Berichte aus den Arbeitsgruppen

AG „Praxis der Mathematischen Optimierung“

Die 78. Sitzung der AG *Praxis der Mathematischen Optimierung* fand am 19. und 20. April 2007 unter dem Titel „Stochastische Optimierung in der Energiewirtschaft“ im Dorint Hotel Aachen City statt. Dies wurde ermöglicht durch die großzügige finanzielle Unterstützung und das Engagement des Gastgebers ProCom GmbH (Aachen). Die Sitzung wurde gemeinsam mit Dr. Max Scheidt (ProCom GmbH) vorbereitet und organisiert. Während der Vorbereitungszeit und der gesamten Veranstaltung war deutlich spürbar, dass die gastgebende Firma sowohl tiefe Branchenkenntnisse als auch ein ausgezeichnetes Know-how nicht nur im Umfeld der Energieoptimierung, sondern in verschiedenen Gebieten der praxisrelevanten mathematischen Optimierung hat – dies gekoppelt mit dem positivem unternehmerischen Sinn eines mittelständigen Familienunternehmens mit nunmehr 75 Mitarbeitern und Mitarbeiterinnen. Ein erfreuliches Faktum für die GOR und unsere Arbeitsgruppe, dass die Methoden, von denen wir glauben, dass sie in der Praxis sehr nützlich zum Einsatz kommen sollten, nicht nur bei den üblichen Verdächtigen, d.h. den großen Industriefirmen und Banken, sondern auch bei kleineren und mittleren Unternehmungen Einzug gehalten haben.

An dieser Sitzung, die eher das Format einer wissenschaftlichen Konferenz hatte, nahmen fast 70 Teilnehmer und Teilnehmerinnen aus Brasilien, Dänemark, Finnland, Holland, Norwegen, Schweiz, USA und Deutschland teil. Dabei überwog der Anteil von Anmeldungen aus der Industrie und Softwareanbietern gegenüber denen aus Forschungs- und Hochschulinstituten. Die 15 Vorträge befassten sich mit den wichtigsten Problemstellungen und Anwendungen der stochastischen Optimierung in der Energiewirtschaft und gaben einen interessanten, die aktuellen Anforderungen, Möglichkeiten und Restriktionen wiedergebenden Überblick über die „Stochastische Optimierung in der Energiewirtschaft“. Die verschiedenen Teilaspekte des Gesamtthemas, die behandelt wurden, erstreckten sich von der Integration der Windkraft, Fehlerketten in Kernkraftwerken und dem Scheduling von Wasserkraftwerken über die Risikobetrachtung bei Handelsaktivitäten bis hin zu verschiedenen Softwaresystemen, die stochastische Optimierungsmethoden unterstützen.

Die rege Teilnahme an dieser Veranstaltung deckt sich mit der Feststellung, dass heutzutage die Energiewirtschaft ohne Einsatz der mathematischen Optimierung nicht mehr denkbar ist. Dabei ist vor allem die stochastische Optimierung von Bedeutung, denn der moderne liberalisierte Energiemarkt bringt eine Menge von Risiko und Unsicherheiten mit sich, die beim Entscheiden berücksichtigt werden müssen, insbesondere für mittel- und langfristige Planungen und Vorhersagen.

Die Optimierung der Betriebsplanungsprozesse mit Hilfe von IT und quantitativen Methoden ist somit in der Energiewirtschaft heute ein De-facto-Industriestandard.

Nach der Öffnung der Strommärkte stehen die Energieversorgungsunternehmen vor neuen Risiken und zugleich vor neuen Chancen. Der ex ante unsichere Marktpreis bestimmt zunehmend den Umfang der eigenen Energieerzeugung. Hatte die klassische Kraftwerkseinsatzplanung noch die Bestimmung des kostenoptimalen Produktionsplans zum Ziel, ergeben sich in liberalisierten Energiemärkten mittels einer ganzheitlichen Betrachtung des Portfolios aus Kraftwerken und Handel vielfältige Chancen zur Verbesserung der Ertragslage.

Marktgängige Softwaresysteme verfügen heute über die Möglichkeit, das gesamte Portfolio aus Erzeugungs- und Handelskomponenten abzubilden. Damit wird die Transparenz des gesamten Planungsprozesses verbessert. Zugleich werden Risiken sichtbar, die überwacht und abgesichert werden müssen. Risiken und Unsicherheiten werden aber in der Regel in heutigen Optimierungssystemen nicht explizit berücksichtigt. Im deterministischen Ansatz werden alle

Informationen als sicher betrachtet. Tatsächlich herrschen relative Unsicherheiten bezüglich verschiedenster exogener Faktoren, wie z. B. bezüglich des Preises im Spot- und Terminhandel, der Lastprognose, der erwarteten Windkrafteinspeisung, des Wasserdargebots und der Kraftwerksverfügbarkeit.

