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Coordinated TSO and DSO network development plan on the islands of Cres and Lošinj

SUMMARY

The paper presents an example of coordinated transmission and distribution network planning based on analyses conducted as part of the study on long term distribution network development plan for islands of Cres and Lošinj in Croatia. The observed area of two large and several smaller islands is supplied with electricity by one long radial 110 kV TSO owned line and parallel radial 35 kV DSO owned line. Due to transmission capacity of 35 kV line limited to 40% of the area peak demand, which is highly conditioned by tourism, the (N-1) criteria is not complied with in case of unavailability of 110 kV line during the two-month period in summer high season. Construction of the second 110 kV line as a common solution is extremely costly, due to necessity of laying down several kilometres of submarine cables. The paper provides the cost benefit analyses of this basic scenario and other possible alternative scenarios, including also investments in DSO network, to determine the most cost-effective solution. Due to the values of the demands and networks lengths, the presented example is close to a worst case scenario concerning the reliability of supply requirement, requesting thus some atypical distribution network analyses, elements and even conducted field tests of operation. The results clearly show that coordination of TSO and DSO planning is beneficiary concerning efficiency of investments in the networks. However, further analyses are recommended presuming contribution to satisfying the (N-1) criteria by use of non-traditional (“non-network” or “third party”) solutions.

KEYWORDS

(N-1) criteria, TSO/DSO alternatives and cooperation, high-temperature low-sag conductors, CBA

INTRODUCTION

Islands of Cres and Lošinj as well as Silba and several surrounding small islands are supplied with electricity by one 110 kV TSO owned and operated line and one 35 kV DSO owned and operated line from TS 110/20/35 kV Krk, which is well connected with the main transmission network. As shown in Figure 1, electricity distribution on islands of Cres and Lošinj is provided from five TS 35/20 kV (Cres, Hrasta, Osor, Lošinj 1 and Lošinj 2) and one TS 35/0,4 kV. Considering also TS 35/10 kV Silba, which supplies several distant smaller islands, it sums up to a total distance of about 110 km, or about 120 km of basically radial 35 kV overhead or cable lines. The corresponding transmission network supplying this area consists of just one radial 65 km long 110 kV line and TS 110/35 kV Lošinj, leaving the area with peak load of 24,8 MW without (N-1) criteria backup supply in case of unavailability of 110 kV line, except for limited capacity of up to 10 MVA through 20/35 kV 8 MVA transformer in TS 110/20/35 kV Krk and old Cu 3x50 mm^2 overhead lines along the islands of Cres and Lošinj.

