ELECTRICAL NETWORK OPTIMIZATION

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Contents

Summary

Electrical network optimization refers to the determination of the necessary network reinforcements that guarantee the security of supply to electrical loads. This optimization follows the Least Cost Planning concept for both distribution and transmission systems. The optimal transmission system expansion planning is the most important, but representative as well, electrical network optimization problem (and it is deeply analyzed in detail). It is a quite interesting but complicated optimization problem since it is influenced by numerous factors and parameters (technical, environmental, financial, social, etc.). The criteria used to determine the "optimum" expansion plan may vary significantly according to the specific system conditions and the organization of the Electricity Supply Industry. In all cases, optimization is performed with respect to technical constraints that reflect mainly security criteria.

1. Introduction

Electric network is the set of devices used to transport electric power from the power plants to the consumers. These devices include OverHead transmission Lines (OHL), underground or submarine cables, switching equipment (breakers and disconnectors), substations (i.e. subsystems equipped with transformers and autotransformers that allow the power transfer between systems operating at different voltage levels) and reactive

power compensation devices (capacitors and reactors). OHLs and cables are modeled as branches while busbars at substations are modeled as nodes in a node-branch model. This network is distinguished into two subsystems, namely the transmission system and the distribution system.
Transmission system (OHLs, cables and their switching equipment) accommodates the transfer of bulk quantities of electric power (hundreds or thousands MW) in long distances (hundreds or thousands km) from the generation sites to high voltage substations located near the load areas. These substations are the boundaries of the transmission system where electric power is transferred to the distribution system(s) through transformers. Transmission systems operate at high voltage levels (from 150 kV up to 1000kV) and their structure involves closed loops that allow higher reliability in transferring the electric power from the generators to the loads.

Distribution networks are used to distribute rather smaller quantities of power (tens of MWs) in rather short distances (up to 30-40 km). They transfer power from the high voltage substations to the distribution substations (very close to the end-users) using similar devices as the transmission systems. Distribution systems operate at medium voltage levels (from 3 kV up to 110 kV) and in the majority of the cases they are operated in a radial structure.

Historically, electricity networks have been developed during past decades; during this period the Electricity Supply Industry (ESI) was dominated by vertically integrated electricity companies (production, transmission, distribution) operating at National or Regional level in a monopolistic regime. In the last decade, especially in developed countries, ESI is in a procedure towards de-regulation (liberalization) and establishment of an electricity market. Electricity is considered a “commodity” which is freely traded in a market. Several actors may participate in electricity markets such as producers, loads, suppliers, distributors, traders, etc. Competition has been established mainly in production and trading. Under this new environment electricity networks are common carriers that serve all market participants and they are considered (in most of the cases) as natural monopolies. Power transmission and distribution are considered as “services” which are properly remunerated by the users of the corresponding system(s). Since electricity networks structure and operation (mainly transmission systems) may influence the power transfers from the generators to the loads and consequently the operation of the markets, their operation has to be transparent and non-discriminatory. To guarantee transparency and avoid any discrimination, transmission systems in liberalized markets are under the responsibility of Transmission Companies (TRANSCOs) or Transmission System Operators (TSOs) which are enterprises independent of the market participants. Accordingly, Distribution System Operators (DSOs) have been established for the distribution activities. The main activities of these organizations are the operation and the expansion planning of the transmission and the distribution systems correspondingly, which are performed under specific legislation (Grid Codes).

Optimization of electricity networks is of major importance since they are the main infrastructure to serve electricity markets and their operation affects all the ESI participants. This optimization follows the Least Cost Planning principles, i.e. the minimization of the total cost of operation plus investment over a long planning horizon. The problem of the transmission system optimal expansion planning is not only the most important but quite interesting and complicated one and it is presented in the next sections. Distribution system optimization follows similar concepts.

2. Transmission System Optimal Expansion Planning

Due to the temporal and spatial distribution of both the generating units and the loads, transmission systems play a key-role in security of supply and influence significantly the ESI. The continuous increase of electricity demand requires the expansion and reinforcement of the existing transmission systems in order to accommodate the increasing transmission needs. Expansion of transmission systems includes the installation of new devices (mainly OHLs and cables) or the reinforcement of existing transmission corridors and the upgrade of existing substations.

