OSCOGEN

Optimisation of Cogeneration Systems in a Competitive Market Environment

NEWSLETTER

Issue 3 June 2002

Editorial

This is the third issue in a series of semi-annual newsletters that report on the progress made in the research project OSCOGEN (Optimisation of Cogeneration Systems in a Competitive Market Environment). The major aim of the project is the development of a comprehensive, to a large extent stochastic, and state-of-the-art prototype model-based tool for the optimal operation of cogeneration plants in liberalised energy markets. OSCOGEN was launched in November 2000 and will be completed in January 2003. It is partially funded by the European Commission (FP5/EESD; Contract No. ENK5-CT-2000-00094), the Swiss Federal Agency for Education and Science (Contract No. BBW 00.0627), and the Slovenian project partner and district heating supplier TE-TOL (Contract No. CEU-BS-1/2001). The present issue covers some basic elements of power exchange spot trading in Europe, the current plans regarding the development of an OSCOGEN bidding tool, the approach taken for heat demand forecasting, and a brief outlook on various actions planned for the near future, including the organisation of a 2-day international OSCOGEN Workshop in Austria scheduled for the end of the year. As in previous issues, a detailed and up-to-date list with the institutions and key contacts involved in the OSCOGEN project has been included at the end of the newsletter. All non-restricted project reports ('Deliverables') and OSCOGEN Discussion Papers available so far, and this and previous issues of the OSCOGEN Newsletter can be downloaded free of charge from the project's website at www.oscogen.ethz.ch. For any remaining questions we kindly invite you to get in touch with us directly.

Reinhard Madlener, Editor-in-Chief
CEPE – Swiss Federal Institutes of Technology
Zurich, Switzerland

Christoph Weber, Project Coordinator
IER – University of Stuttgart
Stuttgart, Germany

Introduction

The OSCOGEN research team organised another very successful two-day project meeting, held 28 Feb – 1 Mar 2002, which was hosted this time by the Centre for Energy Policy and Economics (CEPE) at the Swiss Federal Institute of Technology Zurich (Figure 1).

Figure 1. 6th OSCOGEN project meeting at CEPE, Zurich (28 Feb – 1 Mar 2002)

The Zurich meeting particularly focused on the following issues:

- Refinement of the TEWAG model (introduced in Issue 1 of the OSCOGEN Newsletter)
- Development of a real option unit commitment model with stochastic heat prices
- Power exchange bidding systems in Europe: theoretical and empirical aspects
- Forecasting of heat demand for TE-TOL's heat distribution system
- Enhancement of the genetic algorithm model
- Reporting on the validation phase
- Needs for website updating
- Contributions to the 3rd OSCOGEN Newsletter
- Organisation of the int'l OSCOGEN workshop
- Commitment check-up and planning

Work progress so far (we are in month 20 out of 27 now) has been pretty much according to the plan, with only minor deviations. Several new project reports and discussion papers have been made available via the website, part of which are subject to restricted dissemination, though.

Exchange-Based Spot Market Trading for Electricity in Europe

Because it is of central relevance in the current phase of the OSCOGEN project, in this section we provide a brief introduction on the basic trading mechanisms and products prevalent at the European exchange-based spot markets for electricity. The recently merged EEX/LPX exchange in Germany will receive more attention from us than others, as the products traded and the underlying auction mechanisms there are of particular interest to the OSCOGEN research consortium for the development of a practical bidding tool for CHP operators. A concise overview of other electricity spot market exchanges in Europe, that are either already in place or currently under development, is also included – covering APX in Amsterdam/The Netherlands, EXAA in Graz/Austria, Borzen in Ljubljana/Slovenia, GME in Rome/Italy, Nord Pool in Oslo/ Norway, OMEL in Madrid/Spain, Powernext in Paris/France, and APX UK/UKPX in London/UK.