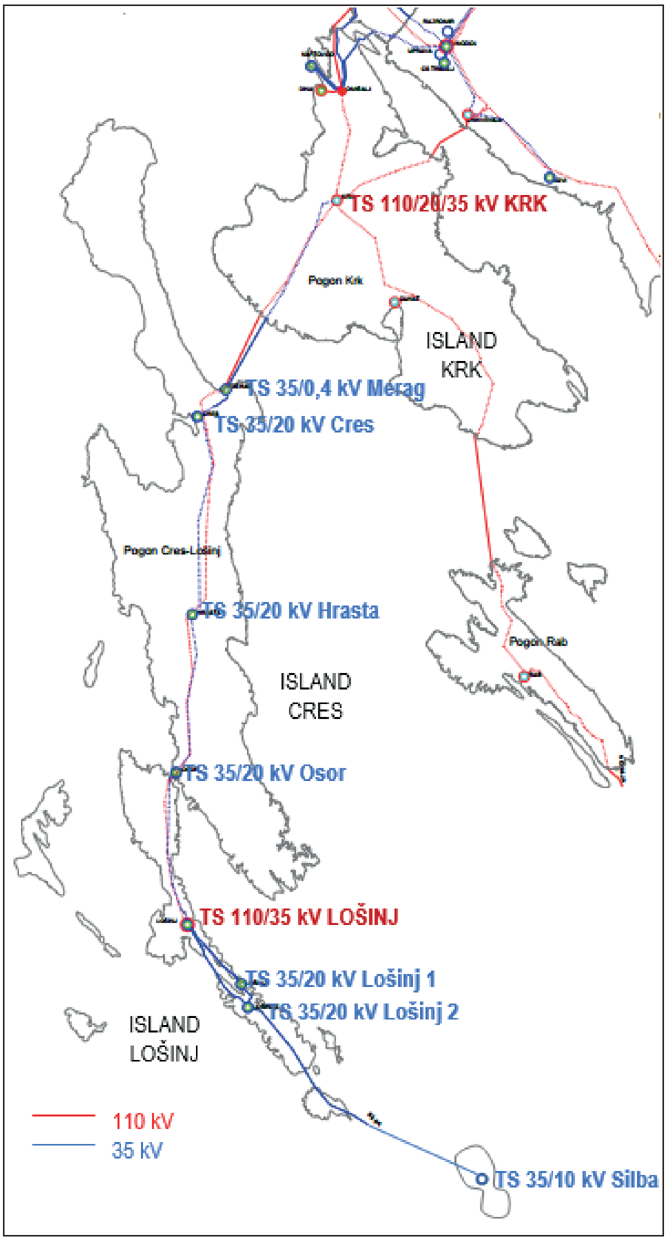


Figure 1: Transmission and distribution network for supplying the islands of Cres and Lošinj

Several alternatives for backup power supply according to (N-1) criteria in case of unavailability of 110 kV line Krk-Lošinj were analysed. The second 110 kV line to TS 110/35 kV Lošinj, as a traditional and technically favourable solution, requires laying down several kilometres of submarine cables, which is extremely costly, especially considering that demand of islands of Cres and Lošinj is highly conditioned by tourism and thus without backup supply according to (N-1) criteria only during one to two months in summer high season. Therefore, alternative solutions have been examined considering 35 kV distribution network, but the value and the location of most of the load in Lošinj area, about 70 km from TS 110/20/35 kV Krk as supplying point for 35 kV network, asked for atypical distribution network elements, such as of high-temperature low-sag conductors, three winding transformers 110/20/35 kV and long 35 kV submarine cables. Additionally, to deal with extreme voltage drops along 35 kV network, voltage regulation with two 110/35 kV transformers (in TS 110/35 kV Lošinj) operating in series (35/110 kV and 110/35 kV) is analysed and even examined in practice. Finally, for the case of long term unavailability of 110 kV submarine cable Krk – Cres, an emergency action plan for 110 kV overhead line connecting to 35 kV network is prepared.

ALTERNATIVES FOR 110 kV AND 35 kV NETWORK DEVELOPMENT CONCERNING (N-1) CRITERIA

Load flow calculations in case of peak load and unavailability of 110 kV line Krk-Lošinj are performed to determine backup power capacities of different alternatives for 110 kV and 35 kV network development, but also as a part of the process of detailed design of reconstructions of overhead 35 kV lines and assessment of the costs. One of important features of the study [1] is performing the load flow calculations for high loads inherent to (N-1) condition with the values of conductors resistances at temperatures of up to 120 °C, according to each line design parameters calculated based on IEEE Std. 738-2006.

The analyses were performed for the peak demand of the area of islands of Cres and Lošinj (with Silba) of 24,8 MW in 2016 and predicted increase to 34,3 MW in the observed 20-year period. Considering the existing network, the (N-1) criteria is: (1) complied with during the entire observed period in cases of unavailability of a single 35/10(20) kV transformer or 35 kV line, (2) complied with for the peak demand of 32,5 MW (16 years in the future) in case of unavailability of a 110/35 kV transformer, and (3) not complied with in the most severe case which is unavailability of 110 kV line Krk – Lošinj – the backup supply is in the current distribution network available only for 10 MW of peak demand, limited by the 20/35 kV 8 MVA transformer in TS 110/20/35 kV Krk,

Analyses of 110 kV and 35 kV network development alternatives aimed at satisfying (N-1) criteria were based on the following assumptions:

- Load flow calculations for cases of unavailability of single transformers 110/SN and 35/10(20) kV as well as 35 kV lines conducted with commonly used parameters for 20 °C
- Load flow calculations in case of unavailability of 110 kV line Krk – Lošinj:

  — Conductor resistance modified to design temperatures of up to 90 °C for cables and 120 °C for overhead lines (depending on the loading)

  — Due to very high active power losses (10% do 15%), as well as voltage drops and reactive power flows, transmission capacities (in MW) of the lines and transformers are up to 20% lower than nominal values.

