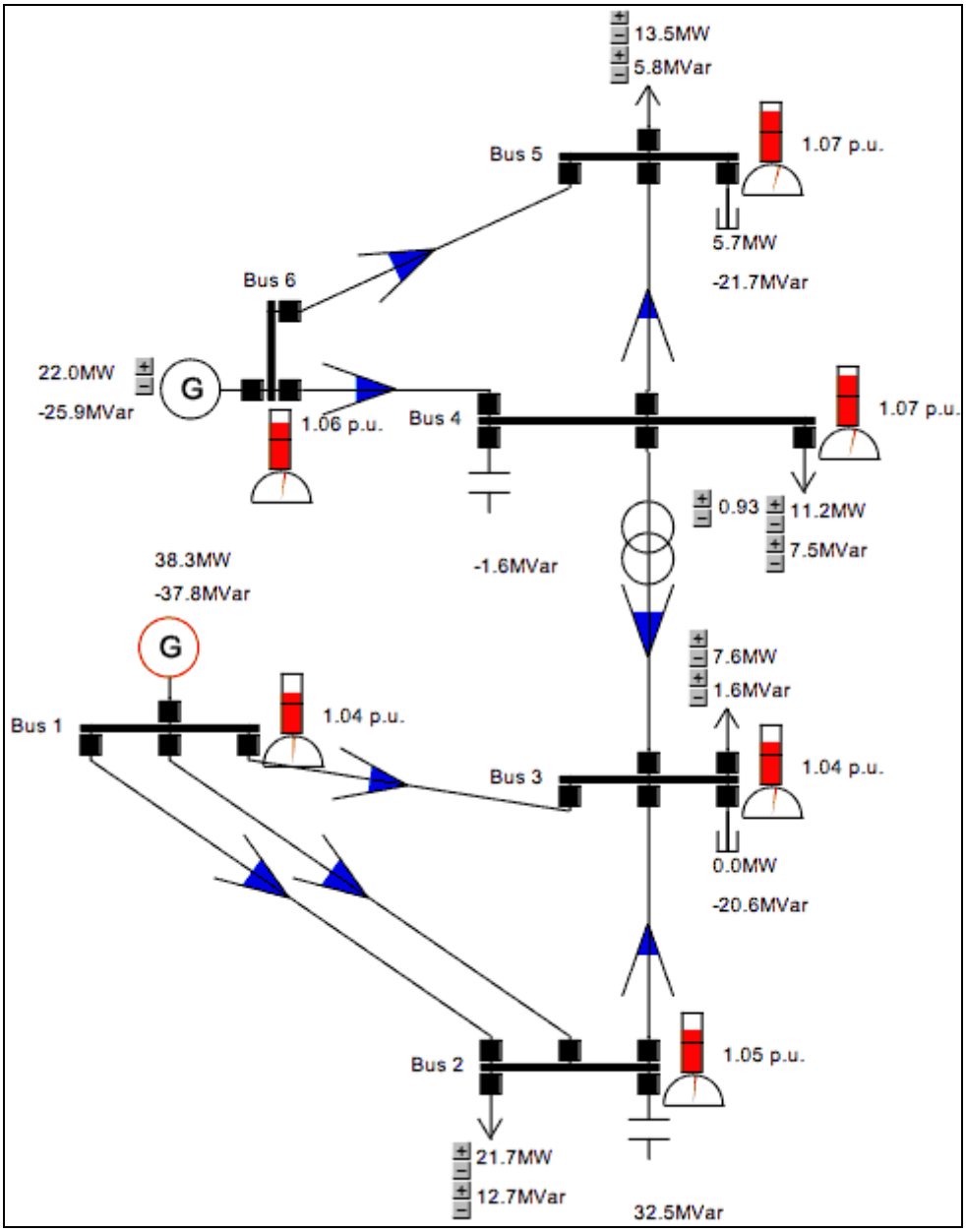
Power Systems Laboratory

Swiss Federal Institute of Technology (ETH) Zürich

Annual Report 2002



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1. Power Systems Laboratory

Head:	Prof. Dr. G. Andersson	
Secretariat:	A. Wieland	until 15.7.2002
	R. Zerjeski	from 17.6.2002
Scientific Staff:	Dr. sc.techn. J. Allmeling	
	Dipl-.Ing. W. Hammer	
	Dipl.-Ing. A. Karpatchev	
	Dipl. El-Ing. G. Koeppel	from 1.9.2002
	Dipl. Wirtsch.-Ing. Th. Krause	from 21.5.2002
	M. Milosevic, M.Sc. El.Eng	from 18.8.2002
	R. Sadicovic, M.Sc. El.Eng	from 1.2.2002
	Dipl. El.-Ing. Ch. Schaffner	
	M. Zima, M.Sc. El.Eng.	
Scientific Associate:	Prof. em. Dr. H. Glavitsch	

1.1 External lecturers

Dr. R. Bacher:	Bacher Consulting , Baden
Dr. D. Reichelt	Bearing Point, Zürich

2. Teaching

The lectures and laboratory classes listed in the following two sections are part of the standard curriculum of the Electrical Engineering Department and are conducted by the staff of the Energy Transmission and High Voltage Laboratory. Details of the entire electrical engineering curriculum can be provided on request (list of lectures, option proposals).
We use standardised terms to characterise the listed lectures and laboratories:

Semester — hours per week[1]
Title — **Lecturer**
German title

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1 V = lecture; U = tutorial; G = lecture with assoc. tutorial; P = laboratory class; S = seminars

2.1 Lectures provided by the Power Systems Laboratory

1st – 3rd semester
PPS seminar: Aspects of a sustainable energy supply — **Koeppel, G**
(Aspekte einer nachhaltigen Energieversorgung) — **Krause, Th.**

In the past, electricity markets were characterized by vertically integrated utilities operating as regulated monopolies. However, the ongoing liberalisation process, the Kyoto-protocol as well as upcoming technologies are pressing on a reorganisation and redirection of the electricity market.

The offered seminar addresses several issues related to this reorganisation process. Main topics are distributed generation, particularly aspects of renewable energy sources (solar and wind power) as well as economical and ecological issues of liberalized markets. The students are each writing and presenting a report covering single aspects, learning how to search for information as well as how to write and present scientific reports.

5th semester — 4G
Electric power systems — **G. Andersson**
(Elektrische Energiesysteme) — **K. Fröhlich**

Structure of electric power systems; symmetric three phase systems; modelling of power transformers and generators; analysis of symmetrical and unsymmetrical three phase systems; transient switching phenomena; basics of current

interruption; principles and applications of distribution- and transmission switchgear; basics of insulation coordination.

