Market Optimization of a Cluster of DG-RES, Micro-CHP, Heat Pumps and Energy Storage within Network Constraints: The PowerMatching City Field Test

René Kamphuis[1], Bart Roossien[1], Frits Bliek[2], Albert van de Noort[2],
Jorgen van de Velden[3], Johan de Wit[4], and Marcel Eijgelaar[5]

[1] Unit Efficiency and Infrastructure, Energy research Centre of the Netherlands,
Westerduinweg 3, P.O. Box 1, 1755 ZG Petten, The Netherlands
`kamphuis@ecn.nl, roossien@ecn.nl`
[2] KEMA Gase Consultancy Services, Groningen
`f.w.bliek@gasunie.nl, albert.vandenoort@kema.nl`
[3] Humiq, Groningen
`jorgen.van.de.velde@ihumiq.nl`
[4] Humiq, Groningen
`johan.de.wit@humiq.nl`
[5] Essent, Den Bosch
`marcel.eijgelaar@essent.nl`

Abstract. The share of renewable energy resources for electricity production, in a distributed setting (DG-RES), increases. The amount of energy transported via the electricity grid by substitution of fossil fuels for mobility applications (electric vehicles) and domestic heating (heat pumps) increases as well. Apart from the volume of electricity also the simultaneity factor increases at all grid levels. This poses unprecedented challenges to capacity management of the electricity infrastructure. A solution for tackling this challenge is using more active distribution networks, intelligent coordination of supply and demand using ICT and using the gas distribution network to mitigate electricity distribution bottlenecks.

In the EU FP6 Energy Program Integral[1] project, a large scale heterogeneous field test has been designed for application of the software agent based PowerMatcher technology. The test is conducted in a suburb of Groningen, Hoogkerk, and entails approximately 30 homes with either a 'dual fuel' heating system (electrical heat pump with gas-fired peak-burners) or a micro-CHP. Homes also may have PV. Furthermore, a wind production facility and nodes with electricity chargers for EVs and electricity storage are part of the Virtual Power Plant cluster, constructed in this way.

Domestic heating systems have intrinsic operational flexibility in comfort management through the thermal mass of the dwellings. Furthermore, the field test comfort systems are equipped with possibilities for hot water storage for central heating as well as for tap-water. Finally, having additional gas-fired heating capacity for electrical heat-pumps adds to increasing flexibility by switching the energy source dependent on the status of the electricity grid.

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Purpose of the field test is using this flexibility to react to phenomena in the electricity system.

- From a commercial perspective, the aggregated cluster reacts on small-time scale events like real-time portfolio imbalance, compensation of ramp-up and ramp-down induced phenomena of large generators and compensating for variable output of renewables like PV and Wind. Aim for the latter is to reduce the margin between realization and forecast of a portfolio containing these resources.
- From a distribution perspective, the total load on the transformer is monitored and coordination also involves diminishing this load during peak periods to improve the utilization of grid components and increase their lifetime.

An extensive socio-economic study is performed on user perception of the control of these new types of installations. In this paper, the component configuration and set-up of the field-test and the architecture of the ICT-network for coordination are discussed. The test has commenced in December 2009.

1 Introduction

In the EU there are strict targets for 2020 in terms of energy efficiency increase (20%), carbon dioxide reduction (20%) and energy produced from renewable energy sources (RES) (20%). In certain countries, plans exist to set these targets even higher for individual nations as for instance the Netherlands. However, the introduction of renewable embedded generation, in a dispersed setting, at a large scale and spread over a large area reaches the limits of central control. Central coordination concepts, influencing prosumers at low levels in the grid, lead to an increase in complexity, system management and cost. Dispersed generation with distributed ICT and bottom-up coordination mechanisms isolates responsibilities and allows decision-making and coordination based on the local primary process connected to the supplier or demander of electricity. It also allows DER units to connect and disconnect at will and pre-empts for all (future) DER types. Also, multi-actor interaction requires local and global balancing of stakes and local and global coordination exceeding ownership boundaries, facilitating decision making locally on local issues and alignment to liberalized energy markets.

In the market design of traditional electricity grids, end-users having shift-able energy or capacity are treated in a similar way as end-users demanding energy at peak prices. All end-user consumption is averaged in profiles, according to which cost are attributed following the mix in the development of commodity prices, bilateral contracts and so on in the markets forming the portfolio. Therefore, the full potential of flexibility on the demand side is not unveiled. Indeed, the way small customers are accounted for in current markets even acts against utilizing flexibility. A similar story can be told for integration of variable output DG-RES resources, which sometimes lead to more carbon emission because of the required extra generation capacity needed to compensate for intermittent fluctuations.