  — Criteria for determination of backup supply limit at 35 kV network [2]:

  Allowed overload of transformers[1] up to 20%.

  Allowed voltage drop at 35 kV busbars in TS 35/20 kV up to 15%[2]. The analysed methods for voltage regulation: (1) use of voltage regulation 2x10x1,5% in TS 110/35 kV Lošinj (sectionalised 35 kV busbars and transformers in series: 35/110 kV and 110/35 kV), (2) use of capacitor banks (limited effects due to high voltage drops and consequently even higher required reactive power), and (3) use of autotransformers at 35 kV level.

- All network development alternatives assume replacement of TR 20/35 kV 8 MVA Krk with new transformer of minimal nominal rating of 20 MVA[3].
- Concerning the reconstruction of the 35 kV lines Cres – Hrasta – Osor – Lošinj (total length of 42,5 km), three scenarios are analysed: replacement of the existing Cu 3x50 type conductors with the same new lines, conductors of ZTACIR 3x79 type or ACCC 3x115 type.

The following investments in 110 kV and 35 kV network have been analysed:

Base scenario: no investments in network development (reconstruction of overhead 35 kV line Cres – Lošinj with the same Cu 3x50 type conductors);

0. *Reference scenario:* 35 kV submarine cable Novalja – Silba (24 km), reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors and 2 x TR 110/20/35 kV 40/20/20 MVA (Krk and Novalja);

1. *Alternative 1*: reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors and selection of one sub-alternative for transformer in TS 110/20/35 kV Krk:

1 Overload of overhead lines is not considered, because the observed cases include extreme power flows lasting several hours in summer evenings, with high probability of high ambient temperature and absence of wind.
2 There are no 35 kV customers in 35 kV distribution network in this area.
3 Precondition for use of recently completed new submarine 35 kV cable Krk – Cres and reconstructed overhead line (with ZTACIR 3x79 type conductors). Selection of a transformer has been subject of the analyses.

1. TR 20/35 kV 20 MVA,
2. TR 110/20(35) kV 20 MVA,
3. TR 110/20(35) kV 20 MVA and existing TS 20/35 kV 8 MVA, or
4. TR 110/20/35 kV 40/20/20 MVA;

2. *Alternative 2*: parallel 110 kV overhead line Krk – Cres operating at 35 kV, reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors and TR 110/20/35 kV 40/20/20 MVA Krk;

3. *Alternative 3*: 110 kV line Krk – Cres, reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors and TS 110/35/20 kV Cres constructed as:

    1. simple single-transformer substation with TR 110/20/35 kV 40/20/20 MVA transported from TS 110/20/35 kV Krk, or
    2. standard two-transformer substation;

4. *Alternative 4*: TS 110/20/35 kV Cres with TR 110/20/35 kV 40/20/20 MVA transported from TS 110/20/35 kV Krk and reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors; depending on size of substation and rated power of TR 110/20/35 kV there are four sub-alternatives:

    1. simple single-transformer TS 110/20/35 kV Cres with TR 110/20/35 kV 40/20/20 MVA,
    2. standard two-transformer TS 110/20/35 kV Cres with TR 110/20/35 kV 40/20/20 MVA,
    3. simple single-transformer TS 110/20/35 kV Cres with TR 110/35/20 kV 40/40/20 MVA, or
    4. standard two-transformer TS 110/20/35 kV Cres with TR 110/35/20 kV 40/40/20 MVA;

5. *Alternative 5*: second 110 kV line Krk – Lošinj and reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors;

6. *Alternative 6*: second 110 kV line Krk – Lošinj, reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors and TS 110/35/20 kV Cres in one of two sub-alternatives:

    1. simple single-transformer substation with TR 110/20/35 kV 40/20/20 MVA, or
    2. standard two-transformer substation.

Overview of analysed investment alternatives in 110 kV and 35 kV network to satisfy (N-1) criteria is shown in Figure 2 and in more details in Table 1. The results are sorted in increasing order of available backup supply for demand rising from 24,8 MW to 34,3 MW in 20 years.