6th semester 4 G
Modelling and analysis of power networks **Andersson, G.**
(Modellierung und Analyse elektrischer Netze)

The electrical power transmission system, the network control system, requirements for power transmission systems (supply, operation, economics), network planning and operation management, models of N-port components (transmission line, cable, shunt, transformer), data specification in per unit (p.u.), linear modelling of networks, linear und non-linear calculation (Newton-Raphson), non-linear load flow (specification and solution methods), three-phase und generalized short circuit current calculation. Introduction to power system stability, equal area criterion.

7th semester 4 G
Optimization of liberalized electric power systems **Bacher, R.**
(Optimierung liberalisierter elektrischer Energiesysteme)

Mathematical optimization methods, Karush-Kuhn-Tucker optimality conditions, Equality constrained non-linear optimization, Linear Programming (LP) (Simplex, Interior Point), Quadratic Programming (QP) and applications; non-linear optimization; goals of a power exchange (PX), of the "independent system operator" (ISO), of the regulatory institutions, of the new electric power utilities; principles of optimization of a power exchange: Offer-Bids; optimal regulated network operation: Payments for network use, long- and medium term network optimization as goals; handling of network security limitations by optimization methods; optimization methods to determine the efficiency of networks; optimization of ancillary services as part of the liberalized electric power system.

7th semester 2 G
Portfolio and risk management in a liberalized electricity market **Reichelt, D.**
(Portfolio und Risk Management im liberalisierten Strommarkt)

Open electricity market; Swiss electricity market law; power trading (OTC); transmission system operator (TSO); ancillary services; congestion management; Swiss electricity price index (SWEP); European power exchanges (EEX, LPX); financial products: futures, options, swaps; risk management: value at risk, profit at risk, simulations; hedging strategies; marketing of electricity (product development); further developments in the European electricity market.

8th semester 4G

Dynamics of power networks and protection of transmission lines **Andersson, G**
(Dynamik von Netzen und Leitungsschutz) **Reichelt, D**

Dynamic properties of electrical machines, networks, loads and connected systems, models of power stations and turbines, regulation of turbines, power and frequency control, power exchange among networks, model of the synchronous machine connected with the network, biaxial theory, transient model, block diagram, behaviour of the machine in case of disturbances, transient stability, area criterion, model for small disturbances, voltage control and static stability, condition of protection systems, (selectivity, reliability, reserve, economic efficiency), principle of protection, protection of transmission lines, distance protective system, earth return circuit, influence of fault impedances, location of power supply, trigger characteristics and staggering, balanced protective system, phase comparing protection, direction monitoring protection, (digital) protective gear, algorithms, fault location, intelligent alarm signal processing, use of expert systems.

2.2 Student projects

To be admitted to the diploma examinations of the 7th and 8th semester, students of the electrical engineering department have to carry out two projects. Each student can freely choose his subject area, but usually the two projects have to originate from different subject areas. According to the curriculum, two days of the week during the semester period are to be devoted to this work. In general, the subjects are derived from topical research and development tasks. As we have close collaboration with the FKH some of the student projects as well as diploma work (see the following section) are supervised by staff of the FKH (Fachkommission Hochspannungstechnik Zürich).

Th. Mühlemann	Technische Aspekte bei der Einführung des Strommarktes (Technical aspects of the implementation of the electrical energy market)
T. Kessler	Abstimmung über das Elektrizitätsmarktgesetz/ die Elektrizitätsmarktverordnung vom 22. September 2002 (Plebiscit on the electricity market legislation)
Yi Wu	Ist der Strom grün oder strahlend? („Current: green or radiating“)

2.3 Diploma projects

Allocated time is four months. The majority of students devote their time to this work in the winter semester. The student has the option to carry it out either before or after the formal diploma examination (dates in spring and autumn).

Summer semester 2002

P. Jansson	Optimal placement of Phasor Measurement Units (PMU) in a power system

Winter semester 2002/ 2003

Adrian Bürgler	Wirtschaftliche Beurteilung von FACTS-Geräten im europäischen Strom-Markt (Assessment of the economics aspects of FACTS devices in the European electricity market)
Martin Geidl	Implementation von FACTS-Geräten mit Lastfluss-Optimierung in einer interaktiven Netzsimulations-Umgebung (Implementation of FACTS devices with load flow optimization in an inter-active network simulation environment)

2.4 Excursions

4.6.2002	Etrans / EGL Presentations about protection equipment for transformers, switchgear and about the Swiss electricity market. Also visit of dispatching center, which is the core component for all transit power flows through Switzerland, and substation Laufenburg, one of the largest European substations.
2.7.2002	ABB, Substation Automation Two presentations about system standards, and wide areas measurement systems and visiting the laboratory with presentation of the simulation of the wide area measurement
17.12.2002	DeriWatt, Dietikon Futures and forward trading, risk management

2.5 PhD Thesis See section 3.1

3. Research activities of the Power Systems Laboratory

Note: Some of the recently completed PhD theses can be downloaded from the Internet: http://www.eeh.ee.ethz.ch

3.1 Completed PhD Thesis

Ein Symmetrierkompensator für Hochspannungsleitungen

(Compensator for symmetrization of power lines)

Candidate:	Gunthard Orglmeister
Thesis:	ETH No. 14537
Examiner:	Prof. Dr. G. Andersson, ETH Zürich
Co-eximiners:	Prof. em. Dr. H. Stemmler, ETH Zürich
	Prof. em. Dr. H. Glavitsch, ETH Zürich

Abstract

According to today's common practice at power grid utility companies any persistent fault - even a single phase one - in an electric power transmission line leads to complete three phase interruption of the line. The fact that more than 85 % of the faults in power transmission lines are single phase faults gave rise to the idea to continue the use of the two sound conductors not affected for the transport of electric energy and to thereby increase the reliability and the average transmission capacity of the power grid.

However, the asymmetrical transmission over a three phase transmission line with one unconnected conductor would lead to undesired zero and negative sequence currents at generators and loads. Therefore, special equipment is necessary to symmetrise the currents and voltages at the terminals of the transmission line. The asymmetrical currents have to be limited to the transmission line itself.

