ECN-M--08-022

A field test using agents for coordination of residential micro-chp

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Presented at the 14th International Conference on Intelligent System Applications to Power Systems (ISAP), November 4 - 8, 2007, Kaohsiung, Taiwan

November 2007

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Abstract-- **In the Netherlands decentralised generation of heat and power by μ-CHP units in households is expected to penetrate the market at high speed in the coming years. Using ICT these μ-CHP units can be integrated into a Smart Power System or Virtual Power Plant. Other local production and consumption of electricity such as PV, wind, heat pumps and electrical vehicles can be added to this cluster. The main goal of a Smart Power System is to optimize the value of decentralised power production and consumption in view of the total energy value chain.**

The PowerMatcher is a multi-agent based control concept (and software package) for coordination of demand and supply in electricity networks with a high share of distributed generation. The concept is demonstrated in several real life field tests. One of these field tests is a virtual power plant consisting of 10 μ-CHP units reducing the local peak demand of the common low-voltage grid segment the μ-CHP units are connected to. In this way the VPP supports the local distribution network operator (DNO) to defer reinforcements in the grid infrastructure (transformers and cables). To realize this VPP, an ICT-communication network containing a hardware and software infrastructure has been added to a test rollout of μ-CHP installations in The Netherlands. Main conclusion from the field test is that a peak reduction of 30 - 50% can be achieved, depending on summer or winter season.

Index Terms-- Distributed Generation, Virtual Power Plant, CHP, Smart Grids, Multi Agent Systems, Electronic Markets

I. Nomenclature

APX	-	Amsterdam Power eXchange
CHP	-	Combined Heat and Power
DNO	-	Distribution Network Operator
ECN	-	Energy research Centre of the Netherlands
ICT	-	Information and Communication Technology
LMP	-	Locational Marginal Pricing
PV	-	Photo-Voltaic
SPS	-	Smart Power System
UMTS	-	Universal Mobile Telecommunications System
VPP	-	Virtual Power Plant

This project was financially supported by the Dutch Ministry of Economic Affairs, within EOS: Demonstration, as executed by SenterNovem, and in cooperation with the Smart Power System (SPS) consortium.

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II. Introduction

Natural gas as an energy carrier has the potential to offer flexible power. By using μ-CHP, these opportunities can also be made available at the lowest electricity distribution level. This potential flexibility can be utilised by clustering large numbers of installations into a *virtual power plant* (VPP). Integrating μ-CHP together with other decentralised units, such as PV, wind turbines, heat pumps and local storage, by using ICT turns the system into a *Smart Power System* (SPS, [1]).

The flexibility of a Smart Power System can be put into value in different ways. Some of these are:

- trading the output on a power market, e.g. a day-ahead power market such as the Dutch APX or the Scandinavian Nord-Pool;
- offering the flexibility of the SPS on the imbalance or spinning reserve market;
- support of the local *distribution network operator* (DNO), e.g. by reducing the local peak demand or preserving network constraints.

ECN and Gasunie are performing a real life field test in The Netherlands, in which a cluster of μ-CHP units is operated as a virtual power plant, demonstrating their ability to contribute to a common control goal. The field test uses 10 domestic Stirling based μ-CHP units, $1kW_{el}$ each, at consumer premises. The emphasis in the field test will be on grid-support services, although the trading purposes will be investigated in additional simulation studies.

The main goal of the field test is to demonstrate the ability of a cluster of μ-CHP units operated in a virtual power plant to reduce the local peak demand of the common low-voltage grid segment the μ-CHP units are connected to. In this way the VPP supports the local distribution network operator (DNO) to defer reinforcements in the grid infrastructure (substations and cables). Although not all μ-CHP units included in the field test are connected to the same low-voltage cable, during the trial a connection to a common substation (i.e. low-voltage to mid-voltage transformer) is assumed.

An additional goal is active involvement of the end-users in the energy value chain, both by giving them feedback with the monitoring results of the field test and by showing them that automated control of their comfort leads by no means to comfort degradation.

