ECN-M--07-020

Massive coordination of dispersed using powermatcher based software agents

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To be presented at the 19th International Conference on Electricity Distribution, Vienna, 21-24 May 2007

January 2007

MASSIVE COORDINATION OF DISPERSED GENERATION USING POWERMATCHER BASED SOFTWARE AGENTS

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ABSTRACT

One of the outcomes of the EU-Fifth framework CRISP-project [http://crisp.ecn.nl], has been the development of a real-time control strategy based on the application of distributed intelligence (ICT) to coordinate demand and supply in electricity grids. This PowerMatcher [1] approach has been validated in two real-life and real-time field tests. The experiments aimed at controlled coordination of dispersed electricity suppliers (DG-RES) and demanders in distributed grids enabled by ICT-networks. Optimization objectives for the technology in the tests were minimization of imbalance in a commercial portfolio and mitigation of strong load variations in a distribution network with residential micro-CHPs. With respect to the number of ICT-nodes, the field tests were on a relatively small-scale. However, application of the technology has yielded some very encouraging results [2][3] in both occasions.

In the present paper, lessons learned from the field experiments are discussed. Furthermore, it contains an account of the roadmap for scaling up these field-tests with a larger of number nodes and with more diverse appliance/installation types. Due to its autonomous decision making agent-paradigm, the PowerMatcher software technology is expected to be widely more scaleable than central coordination approaches. Indeed, it is based on microeconomic theory and is expected to work best if it is applied on a massive scale in transparent market settings. A set of various types of supply and demand appliances was defined and implemented in a PowerMatcher software simulation environment. A massive amount of these PowerMatcher node-agents each representing such a devicetype was utilized in a number of scenario calculations. As the production of DG-RES-resources and the demand profiles are strongly dependent on the time-of-year, climate scenarios leading to operational snapshots of the cluster were taken for a number of representative periods.

The results of these larger scale simulations as well as scalability issues, encountered, are discussed. Further issues covered are the stability of the system as reflected by the internal price development pattern that acts as an 'invisible hand' to reach the common optimisation goal. Finally, the effects of scaling-up the technology are discussed in terms of possible 'emergent behaviour' of subsets in the cluster and primary process quality of appliances operating concertedly using the PowerMatcher.

INTRODUCTION

In the transition process of the electricity infrastructure to embed a larger proportion of renewable energy resources, small-scale distributed generators and flexibility on the demand side play an important role. Currently, micro-CHP is one of the first technologies promising to be introduced in the UK, Germany and the Netherlands in the transition to a more DG-RES dominated energy infrastructure. National initiatives are underway to promote the successor of the high-efficiency central heater, the HRE-heater (High-Efficiency (in Dutch: Rendement) and Electricity generating). Besides these developments on the supply-side, the demand-side currently is undergoing radical changes. In current market settings, having shiftable load, real-time prices and real-time performance data may lead to significant financial benefits. In the US and Australia demand response resources, enabled by ICT-connectivity on small appliances, has already been applied extensively in the US and Australia to optimize the grid as a standard resource, but also in critical situations [4].

Current ICT (software, hardware and connectivity) used for control of the power system only influences the upper grid levels using a top-down dispatch mechanism. Extending the span of control to lower levels using a centralized approach appears to be a formidable task from the control and ICT perspective. Orchestrating and maintaining a fine-grained ICT-network parallel to the power grid with communication nodes at major user devices maintaining high reliability and security constraints represents a challenge.

In a more bottom-up vision on the grid, a number of concepts are currently being developed. These include Large Scale Virtual Power Plants and MicroGrids, currently standing in the lime light of a number of EU-projects [5],[6]. Also, the economic model of the grid will have to account for the higher level of distributed generation for aggregation costs apart from distribution costs. At ECN, for a number of years now, there has been a development of a coordinating strategy concept, the PowerMatcher[1], for bottom-up control using software agents in a context of micro-economic markets. The PowerMatcher can be imagined as an invisible hand, leading an aggregated set of appliances to a common control objective.

