

TRANSMISSION NETWORK INVESTMENT CRITERIA

Summary:

This paper analyzes the problem of planning and investments in the Southeast Europe (SEE) transmission system within new open electricity market environment which is to be established in the near future. Transmission system planning criteria and methodology for projects prioritization are suggested from the SEE regional perspective. It should be stressed out that the SEE region includes many countries (9 Contracting Parties and 5 Participants to the Energy Community Treaty among them) with their own transmission system operators differently organized and positioned with respect to production and supply companies, with different obligations raised from national legislation and grid codes concerning transmission network planning issues. Finding a way to commonly plan and develop regional transmission system is not an easy task, and it should be fully coordinated and stimulated by all parties concerned.

Key words: planning and investments, Southeast Europe transmission system, planning criteria, methodology for projects prioritization

1. INTRODUCTION

Transmission network planning has been strongly influenced by the electricity market opening. Several facts are very important for transmission planning process under new conditions. These facts are:

- significant uncertainties that appear in a deregulated environment comparing to those that appear in a non-deregulated monopolistic environment,
- lack of input data needed for planning process,
- different transmission development objective functions, depending on the view of market players and participants (producers, traders, suppliers, consumers, regulators, operators),
- certain disproportion between technical, economical, environmental and social requests.



Figure 1 Geographic position of the Contracting Parties to the Energy Community Treaty

In the SEE region transmission network is owned and controlled by SEE TSOs. Area of interest for this paper spreads over territories of Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, Montenegro, Romania, Serbia, UNMIK, Slovenia and Turkey. Each of them has its own transmission system operator who is responsible for network reliability and security, as well as operational and planning aspects.

