VIRTUAL POWER PLANT FIELD EXPERIMENT USING 10 MICRO-CHP UNITS AT CONSUMER PREMISES

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ABSTRACT

It is expected that μ-CHP units in households will penetrate the market in the Netherlands at high speed in the coming few years. As a result, the consuming households will then also produce electricity, which makes them suitable for local management of the grid. Using ICT, the μ-CHPs can be clustered in a virtual power plant (VPP). One application of such a VPP is the reduction of peak loads in the local substation by shifting the μ-CHP operation to moments when there is a large demand in electricity. In a field test conducted by ECN and Gasunie, it was found that a cluster of 10 households, each equipped with a μ-CHP is able to reduce the substation peak load with 30-50% without infringement of the user comfort.

INTRODUCTION

In the North-Western region of Europe, decentralised generation of heat and power by combined heat and power units in households (μ-CHP) is expected to penetrate the market at high speed in the coming years, because of the existing gas infrastructure. These μ-CHPs have the potential to offer flexible power that can 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-CHPs together with other decentralised units, such as PV, wind turbines, heat pumps and local electrical storage, by using ICT turns the system into a Smart Power System (SPS, [1]).

In The Netherlands, ECN and Gasunie have conducted a field test in which a cluster of ten Stirling based μ-CHP units of 1 kW electric each has been operated as a virtual power plant. The main goal of the field test was 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 were 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.

MARKET-BASED CONTROL USING MULTI-AGENT TECHNOLOGY

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. Recently, a systems-level theory of large-scale intelligent and distributed control was formulated [2], [3]. This theory unifies microeconomics and control theory into a multi-agent system, and subsumes the agent research applications and simulations as described above.

ECN has developed the PowerMatcher [6] 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 [5]. 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 [4]. Each device is represented by a software agent that tries to operate the process associated with the device in an economically optimal way, so no central optimisation algorithm is needed and the communication overhead in contact with an auctioneer is very limited. The only information that is exchanged between the agents and the agent platform (the electronic market) are bids [7]. These bids express to what degree an agent is willing to pay for or receive a certain amount of electricity. As a response the market clearing

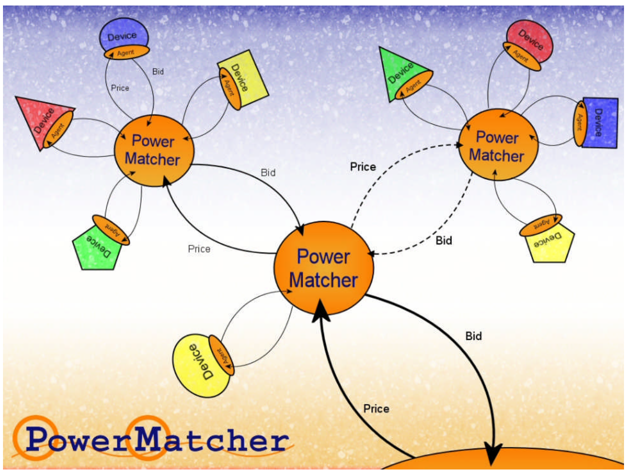

Figure 1: The PowerMatcher architecture; coming from a hierarchy based mechanism, growing towards a more organic, network of networks.

price is returned, so the agent knows how to act; start producing (resp. consuming), or wait for the next bidding round. The electronic market is implemented in a distributed manner via a network structure in which so-called PowerMatchers, as depicted in figure 1, 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.

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 so called business agents may input their business oriented 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 based on real-time load profiles. The main difference with traditional demand response is that the device agents are operated autonomously, yet reaching the desired result.

FIELD TEST DESIGN

The field test focused on the network utilization factor of the local distribution grid in three different settings. The first setting is the baseline setting, in which only the domestic load profiles of 10 households, while no μ-CHPs were present. A load pattern was used, developed by IVAM[1], comprising the electricity demand of households in The Netherlands. The second setting comprises the load profile of 10 households plus a μ-CHP in each household, operated in a standard heat-demand driven manner (fit-and-forget). In the third setting, the μ-CHPs are controlled by the PowerMatcher intelligent control in peak-load reduction mode, without any intrusion on comfort for residents.

The households participating in the field test were provided with ICT containing a virtual power plant node or VPP-node. The agents run on these VPP-nodes, communicating with the local infrastructure (μ-CHP, thermostat, and e-meter through power line and with the PowerMatcher server through wireless communication (UMTS). This server was placed at the 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 virtual substation places bids on the market based on the IVAM demand pattern, issuing 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.

An additional simulation study was done to verify the findings in the field test and to investigate circumstances not engaged in the field experiment.

RESULTS

A number of households were located in remote areas, where UMTS communication was not always reliable. In the field test only 5 μ-CHP units were consistently in operation without disturbances.