POWER MATCHER ARCHITECTURE

The PowerMatcher was designed according to specifications derived in the CRISP-project [7]. The software consists of an auctioneer part and an agent part. The software is developed in C# (a Java-like successor of the object oriented C++ language) using the .NET-framework. In order to adapt the software for a specific situation, specific interfaces have to be implemented per client-node type. These pertain to the primary process interface and the communication interface. Primary process interfaces include systems connecting standard industrial PLCs (Programmable Logic Controllers) in wind turbine control systems in windparks, building management systems (Priva/TopControl, LONWorks, BACNet), domestic heatpumps (Itho) and micro-CHP controllers (WhisperGen, Crouzet). Communication protocols for distributed operation implemented include UMTS, GPRS and ADSL.

Because an extensive data collection and measurement program was part of the two field test projects, local nodes were implemented on standard industrial PCs with database functionality added. In order to relieve the burden of communication line set-up and facilitating multithreading in the auctioneer, between the first and the second field-test software versions, the auctioneer/agent communication was changed from an auctioneer polling the agents to a discovery protocol from the agents to the auctioneer.

FIELD TEST EXPERIENCES

Until now, there have been two field-tests with the PowerMatcher control strategy. In the first [3], optimization of a commercial portfolio of a programme responsible party on the Dutch day-ahead and imbalance market was performed. In the second, optimisation was performed from a DNO (Distribution Network Operator) perspective: flattening the load curve in an LV-Grid with a number of local co-generating micro-CHPs.

The PowerMatcher approach shifts the responsibility for operating appliances in a grid-friendly manner to the lowest possible level. This means the scope of autonomous operation also has to be confined to a very limited number of operational parameters depending on the primary process, served by the power consuming/producing entity. From a software engineering viewpoint, the PowerMatcher communicates via a very thin interface to a coordinating platform in the cluster. Based on the current state of the primary process of the electricity consuming/producing device, bids (the amount of power in a number of ascending price categories) are sent and allocations are returned after a market round. In the PVP-test, the distribution of generators and loads in the portfolio at certain occasions was not equilibrated enough to get a market equilibrium at all times; the portfolio, then, still optimally coordinates between the demand and supply side, but also imports and exports electricity. This particularly occurred, if the two wind parks in the portfolio produced less than the day-ahead forecast in periods, where this could not be compensated by demand and supply flexibility. On the other hand, over-realisation of production in the portfolio in most cases could be compensated for by autonomous supply reduction of other suppliers and demand shifting.

