Jürgen Schlabbach
Karl-Heinz Rofalski

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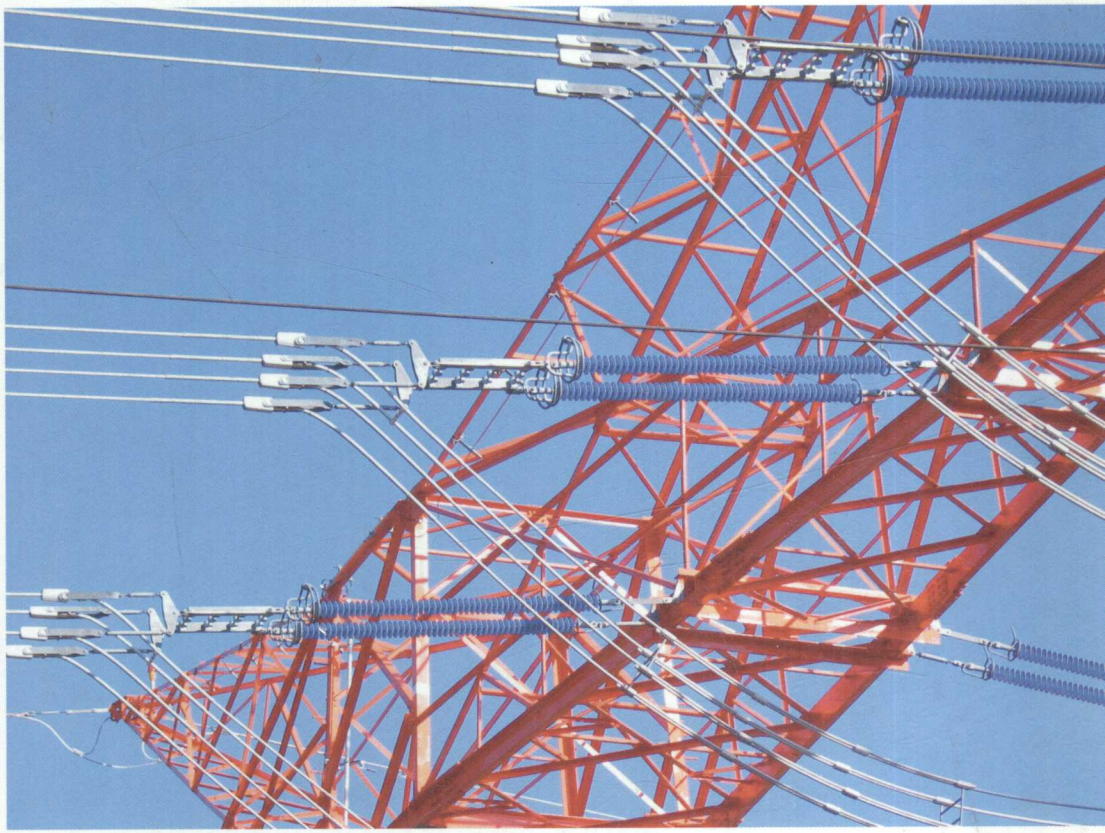
Power System Engineering

Planning, Design, and Operation of Power Systems and Equipment



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The Authors

Prof. Dr.-Ing Jürgen Schlabbach
University of Applied Sciences
Bielefeld

Dipl.-Ing. Karl-Heinz Rofalski
Bad Homburg

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Power System Engineering

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Foreword

The supply of electrical energy at competitive prices, in sufficient quantity and quality, and under the aspect of safe supply through reliable equipment, system structures and devices is of crucial importance for the economic development of countries and for the well-being of each individual. When planning power systems different boundary conditions must be considered, which are based on regional, structural, technical, environmental and financial facts, having a considerable impact on the technical design in many cases. Each investment decision requires a particularly careful planning and investigation, to which power system engineering and power system planning contribute substantially.

This book deals with nearly all aspects of power system engineering starting from general approach such as load estimate and the selection of suitable system and substation topology. Details for the design and operational restrictions of the major power system equipment, like cables, transformers and overhead lines are also dealt with. Basics for load-flow representation of equipment and short-circuit analysis are given as well as details on the grounding of system neutrals and insulation coordination. A major chapter deals with the procedures of project definition, tendering and contracting.