A specific scenario is analysed for the case of long term[4] unavailability of 110 kV submarine cable Krk – Cres. The emergency action plan assumes (1) connecting of 110 kV overhead line to the new 35 kV submarine cable and (2) use of 35 kV overhead line with the old 35 kV submarine cable[5], enabling thus double 35 kV line Krk – Lošinj. Due to transmission capacity limit of the old 35 kV submarine cable of 9,7 MVA and high voltage drops, (N-1) criteria is complied with up to the 25,8 MW of demand of islands of Cres and Lošinj (with Silba), regardless of the types of conductors of 35 kV lines (Cu 3x50, ZTACIR 3x79 or ACCC 3x115).

1. The conclusions of the analysis aimed to satisfy (N-1) criteria are the following:
2. For full (N-1) criteria up to the existing load at least one more 35 kV line Krk – Cres is needed.
3. For full (N-1) criteria until the end of the observed 20-year period one more line is needed to Lošinj area (at 110 kV or cable line at 35 kV).
4. For full (N-1) criteria for longer period at 35 kV (DSO only investment) requires reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors and new submarine 35 kV cable Novalja - Silba.
5. Alternative to 35 kV cable Novalja – Silba is construction of second 110 kV line to TS 110/35 kV Lošinj.
6. Concerning reconstruction of 35 kV overhead lines and supply from TS 110/20/35 kV Krk (and Novalja), ZTACIR 3x79 type conductors are only marginally better than Cu 3x50 type ones.
7. TS 110/20/35 kV Cres is required concerning (N-1) criteria in case of the demand of islands of Cres and Lošinj (with Silba) larger than 40 MW, with condition that backup supply of TS 110/35 kV Lošinj is provided at 110 kV level (i.e. another 110 kV line constructed). In that case simple single-transformer TS 110/20/35 kV Cres 40/20/20 MVA is sufficient.
8. Considering transmission capacity of 35 kV network and operating flexibility, optimal transformer for TS 110/20/35 kV Krk (and Novalja) is TR 110/20/35 kV 40/20/20 MVA.

