FLEXIBILITY DYNAMICS IN CLUSTERS OF RESIDENTIAL DEMAND RESPONSE AND DISTRIBUTED GENERATION

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ABSTRACT

Supply and demand response is a untapped resource in the current electrical system. However little work has been done to investigate the dynamics of utilizing such flexibility as well as the potential effects it could have on the infrastructure. This paper provides a starting point to seeing the potential flexibility available as well as the characteristics of a virtual power plant as a result of utilizing some of this potential.

INTRODUCTION

With the increasing share of non-controllable renewable energy sources, it is becoming more difficult to maintain the power balance in the electricity grid. Devices of end-customers (as well as producers) shift-able in time can be utilized in an intelligent, economically optimal way to reduce investments and operational costs needed for a future reliable energy grid. One of the major hurtles is quantifying what flexibility provided by these shift-able devices is available for balancing and ancillary services and how using this flexibility impacts a utilities predicted customer profile. The response of flexible loads, distributed generation and electricity storage will be crucial for power systems management in the future electricity grid.

Our paper gives insight in how to predict such behaviour and how can be incorporated into the daily operation of utilities. In that, the presented work is highly relevant for commercial operation of virtual power plants, creating value out of flexible demand and distributed generation on the wholesale markets, and active management of distribution networks, e.g. congestion management.

RELATED WORK

Much work has already been done with regards to flexibility in the electricity grid. In [3], flexibility is classified into its different types and a common interoperability framework is created. This ensure that buyers, suppliers, developers, maintainers, operators, managers and technicians involved with the portfolio management and grid operations use a common language with regards to flexibility. Further, [4] investigates the effect that the market structure can have on the elasticity of the demand for electricity as well how this elasticity can be taken into consideration when scheduling generation and setting the price of electricity in a pool based electricity market. However, while the previous two works identify the types of flexibility and potential effect of elasticity on the electricity markets they do not investigate quantifying the availability of flexibility. [5] begins this task by estimating the potential of controllable loads for balancing by statistical analysis of measurements.

DISTRIBUTED COORDINATION OF SUPPLY & DEMAND

The intelligent distributed coordination technology called PowerMatcher, is a multi-agent based system that uses electronic exchange markets to coordinate a cluster of devices that produce or consume electricity. A multi-agent system is a structured framework for implementing complex, distributed, scalable and open ICT systems in which multiple software agents are interacting in order to reach a system goal.

Such a software agent is a self-contained software program that acts as representative of something or someone (in this case a device or an energy demand from the user). The different PowerMatcher agents and their interactions are shown in figure 1.

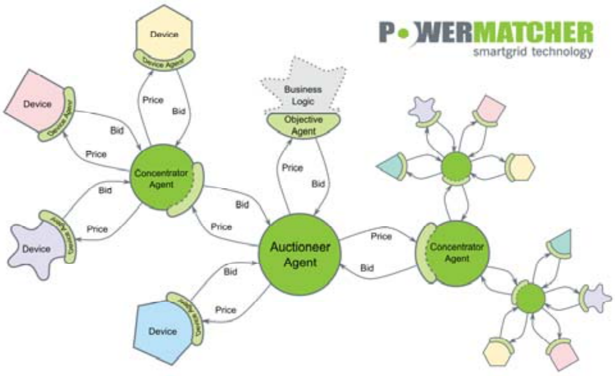

Figure 1: Schematic overview of the PowerMatcher concept.

Every device in a cluster is represented by a device agent, a piece of software that looks after the interests of that device. Such agents attempt to operate its associated processes in an economically optimal way, whereby no central optimization algorithm is necessary. An electronic market (the auctioneer) in the multi-agent system allows the agents to trade resources, i.e. electricity, that are necessary for the agent to carry out its task. The only information that is exchanged between the agents and the auctioneer are bids. These bids express to what degree an agent is willing to pay or be paid for a certain amount of electricity. Bids can thus be seen as the priority or willingness of a device to turn itself on or off.