The purpose of this book is to serve as a reference and working book for engineers working in practice in utilities and industry. However, it can also be used for additional information and as a hand-book in post-graduate study courses at universities. The individual chapters include theoretical basics as far as necessary but focus mainly on the practical application of the methods as presented in the relevant sections. Carrying out engineering studies and work moreover requires the application of the latest edition of standards, norms and technical recommendations. Examples are given based on projects and work carried out by the authors during the last years.

The preparation of this book was finalised in *March 2008* and reflects the actual status of the techniques, norms and standards. All comments stated in this book are given to the best of knowledge, based on the comprehensive technical experience of the authors.

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juergen.schlabbach@fh-bielefeld.de rofalski-hg@gmx.de

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Introduction

1.1
Reliability, Security, Economy

Power system engineering is the central area of activity for power system planning, project engineering, operation and rehabilitation of power systems for electrical power supply. Power system engineering comprises the analysis, calculation and design of electrical systems and equipment, the setup of tender documents, the evaluation of offers and their technical and financial assessment and contract negotiations and award. It is seen as an indispensable and integral part of the engineering activities for feasibility studies, for planning and operating studies, for project engineering, for the development, extension and rehabilitation of existing facilities, for the design of network protection concepts and protective relay settings and also for clearing up of disturbances e.g. following short-circuits.

The supply of electricity – as for other sources of energy – at competitive unit price, in sufficient quantity and quality, and with safe and reliable supply through reliable equipment, system structures and devices is of crucial importance for the economic development of industries, regions and countries. The planning of supply systems must take into account different boundary conditions, which are based on regional and structural consideration that in many cases have a considerable impact on the technical design. Given that, in comparison with all other industries, the degree of capital investment in electric utilities takes the top position, not only from the monetary point of view but also in terms of long-term return of assets, it becomes clear that each investment decision requires particularly careful planning and investigation, to which power system engineering and power system planning contribute substantially.

The reliability of the supply is determined not only by the quality of the equipment but also by careful planning and detailed knowledge of power systems, together with a consistent use of relevant standards and norms, in particular IEC standards, national standards and norms as well as internal regulations. Furthermore, the mode of system operation must conform to the conditions specified by standards, including the planning process, manufacturing of equipment and commissioning. Just as faults in equipment cannot be totally excluded because of technical or human failure, likewise the equipment and installations cannot be

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designed to withstand any kind of fault: accordingly, the effects of faults must be limited. Thus, violation of or damage to other equipment must be prevented in order to ensure undisturbed system operation and reliable and safe supply to the consumers.

The security of the electrical power supply implies strict adherence to the conditions specified in standards, norms and regulations concerning the prevention of accidents. In low-voltage systems the protection of individuals is seen of primary importance; at higher voltage levels the protection of equipment and installations must also be considered.

1.2 Legal, Political and Social Restrictions

Electrical power systems are operated with certain restrictions imposed by legal requirements, technical standards, political issues, financial constraints and social, political and environmental parameters which have a strong influence on the system structure, the design and the rating of equipment and thus on the cost of investment and cost of energy, without any justification in terms of aspects of security, reliability and economy. Some general areas pertaining to regulations, guidelines and laws for electrical power supply are simply stated below, without any elaboration at this stage.

- Concession delivery regulations
- Market guidelines for domestic electricity supply
- Electrical power industry laws
- Energy taxation
- Laws supporting or promoting "green-energy"
- Environmental aspects
- Safety and security aspects
- Right-of-way for overhead-line and cable routing.

Such regulations, laws and guidelines will have an impact on planning, construction and operation of power systems, likewise on the reliability of the power supply, the cost structure of equipment, the cost of electrical energy and finally on the attractiveness of the economic situation within the particular country.