FACTS devices based on power electronics have now been in use for several years in power lines to control the power flow, the reactive power and the terminal voltages. Why should they not be used for the symmetrisation of currents as well? In this thesis a new FACTS device based on the structure of existing reactive power compensators has been developed and tested for the forced symmetrisation of the currents and voltages at the terminals of high voltage transmission lines. The device consists of a three phase three pulse voltage source inverter connected via a transformer in parallel to the terminal of the transmission line. At the connection point it draws all asymmetric current

components out of the line and it injects symmetrical ones. For this compensation it has to store the transmitted energy for half a period of fundamental frequency in the dc link capacitors.
For the device used a multi level digital control algorithm based on a Dead Beat controller and integrating oscillators had been developed and compared with other control algorithms. By the means of extensive computer simulation and measurements in a laboratory model constructed especially for this purpose, the functionality of the new device and its control has been proved.

The device is able to restore symmetrical currents and voltages at the connection point within one period of fundamental frequency. Besides, for the symmetrisation the newly developed FACTS device can be used for reactive power compensation: The amplitude of the voltage at the connection point can also be stabilised as long as no over currents in the conductors occur. Therefore the new device can be considered as a useful means to increase the supply capacity, quality and reliability of existing power grids.

3.2 Current projects

PLECS - Piece-wise linear electrical circuit simulation with Simulink

Jost Allmeling, Wolfgang Hammer

The development of power electronic systems usually involves the design of both the electrical circuits and the control algorithms. To study the behaviour of these complex systems, simulation is essential. For the simulation of purely electrical circuits powerful programs like Spice and Saber exist. They allow the user to enter the circuits as netlists or schematics. However, incorporating complex control stuctures requires a thorough knowledge of the specific program.

Simulink, an extension to Matlab, is a program for simulating dynamic systems. It is widely used for the simulation of control systems, since even complex structures can be built easily and Matlab provides powerful evaluation of the simulation results. Therefore, Simulink is also convenient for the design of closed loop controlled power electronic systems. However, systems containing electrical circuits cause difficulties, in that they cannot be modelled in a straightforward way. Simulink accepts neither schematics nor netlists for electrical circuits. Instead they must be represented by mathematical formulae - be it state-space equations or nodal formulation - which must be set up individually for every topology. This process is time-consuming and error-prone.

In order to facilitate fast and easy simulation of power electronic systems, the program PLECS has been developed. PLECS is a toolbox for piece-wise linear simulation of electrical circuits within the Simulink environment. Circuits to be simulated with PLECS may consist of ideal resistors, inductors, capacitors, transformers, voltage and current sources, meters, and switches. These latter elements - sources, meters, and switches - form the interface between the electrical circuit and the control system. This points towards modelling the electrical circuit as one single Simulink subsystem. Its inputs are the commands for controlled sources and switches. Measurements taken by the voltmeters and ammeters are provided as the outputs of the subsystem.

PLECS provides linear elements and switches. At any time the switches in PLECS are either short or open circuits. This means that before and after the instant of switching the circuit is purely linear and hence its overall behaviour is piece-wise linear. Switches are the basis for power electronic components. They can be controlled externally or internally or a combination of both. External in this context means that the control signal does not directly depend on voltages or currents in the system. Examples of externally controlled switches are breakers and half-bridges of VSIs. Internal control variables are voltages or currents that can be measured in the circuit. The simplest example of a purely internally controlled switch is a diode, which is switched on by a positive voltage and off by

a negative current. Power electronic components such as thyristors, GTOs and IGBTs operate according to a logical combination of external and internal switching conditions.

Fonds Filep

Power electronics circuits are dynamic systems with a high number of successive switching states. Their principle of operation is particularly difficult to teach in lectures with printed material and presentation slides only. Therefore, an educational project has been launched in order to develop a user interface that enables students to simulate electrical circuits and to understand their principle of operation by means of animated schematics. Dynamic processes and parameter dependencies can be illustrated more easily with animated simulation than with static media. PLECS has been chosen as the simulation platform since many students are already familiar with Matlab/Simulink from undergraduate courses and projects. The project is carried out in collaboration with the Power Electronics Systems Laboratory and is funded by the Fonds Filep of ETH Zurich.

Venture 2002

In May 2002 Jost Allmeling and Wolfgang Hammer were awarded a prize in the business plan competition Venture 2002 for their transfer project PLECS. They were among the ten winning teams with the best business plans in Switzerland. Venture 2002 was organized by McKinsey & Company, Switzerland, and ETH Zurich.

Plexim GmbH

In June 2002, Plexim GmbH was founded as an ETH spin-off company by Jost Allmeling and Wolfgang Hammer. Plexim is hosted by the Power Systems Laboratory which also provides the required office space. The principal activity of Plexim is the further development and the marketing of PLECS. For more information see www.plexim.com

Increased transmission capacity by forced symmetrization

Andrei Karpatchev

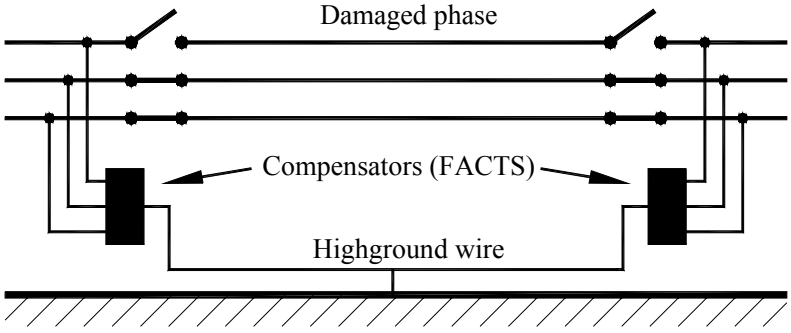
Goal of the project

The research project deals with an investigation of possibilities for enforced symmetrization on a damaged transmission line to ensure power transmission through the line even in a faulty state. The utilization of two remaining healthy phases of a three-phase transmission line with a damaged phase can be an economical way to enhance the system reliability.

Active symmetrization as mean to ensure transmission capacity

The electrical power sector experiences nowadays a considerable need in techniques for increasing the capability of transmission systems. Firstly, the reason for this lies in increasing power flows due to increasing power consumption and, secondly, due to the deregulation of the electricity market demanding power flows to be more flexible. The conservative expansion of the high voltage grid is often not possible, because the approval of new overhead transmission lines meets strong opposition in society. Furthermore it takes a long time and is generally a risky long-term financial investment. In the present planning of high voltage networks the (n-1) criterion is mostly respected. This means, that the network should not be subject to any overload or voltage drop below a strict given limit when any network element is disconnected.

Based on the statistics, the single phase-to-ground faults are the most frequent faults in transmission systems. The percentage of faults due to the phase-to-phase and three-phase faults is considerably smaller. Present planning procedures are often based on single outages of three-phase circuits, which do not take the actual fault pattern into account. For the single-phase faults it is necessary to avoid unsymmetrical conditions or unsymmetrical currents in the network. The reason for this is that the currents in the zero-sequence system mean earth currents, and those can be dangerous for people and cause adverse interaction with other systems. The currents and voltages in the negative-sequence system are a concern to rotating synchronous machines like generators and motors, but if no such machines are connected to a network part, the negative-sequence voltages can be tolerated on that part.