Overall, the aim of this section is to improve the understanding of how generators can place their bids, and which products they can trade, on the various power exchange spot markets across Europe. In the next section we will then discuss several design issues that need to be addressed for the development of a bidding tool that generates optimal bids for CHP plant operators in liberalised markets – given certain production characteristics and concrete market situations (e.g. in terms of input fuel and electricity spot prices, heat demand). Note that although some power exchanges do offer trade in future markets, the focus within the OSCOGEN project is essentially restricted to the spot market only.

Basic structure of exchange-based spot market power trading

The exchanges normally provide trading in contracts for power delivery during a particular hour of the next day – in so-called *hourly day-ahead markets*.[1] Figure 2 depicts the basic structure of an exchange-based spot market power trading system.

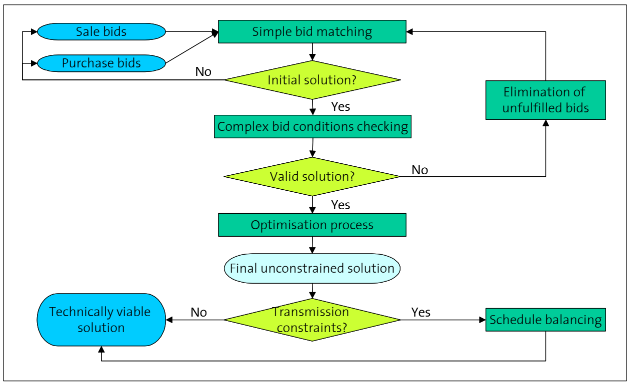

Figure 2. Basic structure of a bidding system

[1] An exception are the UK power exchanges, where half-hour contracts are traded.

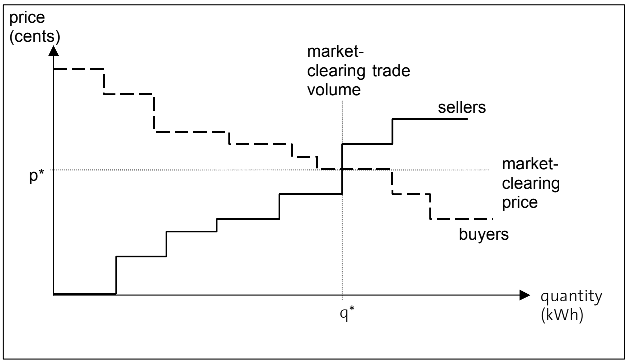

Figure 3. Power exchange market bidding mechanism (simple matching)

(1) Auction-based price determination

The most common price determination mechanism is a *daily double-sided auction* for every hour of the (next) day, where transactions are matched at a single price and at a fixed point in time. By submitting sales (purchase) bids, participants indicate how much they are prepared to sell (buy) at what prices. Typically they may attach *special execution orders* to their bids, and very often they are allowed to offer, or ask for, the same quantity of electricity for a period of consecutive hours (*block bids*). Some exchanges include the block bids in the simple bid matching by changing the blocks into price-*in*dependent bids for the hours concerned (e.g. APX, EEX in hourly auctions, Nord Pool). Others use *continuous trading* to settle block contracts, a form of trading which is described further below.

For the actual price determination in the auctions, all the submitted bids are collected in the order book, or bid register, and after expiry of the call phase aggregated to derive a market demand and supply curve (Figure 3). The price level at the intersection of the two curves is referred to as the *market clearing price* or *initial auction price*. If the two curves do not intersect, normally there is a second round of submitting bids, in order to be able to determine the auction price.

The calculation of the initial auction price ignores any execution conditions or grid capacity constraints. First, all the conditions related to the bids have to be checked. If not all conditions are satisfied, the price solution is not valid. In this case one of the unfulfilled bids is eliminated and the price calculation run again. This checking process continues iteratively until all the remaining bids can eventually be fulfilled.

Sometimes the *valid price solution* that results from the checking of the bid conditions *is optimised* in a successive step (e.g. APX, OMEL). This process tries to minimise the amount of money that removed bids would earn if they had not been removed.