In both monopolies and de-regulated markets, planning of transmission expansion is a major issue and it is performed in long-term time horizon following the Least Cost Planning principles. Some crucial factors should be underlined here:

- investments in transmission systems are usually not profitable; they require high capital cost while the pay-back period is usually significant (up to 40 years);

- the realization of new transmission projects requires considerably long time (possibly several years). This is mainly due to the licensing procedures and the expropriations needed, but also due to the increasing protest by the public to the erection of the projects (especially in developed countries). Besides, there is a significant construction phase especially for long overhead lines.

3. Transmission System Operational Requirements

For a better understanding of the methodologies applied for the transmission systems planning, it is crucial to define the operational requirements set by the transmission system operators. Although they may vary significantly among the transmission system operators, the basic requirements are outlined below:

- Security: a transmission system is subject to random events (lightning, short-circuits, accidents, etc.), which may cause the loss of transmission lines or cables. In case of such contingencies the remaining system must be able to operate safely and it should not be led to major disturbances (i.e. brown-outs or even complete black-outs). This requirement refers both to the security of supply and the security of the equipment.

- Smooth operation: the electric power characteristics (voltage, frequency, power quality, etc.) should be kept within predefined limits, i.e. within a range of acceptable values.

- Reliability: the system should be able to provide the customers with electricity continuously even if some devices are out of operation due to outages or scheduled maintenance. Any interruptions cause inconvenience to the customers and curtailed revenues for the producers. Furthermore, restoration of service is always costly.

- Minimum environmental impact.

- Transmission services should be provided at minimum cost.

4. Statement of the Optimization Problem

The optimization of transmission system expansion is a quite complicated problem as it involves a variety of parameters (technical, economic, social, environmental, etc.) that should be taken into consideration for each specific transmission system. Since the conditions among systems vary, the concepts and methodologies applied also vary, depending mainly on the organization of the ESI sector. In general, the aim of the transmission expansion optimization is to determine the most economical expansion policy of an electricity transmission system over a finite planning period.

In monopolistic regimes, since the transmission system influences (sometimes dramatically) the operation and the economics of the rest ESI subsystems (mainly the generation but the distribution as well), the transmission planning optimization is closely related to generation expansion planning. It is quite often that optimization of transmission expansion is performed jointly with the generation expansion. Although conditions may vary among systems, for a monopolistic regime the optimization problem can be stated in general as follows:

Given for a planning horizon of *N* years:

- the existing transmission system configuration,
- the projected loads over the planning period (*N* years),
- the available right-of-ways for new transmission corridors and sites for new substations,
- the estimated configuration (synthesis) of the generation system (new generators and generators' retirements),
- the cost of both the new transmission elements and their upgrades (i.e. per km cost of OHLs and cables, transformers, autotransformer and compensation devices etc.),
- the cost of generation for existing and foreseen generators,
- the estimated cost of unserved energy,

Find:

The transmission system expansion plan (i.e. **when** new transmission facilities are needed, **where** should they be located and **what** should they be) that optimizes the "planning criterion" i.e. the objective function of the optimization problem solved. The objective function to be optimized may vary as outlined in Section 4.3.

In deregulated electricity markets, the transmission system optimization is performed independently of the expansion planning of the rest ESI subsystems. Since the behavior of the market participants is in general unknown, transmission planning is performed

under high uncertainties (concerning the new generation sites and future generators, power exchanges, etc.). These uncertainties are usually treated through alternative scenarios for the new generators. Although the planning criteria may vary among TSOs, the problem of the transmission system expansion optimization can be stated in general as follows:
Given for a planning horizon of *N* years:

- the existing transmission system configuration,
- the projected loads over the planning period (*N* years),
- the available right-of-ways for new transmission corridors and sites for new substations,
- the cost of both the new transmission elements and their upgrades (i.e. per km cost of OHLs and cables, transformers, autotransformer and compensation devices etc.),

Find:

The transmission system expansion plan (i.e. the new transmission projects and corresponding time of commissioning) that optimizes the “planning criterion,” i.e. the objective function of the optimization problem solved as outlined in Section 4.3.

