E-ISLAND: EXPANDABLE INTERNET SUSTAINED LOAD AND DEMAND SIDE MANAGEMENT FOR THE INTEGRATION INTO VIRTUAL POWER PLANTS

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ABSTRACT

E-island is a R&D project carried out by a public private partnership consortium. Its members are the University of Applied Sciences Hamburg (HAW, Prof. Dr.-Ing. F. Schubert), the department of economics and employment of the city of Hamburg, SUmBi eng. Cons. (Dipl.-Ing. H. Schäfers) and Envidatec GmbH. The project's central aim was to model a network of 20 load management systems situated in public facilities at medium voltage level. The network was the basis for the examination of two tasks:
a) Make use of load balancing in individual public facilities to secure a day ahead prediction of the load uptake of a total of 150 public facilities.
b) Find out how much manageable load could be pooled from 20 public facilities with the aim of selling it as reserve capacity on the tertiary reserve capacity market.
We found that the examined system would be able to activate 1.5 - 3 MW positive and around 5 MW negative reserve capacity very quickly. The activated load derived mainly from switchable building infrastructure (heating, ventilation and air conditioning), its amount depending on type of day, time of day, type of reserve capacity needed (positive or negative) etc.
If the system is used for providing reserve capacity as a means for securing a predicted load schedule, it is essential to have a fairly accurate load prediction for the next day since the range of positive reserve capacity is only about 10% of the total load uptake of all buildings.
If the system was successfully implemented it could provide a reasonable financial benefit for the public facilities of the city of Hamburg.

INTRODUCTION

"E-island" (German title: "Insel") is a R&D project financed by the German ministry of education and research (BMBF). The project ran from 11/2006 until 03/2010. It was carried out by a public private partnership consortium led by the University of Applied Sciences Hamburg: The other members are

- the department of economics and employment of the city of Hamburg,
- SUmBi and ENVIDATEC, two German engineering companies.

The project was furthermore supported by REAP (*Resource Efficiency in Architecture and Planning*), a newly founded multidisciplinary research centre at Harbor City University, Hamburg, and the department of environment and planning of the city of Hamburg.

PURPOSE

The project's aim was to build a model (Matlab/Simulink) of a demand side management network containing 20 public facilities equipped with load management devices in a balancing group of 150 facilities, all at medium voltage level. Simulation runs were carried out to examine

1. whether and to what degree a network of 20 load management systems can be utilized to ensure a predicted load schedule for all 150 public facilities at medium voltage level (supposing we had real time load uptake information via smart metering).
2. how much reserve capacity such a system could provide during which times of the day.

The modeled system structure is displayed in figure 1.

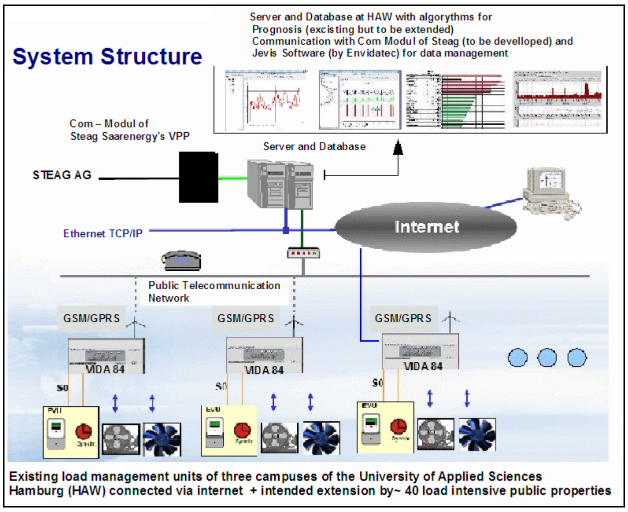

Fig. 1: Modeled system structure of „E-Island".

THE FACILITIES INVOLVED

Some of Hamburg's most load intensive facilities have peak load management devices installed for a number of years now. The initial thesis to this project therefore was that these could be used more efficiently if they did not reduce the peak load uptake of their "host facility" but worked as a "team" in order to reduce the load uptake of all public facilities. Furthermore the question was how much more load there was that could be made available in other facilities. To answer this the 20 most load intensive public facilities were examined with regard to the sort and amount of technical equipment suitable for demand side management purposes (HVAC etc). The following table 1 gives the results of these inspections. It shows how much shiftable load could be identified in each of the examined facilities.

