Power System Planning: Part I—Basic Principles

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Abstract. Power system planning is an activity related to the development of plans for designing and construction of the system and its elements, which will satisfy assumed future needs, starting from the given state. First paper presents basic principles of power system development planning with its concepts. Electrical energy losses as well as forecasting of energy consumption are taken in consideration. Basic principles of development planning for each subsystem (generation, transmission and distribution) are presented. In the second paper, practical application of techno-economic analysis of the transition from the voltage level of 10–20 kV in Gračanica is presented with two different investment costs using four different approaches.

1 Introduction

Power engineering represents the energy sector responsible for the generation, transmission and distribution of electrical energy to consumers. Power system is a complex dynamic system, consisting of a set of power plants, transmission lines, transformers and consumers that are interconnected so that they act as a unique unit. Power system can be divided into four functionally independent units interconnected in one system:

- generation subsystem;
- transmission subsystem;
- distribution subsystem;
- consumption subsystem.

The basic task of these subsystems is to ensure reliable, high quality and rational power supplying of different consumer types.

Power system planning is an activity related to the development of plans for designing and construction of the system and its elements, which will satisfy assumed future needs, starting from the given state. The main goal of power system exploitation is to use currently built objects and systems in the best possible way. Time interval of power system planning and exploitation is given in Fig. 1.

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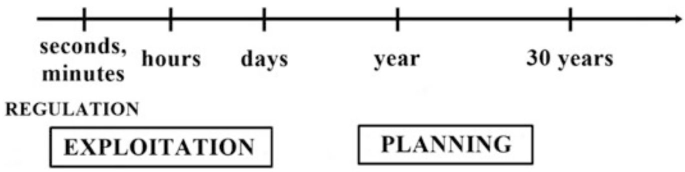

Fig. 1. Time interval of power system planning and exploitation

2 Principles of Power System Development Planning

Power system development planning is a process that is related to the planning of the total energy flows development and it can not be observed separately from other energy sectors. General strategy of energy development in certain country is the first step in planning system development.

The country's energy development strategy is based on the development of three global plans:

- socio-economic development plan of the country;
- plan for development of total energy consumption and primary energy resources and power flows;
- plan for the development of power engineering under the total energy development.

In terms of time decomposition of the problem, there are three following categories of power system planning development:

- Long-term development planning, with a planning horizon of 10–30 years in the future. Such procedures define a long-term development strategy.
- Mid-term development planning, with a planning horizon of 5–10 years in the future. This is also the most important stage of planning. At this stage decisions on construction of power system facilities are developed.
- Short-term development planning, with a planning horizon of 1–5 years in the future. At this stage, decisions that were made are being adjusted with a new situation.

Spatial decomposition corresponds to the division of power system into functional units of generation, transmission and distribution of energy as well as consumption.

- Consumption development planning represents the prognosis of different parameters that describe consumption of some consumers in the future. The most commonly forecasts are total electricity consumption, peak and minimum power consumption, load factors, etc.
- Generation capacities development planning is a procedure in which a decisions on the construction of new power plants and generating units are made. Within this procedure, transmission and distribution network are neglected so the whole power system is considered to be one node.

- Transmission and distribution development planning is an activity in which a decisions to build new elements (transmission lines, transformers, distribution systems) of transmission and distribution networks are made [1].

3 Power System Planning Concepts

Power system planning is based on four basic concepts:

- security and stability;
- reliability;
- power quality;
- economy.

3.1 Security and Stability Concept

Planning of power systems is based on $n - 1$ concept of security, where systems can withstand all possible single disturbances without disturbing steady state condition. In this case, n is the total number of elements (generators, transformers, lines) that can by affected by the fault.

The $n - 1$ concept of security is defined as follows: The failure on one of the total n elements of the system (generators, lines, transformers, consumers and others) must not have influence on the correct operation of the power system with the residual $n - 1$ components [2].

Power system stability is the ability of an electric power system to regain a state of operating balance after being subjected to physical disturbance, with most system variables bounded so that practically the entire system remains intact [3].

3.2 Reliability Concept

Reliability represents the probability of proper functioning of the system and providing electrical energy supply to consumers. This probability is related to certain reliability indicators that are related to the size of the power disbalance, the reduction in delivery, the amount of undelivered energy, the frequency of occurrence and the duration of the failure.

These indicators are:

- LOLP ("Loss of Load Probability")—the number of hours in a year when production can not satisfy daily peak consumption;
- LOEP ("Loss of Energy Probability")—production of insufficient energy;
- EDNS ("Expected Value of Demand Not Served")—inability to satisfy consumer needs;
- EENS ("Expected Value of Energy Not Served")—expected value of the energy not delivered;
- F&D ("Frequency and Duration")—frequency and duration of failures that cause loss of load.

