Market Simulations

Per Carlsson*

September 2004

Abstract

Supply and demand for electricity show conciderable fluctuations with season and time of day.

Novel market-based methods for supply – demand matching are currently investigated in a European project. This report covers a first set of simulations using the CONSEC algorithm on the time-scale of day-ahead power markets. Furthermore it describes simulations under preparation within the project.

The main purpose of the first simulations was to test the algorithm against the simulation setup. The results verify that a market based on the CONSEC mechanism works properly and that the algorithm handles the market efficiently.

1 Introduction

This report presents ongoing simulation work performed within the CRISP projects including results on a first set of simulations. The simulations presented in the report use an electronic market approach to supply – demand matching (SDM). The market mechanism that we have used is the CONSEC mechanism presented in previous work [1]. In the following we assume that the reader is acquainted with the mechanism. In this report we

- show that the CONSEC mechanism manages to handle day-ahead power markets,
- discuss simulation outcomes, and
- describe the scenarios of the upcoming CRISP simulations.

The simulations aim at a deeper understanding of the potentials of SDM within power grids. Going a step beyond SDM, we also have the challenge of load shedding. That is, load shedding occurs when the strain on a power

*EnerSearch and Computing Science, Department of Information Technology, Uppsala University, Office: Computer Science Department, Lund University, Box 118, SE - 221 00 Lund, Sweden, Email: Per.Carlsson@cs.lth.se

system is so high that it moves towards a blackout. It is an essential tool in the hands of grid responsible parties, at the same time it is an instrument that no one wants to utilise due to its severe side effects. Selective or "Intelligent" load shedding (ILS) based on a market approach is a new, interesting alternative for the future. Basic ideas of such a system are part of ongoing work as well.

1.1 Supply Demand Matching

SDM can be seen as a natural step further from traditional demand side management (DSM). It is an instrument that fits better into deregulated power markets.

Traditional DSM consists of top-down approaches to reduce consumption e.g. when the system is under pressure. It could be a system for sending a signal to residential loads such as tap-water heaters and building heating [8, 9], or a system involving tailored industrial actions [7]. In the CRISP project we focus on techniques that are structured bottom-up, with much of the initiative distributed among the end users.

In this way consumers stay in control of their equipment and with sufficient incitements they may utilise their flexibility to avoid consumption during peak load periods. They could change consumption patterns such that consumption is reduced or moved to surrounding time periods (either bringing consumption forward or delaying it), Figure 1.

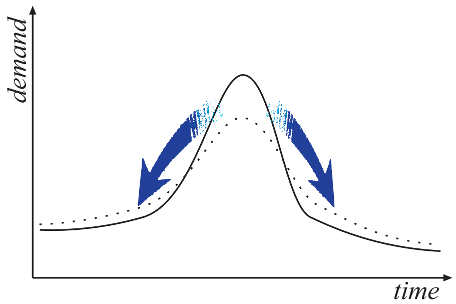

Figure 1: *SDM utilises end user flexibility to move consumption from high demand periods to surrounding periods. In the figure the solid curve depicts a demand curve without SDM. The arrows and the dotted curve indicate that SDM changes demand patterns. Controllable small scale production could move in the opposite direction.*

The new active parties on the scene are not only consumers, but also small scale producers. Distributed energy resources (DER) including *distributed generation* (DG) and decentralised generation[1] is a growing part of

[1]We make a small distinction between distributed generation and decentralised gen-

power systems. This raises a number of issues in resource management, and it introduces new possibilities. A good SDM system utilises both consumption side and small scale production, as well as large scale production and import/export to balance the power system.

1.2 Motivation for SDM

A major reason for introduction of SDM capability in power grids is spikes in demand relative supply, Figure 2. It might be that production capacity and grid capacity still can be designed to handle these spikes in a traditional way. That is, production (import included), transmission, and distribution are constructed to handle even extreme peak demand situations that occur for a few hours, possibly with years in between. This is hardly economically justifiable. An attractive alternative is to look at the potentials of consumption side and of small scale production. Today both categories are outside the realm of dynamic power markets[2] as well as of other means for matching of supply and demand.

An experience from both the Nordic and the Dutch day-ahead power markets is that when the power system is strained, rather limited increase in demand may lead to severely high price spikes, as shown in Figure 2. The last day in the figure, we can see that the market price was a factor four higher during an hour when 17,000 MWh/h were traded compared to an hour when 16,000 MWh/h were traded. In our opinion, a main reason for this is that consumption is exogenous to dynamic power markets — i.e. the price instrument does not directly influence consumption to any larger extent.