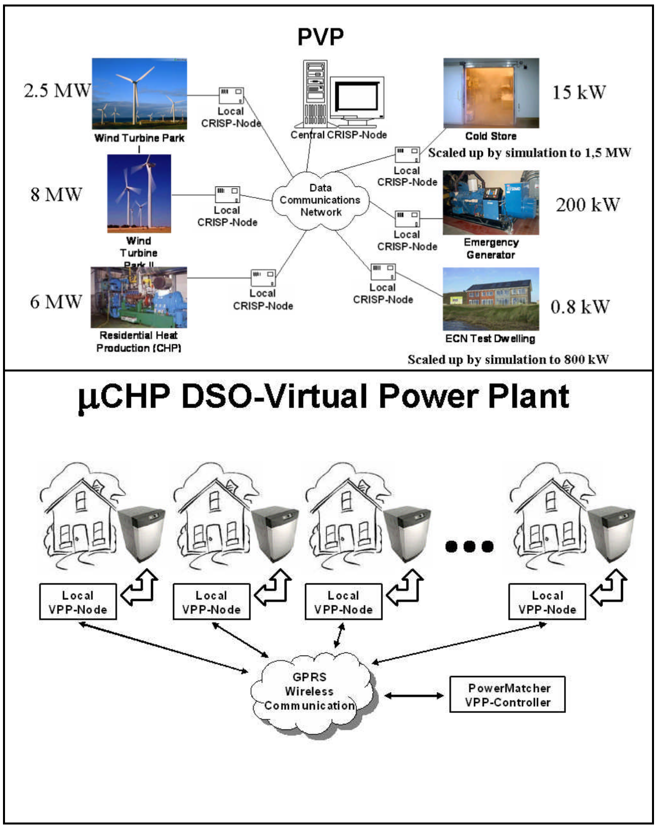

Figure 1 Field test settings

The PowerMatcher operates on a subsequent timeslot market-mechanism [1-15 minute intervals] with no communication between timeslots. Thus, encapsulating individual learning of the agents from bids and received allocations appear to be very important in further developments. This especially holds for the optimization of energy storage buffers.

As to the architecture and the implementation in the field-tests, it was possible to show, that a data communications infrastructure could be rolled-out and that a heterogeneous set of processes and process automation systems could be connected to the infrastructure in a flexible manner. Major difficulties were encountered in the implementation of communication protocols, originally expected to be straightforward. Especially navigating along the interpretation differences for message exchange between the implementers of .NET-remoting via UMTS and the designers of the standard took quite a lot of time. A similar situation was found for the implementation of protocol for a PLC thermostat that had to be adapted to be used in the second test.

Another important issue is end-user involvement and continuous support during the tests [8]. Therefore, during the first field-test intermediary meetings with a number of commercially active parties and an end-symposium with a presentation of the final results was organized. In the second field-test control hardware for heating equipment in homes was replaced with innovative variants with a more distant coupling between momentary user wishes and appliance behaviour via market mechanisms. User perception of comfort control, thus, sometimes slightly deviated from expected and needs individual attention during deployment.

MASSIVELY UPSCALING THE TECHNOLOGY

A simulation and verification environment of the PowerMatcher was defined to study the effect of massive numbers of agents in a number of different external contexts. In a generic way, the following devices with shiftable load or generation were included:

- An electricity consuming heat-generator. One could imagine a heat-pump in a residential home. Bids, generated in a certain price category, are dependent on the current deviation of the ambient temperature in a home, heated by the generator, from a set-point varying over the day.
- An electricity and heat producing co-generator. For this type of apparatus one could imagine a micro-CHP or a fuel cell. Bids vary as in the previous case from the set-point deviation. The heat demand for the next time-step is determined by the set-point deviation.

Fixed load or generation devices were included, that have a seasonally dependent behaviour.

- A solar radiation incidence dependent electricity producer. E.g. a solar cell. Sells full capacity in every price category.
- A fixed time-dependent load e.g. the lighting load of a house. This load buys unconditionally in each price category.

The grid environment in this constellation was defined by an external importer/exporter as actors. It acts as an intermediary that bids in depending on the current external market price-level and the transformer load compared to the maximally allowable load.

- An electricity storage battery with a certain load- and unload-efficiency and a volume.

A generic, simple physical model of a residential home is added to the simulation with a heat capacity and a gain/loss of heat per time-unit depending upon the difference of the ambient temperature in the home and outside temperature. Bids were specified by defining a set of 'eagerness'-figures to state the fraction of the total power of a device for selling or buying at a certain internal process state at different price levels.

In the simulations, 400 residential homes, each with 4 types of loads, were considered. Simulations were done in 15 minute time operational time-steps over a consecutive period of three days in a specific meteorological season. In figure 2 the results for a Spring/Autumn three day-period are depicted. In the upper plot the lower graph gives the outside temperature in dark-blue, the set-point temperature in blue and realized temperature for the heat pump heated dwelling and the co-generator heated dwelling in red and green respectively.

The difference between the internal temperature and the external temperature determines the current heat demand of either a heat-pump or a micro-CHP heated house. Slightly different 'eagerness' for selling and buying electricity, at different values of deviations from the set-point, lead to small differences between the realised heat-pump and co-generator temperature profiles as compared to their set-points.