The trade volumes of the matched bids have also to be checked against the available transmission grid capacities. If there are *transmission constraints*, the schedules have to be balanced in order to get a technically viable solution. *Schedule balancing* is done

- by only adjusting the trade volumes (e.g. OMEL);
- by adjusting the trade volumes and re-running the iterative bid matching (e.g. APX); or
- by splitting the market in several areas (e.g. EXAA, EEX, GME, Nord Pool). This takes place before (e.g. APX) or after (e.g. OMEL) the optimisation process.

(2) Continuous trading

For block bids, some exchanges (e.g. Borzen, EEX) provide an alternative trading mechanism to the auction-based system described above, the so-called *continuous trading*. Continuous trading is usually preceded by an opening auction and followed by a closing auction. Both auctions are similar to the auction of hourly power described before.

Continuous trading differs from auctions in the following points: First, participants have access to the bid register. Second, each incoming bid is immediately checked, and if possible matched, according to price/time priority. Finally, the contract price is not the same for all transactions, as it is determined according to the bid register at the time of the bid matching.

European Power Exchange (EEX), Germany

The two German power exchanges in Leipzig (LPX, operational since Jun 2000, 80 participants as of March 2002) and Frankfurt (EEX, operational since Aug 2000, 60 participants as of Jan 2002), respectively, are currently in a period of transition, since the announcement has been made in October 2001 that the two exchanges will be merged after all. The EEX "new" in Leipzig will offer its spot market participants an *auction market* as well as *continuous trading*. The system of the auction market corresponds more or less to the trading system that existed at LPX, while the system of continuous trading, in contrast, is similar to the one that was in operation at the former EEX.

(1) Auction market

On the EEX auction market (weekdays only), *hourly contracts* for every hour of the next day (minimum delivery of 0.1 MW for one hour) are traded as well as ten different standardized *block contracts*. All products are traded simultaneously in two-sided auctions with a *closed order book* (sealed bids). Sellers and buyers submit bids on a particular single hour contract that consist of 2 to 64 price/volume pairs within a price scale determined by EEX. Block bids consist of a desired average price and volume per hour for the corresponding block. All bids have to be assigned to one of the *bid areas*, into which the market is divided by EEX.[2]

In the *first price-calculation* of the auction for hourly contracts, bids for block contracts are integrated by changing the blocks into price-independent bids for the hours concerned. Then price/volume combinations for every hour are transformed into a sale and a purchase curve of every participant by using linear interpolation. The resulting supply and demand curves are aggregated to a supply and a demand curve for Germany. The price level at the intersection of the two curves is referred to as the *market clearing price*. If no intersection of the demand and supply curves can be determined, EEX may announce a second auction and allow the participants to transmit new bids.

After completion of the *first price calculation*, the average price conditions for block bids are checked. In case not all block bids can be fulfilled, the bid with the highest difference to the average price of the hours concerning the bid is not considered in the *second price calculation*. If the remaining block bids cannot be fulfilled with the market clearing price of the second price calculation, again one bid will be eliminated and a *third price calculation* will take place – and so on until all the remaining block bids can be fulfilled.

In a next step the individual supply and demand curves are aggregated per bid area resulting in a market clearing price for every bid area. Different prices in the bid areas are adjusted by using price independent demands and supplies to create power flows from bid areas with low market clearing prices to bid areas with high market clearing prices.[3]

(2) Continuous trading

Continuously traded products at EEX (weekdays only) are *base-load* (1 MW delivery over the period midnight – midnight), *peak-load* (1 MW delivery in the period from 8:00 a.m. to 8:00 p.m. on working days), and *weekend base-load* (1 MW delivery for all 48 hours of the weekend). Sellers and buyers submit orders with

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[2] Normally, the bid areas correspond with one or more transmission system operator (TSO) areas, as defined in the Verbändevereinbarung of 13 Dec 1999.