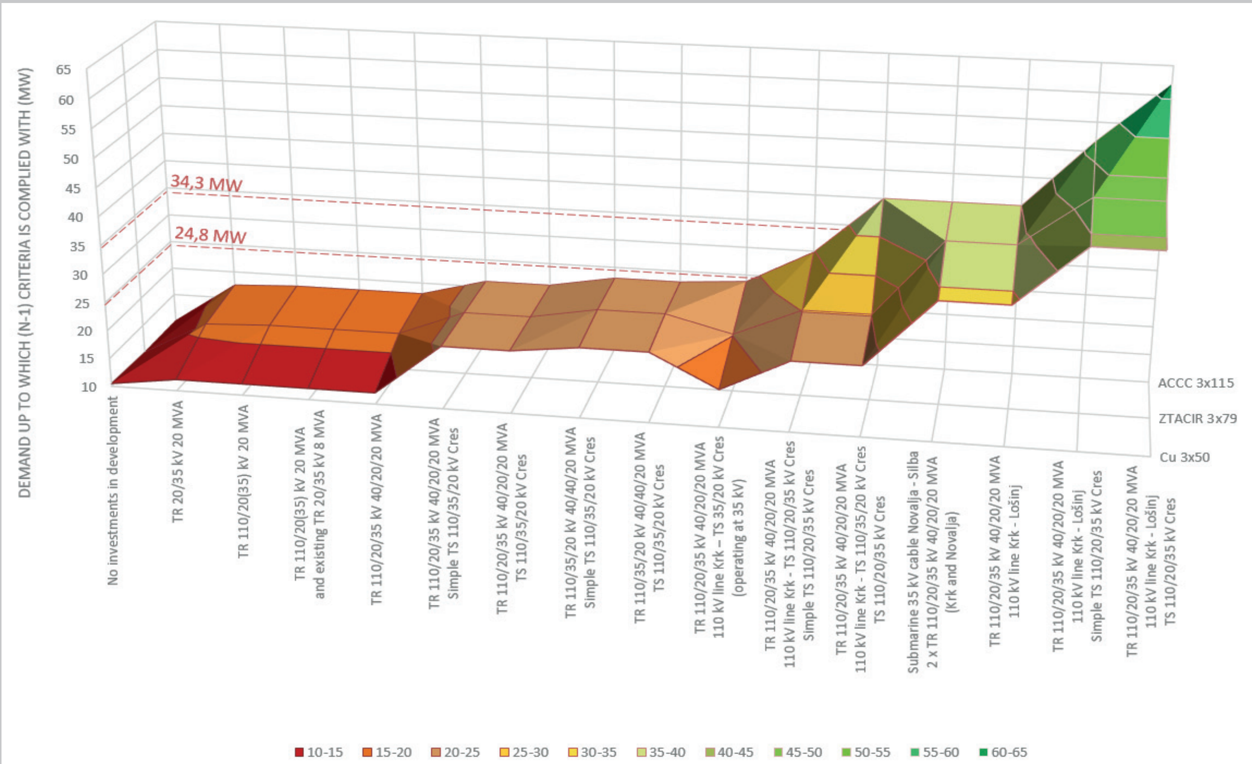


Figure 2: The demand of the islands of Cres and Lošinj (with Silba) up to which (N-1) criteria is complied with for different investment alternatives of 110 kV and 35 kV networks development

4 Up to several weeks, including time needed for special equipment to arrive on site.
5 This solution includes the assumption that the existing old submarine 110 kV oil cable is taken out of the sea after the new cable is laid down.

COST BENEFIT ANALYSIS OF ALTERNATIVES FOR 110 kV AND 35 kV NETWORK DEVELOPMENT CONCERNING (N-1) CRITERIA

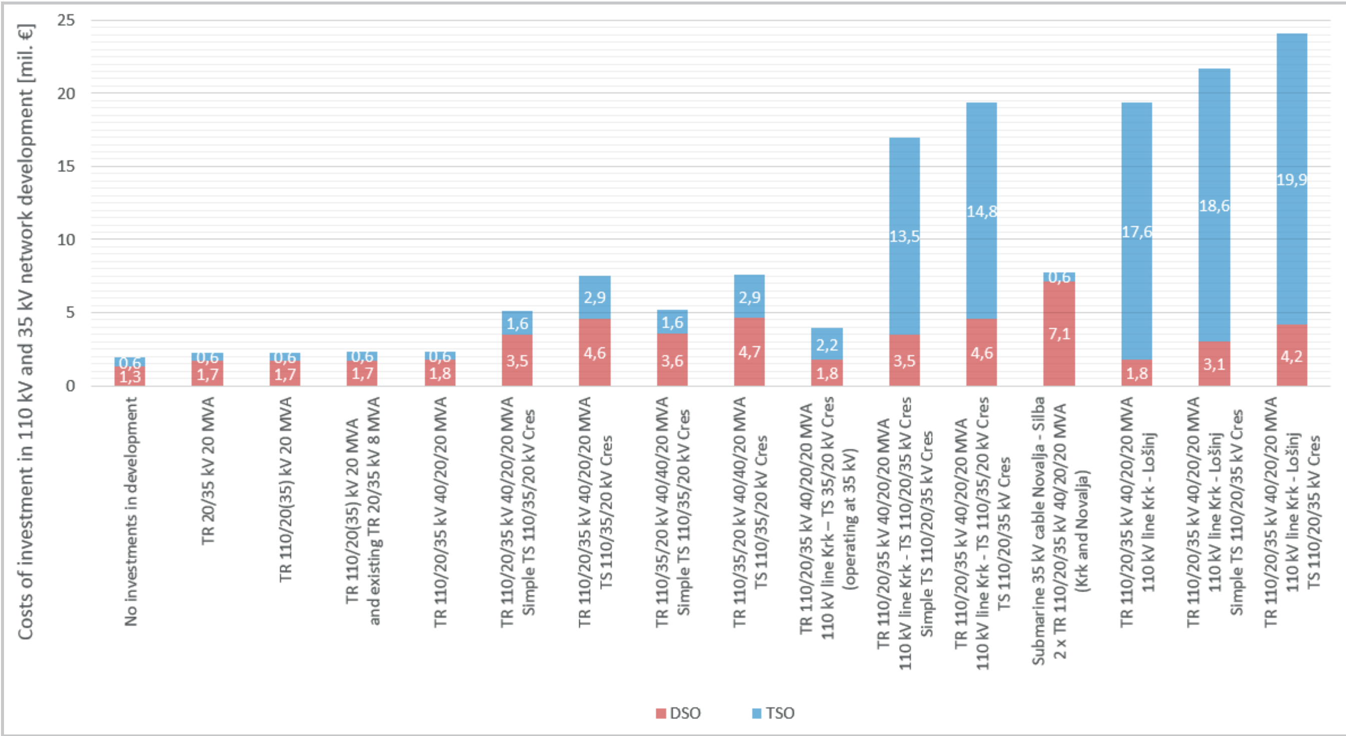
Overview of the results of backup supply determination for different investments in 110 kV and 35 kV network development concerning (N-1) criteria in case of unavailability of 110 kV line Krk – Lošinj is provided in Table 1. For each alternative the list of main investments is provided, including total nominal costs for DSO and TSO.