The increasing demand for reliable power delivery is another motivation both for enhanced SDM capabilities and for ILS.

Yet another motivation is that the grid topology changes. In the beginning of the era of electricity, power grids where small isolated islands centered around small power plants and often close to factories that motivated the investment in electicity production. The topology changed, and today power systems are not even limited by national borders. Large scale production has dominated these grids, but today the trend is moving back towards production localised close to the end users. The motivations are economical as well as environmental.

Altogether this gives that SDM systems that are open for small scale participants (small scale producers as well as consumers) are highly interesting. We further believe that electronic markets are the most interesting

eration. Distributed generation is localised close to (or co-located with) consumption. Decentralised generation is small scale production such as wind farms, often localised in areas where power consumption is low.

[2] We use the notation of "dynamic power markets" for markets with the horizon of day-ahead markets and markets that are closer to real-time.

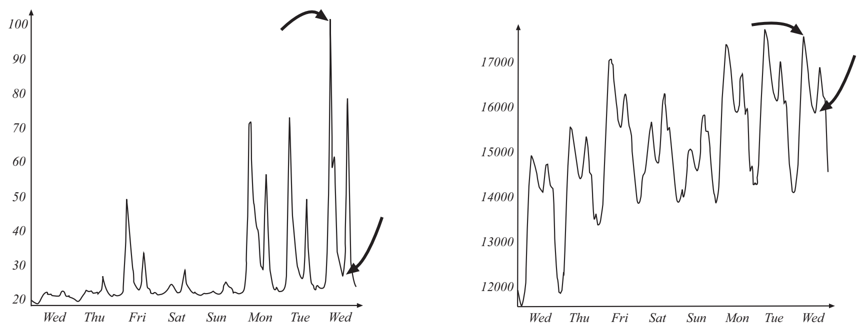

Figure 2: *Peak prices and volumes traded on the NordPool day-ahead market (February 2001). In the left pane prices in Euro/MWh, in the right pane traded volumes, MWh/h.*

SDM concept.

1.3 CRISP

The CRISP project[3] "aims to investigate, develop and test how latest advanced intelligence by ICT technologies can be exploited in a novel way for cost-effective, fine-grained and reliable monitoring, management and control of power networks that have a high degree of Distributed Generation and RES penetration." [3]. The project runs for three years, involving both academic parties and industry. CRISP is financially supported by the European commission, contract nr ENK5-CT-2002-00673:CRISP.

Within the project we find work on supply – demand matching as well as intelligent load shedding.

2 A First SDM Simulation

For this report we have set up a first small simulation. The simulation scenario models a local market within a low voltage (LV) cell, Figure 3, where the majority of the actors are traditional residential consumers but some of them have a production capacity (micro-CHP units).

In this market scenario we

- simulate a day-ahead market,
- use a small set of actors, some with production capacity (micro-CHP units), and

[3] CRISP: Distributed intelligence in *cr*itical *i*nfrastructures for *s*ustainable *p*ower.

- use simple models when constructing agent behaviour on the market as we are mainly interested in the proof of concept for the market setup and the CONSEC algorithm.

With this simulation we want to gain experience on the potentials and outcome of CONSEC markets [1], and the model is fully sufficient for this.

