

A HETERARCHIC HYBRID COORDINATION STRATEGY FOR CONGESTION MANAGEMENT AND MARKET OPTIMIZATION USING THE DREAM FRAMEWORK

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ABSTRACT

Software agent-based strategies using micro-economic theory like PowerMatcher[1] have been utilized to coordinate demand and supply matching for electricity. Virtual power plants (VPPs) using these strategies have been tested in living lab environments on a scale of up to hundreds of households. So far, the coordination configuration of a VPP is fixed in these settings. The DREAM [2] framework architecture uses heterarchies to make parts of a VPP flexible in coordination strategy depending on the current operational grid status. In this way, a sub-VPP, serving one coordination objective, can decouple from and couple to an overarching VPP with another coordination objective dynamically.

In this paper a grid congestion simulation with an overarching VPP coordinating demand and supply for electricity market optimization [3] and a sub-VPP reacting to a heat-pump congestion event in winter and a PV overproduction event in summer is described. The simulation was run in a static simulator [4]. The LV-segment consisted of ‘flameless’ residential areas with well-insulated homes with primarily heat pumps for heating and some renovated homes with local gas-fired co-generators of heat and electricity. Households additionally had solar cells, batteries and EV charging units. The goal of the additional coordination sub-VPP was to solve grid stability issues like congestion due to heat pump loads in winter and overproduction by PV in summer in this physical part locally, while the rest of the cluster remained unaffected and still optimizing for the commercial goal.

The results were analyzed in terms of infringement of comfort parameters and performance in adapting the flexible load and generation. It appeared, substantial load shedding and load shifting of devices is possible to show the synergy in solving the grid stability issues evenly sharing the discomfort to the individual heating devices. By changing their charging strategy, the new algorithm also showed heat storage and electricity storage devices providing additional support.

INTRODUCTION

The simplest definition of flexibility can be given as a bandwidth around a required momentary power value of a connection or a device. The flexibility can be discriminated in a part to be used in normal operation,

that, for example, might be expressed in a PowerMatcher bid-curve [1]. This part may be utilized by a commercial party in normal grid operation to balance the portfolio. The timescale for it to be mobilized is in the order of tens of seconds to minutes. Another part can be utilized as a contingency reserve by a grid operator to prevent the operation of the power system to go into a critical situation. The second part typically has to be used in the seconds scale. In micro-economic terms, primary processes, using electrical energy, have different utilities for flexibility on these different time scales. This economic utility can be translated in a price that can be used for coordination.

COMBINING MICRO-ECONOMIC COORDINATION MECHANISMS

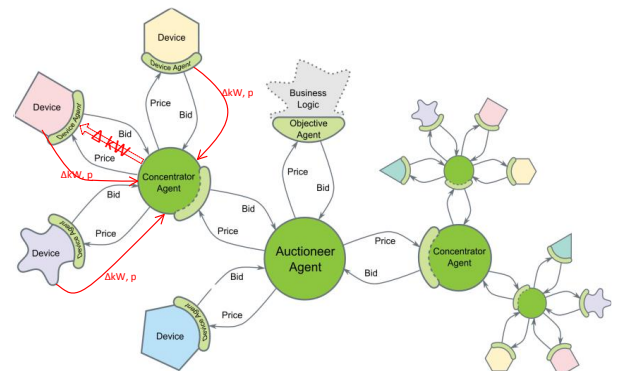


Figure 1 PowerMatcher incorporating bid-ladder bids

PowerMatcher, as an agent-based software technology, so far, has been used to operate in a polling or event-based manner with bidding in a bottom-up way. The protocol consists of the sending bids to an auctioneer agent in the form of bid curves based on the current cost and utility of a primary user process and allocation by the auctioneer in the form of equilibrium prices. Figure 1 depicts the topology for a PowerMatcher based virtual power plant application. The operational mode is soft controlled with interaction times in the order of 30 seconds to several minutes dependent on the ICT-network and the response time characteristics of the power generating or consuming processes. The ability to exert an additional, seconds timescale reaction to power system events can be used for intelligent load shedding and generation management during operation near to real-time critical circumstances. Response to events on a short timescale requires a mechanism, that allows operation initiated from the

Concentrator Agent level directly mapped to grid components that can generate a quick flexibility response.

A light-weight, fast-response time mechanism for reserve capacity markets is aggregating bids into so called bid-ladders. In red in figure 1 the implementation of such a mechanism via a bid-ladder (ΔkW , price) contribution within PowerMatcher is depicted. At the Concentrator Agent level, ΔkW /price pairs are received from the device agents. These are assembled to a price sorted list of offers of available power for increasing generation/decrease of demand (ramp-up) and for decrease of generation/increase of demand (ramp-down). Going in a part of a physical network from one grid operational state to another then only affects one or more of the Concentrator Agents in the topology.