Symmetrization means the suppression of both zero- and negative-sequence currents on
the network side of both breakers so that the network does not experience any unsymmetrical conditions. This can be performed by the installation of two FACTS-devices as shunt or serial elements at the line terminals (see figure)

Different arrangements and strategies are considered in the work. To try all the different arrangements a special system simulator was developed. It is based on power flow calculation with multiple symmetrical system representation and allows simulating the effect of symmetrization in a complex meshed network. The fault currents in the negative- and zero-sequence systems can be studied directly. Results of simulation of some fault cases of IEEE sample networks are represented. Implementation of the symmetrization technique can be a competitive solution to the common extensive methods for providing system availability. Shorter installation times, greater ease of obtaining administrative permission and possibility to use the installed equipment for auxiliary system services are supportive arguments for the new technology.

References

[1] A. Karpatchev, G. Andersson, H. Glavitsch "Increased transmission capacity by forced symmetrization", IEEE/PES transmission and distribution conference and exhibition 2002: Asia Pacific, Yokohama, Japan, pp. 813-817, October 6-10, 2002.

Development of a model for the evaluation of storage requirements in secluded and microgrid electricity systems

Gaudenz Koeppel

Introduction

Due to both the liberalisation process in the electricity market as well as recent developments for smaller and regenerative power plants, more and more small, remotely located power plants have been installed. The proliferation of this so-called distributed generation has stimulated discussions, particularly since authorities and network operators have recognized the associated possibilities and problems. Advantages of distributed generation are e.g. reduced transmission losses because the power generation is closer to the customers or reduced CO_2-output because of the implementation of small and renewable power generation units using solar or wind energy. Open questions on the other hand are, among others, how to account for emerging connection costs and to whom or how to protect the grid as well as the production units in case of failure.

With larger penetration of renewable sources in these grids, storage-related issues come up. Because the production forecast models of solar and wind powered as well as heat-controlled combined-heat-and-power (CHP) plants are not yet sophisticated, grid sections or microgrids with no or very limited connections to the rest of the transmission network need to be able to store surplus electricity production for later use.

The idea is to develop a model, which will return as output the requirements for storage capacity and throughput as well as an economically optimum ratio of storage versus transmission capacity to neighbouring networks in case of an existing network connection. The input will be production curves of renewable energy systems, possibly depending on geographical information systems (GIS) and weather data, production curves of conventional power and CHP plants as well as load profiles of residential areas and industries connected within the observed network part. The model will work with different time frames as weeks, days or years. The intention for this model is to contribute to the ongoing discussion, whether and to what extent storage is needed in systems with larger shares of renewable generation.

Objective

This project was started in September and is therefore still at the very beginning. Presently, a literature study is carried out and a report focusing on distributed generation issues, also in relation to Switzerland, will be available by the beginning of next year. Following this report, various load and production curves simulation models, as e.g. loss-of-load-probability (LOLP) or Monte-Carlo simulations, will be studied to be able to define the task in more detail.

References

[1] Wood, A.J., Wollenberg, B.F.: "Power generation, operation, and control", 2nd Edition, John Wiley & Sons, New York, 1996

[2] Conejo, A: "Optimal reservoir utilization of pumped hydro storage plants in probabilistic production costing models intended for generation expansion planning", PhD Thesis at the Royal Institute of Technology, Stockholm, 1990

Isolated rural distribution networks with a large penetration of renewable sources

Mirjana Milosevic

Participating institutions

Chalmers University of Technology, Sweden
MIT, Cambridge, MA, USA
University of Tokyo, Japan
Shanghai Jiao Tong University, China
World Bank, Washington DC, USA
Project sponsord by Alliance for Global Sustainability

Goal of the project

The principal scientific aim of this project is the development of methods for assessing the performance of rural electricity distribution networks with a large penetration of renewable sources of energy (like wind, sun and flow-of-river). The research concentrates on the development of models for reliability analysis of the supply, but some of the models can also be used in voltage quality assessment studies. Additional results of the project are expected on the development of techniques for improving the
performance and/or reducing the cost.

Abstract

The integration of energy sources requires an interface to the electrical system. This system is different for different energy sources, but in almost all cases it consists of an power electronic system converting a dc voltage or an ac voltage of varying frequency, or different from the system frequency, to an ac voltage of the system frequency, usually called the fundamental frequency. The requirements on the permissible deviation within 0.1 Hz, or even smaller values are accepted in power systems used in the industrialized countries. In smaller systems, like the ones studied in this project, much larger frequency deviations must probably be

accepted for an economic operation. This requires higher demands on the converters between the energy sources and the network.
Thus, it means that models for the interaction between the network side and the energy sides of the converters are needed. One application of these models is the specification of the design criteria of the power electronic equipment and for determining the electrical conditions at the energy source. Another application is for studying the interaction among several converters in a network and determining the possible adverse condition that could arise.

One of the aims of this project is to develop models for the applications above. Since the converters to be used in these power systems must be mass-produced, the developed models must be generic to cover different designs.

The integration between several power electronic systems integrated in power systems is a new topic. The converters can be very close to each other, and it is quite possible that interactions of adverse nature could occur. The converter control has a very strong influence on the interaction. In the worst case these adverse interactions could jeopardize the stability of the system and consequently the supply of electricity to the consumers.

The activities of this project are:

- Development of models of the interface between the energy sources and the network
- Studies of the stresses on the power electric equipment in typical model networks
- Studies of the interaction between the converters in typical model networks

Energency control of power systems, design of system protection scheme.

Marek Zima

Deliberalization of the electricity market in many countries yields frequent changes of generation and transmission pattern. This together with the continuous growth of the load demand causes significant stresses of the power systems, often beyond their limits. This in turn results in more frequent contingencies leading to severe consequences – risk of failures, blackouts and financial losses.

Since the extensions of the transmission systems are kept to a minimum for various reasons (mainly environmental), better utilization of existing assets becomes necessary. Various means can be used for this purpose, ranging from on-line monitoring of available transmission capacity to improved control, especially under emergency conditions. To deal with the latter is the task of System Protection Schemes (SPS) [1]. Conventional/traditional SPSs designs are based on the predefined worst scenarios obtained by off-line simulations, which are used to define certain rules. These rules are applied to tuning of local relays (underfrequency, undervoltage etc.) that shall operate in a way eliminating incipient instability. However, assumptions used for setting these rules are too conservative and often leave a significant unused transmission margin.

