INTELLIGENT ENERGY MANAGEMENT USING POWERMATCHER: RECENT RESULTS FROM FIELD DEPLOYMENTS AND SIMULATION STUDIES

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ABSTRACT

Response of demand, distributed generation and electricity storage (e.g. vehicle to grid) will be crucial for power systems management in the future smart electricity grid. In this paper, we describe recent results using PowerMatcher a smart grid technology that integrates demand and supply flexibility in the operation of the electricity system through the use of dynamic pricing. Over the last few years, this technology has been researched and developed into a market-ready system, and has been used in a number of successful field deployments. Recent field experiences and simulation studies show the potential of the technology for network operations (e.g. congestion management and black-start support), for market operations (e.g. virtual power plant operations), and integration of large-scale wind power generation. The scalability of the technology, i.e. the ability to perform well under mass-application circumstances, has been demonstrated in a targeted field experiment. This paper gives an overview of the results of two field deployments and three large simulation studies. In these deployments and simulations, demand and supply response from real and simulated electrical vehicles, household appliances and heating systems (heat pumps and micro co-generation) has been successfully coordinated to reach specific smart grid goals.

INTRODUCTION

This paper describes recent experiences with dynamic pricing using the PowerMatcher Smart Grid Technology. Demand response, response of distributed generation and operations of electricity storage (e.g. using vehicle to grid) will be a crucial part of power systems management in the future. There are two main reasons why these Distributed Energy Resources (DER) will play a major role in electricity systems operation in the future:

- The rising share of both **renewable energy sources** and **distributed generation** in the energy mix decreases the controllability of the supply side. The rise in needed balancing power can be fulfilled by utilising the flexibility potential in demand and distributed generation.
- The **electrification of everything** will drive our **ageing electricity networks** to their limits. As an alternative to grid reinforcements, the flexibility potential in local demand and generation can be used to cope with grid overload situations.

Dynamic pricing is key in the development of a uniformed and multi-purpose mechanism to utilise device flexibility at the premises of the end-customer. The PowerMatcher smart grid technology [1] is an example of such a mechanism. The PowerMatcher is a distributed software system for market integration of small and medium sized DER units, ranging from household appliances via electric vehicles to industrial installations of 5 to 10 MW. It is a general purpose mechanism for near-real-time coordination (balancing) in smart electricity grids. Designed for scalability, it targets the huge numbers of distributed generators, demand response units, and electricity storage that need to participate in future electricity system operations. Since its incarnation in 2004, the PowerMatcher has been implemented in three major software versions. In a spiral approach, each software version was implemented from scratch with the first two versions being tested in simulations and field experiments [2], [3], [4], [5]. The results described in this paper are based on the third version of this system. A more in-depth treatment of the results presented can be found in [6].

FIELD TRIAL: POWERMATCHING CITY

Over the years, a number of small pilots have been successfully conducted with the PowerMatcher technology to demonstrate its feasibility and potential. The experiences and lessons learned from these pilots were used to create Europe's first fully developed Smart Grid: PowerMatching City. PowerMatching City is a living lab environment based on state-of-the-art off-the-shelf consumer products that have been altered to provide flexibility to and allow coordination by the smart grid. One of the unique aspects in PowerMatching City is that it takes the, sometimes conflicting, interests of three main stakeholders in a smart grid into account: the prosumer (a consumer who also produces energy), the distribution network operator (DNO) and the commercial aggregator (CA), e.g. the utility or energy service company.

The back-bone of PowerMatching City is 22 common Dutch households, located in the suburb of Hoogkerk near the city of Groningen, the Netherlands. Each are fitted with either a domestic combined heat and power unit (micro-CHP) or a heat pump with gas fired heater and 14 m2 of photovoltaic panels. Some households also contain intelligent household appliances. Further, a 5 kWh battery and two electric vehicles, each having a 37 kWh battery and a 5 kW controllable modular charger have been added to the cluster. Finally, outside the district, a 2.5 MW wind turbine is available. All devices are interfaced with PowerMatcher software to operate PowerMatching City as a virtual power plant (VPP).