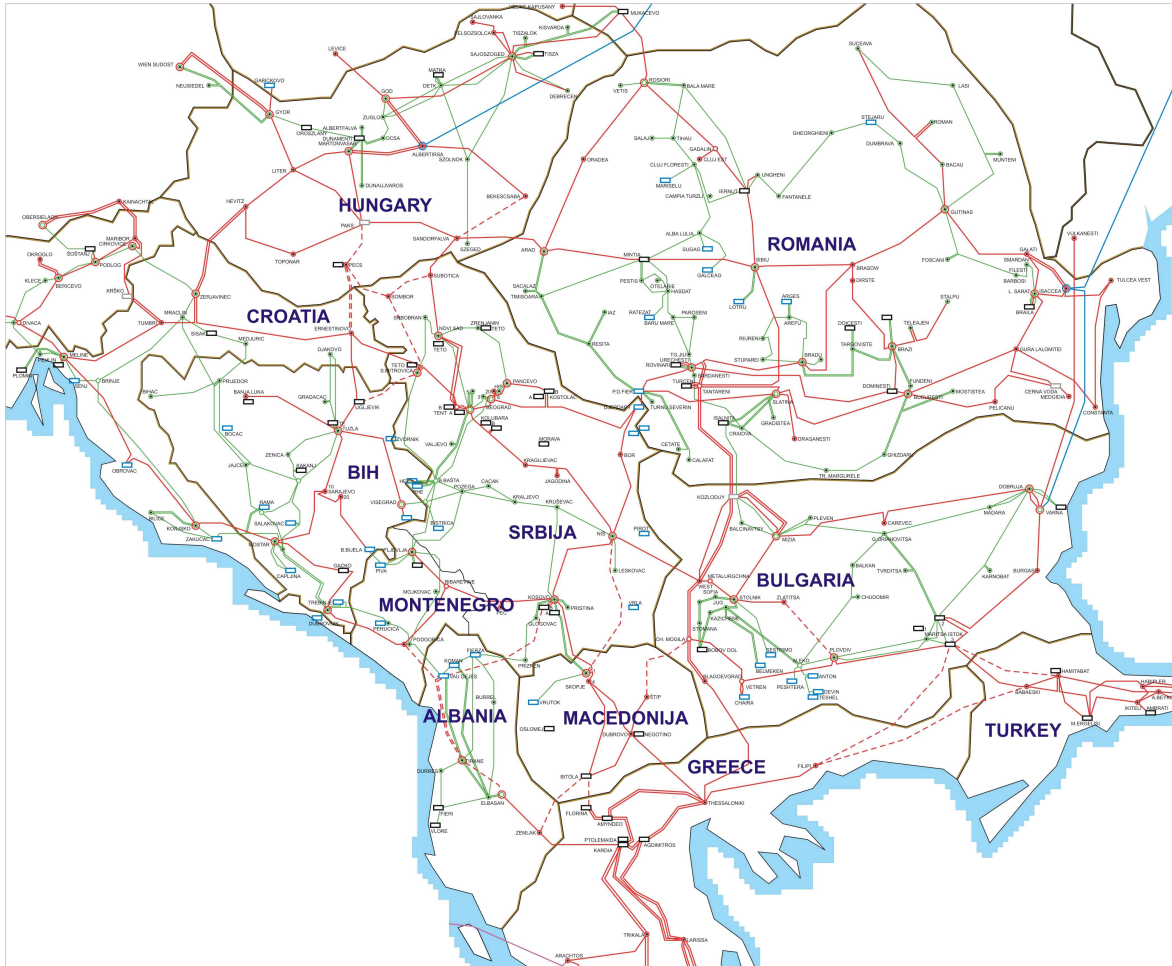


Figure 2 SEE transmission system

The 8th Athens Forum concluded that transmission investment criteria have to be defined from a regional perspective, and transmission projects have to be prioritized according to those criteria. The aim of that conclusion is to support market activities inside the Energy Community and to remove barriers caused eventually by transmission network for free market trading.

This paper elaborates the problem of transmission investments in an open market environment (Chapter 2) defining the most relevant uncertainties in the SEE region, reviews past experience in transmission network planning, analyzes transmission planning criteria which have been used by different SEE TSOs (Chapter 3), reviews national grid codes and a draft version of the regional grid code (Chapter 4), suggests transmission investment criteria from a regional perspective and proposes a methodology for project prioritization (Chapters 6 and 7), based on the certain prerequisites and assumptions (described in Chapter 5).

2. TRANSMISSION NETWORK PLANNING IN AN OPEN ELECTRICITY MARKET

Transmission network planning inside the vertically integrated power companies were mostly performed in order to determine network configuration in the future that will support power plants economical dispatch and satisfy predefined technical requests with minimum construction, operation and maintenance costs. Transmission network planning inside the SEE power supply companies in the past was characterized by the following:

- (n-1) criterion was applied and was dominant in planning,
- only peak load situations were analyzed (minimum load situations were also analyzed somewhere to observe voltage profile),
- probabilistic methods were generally not used, so probability of network failures and overloadings were not observed,

- economical criteria were not dominant in decision making process,
- uncertainties in input data (production plan, generators dispatch, load growth, etc.) and related risk of wrong investments were not treated satisfactorily.

In an open market environment there are significant uncertainties, which have to be taken into account during transmission system planning. The most significant uncertainties are:

- power plants construction,
- power plants decommission,
- generators engagement (bidding behavior),
- load growth predictions,
- demand elasticity,
- market prices,
- market transactions,
- bilateral contracts,
- regulatory aspects,
- market organization, etc.

There are some important issues which have to be considered concerning transmission system planning in an open market environment:

- network planning has to include the most important uncertainties in the future,
- traditional mathematical optimization methods and deterministic models are not appropriate for market conditions without significant improvements,
- each network investment decision include some risk, so risk analysis techniques should be applied in network planning,
- investment decisions depend on applied planning criteria which should be defined according to a strategic view on transmission role in the market (economically optimal or satisfactory secure network, allowance of full competition no matter of development costs etc.),
- having in mind the necessity for uncertainties inclusion in the planning process, risk analysis and economical calculations, the probabilistic planning methods have advantages comparing to deterministic ones,
- network development in an open market conditions should be initiated by market oriented signals such as location marginal pricing or congestion costs.