III. MARKET-BASED CONTROL USING A MULTI-AGENT SYSTEM

In market-based control, a large number of software agents are competitively negotiating and trading on an electronic market, with the purpose to optimally achieve their local control action goals. In [2] the first agent research applications and simulations carried out under the heading of market-based control were brought together. Most of the early research was aimed at climate control in office buildings with many office rooms, where local control agents compete in the allocation of cool (or hot) air.

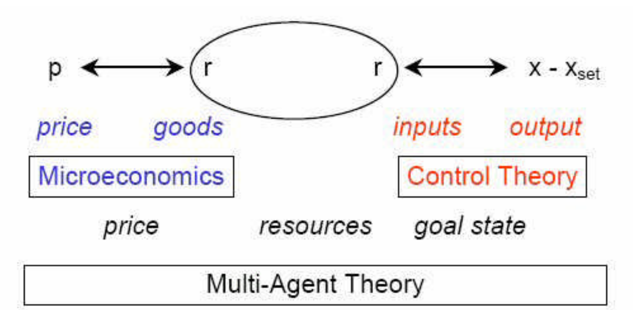

Figure 1: Microeconomics and control theory unified in a multi-agent system

Recently, a systems-level theory of large-scale intelligent and distributed control was formulated [3], [4]. This theory unifies microeconomics and control theory into a multi-agent system (see figure 1), and subsumes the agent research applications and simulations as described above. A central result is the derivation of a general market theorem that proves two important properties about agent-based microeconomic control: (1) computational economies with dynamic pricing mechanisms are able to handle scarce resources for control adaptively in ways that are optimal locally as well as globally ('societally'); (2) in the absence of resource constraints the total system acts as a collection of local independent controllers that behave in accordance with conventional control engineering theory.

The PowerMatcher concept

The PowerMatcher is a control concept for coordination of supply and demand in electricity networks with a high share of distributed generation, that implements the above market-based control theory. It is concerned with optimally using the possibilities of electricity producing and consuming devices to alter their operation in order to increase the over-all match between electricity production and consumption.

In the PowerMatcher concept each device is represented by a control agent, which tries to operate the process associated with the device in an economically optimal way. The electricity consumed or produced by the device is bought, respectively sold, by the device agent on an electronic exchange market [5-8]. The electronic market is implemented in a distributed manner via a network structure in which so-called PowerMatchers, as depicted in figure 2, coordinate demand and supply of a cluster of devices directly below it. The PowerMatcher in the root of the tree performs the price-forming process; those at intermediate levels aggregate the demand functions of the devices below them. A PowerMatcher cannot tell whether the instances below it are device agents or intermediate PowerMatchers, since the communication interfaces of these are equal. This ensures a standardised interface for all types of devices.

The root PowerMatcher has one or more associated market mechanism definitions, which define the characteristics of the markets, such as the time slot length, the time horizon, and a definition of the execution event (e.g. "every 5 minutes", "every day at twelve o' clock"). When an execution event occurs, the root PowerMatcher sends a request to all directly connected agents to deliver their bids. The device bids are aggregated at the intermediate matchers and passed on upwards. The root PowerMatcher determines the equilibrium price, which is communicated back to the devices. From the market price and their own bid function each device agent can determine the power allocated to the device.

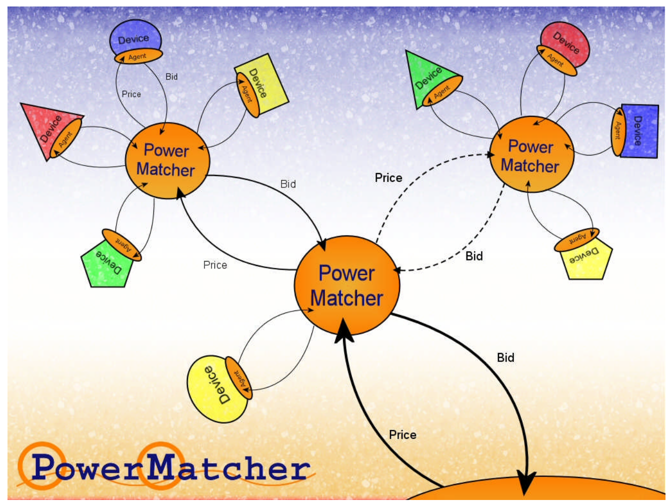

Figure 2: The PowerMatcher architecture; coming from a hierarchy based mechanism, growing towards a more organic, network of networks.