Above mentioned disadvantages can be overcome by an on-line scheme, which would take into account actual network conditions and provide a high degree of coordination in control. Such a SPS could rely on the phasor measurement units placed throughout the network to be able to provide a wide area view, since majority of dangerous phenomena in power systems have such an origin (voltage, frequency, small-signal etc.).

The goal of this research project is to determine constraints for physically feasible SPS application, investigate and design an algorithm mitigating one or more instability phenomena.

Applicability of existing research activities has been studied. As a prospective method appears use of so called trajectory sensitivities (TS). TS have been applied so far for post-mortem analysis of large disturbances of power systems [3]. A potential for quantification of an impact of a parameter change on the nominal trajectory is presently studied, especially a possibility to implement it in model predictive control.

This project is done partly at ETH and partly at one industry partner ABB (which is actually sponsoring the project) in order to take into consideration practical aspects of possible future implementation.

References

[1] M. Zima: „Special protection schemes in electric power systems – Literature survey“, Swiss Federal Institute of Technology, E-collection, http://e-collection.ethbib.ethz.ch/cgi-bin/show.pl?type=bericht&nr=96, June 6th, 2002

[2] Ch. Rehtanz, M. Larsson, M. Zima, M. Kaba, J. Bertsch: “System for wide area protection, control and optimisation based on phasor measurements“, Power systems and communication systems infrastructures for the future, Beijing, September 2002

[3] I. A. Hiskens, M. Akke: „Analysis of the Nordel power grid disturbance of January 1, 1997, using trajectory sensitivities”, IEEE Transactions on Power Systems, Vol. 14, No. 3, August 1999, pp.987-994

Evaluation of transmission pricing methods in liberalized markets

Thilo Krause

Introduction

That a countries' electricity market has been liberalized is a common but likewise unspecific proposition. "Delivered power is a bundle of many services. These include transmission, distribution, frequency control and voltage support, as well as generation. [...] Each service requires a separate market, and some require several markets"[1]. Recent developments in Europe have shown that competitive structures may be introduced more easily to specific sub-markets while others still remain regulated.[2] This applies especially to transmission (and distribution) markets, which appear to be natural monopolies. Microeconomic theory suggests, that natural monopolies should be regulated for securing social welfare [3]. In case of transmission networks the objective is to define a regulatory framework, which states technical and economical principles to ensure the quality of the transmission service. Whereas physical laws mainly determine technical requirements, the economical principles remain heavily under discussion. In this context the pricing of the transmission service plays a crucial role in order to guarantee the reliability of the transmission grid. Transmission pricing has to "a) promote economic efficiency b) compensate grid companies fairly for providing the transmission service c) allocate transmission cost reasonably among all transmission users d) maintain the reliability of the grid"[4]. Although several paradigms have been proposed, reaching from embedded to marginal pricing methodologies, it is agreed, that there is still a need for both efficient and practicable concepts [5].

Objective

At the moment the research work is at an early stage, incorporating mainly literature studies. A report evaluating different transmission pricing methodologies will be available in January 2003. The report serves as initial study for the overall project. The objective for the next research stage is to apply the studied methods in a first step to characteristic network topologies and, in a second step, to assess the performance by multi-criteria decision finding. The results gained will guide the further development of a transmission pricing method, possibly related to Switzerland and its position as "hub" in the UCTE.

References

[1] Stoft, S. (2002): "Power system economics. Designing markets for electricity". IEEE Piscataway 2002.

[2] Siner, M.; Doyle, C. (1999): "Europe's Network Industries: Towards competition". In: Vaitilingam, R. (1999): A European market for electricity. Monitoring European deregulation. London 1999. pp. 1-23.

[3] Varian, H. (2002): "Intermediate microeconomics", Norton, New York.

[4] Cannella, M.; Disher, E.; Gagliardi, R. (1996): Beyond the contract path: "A realistic approach to transmission pricing". The Electricity Journal. 1996. pp. 26 – 31.

[5] Shirmohammadi et. al. (1996): "Some fundamental technical concepts about cost-based transmission pricing. IEEE Transactions on Power Systems. Vol. 11. 1996. pp. 1002-1008.

Control of advanced AC transmission systems

Rusejla Sadikovic

Industrial Partnership

ABB Corporate Research Ltd., Baden

Goal of the project

The overall goal of this project is to develop an entire control system architecture, which avoids complete system redesign in order to permit a most effective system expansion in terms of new transmission capabilities and more effective network utilization. For the realization of such a controller design the following specifications are defined:

- No adverse interactions occur when the controllability is lost due to faults or changes in system topology.
- No adverse interactions occur in normal operation, and when normal changes in control set points are introduced.

Abstract

Problems related to controllable transmission paths in an AC system are intensive planning studies and redesign of control and protection systems, adverse control interactions with other controllers. Nowadays, there are controllable power electronic devices, which can be integrated into the system to permit power flow control, reactive power compensation or ancillary services like damping oscillations. The problem is that the controller design of such controllable component incorporates and affects the whole system. This results mostly in redesign of other network controllers.

Applying a control architecture, which permits the operation of a controlled transmission path without affecting the rest of the system, can eliminate these problems. That control architecture is called Non-Intrusive System Control, NISC™.

NISC™ avoids complete system redesign. It permits a most effective system expansion and more effective network utilization by considering the required transmission functions first. The goal of the NISC™ architecture is to simplify the design process so that new controlled transmission paths can be designed without extensive system studies. For the operation of a new transmission path the NISC™ architecture avoids adverse control interactions within the entire system without causing a redesign of controllers already implemented. Therefore a high degree of robustness and an effective design procedure can be achieved. Additionally, the proposed architecture allows for a proper reaction to critical events and avoids insufficient and hence wrong operation after the power system state changes.

References

[1] Ch. Rehtanz, D. Westermann: "Non-intrusive control system architecture for AC power transmission"; Seventh International Conference on AC-DC Power Transmission, 2001. IEE Conf. Publ. No. 485 Stevenage 2001, pp. 256-261.

Flowdemo.net: Interactive, internet-based tool to visualize power flow in an electric transmission system

Christian Schaffner

Abstract

Flowdemo.net is an *interactive load flow visualization software* for education in electrical engineering. What differentiates it from similar tools is that it can be run via any Internet browser or, alternatively, as a stand-alone application. Thus there is no special installation needed for the user. Lecturers can use it to visually demonstrate load flow in electric transmission systems in a convenient way: They access predefined examples stored in a database on the server. After wards students can access the same examples via an Internet browser to deepen the new knowledge.

