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Macedonian Transmission Grid Capability and Development

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Abstract. The main task of the transmission grid is to guarantee evacuation of electricity from production facilities and, at the same time, supply the electricity to all customers, in a secure, reliable and qualitative manner. During the last years, transmission grid goes through the period of fast and important development, as a result of implementation of renewable and new technologies and creation of internal European electricity market. Due to these reasons, capacity of the existing grid needs to be upgraded either with optimization of existing infrastructure or constructing the new transmission projects. Among the various solutions for strengthening the grid, the one with the minimal investment expenses for construction is selected.

While planning the national transmission grid, MEPSO planners apply multi-scenarios analyses, in order to handle all uncertainties, particularly in the forecasts on loads, production and exchange of electricity, location and size of the new power plants, hydrological conditions, integration of renewable sources and the evolution of the electricity market. Visions for development of European transmission grid are also considered. Special attention in the development plan is paid to modelling of power systems in the region of South-Eastern Europe and covering a wider area of the regional transmission grid with simulations of various market transactions. Macedonian transmission grid is developed to satisfy all requirements for electricity production/supply and transits, irrespective which scenario will be realized on long-term basis.

Transmission development plan gives the road map for grid evolution from short-term and mid-term period towards long-term horizons (15-20 years ahead). While creating long-term visions, a big challenge in front of transmission planners is implementation of NPP.

The paper gives overview of the planning process of Macedonian transmission grid, comprising: definition of scenarios, planning methodology and assessment of transmission system adequacy. Capabilities of connection of NPP to the transmission grid on a long-term horizon are highlighted.

1 Introduction

Paper gives overview of approach and assumptions used in preparation of development plans of Macedonia transmission network. Intention is to provide an understanding of the characteristics of the transmission system from the viewpoint of a NPP and the special requirements of NPP with regard to its grid connection, quality and reliability of its electrical supply. While designing the network on a long term horizon and studying the connection of NPP, it is very important to ensure that all the interactions between the electrical grid and the NPP will be considered.

2 Planning of the Transmission Grid

Planning of the transmission grid ensuresthat Macedonian Transmission System Operator – MEPSO provide public service in a safely manner, implying secure and timely supply of electricity at a reasonable delivery price and care for the environment.

First step of the planning process is data collection and preparation of electricity balance. It gives basic estimation of customers' need and expectation imposed on the transmission network on a mid-term and long-term horizon. Electricity balance isworked out in different scenarios and cases that are processed into market and grid simulations. The final outcome is general investment plan for transmission grid that comprises selected solutions for development/reinforcement of the network.

Special attention is paid to modelling of power systems in the region of South-Eastern Europe and covering a wider area of the regional transmission grid with simulations of various market transactions.

For each analyzed reference year a model of the transmission grid is prepared first, including several representative scenarios.Follows identification of the problems and critical outages, and at the end the variants for resolving them are defined. Between various competing solutions for strengthening the grid that contribute to overcoming the problems, the one with the minimal investment expenses for construction is selected.

3 Technical Analyzes and Criteria for Planning

Technical criteria and all type of analyzes that are used in the planning process are defined in the Grid Code [2] and applied in the Study [1].

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While identifying problems in the grid and investigating possible solution, two types of simulations are executed: market and grid. It is strongly recommended coordination and iterative application of both types of simulations.

In **market simulations** grid is represented in a simple way. Objective is to execute large number of simulations of power system operation, ultimately for all 8760 hours during the year and different scenarios in regard to hydrology, power exchange, generation development and other market uncertainties. Generation and demand profiles are estimated in detail. For every hour of the year a snapshot for load, generation and exchanges between countries can be obtained. This means that every hour in the year is available to be used as an input for grid simulations.Market simulations should clearly differ structural against incidental bottlenecks in the grid.

Grid simulations are run on specific planning scenarios and regimes that are selected based on market simulations and definitions given in the Grid Code [2]. Grid simulations assume simple representation of production and demand profiles, while the network is represented in full detail.

Grid simulations are done by special software packages (MEPSO uses PSS/E) that have different calculation tools and modules for:

- Steady-state load flow (loading of lines and transformers, voltage profile at all buses, active and reactive generation, active power losses in the system)
- Transfer capability of the grid (NTC, GTC)
- Optimal power flow (optimization of active/reactive flows and voltage profile)
- Short circuit faults
- Voltage stability
- Dynamic stability
- Reliability (EUE, LOLP)

Analyzes of the performance of the transmission networkbegin with simulations of steady state normal operating regime. In addition, reliability and security of the grid is investigated using N-1 principle.