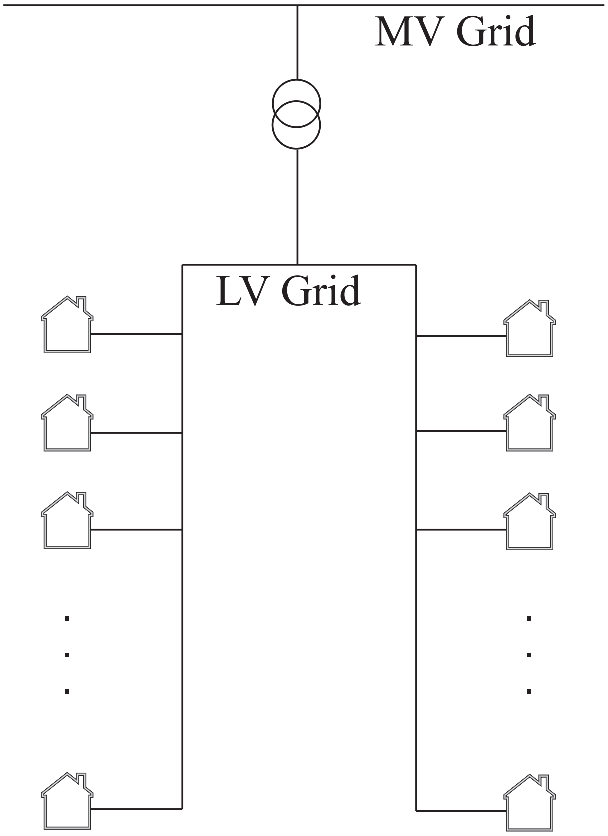

Figure 3: *The market of the simulations cover an entire low voltage grid.*

The market of the LV cell is strictly local. There is no action on the external day-ahead market. (In the following, we refer to the external market as the "global" market.) External prices are input to the local market. The prices of the global market could be based on e.g. the Nordic NordPool day-ahead market. The only difference is that we assume that there are different buying and selling prices offered on the global market. That is, a local producer is payed less for the energy he delivers to the global market compared to what a local consumer has to pay for what he buyes from the same market. The gap between buying and selling prices gives an incitement for a local matching of production and consumption, and the global prices become minimum and maximum prices on the local market.

2.1 Simulation Setup

We simulate a 24 hour local day-ahead power market situated in Sweden. A substantial part of the total electricity consumption in Sweden is used for building heating (in the residential sector approximately half the consumption). This is due to a combination of climate and historically low electricity prices. This gives that peak load situations mainly arise on weekdays during the winter season. Hence, the main simulation scenario is a day when heating is needed.

2.1.1 Market Prices

Prices on the global market are derived from NordPool prices a day in August, 2004. Price fluctuations between hours are modest due to the season. (The effect of using summer prices instead of winter prices in the simulation is that consumer savings due to utilisation of their flexibility are less than they would have been with winter prices.)

We have defined external market selling and buying prices such that there is a fixed span between the prices.

2.1.2 Actors

We have varied the number of actors on the local market from fifteen to thirty, and among them the number of actors with a controllable production capacity (a micro-CHP unit producing 10kW electricity).

Actors with a production capacity are assumed not to have an electricity demand for building heating or hot water production, as heat is derived from their CHP units.

Other actors are assumed to have a heater capacity between seven and fifteen kW, and a hot water boiler with a capacity between one and four kW.

All actors have a washer with a capacity of 1.5 kW and some controllable load such as a battery charger with a capacity of 1 kW.

We believe these loads to be typical loads that a smart home could use to act on a power market. There are other examples of loads that could be integrated, such as refridgerators and freezers, but we have left them out.

A large number of loads within a home are used in a more unpredictable and from a market viewpoint uncontrolable way. Lighting, TV sets, and computers are typical examples as well as stoves. These loads are left out of these simulations. In future market simulations we believe that a prediction of the aggregate behaviour of all such loads within an LV-cell could be added.

2.1.3 Bids

Bids are expressed in (positive and negative) demand functions. These are represented by sample arrays, hence they are assumed to be piecewise linear.

The number of samples in the bid arrays is rather large, approximately 200 sample points in earch bid array. The number of sample points could be higher to increase the possibility to express the shape of a demand curve, or it could be lower to increase communication speed when this is an issue.

We have assumed that an agent with a CHP unit wants to run the unit for at least four consecutive hours. (We assume that actors with micro-CHP units have sufficient heat buffering capacity for this.) Hence the agents representing them have entered bundle bids on bundles of four consecutive hours. We wanted some actor to act on a 24 hour bundle level, and decided to define one of the CHP actors such that he wanted to run all day around. Hence the local production varies from approximately 10 kW and upwards (depending of the total number of local producers).

On consumption side the simplified agents are constructed such that for each hour they define their energy demand related to heating in the range 25 – 50% of their capacity. They split this volume into three parts; one part that is fixed in time, one part could be moved an hour, and the third part is put into a four hour bundle bid. In the simulations we have varied the flexibility expressed in the agents' bids (between zero flexibility and an even split over the three parts).

Washing mashines are assumed to have a rather high flexibility, and enter substitute buy bids on eight hour bundles. The flexibility of the last load, that could be a battery charger, is even larger and with a certain probability it enters a 24 hour substitute buy bid.