Bids are sent at irregular (event-based) intervals, i.e. only if the local state changes, resulting in a new agent bid. This keeps the communication between PowerMatcher entities to a minimum. The auctioneer collects the bids and calculates the market clearing price. This is the price at which the sum of all bids is zero, such that there is no net consumption or production. The market clearing price is communicated back to the device agents, which react appropriately by either starting to produce or consume electricity, or wait until the market price or device priority (state) changes.[2]

OBJECTIVE

With larger amounts of renewable energy being incorporated into the electric grid, maintaining power balance is becoming ever more difficult. With enough gas fired or high emission power plants you accommodate these instabilities. However, this is expensive and has a negative impact on the environment. At the same time there is untapped potential at the household level. The aim of the following studies was to investigate the characteristics of flexibility of households, while maintaining user comfort levels. Specifically, the focus will be on the aggregated behaviour of large clusters of households using a supply demand coordination algorithm.

EXPERIMENT SETUP

In the projects Flexines and EcoGrid the behaviour of available flexibility in households was studied. Simulations were performed for a one week span at a one minute resolution with a cluster of 1000 households equipped with smart appliances (washing machines, refrigerators, freezers, dryers, and dish washers).[6] The penetration of devices was based on Dutch national studies. See table 1 for 1000 household cluster breakdown. All device models have been validated with real device data and configured based on currently installed systems in the Netherlands. [1] Further, each device is capable of running with two controllers. The first one is the default manufacturer controller, which does not communicate with other devices or markets. This is the business as usual or reference case. The second controller is a PowerMatcher agent that allows the device to trade on an electronic market.

Table 1: Device penetration in cluster.

Appliance	Penetration
Refrigerator	100%
Freezer	79%
Washing machine	100%
Tumble dryer	59%
Dish washer	47%

Investigating the potential flexibility of the cluster requires a two-step approach. In the first step, a simulation is run with the business-as-usual controllers only. The power profile of this simulation represents how household devices are currently being used. In the second step, the simulation is performed a second time, but now with the PowerMatcher controller. The devices in the cluster are started with the same initial conditions and have the same behaviour as in the first simulation. The objective of the PowerMatcher technology is to follow the profile obtained with the business-as-usual controller. This way, the power profile of the cluster does not change, but information about the flexibility potential of the cluster is unveiled in the market.

In the second scenario the same cluster was used to evaluate the effect on available flexibility by steering the cluster to run at different power values than that of business as usual. This was done over a number of different set profiles, between 0 and 400 kW, and the extreme effects will be analyzed.

RESULTS

It was first investigated what potential was available in such a cluster of households. As was stated above, the cluster was simulated to run in business as usual mode, no coordinated control, and then re-run following this profile to see real time the available flexibility potential. In figure 2, below, the flexibility potential over one day be seen. The red line is the actual allocation that the total cluster maintained. The green area is the flexibility available at a given moment of the cluster. By flexibility, we mean the ability to ramp up or down from the current allocation. It can be seen that there is quite some flexibility to deviate from the business as usual allocation.

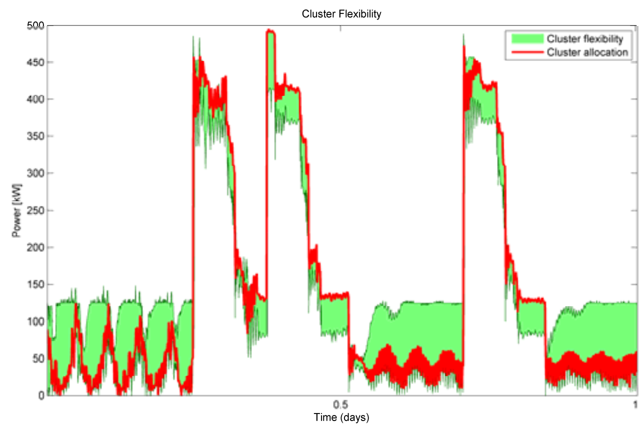

Figure 2: Potential of a Heterogeneous Cluster

Specifically, it was seen, that over a period of a week, on average the cluster could ramp up 170% and down 27% relative to its actual realized allocation (i.e. its power profile) when no flexibility was delivered throughout the whole period. (See the figure above depicting one day).