The field test was conducted in May 2007, which was an exceptionally warm month for The Netherlands. Therefore there was no space heating demand in the households, only demand for tap water heating. All households are equipped with 120 litre tap water storage. Figure 2 shows the operation for a single day during the field test in which five μ-CHPs were participating. The demand curve (green) is the total electricity demands of the households and four peaks can be identified. The PowerMatcher shifts the μ-CHP production (blue) so that electricity is produced when there is a high demand for electricity. The third peak is the least compensated. The second peak takes care of the larger

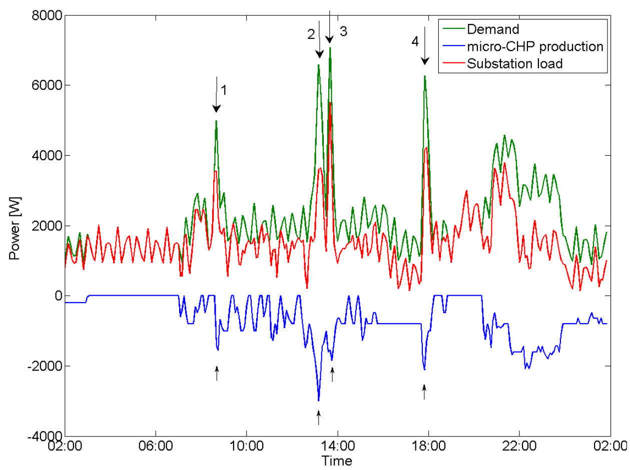

Figure 2: Field test results of clustered control of 10 micro-CHPs at consumer premises aimed at reduction of domestic peak demand. Synchronisation of CHP output (red) with domestic peak-demand (green) leading to peak load reduction at the transformer (blue).

[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.

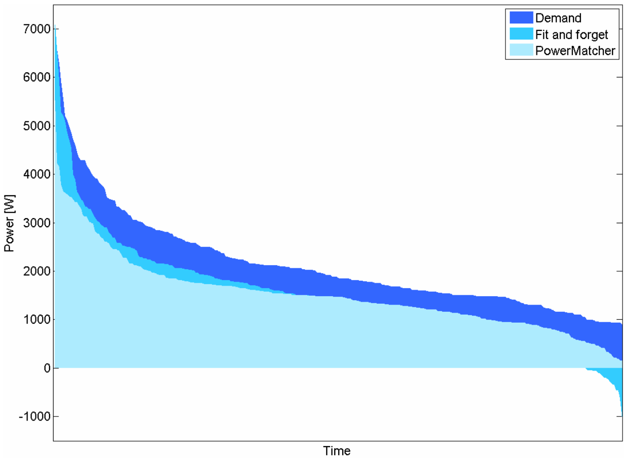

Figure 3: Load duration curve of the substation demand pattern without μ-CHP, with μ-CHP in a fit and forget strategy, and with PowerMatcher coordinated μ-CHP.

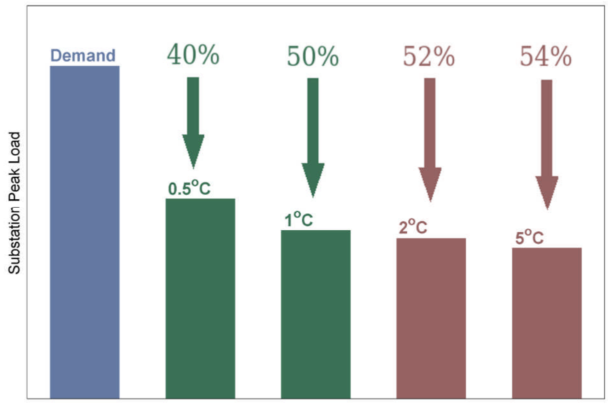

Figure 4: Simulation results for a period in November for different allowed deviations of the room temperature set point.

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 be compensated better during the winter season because of a continuous space heating demand. Simulations have confirmed this expectation.

The final substation load in figure 2 is depicted in red. A different way to look at the results is by means of a load duration curve. Figure 3 shows such a curve for a period of one week where three scenarios have been drawn: 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.

The PowerMatcher coordinated μ-CHP show a significant drop in peak load. Even the highest (third) peak from figure 2 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%. After validation of the simulation on the measured field test data it became clear that 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, possibly since the households in the field test were already environmentally friendly.

Unfortunately it was not managed 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%. 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.

A number of simulations were performed to study the effect of the allowed deviation of the room temperature set point on the peak load reduction. Figure 4 shows the substation peak loads for five different scenarios: the peak load when there are no μ-CHP units in the grid and four cases with PowerMatcher controlled μ-CHP units, each time with a different temperature bandwidth. A deviation of half a degree Celsius from the room temperature set point reduces the peak load with about 40% on a typical winter day. When the temperature deviation is doubled (1ºC), the total peak load reduction is 50%. However, increasing the temperature deviation even more (2 ºC and 5 ºC) results in a minimal additional effect on the peak load reduction. So not only is a temperature deviation of 1ºC perfectly acceptable in terms of user comfort, it also results in near optimal peak load reduction.

CONCLUSIONS

It has been shown that the PowerMatcher agent concept works very well for virtual power plant control. Without any infringement of user comfort, the market-based control leads to substantial peak load reduction of 30% in summer and 50% in winter. A Fit-and-Forget policy did not provide benefits to the DNO in comparison to the baseline case. The load-duration curve was lowered on average by adding the μ-CHPs. However, the peak load remained virtually unchanged.

The PowerMatcher can also exploit the use of the CHP's booster mode in an optimal way, producing on average more electricity than in a fit-and-forget policy, without consuming significant more amounts of gas.

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 as an improved alternative for demand response programs.

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