The green curve in the middle plot, with a scale on the right hand side, indicates the momentary market equilibrium point varying between 1 and 100. Maximum supply excess is represented by 100; maximum demand excess by 0. The importer and exporter amounts in the middle plot are represented by the green and red lines respectively. It can be seen, that the internal market price formation, the result of applying the PowerMatcher-algorithm, is balancing supply and demand during the simulation period and acts as a control signal for the cluster. Finally, in the lower plot of figure 2, the amount absorbed or delivered by the buffer is shown, together with the artificial, time-dependent, price per unit (represented on the right-hand scale). Given this boundary-price with a minimum during the morning, the heat-pump and the storage unit can be seen to compete for cheap electricity. During the day and, especially, the evening, the buffer is emptied because it competes with an increasing, time-dependent, external price. In this season, solar generation is relatively low, while, especially in the evening, the lighting load adds to the import.

The behaviour of the market equilibrium signal for a more unbalanced portfolio is depicted in figure 3 for a number of season-bound external meteorological circumstances with varying PV-yields, outside temperatures (thus, heat demands) and lighting load profiles (varying in duration and required power). It can be seen, that market equilibrium (on a scale between 0 and 100 for the lowest and highest price categories) is maintaining the supply, demand and storage load/unload balance using the economic agent algorithm and leads to reproducible results over a consecutive period of three days in three different seasons. The price-based allocation, based on the primary process status acts as a common control signal. The interests/eagerness of each participant in the cluster for achieving the common target are considered. Further investigations are necessary to unveil the effects of bringing more heterogeneity in the cluster and especially to bring in the variability of user behaviour in each of the dwellings.

CONCLUSION AND FURTHER WORK

The field-tests and simulations show, that using flexibility in operation on the demand, supply and storage side using a PowerMatcher approach appears to be feasible on the small-scale field-test level as well as on the large scale simulation level to reach an optimisation goal. Relatively small internal adaptations of the control strategy of appliances allow utilizing a local context cluster for an optimisation goal including optimal buffering of a shared resource. Due to the limited communication interface and the relatively simple balancing algorithm, the scalability of the algorithm appears to be very good.

