FIELD-TEST UPSCALING OF MULTI-AGENT COORDINATION IN THE ELECTRICITY GRID

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ABSTRACT

With the share of distributed energy resources and renewable energy source (DER/RES) rapidly increasing in the electricity grid, a new way of coordination is required to look after the interests of all the stakeholders. The PowerMatcher multi-agent coordination concept has been demonstrated in two relatively small field tests, in which a single optimisation goal was achieved. Currently, a new field test is designed to test the PowerMatcher concept, where it coordinates up to one hundred DER/RES devices in approximately thirty households, with different stakeholders and multiple (potentially conflicting) optimisation goals involved.

INTRODUCTION

To meet the European Union five times twenty target (20% renewable energy, 20% reduction of CO_2 emissions and 20% reduction in energy consumption in 2020), there is a strong focus on the development and implementation of renewable (wind, solar) and highly efficient energy resources, e.g. combined heat and power (CHP) and heat pumps. The result is an increasing share of (partially) stochastically-behaving distributed generation in the electricity grid, which usually does not follow the electricity demand. For both technical and commercial optimisation of the electricity infrastructure and electricity generation, ECN has developed the PowerMatcher concept [1-2], which implements market-based coordination using multi-agent technology. The PowerMatcher was first tested in the CRISP field test [3], where a cluster of four types of (partially simulated) flexible devices (heat pump, CHP, diesel generator and cold store) were used to reduce the imbalance caused by two wind turbines. This article will discuss a more recent field test which utilised a cluster of nine micro-CHP units to reduce the peak load of a substation. Furthermore, a larger upcoming field test in which thirty households will participate with a variety of energy resources will be discussed.

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 of optimally achieving their local control action goals. A systems-level theory of large-scale intelligent and distributed control was formulated [4-5], which unifies microeconomics and control theory into a multi-agent system for market-based control.

ECN has developed the PowerMatcher concept for coordination of supply and demand in electricity networks, with a large share of distributed generation that implements the above market-based control. It is developed to optimally use electricity producing and consuming devices to alter their operation in order to increase the over-all match between electricity production and consumption [6]. Each device is represented by a software agent. These agents attempt to operate the associated process in an economically optimal way, whereby no central optimisation algorithm is necessary and communication with an auctioneer is 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 or be paid for a certain amount of electricity. As a response, the market clearing price is returned to the agent which reacts appropriately; start producing (or consuming), or wait for the next bidding round. The market is implemented in a distributed manner via a network structure. As depicted in figure 1, so-called PowerMatchers, coordinate the demand and supply of a cluster of devices directly below it. The PowerMatcher in the root of the tree performs the price-forming process, while those at intermediate levels aggregate the demand functions of the devices below them. Since the communication interfaces of both device agents and intermediate PowerMatchers are equal, an individual PowerMatcher is unable to distinguish between the instances below it. This property ensures a standardised

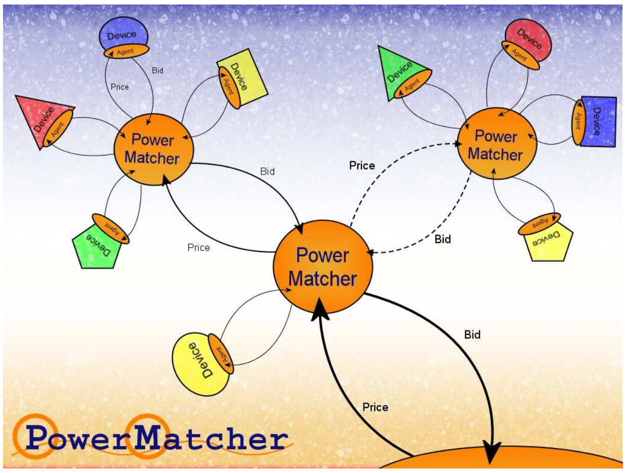

Figure 1: The PowerMatcher architecture; coming from a hierarchy based mechanism, growing towards a more organic, network of networks.

interface for all types of devices.
A number of different architectures may be derived from the above general concept. For one, intermediate matchers can have local responsibilities such as preserving network constraints, leading to different price-forming scenarios such as locational marginal pricing (LMP) [8]. Also, at each level in the network so called "business" agents can input their business oriented goals to the PowerMatcher nodes in the form of standardised bid functions. 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 based on the status of their primary process, yet reach the desired result.