[3] The net contractual flow between the TSO areas is calculated by aggregating the individual supply and demand curves per bid area, yielding a market clearing price for each bid area (area price). Price-independent *demands* are introduced to bid areas where the area price is *lower* than the market clearing price, and price-independent *offers* are introduced to bid areas where the area price is *higher* than the market clearing price. This creates a (contractual) power flow between bid areas where the offers and demands introduced sum up to zero. Price levelling out is started in those areas with the highest and lowest area price deviations, respectively. As long as the calculated (contractual) power flow is below the transmission capacity allocated by the TSO to EEX, then the area prices are levelled out completely and the market clearing price becomes effective in all areas. If the transmission capacity is exceeded, in contrast, then a price mechanism is used to relieve the transmission constraints, resulting in bid areas with different bid area prices. Graphically, the supply and demand curves will have to be shifted along the volume axis at a distance equal to the allocated capacity.

or without price limits (*limited orders vs. market orders*), and can further add certain execution conditions and trading restrictions.

At EEX continuous trading is preceded by an opening auction and followed by a closing auction. Both auctions are similar to the auction of hourly power, except for an order book balancing phase in the event of any surplus. Unexecuted orders are made available to the market at the auction price for a limited period of time. At the end of the opening auction, all remaining orders are forwarded to the next possible trading form in accordance with their respective trading restrictions.

In continuous trading, the order book is open, displaying price limits, the accumulated order quantities and the number of orders for each limit. Each incoming order is immediately checked and executed, if possible, according to price/time priority. The price is the most favourable of all the price limits in the order book, the price limit of the incoming order, and the reference price (which is defined as the last price determined for the product in question).

All orders remaining in the order book at the end of continuous trading participate automatically in the closing auction. Thereafter, any outstanding orders are being deleted.

Other European power exchange spot markets

In what follows, we provide a concise overview of the various spot markets established at selected European power exchanges, when they were put into operation, and approximately how many participants they have (based on the latest information available at the time of writing).

APX (The Netherlands)

- Day-ahead market (operational since May 1999)
  - auctions for hourly contracts and complete flexible block contracts
  - 36 participants (as of Jan 2002)
- Adjustment market (operational since Feb 2001)
  - continuous trading
  - 17 participants (as of Jan 2002)

APX UK (United Kingdom)

- Operational since March 2001
- Hour-ahead market with half-hour contracts
  - continuous trading up to four hours prior to delivery
  - 30 participants (as of April 2002)

Borzen (Slovenia)

- Operational since Jan 2002
- Day-ahead market
  - hourly contracts
  - block contracts (base-load, peak-load, off-peak-load)
  - 16 participants (as of April 2002)
- Week-ahead 'Preferential dispatch' market
  - base-load contracts
  - peak-load contracts
  - static and dynamic price volatility limits

EXAA (Austria)

- Operational since March 2002
- Day-ahead market with hourly contracts
  - market splitting in case of transmission constraints
  - 13 participants (as of March 2002)

GME (Italy)

- Not yet operational (launch planned for Oct 2002)

Planned markets:

- Day-ahead market
- Adjustment market (with two sessions)
  - market splitting in case of transmission constraints
- Congestion management market
- Reserve market
- Balancing market

Nord Pool (Norway, Sweden, Finland)

- Day-ahead market (operational since 1993)
  - hours and five standardized blocks
- Adjustment market (operational since March 1999)
  - continuous trading up to two hours prior to delivery
- Market splitting in case of transmission constraints
- 216 participants (as of Dec 2001)

OMEL (Spain)

- Operational since Jan 1998 (particip. mandatory)
- Day-ahead market
  - simple and complex bids for hourly contracts
- Hour-ahead (adjustment) market
  - simple and complex bids for hourly contracts
  - 6 sessions 135 minutes prior to delivery
- 79 participants (as of Sep 2001)

Powernext (France)

- Operational since Nov 2001
- Day-ahead market
  - hourly contracts only (so far)
  - 18 participants (as of April 2002)

UKPX (United Kingdom)

- Operational since March 2001
- Hour-ahead market with half-hour contracts
  - continuous trading up to four hours prior to delivery
  - 44 participants (as of April 2002)

Plans for the Development of an OSCOGEN Bidding Tool

For the trading of electricity at the day-ahead spot market, the CHP plant operator has to submit his bid curves to the market, indicating the amounts of electricity he/she wants to sell or buy at what prices. An example of a bid curve for one hour is depicted in Figure 4.

