TOWARDS FUTURE ELECTRICITY NETWORKS

Jahresbericht 2007

Autor und Koautoren	Antonis Papaemmanouil / Göran Andersson
beauftragte Institution	ETH Zürich - Power Systems Laboratory
Adresse	Physikstrasse 3, CH-8092, Zürich
Telefon, E-mail, Internetadresse	044 632 6904, papaemmanouil@eeh.ee.ethz.ch, http://www.eeh.ee.ethz.ch/psl/
BFE Projekt-/Vertrag-Nummer	102292 / 152898
BFE-Projektleiter	Dr. Thilo Krause
Dauer des Projekts (von – bis)	01.09.2007 – 31.08.2007
Datum	30.11.2007

ZUSAMMENFASSUNG

This is the first Annual Report within the framework of the project "Towards Future Electricity Networks" which is ongoing at the Power Systems Laboratory of ETH Zurich. Since the beginning of the project our work has been focused on the following:

- Analysis of the European interconnected electric power grid including market analysis
- Development of a market based Optimal Power Flow (OPF) considering multi-objective optimisation
- Study of different way to internalize external costs

In the beginning of December a first project meeting was held at Chalmers University of Technology in Gothenburg where plans for collaboration were discussed and the concrete next steps were agreed upon. As themes for collaborations combined generation and transmission expansion planning and forecasts of the future load growth in Europe were identified.

.

Projektbeschreibung und Ziele

The European electricity system is undergoing, and will also in the future undergo, significant changes due to new requirements concerning environment, economy, security of supply, and technology. These new requirements will have implications both for the power production, i.e. generators, and for the transmission and distribution networks can be summarized in [1]:

- Security of supply
- Environmental compatibility
- Economic viability

Traditionally the long term planning and analysis of electric power systems has put a lot of emphasis on the power production side of the electric power system. Quite often the main purpose has been to show that the annual energy balance be satisfied, and different expansion plans have been evaluated. This is still an important part of the power production planning, but the above requirements in Europe and other places in the world call for new methods and tools to analyze the development of the electricity system, including the transmission and distribution systems.

The overall goal of this project is to develop an analysis and planning tool that takes into account the above discussed considerations. More explicitly the tool should, in addition to standard power planning tools, embrace

- Power Plants of the Future
- Load growth in the system
- Power Transmission System
- Indirect costs caused by the electric power system
- Environmental and Societal standards

From a Swiss perspective this project is particularly of interest of the following reasons:

1. The transmission capacity between Switzerland and Germany, and also the capacity between Switzerland are often exhausted and transmission congestion management has to be implemented to distribute the capacity among the different actors.
2. The shortage of power in the Swiss system forecasted by numerous studies, often referred to as the “Stromlücke” will be analysed from a European perspective. With the tools and models to be developed it can be seen if this is a specific Swiss problem or other regions/countries will face similar situations.
3. The hydro power plants with storage will in the future play an important role as balancing and regulating power. This opens new possibilities for the Swiss hydro power that can be further studied and analysed in the project.

According to the project, the pathway to the future electricity networks crosses miscellaneous energy policies and strategies, generation forms and transmission constraints as depicted in the figure below (Fig. 1).