Combining bid-curve markets on the commercial level and bid-ladder markets on the concentrator-level, the requirements of intermediate response times and of short response times required by DSO operation can be satisfied simultaneously. It also provides an approach that retains the scalability of agent based control. As in the PowerMatcher use case, in the combined approach, no absolute price information is necessary. PowerMatcher prices are only used for internal coordination. The bid ladders are scaled and normalized to the same unit as the PowerMatcher bid curves (the power matcher simulation use case has 100 steps for the price vector). The simplest approach going from a bid curve to a bid-ladder bid is shown in figure 2. The figure indicates the equilibrium price based on the bid curves.

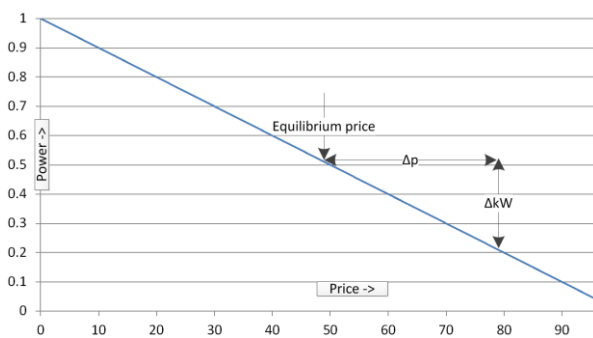


Figure 2 Constructing bid-ladder bids from a demand curve

Given the fact, that a primary electricity consuming process allowed deviation, ΔkW , from the currently generated power, can be priced at a Δp , because the reduction in load leads to a loss of primary process economic utility.

Combining bid-curve and bid-ladder coordination markets requires one additional functional requirement to PowerMatcher device agents. On receiving a price from the Auctioneer via the Concentrator, the device wanting to participate has to formulate two bid ladder bids, which

essentially contains a ΔkW (positive or negative) for ramp-up or ramp-down. Then, in case of a grid-event requiring a ΔkW for the devices, connected to the Concentrator, the Concentrator collects the bid ladder bids and traverses the bid ladder until the required amount of power is reached at the lowest price. For only those devices, which are selected to contribute, the a ΔkW is allocated and a signal is sent. In this way, a certified response can be achieved.

The price for the ΔkW -bid not necessarily has to be related to the bid curve bid. It reflects the value of the impact on and economic utility of the current primary process. In order to avoid rebound effects, the agents contributing to the immediate resolution of the critical situation, also have to adapt their bid curve bidding strategy and extend their process limits. In this way, the desired power modification can be achieved, until the condition can be cleared by the grid operator. Using the bid ladder mechanism, the contributions from different types of devices can be obtained disturbing primary processes to the minimal extent reaching the optimal common economic utility for all the devices connected in the local cluster optimum.

SIMULATION SET-UP

A static simulator [5] was adapted and used to configure a number of high DG-RES residential neighbourhoods equalling an MV and number of LV sections. 240 residential homes were investigated with an equal mixing of lifestyles and energy usage. Lifestyles were either based on families with double income/no kids, single income 2 kids and retired. Dwellings were 90% of well-insulated and 10% of renovation type. The insulated houses had heat pumps (1.3 kW) with a COP of 3.0. The renovation houses were equipped with Stirling micro-CHPs with 1.3 kW and a heat to power ratio of 7.0. Furthermore PV (1 kW; with typically Netherlands solar radiation incidence) and domestic EV charging (20 kWh, 8 kW) were taken into account. The simulation environment has the possibility to simulate grid events like congestion due to overload or over-generation.

SIMULATION RESULTS

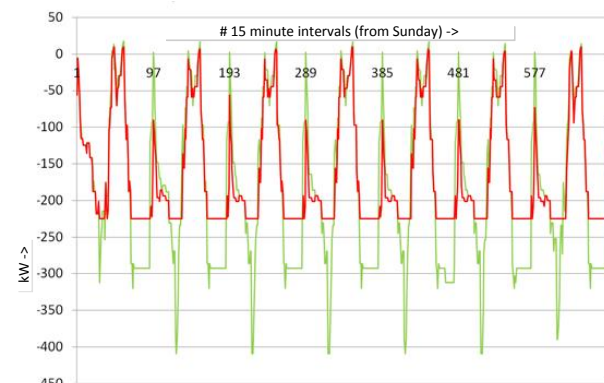


Figure 3 Grid segment imposed load constraint

Figure 3 presents the load in the grid segment over one week in the unconstrained situation in green. In the red graph a reduction in used capacity to a factor of 0.55 is applied. If the limits are exceeded, the capacity to apply a Δ -kW in the bid ladder markets is mobilized to compensate. Additional Δ kW-allocation on these markets leads to a change in the realized temperature profiles of the heating systems due that no longer can satisfy the heat demand.