A number of different architectures may be derived from the above general concept, in which intermediate matchers can have local responsibilities such as preserving network constraints, leading to different price-forming scenarios such as locational marginal pricing (LMP) [9]. Also at each level in the network business agents may input their goals at PowerMatcher nodes in the form of standardised bid function. Thus a DNO may trigger demand (and supply) response actions in a PowerMatcher market. The main difference with traditional demand response is that the device agents are operated autonomously, yet reaching the desired result.

IV. FIELD TEST DESIGN

The households participating in the field test were provided with a virtual power plant node or VPP-node (see figure 3). The agents run on these VPP-nodes, communicating with the local infrastructure (μ-CHP, thermostat, e-meter) through power line and with the PowerMatcher server through wireless communication (UMTS). This server was placed at our ECN premises and contained the market coordination algorithm. The end users communicated with the system by means of the thermostat. An earlier field test showed the importance of an adequate back-up strategy in case of malfunctioning of the system, which was provided by the conventional thermostat control. The resulting system served as a virtual power plant, controlling the user's heat demand without infringing the user's thermal comfort.

The main goal for the field test has been formulated as follows: demonstrate the ability of a cluster of μ-CHP units operated in a virtual power plant to reduce the local peak demand of the common low-voltage grid segment. Since the μ-CHP units were not bound to one location, a virtual substation has been included in the cluster. The demand pattern of this substation is based on a pattern, developed by IVAM [1], that comprises the electricity demand of a 100 households in The Netherlands. The substation agent was placed at the central PowerMatcher server.

Figure 3: VPP-controller

V. FIELD TEST DATA ANALYSIS

In the field test only 5 μ-CHP units were consistently in operation without disturbances. The other 5 units were placed in remote locations where UMTS communication was unreliable. The virtual substation places bids on the market based on the IVAM demand pattern, resulting in high prices in the market in peak periods and low prices otherwise. High market prices trigger the μ-CHP units to produce electricity, thus reducing the substation load. In house the μ-CHP units will only produce in case of heat demand, either for space heating or for tap water heating. No waste heat is produced.

Figure 4 shows the operation for one day in May 2007. Five μ-CHP units were participating. There is no space heating demand, only demand for tap water heating. The figure shows four demand peaks at the substation, of which the third peak is the least compensated. The second peak takes care of the larger part of the heat demand for tap water. At the third peak, following immediately after the second peak, the heat demand is already largely satisfied. Such a sequence of peaks can no doubt be compensated better during the winter season because of a continuous space heating demand. Simulations have confirmed this expectation.

[1] IVAM is a research and consultancy agency in the field of sustainability, originating from the Interfaculty Environmental Science Department of the University of Amsterdam.

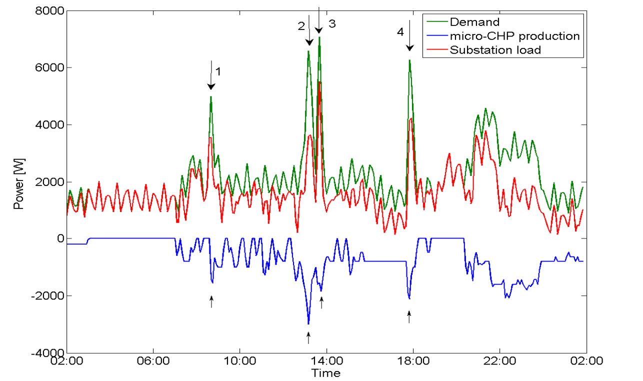

Figure 4: Time series of the substation demand pattern (green), the total μ-CHP production (blue) and the net substation load (red) for 5 μ-CHPs with PowerMatcher coordination.