N-1 principle is fulfilled if all technical criteria, defined further in the text, are respected, when contingency event

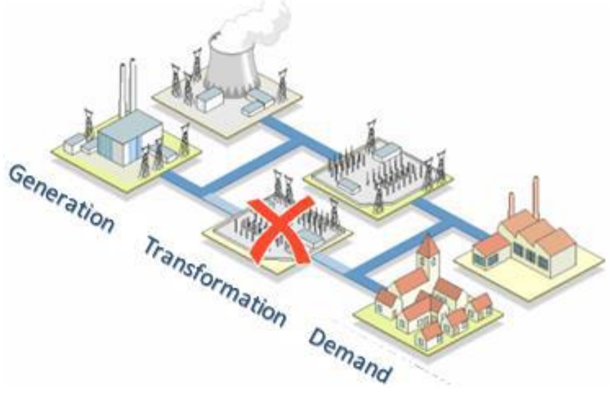

Figure 1. Illustration of N-1 principle

occurs in the network. Contingency event involve different outages of the transmission elements, such as: generator, transmission line, transformer, shunt, etc. N-1 principle comprises single outages of all transmission elements in the national grid, single outage of 220 kV and 400 kV transmission elements of neighboring systems and single outages of interconnection lines in the wider region.

Extreme contingencies, such as busbar outage, complete power plant outage, double circuit outage or simultaneous outage of two different lines (N-2) are not included in the planning process, but rather investigated for specific analyses – preparation of defense plan or design of the connection of NPP.

Network parameters in studied scenarios and regimes should satisfy **technical criteria** for planning, both for steady state and dynamic stability:

- Criterion for cascade outages – a single contingency should not lead to cascade tripping and interruption of power supply.
- Loading criterion – loading of elements in normal operational regime and contingency regimes should be kept inside the predefined loading limits of the equipment.
- Voltage criterion – bus voltages in normal operational regime and contingency regimes should be in the predefined voltage ranges:
  - 380 - 420 kV for 400 kV voltage level (±5% of nominal voltage)
  - 99 - 121 kV for 110 kV voltage level (±10% of nominal voltage)
- Criterion for max outage of load/production – should not exceed power of the biggest consumer or biggest generation unit in the system.
- Short circuit criterion – maximum short circuits level should be less than design values of the equipment; at the same time minimum short circuit values should guarantee reliable operation of relay protection.
- Criterion for voltage stability – here is used experience and recommendations of ENTSO-E.
- Criterion for dynamic stability:
  - Dynamic stability – faults that are cleared by operation of protection devices should not results of loss of stability and tripping of generation unit.
  - Small-signal stability – power swings in the systems originated by switching actions or large power transits across the network should not result in non-dumped oscillations.

4 Cost – Benefit Analyzes, CBA

The goal of project assessment is to characterize the impact of transmission projects, both in terms of added valuefor society as well as in terms of costs. Last few years, ENTSO-E has developed this multi-criteria CBA, which compares the contribution of a project to the different indicators on a consistent basis [2,5]. The methodology is used both for common project appraisals carried out for the TYNDP and for individual project appraisals undertaken by TSOs in national studies.

The Benefit Categories are defined as follows:

B1. Improved security of supply (SoS) is the ability of a power system to provide an adequate and securesupply of electricity under ordinary conditions.

B2. Socio-economic welfare (SEW) or market integration is characterized by the ability of a power system toreduce congestion and thus provide an adequate GTC so that electricity markets can trade power in aneconomically efficient manner.

B3. RES integration: Support to RES integration is defined as the ability of the system to allow the connection ofnew RES plants and unlock existing and future "green" generation, while minimizing curtailments.

B4. Variation in losses in the transmission grid is the characterization of the evolution of thermal losses in thepower system. It is an indicator of energy efficiency and is correlated with SEW.

B5. Variation in CO2 emissions is the characterization of the evolution of CO2 emissions in the power system. Itis a consequence of B3 (unlock of generation with lower carbon content).

B6. Technical resilience/system safety is the ability of the system to withstand increasingly extreme systemconditions (exceptional contingencies).

B7. Flexibility is the ability of the proposed reinforcement to be adequate in different possible future developmentpaths or scenarios, including trade of balancing services.