VIRTUAL POWER PLANT FIELD TEST

In the Netherlands, ECN and Gasunie have conducted a field test in which a cluster of ten Stirling based micro-CHP units of 1 kW electric each have been operated as a virtual power plant. The micro-CHPs controlled both space and tap water heating. The main goal of the field test was to demonstrate the ability of a cluster of micro-CHP units, operating in a Virtual Power Plant (VPP), to reduce the local peak demand of the common low-voltage grid segment the micro-CHP units are connected to [10]. In this way, the VPP supports the local distribution network operator (DNO) to defer reinforcements in the grid infrastructure (substations and cables). Not all micro-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. MV/LV transformer) was assumed.

Field test design

The households participating in the field test were provided with a virtual power plant node or VPP-node. The software agents run on these VPP-nodes, communicating with the local infrastructure (micro-CHP, thermostats) through a power line with the PowerMatcher server through wireless communication (UMTS/GPRS). This server was placed on ECN premises and contained the market coordination algorithm. The end users communicated with the system by means of the thermostats used to control the space and tap water heating. An earlier field test showed the importance of an adequate back-up strategy in case of a malfunction in the system, this was assumed by the conventional thermostat control. The resulting system served as a virtual power plant, controlling the user's heat demand without infringing their thermal comfort.
The main goal for the field test was to demonstrate the ability of a cluster of micro-CHP units operating in a VPP to reduce the local peak demand of the common low-voltage grid segment. Since the micro-CHP units were not bound to one location, a virtual substation was included in the cluster. The demand pattern of this substation was based on a pattern, developed by IVAM[1] that comprises the electricity demand of one hundred households in the Netherlands. The substation agent was placed at the central PowerMatcher server.

Field test results

The field test focused on the network utilisation factor of the local distribution grid in three different settings. The first setting was the baseline setting, in which only the domestic load profiles of nine households and no micro-CHP were present. This load profile was provided by the IVAM demand pattern. The second setting was comprised of the load profiles of nine households plus a micro-CHP in each household and operated in a standard heat-demand driven manner (fit-and-forget). In the third setting, the micro-CHP was controlled by the PowerMatcher intelligent control in peak-load reduction mode without any intrusion of comfort for residents.
A number of households were located in remote areas where UMTS communication was not always reliable. In the field test, only five micro-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 were equipped with 120 litre tap water storage, from which the flexibility for optimisation was obtained. Figure 2 shows the operation for a single day during the field test. The demand curve (green) is the total electricity demand of the households and four peaks can be identified. The PowerMatcher shifts the micro-CHP production (blue) in such a way that electricity is produced when there is a high demand for electricity. In the net result load, depicted in red, it can be observed that the third peak is the least compensated. This is caused by a larger part of the heat