Today, the SEE TSOs still plan their networks as before, without taking into consideration future market conditions. Technical (n-1) criterion is still the main rationale for network strengthening, the economic criteria have not been applied, the deterministic methods have been dominantly used, almost neither of them use probabilistic methods (except Romania), uncertainties have not been included into the planning process, there are not enough, or not at all, market signals which may lead to network investments.

3. EXISTING PLANNING CRITERIA

Based on the questionnaire that was given to eleven SEE TSOs (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, Montenegro, Romania, Serbia, UNMIK, Slovenia and Turkey) about transmission network planning issues, it may be concluded that:

- SEE TSOs are responsible for transmission network planning, and development plans have to be approved by national regulatory authorities everywhere;
- SEE TSOs are obliged by national laws to prepare transmission development plans up to 20 years ahead. The most often time horizons for planning are 1 year ahead and five years ahead;
- Transmission investments are mostly financed through transmission fees and loans. Only Turkey allows private investors to construct transmission facilities;
- Transmission planning criteria are published in the national grid codes;
- The main technical criterion for transmission system development is the (n-1) security criterion, which is applied everywhere. It is mostly related to the loss of single line, transformer or generator, when following events are not permitted: hermal overloadings of branches, oltage declination below permitted range, oss of stability, loss of load, interruption of power transits, and isturbance spreading over power system.
- The (n-2) criterion is used only in Montenegro and Romania (in Romania only for grid connection of the nuclear power plant);
- Other technical criteria for transmission system planning are not used, except in Romania where stability criteria and compensation facilities installation criteria are prescribed;

- SEE TSOs usually do not define different thermal ratings for winter and summer operational circumstances, or for normal and emergency conditions. Different ratings are defined somewhere (Albania, Montenegro, Serbia, Turkey, UNMIK) for winter and summer operation with respect to the outside temperature, and different ratings are defined somewhere for normal and emergency conditions with respect to the protection systems settings (Macedonia, Montenegro, Slovenia);
- There are no TSOs in the SEE which evaluate the probability of the (n-1) events during transmission system planning;
- SEE TSOs usually conduct load flow computations, security analysis and short circuit calculations during planning process. Optimal power flows (Bulgaria, Turkey, UNMIK) and stability analysis (B&H, Bulgaria, Macedonia, Romania, Turkey) are also conducted somewhere;
- Probabilistic analyses during transmission system planning process are performed only in Romania;
- Economic criteria are applied somewhere (Albania, B&H, Croatia, Macedonia, Romania, Serbia, UNMIK) in the transmission network planning;
- The most often used economic criterion is the profitability index as the ratio between benefits and costs of transmission investments;
- SEE TSOs which apply an economic criterion usually estimate reduction of the cost of losses, loss of load costs, re-dispatching costs, congestion costs and benefit from telecommunication lines;
- Undelivered electricity costs in the SEE are lower than 3 €/kWh. The lowest value is applied for planning purposes in UNMIK (0.4 €/kWh), and the highest value is applied in Croatia (2,56 €/kWh). Some countries have not defined those costs;
- Generally, additional planning criteria are not applied for interconnection lines. Some countries apply different planning criteria based on the system operational costs (Macedonia) and difference between energy prices (Serbia);
- Uncertainties are mostly taken into account by using multi-scenario analysis. The most important uncertainties are:
 - new power plants size and location,
 - generators engagement,
 - hydrological conditions,
 - market transactions,
 - country power balance (demand/supply).
- Risk assessments are not conducted by the SEE TSOs.