Within the OSCOGEN project, in a first step a tool for trading electricity was developed that can be used to automatically generate bid functions on the basis of an optimal unit commitment plan. The main challenge of this task is to include the large uncertainties regarding the price that can be achieved at the spot market. These price uncertainties cannot be neglected if the tool is to be used in practice, and they require the use of stochastic optimisation methods. For the tool to become relevant in daily practical work, the following quality requirements have been specified:

- Short run time
- User friendly, easy graphical user interface
- Account for price uncertainties
- Good representation of technical aspects of different units
- Comprehensive data representation of the results

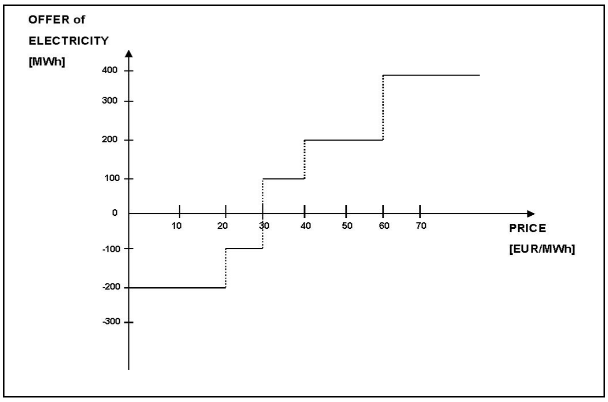

Figure 4. Bid-curve for a particular hour (illustration)

Aiming to maximise his/her profit, the CHP operator has to ensure an adequate treatment of the uncertainties of the electricity prices at the spot market. In the past, the time series for the spot prices at different markets (e.g. LPX, APX) showed marked jumps and could not be predicted very accurately. Therefore, we have set up a stochastic optimisation model, whose solution yields a robust bid curve that provides the highest revenues *on average*.

As minimum operation and minimum down times play an important role within the unit commitment for cogeneration systems, the calculation of the offer curve cannot be effected independently for each hour. This makes the stochastic optimisation used much more complex. Particularly, the model takes the actual status of the units and the forecasts for the heat and electricity demand as inputs. Based on this information, it determines an optimal unit commitment plan for the next 24 hours and provides a proposal for the bidding curves for each hour.

Compared to solutions from using heuristic procedures, solutions determined from stochastic optimisation have the advantage that all possible combinations of values of the uncertain model parameters ('scenarios') are considered. Hence they are weighted according to their probability of realisation. Theoretically, it has been shown that the solution of a stochastic optimisation problem outperforms the solution of a corresponding deterministic optimisation problem (and thus also the solution of a heuristic procedure).

The stochastic programming method typically consists of the following four steps:

- Scenario generation for spot market prices using Monte Carlo simulations
- Creation of a scenario tree out of the Monte Carlo simulations by scenario reduction
- Set-up of the stochastic optimisation model
- Determination of the bidding curves for the different hours out of the solution of the stochastic optimisation problem

The advantage of this method is that it determines the offer curve which yields the highest average profit. In contrast to other methods, it does not calculate different offer curves, which are then evaluated using a certain ranking. A disadvantage of the proposed approach is that, like most other stochastic models, it is more difficult to implement than heuristic procedures or deterministic models. Yet, these difficulties have already been overcome within the OSCOGEN project.

The final results of the stochastic optimisation will be displayed in a Microsoft Excel® spreadsheet (see Figure 5), so that the user has a quick overview over all his/her bid functions. The first row shows the possible spot prices, the following rows show, for the hours defined, the amount of electricity that should be sold or bought at the price indicated (negative values indicate purchases, positive values sales).