3.3 Power Quality Concept

The basic indicator of power quality is the continuity of the supply to consumers. Voltage and frequency are two most important variables that characterize proper functioning of each power system. Standards of power quality is related to these mentioned variables.

Definition of the concept of 'power quality' according to IEC 61000-4-30: The electrical energy characteristics at a particular point of the power system observed in comparison to the reference technical parameters.

3.4 Economics Concept

This concept is based on an analysis of the revenues and costs associated with each project, and the most sensible plan is made on the basis of determining the minimum or maximum of one or more selected criteria. Attention should be paid to investment costs as well as to the costs of exploitation and management, while avoiding any of the above concepts for minimizing the investment during the lifetime of the system.

From various solutions available for a problem, a planner should select the best, in terms of both technical and economic considerations.

Three methods may be used for economic appraisal of a project:

- Present worth method—All input and output cash flows of a project are converted to the present values. In this method, if the economic lives of the plans are different, the study period may be chosen to cover both plans in a fair basis. For instance, if the economic lives of two plans are 3 and 4 years, respectively, the study period may be chosen to be 12 years.
- Annual cost method—All input and output cash flows of a project are converted to a series of uniform annual input and output cash flows. A project with a uniform annual output less than its respective input is considered to be attractive. This method is especially attractive if the plans economic lives are different.
- Rate of return method—There are some input and output cash flows during the economic life of a project. If we consider an interest rate at which these cash flows are equal (i.e., the net is zero), the resulting rate is named as Rate Of Return (ROR). ROR should be compared with the Minimum Attractive Rate Of Return (MAROR). Provided ROR is greater than MAROR, the plan is attractive. From those attractive, the one with the highest ROR is the most favorable [4].

The basic criteria for development planning of the Bosnia and Herzegovina power system transmission network is to minimize total (investment and exploitation) costs, while meeting the requirements of the power system security. Therefore, in planning of transmission network development it is necessary to apply both technical and economic criteria, in order to achieve the technical and economic optimum [5].

4 Electrical Energy Losses

The loss of electrical energy/power is usually defined as the difference between the power supplied to the transmission system and the registered power consumed at the final customer's measuring point.

Calculation of power losses in the power grids at any voltage level should normally be performed under the calculations of voltage and power flows. These are sufficient information to determine the electrical power losses on each system element.

By summing up the losses on individual elements of the system, the total losses of electric power are obtained.

4.1 Classification of Electrical Energy and Power Losses

Electrical energy losses can be divided into two groups:

- technical and
- commercial (non-technical).

Technical losses are the result of exploitation and they represent the biggest part of the overall losses in the network. They are caused by the fact that the elements of the system are under voltage and that the current flows through them.

They can be divided into:

- voltage-dependent losses,
- current dependent losses [6, 7].

Voltage-dependent losses are independent of the load and they occur in the elements, regardless of whether the current flows through them or not. They are present as long as the elements are under voltage. Voltage changes are relatively small, so voltage-dependent losses are relatively constant. These include: losses in transformers under no-load conditions, dielectric losses in cables and capacitor batteries, losses of arrester currents of air lines.

Current dependent losses depend on the load (variable losses) and they occur in network elements (lines and transformers) as a result of the current flow through these elements, which depends on the power of the consumer. The amount of these losses is directly proportional to the square value of current.

Non-technical losses are the result of electrical energy that is not measured for some reason. They arise as a consequence of their own consumption (known as "hidden" consumption), illegal use of electrical energy (theft), unmeasured delivered electrical energy (e.g. part of public lighting) as well as errors in the process of measuring and processing data. Non-technical losses are often referred to as "commercial" losses [8–10].

Technical losses can be reduced with and without additional investments. Methods that require additional investments are:

- increasing the cross-section of the conductor;
- adding new transformer stations in the network;
- reactive power compensation;

- using the three-phase lines;
- switching to a higher voltage level;
- direct transformation of 110/x kV usage;
- replacement of old equipment with new ones with fewer losses in exploitation.

Another set of methods that do not require additional investments are:

- improving the power supply;
- control of the load diagram and uniformly use of power capacities;
- managing the load schedule between the individual phases (especially the 0.4 kV network);
- finding optimal transformer power and location.

According to the cause and location of power loss occurrence it is possible to divide losses into three groups:

- losses due to the heating of the conductor through which the current flows—thermogenic losses,
- losses due to the magnetization of the conductor environment through which the current flows—the losses of magnetization,
- losses due to the imperfection of the conductor.