4. GRID CODES REVIEW

Based on the review of the national grid codes and a draft version of the regional grid code related to the transmission network planning issues, it can be concluded that:

- Grid codes prescribe TSOs obligations related to transmission system planning reports and studies. Planning horizons vary from short-term (up to 1 year ahead) to long-term (up to 20 years ahead);
- Grid codes define the role of the transmission systems. National transmission systems have to enable reliable and secure system operation and continuous load supply. Regional aspects of national transmission systems are not mentioned in national grid codes so there is no reference point for regional transmission system planning;
- All national grid codes prescribe the usage of the (n-1) criterion in transmission system planning. Explanation of that criterion is very similar between countries and not permitted consequences of single outages are pretty much the same;
- Other technical criteria, such as short-circuit or stability criteria, are prescribed somewhere in national grid codes;
- Transmission investments economic rationalization is not mentioned in the national grid codes, except in general terms in B&H and Romanian ones;
- Probabilistic technical criteria for transmission system planning (loss of load probability) are mentioned only in Romanian and Turkish grid codes;
- National grid codes are prepared in line with a draft version of the regional grid code, and there are no larger disproportions between the national grid codes and the regional grid code concerning transmission system planning issues;
- Draft version of the regional grid code assumes creation of a working group which would plan the network on a regional level, especially directing attention towards interconnection lines and those internal lines that have large impact on transfer capacities between different countries. National grid codes do not envisage any working group at a regional level which may deal with regional and/or national transmission system planning issues;

- It seems that national grid codes and a draft version of the regional grid code do not satisfactorily respect market issues in transmission planning, especially concerning planning uncertainties, economic considerations of transmission investments, balance between security and costs, promotion of the private financing and congestion costs.

5. PREREQUISITES AND ASSUMPTIONS

The basic assumption for the work conducted within this paper is that the regional electricity market will exist in the near future at the territory of South East Europe. Planning criteria and methodology are thus suggested to be respected by the SEE TSOs. Well defined planning criteria and methodology at the regional level may help the SEE countries to develop their power systems and infrastructure that will serve common electricity market in accordance with the Energy Policy for Europe (EPE). Meeting the objectives from the EPE related to sustainability, competitiveness and security of supply will surely help the SEE countries to better integrate into future common European electricity market.

Important assumption for the work conducted in this paper is that a stable regulatory framework and necessary degree of co-ordination between the SEE TSOs in terms of technical standards, balancing rules and congestion management mechanisms will be achieved in the near future. More sufficient unbundling of the TSOs from production and supply companies may lead to more incentives to develop the network in the overall interest of the market and the SEE region as a whole. The SEE transmission network planning criteria and methodology are defined by observing national networks at the territory of the SEE, under the responsibility of the SEE TSOs, as unique network, with the aim to promote and ensure market activities inside the Energy Community. Planning criteria and methodology are defined taking into account national requests defined in national grid codes as much as possible, but suited to the regional electricity market needs. They serve primarily to support market activities with satisfactory level of overall system adequacy and security, based on technical and economical considerations. They also serve to estimate the level of future SEE power system reliability and to identify and prioritize transmission investment candidates from a regional point of view. In other words, the SEE region is observed as one power system with same obligations and rights for all market participants and transmission network planning criteria and methodology are set to keep the overall system adequacy and security in the most economical way.

Important assumption for the effective usage of planning criteria and methodology proposed in this paper which will lead to transmission network investments with regional significance is an acceleration of authorization procedures (construction of a new transmission line may last more than 10 years in existing situation). Dynamic and fast development of the SEE transmission system will support predicted fast growth of trading activities inside the electricity market and fast integration of renewable energy sources (construction period for a new wind power plant is up to three years), which will be impossible if complicated authorization procedures remain unchanged. Environmental aspects in the SEE transmission system development have to be observed and respected in the most efficient manner. This will help to speed up the construction of transmission facilities by making them more acceptable for the public.

Private initiatives and public-private partnership in the SEE transmission system planning and development should be stimulated by market oriented signals. Private interest is important aspect with respect to economic rationalization of network investments and has to be respected and promoted. The SEE transmission system planning should include the most important uncertainties that may arise in the future. According to the planning horizons (short, medium, long term planning), there are different types of uncertainties which have to be included in analyses. The most important uncertainties which should be observed in the network planning are:

- new power plants size and locations,
- hydrological conditions,
- generators bids,
- branches and generators availability,
- load prediction,
- regional power balance.