While this information is valuable, it does not however, evaluate the effect of using flexibility on the cluster profile and this is especially interesting to stakeholders such as utilities, distribution network operators (DNOs) and transmission system operators (TSOs). Therefore, as a continuation we further studied the behaviour of this profile upon using some of its flexibility. We visualize how the available flexibility in the cluster changes when part of the flexibility is actually used at a certain time. For instance, in figure A between 9:00 and 14:00 hours, there is a large amount of ramp up flexibility available. In figure B, this flexibility is partially utilized from 9:00 hours on as can be seen by the jump in the red line. As a result of this, (i) the available ramp up flexibility decays over the next few hours and (ii) the cluster's power load is considerably lower in the time period around 15:00 hours.

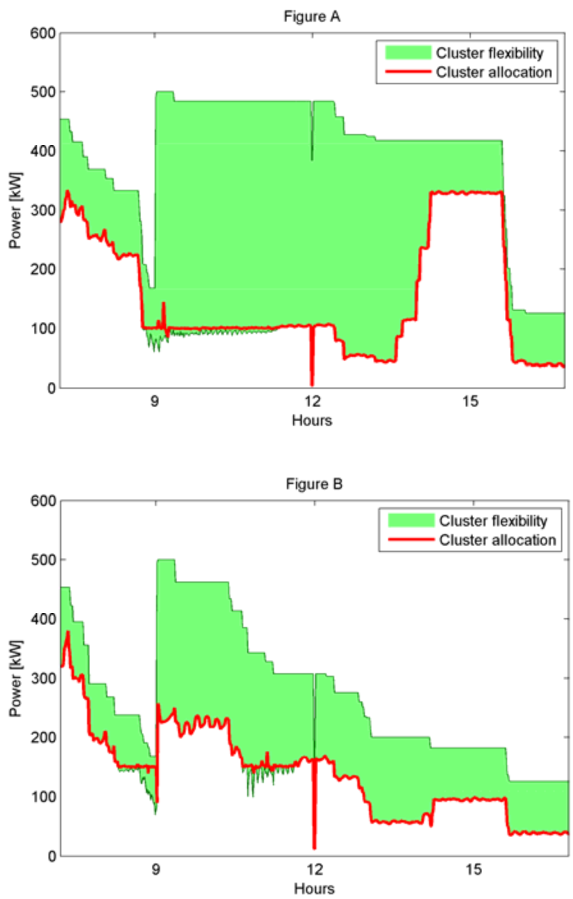

Figure 3: Figure A is the available flexibility by forcing cluster to follow 100kW, figure B is that of 150 kW.

This shows that high utilization of flexibility early on provides a high risk of not being able to fulfil energy obligations later on.

CONCLUSIONS & FUTURE WORK

There is an increasing need for flexibility in order to accommodate the ever present decentralized generation into the grid such as wind and solar generation. As a result, maintaining power balance is becoming ever more difficult.

An economical solution to accommodate potential instabilities would be to utilize available flexibility in the existing system using a real time coordination algorithm. It was shown that there is significant potential flexibility that could be tapped for grid balancing and ancillary services.

However, it has been shown that using high amounts of flexibility early on could create and instance where the cluster is no longer able to fulfil its energy obligations later on. Therefore, utilizing flexibility can yield opposite effects if not used correctly. However, with PowerMatcher and its simulation tool, we can forecast the behaviour of such a virtual power plant. Future studies will focus on such work including investigating the impact of utilizing flexibility as well as create mechanisms to predict such behaviour. Characterization of this will enable grid operators to effectively utilize the flexibility across different stakeholders.

Acknowledgments

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