All bids are almost flat, i.e. a consumer agent wants its need to be fullfilled but utilises user flexibility to do this at as low cost as possible, Figure 4. In the same way, CHP producers choose to produce almost the same amount of electricity at the minimum price payed by the global market as they would at the maximum price. We have set up the agent behaviour in this way to focus the opportunities given by the mechanism, not to say that this is a fully rational behaviour. A consequence is that local market prices tend to hit the borders set by the global market.

2.1.4 Computational Platform

Current implementation is written in $C^{\#}$ and the simulations have been run on a standard PC. The computer was equiped with a 3 GHz processor, 2 Gb of memory, and Windows XP.

2.2 Results of the SDM Simulation

As said in the introduction, we used the Consec algorithm [1] when performing these simulations.

The worst running time of the market computations that we have experienced with the described setup is in the order of a minute. There is a

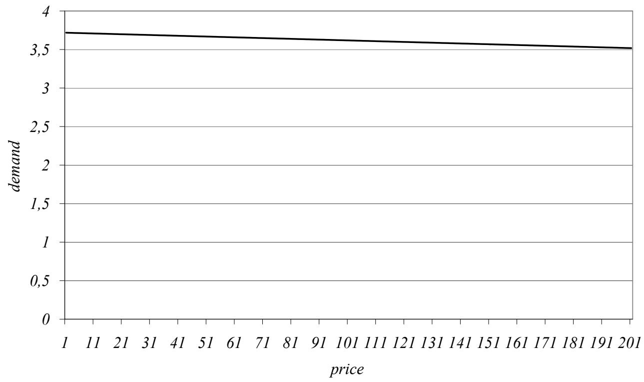

Figure 4: *The demand functions of the actors are rather flat linear functions. In this case the demand on a single bidding track varies between approximately 3.5kW and 3.7kW depending on price level.*

significant variation in running time caused by the construction of the algorithm. The combination of an exponential search step and an ordinary binary search gives that the number of search steps could vary substantially.

2.2.1 Local Market Balance

Prices on a local power market obviously depend highly on the balance between local production and consumption. This is clearly illustrated by Figure 5 and 6. The figures show local market prices on a market with 30 actors, in the first case nine of them have production capacity, in the second three of them have it. Everything else is equal. In the figures we can see that the local equilibrium prices are significantly lower in the case when the relative number of producers is higher.

We note that in both simulations the prices over four hour bundles often tend to be equal or close to equal. This is due to a large impact of substitute buying bids on four hour bundles. That is, actors with a high price sensitivity have a clear impact on the market outcome.

2.2.2 Price Sensitivity

An interesting aspect is how different market behaviour affects the market outcome. This is clearly essential from the perspective of the individual actor as well as from a systems viewpoint. One factor is how the price sensitiveness

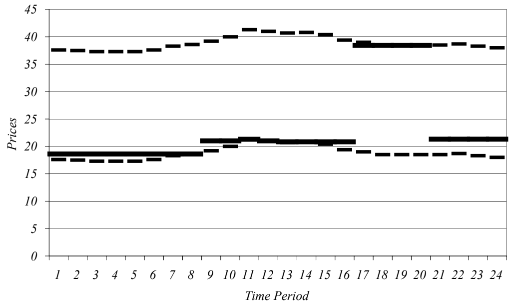

Figure 5: *With a large proportion local production the local market prices are close to the minimum prices, in this case we have thirty actors and nine of them have production capacity. From top to bottom we have maximum prices, local market prices (thick line segments), and minimum prices.*

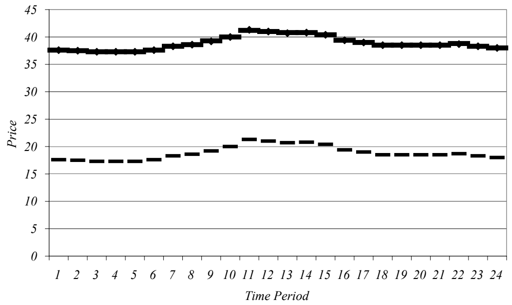

Figure 6: *We change the balance between local production and local consumption by decrease of the number of producers on the local market (from nine to three) holding the number of actors constant. The effect is relatively higher local market prices. From top to bottom we have maximum prices (diamonds), local market prices (thick line segments), and minimum prices.*

expressed in substitute bids affects the outcome.

Here we focus on the consumers, as we assumed that CHP producers wants to run their units for a number of consecutive hours.