The optimization of the objective function is, in all cases, subject to a set of constraints that may vary significantly upon the ESI organization, social and economic conditions, etc. From the technical point of view, some basic security constraints should be taken into consideration (representing roughly the operational requirements), i.e. to guarantee the smooth and secure system operation. Technical requirements may vary among TSOs though.

In more developed and mature electricity markets, transmission is treated as a “service”. In such markets different concepts are applied aiming to alleviate any system constraints since operational requirements are treated as “ancillary” services.

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Biographical Sketches

John Kabouris is serving at the Hellenic Transmission System Operator (DESMIE S.A.).

John Kabouris received the Diploma in Electrical and Computer Engineering from the National University of Athens (NTUA) in 1985. After his military service (1986-1988), he undertook graduate studies in Electrical Engineering at the NTUA, leading to the Ph.D. degree (1992).

He worked for the Public Power Corporation (PPC) from 1991 until 2001. His main activities were related with transmission expansion planning and integration of renewable energy sources into electricity grids. In 2001 he joined the Hellenic Transmission System Operator (DESMIE S.A.). He is currently the head of the transmission system planning studies department of DESMIE S.A. From 1999 he teaches electrical power systems in the Technological Education Institute of Piraeus.

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He has published more than sixty papers in journals and international conferences.

George C. Contaxis is Professor of Power System Planning and Operation at the Department of Electrical and Computer Engineering of the National Technical University of Athens. He holds a Mechanical-Electrical Engineering degree from NTUA (1971), a MSEE degree (1973) and a Ph.D degree (1977) from the Electrical Engineering Department of Georgia Institute of Technology. He is senior member of IEEE.

Prof. Contaxis has worked, as Teaching/Research Assistant and as Research Associate, for 5 years at the Department of Electrical Engineering of Georgia Institute of Technology (Atlanta, USA, 1972-July 1977). During this period he participated in projects funded by the National Science Foundation and the Bonneville Power Administration. These projects were related to Security Assessment of Power Systems.

From August 1977 until May 1979 he has worked as Analyst at the Planning Department of Southern Power Company. During this period he participated in the development of computer software systems related to power system expansion, production costing and reliability.

From January 1985 until August 1985 and during the summer months of 1986 he has worked as Visiting Professor at the Department of Electrical Engineering of Georgia Institute of Technology. During this period he participated in projects funded by Electric Power Research Institute (EPRI).

From April 1980 he is working at the National Technical University of Athens. He is teaching courses related to power system planning, and optimum operation of power systems. He has participated in research projects funded by the General Secretariat for Research and Technology, the Public Power Corporation of Greece, the Center for Renewable Energy Sources (CRES), the International Atomic Energy Agency, the European Commission among others. He was project coordinator in 20 research projects. He is author of 3 books and 80 publications in international magazines or conference proceedings.

Prof. Contaxis has served as Secretary/Treasurer (1987-1991), as Vice-Chairman (1992-1996) and as Chairman (1997-2001) of the Greece Section of IEEE (Institute of Electrical and Electronic Engineers). Since 2001 he was appointed by the Executive Committee of IEEE Region 8 as Chapter Coordinator for the PE and PEL Chapters of the region. He has been a member of several technical committees and working groups of the Technical Chamber of Greece and member of working groups of IEEE and CIGRE. He was member of the educational and professional activities committee of the Technical Chamber of Greece in the area of Electrical Engineering. He has been a member of organizing committees of workshops, seminars and conferences. From September 1990 to August 1994 he was Director of the Electric Power Division of the Department of Electrical and Computer Engineering. From September 1994 to August 1998 he was Vice-Chairman of the Department of Electrical and Computer Engineering. From September 2000 till his sudden and premature death on 1 November 2004 he has served as the Chairman of the Department of Electrical and Computer Engineering.