Total costs of the project are rough estimation of all expenditures.The following items should be taken into account:

- Expected cost for materials and assembly costs.
- Expected costs for temporary solutions which are necessary to realize a project.
- Expected environmental and mitigation costs.
- Expected costs for devices that have to be replaced within the given period (regard of life-cycles).
- Dismantling costs at the end of life of the equipment.
- Maintenance costs and costs of the technical life cycle.

5 Multi-Scenario Analyses

Several important uncertainties, which affect the planning procedure, may be identified, particularly in the forecasts on loads, production and exchange of electricity, location and size of the new power plants, hydrological conditions, the integration of renewable sources and the evolution of the electricity market. The uncertainties in the development plans are considered in a **multi-scenario analysis**[1].

During the planning process a large number of scenarios are considered and investigated in detail. The general plan for developing the transmission grid is determined on the basis of all examined scenarios, so that the final configuration includes the improvements which have proved to be technologically and economically justified in the highest number of scenarios.

The research focus of the Study [1] was the period 2010–2020. Several reference years were processed and analyzed, including large number of scenarios, certain problems were identified and solutions to overcome them were proposed. The solutions represent capital investments of several million euros and lifespan of over 40 years. Each proposed solution should have a long useful life and should comply with the technical criteria during that period. The reviewed problems and offered solutions in 2015 and 2020 may not be correctly assessed without an assessment of their characteristics during the following 10 to 15 years. Having in mind relatively long lifespan of high voltage equipment, the investment decisions made today or in near future will define the performance of the grid in the upcoming decades. Therefore, it is recommended to govern the development priorities in accordance with the strategic value of the expected results, instead of the short-term local benefits.

6 Macedonian Transmission Grid Long-Term Capability

In reference to the Study [1], MEPSO has created list of priority projects for constructions of new transmission capacities and reconstruction of existing transmission facilities. Investment plan for next decade comprises 18 projects with total cost of 82.5 million euros. Most important projects are new three interconnectionsa[2] from Macedonia to Albania, Serbia and Kosovo, new 400/110 kV SS Ohrid and revitalization of existing 110 kV grid in western, eastern and central part of Macedonia.

According to the development plan and vision for the 400 kV transmission grid in the Republic of Macedonia, optimal grid structure will be established including one 400 kV node at each of the consumer regions in the country. This way, the transmission activities will focus on the

[1] System planning studies are often based on deterministic analysis, in which several representative planning scenarios are taken into account. Additionally, studies based on a probabilistic approach may be carried out, but it asks for statistical tool for the assessment. This approach aims to assess the likelihood of risks of grid operation throughout the year and to determine the uncertainties that characterize it. The objective is to cover many transmission system states throughout the year taking into account many cases.

[2] Commissioning of new 400 kV interconnection Stip (MK) – Nis (RS) is expected for next year. 400 kV interconnection Bitola (MK) – Elbasan (AL) should be completed in next 3 years. This project includes construction of new 400/110 kV substation Ohrid. The project is part of Corridor 8. Com-

400 kV voltage level, whereas the 110 kV gains local significance.

The cross-border transmission capacities of the Republic of Macedonia are fully satisfying the requirements for import of electricity for the whole analyzed period 2010–2020, and at the same time allow for uninterrupted electricity transit throughout the region.

The calculations show that the system is stable during all of the examined faults. It means that the transmission grid fulfils the criterion for transient stability of the power system.It may be considered that the short-circuit currents will not cause transient instability of the generators when protection devices are operated properly.The system is stable also during mid-term transition processes in case of outage on one of the larger generator units. The Macedonian Power System is relatively small in comparison to the European power system. Hence, only small part of the power that is scarce during the generator outage is covered from the reserves for primary regulation of the domestic generators (several MW), whereas the rest of the imbalance is provided through the interconnections to the other systems.

Investments in priority projects will increase reliability of transmission grid and create fair and non-discriminatory conditions for all network users. At the same time, while investing in new interconnection projects, MEPSO supports integration and development of regional electricity market.

7 Specific Requirements for Connection of NPP to Transmission Grid

Integration of NPP in the power system requires detailed investigations and analyses defined from IAEA. Nuclear infrastructure, defined in standard IAEA documentation has 19 requirements that should be fulfilled [6]. Among all requirements, one outlines analyses of the performance of transmission grid.

At the beginning of the NPP project, it will not be possible to provide all the detailed parameters, as the design of the nuclear unit may not have been selected or finalized. Hence, initial studies will need to be done using typical values, but can be refined when actual plant data is available.

In addition to standard requirements for transmission grid development and connection of generators [4], connection of NPP needs increased security and reliability performance of the transmission grid that serves for evacuation of produced electricity [3].