22.04.2002		offer curve for spot market								
Prices in EUR/MWh		6.6	9.0	15.4	21.5	17.0	23.5	27.0	34.0	35.0	remarks
Hourly bids	00:00-06:00	-350	-300	-200	100	200	350	400	430	530	
	06:00-10:00	-400	-400	-300	0	100	300	400	430	530	
	10:00-12:00	-500	-450	-350	-50	0	200	300	300	400	
	12:00-14:00	-550	-450	-400	-150	-30	180	280	280	380	
	14:00-17:00	-500	-450	-360	-150	-50	100	200	370	420	
	17:00-19:00	-500	-450	-360	-200	50	100	250	370	420	
	19:00-21:00	-450	-400	-320	-100	50	150	280	370	430	
	21:00-22:00	-430	-400	-250	-100	100	200	350	370	530	
	22:00-00:00	-400	-350	-200	100	180	350	400	430	530	

Figure 5. Illustrative result in spreadsheet format (pos. values for sales, neg. ones for purchases)

Short-Term Heat Demand Forecasting

Time series analysis for heat demand shows that heat demand can be characterized by the following stylized facts:

- Time of day effect and seasonal effect
- Weekday / weekend effect
- Time varying volatility
- High negative correlation between heat demand and outside air temperature

Figure 6 shows the hourly heat demand in the Ljubljana district heating system during the period from 10 October 2000 to 30 April 2001 (5'088 observations in total).

Heat demand is a very important factor for both the short-term and long-term production planning models as its predictions can provide a basis for the optimization of the production process. If the prediction of the heat demand is inaccurate, it may result in non-optimal unit commitment, which has to be corrected afterwards causing higher costs.

Two basic concepts were used when building short-term heat demand forecasts (STHDF) for TE-TOL: time series models on the one hand, and artificial neural network (ANN) models on the other hand. In both cases the maximum forecast horizon was set to one week. The total database was divided into a training set (in-sample period) and a test set (out-of-sample period).

In real life applications STHDF typically use forecasted temperature as input data. In OSCOGEN, while temperature forecasts are not yet available, the actual temperature was used in the forecast exercise for all models dealing with the outside air temperature as the explanatory variable. The accuracy of the models was compared by mean average percentage error (MAPE). Some results are presented below (Table 1).

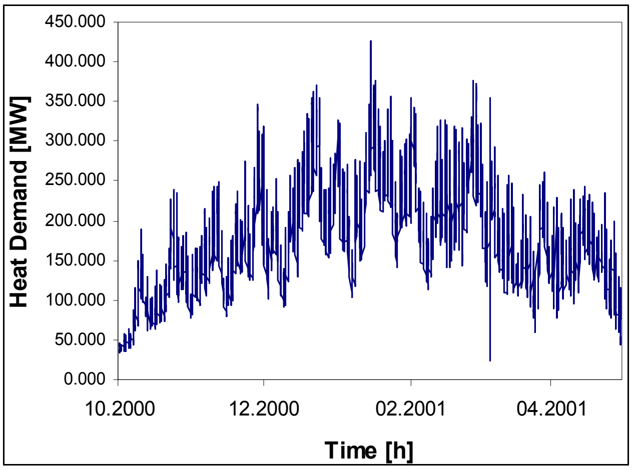

Figure 6. Hourly heat demand in the Ljubljana district heating system

Time Series Models

Autoregressive integrated moving average (ARIMA) models have been used and all in all 24 different models have been developed. The models can be grouped into two groups: (i) global models, which deal with the whole sample based on hourly frequency and (ii) separate models, which deal with each hour of the day separately. For some of the global models seasonal differencing is also included (SARIMA models) and sometimes log data transformation has been used to avoid negative heat demand forecasts.

Artificial Neural Network (ANN) Models

Application of the ANN technology for forecasting in power systems has received much attention in recent years. The main reason why ANN became so popular lies in its ability to learn complex and non-linear relationships that are difficult to model with conventional techniques. Even for input samples quite different from learning samples neural network methods can give good results. That capability enables the ANN-based system to model the correlations between the heat demand and such factors as temperature and other climatic conditions, time and type of the day, season, etc. Various architectures of neural networks were analysed to find the most appropriate solution for this kind of problems, but the multi-layer perceptron is found to outperform the other ANN models. In this case the ANN architecture of an existing short-term electricity load forecasting model was used. For training of the multi-layer perceptron, an enhanced back-propagation algorithm was implemented.