In figure 5 for the same period as in figure 4 the load duration curves has been drawn for three different scenarios: total substation demand, substation demand with μ-CHP units in a fit and forget strategy, and with PowerMatcher coordinated μ-CHP units. The fit and forget strategy is based on (simulated) conventional control with comparable heat demand as in real life. The conventional strategy is unable to reduce the peak load of the substation, and if it would have done so it would have been based on coincidence. Also we see a net supply to the grid during some periods. The PowerMatcher coordination leads to a much more flattened load duration curve.

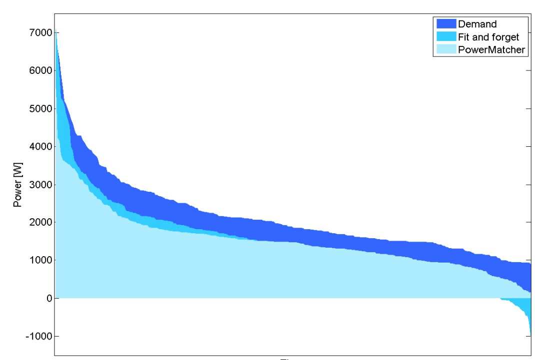

Figure 5: Load duration curve of the substation demand pattern without μ-CHP, with μ-CHP in a fit and forget strategy, and with PowerMatcher coordinated μ-CHP.

The PowerMatcher coordinated μ-CHP show a significant drop in peak load. Even the highest (third) peak from figure 4 leads to a peak period of around 5 kW, which is way below the uncoordinated case which reaches 7 kW, a reduction of almost 30%. In simulated cases even more reduction could be reached for households with a higher tap water demand. It should be noted that the households in the field test showed less than average tap water usage.

Unfortunately we didn't manage to put the whole system in place before the winter season ended. Therefore supporting simulations were made for the winter season, indicating a further possible peak reduction up to 50%. This figure is even more plausible since simulations showed up to a large extent the same results for the summer season as the actual field test outcome. Another finding of the simulations is that in the PowerMatcher coordinated strategy the gas usage is almost equal to the gas usage for conventional control, but the electricity production is 7% higher, due to the fact that the PowerMatcher exploits the booster mode of the μ-CHP better, which has a higher electricity efficiency.

VI. User experiences

The end users in the field test showed a high interest in their energy usage and especially in a comparison with other users. This may become an important feature of distributed generation by households.

The allowed bandwidth of the room temperature turned out to differ for the different households. Some end users allow a bandwidth of 2ºC (1ºC above and 1ºC below the setpoint), while others allow much less deviation. Note that a 2ºC bandwidth only denotes a maximum deviation of 1ºC, not a continuous deviation. The bandwidth is the main factor for the flexibility of the μ-CHP and hence the value for the VPP.

The apparent loss of control over thermal comfort seems to be a main obstacle for participating in a virtual power plant cluster. It is important to stress that the μ-CHP only negotiates on the optimal times for operation, without infringing the thermal comfort. In this respect the virtual power plant control is not different from any other type of thermostat control.

The reaction time of the μ-CHP in the field test is not as fast as the conventional gas heaters used in The Netherlands, resulting in slower heating of the room. Misinterpretation of this characteristic may lead to problems in the acceptance of the virtual power plant control. Good information on this issue is required. With newer generations of μ-CHP, having a built-in supplementary burner, this problem may disappear.

A good helpdesk is indispensable for a successful field trial. Disturbances at first were not handled adequately because too many parties were involved. After establishing one point of handling at the ECN premises we easily could localise and solve problems by remote connection. Remote maintenance may even become a main feature of a Smart Power System.

