

# NEW PROCEDURE FOR TRANSMISSION NETWORK PLANNING IN CROATIA

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## Abstract

Transmission network planning has been significantly influenced with an electricity market opening. Transmission network has a task to ensure an efficient electricity market and to support competitiveness between producers. This paper describes the problem of transmission network planning under new circumstances and explains a new procedure for transmission network planning in Croatia which includes redefined planning criteria and methodology.

## Key Words

Power system planning, open electricity market, transmission network planning, criteria, methodology

## 1. Introduction

Electricity market opening process has started in Croatia recently. Power Supply Company HEP (Hrvatska elektroprivreda) was restructured into HEP – Group with several daughter companies, HEP – Production Ltd, HEP – Transmission Ltd, HEP – Distribution Ltd and HEP – Supply Ltd among others. Independent System and Market Operator (CROISMO) was established from the former dispatching centre and it was separated from HEP – Group legally and financially. Transmission and distribution activities, recognized as natural monopolies, are controlled by the Croatian Energy Regulatory Council (CERC). HEP – Transmission is the owner of transmission assets, while CROISMO uses transmission assets in order to allow transactions and to make balancing between production and consumption. Transmission network planning is an obligation for both of them, but final approval has to be given by CERC. Energy Regulating Agency also approves transmission fee, and increasing of it if some network investment has to be financed. It was recognized that electricity market opening causes many changes in transmission network planning, so new criteria and methodology are needed in the future. In vertically organized company security (n-1) criterion was used for transmission network planning.

Some directives for transmission planning concerning voltage level (400 kV was preferred instead 220 kV), number of circuits for new lines (two circuits on each new line), neighbouring networks treatment (planning of self-sufficient network but with strong interconnections) were also defined by HEP. Specific economic criterion wasn't used.

With a new organization of Power Supply Company and introduction of market principles in electricity sector, transmission network planning approach has to be redefined and improved. First steps were done and new procedure which includes criteria and methodology has been defined.

## 2. Electricity market opening - influence on transmission network planning

Transmission network planned configuration strongly depends on input data (production, consumption, exchanges) and criteria that were used for the planning purposes. Input production data comprise location and installed power of new power plants, their dispatch dependent on hydrological conditions and their production costs. Input data about consumption include peak and minimum load, load duration curves, and load proportion on each network node. Exchanges of electricity are result of long term contracts or some assumptions about available production capacities in surrounding power systems. Planned transmission network configuration could be under-constructed or over-constructed depending on the input data. Opening of an electricity market makes more uncertainties and stresses those which were already known in the vertically organized companies [1]. Those uncertainties, recognized in Croatia as the most important, are as follows:

- Location of the new power plants and their dispatch taking into account hydrological conditions.
- Consumption growth, load duration curve shape, and the influence of the electricity price on consumption.
- Organization of the electricity market, unknown market transactions and interconnection lines utilization.

Introduction of the new subjects into electricity market (producers, suppliers, traders etc.) and establishment of separated production, transmission and distribution companies, have an influence on the availability of input data. Planners are now faced with the problem of collecting all necessary data needed for the planning purposes because they are divided among several companies and some of them are treated as confidential.

Introduction of the Energy Regulating Council makes new uncertainties concerning electricity price and transmission fees, renewable energy politic, and approvals for new connections on the transmission network.

### 3. Transmission network planning criteria and methodology

New transmission network planning methodology is a combination of technical and economical analyses. It is defined according to the new circumstances which are expected to occur. Modelling of the most important uncertainties has been suggested also.

Transmission network in Croatia was defined according to the voltage levels and it includes 400 kV, 220 kV and complete 110 kV network. Transformer stations 110/35 kV and 110/10 kV are excluded from the methodology, although SS 110/35 kV (110 kV busbars and transformers) and SS 110/10 kV (110 kV busbars) are mostly owned by the transmission company (HEP – Transmission Ltd).

According to the time frames, planning process is divided into:

- short time planning – time frame up to 5 years,
- middle time planning – time frame between 5 to 10 years,
- long term planning – time frame between 10 and 30 years.