Zur Herleitung robuster Entscheidungen bieten sich im mittel- bis langfristigen Bereich grundsätzlich stochastische Optimierungsverfahren an. Jedoch sind diese vielfach noch sehr zeitintensiv in der Berechnung.

Auf der Basis der im Tagungsband veröffentlichten Zusammenfassungen der Vorträge werden diese im Folgenden in der alphabetischen Reihenfolge der ersten Autoren kurz wiedergegeben.

Risikomanagement in der Stromerzeugungs- und Handelsplanung
Boris Bläsig, RWTH Aachen Institute of Power Systems and Power Economics (IAEW),
RWTH Aachen University, Germany

Due to increased cost pressure on power generation and trading companies, caused by operation under market conditions, a cost-efficient management of the risks becomes more important. As a result of the liberalization of the markets for electrical energy companies are exposed to higher uncertainties within power generation and trading planning, e.g. the volatility of the electrical energy prices and of the prices for primary energies especially natural gas. Additionally, bankruptcies of companies in the energy sector, e.g. ENRON or TXU Europe, have shown that the loss of trading partners can cause a major disprofit, if not hedged appropriately. Together with risk management regulations, the need for risk management is increasing. The objective of this work is the development of adequate methods for generation and trading planning, i.e. maximization of the contribution margin, taking the risks into account. The risk management process comprises identification and analysis of the risks and their impacts as well as the control of the occurring risks. In this work two approaches, a separate ex-post and an integrated risk management method, have been developed using appropriate algorithms. The ex-post approach keeps the schedule of the power plants from the generation planning and optimizes the trading decisions by means of risk management concepts. The integrated approach yields the optimal generation and trading decision in terms of maximal contribution margin as well as minimal risk in one step. The multicriterial optimization of the maximal contribution margin as well as the minimal risk is implemented either by risk constraints which restrict the risk to a maximum or by utility functions which map the combination of contribution margin and risk to a single criterion. The investigations of two different systems, a hydraulic and a thermal dominated system, demonstrate the results of the different risk management methods. The integrated method illustrates that redispatch of hydraulic power plants can lower the risk. This is due to the long term time-coupling constraints of the storage capabilities of hydraulic power plants. The redispatch of thermal power plants does not allow to control the risks. Investigation of the effectiveness of the risk management methods using different power markets show improvement of the risk control participating in these markets compared to the redispatch. Entering markets for weather and primary energy derivatives reduces the risk of the portfolio. The investigations show the tradeoff between contribution margin and risk. Depending on the risk aversion of the company the risk can be reduced for the trade-off of a lower contribution margin. Comparing the results of the ex-post and the integrated risk management, it can be summarized that the integrated approach is more effective. This is due to the advantage of the integrated risk management method using both redispatch of the power plants for risk management reasons and for adaptation to changed trading decisions.

Stochastic Optimization: Solvers and Tools
Michael Bussieck, GAMS GmbH, Cologne, Germany

With all the uncertainty in price, demand and availability of production capacity there is considerable demand for stochastic optimization in operational, tactical and strategical planning in the energy sector. Nevertheless, there exists a fairly small number of commercial applications building on stochastic optimization techniques. Available stochastic optimization software tools have been reviewed. There is a zoo of tools, including modeling software, scenario management tools, and stochastic optimization solvers that attract different crowds of users. Bussieck presented and analyzed a sample of these tools from each category. The variety and complexity make a concise analysis of these tools difficult for non-experts which limit their spread and therefore the dissemination of stochastic optimization. From a practical perspective, stochastic optimization has not reached its full potential. Some of the community's efforts could be channeled into making stochastic optimization available to a broader audience by providing instructive and non-trivial examples. Such examples need to allow users to reproduce and modify these experiments in their own computational environment.