Facility	Ppeak (MW)	P off (MW)	%	P on (MW)	%
Univers.	5,7	2	35%		
Centr. Market	3,39	0,8	24%	1,5	44%
M. tunnel	2,54	2	79%	6	236%
HAW	1,69	0,8	47%		
LPV	1,22	0,7	57%		
Bot	0,91	0,35	38%		
Museum	0,88	0,5	57%		
Hyg. Inst.	0,816	0,28	34%		
LVA	0,686	0,35	51%		
GS Mbg	0,511	0,25	49%		
HAW Bgf	0,724	0,2	28%		
Opera	0,852	0,15	18%		
BSZ BGDF	0,494	0,2	40%		
GS Sth	0,564	0,12	21%		
BSH	0,115	0,05	43%		
Ang. Phys	0,8	0,1	13%		
BSU	0,44	0,2	45%		
Exp Pys	0,36	0,1	28%		
Stell	0,308	0,04	13%		
Conc.Hall	0,447	0,15	34%		
P&B	0,588	0,26	44%		
Rest	16,035				
Sum	**35**	**9,6 / 3,2**	**9%**	**7,5/5**	**14%**

Table 1: Load uptake and shiftable load in the examined facilities.

The first column displays the typical (week) daily peak load of the facilities. The second column indicates the amount of load that could be switched off or shifted in the facilities. Nota bene: The figures display the maximum amount of shiftable load (every shiftable device turned off at the same time). Since the devices connected to each load management controller have specific service obligations they can only be switched for several minutes during an accounting period (15 minutes). Furthermore all devices have their specific run times. Both aspects lead to the situation that the resulting available reserve capacity is only 10 to 30% of the indicated "P off" value in column two.

Since peak load management devices are designed to switch off load they cannot provide negative reserve capacity. Therefore two facilities were identified as possible contributors for negative reserve capacity: The central market where chillers could be switched on and a motorway tunnel under the river Elbe where large ventilation devices could take up surplus energy.

SIMULATION APPROACH

For each facility submodels of all the specific technical devices with their respective load shifting capabilities were built in Matlab/Simulink. These submodels were connected to another submodel of a standard load management device being the controlling unit for each facility. After testing and validating the model concept for the load management devices and the connected loads the model of a central three level controller was added on an overlying hierarchical level.

Implementing this structure, a concept of distributed intelligence (at the facilities) was modeled containing a cascading controller concept. The inner control loop contains the technical building equipment and the load management controller of each facility. The outer control loop contains the main or central controller and all the facilities.

Figure two displays the controller concept.

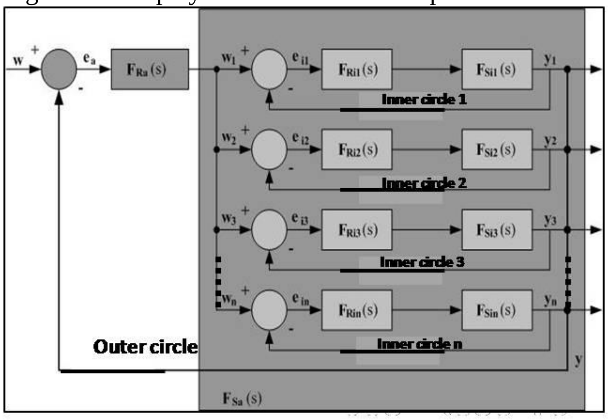

Figure 2: Controller concept.

The model of the load management controller was designed as a simple peak load controller as can be bought as "off the shelf" standard technology. The reason for this being the question (see above) whether it would be possible to simply integrate already existing peak load management devices into a new and more intelligent ("smart") system design.

To get accurate load data from the existing facilities, smart meter were installed to record the load uptake every minute. Historical load data with a 15 minute resolution as well as measured data from the smart meters were used to produce day ahead load schedules for the sum load uptake of the 150 facilities. Due to funding limitations we were not able to use a professional load prediction tool but had to use a simple self designed prediction algorithm.