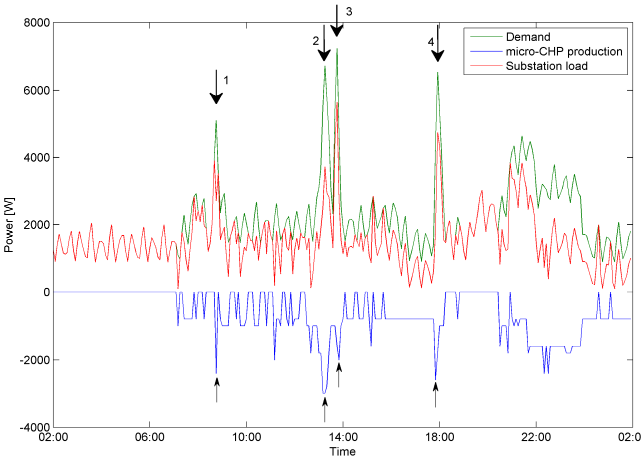

Figure 2: Field test results of clustered control of 5 micro-CHPs at consumer premises aimed at reduction of domestic peak demand. Synchronisation of CHP output (blue) with domestic peak-demand (green) leading to net substation load (red).

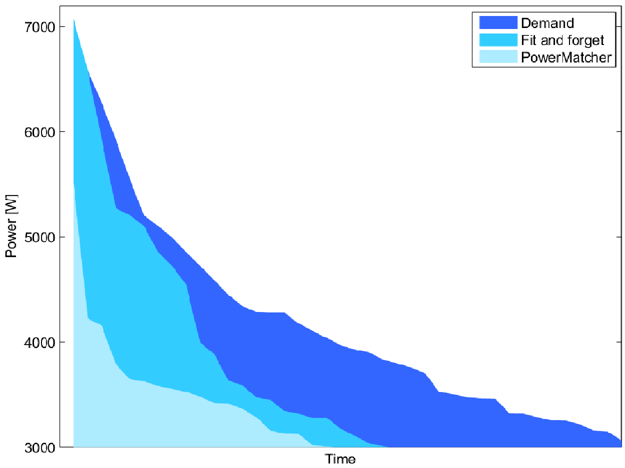

Figure 3: Load duration curves of the net substation load with no CHPs ('demand'), with traditional controlled CHPs ('fit-and-forget') and with PowerMatcher controlled CHPs.

demand being for tap water in the second peak and as a result, the heat demand during the third peak is already largely satisfied. Simulations have confirmed that such a sequence of peaks is expected to be compensated more efficiently during the winter season because of a continuous space heating demand.

In figure 3, for the same period as in figure 2, the load duration curves have been drawn for the three earlier described scenarios. The conventional "fit-and-forget" strategy was unable to reduce the peak load of the substation and if it would have done so it would have been based on coincidence. The scenario with the PowerMatcher coordinated micro-CHPs shows a significant drop in peak load. Even the highest (third) peak from figure 2 leads to a peak reduction from the uncoordinated case which 7 kW to a peak of around 5 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 did have 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 which indicated a further possible peak reduction of up to 50%.

MULTI-GOAL OPTIMISATION MODEL

The micro-CHP field test comprised only one objective, peak load reduction in a relatively small network. However, in real-life situations, large networks with many stakeholders involved and having multiple optimisation objectives for different scenarios should be expected. Each stakeholder has its own interest and these interests will conflict at certain periods in time. For example, a low price of electricity may stimulate consumption of electricity, but the immediate resulting increase in consumption may overload the grid locally. In one of the field tests of the European project INTEGRAL, the PowerMatcher is being tested in these conditions.

INTEGRAL field test objectives

The INTEGRAL project aims to build and demonstrate an industry-quality reference solution for distributed energy resources (DER) aggregation-level control and coordination based on commonly available ICT components, standards and platforms. Three field tests will be conducted in this project under respectively normal, critical and emergency operation of an electricity grid with a large share of DER and renewable energy sources (RES). The three field tests will lead to an integrated control concept.

The field test Demonstrator A of the INTEGRAL project, also known as *PowerMatching City*, aims to demonstrate control of DER under normal operational circumstances and how this can support the implementation of RES in the electricity grid. During the field test, the implementation of the PowerMatcher concept takes into account stakes of three different stakeholders:

- The Prosumer is a consumer that is capable of generating electricity also by means of DER/RES devices like a micro-CHP or a PV solar system. Such a Prosumer primarily wants to maximise the economic value of their investment in such devices. This means, in practice, that they want to maximise the revenues of the electricity that they produce as well as minimise the costs for their consumption of energy.
- The Distribution System Operator (DSO), whom operates the grid, wants to limit load fluctuations as much as possible by optimising the usage of their assets in this way.
- The Commercial Aggregator (CA) trades electricity, in other words, delivers electricity to the Prosumers or buys it.