In this simulation case we used a market with fifteen actors, one third of them with production capacity. With this balance we got market prices that did not allways hit the borders.

In two simulations we let the consumers act differently when it came to their demand related to building heating. In one they calculated their demand hour by hour, and expressed all of this demand in single hour bids. In the other case they utilised a high degree of price sensitivity, expressed such that they split their demand of each hour in three even pieces, Figure 7. One of these was expressed in a single hour bid, the second was part of a two hour substitute buy bid, and the last one was part of a four hour substitute bid, Figure 8. Everything else was equal. (A limiting factor when it comes to the substitute bids is that the agent was constructed not to risk an allocation higher than his capacity.)

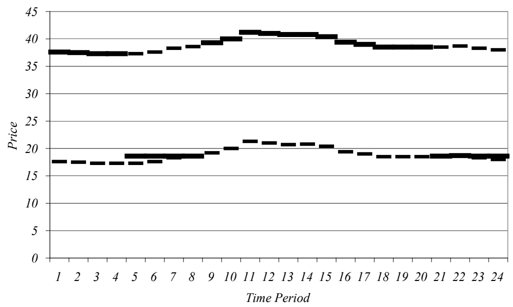

Figure 7: *Two simulations with fifteen actors. In the first one the actors express low price sensitivity.In four out of six four-hour bundle blocks the local market price equals the global market price. In the other two the local production was high relative the local consumption.*

The average price of the first simulation turns out to be 12% higher than in the second one. Furthermore, the price of adjacent hours (hours that are bundled together) tend to be equal in the simulation of Figure 8. This is due to the influence of substitute buy bids.

If we look at the corresponding allocation to a consumer it is radically different in the two simulations. In the first one we have almost the same consumption over all hours (since this is what the agent calculates as needed), Figure 9. An exception is a single hour when some other loads are consuming, it might be a washing machine and/or a battery charger that adds to the total consumption.

In the second simulation the allocation varies more from hour to hour, see Figure 10.

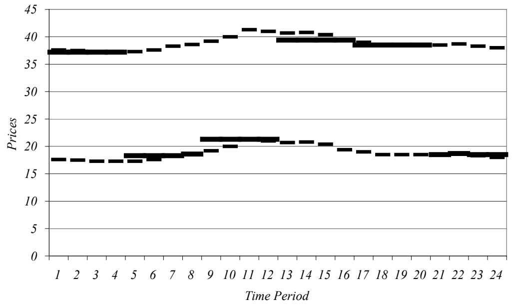

Figure 8: *Two simulations with fifteen actors. In the second one the actors express a rather high price sensitivity. In this case, the consumers are able to decrease the local price of one four hour bundle significantly, and the highest prices of the others are lower too.*

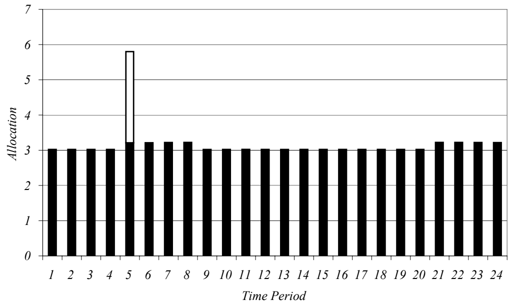

Figure 9: *The allocation of a single consumer in the simulation with low price sensitivity. The black part of the columns corresponds to single hour bids, the white part corresponds to substitute bids. We note that most of the consumption is fixed.*

3 Conclusions from the First Simulation

The simulation results are promising. We conclude noting that:

- The Consec algorithm performs well, calculating market prices with the expected properties

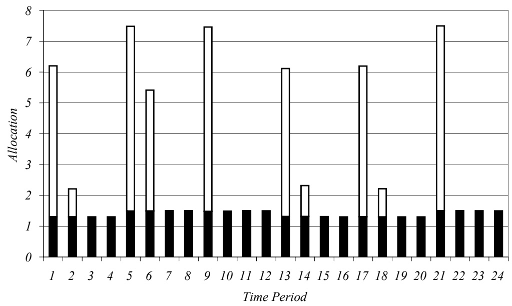

Figure 10: *The allocation of a single consumer in the simulation with high price sensitivity. A substantial part of the consumption is moved arround to utilise lower prices. As in the previous figure, the black part of the columns corresponds to single hour bids, the white part corresponds to substitute bids.*

  - when $p_i^{min} < p_i^* < p_i^{max}$ supply and demand on the local market is in balance over hour i,
  - when $p_i^* = p_i^{min}$ local supply is at least as high as local demand, and
  - when $p_i^* = p_i^{max}$ local demand is at least as high as local supply, and finally
  - the computing time of a 24 hour market is feasible, it is in the order of a minute. We note that the number of actors on the market does not affect the performance of the algorithm (the bids are aggregated as part of preprocessing). Solely the number of time periods (traded commodities) and the precision of the result affects computing time.