Not only the energy price picture does not map the system costs to the real world; indeed, a similar mechanism also holds for mapping the distribution cost to the real world. As an example, consider having a large HVAC-related domestic load at peak commodity price periods in moderate climate zones. Effects on the system are accounted for via the profiling of the household and the fixed capacity tariff limits.

Fixed capacity tariffs are no problem if they are time-dependent. Ideally, with a perfect mapping of cost on environmental impact, operating the electricity system using commercial markets would be optimal. However in reality there are a lot of market imperfections and there is no level playing field between different countries.

In the market view in this experiment an abstracted, more or less optimal mapping is assumed to pick up the optimal operation perspective for each device. Stakeholders in the experiment are the energy delivery related parties like retailers, traders and prosumers and the capacity related parties like transmission, distribution operators and – again - prosumers. Benefits for them using the technology developed are different per stakeholder. For retailers and prosumers, the overall energy bill will be lower due to sharing the revenues of the coordination mechanism. For the program responsible parties and the balancing responsible parties the benefits will come from much more accurate knowledge of their actual market position in real-time as well as the opportunity to foster the benefits of helping to diminish the overall system imbalance (both actively and passively). The INTEGRAL project aims to build and demonstrate an industry-quality reference solution for DER aggregation-level control and coordination, based on commonly available ICT components, standards and platforms. In one of the experiments of this project, the PowerMatcher technology [IEEE-PES, 2008, IEEE-NGI, 2008] is used for bottom-up coordination of a heterogeneous cluster of energy supply, demand and storage with a large number of smart IT-nodes in a communication network, each presented by a software agent.

2 ICT in Automated Grids, Smartgrids and Intelligent Grids

Discrimination has to be made between Automated Grids, Intelligent Grids and Smart Grids once looking at the integration of ICT-technology with electricity grids. In automated grids, which have been around for quite some time now, functions operated manually by an operator, are substituted with automated functions. Intelligent grids are grids equipped with distributed ICT to achieve a common optimization goal via an ICT enabled application. Intelligent in this sense means operating grids using extended context information from the capillary level (at the level of individual devices) to the highest HVDC connection level. Intelligent also means application of results of ICT research like knowledge base systems and advanced computational techniques like neural networks. ‘Smart’ grids, according to the SmartGrids platform strategic deployment document [SmartGridsSDD, 2008] have to be defined as follows:

> *‘’A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies. ‘’*

SmartGrids, thus integrate all intelligence for optimization for all actors in the value chain, including traditional stakeholders, but also new actors.

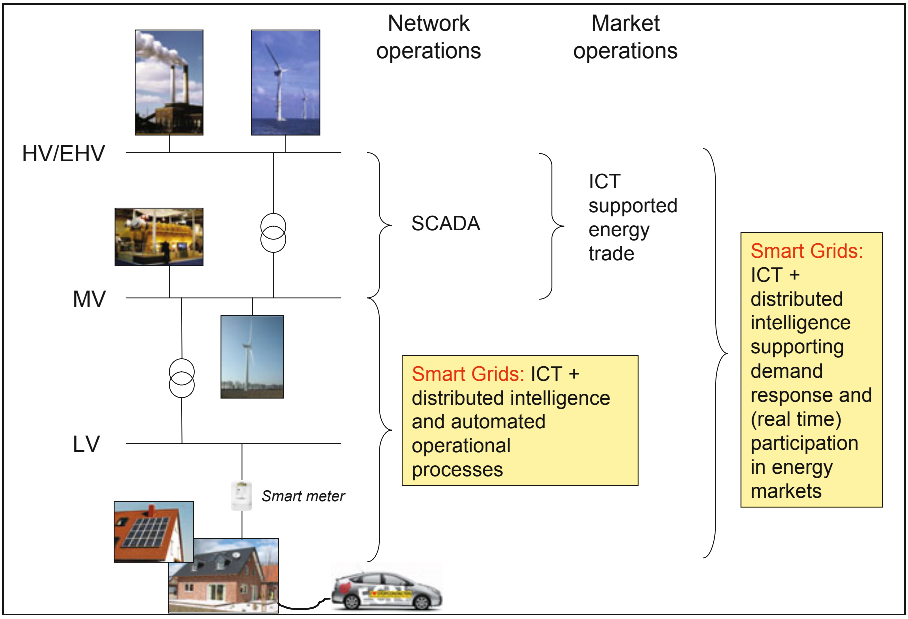

Fig. 1. Loosely and tightly coupled ICT in electricity networks

In using ICT in Power Systems, one can use tightly bound layers parallel to the physical infrastructure or loosely coupled layers built using existing mainstream ICT-technology and infrastructures. Tightly coupled layers will be used for direct, fast control (e.g. deterministic switching in real-time); loose coupling for coordination purposes (supply-demand matching). The art of architecture design of ICT in Power Grids lies in attributing a limited number of low-level functions directly coupled to the physical infrastructure and designing functionally rich applications using the loosely coupled networks.