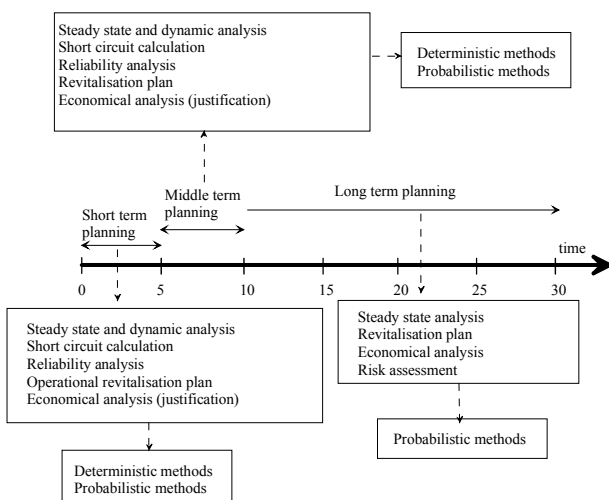


Figure 1 Time frame of transmission network planning

Purpose of transmission network planning and type of analyses are different for different time frames which are studied (figure 1). Short time planning has to give an answer to the question which lines construction has to start immediately. Middle time planning has to point on the lines for which all necessary certificates and approvals have to be collected and routes to be investigated and reserved in the general area occupation plans. Long term planning has to determine strategic issues concerning transmission network development, like voltage levels which will be used, new SS 400/x kV locations, interesting new interconnection lines, possible electricity paths etc. Uncertainties are especially significant for long term planning, although they exist in middle and short term planning, so different methods to deal with them are used for different types of planning according to the time frame.

#### 3.1 Technical analyses

Technical criteria for transmission network planning have been defined in Croatian grid code [6]. The main criterion is (n-1). It says that in the case of unavailability of one network branch (overhead line, cable, and transformer), or one generator connected to the transmission network, following events must not happen:

- Permanent disturbance of operational variable limits (voltage, frequency) and equipment loading (maximum permitted current), which could be dangerous for safe operation of power system, or which could cause equipment damages and expected life time reducing.
- Loss of stability of some power plants or electrical power system in general.
- Necessary change or interruption of long term contracted electrical energy exchanges (import, export, transit).
- Electrical energy supply interruption despite of usage of the reserve capacities in the network.
- Disarrangement spread over electric power system as a consequence of the protection activity.

N-1 criterion is used on only one circuit of double circuit lines, and it doesn't include busbar faults, but it includes cascade loss of several branches if that is predicted with the well-adjusted protection devices in the system. Analyses of (n-1) security have to be provided for peak load situation with maximum generator output. When unavailability of one generator is analyzed, the largest one in a power plant has to be chosen. Technical analyses are performed using PSS/E software mainly. AC power flows are calculated and (n-1) security is checked for each scenario concerning generator dispatch and possible exchanges. Several other technical analyses have to be performed also for short and medium term planning:

- voltage profile calculation,
- short circuit calculation,
- stability analyses.

For voltage profile analysis it is necessary to model off-peak situation also. Optimal compensation devices location and installed capacity are determined using domestic "Optlok" program package. Based on many possible operational situations with different probability concerning consumption, production, branches availability and exchanges, it determines optimal location and installed capacity of compensation devices (shunt condensers, shunt reactors, static Var compensators etc.) calculating three variables: voltages, power losses and closeness to the voltage instability. Influence of each variable on compensation device optimal location and installed power are estimated using different weighting factors.

Short circuit calculation is performed in order to check the ratings of the existing equipment in the network, especially breaking capability of the circuit breakers. Short circuit is calculated according to the IEC 909/1988 standards.

Stability analyses comprise angle and voltage stability calculations for large and small disturbances. PSS/E software is used for these purposes. If some kind of instability is detected, special methods have to be suggested (high speed protection, high speed excitation systems, power system stabilizers installation, controlled system separation etc.) in order to achieve stable operation.

For each type of transmission network planning according to the time domain, revitalization list for existing transmission installations has to be defined. That list includes electrical and construction parts of overhead lines, cables, bays, transformers and construction parts of transformer stations. For short term planning operational revitalization methodology is used, in which equipments need for revitalization is estimated using their real condition and their role in the electric power system. For middle and long term planning revitalization list is made using comparison of equipment life with expected life time estimated in [2]. Deviations from the operational or long term revitalization criteria are reasonable for the following situations:

- uprating of a line because expected line load in the future is greater than thermal rating taking into account (n-1) security,
- connection of a new power plant or interpolation of a new transformer station into existing line, if availability of that line is such that could causes periodical interruptions.

### 3.2 Economical analyses

Main goal of the economical analyses is the comparison between new equipment costs and benefit. Main criterion is Net Present Value (NPV) defined as shown in (1).

$$NPV = \sum_{n=1}^N (EB_n - EOMC_n - EI_n) / (1+i)^n \quad (1)$$

where:

- $EB_n$  - expected benefit in year  $n$ ,
- $EOMC_n$  - expected operational and maintenance costs in year  $n$ ,
- $EI_n$  - expected investment for a new transmission installation,
- $N$  - estimated life time or observed time frame,
- $i$  - discount rate (8, 10 or 12 %).