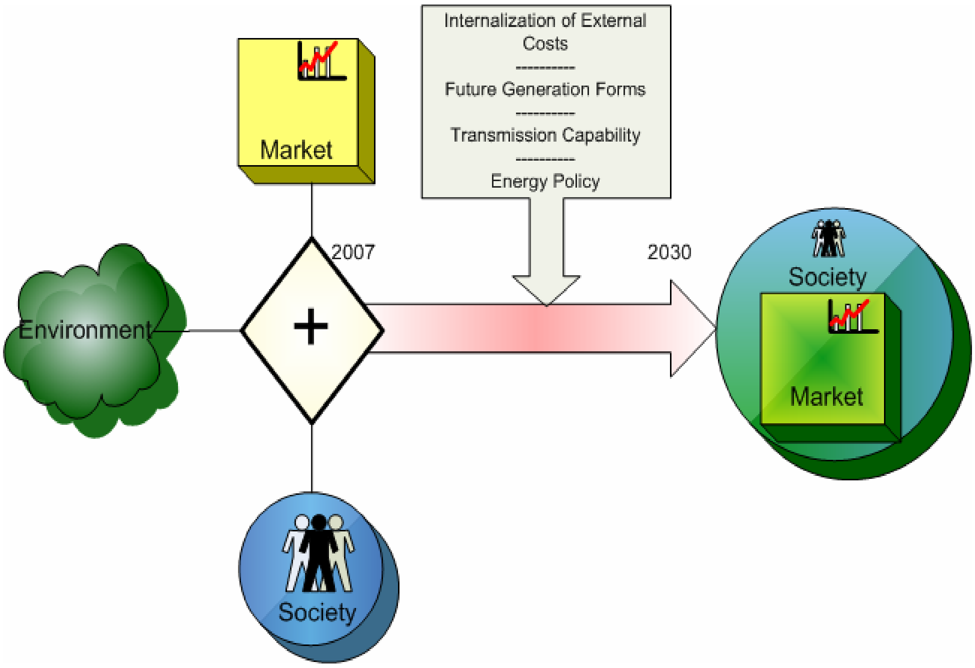

Fig. 1 Pathway to the future electricity networks state

Lösungsansatz

The suitable method concerning our investigations considered to be the Optimal Power Flow (OPF) and the specific form of OPF to be developed here is called **Sustainability based OPF (SOPF)**, which is described below.

Sustainability based optimal power flow (SOPF): an optimal power flow in respect of external costs in production as well as of transmission constraints, for a social welfare analysis in order to take into account not only economic criteria, but also criteria of environmental and societal prosperity and grid security issues.

The aggregated characteristics of the SOPF are:

- Multi-criteria optimization (economy, environment, security)

  Sensitivity analysis using weighting factors and trade-off curves
- Inclusion of internal and external costs for each generation technology
- Simulation of market behaviour
- Consideration of topological grid issues and losses

An integral part of the project is the collaboration with Chalmers University of Technology. At Chalmers a project is carried out where the focus is on the future power generation system of Europe. A very detailed and complete data base is developed over the current power plants in the European system and different scenarios for the evolvement of the power generation capabilities over the next decades are developed. Special considerations in these scenarios are given to the CO_2 emissions of the power plants. A very fruitful collaboration with the group at Chalmers is foreseen.

Durchgeführte Arbeiten und erreichte Ergebnisse

Since the beginning of the project, the following has been done or is ongoing.

As the interconnections within the European energy system were built to increase the reliability and the security of the system, which means that the interconnections were not dimensioned for continuous bulk power transfer required by the current market situation, congestions and outages are more and more frequent [2]. As a consequence most often not only new generation is needed but also new transmission capacity to support the extra generation capacity. Furthermore, a conclusion of the work at Chalmers is that there are very few physical locations available for new power plants in Europe, basically the sites with existing power plants, and with new load centers growing up new transmission capacity is required. It should be pointed out that enhanced transmission capacity does not necessarily mean that new transmission lines are built; FACTS devices and other new technologies could also be an option to increase the power rating of existing lines. It should also be noted that it has been claimed that regulatory failures are responsible for congestions many cases, [3].

In order to be able to evaluate the future investments in generation and transmission over a time horizon of 30 – 40 years, a simplified model, but still realistic, of the European interconnected network is needed. For that reason data about the energy transfers between the countries have been gathered to identify the weak points within the transmission network, and to evaluate the investments potential. The target is the creation of a 380 - 400KV transmission lines database with transmission lines characteristics, capacities and locations for the UCTE grid. Also the interconnections with neighboring systems, particularly with NORDEL are of importance and should be included. The main sources are the UCTE [4], the European Transmission System Operators (ETSO) [5], the national TSOs, and the European Commission [6]. An approximate model of the European Interconnected System for studying the effects of cross-border power transfers has been developed by other authors [7], but as real data are hard to obtain due to confidentiality reasons certain assumptions had to be made in this model. This model is a good basis, but for this project more accurate and reliable models are needed. The aim is to further develop and update this model so that realistic scenarios of the future European transmission system can be studied and analyzed. This will be elaborated in a report to be finished in the first months of 2008.