Table 1: Overview of alternatives of 110 kV and 35 kV network development concerning costs of investments and demand up to which (N-1) criteria is complied with

Alternative		Main investments	Investment (€) DSO / TSO	Demand of islands of Cres and Lošinj (with Silba) up to which (N-1) criteria is complied with (MW)		
				Cu 3x50	ZTACIR 3x79	ACCC 3x115
				1.063.000	1.148.000	1.275.000
No investments		No investments in development	255.000 600.000	10,5		
Alternative 1	1	TR 20/35 kV 20 MVA	404.000 600.000	12	16	17,5
	2	TR 110/20(35) kV 20 MVA	401.000 600.000	12	16,5	18
	3	TR 110/20(35) kV 20 MVA and existing TR 20/35 kV 8 MVA	452.000 600.000	12	16,5	18
	4	TR 110/20/35 kV 40/20/20 MVA	486.000 600.000	12	16,5	18
Alternative 4	1	TR 110/20/35 kV 40/20/20 MVA Simple TS 110/35/20 kV Cres	2.219.000 1.600.000	21	21	21
	2	TR 110/20/35 kV 40/20/20 MVA TS 110/35/20 kV Cres	3.319.000 2.900.000	21	21	21
	3	TR 110/35/20 kV 40/40/20 MVA Simple TS 110/35/20 kV Cres	2.284.000 1.600.000	22,3	23	23
	4	TR 110/35/20 kV 40/40/20 MVA TS 110/35/20 kV Cres	3.384.000 2.900.000	22,3	23	23
Alternative 2		TR 110/20/35 kV 40/20/20 MVA 110 kV line Krk – TS 35/20 kV Cres (operating at 35 kV)	486.000 2.170.000	16,6	20,1	23,8
Alternative 3	1	TR 110/20/35 kV 40/20/20 MVA 110 kV line Krk - TS 110/20/35 kV Cres Simple TS 110/20/35 kV Cres	2.219.000 13.480.000	22,3	25,1	29,8
	2	TR 110/20/35 kV 40/20/20 MVA 110 kV line Krk - TS 110/35/20 kV Cres TS 110/20/35 kV Cres	3.319.000 14.780.000	22,3	25,1	40
Reference plan: (N-1) at 35 kV		Submarine 35 kV cable Novalja - Silba 2 x TR 110/20/35 kV 40/20/20 MVA (Krk and Novalja)	5.871.000 600.000	34	38,5	40
Alternative 5		TR 110/20/35 kV 40/20/20 MVA 110 kV line Krk - Lošinj	486.000 17.630.000	34	38,5	40
Alternative 6	1	TR 110/20/35 kV 40/20/20 MVA 110 kV line Krk - Lošinj Simple TS 110/20/35 kV Cres	1.786.000 18.630.000	44,3	47,1	51,8
	2	TR 110/20/35 kV 40/20/20 MVA 110 kV line Krk - Lošinj TS 110/20/35 kV Cres	2.886.000 19.930.000	44,3	47,1	62