New candidate satisfies economical criterion if NPV is greater than zero. To calculate NPV for each network strengthening candidate it is crucial to estimate its benefit. Following types of benefit due to the network strengthening are considered:

- expected benefit in unsupplied electrical energy,
- expected benefit in electricity losses reduction,
- expected benefit in congestion costs reduction, and
- expected benefit in re-dispatching costs reduction.

Value of unsupplied electrical energy per kWh in Croatia has been estimated as ratio between gross domestic product (GDP) and annually supplied electrical energy. For year 2002 that ratio is around 2,5 €/kWh. The same value is used for all consumers. More accurate value has to be defined by CERC in the near future.

Losses in Croatian transmission network are between 3,5 and 4,5 %. New branches (lines, transformers) don't reduce losses significantly, but that reduction is included into economical function in order to motivate transmission subjects to reduce losses as much as possible.

Problems with possible congestions has been studied recently [5], but due to many uncertainties possible congestion costs can not be estimated right now. The most important reasons are unknown regional market organization, methods for congestion management which will be used, and unknown future transactions on the market. With the resynchronization of the 2<sup>nd</sup> UCTE synchronous zone and establishment of the regional southeast Europe electricity market congestion costs may become significant reason for network strengthening and they could take a great part in economical justification of network investments.

Possible way to deal with the network overloading is re-dispatching of the generators if it is possible. Re-dispatching costs are included in the economic function.

There is no need to include environmental costs into economic function right now because there haven't been any requests by CERC concerning that problem yet.

Second economic criterion that can be used for transmission network planning in Croatia is the profitability index (2), defined as a ratio between expected annual benefit of some network installation and its investment annuity (assuming that the life time of all network installations is around 45 years).

$$p = \frac{EB_n}{a} \quad (2)$$

$$a = \frac{i \cdot EI}{1 - \frac{1}{(1+i)^T}} \quad (3)$$

where:

- $EB_n$  - expected benefit in year  $n$ ,
- $a$  - investment annuity,
- $EI$  - expected investment for a new transmission installation,
- $T$  - estimated life time of a network installation (~45 years),
- $i$  - discount rate (8, 10 or 12 %).

Using the profitability index, economical criterion is satisfied if that value is greater then 1 for each investigated time horizon. Network configuration has to include every branch which satisfies economic criterion.

### 3.3 Uncertainties

The main uncertainties in transmission network planning for Croatia, described in chapter 2, will be modelled using two approaches:

- multi scenario analysis,
- usage of probabilistic methods.

Uncertainties concerning locations and installed capacity of new power plants will be modelled with several scenarios, which include their dispatch also, especially depending on the hydrological conditions (almost half of installed production capacities in Croatia is in hydro power plants).

Uncertainties concerning consumption will be modelled using probabilistic methods and assuming that consumption behaves according to the Gaussian probability distribution. Some uncertainties concerning consumption, especially in long term planning, will be modelled using several scenarios (depending on the substitution of electricity with gas).

Development and implementation of new mathematical procedures are expected in the future, and this is the main task to improve the procedure of transmission network planning in Croatia. Some aspects of regional transmission planning described and used in [4] are also

possible step ahead because new criterion for the planning of interconnections has to be defined also.

Final agreement between interested subjects (HEP – Transmission, CROISMO, CERC and scientific organizations) about the problem with investments which are technically but not economically justified ( $NPV < 0$ , or profitability index  $< 1$ ) hasn't been reached yet, and discussions are still going on about that issue. If there will be no possibility for all parties to agree about clear distinction between technical and economical criterion decision is expected from the Energy Regulatory Council.

### 3.4 Planning procedure

Procedure for the transmission network planning has been proposed by the Energy Institute "Hrvoje Pozar" (figure 2). Approval form HEP – Transmission, CROISMO and CERC is awaited. This procedure consists of the following steps:

1. Input data collection (unique transmission network planning data base creation), definition of the scenarios.
2. Modelling of the transmission network for deterministic and probabilistic analyses.
3. Creation of the existing equipment revitalization plans.
4. Identification of the possible network limitations, (n-1) analysis.
5. Creation of the list of possible candidates for network strengthening, (n-1) analyses, economical analyses.
6. Voltage profile analysis on the economically optimal network.
7. Short circuit analyses.
8. Stability analyses.
9. Definition of the final network configurations depending on the scenarios.