Scenario Tree Approximation and Risk Aversion Strategies for Stochastic Optimization of Electricity Production and Trading
A. Eichhorn, H. Heitsch & W. Roemisch, Dept. of Mathematics, Humboldt University, Berlin

Stochastic optimization techniques are highly relevant for applications in electricity production and trading since, in particular after the deregulations of many electricity markets, there is a high number of uncertainty factors (e.g., demand, spot prices) to be considered that can be described reasonably by statistical models. In this talk, two aspects of this approach were highlighted: scenario tree approximation and risk aversion. The former is a procedure to replace a general statistical model (probability distribution), which makes the optimization problem intractable, suitably by a finite discrete distribution (scenarios). This is typically an indispensable first step towards a solution of a stochastic optimization model. On the other hand, this is a highly sensitive concern, in particular if dynamic decision structures are involved (multistage stochastic programming). Then, the approximate distribution must exhibit tree structure. Moreover, it is of interest to get by with a moderate number of scenarios to have the resulting problem tractable. In any case, it has to be relied on suitably stability results to ensure that the obtained results are indeed related to the original (infinite dimensional) problem. These stability results involve probability distances and, for the multistage case, a filtration distance that evaluates the information increase over time. Eichhorn et al. presented respective approximation schemes relying on Monte Carlo sampling and scenario reduction and combining techniques. The second topic of this talk was risk aversion. Namely, the authors presented the approach of polyhedral risk measures which are given as (the optimal values of) certain simple stochastic programs. Well-known risk measures such as CVaR and expected polyhedral utility belong to this class and, moreover, multi period risk measures for multistage stochastic programs are suggested. For stochastic programs incorporating polyhedral risk measures it has been shown that numerical tractability as well as stability results known for classical (non-risk-averse) stochastic programs remain valid. In particular, the same scenario approximation methods can be used. Finally, they presented illustrative numerical results from an electricity portfolio optimization model for a municipal power utility.

Current and Future Challenges for Production Planning Tools
Torben Franch, ProCom GmbH, Aachen, Germany

Over the past ten years, production planning in power and heat generation has changed dramatically. In the good old days of cost pricing, production planning was mainly a matter of securing efficient use of fuels. The deregulation of energy markets has changed that fundamentally. Volatile power prices, fluctuating fuel prices, competition and new market platforms has increased the complexity of production planning and most importantly, eliminated the certainty of the financial results. Poor production planning today leads to inferior financial results. Over the past decade, new tools and methods have been developed to support and assist production planning leading to improved quality and hence profitability. However, compared to e.g. financial trading, the available tools still have some

development to undertake before production planning tools and methods are effectively meeting the commercial challenges of today's energy markets.

Valuation of Electricity Swing Options by Multistage Stochastic Programming
Karl Frauendorfer, Institut für Operations Research und Computational Finance, St. Gallen, Switzerland

Electricity swing options are American-style path-dependent power derivatives. Frauendorfer considered an electricity market driven by several exogenous risk factors and formulated the pricing problem for a class of swing option contracts with energy and power limits as well as ramping constraints. Efficient numerical solution of the arising multistage stochastic program requires aggregation of decision stages, discretization of the probability space, and reparameterization of the decision space. He reported on insightful numerical results and discussed analytically tractable limiting cases.

Stochastic Programming Models in an Energy Trading House
Nicole Gröwe-Kuska, Vattenfall Trading Services GmbH, Hamburg, Germany

The stochastic programming models of interest for a trading house are mainly determined by the business model of the power company, by the served power markets and products and last but not least by the division of labour at the trading house.

After highlighting the role of Vattenfall Trading Services in the value chain of the Vattenfall goup, the author discussed in detail stochastic programming models for portfolio and dispatch management.

Stochastic model of the German Electricity System

Nina Heitmann, Max-Planck-Institut für Plasmaphysik Gruppe für Energie- und Systemstudien, Garching, Germany

The German electricity system is expected to undergo major transitions in the future. Drivers of the expected change are the political decision to phase out nuclear energy and the confession to fulfil the Kyoto protocol. A detailed discussion of the possible future options, including increased application of renewable energies, especially wind energy, and require modeling tools capable to describe the characteristics of the new technologies. Heitmann presented a model of the German Electricity System which is able to describe the system in arbitrary spatial and temporal resolution. Due to the high temporal resolution the model generator is particularly suitable to analyse the influence of uncertain and fluctuant parameters like the wind supply to the existing electricity System. Germany is represented by 29 knots within Germany and 13 knots of neighbouring countries. Major transmission lines between these knots are modelled in a stylised manner. The model calculates the optimal capacities as well as the energy flows. She discussed stochastic programming options as latest extension of the model generator. The stochastic parameters are the fuel costs. It is also attempted to handle the supply of wind energy in a stochastic way.