Transmission network has to be designed to serve the needs of its consumers. Connection of new power plants brings probably the largest uncertainty in network development. As many as necessary scenarios concerning Generation Investment Plan have to be analyzed. In accordance to the European Energy Policy special attention should be directed on the integration of renewable sources into the grid. One generation

investment scenario may be defined assuming high integration of renewable sources on distribution (small wind power plants, fuel cells, small hydro etc.) and transmission level (large wind power plants).

Transmission system investments are financed by the SEE TSOs through transmission fees and loans according to national legislation. National regulatory authorities have to approve network investments and allow the inclusion of investment costs into transmission fees. This paper does not observe the problem of investments financing. Problems may arise if some SEE TSO is not satisfied with the SEE transmission system development plan, made according to the criteria and methodology defined here, and rejects to invest in some new line with a regional market significance (with not so obvious benefit for national network and system under control of that TSO). Some mechanism for investments financing on the territory of one TSO but beneficiary for other TSOs or market players/participants has to be found at least in the framework of the Energy Community. Otherwise, the adoption of planning criteria and methodology suggested in this paper will be more complicated, if not impossible. Private investments should be stimulated also by the SEE TSOs, regulatory authorities and respective EU bodies.

With the market development it is expected that congestion costs will become a very influential factor for interconnection lines construction. Nevertheless, transfer limits on interconnection lines in the SEE are often related to some internal network problems, and rationalization of some investments in new interconnection capacity may cause that internal problems stay hidden. Furthermore, the SEE TSOs may declare lower values of Net Transfer Capacity in order to protect domestic power producers from market activities or to keep unnecessary high level of security of a system under their control because of different reasons.

Having in mind that planning criteria and methodology are set in this paper for the SEE region as a whole, the treatment of interconnection lines and internal national lines should be the same. It means that suggested criteria and methodology have to be applied equally to interconnection lines between different SEE TSOs and to internal power lines inside national networks. Planning criteria for power lines between the SEE countries and other markets and power systems should be based on economical rationales, taking into account possibilities for expanding market activities (power import, export) and differences in electricity prices on different markets.

6. TRANSMISSION NETWORK INVESTMENT CRITERIA

Technical criteria for the SEE transmission system planning are used for technical evaluation of the candidate projects for transmission network reinforcements. Table 1 presents the summary of suggested SEE transmission system technical planning criteria. Technical criteria include:

- 1) The (n-1) criterion,
- 2) Voltage and reactive power criterion,
- 3) Short-circuit criterion, and
- 4) Stability criterion.

The profitability index is defined as the ratio between expected annual benefit from a candidate project and the annuity of its expected costs (construction, operational and maintenance costs), and suggested as the economic criterion for transmission system planning. Profitability indices for candidate projects have to be calculated for all time frames (planning years) within the planning horizon. Observed candidate project is economically profitable if its profitability index is larger than 1 within planning period. If profitability index is not larger than 1 for all studied years a candidate project is considered as not economically profitable.

$$PI_i = \frac{EB_i}{EC_i} > 1 \quad (1)$$

where: PI_i is the profitability index in year i ,
 EB_i is expected benefit from construction in year i ,
 EC_i is the annuity of candidate project expected costs.

The most important transmission candidate project is the one with the highest value of the profitability index. Economically profitable transmission candidate projects should be included into planned network configuration according to declined profitability indices (from the highest profitability index of a candidate project to the lowest but greater than 1). Planned transmission network configuration should not contain any economically not profitable candidate project.

The following types of benefit from candidate projects construction may be estimated for the purpose of economic criterion evaluation:

- benefit due to reduction of expected annual undelivered electricity costs,
- benefit due to annual losses reduction,
- benefit due to reduction of annual re-dispatching costs,
- benefit due to annual congestion costs reduction.

The following types of costs from candidate projects construction may be estimated for the purpose of the economic criterion evaluation:

- investment costs,
- operation and maintenance costs.