The main controller was used to balance deviations between the day ahead load schedule and the "real time" load uptake of all 150 facilities using the reserve capacity coming from the demand side management network. The controller also processed simulations of third party requirements for reserve capacity (e.g. tertiary reserve calls coming from a TSO). Simulation runs of the daily system behaviour were carried out for a year (365 days).

RESULTS AND CONCLUSIONS

Results show that the simulated network of 20 load management devices in load intensive facilities is well able to provide enough reserve capacity to maintain a day ahead load schedule for a balancing group of 150 facilities. The reserve capacity could as well be used by the distribution or transmission network. The following figures show simulation results for a typical day (Wednesday 2nd July 2008).

Figure 3 illustrates how occurring deviations from the schedule (indicated by arrows) are balanced out.

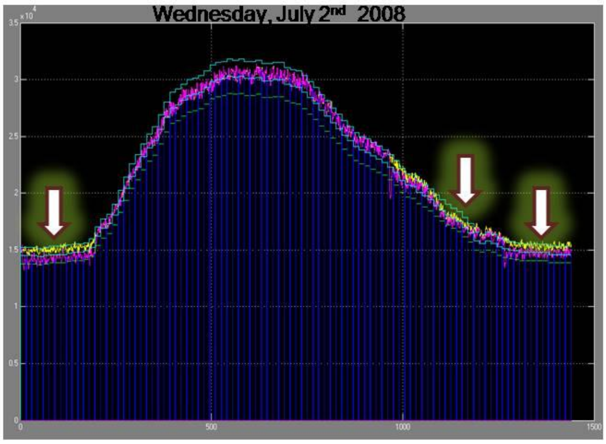

Figure 3: Balancing the load schedule on a typical day.

To be seen:

- Light blue line (middle): Day ahead schedule. 15 minute values.
- Yellow curve: Original sum load uptake (all 150 facilities) every minute.
- Pink curve: Adjusted load uptake by applying part of the reserve capacity the load management network provides.
- Dark blue and green lines (above and below load curve): Allowed deviation limits (5% of scheduled load value)
- Time is displayed in minutes of one day (1440)
- Load uptake in kW

Figure 4 shows a simulation of a delivery of tertiary reserve capacity (2.5 MW midday and 1 MW night, indicated by arrows). The delivery is possible but load noise seems to increase due to a higher number of switching operations. This could probably be minimized using frequency converters for the devices and an optimized controller. Both issues will be examined in an adjacent research project. An optimized main controller (probably containing a fuzzy logic) will also be necessary because we still see some unwanted step responses at the beginning as well as at the end of a reserve capacity deliverance.

Another open question is the prequalification of such a system for the tertiary (or secondary) reserve capacity market since one condition for market access is the proof of a stable load deliverance. A system like the one examined will only be able to provide an “as good as” approach because of the inherent load noise.

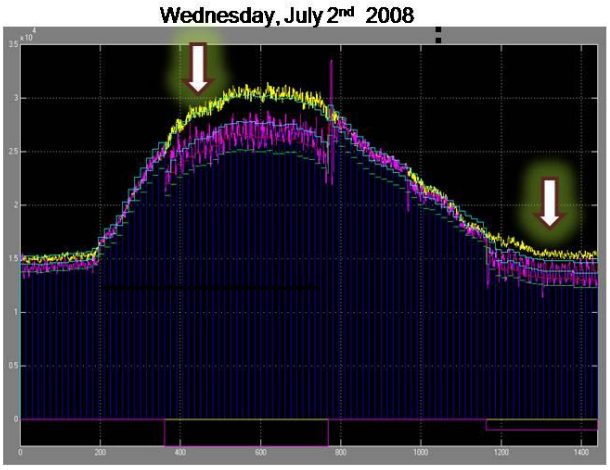

Figure 4: Deliverance of 2.5 MW (midday) and 1 MW (night) pos. reserve capacity (RC).

To estimate the maximum amount of positive reserve capacity on a typical day the main controller can be set to an “all off” state. This results in the devices being switched off as often as possible. The resulting load curve for such a regime is displayed in Figure 5.