The observed nominal costs for DSO and TSO are shown in Figure 3. They include evaluation of the existing TR 20/35 kV 8 MVA and TR 110/20 kV 20 MVA in TS 110/20/35 kV Krk, while for the second transformer in TS 110/35/20 kV Cres using of an old one is assumed (at no costs). For all alternatives except »No investments in development« reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors is assumed, as the only feasible short term solution. The comparison of costs shows that all investments that require laying down new submarine 110 kV cable Krk – Cres are more than twice as expensive as other observed alternatives. Therefore, the study [3] relied predominately on the investments in 35 kV network, including reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors, new submarine 35 kV cable Novalja – Silba and two new TR 110/20/35 kV 40/20/20 MVA (Krk and Novalja), as the reference scenario.

Figure 3: DSO and TSO costs for different investment alternatives of 110 kV and 35



kV network development on islands of Cres and Lošinj (with Silba)

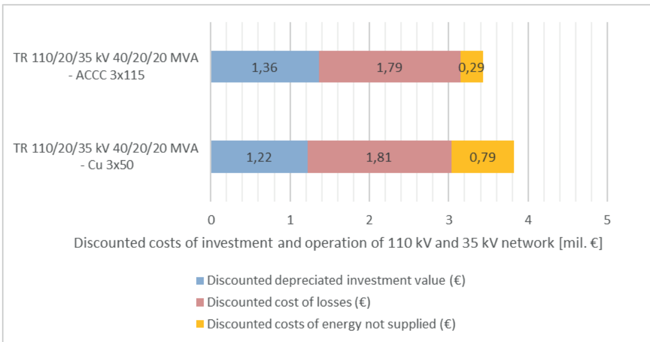
For the selection of optimal alternative of network development besides investment costs also operational costs of energy losses and energy not supplied during the observed 20-year period have to be considered. The common method of comparison of total discounted costs of depreciation, losses and energy not supplied has been applied [4].

Evaluation of losses and energy not supplied is conducted based on one-year SCADA hourly load data of all transformers in 110 kV and 35 kV network, considering also the predicted increase of demand up to 38% in the observed 20-year period. The following input parameters have been applied: (1) price of power losses dependent on load 97 €/kW, (2) price of power losses non-dependent on load 410 €/kW, (3) off-season (October-May) price of energy not supplied 2,5 €/kWh, (4) high-season (June-September) price of energy not supplied 5 €/kWh, (5) price of power not supplied 0,75 €/kW, (6) peak load duration for energy not supplied evaluation 2.828 h, (7) duration of losses dependent on load 1.084 h and (8) discount rate 8%. Assuming overall (including low voltage network) 40% share of energy losses non-dependent on load, the equivalent price of energy losses used in economic evaluation is 72 €/kWh. The prices of energy not supplied are derived based on income and energy consumption related to (1) tourism and (2) all other activities. The equivalent price of energy not supplied is 3,6 €/kWh.

The energy not supplied was evaluated separately for overhead 110 kV line and submarine 110 kV cable Krk-Cres, which, although unlikely, could require an extremely long time to repair (several weeks). For the overhead line backup supply capacities for different alternatives as shown in Table 1 have been considered. For the submarine cable higher of the same values or the value for emergency operation of 110 kV line at 35 kV level (25,8 MW) have been considered. For the overhead line the total yearly unavailability of 4 h is conservatively assumed based on the past unavailability data for all 110 kV lines in Croatian Primorje region. For the submarine cable a very radical model of unavailability during high-season weeks with probability of 5% has been assumed. However, considering the backup power supply of at least 25,8 MW in emergency operation, the contribution of the submarine cable to the total energy not supplied is much lower than the contribution of the overhead line.