Benchmarking of Hydroelectric Stochastic Risk Management Models using Financial Indicators
Niko A. Iliadis, M.V.F. Pereira, S. Granville & R.M. Chabar, Power System Research (PSR) – R&D and Technological Solutions Consulting Company, Rio de Janeiro, Brasil

The objective of this contribution was to present a benchmarking of financial indicators implemented in hydroelectric stochastic risk management models and then propose a formulation of the most appropriate indicator or the SDDP (Stochastic Dual Dynamic Programming) algorithm. The authors presented three model formulations using a tree approach for hydroelectric optimisation using three

procedures for financial risk control: Minimum Revenues (Rmin), Value-at-Risk (VaR) and Conditional VaR (CVaR). According to their properties and their formulation in each model they compared them theoretically based on two criteria: their adequacy for electricity portfolio optimisation subject to risk constraints and the feasibility of their implementation inside the state of the art (SDDP) algorithm appropriate for large scale energy systems. Using numerical examples they verified the statements derived from the theoretical comparison. A hybrid Stochastic Dynamic Programming (SDP) / Stochastic Dual Dynamic Programming (SDDP) formulation is adopted to solve this large-scale optimisation problem. The author proposed a linear CVaR formulation inside the SDDP algorithm using a Lagrangian Relaxation and a post-processing algorithm for the calibration of the relaxed simplex multipliers.

Power sourcing optimization using the stochastic programming functions in AIMMS
Ovidiu Listes & Frans de Rooij, Paragon Decision Technology, The Netherland

Due to uncertain demand and fluctuating future prices, several problems in the current energy market require the solution of stochastic optimization models. Examples include tactical valuation of hedging instruments or strategic power system expansion problems. AIMMS is the advanced modeling environment which presently offers support for automatic formulation of multi-stage stochastic models, starting from existing deterministic formulations. This allows the user to model and solve decision problems under uncertainty, without the need to reformulate the underlying deterministic model. The authors presented an example of an energy application implemented in AIMMS, in which the automatic generation of stochastic models is illustrated. They also reviewed a business case from AREVA T&D Corporation and discuss how AIMMS capabilities for stochastic modelling could be used to such an extensive case.

Hydro Optimisation and Stochastic Modelling
Birger Mo, SINTEF Energy Research, Norway

The paper gave an overview of stochastic optimisation methods for hydro scheduling with special focus on representation of uncertainty based on our Scandinavian experience. The main uncertain variables to the hydro scheduling problem are inflows to the different reservoirs and future market prices. The complexity of a stochastic dynamic optimisation problem depends on the following properties of the problem: the number of stages in the problem, the number of state variables and the number of uncertain variables. For a general hydro scheduling problem there might be a large number of stages, different state variables and different inflows. The practical solution methods applied to the hydro scheduling problem therefore usually consist of an optimisation part and a Monte Carlo type simulation part. There is a strong relationship between different types of stochastic optimisation methods (e.g. Stochastic Dynamic Programming, Stochastic Dual Dynamic Programming (SDDP), Deterministic Equivalents) and the models used to describe uncertainty. The paper described the pros and cons of the different methods applied and corresponding models for the uncertain variables.

Risk Analysis and Optimization Issues in Nuclear Energy
Panos Pardalos, Steffen Rebennack & Victor Yatsenko, University of Florida, Gainesville, USA

One of the main problems for nuclear power plants is the evaluation of risk. Different mathematical formulations of failure probability evaluations for the chains of technical elements of nuclear power plants have been proposed. But such calculations require the probability of an initial event which serve as origin of the chain of failures. To know such initial probabilities is a difficult problem. The main reason is the lack of information for such large working technical systems. In these cases, one of the research tasks becomes the modeling of initial critical states and calculation of initial probabilities. In technical systems with advanced technology, such as nuclear plants, there still exist some hidden

accidents. An analysis of such accidents is focused on active failures that initiate the occurrence of the main accident. However, active failures could not cause the accident by itself, because several barriers or protective systems are installed to prevent its expansion in such an advanced system. In this case, for an abnormal event which can lead to severe accident, the failure of its protective system must be accompanied with it. This situation occurs if the protective system fails without notice before the accident. Thus, the latent failure condition, whose occurrence caused by the accident, must be considered in the prevention of accidents. Analysis of such problems has shown that processes in nuclear power plants need a system analysis of physical concepts. In this talk, the authors presented a qualitative description of the physical processes in nuclear power plants and describe possible failure chains. They concentrated on analysis of existing concepts of failure detections, concepts of probability calculation, and numerical results about development failures in a collection of technical elements.