Creation of the data base for transmission network planning was suggested, as a first step in the new procedure implementation. This data base will include all technical and economical data needed for transmission planning. Technical data will include production data (historical production depending on hydrological conditions, existing generators and unit transformers parameters, basic data for new power plants concerning their location and installed capacity), consumption data (historical data about consumption, predicted load duration curves, mean values and standard deviations, load distribution on network nodes, reactive power consumption etc.), network data (topology, parameters, compensation devices, protection settings, availability of branches) and historical data about power system (blackouts, results of different studies concerning transmission network). Economical data will include average prices of network equipment based on domestic and foreign experiences, historical operation and maintenance costs, costs of production, costs of ancillary services, unsupplied electrical energy costs, transmission fees and electricity price.

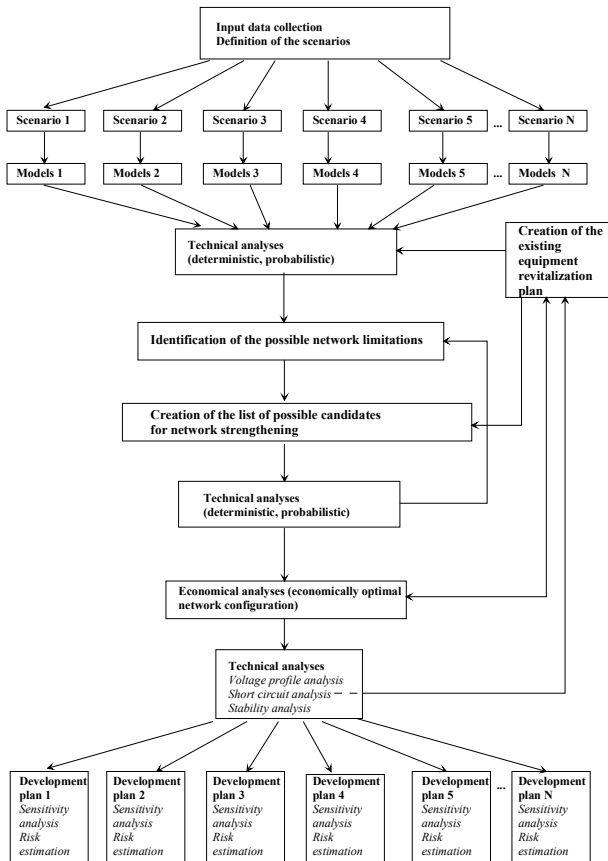


Figure 2 Transmission network planning procedure

#### 4. Application

Described procedure for transmission network planning was applied for the short and medium term planning of Croatian network [7]. Time horizon till 2010 was observed. Expected configuration in 2005 after the reconnection of the 2<sup>nd</sup> UCTE synchronous zone was the basis for analyses. It was assumed that two important transformer stations in Croatia, 400/110 kV Ernestinovo and 400/220/110 kV Zerjavinec (under construction), will be finished and that 400 kV network in Bosnia and Herzegovina will be completely reconstructed on a pre war configuration.

Neighbouring power systems and the rest of the UCTE were modelled according to the official plans collected from different sources (common projects, questionnaires, reports, etc).

With the respect on the new power plants construction only one scenario was defined for time horizon in 2005 (no new power plants in Croatia). For time horizon in 2010 two scenarios were defined depending on the location of the new 400 MW combined cycle power plant (CCPP) that will be constructed around 2007 (official plan by HEP – Production Ltd). Locations inside the existing power plants (TPP Rijeka and TPP Sisak) were observed.

Three scenarios were defined in 2005 and 2010 concerning the power plant dispatch dependent on the hydrological conditions (normal, very dry and very wet hydrology).

Possible exchanges were taken into account with six more sub scenarios. In first two sub scenarios domestic thermal power plants are into operation during normal and very wet hydrology and Croatian power system is balanced, another two sub scenarios assume that 800 MW is imported from Slovakia and Germany during normal and extra dry hydrology, and the last two sub scenarios assume that 600 MW is imported from Serbia and Bosnia and Herzegovina during the same hydrological conditions.

Consumption growth and load duration curves were modelled using the mean value (standard deviation is zero). According to the official plans it is expected that the peak load will be increased from 2800 MW in 2001 to 3171 MW in 2010. Dependence of the load on climatic conditions wasn't modelled.

Uncertainties concerning new power plant location and dispatch dependent on the hydrological conditions caused six scenarios for year 2005 and twelve scenarios for year 2010 to be analysed. It was shown latter that results are slightly sensitive only on the scenarios defined because of unknown new power plant location.