3 Thermal Flexibility as a Means for Electrical Flexibility

As already mentioned, having flexible electricity generation or production, especially once aggregated, leads to economic value increase. In the comfort system of the homes in the field-test buffering of heat can be achieved through a hot water storage tank. A flexible coupling to electricity production/consumption in the case of the heat pump and the micro-CHP is possible in this way. The heat-pump can produce hot water by electricity or by an additional gas-fired peak burner in a common storage tank. The hot water can be used for heating and to produce tap-water. The micro-CHP, when used for heating, produces electricity and heat, which can either be directly used in the house or can be buffered in the tank. The upper level of the tank is primarily used for tapwater;

the bottom part for space heating. The bottom capacity is used in the home heating season buffering on expected electricity price changes. The upper part above the ‘comfort level’ is used for providing additional flexibility, especially in the summer season.

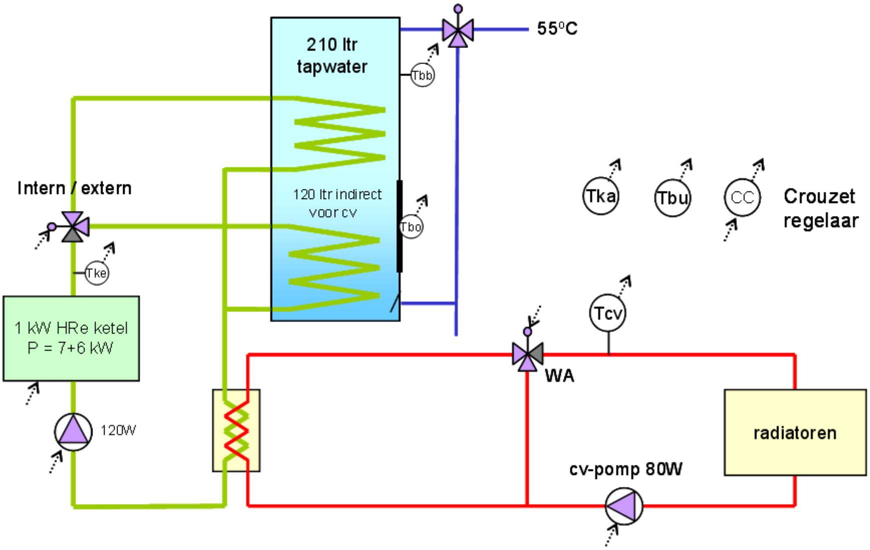

Fig. 2. Hydraulic scheme of a heating system with storage capability

4 Configuration and Use Cases in the Powermatching Fieldtest

The field test is currently taking place in a residential area in Hoogkerk near Groningen in the Northern part of the Netherlands (http://www.powermatchingcity.nl). The ‘PowerMatching City’ (see Figure 3 upper part) field-test A has three hierarchic levels. At the first hierarchic level, a cluster of residential houses is configured, in which generation and load flexibility is delivered by the heating systems in the houses as discussed. In this sub-cluster setting, PV is a must-run generator and must-run loads are lighting loads. A power distribution agent monitors constraints on the LV-distribution network. Finally the lowest level for coordination is the home context level, operation of devices behind-the-meter.

A further node is located at the ECN facilities and includes electricity storage and an electric vehicle charging unit near a test dwelling. The ECN node further has the wind-park Kreileroord connected, for which day-ahead forecasts of power output from the high-resolution HIRLAM meteorological model, covering Western Europe, are determined as in the CRISP-field-test [AAMAS, 2005]. At the Groningen Gasunie research lab and at the RenQi educational facility a variety of devices (PV, urban wind, scooter chargers) is installed to form the third sub-cluster.