Selected results

In Figures 7 and 8 the results for 3-day-ahead and 7-day-ahead forecasts, respectively, are presented. It can be observed that the performance of both models is similar (see Table 1).

It is evident from the above results that in general heat demand forecasts are sufficiently accurate, but for some special cases there are rather large errors. Analyses show that this is caused by unexpected heat consumption in the system. Since the number of such cases tends to be small we can conclude that the developed tools passed the verification phase satisfactorily and can be a great aid in improving the CHP system operation.

Table 1: MAPE error for test period (April 2001)

3 day forecasts		7 day forecasts	
TS	ANN	TS	ANN
7.52%	8.02%	8.21%	8.41%

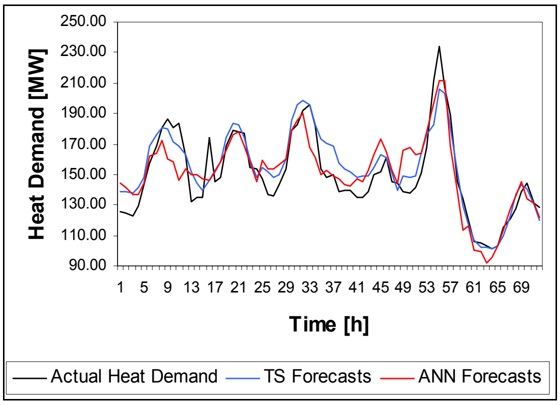

Figure 7. 3-day ahead forecasts

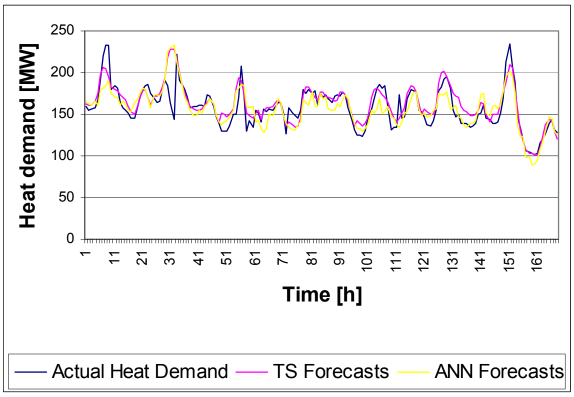

Figure 8. 7-day ahead forecasts

Dissemination of Results from the OSCOGEN Project

Poster and printed copies of Newsletter

An OSCOGEN poster (format 110 x 80 cm), summarizing the aim and scope and contents of the project and providing some details on the research, industrial and funding institutions involved, has been created by CEPE in February this year and distributed to the consortium members, together with hard copies of the first and second issue of the OSCOGEN Newsletter, for a wider dissemination and use.

International workshop

Preparations for the international 2-day OSCOGEN workshop scheduled for the end of 2002 have been initiated. Details regarding the exact timing, planned programme, and participation will be announced on the OSCOGEN Website as soon as they become available.

Conference paper in preparation

Currently, a conference paper on the OSCOGEN project is in preparation, co-authored by a significant number of OSCOGEN researchers. The paper is going to be presented by Dejan Pavaran and Robert Golob from the University of Ljubljana, Faculty of Electrical Engineering, at the 2nd Balkan Power Conference in Belgrade, Yugoslavia, 19-21 June 2002.

OSCOGEN Website (www.oscogen.ethz.ch)

The OSCOGEN Website will be further extended and improved. Particularly, all recently approved and publicly available reports will be added, and a more detailed description on the planned international workshop provided.