Standard calculation technique for grid connection of a power plant should be extended with additional analyses:

- Load flow calculations while applying special standard with **N-2 principle**, considering double outages.
- Probabilistic reliability assessment.
- Substation reliability assessment.

A new nuclear unit is almost certain to be the largest single generating unit on the system. This is significant because there is a practical limit to the size of generating unit that can be installed in an electrical power system if the system is to remain stable and secure after the unplanned disconnection of that generating unit. The study should consider the issue of the **size of nuclear units**. If the size of the nuclear unit is likely to be close to 10% of the minimum electrical demand in the country, the study should include plans for ensuring that frequency and voltage will remain within acceptable limits after a trip of the nuclear unit, and for meeting the electricity demand in the country when the nuclear unit is shut down. In order to asses reserve capacities in case when nuclear unit trips, dynamic simulation should be run, while monitoring the frequency in the system and tripping conditions of the rest of the generators in the system. Under-frequency load-shedding scheme should be integrated into the simulation.

NPP are normally required to have multiple sources of electricity, including a minimum of **two independent off-site power sources** (i.e. two connections from the transmission system to the NPP), and **on-site power sources** (typically a combination of batteries and diesels or small gas turbines). General design criteria normally ask for at least two independent connections between NPP and the grid. The first connection is the connection for export of power from the generator to the main grid via the generator transformer. The second connection provides a supply to the nuclear unit via the station transformer if the first connection is not available. The connections to the generator transformer(s) and station transformer(s) should be designed in such a manner that one fault cannot render all connections inoperable. There should be a reliable off-site power supply mechanism for safe operation during an outage including redundant power sources in case of grid failure.

It is necessary to make provisions to prevent common cause failures i.e. those that simultaneously affect the two or more external connections to the grid system. This could include flooding of the substation, catastrophic failure of a piece of equipment that damages other equipment, or a failure of the low voltage supply or batteries within the substation. If such a common cause failure occurs the nuclear unit would be shut down using the on-site supplies, such as diesel generators.

pletion of the project will create conditions for integration of electricity markets of Italy and Southeastern Europe and regional benefits fully justify the investment.

Optimistic development plan for Kosovo's power system envisage construction of new big thermal power plant that will create extra power production. In order to evacuate this extra power, there is a need for new interconnections from Kosovo to neighbors on 400 kV level. Beside planned interconnection Kosovo (KS) – Tirana (AL), additional 400 kV line between Macedonia and Kosovo is also planned.

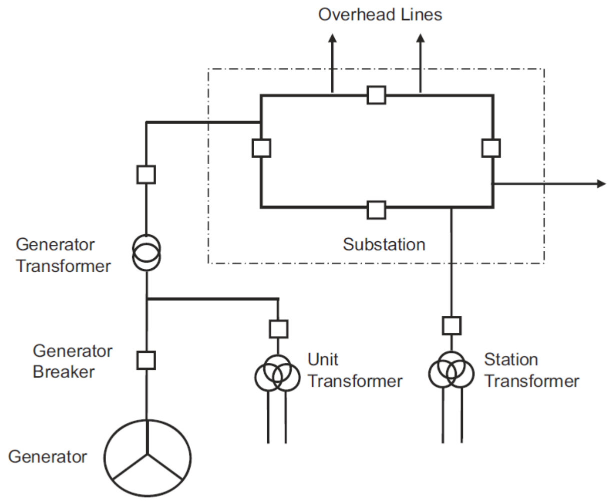

Figure 2. NPP connection to a single substation.

A stable and reliable grid would be one where voltage and frequency are controlled within pre-defined limitsand disconnections are infrequent events. Events that disconnect parts of the grid, or lead to blackout of a major part of the grid are rare (much less thanonce per year). This applies particularly to that part of the grid to which the NPP is connected. The grid recovery following a regional blackout should **restore power for essential services**, including off-site powerfor NPPs, in less than two hours.

The ability of generating units at NPPs to provide voltage control and a range of reactive power is similar tothat of large fossil fuel units. To provide **voltage control** from a nuclear unit generally does not affect the control of the nuclear reactor in normal operation. However, there is a potential nuclear safety problem for the nuclear unit if there is a disturbance that results in is landing of the NPP at a time when it is exporting a large amount of reactive power; this can transiently cause abnormally high voltage locally that could affect safety systems. Other potential safety problem is when a nuclear unit trips at a time when it is exporting a large amount of reactive power to the system, then the local grid voltage will fall after the trip. The voltage control arrangements on thegrid should ensure that the grid voltage will remain within the acceptable range after such an event.