For the planning purposes, investment costs may be estimated by using unit equipment price values. Unit equipment price values for the SEE region which will be used for planning purposes have to be determined by the SEE TSOs. Discount rate which will be used for the SEE transmission system planning should be determined by relevant institutions (the SEE regulatory authorities, the SEE TSOs etc.).

7. METHODOLOGY FOR PROJECT PRIORITIZATION

The SEE TSOs are obliged to plan transmission systems under their control. Their plans will include new facilities and objects, but planned primarily to satisfy their national requirements, obligations and criteria. Regional and market significance of these projects may be invisible or not estimated and taken into account. Unique list of candidate projects in the SEE should be determined and each of the SEE TSOs should define candidate projects according to their national plans and considerations. This list has to include technical and economical parameters of candidate projects. The list of candidate projects prepared by each SEE TSO shall be divided into two parts:

1. candidate projects with local significance, and
2. candidate projects with possible regional significance.

Only candidate projects with possible regional significance should be evaluated at the SEE regional level, examined according to pre-defined technical and economical criteria and prioritized according to the methodology described here.

Load flow and security analyses have to be conducted within planning time-horizon in order to examine future network operation and identify possible constraints that may occur. Network modeling for load flow and security analyses shall be prepared by the SEE TSOs, representing a network on the territory of their control. Models shall be merged and one official model of the SEE transmission network shall be prepared for each studied year within the planning horizon. Network shall be modeled in the PSS/E format (Power System Simulator for Engineers, Siemens PTI) that is used by all SEE TSOs. Concerning analyzed demand situations, three load levels shall be modeled: 1 winter peak load, 2 summer maximum load, and 3 summer minimum load.

Initial models should be used to create different models representing future uncertainties. Load flow and security analyses should be performed for all future scenarios and network constraints should be recorded. List of recorded network constraints for all analyzed planning scenarios in a studied year is the base for project candidates' technical and economical evaluation that follows.

For the purpose of economical evaluation of candidate projects, declared by the SEE TSOs as "projects with possible regional significance", and their prioritization, probabilistic analysis should be performed. Probabilistic analysis should be conducted for different demand (load) levels. Probabilistic analysis should be performed for all planning scenarios defined according to future uncertainties. For each planning scenario benefits from candidate projects shall be evaluated. Separate application of technical and economical criteria in transmission system development evaluation and projects prioritization procedures should be allowed, depending on readiness and availability of software tools. Starting from the common list of candidate projects, nominated by the SEE TSOs as "projects with possible regional significance", and conducted analyses of load flows and (n-1) security, candidate projects should be included into network topology one by one, and new load flow and security analysis have to be performed for all analyzed planning scenarios in a studied year. New list of network constraints has to be created, and constraints that are removed when new project is included into network topology have to be highlighted.

Candidate projects which are included in the reviewed list of candidate projects are technically prioritized according to network constraints that are removed by candidate projects:

- first group contains candidate projects that remove network constraints with (n) available branches (the highest level of technical prioritization), and
- second group contains projects that remove network constraints with (n-1) available branches (lower level of technical prioritization).

Inside these two groups of candidate projects, further technical prioritization is made according to:

- the number of planning scenarios in which a candidate project removes network constraints (more planning scenarios with network constraints that are removed by a candidate project, more technically significant is a project),
- voltage level of overloaded transmission lines (removal of overloads on 400 kV lines are more significant than on 220 kV lines), and
- the number of network constraints that are removed by a candidate project (more constraints are removed, more technically significant is a project).

Candidate projects that are included in the reviewed list of candidate projects and prioritized according to the technical criteria should be further evaluated and prioritized according to the economic criteria. Evaluation and prioritization of candidate projects according to the economic criteria is based on the profitability indices, or on the basis of the ratio between annual expected projects benefit and costs annuity for a studied year. Candidate projects should be included into network topology in a model for probabilistic analysis, one by one, and their benefits should be estimated. Costs should be estimated using same unit equipment prices. Profitability indices should be calculated for all planning scenarios and average profitability index as a ratio between total sum of profitability indexes for planning scenarios and the number of analyzed planning scenarios should be determined. Prioritization of the projects should be made according to maximum average profitability index. Transmission facility or object with maximum average profitability index should be included into network topology for a studied year, and all calculations have to be repeated in order to find out a candidate project with the second highest average profitability index. This procedure shall be repeated until there are no other candidate projects with the profitability index larger than 1 in any planning scenario. Transmission system planning process consists of different mutually dependent analyses (technical and economical ones), so it is necessary to define the planning procedure that will be respected during planning process (Figure 3).