- The market outcome is affected by

  - the balance between local production and consumption, and
  - the price sensitivity of actors

  the way it should.

From this we draw the conclusion that a CONSEC market on the level of day-ahead power markets is feasible and can be handled efficiently.

4 Future Simulation Scenarios

In the ongoing simulation work within the CRISP project we have identified four SDM simulation scenarios. They range from a small local market covering a low voltage (LV) cell within a power grid, over middle voltage (MV) grids, to a high voltage (HV) transmission grid. The market perspectives of the simulations range from day-ahead (or a few days ahead) down to fine-tuning markets operating a few minutes ahead of real-time. The simulation work is joint effort of EnerSearch and ECN. For a more extensive description of the CRISP work on SDM and ILS we refer to the CRISP deliverables, [2, 6].

The scenarios cover a number of interesting research questions on the potentials of ICT based SDM, possibly combined with ILS capabilities.

Further we are interested in market based ILS and the last scenario is focused on this problem.

4.1 Scenario One

One of the ideas that caught more interest a few years back in the era of the IT boom was captured in the notion of the *smart building* or an *intelligent home*. Among the more spectacular ideas was that in a near future the refridgerator itself might well order milk when running out of supply. A lot of other more or less interesting possibilities where part of the concept, but apart from different alarm systems it was hard to really see a motivation for the cost.

A clear candidate for becoming the major motivation for smart building concepts is electronic power markets. In the smart building we can envision devices communicating with a market portal expressing their demand for electricity, heat and cooling, etc. That is, within such a system we could find a number of agents representing heating (cooling) systems, washing mashines, refridgerators, freezers, etc. These agents do not act individually on an external market, but a market portal agent aggregates the behaviour and preferences of the system and acts on the power market(s). Such a portal agent could be contained in equipment such as the ECN E-box [5].

These ideas lead to the first simulation scenario. It is based on the low voltage grid of a residential area with a number of homes, some of them equiped with DG resources. The size of the cell is some 30 to 40 homes all connected to a common MV/LV transformer station, Figure 3. The DG resources could be e.g. micro-CHP (combined heat-power) units or photovoltaic (PV) systems. Local power production using micro-CHP even in small scale residential settings is a rather new, interesting, and (when it comes to e.g. grid structure) challenging option. As with larger CHP production units, the idea is to replace traditional boilers in heating systems with CHP units. An overview of their potentials, economically as well as from technical and enviromental viewpoints, can be found in the literature [4, 10]. Indirectly we could derive an argument for electronic power markets with small scale participants from these papers — a main problem they refer to is the low (fixed) prices that are for local power fed into LV grids. The drive for introduction of PV systems is environmental concerns.

In this scenario we have a local market that *does not* take part in the price formation on higher level markets. Market prices on an external market are taken as input to the local price formation. The external market prices could resemble prices on the Nordic and Dutch day-ahead markets with an essential exception. There is a span between selling prices and buying prices of the external market. That is, when a local producer sells power to it he is payed less than the price a local consumer has to pay for energy he buyes from the same market. This price span is what drives a local market; a matching between local production and consumption is beneficial for at least one of the parties, possibly both as the local market price will end up between the two external prices. Let p_{buy} be the price the external market payes for locally produced energy, p_{sell} the price when the external market delivers energy, and p_{local} the local price. Then we have that $p_{buy} \leq p_{local} \leq p_{sell}$. This because any local demand higher than the local production gives an import from the external market at price p_{sell}, and any local supply higher than the local consumption gives an export at price p_{buy}.

In the modelled scenario we get a reduced power exchange with the external market, i.e. a reduced flow between the LV cell and the MV grid.

4.2 Scenario Two

In the second scenario we move to the MV level. Actors on this level could represent entire LV systems, as well as (mainly industrial) consumption that is connected to the grid on the MV level as well as production units that are connected on the 10/20 kV level (e.g. wind based production).