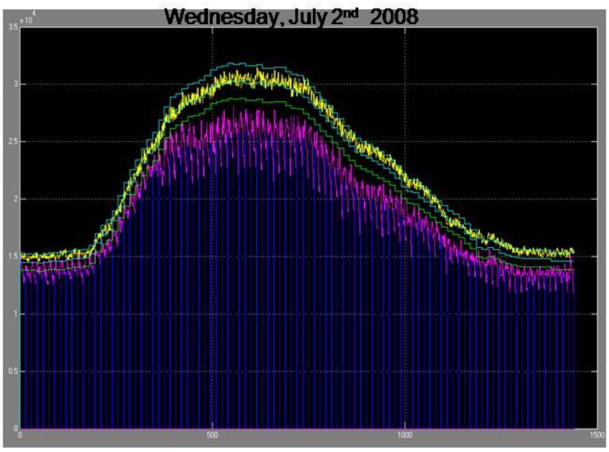

Figure 5: Determination of the maximum amount of positive reserve capacity (“all off scenario”).

The figure shows that during night time the system would not be able to deliver more than 0.5 to 1.5 MW positive

reserve capacity due to the fact that most devices are not running. This applies as well to weekends and holidays. However, during day time (of week days) the system would be able to deliver 3 to 5 MW positive reserve.
In the same manner the controller can be set to an "all on" regime which is helpful to determine to maximum amount of negative reserve capacity. Figure 6 displays this. Since the negative reserve capacity only results from two facilities using a limited number of devices which do not have to be interrupted the resulting curve contains much less load noise than in the case of a positive reserve deliverance.

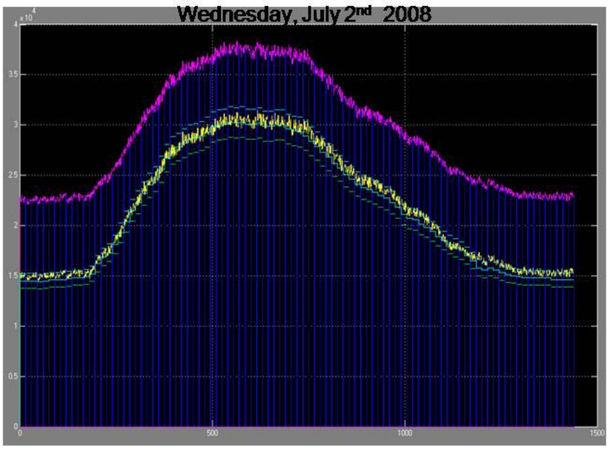

Figure 6: Determination of the maximum amount of negative reserve capacity ("all on scenario").

Since the devices involved are available 24h there is no difference (for this system) in the amount of negative reserve capacity during the day or on weekends or holidays.

LIMITATIONS

To be able to balance deviations from a predicted load schedule, the accuracy of the load uptake prediction is essential. If an occurring prediction error is larger than the amount of reserve capacity at hand the controller will not be able to balance the occurring deviation. Unfortunately this was the case for about 10% of the simulated days. 60% of the simulation runs resulted in well kept schedules for the whole day. 98% of all simulated quarters of the hour could be kept within the 5% deviation. Most of the problematic days were "untypical" days such as Mondays and Fridays being treated like normal week days which in fact they are not. Other problems included different holiday schemes for school and university facilities, unidentified bank holidays and/or thermal distinctions (very hot or cold days etc).
We are certain (but cannot prove at the time being) that a professional prediction algorithm would lead to clearly better results.

IMPLICATION

Being able to secure a load schedule for the examined facilities would result in the possibility to form a balancing group with direct market access. For this balancing group, electricity could be purchased directly at the stock market and reserve capacity sold to the reserve capacity markets. Calculations were done to compare the stock market electricity prices to the actual supply costs of the facilities. Results indicate that the direct electricity purchase (e.g. at the German EEX) for the facilities in the balancing group and the sale of reserve capacity (to the TSO) could lead to a seven-digit financial advantage for the city of Hamburg. In future DSO could also develop innovative services using the reserve capacities of demand side management networks like the one modeled in this project.
And: Closely examining the daily load uptake of the load intensive facilities of a city brings about a number of ideas for energy optimization ;-)