8. CONCLUSIONS

In the course of the work on this topic we became aware of the following:

- Planning criteria used by the SEE TSOs today are generally similar and mainly concentrated around the (n-1) security criterion;
- Market oriented transmission investments and investments from regional perspective are not mentioned and satisfactorily treated in the national grid codes;
- National transmission networks are mainly planned according to technical considerations and economic rationalization of new investments generally stays out of interest;
- Methods used by transmission planners are based on deterministic approach and probabilities of different events (network failures, generator dispatch, branches availability etc.) are not treated satisfactorily which does not allow better economical considerations of network development and inclusion of economic criteria into decision making process;
- The SEE transmission system planning process has to include different uncertainties which will occur in an open electricity market environment. The most important ones are generation investment plan(s) with size and locations of new generators, generators bidding behavior in the future, hydrological conditions, branches and generators future availability, load growth and regional power balance. This paper suggested multi-scenario approach in dealing with uncertainties and transmission planning procedure is adjusted to that;
- Transmission development in the SEE may be more effective and faster if following requests are to be fulfilled: a) full independency of Transmission System Operators from production and supply companies; b) acceleration of national authorization procedures for transmission facilities construction; c) effective market design and stable regulatory framework; d) introduction of market oriented signals for transmission investments; e) attraction of private investments into transmission development; f) coordination and full cooperation between the SEE TSOs in planning issues; and g) establishment of a stable financing mechanism that will support regionally important projects;

Table 1 Technical criteria for SEE transmission system planning

Planning time-frame	Topology	Analysed operating conditions	Technical criteria satisfaction	Permitted corrective actions
Short	All branches and generators available (n)	SEE peak load SEE minimum load (1-3 years horizon)	$I_{lines} < I_{max\ lines}^*$ $U_{min} < U_{node} < U_{max}$ Stability criteria Short-circuit criteria	- automatic transformers regulation - switching of compensation devices - network sectioning
	One branch (line, transformer) or generator or compensation device unavailable (n-1)	SEE peak load (1-3 years horizon)	$I_{lines} < I_{max\ lines}^{**}$ $U_{min} < U_{node} < U_{max}$	- generators re-dispatching ^{***} - automatic and manual transformers regulation - switching of compensation devices - network sectioning
Mid	All branches and generators available (n)	SEE peak load SEE minimum load (5 years horizon)	$I_{lines} < I_{max\ lines}^*$ $U_{min} < U_{node} < U_{max}$ Stability criteria Short-circuit criteria	- automatic transformers regulation - switching of compensation devices - network sectioning
	One branch (line, transformer) or generator or compensation device unavailable (n-1)	SEE peak load (5 years horizon)	$I_{lines} < I_{max\ lines}^{**}$ $U_{min} < U_{node} < U_{max}$	- generators re-dispatching ^{***} - automatic and manual transformers regulation - switching of compensation devices - network sectioning
Long	All branches and generators available (n)	SEE peak load SEE minimum load (10 years horizon)	$I_{lines} < I_{max\ lines}^*$ $U_{min} < U_{node} < U_{max}$	- automatic transformers regulation - switching of compensation devices - network sectioning
	One branch (line, transformer) or generator or compensation device unavailable (n-1)	SEE peak load (10 years horizon)	$I_{lines} < I_{max\ lines}^{**}$ $U_{min} < U_{node} < U_{max}$	- generators re-dispatching ^{***} - automatic and manual transformers regulation - switching of compensation devices - network sectioning