One of the most interesting use cases studied was the operation of the cluster as a VPP within the portfolio of a commercial aggregator (CA), in this case an energy utility company. The CA used the price profile of the day-ahead spot market to optimise the energy profile of the cluster. Additionally, the CA offered regulatory power to the national system operator for balancing purposes. The PowerMatcher technology was used to ensure that the cluster followed the optimised energy profile and at the same time made real-time adjustments in the cluster allocation to provide regulatory power requested by the system operator, as shown in Figure 1. It was concluded that the VPP successfully followed its optimised energy profile and provided the required regulatory power at the same time.

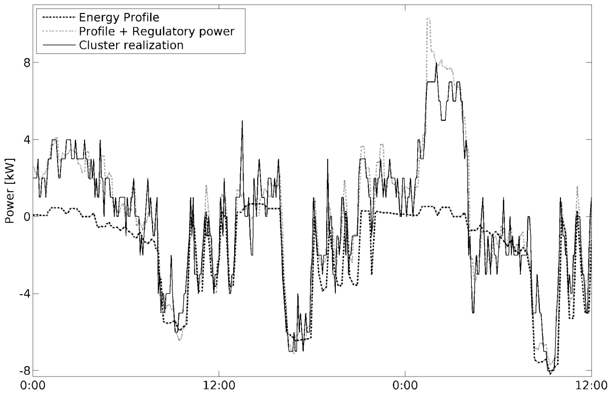

Figure 1: The PowerMatching City cluster operated as a Virtual Power Plant in a real market environment, trading on the spot market (forecast) and regulatory market.

Overall, PowerMatching City demonstrated that PowerMatcher is not only able to perform technical, commercial or in-home coordination, but also optimise VPP operation for a combination of these types of coordination, yielding maximum benefits for all stakeholders.

WIND POWER INTEGRATION

The integration of large-scale renewable power generation in the electricity system has been studied in an comprehensive simulation study. This study simulates 3000 individual households equipped with heating systems reacting to the fluctuating output of solar and wind energy systems in a future scenario of high wind energy penetration. The simulations ran under real-life circumstances, using validated models, measured input time series and under a future energy scenario taken from an existing scenario set for 2040.

The demand and supply flexibility in the households was realised solely by heating systems. Half of the households were equipped with a micro-CHP and the other half with a heat pump. Both devices are used for space heating as well as tap water heating and have heat buffers of 120 litres (space heating) and 90 litres (tap water) allowing for flexibility in their operations. The devices were modelled and validated according to those used in the PowerMatching City field trial.

The outcomes clearly illustrate that automated response of end-user systems supports the integration of renewables at a large-scale. The amount of wind energy actually used in the households increased by 65 to 90%, leading to a reduction of energy supplied from other (e.g. fossil fuelled) sources of 14 to 21%.

DISTRIBUTION CONGESTION MGMT

Important smart grid applications for distribution network operators are related to the avoidance of network overload situations.

Coordination of Electric Vehicle Charging

With the increasing popularity of plug-in hybrid and full electric vehicles, their impact on the electricity infrastructure can no longer be ignored. Electric vehicles can double the amount of energy consumed by households, especially where homes are heated using energy sources other than electricity. With a large number of cars being used for commuting, high simultaneity in cars charging increases the negative impacts on the grid even more. Coordinating the charging behaviour of electric vehicles can postpone, reduce or even eliminate these grid investments. A simulation study has been done to look at the impact of electric vehicles on the peak load of substations in residential districts and how much PowerMatcher could contribute to reducing this peak load. The study uses a stochastic driving behaviour model based on real mobility data and configuration data from real districts in Europe.

