years from the point of view of technology and for 40 to 50 years from the point of view of cable feeders and buildings. Having in mind the trends in the regulation of the electricity supply continuity, substantially more stringent reliability limits, especially in large towns, may be expected. Therefore, it is necessary to include already now the costs of penalty payments for breaching the customer's standards of the electricity supply continuity into criterial functions, although such standards have not yet been fully implemented in this country.

It also follows from the general view of the problem that local conditions and the character of the supplied area must be taken into account. It is not possible to state one type of the network as the most advantageous directively or to take over optimum solutions from other countries or locations without performing a more detailed analysis.

Evidently, in case of the examined network in the centre of a large town the refurbishment of the present two-stage network onto a network with a simpler structure is not convenient. The annual costs derived from investments are similar for all investigated types of networks, both in case of a complete refurbishing of the network and in case when a part of the existing network elements could be used (differences do not exceed 10%). The requirement for a comparable switching capability of a new network that is fully justified when supplying the town centre with important institutions and banks, results in increasing the annual costs. In case (theoretical case) of building a new network, the variant S-SN1 (station-to-station network completed with isolators) would be less costly by 3% only, other variants would be more expensive than the existing network. If the existing equipment were also used when refurbishing the network, the annual costs of all alternative variants would be higher.

Therefore, when considering the evaluation of network variants from the economical point of view, including penalty payments, the disadvantages of cheaper (as far as investment costs are concerned) variants of the MV network with station-to-station arrangement and with reserve cable will become particularly evident.

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