An Optimal Power Flow based on market behavior, [8], has been developed using linear functions for supply and demand [9] in order topological issues regarding new lines, new generation and impacts of congestion in generation to be studied. This is a good start but deemed insufficient for the new conditions in the European electricity system. Therefore, a new concept regarding topological issues, the so called degree of independency, has been developed in the project. The degree of independency is a quantitative indicator of the situation of the network. That means that when the network is overstressed the independencies between the nodes are very small.

The degree of independency is defined as follows:

$$A_{ij} = \frac{n_{ij}}{N_i}, i, j = 1, 2, 3 \ldots k_{nodes}$$

$$n_{ij} = \frac{NTC_{ij} - \left|Pf_{ij}\right|}{NTC_{ij}}, NTC_{ij} \neq 0$$

$$N_i = \frac{D_i - \mathrm{P}_i}{D_i}, D_i \neq P_i, D \neq 0$$

In a complex meshed network like the European interconnected network, the operation of every node (country) affects the others. Under the acceptance that every node is participating in a common market, all nodes (countries) are dependent or not completely independent from each other. For a network with k nodes the matrix of independency is formulated below:

$$\begin{pmatrix} A_{11} & \cdots & A_{1k} \\ \vdots & \ddots & \vdots \\ A_{k1} & \cdots & A_{kk} \end{pmatrix}, A_{kk} = \frac{1}{N_k}$$

For nodes that are not connected the independency is equal to the inverted capability of the node to cover its own demand.

The independency between two interconnected production and load nodes (Fig.2), which are operating under market conditions, is not only dependent on the energy balance but also a dependent on transmission capability. The role of the transmission grid is believed to be play a much more important role in the future European system due to political initiatives, e.g. by the European Commission, and by technical reasons.

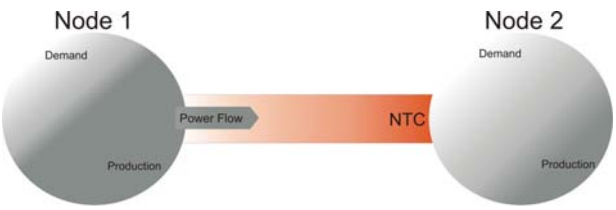

Fig.2 Bilateral Independency

Below the results for a small network consisting of three nodes (Fig. 3) are presented (Fig. 4).