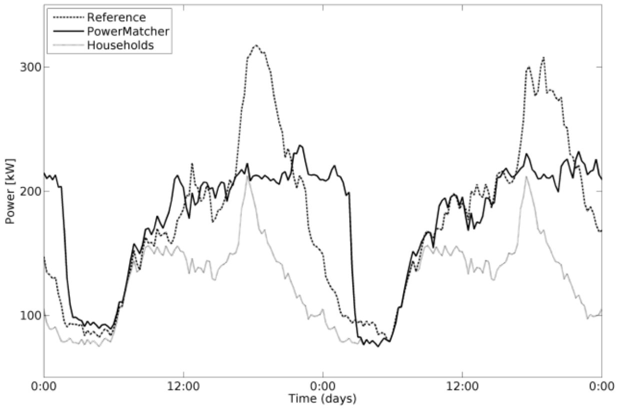

Figure 2: Substation load for two arbitrary days, showing the inflexible demand of the households and the demand profile with and without PowerMatcher coordination of the electric vehicles.

Figure 2 depicts substation load patterns for an urban district in the south of Europe with an electric vehicle penetration of 100%. Without coordination, the peak load is at least 60% higher than that of the households alone. However, when PowerMatcher is used to coordinate charging of the cars, this peak is shifted into the night resulting in a maximum peak load that is almost as low as that of the household demand. Figure 3 shows the substation peak load for a district in the north and south of Europe, as function of the penetration of electric vehicles. Without coordination, only low penetrations of electric vehicles can be realised without causing significant increase in the peak load. However, with PowerMatcher coordination enabled, the peak load is kept almost constant at all penetration levels without violating full-charge deadlines as set by the drivers.

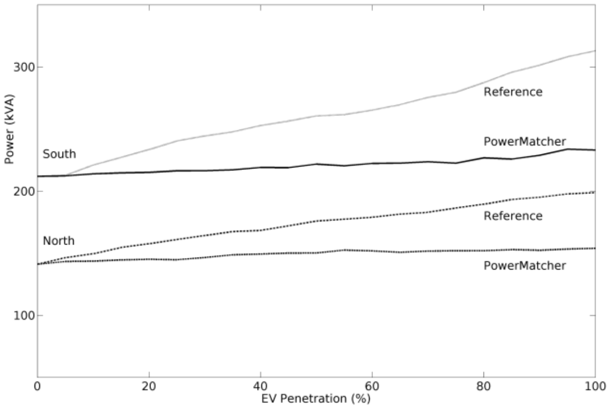

Figure 3: Substation peak load for an urban district in North-Europe and South-Europe with and without PowerMatcher coordination.

It has thus been demonstrated that PowerMatcher is able to coordinate charging of electric vehicles to avoid grid congestion, by only using easily available information from the battery and driver.

Congestion Management by Heat Pumps

A similar simulation study has been performed focusing on demand response by heat pumps in extreme situations such as exceptional cold winter mornings or during a system restoration after a black out.

In buildings, the energy efficiency of space heating and hot tap water preparation can be increased significantly by installing heat pump systems instead of gas boilers or resistive electrical heating. The introduction of the heat pump poses a challenge for distribution grid operators, especially in areas where homes are heated predominantly using natural gas. Here, a switch from a gas-fired heater to a heat pump decreases the overall energy use while it increases electricity usage.

However, in extreme circumstances, the operational simultaneity of the heating systems is high leading to investments in network capacity that will only be used a few short periods in the life time of the network assets. The simulation study assesses whether the PowerMatcher is able to ride through these extreme situations with a lower network capacity. The study was performed within the SmartProofs project. The simulation model consists of 100 households represented by a building model and a combined model of the heat pump and auxiliary heater. Other electricity loads in the households have not been modelled. The capacity of the distribution network is dimensioned at 275 kW, which equals the maximum power of 30 heating systems. In the reference case, the heating system is controlled by a standard thermostat. In the coordinated case, PowerMatcher is used to influence the heat pumps such that the network load is kept within the capacity.