Figure 4 shows the dual optimisation market that is adopted, and depicts the commercial and technical optimisation comprises on which these three stakeholders operate. The objective of this field test is to find an optimal control solution for the electricity consuming and producing devices, under normal conditions, so that the interests of all stakeholders are respected as fair as possible. An essential part of this objective is that it should respect the ideas of the

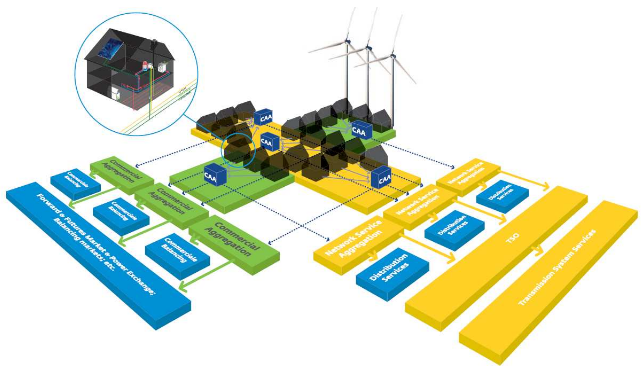

Figure 4: The adopted dual market for commercial and technical optimisation.

liberalised energy markets. This objective should, of course, be reached without sacrificing end user comfort or functionality.

Field test design

The field test consists of a cluster of about thirty real life households with two supplemented laboratory sites, resulting in a total of approximately one hundred DER/RES devices. The devices range from micro-CHP, heat pumps, photovoltaic, (urban) wind, white goods (laundry) as well as electric mobility. Implementation of the coordination will be done by creating a Virtual Power Plant (VPP) based on the PowerMatcher concept. Three types of coordination of DER/RES devices will be developed and demonstrated:

- Technical coordination (stake of the DSO)
- Commercial coordination (stake of the Commercial Aggregator)
- In-home coordination (stake of the household).

The multi-type coordination of the system is achieved by using a multi-layered PowerMatcher network, as shown in figure 5. The PowerMatcher network will consist of a top-level Auctioneer and a number of Aggregators acting as intermediates at three different locations. Each household will be equipped with a HomeMatcher that aggregates the local agents that controls each DER/RES device in a household. The Demonstrator A field test is scheduled to be operational in the course of 2009.

CONCLUSIONS

In this article it has been shown that the PowerMatcher is a proven concept to coordinate the supply and demand of electricity in systems with a large share of distributed energy resources. The PowerMatcher has proven that it can optimise commercial and/or technical objectives through two field tests (CRISP and micro-CHP). A multi-goal optimisation model has been developed for the PowerMatcher as part of the project INTEGRAL and will be field tested in the near future.

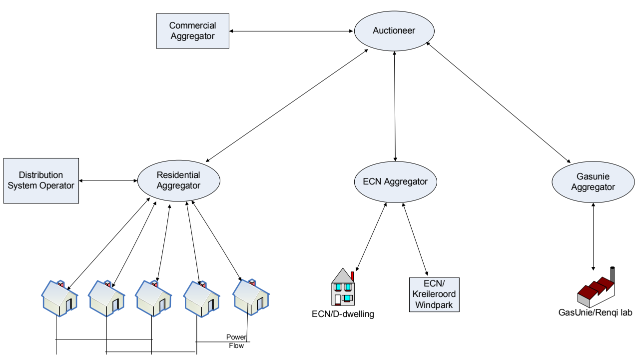

Figure 5: The multi-layered network in PowerMatching City.

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