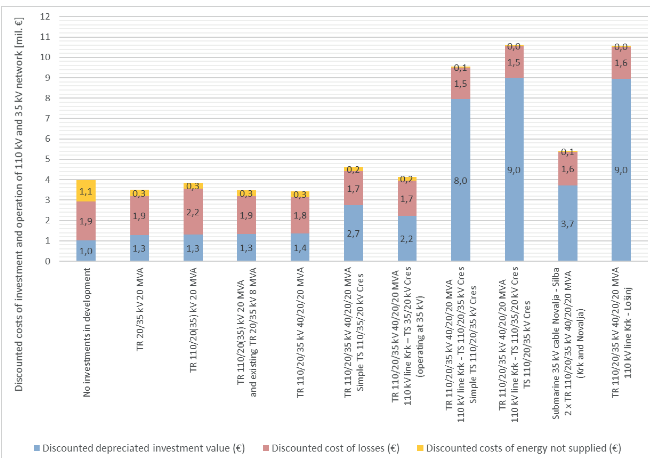
The result of economic justification of reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors instead of Cu 3x50 type ones is shown in Figure 4. Nominal investment cost is 20% higher and discounted depreciated cost is 12% higher. However, with discounted costs of losses 1,4% lower and discounted costs of energy not supplied 64% lower, the total discounted costs of investments and operation are 10% lower. Considering the same discount rate of 8%, use of ACCC 3x115 type conductors is economically justified with nominal investment costs up to 75% higher than using Cu 3x50 type conductors.

Figure 4: DSO and TSO costs of different investment alternatives of 110 kV and 35



kV networks development on islands of Cres and Lošinj (with Silba)

Figure 5 shows discounted investment and operation costs for observed



alternatives of 110 kV and 35 kV network development on islands of Cres and Lošinj with ACCC 3x115 type conductors applied.

The following conclusions summarize the findings of the conducted technical and economic evaluation:

Optimal investment complied with (N-1) criteria up to 18 MW of backup supply includes TR 110/20/35 kV 40/20/20 MVA Krk and reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors (Alternative 1). The total nominal investment is 2.361.000 €, with DSO share of 1.761.000 €, and TSO share of 600.000 €.

Optimal long-term investment complied with (N-1) criteria up to 40 MW of backup supply includes 2xTR 110/20/35 kV 40/20/20 MVA (Krk and Novalja), submarine 35 kV cable Novalja - Silba (24 km) and reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors (Reference scenario). The total nominal investment is 7.746.000 €, with DSO share of 7.146.000 €, and TSO share of 600.000 €.

Additional alternative with costs in between the above values, complied with (N-1) criteria up to 23,8 MW of backup supply, includes TR 110/20/35 kV 40/20/20 MVA Krk, parallel 110 kV overhead line Krk – Cres operating at 35 kV and reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors (Alternative 2). The total nominal investment is 3.931.000 €, with DSO share of 1.761.000 €, and TSO share of 2.170.000 €. However, this is only a temporary solution, assuming use of old submarine 110 kV oil cable (subject to evaluation of the risk to environment) or old submarine 35 kV cable with limited transmission capacity of 9,7 MVA.

Figure 5: Comparison of discounted investment and operation costs for observed 110 kV and 35 kV network development alternatives on islands of Cres and Lošinj

CONCLUSION

The paper presents an example of coordinated transmission and distribution network planning based on analyses conducted as part of the study on long term distribution network development plan for islands of Cres and Lošinj in Croatia. Considering all conducted analyses, optimal network development aimed to satisfy (N-1) criteria in 110 kV and 35 kV network envisages backup supply of islands of Cres and Lošinj (with Silba) through two new transformers 110/20/35 kV 40/20/20 MVA (Krk and Novalja), 24 km of new submarine 35 cable Novalja – Silba and reconstruction of overhead 35 kV line Cres – Lošinj with ACCC 3x115 type conductors. This investments provide similar reliability of supply as would a second 110 kV line, but at 2,5 times lower nominal investment costs or 2 times lower discounted investment and operation costs. The provided results clearly show that coordination of TSO and DSO planning is beneficiary concerning efficiency of investments in both networks. In case the legal obligation of the investment to satisfy (N-1) criteria is at one network operator and investing by the other network operator provides significant reduction of costs, the network operators could decide to request from the regulator special treatment of the investment, if needed. However, they should in any case prove that also “non-network” (or “third party”) solutions have been considered as alternatives contributing to addressing the issue of satisfying (N-1) criteria. Further work on the network development alternatives in this region will focus on such analyses.

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