Alternatives of Risk Modeling in Stochastic Programs for Power Management
Rüdiger Schultz, Institut für Mathematik, Universität Duisburg-Essen, Germany

The author considered risk aversion in stochastic integer programming by minimizing mean-risk objectives or by including stochastic dominance constraints. For both situations he presented structured mixed-integer linear programming equivalents in case the underlying probability spaces are finite. He then turned the attention to decomposition methods taylored to these MILPs. Superiority of these methods over application of general purpose MILP solvers was demonstrated at applications in power management.

Stochastic Programming Strategies for Flexible Nomination Contracts
Marc Steinbach, Institut für Angewandte Mathematik, Universität Hannover, Germany

Flexible nomination contracts are energy derivatives designed as hedging instruments against spot price risk. The holder obtains the right to purchase a specified amount of energy at a predetermined price during a certain period of time. His consumption process is flexible within agreed limits, yielding a payoff structure that depends on the exercise strategy. Because of uncertain future prices, valuating a swing option thus requires the solution of a stochastic dynamic optimization problem. Based on a paper by Haarbrücker and Kuhn, the author presented suitable stochastic programming models and analyzed the theoretical properties. He also presented solution algorithms that exploit the underlying scenario tree structure, and demonstrate their efficiency with computational results.

Building Solutions for 2-Stage and Multi-Stage Stochastic Linear Programs for Energy Optimization Problems Using Xpress-SP
Alkis Vazacopoulos, Dash Inc., New Jersey, USA

Xpress-SP is a Stochastic Programming tool for solving optimization problems involving uncertainty. Xpress-SP can be used to model and solve problems occurring in Supply Chain Management, Energy, Finance, Transportation, etc., by building uncertainty into the optimization problem in order to hedge against future variability. By incorporating uncertainty into the optimization process, Xpress-SP enables superior management of resources by eliminating the overhead costs of conservative planning, reducing penalties for unmet targets, and achieving higher service levels and profits.
In this talk the author demonstrated how to use the modeling, programming, optimization, and visualization tools available in Xpress-SP to build solutions for stochastic problems. Specifically, he showed how to easily build comprehensive solutions – for both analyses and deployment purposes – in a relatively short time frame using Xpress-SP together with Xpress-IVE, and XAD. The author presented the Scheduling in Hydro-Thermal Plants example from the energy industry. In this problem variations in demand for electricity coupled with start-up and production costs in thermal units and maintenance of pumping levels in hydro units can make power management a challenging task.

Analysis of Wind Integration in Existing Energy Systems – Applying Stochastic Programming Techniques
Christoph Weber, Lehrstuhl für Energiewirtschaft, Universität Duisburg-Essen, Germany

The rise of wind and solar energy as ecological, emission free energy sources has always been accompanied by the question, whether the inherent fluctuations in their production do not make them very poor substitutes of conventional, controllable electricity production from coal, gas and other power plants. Put in other terms, the question is whether their installation, being costly by itself, does not induce further costs necessary for the fluctuating renewables to be able to contribute to the overall power supply system. These costs are often summarised under the general term of integration costs. The contribution aims at developing and applying a unifying framework for analysing integration costs. It thereby emphasizes the need of using stochastic programming for determining integration costs adequately. On a conceptual level the different causalities inducing integration costs for renewables are distinguished. Notably distinction is made between costs of variability and costs of (partial) impredictability. Basic analytical relationships for average and marginal integration costs are derived and it is shown how these may be determined using stochastic programming approaches. The use of repeated rolling planning and the implementation of random forecast errors are shown to be further prerequisites for determining adequately the integration costs. The implementation of these concepts on the example of the WILMAR planning tool is discussed. The integration costs are quantified for a simplified version of the German power system. Thereby it is notably shown, how the conventional generation mix, especially the share of coal- and gas-fired plants, affects the height of the integration costs. A large share of inflexible baseload plants increases the height of the integration costs whereas high variable generation costs in base and shoulder load lead to a reduction of integration costs.

Von Frau Susanne Walter (wl@procom.de, ProCom GmbH) können die Vorträge auch für Nichtteilnehmer auf einer CD zum Preis von 70 EUR erworben werden. Die Beiträge werden in einem im Springer Proceedingsband unter dem Titel *Optimization in the Energy Industry* erscheinen.

Den Teilnehmern wird die Veranstaltung als Ganzes, und insbesondere auch das von Susanne Walter und anderen Mitarbeitern der ProCom GmbH bestens organisierte Abendprogramm (Führung durch die Domschatzkammer, Abendessen in der Aachener Erholungsgesellschaft und schließlich am Freitagabend noch die Besichtigung des Aachener Doms) bestens in Erinnerung bleiben.

Josef Kallrath & Alexander Lavrov