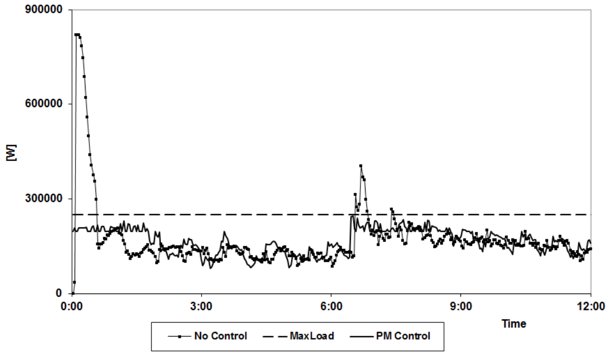

Figure 4: Simulation results for a group of 100 households heated by heat pumps with auxiliary heaters. *Dashed*: Transformer capacity. *Line with dots*: Transformer load in the reference case. *Solid Line*: Transformer load in the PowerMatcher-controlled case.

Figure 4 gives the main result of this simulation. In the business-as-usual case, the transformer load surpasses the rated capacity both during the black-start recovery (after 0:00 hours in the graph) and during the cold winter morning (after 6:00). In the black-start scenario, the transformer is roughly 3 times under dimensioned. In the coordinated case, the transformer load is kept within limits.

This simulation study clearly illustrates the ability of the technology to keep transformer load within rated capacity limits under these extreme load conditions.

DEMONSTRATION OF SCALABILITY

The PowerMatcher has been designed with scalability as the key quality attribute. However, as none of the field trials performed to date approaches a mass-application scale, there is no empirical backing of the theoretical scalability properties. To overcome this, we take an empirical approach by implementing and testing a full top-to-bottom slice of the architecture needed to cluster one million households in a virtual power plant. Side-branches cut away from the architecture are replaced by data mimicking agents generating the data traffic volume of the pruned branch. In this way, the data traffic from a real cluster of Smart Houses is combined with mimicked data sources placed at strategic points in the architecture. Accordingly, we are able to test the full architecture from the smart home to the enterprise systems running at a VPP operator at mass-application data traffic levels. The cluster of real smart homes used are the 22 households in PowerMatching City.

The main purpose of a VPP is to deliver flexibility. If the flexibility potential can be accessed fast enough, it can be used for operations in the balancing market which is the most volatile wholesale market for electricity. In a PowerMatcher-based virtual plant, a change in the desired power output (or input) of the plant translates in a changed price on the internal electronic market being communicated down to the device agents. Accordingly, a metric for the reaction speed of the VPP is the time it takes to communicate such a price update to all agents. The settlement period used in balancing markets is typically 15 or 30 minutes. In order to react to the actual imbalance situation, either in the own portfolio or in the control zone, the reaction time must be smaller than the settlement period. VPP reaction times must allow the operator to react to an imbalance situation occurring in the first part of the settlement period by VPP actions that take effect during the same period. Therefore, a reaction time below 5 minutes is desirable.

Latencies have been measured at four different levels in the architectural slice. The time needed to reach the device agents is lower than 1 minute, which is well under the success value of 5 minutes. This experiment shows that under mass-application circumstances the flexibility potential of the PowerMatcher cluster can be accessed fast enough for operations in the balancing market. This demonstrates PowerMatcher's scalability to mass-application levels.

CONCLUSION

The PowerMatcher is a field-proven technology for integration of distributed generation, demand response and electricity storage into the electricity markets and into distribution network management. Through this technology, a large flexibility potential at medium-sized and small customers can be unleashed and utilized for integration of large-scale renewables and active management of overloaded distribution networks.

The results of the field experiments and simulation studies presented show that the PowerMatcher: (i) improves the wholesale market position of energy trade and supply businesses, (ii) contributes to active management of electricity distribution networks, (iii) raises the electricity system's accommodation ceiling for renewable power generation, and (iv) is scalable to mass-application levels. At the same time, the technology defends the interests of electricity end-customers by maximising own consumption of self-produced electricity and by minimising costs through shifting demand to off-peak hours.

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