It should be considered whether the various capabilities of a NPP generating unit that are requested by the TSO are compatible with the available designs of nuclear units. This applies particularly to the ability for **load-following**, or to operate in **automatic frequency control** mode, as this affects the design of the nuclear reactor and its control system. Preferred mode of operation of nuclear plants is at steady full load and not providing automatic frequency control. Because of the special requirements for nuclear safety, it may be necessary for the technical requirements for the nuclear unit to be different from the technical requirements for other generating unitsin the country.

8 Initial Analyses for NPP Integration in Macedonian Transmission System

Implementation of NPP project has a longstanding timeframe and extends to long-term planning horizons. Therefore, planning includes bunch of uncertainties and this kind of analyzes could not have the same level of detail and quality as for the period covered within the Study [1]. Nevertheless, these analyses should depict general indicators for the network performance in foreseeable future. Analyses will roughly estimate the quality of proposed solutions and should identify potential problems that could be faced in the future and deserves supplementary investigations.

In preparatory phase, project team distributed inquiry to all relevant institutions, covering principal issues, such as: year of commissioning, installed capacity and location of NPP, average growth of demand, year of commissioning of candidate power plants and year of retirement of existing plants.

Based on inquiry and time frame of the NPP project, reference year for initial investigation is selected to be 2040, as the year for possible commissioning of NPP. One option for location of NPP is region of Mariovo, with the intention to benefit from hydrological, seismic, topological,

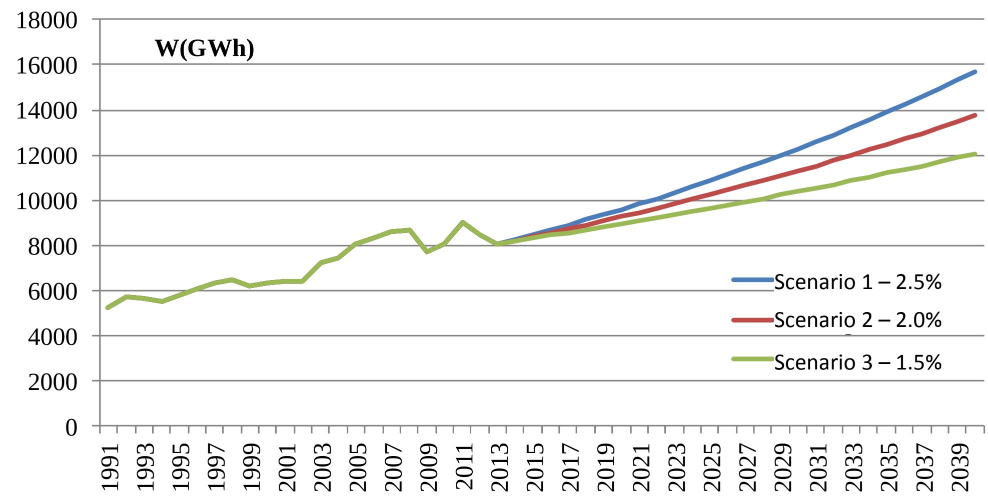

Figure 3. Forecast of electricity demand in Macedonian power system till year 2040.