- Generating plants will be operated in merit order, that is, the generator with lowest production cost will be operated in preference to operating generation with the highest efficiency.
- Criteria of profitability must be reevaluated in the light of laws supporting "green-energy."
- Reduced revenues from energy sales will lead to a decrease in the investments, personnel and maintenance costs, with consequences of reduced availability and reliability.
- Increasing the proportion of "green-energy" generation plants that have low availability leads to an increase in the running reserve of conventional power

stations, with consequences of reduced efficiency of these plants and thus higher costs.
- Reduction of investment for the construction of new power stations leads to a decrease in reserve capabilities and thus to a decrease in the reliability of the power supply.
- Expenditures for coordination during normal operation and during emergency conditions are increased with rising numbers of market participants, with the consequence of an increased risk of failures.
- Power systems of today are planned for the generation of electrical energy in central locations by large power stations with transmission systems to the load centers. A change of the production structure, for example, by increase of "green-energy" production plants and development of small co-generation plants, mainly installed in distribution systems, requires high additional investment for the extension of the power system, resulting in rises in energy prices as well as reduced usage of existing plants.
- The power system structure up to now has been determined by connections of the load centers with the locations of power stations, which were selected on the basis of the availability of primary energy (e.g. lignite coal), the presence of cooling water (e.g. for nuclear power stations) or hydrological conditions (e.g. for hydro power stations). The construction of offshore wind energy parks requires substantial investment in new transmission lines to transmit the generated energy to the load centers.
- Increase of "green-energy" production plants, in particular photovoltaic, wind energy and fuel-cells, reduces the quality of the power supply ("Power quality") due to the increased requirement for power electronics.
- The long periods for planning and investment of power stations and high-voltage transmission systems do not allow for fast and radical changes. Decisions on a different development, for example, away from nuclear power generation towards "green-energy" production, are to a certain extent irreversible if these decisions are not based on technical and economic background and detailed knowledge but are predominantly politically and ideologically motivated.

As an example, the structure of public tariffs for electrical energy in the Federal Republic of Germany is characterized by numerous measures initiated by the government. These taxes, concessionary rates, expenditures occasioned by the "green-energy" law, and so on amounted in the year 2006 to nearly 12.43 billion euro (€)according to data of the VDEW (the association of public utilities in Germany). Included in this are 6.5% for the support of combined cycle plants, 16.8% for concessionary rates for use of public rights of way, 25.6% for expenditures for the "green-energy" laws and 50.4% for energy taxes. Additionally, VAT (Value Added Tax) of 19% is added for private households. For the average electricity consumption of a private household of 4600 kWh per year, these costs as a result of governmental actions amount to almost 100€ per household per year.

1.3 Needs for Power System Planning

Power system planning must take due consideration of the restrictions mentioned above and must develop concepts and structures which are technically and economically sound. This includes the planning and project engineering of generation systems, transmission and distribution networks, and optimization of systems structures and equipment, in order to enable flexible and economic operation in the long as well as the short term. Power system planning also has to react to changes in the technical, economic and political restrictions. Key activities are the planning and construction of power stations, the associated planning of transmission and distribution systems, considerations of long-term supply contracts for primary energy, and cost analysis.

The systematic planning of power systems is an indispensable part of power system engineering, but it must not be limited to the planning of individual system components or determination of the major parameters of equipment, which can result in suboptimal solutions. Power system engineering must incorporate familiar aspects regarding technical and economic possibility, but also those that are sometimes difficult to quantify, such as the following:

- Load forecast for the power system under consideration for a period of several years
- Energy forecast in the long term
- Standardization, availability, exchangeability and compatibility of equipment
- Standardized rated parameters of equipment
- Restrictions on system operation
- Feasibility with regard to technical, financial and time aspects
- Political acceptance
- Ecological and environmental compatibility.

Power system engineering and power system planning require a systematic approach, which has to take into account the financial and time restrictions of the investigations as well as to cope with all the technical and economic aspects for the analysis of complex problem definitions. Planning of power systems and project engineering of installations are initiated by:

- Demand from customers for supply of higher load, or connection of new production plants in industry
- Demand for higher short-circuit power to cover requirements of power quality at the connection point (point of common coupling)
- Construction of large buildings, such as shopping centers, office buildings or department stores
- Planning of industrial areas or extension of production processes in industry with requirement of additional power
- Planning of new residential areas
- General increase in electricity demand.