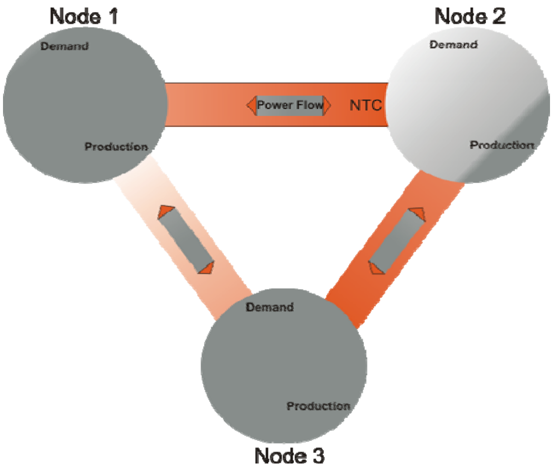

Fig. 3 conceptional network

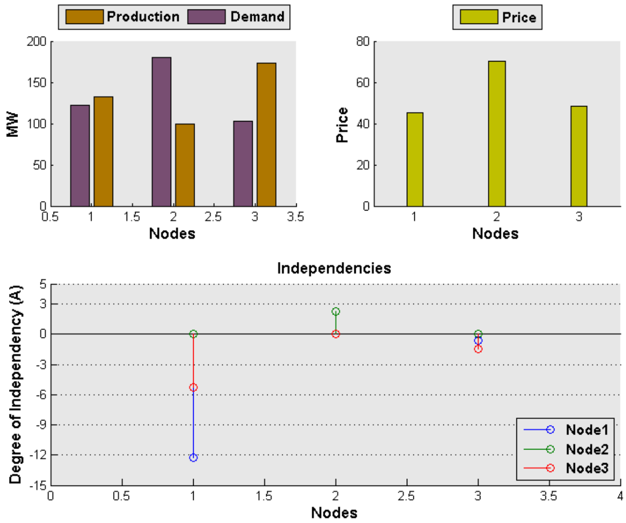

Fig. 4 Nodal prices, demand, production and independencies

Another concept that has been studied during this period is the internalization of external costs. The energy production, as all other industrial activities, is associated with external costs that are imposed on others [10], and are usually not included in the market price. In the energy sector the most considerable cause of negative effects, which affects the external costs, is the usage of fossil fuels in energy production. Fossil fuel fired power plants produce dangerous and harmful gases (CO_2, SO_2, NO_x, etc.) which have a negative impact on the environment and on the human health. In [11] each generation technology is characterised by a value of damage, which is a monetary value of the imposed damage. When external costs are internalized, [12][13], then the marginal cost function of certain generation technologies will be changed, namely the slope will be increased in case that external costs are referred to CO_2 emissions, as the figure below describes (Fig.3). That means that increasing prices for conventional generation forms, new technologies are promoted and new investments are initiated. In order to dispose of a simplified indicator for monetarizing external costs, one idea would be to consider only the price for CO_2 emissions. Another way to take external costs into account would be to impose limits (caps) on e.g. CO_2 emissions. This would be further investigated.

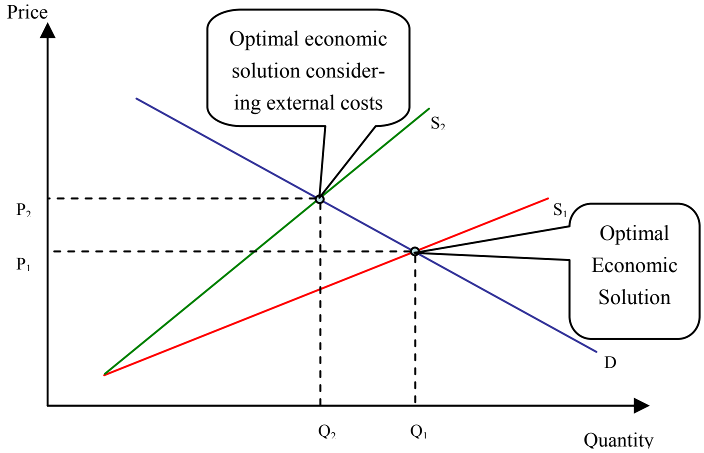

Fig. 5 Internalization of External Costs

As the main target of the project is to combine environmental, societal and economical criteria in the optimal operation, the first steps concerning multiobjective optimization has also been done. In the literature miscellaneous multiobjetive optimization methods can be found [14], most of them applied to optimization problems of two objectives [15][16]. Using a weighting factor analysis, the dependence of the congestion costs (Fig. 6 left hand side) as well as of the social welfare (Fig. 6 right hand side) on the transmission security margin and external costs has been studied for a small network. As shown the congestion costs are very high for strictly secure networks but as the external costs are being internalized, the production reduces and the lines are not congested any more. The problem is that while the production prices increase the social welfare decreases, which is not desired. The trade-off curves will help us to decide the optimal operational level while the external costs cannot be assumed accurately and the security margins can vary in a yearly or seasonal basis.