Optimisation on this level (as on any level) can contribute to an increased overall efficiency in the power grid. Furthermore, SDM in an MV cell could be a way to handle capacity bottlenecks and reduce investment costs.

The simulations are based on the Öland grid, Figure 11. Öland has a single power connection to the Swedish mainland at the middle of the island, and double 50 kV feeders going both south and north from the connection. Approximately a dozen substations connect 10/20 kV grids to these feeders. The Öland grid is strong enough to handle today's power consumption on the island, as well as today's wind based local power production.

There are plans though, to connect up to $40 - 50$ MW wind based production to the northern power lines (at Stora Istad and Kårehamn). If so, large investmens in the grid are needed to handle peak production. The situation is not very specific to Öland, but rather common as large scale wind farms preferably are set up in areas that are scarcely populated. The power

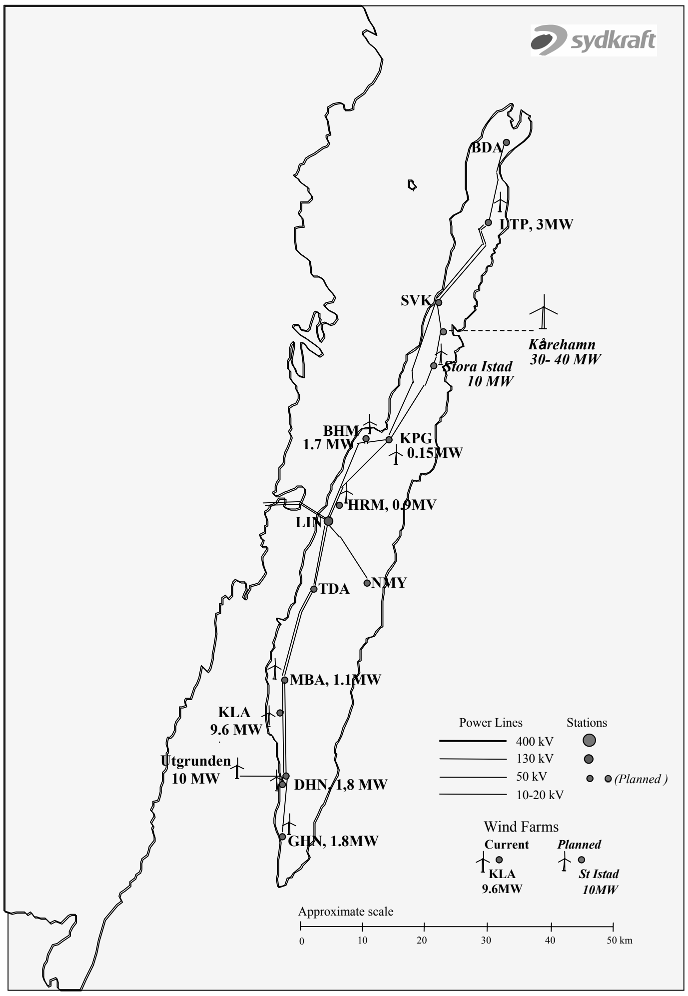

Figure 11: *One of the simulations is related to wind based production on Öland. Öland is situated at the Swedish east coast. The wind farms at Kårehamn and Stora Istad are the planned ones. BHM is the substation at Borgholm.*

grids have been constructed to handle the consumption, possibly with large margins, but they are not strong enough to handle the flow introduced by the new production.

An alternative is to set up a local power market that handles peak production on market terms. In short: A certain volume can be tolerated from a grid perspective, and exported at ordinary prices, but if the producers want to sell more than this they have to do this on the local market. Hence, since the local market aims at increasing the local demand the local market prices tend to be lower than the global prices. The interesting party on consumption side with the grid topology of Öland is the town Borgholm, situated between the planned wind farms and the connection to the mainland.

4.3 Scenario Three

The third scenario involves what a power utility can do together with its customers. In this case we do not assume that the actors in focus are connected to a common LV/MV cell. On the contrary the participating parties can be spread over the power grid.

The target is to reduce capital expenditures and cost. Involved are a wind-turbine, cold stores, heating and cooling in co-generating office buildings and horticultural as well as residential co-generation. An SDM-cluster in this setting combines the interests of a number of medium size power suppliers and power consumers to optimise both production and consumption in relation to e.g. a nation wide power market. It can act in relation to a day-ahead market as well as it acts close to real-time to fine tune shiftable the behaviour of producers and consumers to match the actual production of non-controllable production units such as wind turbines and PV-cells.