* may be defined separately for winter and summer operation

** may be defined assuming permitted short time overloading (within 30 minutes)

*** power plants with fast regulation only (within 30 minutes)

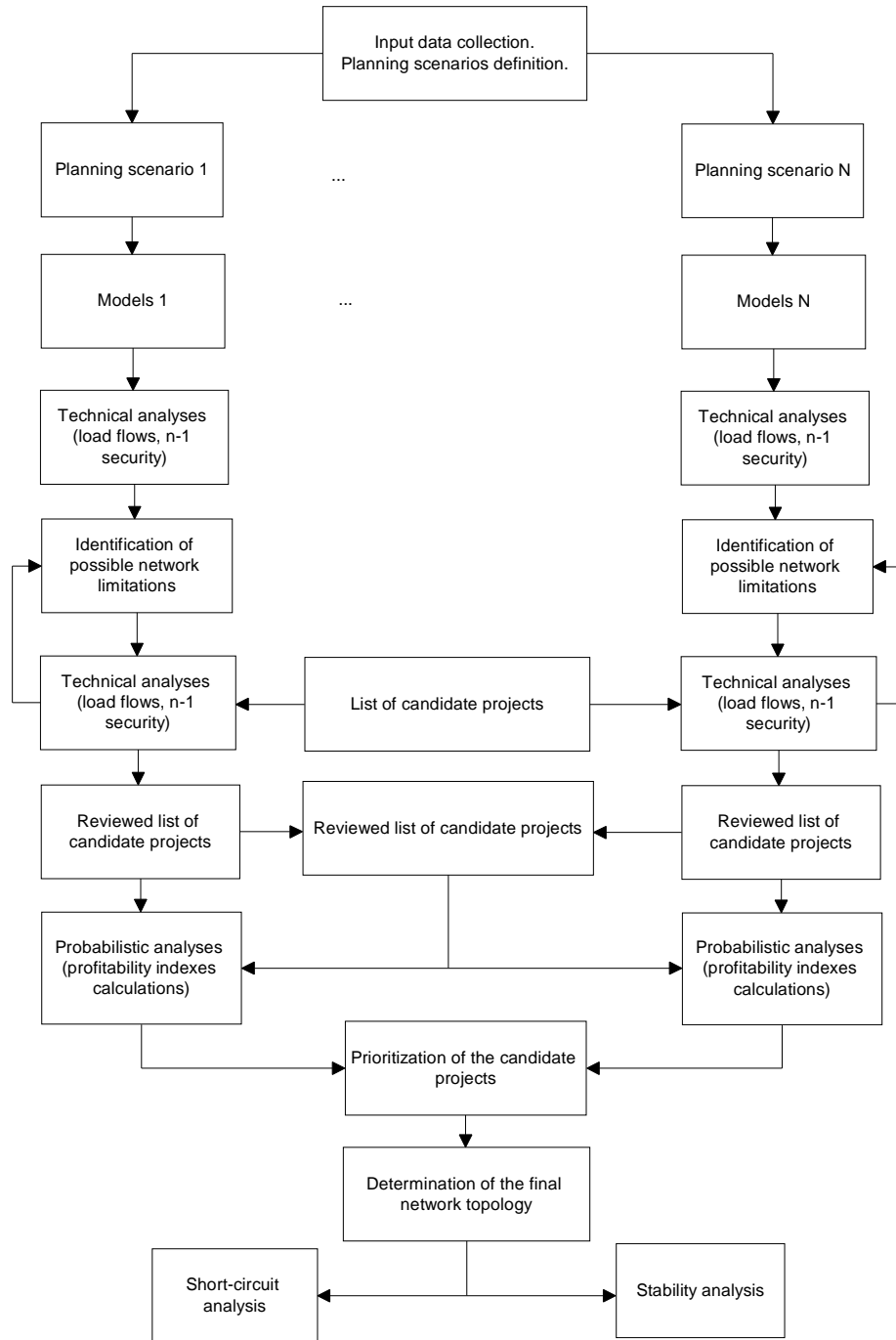


Figure 3 Proposed SEE transmission system planning procedure

LITERATURE

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