The largest part of total losses happened due to the heating of the conductor through which current flows, and depends on the current square and the electrical resistance of the conductor through which the current flows:

$$I(t) = \frac{P(t)}{U(t)\cos\varphi(t)} \tag{1}$$

$$\mathrm{R} = \frac{\mathrm{l}}{\mathrm{qk}} \tag{2}$$

$$\Delta\mathrm{P(t)} = \mathrm{I^2(t)R} \tag{3}$$

$$\Delta\mathrm{W} = \mathrm{R}\int_0^{\mathrm{T}} \mathrm{I^2(t)dt} \tag{4}$$

where

P(t)	the active power transmitted through the line at the time t,
U(t)	the line voltage at the beginning of the line at the time t,
I(t)	the current flowing through the line at the time t,
$\cos\varphi(t)$	power factor at the time t,
R	line resistance,
$\Delta P(t)$	power losses at the time t [11].

5 Forecasting the Consumption of Electrical Energy and Power

Forecasting the consumption of electrical energy and power is one of the most important and significant activities in the power system.

Forecast of consumption is important from the aspect of power generation units engagement, elaboration of plans for repair and economic dispatching.

The forecast of electricity consumption and power can be observed through the time and space framework (local consumption, region, state).

Time and space decomposition:

- Short-term forecast with horizon from one day to one week and hourly time discretization. This prognosis is characterized by periodicity, because daily and weekly load changes have regular repetition. In this type of forecasting it is needed to differentiate the effects of working days, festivals and holidays comparing to the "normal loads".
- The mid-term forecast includes a time period of one month to five years, with a weekly or monthly time discretization. This forecast represents the link between exploitation and power system development planning. Models used for mid-term forecasting should be able to take into account weather and climate influencing factors as there is a significant influence on temperature and weather conditions on load.
- Long-term forecast with a horizon of 5–30 years and annual time discretization. This forecast is necessary for solving global long-term investment plans, especially when designing a new construction plan or extending existing production and transmission capacities.

Spatial decomposition coincides with the division of power system into the functional units of production, transmission, distribution and consumption of electrical energy.

In order to carry out system expansion planning in a cost-effective manner, companies must be able to predict the need for electrical energy delivery and companies must be able to answer three important questions:

- How much power is needed for delivery?
- Where will that power be needed?
- When will that power be needed? [1, 12, 13].

There are many different types of load forecasting techniques and methodologies. Most forecasting techniques can be classified as either qualitative or quantitative as shown in Fig. 2. Qualitative forecasting techniques are subjective, based on the opinion and judgment of informed parties. Qualitative forecasting is appropriate when past data are not available. Quantitative methods forecast future data as a function of past data. They can be used when past numerical data is available and when it is reasonable to assume that some of the patterns in the data are expected to continue into the future [14].

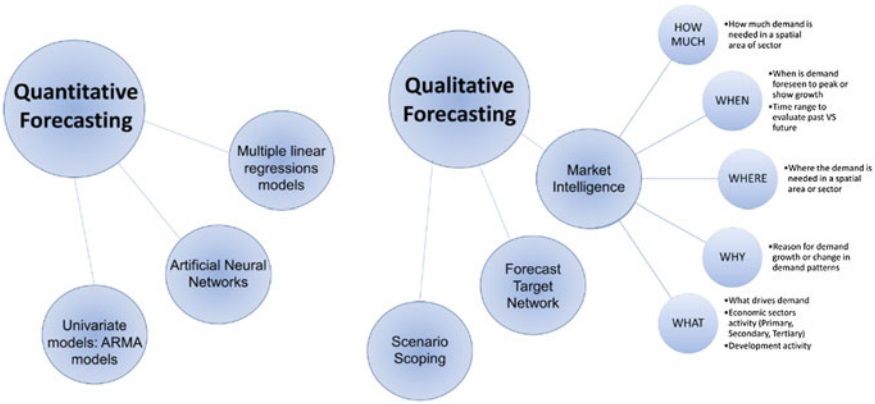

Fig. 2. Quantitative and qualitative forecasting

6 Sources Development Planning

Planning the development of electrical energy sources is one of the most important and most sensitive steps in the process of planning modern power systems.

Decisions made at this stage of planning have a significant impact in planning the transmission network and have dominant impact on the economic and financial indicators. This is the result of a very large investments in electrical energy sources, which reaches around 60–65% of total investment in power system.

In this planning stage decisions on construction of new power plants and generating units are made. Within this procedure, the transmission and distribution networks are neglected and the whole power system is observed as one node in which the total production and consumption of electrical energy is concentrated.

Planning the development of electrical energy sources must satisfy requirements for electrical energy and power that are being increased by the time, with a defined level of reliability, security and power quality with acceptable price.

Development planning of the sources is a continuous process in which the following problems are solved successively:

- determining the size and timing of entering new required generating units in system and
- the choice of types of new generation units that will be integrated into the system, according to the needs expressed through solving the first problem.