Figure 9. Screenshot of the OSCOGEN Website

Since its inception on 11 May 2001 until end of March 2002, the time series with the number of monthly requests for the OSCOGEN website shows a clear upward trend (Figure 10). So far, nearly 61'000 HTTP requests have been received for the website.

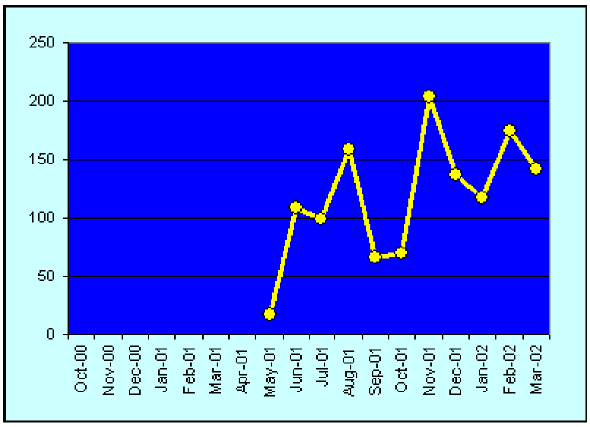

Figure 10. Number of monthly requests received for the OSCOGEN Website (11 May 2001 – 31 Mar 2002)

Next Project Meeting

The next OSCOGEN project meeting, which at the same time will serve for the obligatory mid-term project assessment undertaken by the European Commission, will be hosted by the Commission in Brussels and take place 4-5 June 2002.

OSCOGEN Partner Institutions and Contacts

(PROJECT COORDINATOR)	Institute of Energy Economics and the Rational Use of Energy University of Stuttgart Heßbrühlstraße 49 D-70565 Stuttgart GERMANY www.ier.uni-stuttgart.de	**Contact:** **Dr. Christoph Weber** Tel. +49-711-780 61 51 Fax. +49-711-780 39 53 E-mail. cw@ier.uni-stuttgart.de
	BEWAG Aktiengesellschaft Puschkinallee 52 D-12435 Berlin GERMANY www.bewag.com	**Contact:** **Dipl.-Ing. Alfred Hoffmann** Tel. +49-30-267 149 87 Fax. +49-30-267 101 33 E-mail. hoffmann.alfred@bewag.com
	Centre for Energy Policy and Economics Swiss Federal Institutes of Technology ETH Zentrum WEC C CH-8092 Zurich SWITZERLAND www.cepe.ethz.ch	**Contact:** **Dr. Reinhard Madlener** Tel. +41-1-632 06 52 Fax. +41-1-632 10 50 E-mail. madlener@cepe.mavt.ethz.ch
Faculty of Electrical Engineering University of Ljubljana	Faculty of Electrical Engineering University of Ljubljana Trzaska 25 SI-1000 Ljubljana SLOVENIA www.fe.uni-lj.si	**Contact:** **Dr. Tomaz Stokelj** Tel. +386-1-426 4650 Fax. +386-1-426 4651 E-mail. tomaz@strela.fe.uni-lj.si
	Institute for Advanced Studies Stumpergasse 56 A-1060 Vienna AUSTRIA www.ihs.ac.at	**Contact:** **Dr. Michael Obersteiner** Tel. +43-1-599 91-0 Fax. +43-1-599 91-555 E-mail. oberstei@ihs.ac.at
Institut „Jozef Stefan“	Institut “Jozef Stefan” P.O. Box 3000 / Jamova 39 SI-1001 Ljubljana SLOVENIA www.ijs.si	**Contact:** **Andreja Urbancic, M.Sc.** Tel. +386-1-5885 224 Fax. +386-61-5612 335 E-mail. andreja.urbancic@ijs.si
TE-TOL	Termoelektrarna Toplarna Ljubljana, d.o.o. Toplarniska 19 SI-1000 Ljubljana SLOVENIA www.te-tol.si	**Contact:** **Janez Rupar, inz. str. / Me.E.** Tel. +386-1-5875 370 Fax. +386-1-5875 218 E-mail. janez.rupar@te-tol.si

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Fifth Framework Programme