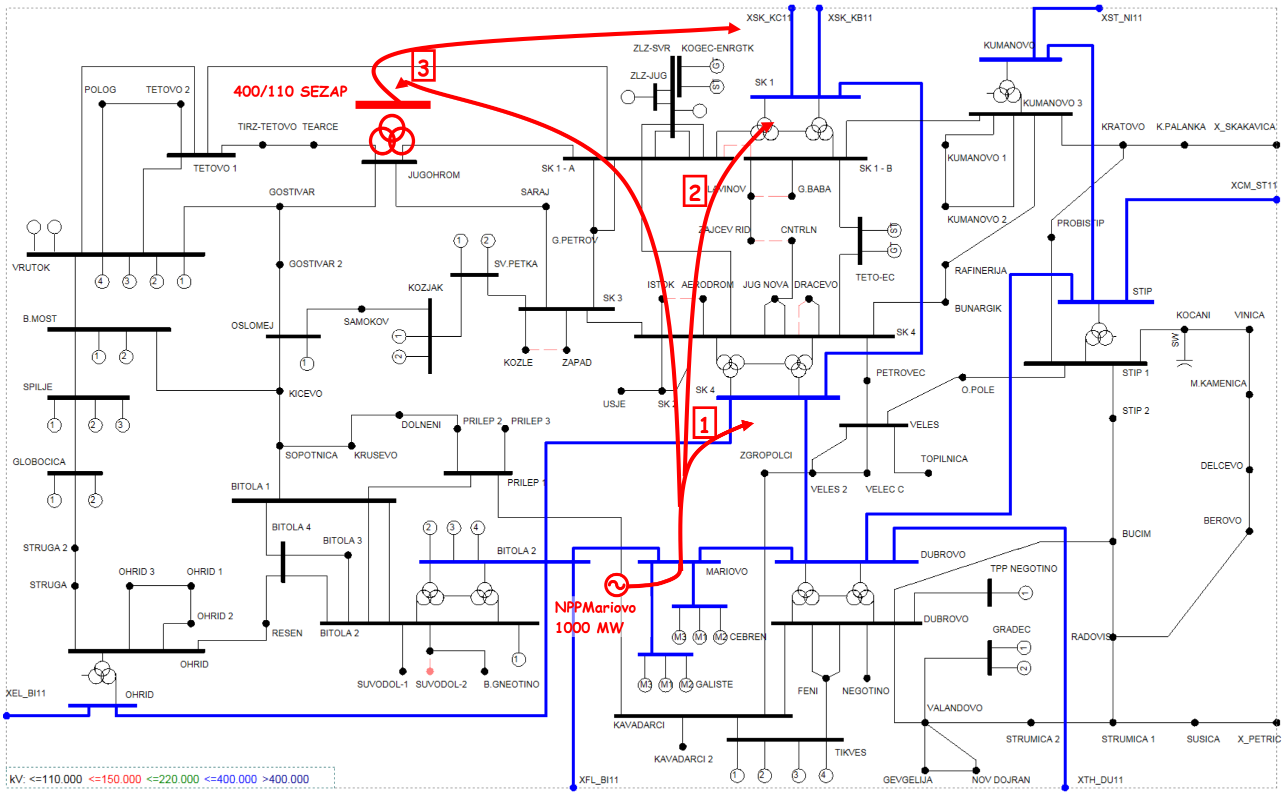

Figure 4. Long-term vision for development of Macedonian transmission grid and NPP integration.

geographical, meteorological and safeguard potentials of this area. Initial analyses shall be done assuming that installed capacity of NPP is 1000 MW. NPP could be connected at 400 kV SS Mariovo that is already included in development plans of transmission grid [1], and its location is in the vicinity of NPP. Forecast scenarios of electricity demand are illustrated in Figure 3.

Integration of NPP into transmission network, and more generally in the power system, is challenging tasks from the viewpoint of security and reliability of operation. The applied technology imposes increased requirements for equipment redundancy, including the connection to the transmission grid(for example, N-2 principle). If considered that connection point of NPP will be 400 kV substation in Mariovo, concentration of installed power in this node requires at least one 400 kV link in addition to the rest of the network. There are few options for the additional link from Mariovo that will be investigated in the next phase of analyzes. New link could be connected either to one of existing 400 kV nodes in Skopje area, or to Polog region in Western Macedonia, see Figure 4.

Taking in mind huge financial construction of NPP project, and countries needs and interests, this project could be easily developed as a joint venture between two or more countries from the region. Therefore, project team assumes that beside Mariovo, two additional locations should be investigated at this stage, one in Albania, the other in Bulgaria. This assumption imposes elaboration of few scenarios concerning bulk power transits from NPP to the rest of the region.

It is expected that initial analyses will give clear answers on following questions:

- Proper concept for evolution of transmission network on a long-term.
- Necessary network upgrades.
- Level of security and reliability of the grid.
- Estimation of necessary power reserves of the system.
- Power flows in national transmission grid and across the region derived from NPP integration.

9 Conclusion

The main objective of transmission grid is to provide evacuation of electricity from power producers and supply to all customers in secure and reliable way. Last decade, transmission grid has gone through fast development due to implementation of new power plants and smart grid solution and creation of electricity market. Existing transmission capabilities should be rationalized and upgraded in the future with careful selection of new projects and development concepts.Planning and development of Macedonian transmission grid are in pace with contemporary trends in electricity industry and state-of-the-art high voltage technology. In this manner, application of novel technologies will keep and raise further quality and security of transmission of electricity.

Integration of NPP in the transmission system is challenging task for network planners.In addition to standard requirements for transmission grid development and connection of generators, connection of NPP requests increased security and reliability performance of transmission grid.

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