4.4 Scenario Four

In this scenario we are one level below the national transmission system operator (TSO). On this level we find large distribution companies such as Sydkraft Nät in Sweden and Eneco in the Netherlands.

The aim is to focus grid balance problems on this level and not only on the level of the national TSO. This could lead to improvement of grid stability and flexibility, avoidance of bottlenecks at the level of a distribution company, and reduce the need for investment in transmission and distribution grids. Furthermore, there are interesting questions related to the integration of renewable energy sources.

The responsible actor in this scenario is the distribution company.

4.5 Intelligent Load Shedding

The last simulations are focusing a problem with harder real-time constraints. Power outages such as the major ones that we experienced during 2003 are rare, but extremely costly. Modern society tends to become increasingly depending on reliable, uninterrupted power supply.

This simulation models an entirely new approach to avoid power outages using load reduction. We want to establish that market based approaches can become a highly interesting option for some load shedding actions. There are situations when the system reaction time is in the order of milliseconds, in those situations there is no time to communicate any messages to end users, the circuit breaker is the only option. In other situations such as the major outages of 2003, experience shows that there is a window of up to a minute from the fault triggering system instability to the actual outage. A market based load shedding (or load reduction) scheme that is prepared to take action could do a lot in a minute.

With this simulation setup we want to present some of the potentials of market-based "intelligent" load shedding.

5 Final Remarks

Electronic power markets are a means to incorporate end user participation on dynamic power markets. By this we can achieve a more efficient allocation of a resource (electric power) that sometimes is scarce.

We hope that the simulations that we currently are preparing in the CRISP project, as above will show some of the potentials of an electronic-market based approach to SDM. The results of our first simulations, presented in this report show that even a rather limited local market clearly has a potential to affect power systems in the wanted direction.

This is a first simulation report, during the comming year more extensive reports on results will be made available from the project. In Section 3 we summarized experiences from the first simulations concluding that day-ahead power markets based on the CONSEC algorithm are feasible and can be handled efficiently. Hence, the mechanism is ready for more extensive tests.

References

[1] P. Carlsson and A. Andersson. A flexible model for tree-structured multi-commodity markets. Technical report, EnerSearch and Department of Information Technology, Uppsala University, 2004. (Submitted for journal publication).

[2] P. Carlsson, Z. Gajic, D. Karlsson, N. R. Ullah, and S. Okuboye. Intelligent load shedding. Technical report, ABB and EnerSearch, 2004. Deliverable D1.5 of the CRISP project, download from http://www.ecn.nl/crisp.

[3] http://www.ecn.nl/crisp.

[4] T. Crozier-Cole and G. Jones. The potential market for micro CHP in the UK. Technical Report P00548, Energy for sustainable development, 2002.

[5] R. Kamphuis. E-box, een residential gateway voor kostenbesparing en duurzaamheid (e-box, a residential gateway for cost savings and sustainability). Technical Report ECN-C-03-017, ECN, 2003. (Available at the ECN web site, http://www.ecn.nl).

[6] R. Kamphuis, P. Carlsson, J. Kester, and H. Akkermans. Market-oriented online supply-demand matching. Technical report, ECN and EnerSearch, 2004. Deliverable D1.2 of the CRISP project, download from http://www.ecn.nl/crisp.

[7] L et al Larsson. *Projekt Mintop.* Sydkraft, Malmö, Sweden, 1988. Project report on a Sydkraft projekt on peak load reduction (in Swedish).

[8] H. Ottosson, editor. *Teknikstyrning av elanvändning, Rapport 1.* Sydkraft, Malmö, Sweden, 1989. Project report on a Sydkraft and Svensk Energiutveckling project on load side control. This first report is a technical report.

[9] H Ottosson, editor. *Teknikstyrning av elanvändning, Rapport 2.* Sydkraft, Malmö, Sweden, 1990. Project report on a Sydkraft and Svensk Energiutveckling project on load side control. This second report covers results and conclusions.

[10] M. Pehnt, B. Praetorius, K. Schumacher, C. Fischer, L. Schneider, M. Cames, and J.-P. Voss. Micro-chp — a sustainable innovation? Technical report, Transformation and Innovation in Power Systems (TIPS), 2004. Download from http://www.tips-project.de.