Description

Flowdemo.net gives a visual representation of a calculated load flow including the network topology, graphical representation of the load flowing through a line, numerical and graphical representation of bus voltages and angles, state of switches etc. The graphical user interface (GUI) of Flowdemo.net displays the

network topology together with graphical and/or numerical representations of the load flowing through a line, of bus voltages and angles, state of switches etc. The user can interact with the calculation by switching on or off lines and components, changing parameters such as the voltage of a regulating generator or the active and reactive power of a load. The GUI is programmed in Java.

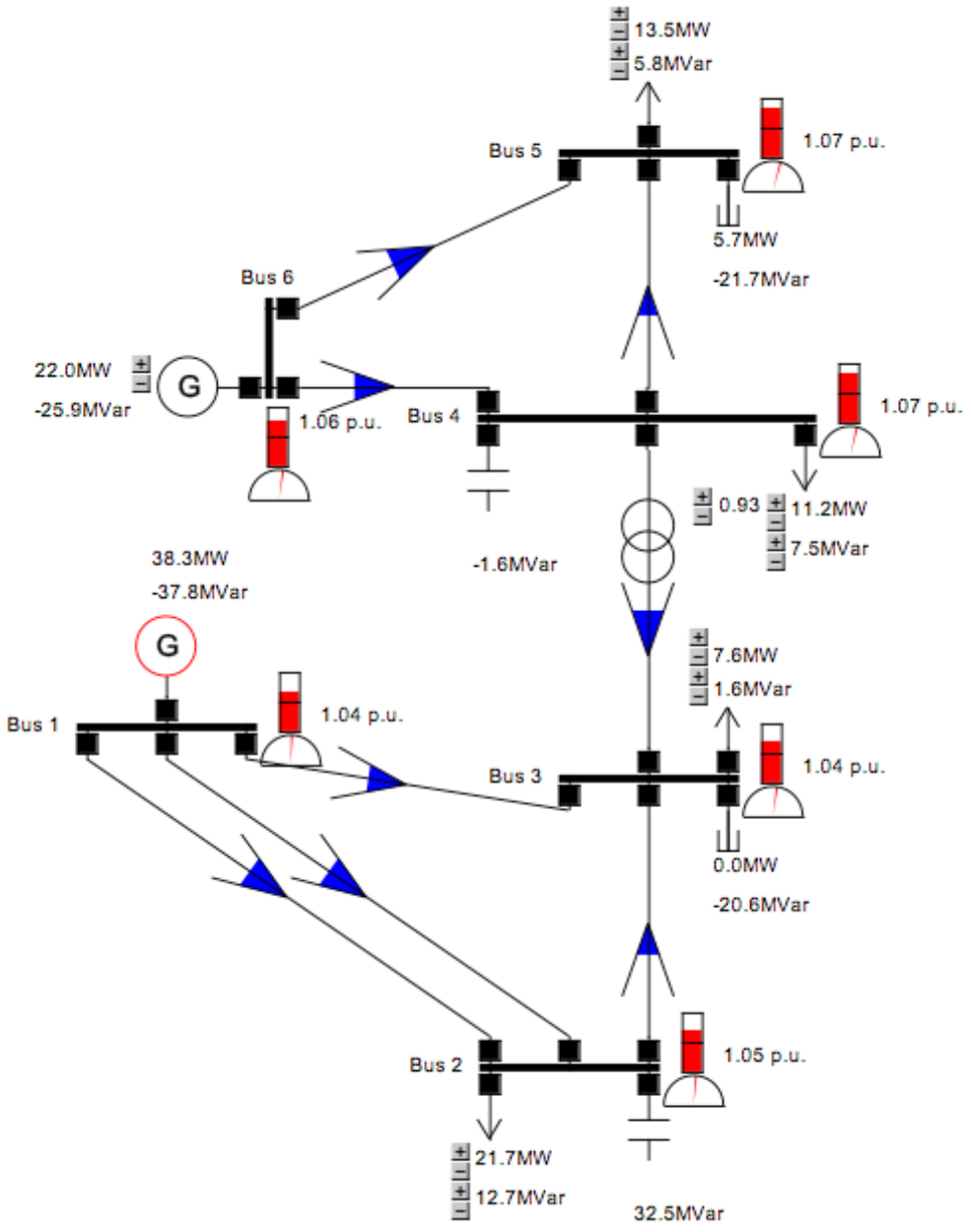


Figure: A 6-bus network in Flowdemo.net:
Voltages, phase angles and load flows are represented graphically..

The calculation is carried out on a server running Matlab that communicates with the Java applet running inside the Internet browser of the client computer.

As Matlab is a well-known and straightforward programming language, new concepts or devices can be implemented easily. Thus it was possible to add FACTS components normally not available in load flow calculation software. As a last point due to the concept of an *application service* upgrades of the software can be done effortlessly: by installing the new version on the server, all clients are immediately up-to-date.

Applications in education

A typical application of Flowdemo.net is as follows: The lecturer prepares demonstration networks and puts the associated net lists on the server. During class he can explain theoretical principles using one of the prepared networks. All he needs is a computer with Internet access and a computer display projector. To strengthen the knowledge students will use the same simulations after class to work through written questions.

New concepts or devices can be implemented directly by the lecturer, since the source code is available. Also, as Matlab is well known by most engineering people, no special further programming knowledge is needed.

New version coming

During the year 2002 many enhancements were implemented into Flowdemo.net:

- A graphical network editor was added that allows the networks to be edited online

- The networks are now stored in a central database, which makes it even easier for lecturers to publish new networks to students

- Flexible AC Transmission Systems (FACTS) such as SVC and TCSC were added to the available components.

The new version will be available early 2003 from http://flowdemo.net

Outlook

There will be a new version developed including optimal power dispatch based on cost curves for generators. It is also planned to allow the control of the amount of power flowing from one region to another. This gives the opportunity to study congestion management or transaction scheduling.

For use in education a tutorial system will be developed allowing the lecturer to include problem descriptions and their solutions directly into the graphical user

interface. This will give the students the possibility to verify their results immediately.

Value of controllable devices in a liberalized electricity market

Christian Schaffner

Abstract

In a liberalized electricity market, the transmission capability of an electrical network is of economic value to the network operator, which is usually regarded as a natural monopoly, combined with the mission to maximize the benefit for its users while giving a reasonable profit to its owners. Due to physical constraints, lines are often only utilized at a fraction of their physical limits. To improve customer benefit one possibility would be to raise the economic value of the transmission lines by increasing the power transfer capability of these lines. Additionally, there will be a gain in overall market efficiency since more energy trading can take place between competing regions with different price structures. Flexible AC Transmission Systems (FACTS) devices also allow the increase of the overall utilization of an electrical power network by controlling the power flow.