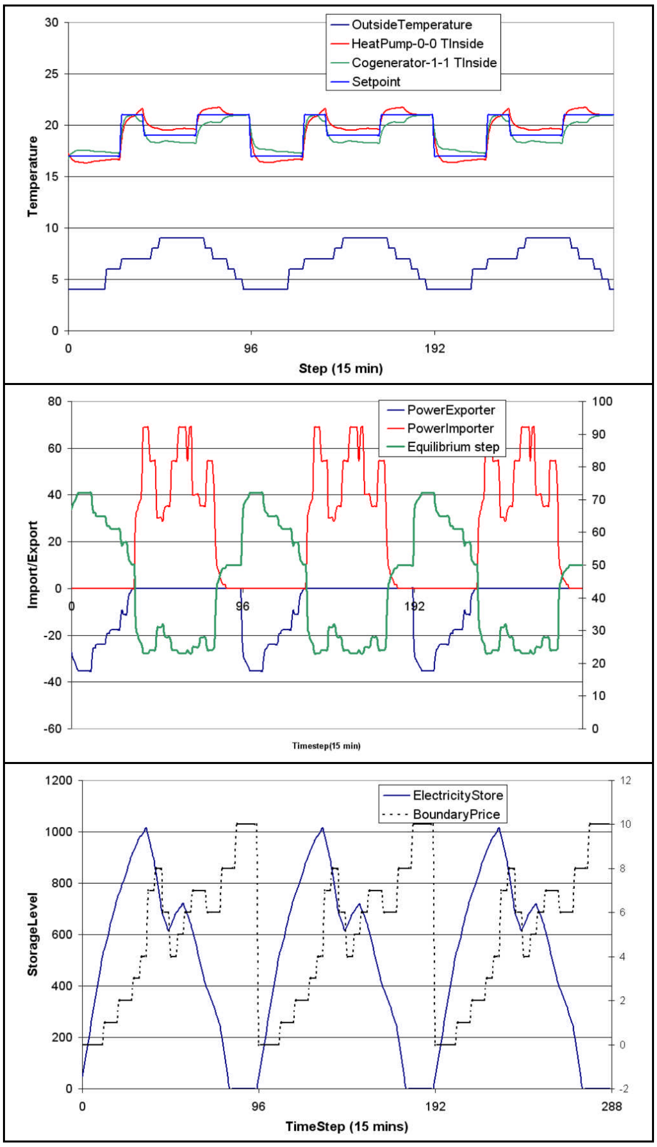

Figure 2 Spring/autumn 3-day scenario

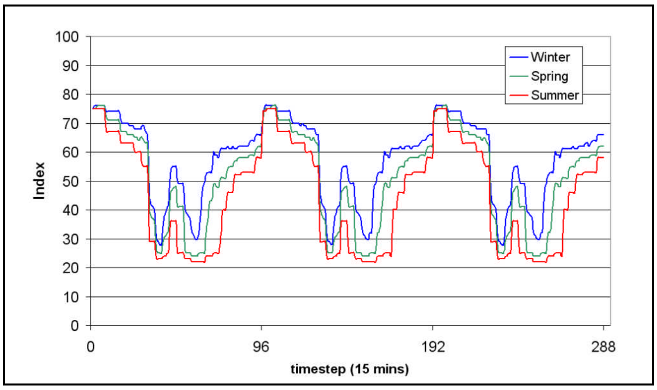

Figure 3 Market equilibrium for three seasons

Further work will be performed in optimising the buffer strategy using techniques that are based on learning from built-up experience and optimisation to comply with more than one simultaneous optimisation target. E.g. simultaneously optimize a market portfolio within distribution network constraints.

Work will also involve right-scaling the PowerMatcher technology and architecture. In this respect, upcoming new WEB service oriented architectures and deployment models on one-hand and appliance communication protocols for small embedded devices like ZigBee are relevant. They will enable energy service providers to extend their portfolio with possible low-cost Value Added Services (VAS).

REFERENCES

[1] K. Kok, C. Warmer and I.G. Kamphuis, The PowerMatcher: Multiagent Control of Electricity Demand and Supply in M. Pechoucek and S.G. Thompson *"Agents in industry: The Best from the Aamas-2005 Industry Track. IEEE Intelligent Systems. March/April 2006*.

[2] G.J. Schaeffer, C. Warmer, R. Kamphuis, M. Hommelberg and K. Kok, 2006, "Field tests applying multi-agent technology for distributed control: virtual power plants and wind energy", *Proceedings of the CRIS Workshop October 2006, Magdeburg*.

[3] C. Warmer, M. Hommelberg, R. Kamphuis, K. Kok, 2006, Wind Turbines and Heat Pumps - Balancing wind power fluctuations using flexible demand, *Proceedings of the 6th International Workshop on Large-Scale Integration of Wind Power, Delft*.

[4] A summary of the IEA/Demand Response Resources project can be found on www.demandresponse-resources.com.

[5] European Commission. Sixth Framework programme. European distributed energy resources projects. EUR 21239. Brussels, 2004. *and* European SmartGrids Technology Platform. Vision and Strategy for Europe's Electricity Networks of the future. EUR 22040, Brussels, 2006.

[6] Fenix. See http://www.fenix-project.org/ for a summary of the project and the current status.

[7] CRISP. Distributed Intelligence in Critical Infrastructures for Sustainable Power. *Project Summary brochure . ECN, 2006. (See http://www.crisp.ecn.nl)*

[8] Jaap Jelsma, René Kamphuis, Wim Zeiler. Learning about smart systems for comfort management and energy saving in office buildings. *ECEEE Summer school contribution 2003, Nice France. ID-6088*.