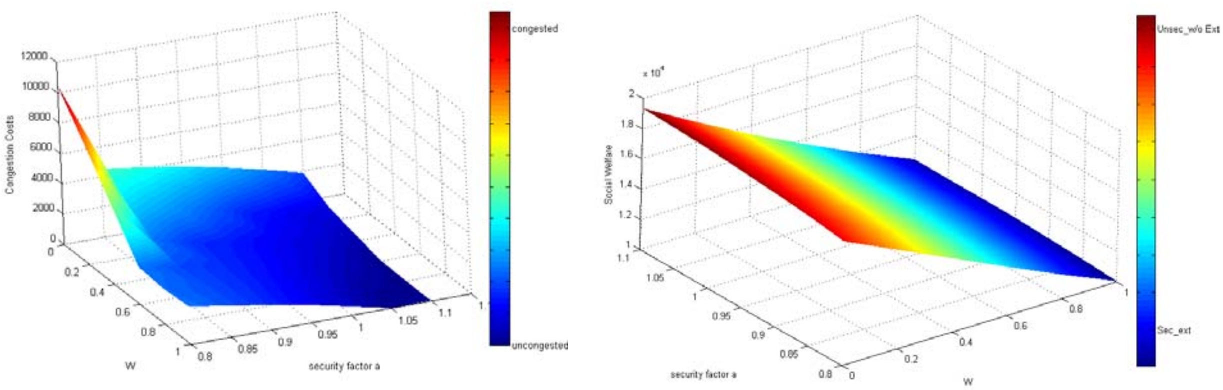

Fig. 6 Weighting factor analysis, see text

Bewertung 2007

The targets for the first phase of the project are:

- ► to analyse the European Interconnected System and gather useful data needed to synthesize a simplified model of the European network.
- ► to develop a DC Optimal Power Flow simulating market behaviour and topological issues
- ► to internalize external costs in generation production
- ► to combine the required operational criteria in a multiobjective optimization

The second and third target has so far been reached. Work is on-going concerning the two other targets and promising results have been obtained. The results of items two and three will be presented in a report to be issued in beginning of 2008.

Ausblick 2008

In 2008 a crucial issue will be to finalize the 380 – 400kV transmission lines data base including all needed data. Besides the improvement of the DC Optimal Power Flow the transmission lines characteristics are of substantial interest allowing us to include transmission losses into the optimization process. The evolution of the multiobjective optimization introducing quantitative indicators for system operation and sustainability is also a desired target as well as the appliance of the mentioned achievements to real systems.

Referenzen

[1] Commission of the European Communities, *An Energy Policy for Europe,* January 2007.

[2] DG TREN, *Analysis of Electricity Network Capacities and Identification of Congestion*, December 2001.

[3] John Bower, *Electricity Infrastructure & Security of Supply: Should EU Governments Invest in Transmission Capacity?*, Oxford Institute for Energy Studies, March 2004.

[4] UCTE, *Union for the Co-ordination of Transmission of Electricity*, http://www.ucte.org

[5] European Transmission System Operators, ETSO, http://www.etso-net.org/

[6] Commission of the European Communities*, Implementation Report, Prospects for the internal gas and electricity market*, January 2007.

[7] Qiong Zhou, Bialek, J.W., *Approximate model of European interconnected system as a benchmark system to study effects of cross-border trades*, IEEE Transactions on Power Systems, Vol. 20, No. 2, May 2005.

[8] Pierre- Francois D. Quet *et al*., *Analysis of Coordinated Multilateral Trades*, HICSS, 2000.

[9] C. A. Berry *et al., Understanding how market power can arise in network competition: a game theoretic approach*, Elsevier, September 1999.

[10] European Commission, *External costs, Research results on socio-environmental damages due to electricity and transport*, 2003.

[11] Stefan Hirschberg, *Comparative Perspective on Current and Future Energy Supply*, ETH Zurich-Seminar, May 2007.

[12] Jeroen Van Laer *et al., Summary: Internalisation of External Costs of Electricity Production in Flanders (Belgium)*.

[13] Peter Rafaj*,* Socrates Kypreos, *Internalisation of external cost in the power generation sector: Analysis with Global Multiregional MARKAL model*, Paper presented to the International Energy Workshop (IEW), 2003.

[14] Jared L. Cohon, *Multiobjective Programming and Planning*, Dover Publications Inc., 2003.

[15] Federico Milano, Claudio Canizares, Marco Invernizzi, *Multiobjective Optimization for Pricing System Security in Electricity Markets*, IEEE Transactions on Power Systems, Vol. 18, No. 2, May 2003.

[16] Mesut Muslu, *Economic Dispatch with environmental considerations tradeoff curves and emission reduction rates*, Elsevier, October 2002.