Since installations of FACTS devices require huge investments, with costs that could be similar to new transmission lines, it is very important to investigate all different aspects of such as a device: For example not only the increased transmission capacity, but also the fact that such a device can be built in such a way that it can be relocated due to seasonal differences in the power transfer between regions.

Objective

In this PhD thesis it will be examined what additional economic value the increased transmission capability provided by controllable devices (such as FACTS) gives in a liberalized electrical power transmission system.

Outline

To achieve the objectives described in the preceding paragraph several research areas in the field of electric power transmission and controllable devices in such systems are examined.

The idea behind our model is that a complicated algorithm using optimal power flow (OPF) is often too complex for the purpose of valuating such projects: Input parameters such as expected future generation mix are often hard to guess and error prone. Therefore it is reasonable to use a simplified model of the underlying electricity system.

This method is based on a model that uses area-constraints and aggregated generation in each area coupled with a double auction market model, based on the production costs of generators.

In different case studies the influence of various parameters on the value of the controllable device is determined. Typical parameters are: Investment costs, running costs, relocatability etc. The impact of transmission congestions on electricity prices, consumer, producer and society profit is also studied.

The valuations carried out show that even if there is limited impact on removing congestions by installing a controllable device, it has a significant monetary value for the owner. In addition to quantitative results, qualitative aspects will describe the most important factors when evaluating this value.

Industry partners will help in defining example systems, providing information on real congestion situations, stability issues etc. In addition, there will be collaboration with other academical institutions in the area of general economical methods for liberalized markets.

Modelling techniques for power electronic devices

Wolfgang Hammer

There is a general trend that power electronics based devices are increasingly being used and considered in power systems applications. These devices can be classified into FACTS devices (Flexible AC Transmission Systems) such as the thyristor controlled series capacitor (TCSC) and the unified power flow controller (UPFC) on one hand, and the more traditional HVDC applications on the other hand.

In order to understand and control the interactions between power electronics devices and the power system they are connected to, there is an increasing need for appropriate models. However, the question which model is appropriate is not a trivial one, as these interactions have many causes (e.g. electromechanical, harmonic, and control interactions) and their characteristic frequencies may range from a fraction of a Hz to several kHz.

Obviously the detailed time domain three-phase simulation will yield the most accurate results for any type of interaction. The drawback of detailed modelling, however, is the computational effort. The long simulation times render it virtually useless for the study of slow phenomena that require the simulation of long time periods. The standard approach for such problems is the quasi-static method, which relies on the assumption that the system operates in a steady state (i.e. the ac quantities being sinusoidal, and the dc quantities constant). By this approach one arrives at models that are very simple and yet capture the behaviour of a system quite accurately up to a few Hz. There remains a frequency range from several Hz up to around fundamental frequency for which the detailed simulation is too slow, and the quasi-static model, too coarse.

Recently, new modelling techniques, based on so-called phasor dynamics, have been proposed that may close this gap [1]. However, the applications reported so far have mostly been concerning FACTS devices. This project focuses on HVDC applications. The systems studied are the conventional line-commutated converter (LCC) and the capacitor-commutated converter (CCC). For the conventional converter a reduced model has been developed which shows good accordance with a detailed three-phase simulation in a frequency range up to fundamental frequency [2].

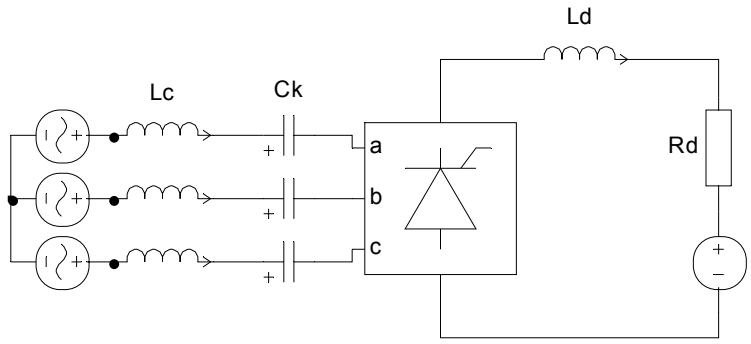


Figure 1: Capacitor commutated converter arrangement with RL-load

In a second step this model was extended to incorporate the dynamic behaviour of the series capacitors of the CCC and their influence on the direct current. A sample simulation run is shown in the figure 2 below. At t_1 = 0.1 s a step change of -5% is applied to the mains voltage and accordingly the direct current begins to drop. At t_2 = 0.2 s the firing angle is reduced as a corrective action. The simulation shows a good accordance between the phasor-based model and a detailed three-phase model.

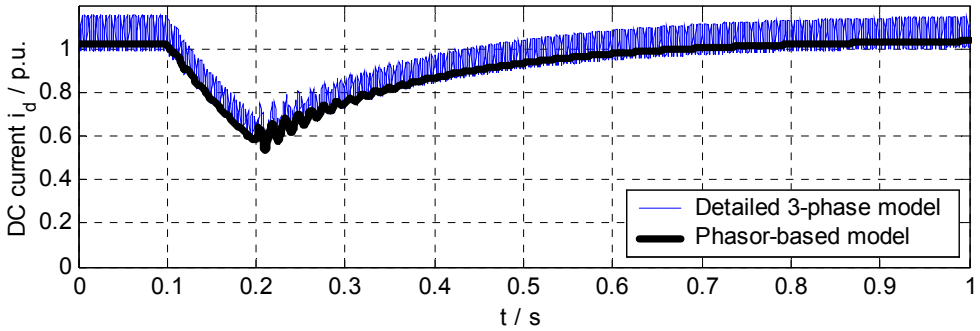


Figure 2: DC current response for a –5% step change of the mains voltage at t_1 = 0.1 s and a -10° step change of the firing angle α at t_2 = 0.2 s.

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[1] A. M. Stankovic, P. Mattavelli, V. Caliskan, G. C. Verghese, "Modeling and analysis of FACTS devices with dynamic phasors", IEEE proceedings of the PES winter meeting, 2000, Vol. 2, pp. 1440-1446.

[2] W. Hammer, "Dynamic modelling of HVDC converters", proceedings of the 9th European conference on power electronics and applications, Graz, 2001.