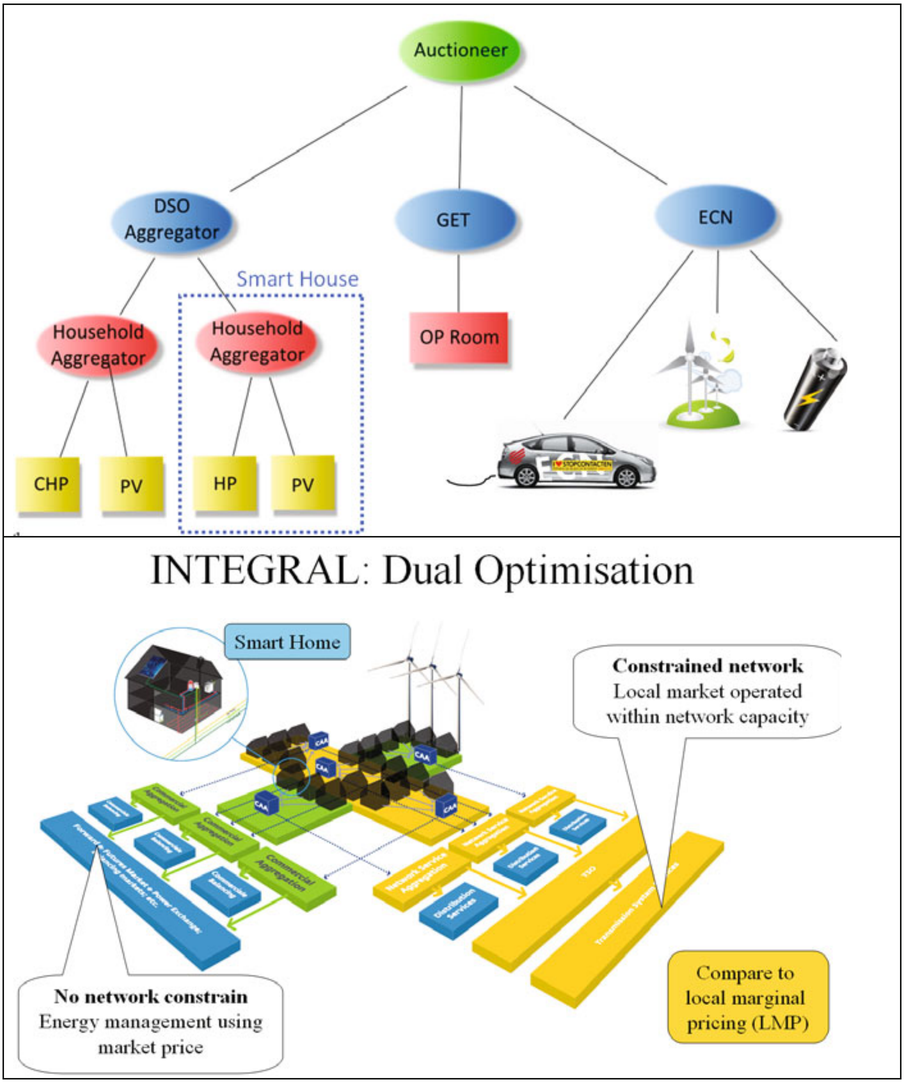

Fig. 3. The PowerMatching city /experiment A field-test configuration and optimisation

The renewable integration and cost optimization use cases at the residential level include:

- **Reduce transformer losses** in high import/export situations. Verification of the result of the coordination action will be done by setting up load the duration curve of the transformer with and without coordination using the PowerMatcher. The effects of conflicting scenarios, like all heat-pumps operating simultaneously, will be determined and the way the coordination algorithm resolves the conflict using the PowerMatcher algorithm.

- **Commercial imbalance reduction** with all loads and generators part of a commercial portfolio. The flexibility of the total cluster will be determined in the form of the total amount of control and reserve power that can be liberated as a function of time and of time-of-year. The achievable ramp-up/ramp-down speed of the Virtual Power Plant will be determined.
- **Valorisation** of renewable electricity. The mechanism pre-emptively lowering pre-production peak consumption, if a forecast of high local production of PV around 12 o'clock in summer with minimal local demand will be shown and, in the same way, lowering flexible generation during the PV-peak.
- **Household monitoring and optimization** behind the meter. Use PowerMatcher technology to optimize 'behind the meter' in a flat or a two-price import and export tariff scheme and maximum capacity constrained operation.
- **Cost-effective use** of energy. Show cost reduction effects in a semi-artificial real-time pricing environment.
- **Provide for customer feedback.** Extensive usability and participatory design is used to provide feedback to the inhabitants of the homes in the field-test. Participation retribution fees have a fixed component, but also variable components linked to 'grid-friendliness' and contribution to the results of the cluster.

Finally, in the field test, the combined effect of having commercial incentives combined with network constraints is modelled. Especially in the winter period, if there is a large heat demand, μ-CHPs, may have incentives to deliver electricity at high market prices, exposing the local distribution grid with overload on transformers (Figure 3; lower part). In this case, an additional PowerMatcher agent counteracts by applying a additional local distribution tariff for a limited period of time. Because operation of the devices strongly depends on the heat demand and the production of renewable resources like solar energy and wind, the field-test is conducted to cover summer and winter as well as autumn and spring.

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