The time period for development of sources must be long enough to enable a series of activities that need to be performed before releasing a new generating unit in work. These are the following activities:

1. Designing (investment program with feasibility study, design and main project).
2. Providing financial resources.
3. Contracting of equipment and actions.
4. Construction of facilities and installation of equipment.

5. Testing of the object.
6. Trial work [1, 12, 13].

7 Transmission System Development Planning

Transmission system development planning is determined by the long-term prognosis of consumer loads and the generation or production of the system. The main question that has to be answered in this stage is when should the network be supplemented with additional components, such as transformers or lines. These components can have different rated voltages. The answer to this question is based on the concept of static system security. The traditional procedure is usually referred to as the horizon-year study and begins by sketching a preliminary solution to the system load levels that are several times greater than the existing load level. The aim is to identify long-term network system needs. The solution is checked by a full power flow calculation.

The stages in transmission system development planning are:

- development of network study for horizon-year conditions,
- creating network and network building to its final configuration in the horizon year.

It's assumed:

- that the existing network represents the initial solution;
- that the information about the location and size of future loads of consumers exists;
- that voltage levels are already indicated.

The basic criteria for network transmission planning is to minimize constructive and exploitative costs while satisfying the requirement to deliver electrical power to consumers safely.

There are two types of transmission lines: overhead lines and underground cables. Technically, the lines are characterized by the voltage level, the number of lines per phase, phase cross-section, the number of parallel lines on the same towers and the type of insulation. Cost-effectiveness is assessed by investment and operating costs.

The basic problems that need to be solved in the planning of transmission lines are:

- selection of the proper voltage level;
- selection of the route;
- selection of material, conductor cross-section, type and characteristics of lines;
- selection of type and design of overhead lines.

Development planning for construction of transmission power plants has similar issues as the planning and construction of transmission lines. It consists of following steps:

- selection of power plant type (for exterior or interior mounting);
- voltage level selection;
- site/location selection (considering energy and urban requirements);
- integration to transmission network;
- compensation of the system buses and single-pole scheme of the plant.

Individual optimization of the basic parameters of transmission networks (lines and transformers) in power transfer is not a good way to obtain a global optimum for the whole system because such approach would result in large number of voltage levels and cross sections of transmission lines, different power of transformers and other parts of the network. To avoid these situations process of standardization needs to be performed. Standardization means the reduction of investment equipment that is achieved by production in large series with a relatively small number of standard elements. Standards are introduced through national and international professional organizations (BAS, ASA, NEMA, IEEE, IEC, CIGRE and others).

For example, the standard cross-sections of the conductors are:

- 150/25 mm^2 Al/Fe and 240/25 mm^2 for 110 kV lines;
- 360/57 mm^2 Al/Fe and 490/65 mm^2 for 220 kV lines;
- $2 \times 490/65$ mm^2 Al/Fe for 400 kV lines [1, 12, 13].

8 Distribution System Development Planning

Planning of the distribution network is a process that is implemented within the procedure of development planning of whole power system, whereby this process must satisfy different requirements of users and owners or network operators. Planning of the power distribution network includes geographic, technical and economic analysis of various solutions to provide reliable and economically acceptable services to network users. Modern methods of planning the development of power grids include several interrelated analyzes. The purpose of planning the development of the power distribution network is to ensure reliable operation and appropriate level of power quality as well as the cooperation with transmission network and connected power plants.

Development planning of distribution network may be divided into:

- short-term development plan (1–5 years)
- mid-term development plan (5–10 years)
- long-term development plan (10 years and over).

The long-term development plan for the power distribution network is usually done for a period of following 10–20 years. The purpose of creating development plans is:

- determining the direction of development of the distribution network by stages and at the end of the planning period;
- appropriate dimensioning for reliable operation and maintenance of power quality according to standards;
- cooperated performance of distribution network with the transmission network and connected distribution network users;
- selecting the location of new objects.

The long-term and mid-term plans for the development of the power distribution network are the basis for the preparation of three-year/annual investment plans.

Through the long-term development plan, the strategy for the development of distribution network for a 20-year plan by stages and consumption areas is being determined. The long-term development plan should be flexible in terms of re-examination in a certain period of time, foe example every 5 years.

In the process of distribution network development, it is necessary to analyze all possible solutions that satisfy the technical and economic criteria of planning [1, 12, 13].

9 Conclusion

The importance of power system planning is presented through this paper. In order to perform power system planning in the best possible way, concepts of security and stability, reliability, power quality and economy have to be satisfied. Each subsystem of overall power system has to be planned separately because of different requests that has to be satisfied. Losses of electrical energy represent very important factor for planning process and they have to be taken into consideration.

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