3.3 Publications and reports

Note: Publications can be downloaded from Internet: http://www.eeh.ee.ethz.ch

Christian Schaffner
“An internet-based load flow visualization software for education in power engineering”, IEEE Power Engineering Society, winter meeting, New York, USA,
27 – 31 January, 2002

Ch. Schaffner, G. Andersson
”Use of facts devices for congestion management in a liberalized electricity market”, VIII SEPOPE, Brasilia, Brazil, invited paper SP-009
19 - 23 May, 2002

N. Dizdarevic, S. Tesnjak, G. Andersson
“Composite load sensitivity in voltage stability problem solved by unified power flow controller”, proceedings of PSCC'02, Sevilla, Spain, Session PS38, Paper 4,
24 - 28 June 2002

N. Dizdarevic, S. Tesnjak, G. Andersson
“Converter rating powers of unified power flow controller”, proceedings of IEEE PES Summer Meeting, Chicago,
21 - 25 July 2002

Ch. Rehtanz, M. Larsson, M. Zima, M. Kaba, J. Bertsch
“System for wide area protection, control and optimisation based on phasor measurements“, Power systems and communication systems infrastructures for the future, Beijing,
September 2002

A. Karpatchev, G. Andersson, H . Glavitsch
“Increased transmission capacity by forced symmetrization”, proceedings of IEEE T&D Exhibition and Conference, Yokohama, Japan,
6 - 10 October 2002
G. Andersson (editor and author of two chapters)
”On voltage and power stability in AC/DC systems”, Cigré WG 14.05 Paris 2002, Paris, France,
29 August 2002

Christian Schaffner, Jean-Samuel Hentz
“Assessing FACTS investments in a liberalised electricity market”, Medpower 2002, Athens, Greece,
4 – 6 November 2002
Marek Zima

"Special protection schemes in electric power systems", Literature Survey Report, Zürich, 2002

G. Andersson (member)
"Definition and classification of power system stability", IEEE/CIGRE joint task force on stability terms and definitions, 2002

3.4 Conferences and visits

A. Karpatchev
Handel an der EEX
(Trading at the European Energy Exchange)
NOK, Baden, Switzerland, 14 January 2002

A. Karpatchev
ETG: Netzleittechnik und Qualtitätsnachweis in der Versorgung
(Power System control and quality verification of the supply)
Bern, Switzerland, 22.January 2002

G. Andersson
Meeting of Swedish National Council for Nuclear Waste
Stockholm, Sweden, 23 January 2002,

G.Andersson, W. Hammer, Ch. Schaffner
IEEE Power Engineering Society, Winter Meeting 2002
New York, USA, 27–31 January 2002

G.Andersson
Visit as departmental academic advisor to Polytechnic University of Hong Kong, Hong Kong, 4-8 March 2002

G. Andersson
Visit to ELTRA, discussions on multi-infeed HVDC
Fredericia, Denmark, 26 March 2002

Ch. Schaffner
VIII Sepope
Brasilia, Brazil, 19-23 May 2002
Ch. Schaffner

G. Andersson
IEEE/PES Fellow Committee
Worcester, USA, 01-05 June.2002

J. Allmeling
IEEE, 33rd Power Electronics Specialists Conference
Cairns, Australia, 23-27 June 2002

G. Andersson, M. Zima
IEEE Power Engineering Summer Meeting,
Chicago, USA, 20-26 July 2002

G. Andersson
14th Power Systems Computation Conference
Sevilla, Spain, 24 July 2002

G. Andersson
CIGRE SC 14 Meeting
Paris, France, 29 August 2002

G. Andersson
Evaluation of electra research programme
Stockholm, Sweden, 2-6 September 2002

G. Andersson
External examiner of PhD exam at the Royal Institute of Technology
Stockholm, Sweden, 23 September 2002

G. Koeppel
2nd International Symposium on Distributed Generation: Power System and Market Aspects
Stockholm, Sweden, 2-4 October 2002

A. Karpatchev
IEEE/PES Transmission and Distribution Conference and Exhibition 2002, Asia Pacific
Yokohama, Japan, 06-10 October 2002

G. Andersson
Meeting of Swedish National Council for Nuclear Waste
Stockholm, Sweden, 22 October 2002

G. Andersson
External examiner of PhD exam, University of Liège
Liège, Belgium, 28 October 2002

Ch. Schaffner
Med Power 2002 Conference
Athen, Grece, 4-6 November 2002

Th. Krause
Wettbewerb versus Sicherheit in der Stromversorgung, 40. Fachtagung der Österreichischen Gesellschaft für Energietechnik ÖVE
(Competition versus security of the energy supply)
Wien, Österreich, 7-11 November 2002

G. Andersson
PSCC'05 Technical Programme Commitee Meeting
Mannheim, Germany, 11 November 2002

G. Andersson
Visit to ABB Corporate Research
Västeras, Sweden, 2 December 2002

G. Andersson
Visit to department of electrical engineering, Technical University of Delft
Delft, Belgium, 13 December 2002

External visitors

Prof. D. Hill, City University of Hong Kong
19 June 2002

Prof. K. David, Prof. W. Chung, Prof. C. Cheng, Hong Kong Polytechnic University
04-05 July 2002

Prof. E. Handschin, University of Dortmund
5 December 2002

Prof. P. Marannino, University of Pavia
10-11 December.2002

3.5 Presentations and seminars

3.5.1 Seminars at ETH

PSCC/TPC meeting at ETH
13-15 February 2002

Robust control of complex systems
Prof. D.J. Hill, City University of Hong Kong
19 June 2002

BFE-Programm Elektrizität (Übertragung und Verteilung)
9. Trendwatching/Begleitgruppen-Sitzung
Lecture by Prof. E. Handschin: Intergration of dispersed generation in power systems
5 December 2002

Research activities in power systems at University of Pavia
Prof. P. Marannino, University of Pavia
11 December 2002

3.5.2 Presentations by PSL personnel

G. Andersson

Future role of universities
Hong-Kong Polytechnic University
6 March 2002

Analysis of multi-infeed HVDC systems
ELTRA, Fredericia, Denmark
26 March 2002

Research in power systems at ETH
ABB Corporate Research, Västeräs, Sweden
2 December 2002

3.6 Colloquia "Aktuelle Probleme der Energietechnik"

"Informationstechnik und innovative Komponenten zur Erhöhung der Übertragungskapazität elekrtischer Energieübertragungsnetze"
Dr.-Ing. Christian Rehtanz, ABB Schweiz AG – Corporate Research, Baden, Schweiz
07 May 2002

„Innovation in der elektrischen Energieversorgung am Beispiel von Internettechnologien"
Dr.-Ing. Christian Rehtanz, ABB Schweiz AG – Corporate Research, Baden, Schweiz
26 November 2002