VII. Conclusions

The PowerMatcher agent concept seems to works very well for virtual power plant control. Without any intrusion on comfort for consumers the market-based control leads to substantial peak load reduction. Other business concepts than peak reduction may also prove added value, such as 'optimal usage of own production', or ‘participating in imbalance services in a semi-autonomous grid’. Improved VPP performance can be reached with next generation μ-CHP systems that have higher electricity efficiency and with larger hot water buffers. In the field test a standard volume was used.

Technical issues may become a hinder for smooth implementation. UMTS proved to be less reliable than expected. Costs have to be brought down and miniaturisation of VPP-nodes is anticipated for in forthcoming projects.

A helpdesk for solving problems is essential to customer satisfaction in trials such as this. If problems are not solved smoothly, users are easily scared away from new concepts. One doesn't get a second chance.

μ-CHP is just one example of a device that has potential for market-based coordination. Other distributed generation may be included such as solar and PV, and storage systems. Also consuming devices may become part of a VPP. Heat pumps and air conditioners can provide ample flexibility in operation to participate in market-based coordination. Thus the PowerMatcher concept may also become a valuable tool in demand response programs.

VIII. Acknowledgements

A large number of people contributed to the implementation of the field test. The project would have been impossible without the support of the households that were willing to take part in the rollout. Eneco Energie, Essent Retail Services, Rendo Energie Service and Cogas Energie enabled the field test. The project has been initiated by the Dutch natural gas company Gasunie in cooperation with ECN and under auspices of the Smart Power Systems Consortium [1], an initiative of Energy Valley with GasTerra, Gasunie, Continuon, TNO, ECN, Essent Netbeheer B.V. , ENECO Netwerk B.V. Essent Energy Services, ICT Automatisering, TietoEnator, KEMA, TU Delft en N.V. Nom. Fred Kuijper was responsible for the technical part of the project. Sjaak Kaandorp, René van der Schilden, Paul Seignette and Roel van Rossum contributed to the design of the controller units and to establishing the ICT network for distributed control. The PowerMatcher development has partially been supported by the EU under the 5th framework programme as part of the project “CRISP - Distributed Intelligence in Critical Infrastructures for Sustainable Power” [10].

IX. References

[1] SPS has its own website: http://www.smartpowersystem.nl/.
[2] S.H. Clearwater (Ed.), “Market-Based Control — A Paradigm for Distributed Resource Allocation”. World Scientific, Singapore, 1996.
[3] J.M. Akkermans, J.F. Schreinemakers, J.K. Kok, “Microeconomic Distributed Control: Theory and Application of Multi-Agent Electronic Markets”, Proceedings of CRIS 2004 — 2nd International Conference on Critical Infrastructures, Grenoble, October 2004.
[4] J.M. Akkermans, J.F. Schreinemakers, J.K. Kok, “Emergence of Control in a Large-Scale Society of Economic Physical Agents”, Proceedings of the AAMAS’04 Conference, 2004.
[5] I.G. Kamphuis, P. Carlsson, C.J. Warmer, J.C.P. Kester and J.K. Kok, “Distributed Intelligence for Supply/Demand Matching to Improve Embedding of Distributed Renewable Energy Sources”, Proceedings of CRIS 2004 — 2nd International Conference on Critical Infrastructures, Grenoble, October 2004.
[6] J.K. Kok, C.J. Warmer, I.G. Kamphuis, "The PowerMatcher: Multi-agent Control of Electricity Demand and Supply", InM. Pechoucek and S.G. Thompson, "Agents in Industry: The Best from the AAMAS 2005 Industry Track, IEEE Intelligent Systems, March/April 2006.
[7] The PowerMatcher has its own website: http://www.powermatcher.net/.
[8] P. Carlsson, “Algorithms for Electronic Power Markets”, Ph.D. Thesis, Uppsala University, Sweden, 2004.
[9] Koen Kok & Hans Akkermans - Transport Network Feasible Solutions in Market-based Allocation of Flow Resources. in: Salvatore Pennacchio (ed.), Emerging Technologies in Robotics and Control Systems, , June 2007. ISBN: 978-88-901928-9-5.
[10] CRISP has its own website: http://www.ecn.nl/crisp/.