Operational revitalization list was defined according to the equipment real condition and the role in the electric power system. Total amount of money needed for the revitalization till 2010 is estimated on approximately 160 millions of euros.

(N-1) analysis has pointed on the weaker parts of the transmission network concerning thermal limits and voltage profile during peak load conditions. For all examined scenarios it was six contingencies leading to some over loadings or unsatisfactory voltage profile in 2005 and two additional contingencies in year 2010 after the network was strengthened in 2005. The list of possible candidates for network strengthening was created and (n-1) analysis was repeated. Lines and transformers which were necessary in order to satisfy the (n-1) criterion were subjected to economical analyses.

Mexico method was used for the estimation of the reduction in unsupplied electrical energy cost, losses costs and re-dispatching costs. Profitability indexes were calculated for each network strengthening candidate, and only two investments were found profitable, so they were included in the network configuration (fig. 3). Those investments are SS 110 kV Vodnjan and OHL 2x110 kV Plomin – Vodnjan on Istria peninsula, and new OHL 110 kV Komolac – Ston in Dubrovnik area. Two profitable network investments were not dependent on the examined

scenarios. Seven other critical branches in some operational conditions were found not profitable for strengthening till examined time horizon.

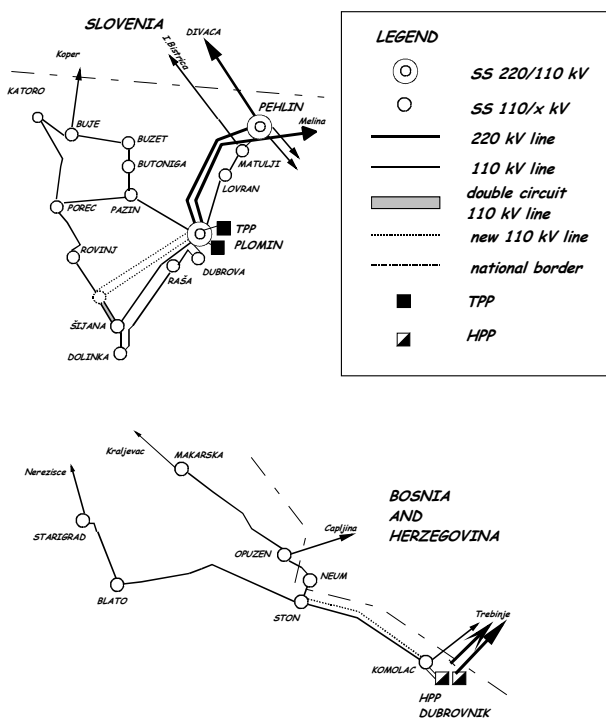


Figure 3 Profitable investments in Croatian 110 kV network till 2010

Economically optimal network was subjected to voltage profile, short circuit and stability analyses. Problems with high voltages during off peak and light load conditions occurred, especially in the 400 kV network. Usage of the existing devices (reactors connected on 110 kV network and tertiary windings of 400/110/30 kV transformers, under excited generators, compensation work of generator connected on 400 kV network) were not enough to keep satisfactory voltage conditions, so optimal location and installed power of 150 Mvar in reactor (as the cheapest solution) connected on 400 kV network were determined. Short circuit analysis pointed on the circuit breakers with unsatisfactory breaking capabilities, and need of 110 kV network separation in the Zagreb area on eastern and western part was confirmed (western part has to be fed by one SS 400/110 kV and the eastern part by second SS 400/110 kV), because breaking capabilities of circuit breakers in several transformer stations 110/x kV are too small comparing with the calculated three pole and single pole short circuit currents.

Stability analyses have shown satisfactory dynamic behaviour of Croatian power system with respect to the large and small disturbances that were examined. Some ideas about excitation system replacements and power system stabilizers installation were suggested in order to improve system dynamic behaviour.

## 5. Conclusions

Electricity market opening process has been started in Croatia after legislative approval from the Parliament in 2002. Further steps were done through the restructuring of the Croatian Power Supply Company (HEP), establishment of the Croatian Independent System and Market Operator (CROISMO) and Croatian Energy Regulatory Council (CERC). Transmission network assets are now owned by HEP – Transmission but operated by CROISMO. Those two subjects are obliged for transmission network planning. New procedure for transmission network planning, which includes technical and economical criteria, has been suggested and discussions about that are going on. Uncertainties in transmission network planning will be taken into account using multi scenario analyses and probabilistic methods. Further improvements are expected in development and implementation of new mathematical procedures and in definition of criteria for the interconnections planning. Regional cooperation between different subjects in southeast Europe concerning that issue is expected.

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