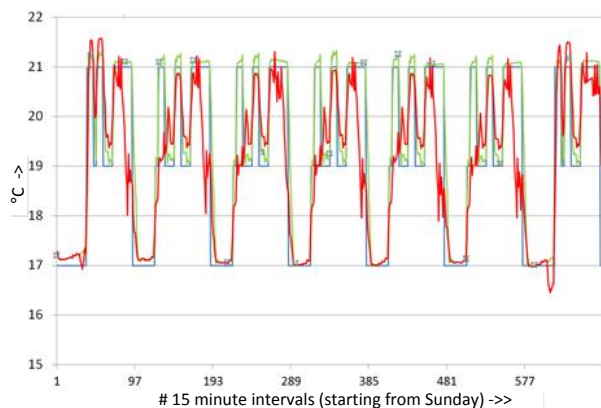


Figure 4 Temperature level in the heat-pump equipped homes

This is shown in Figure 4 for the heat pump equipped insulated homes. The blue profile indicates the life style averaged user defined setpoint. During the heavily congested period, the realized temperature profiles differ significantly from the set-points because the power consumption of the heat pumps is lowered by the bid-ladder based mechanism induced load reduction. Especially because of the impact of the congestion during the evening, the temperatures in the homes can be seen to lower due to the reduction of the power consumption, leading to an overall reduction of comfort. In view of the reduction of the power by 45% below the requested value, however, this reduction is acceptable compared to a power outage which would be otherwise result from the congestion.

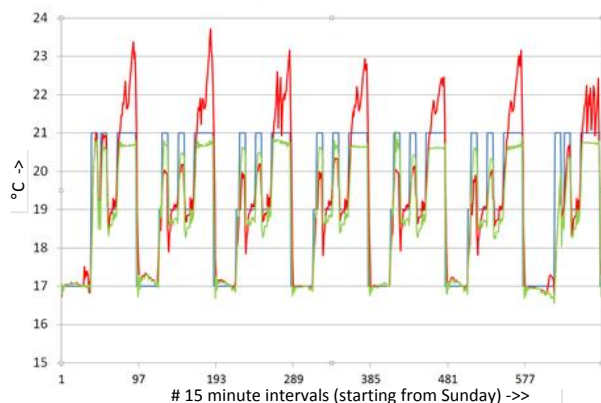


Figure 5 Temperature level in the micro-CHP equipped homes

A reversed effect can be observed for the micro-CHP equipped homes (Figure 5). By generating more electricity, the temperatures in the micro-CHP equipped homes increase during the congested part of the day aiding in avoiding a blackout. The effect here, as shown in figure 5, also can be seen to be most prominent during the evening. Again temperature deviations in the order of 2.5 degrees can be found, leading to a similar comfort deviation as compared to the heat-pumps.

Nightly, home charging EV agents were also included in the cluster calculations. In the constrained capacity periods, the SOC at the end of the planned charging period is 10-15 percent lower than in the unconstrained situation. This is shown in Figure 6. The planned SOC based on the expected driving pattern is shown in blue; the congested and non-congested SOC patterns are shown in red and green respectively. During off-grid operation the SOC is indicated as zero.

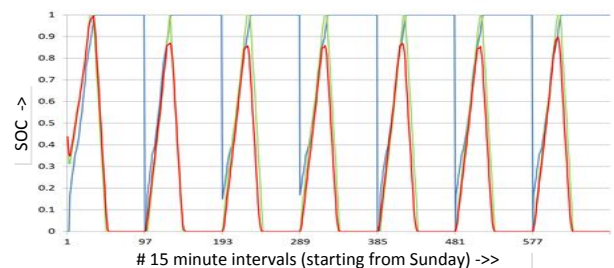


Figure 6 State-of-charge for residential EV-charging

Home bound local storage power units currently get serious interest for stabilizing picogrids and for self-consumption. In Europe and the US, systems like Tesla's power wall are close to market introduction. Therefore, in the congested cluster also a number of power storage units was included to buffer the electricity at a power of 1 kW and a total energy volume of 3 kWh for each household. It can be seen from figure 7, that the battery, during the grid contingency, aids in stabilizing and providing stored power locally by discharging and charging additional energy.

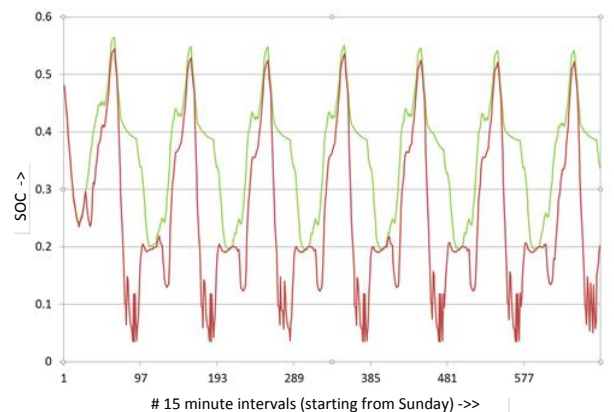


Figure 7 State-of-charge for home battery charging

During the congestion, the battery is discharged automatically to aid in sustained power delivery. After the congested period, the battery is filled again rapidly following a profile close to the strategy for the non-congested period.

The behaviour was also studied during the summer season to get an impression of synergy between the PV generation and the electricity storage. PV-systems in this case were dimensioned at 2 kW per house hold. The results over a week in July in a moderate climate are shown in Figure 8. The PV power as a function of time is indicated in red; the state of charge is indicated in blue. It can be seen, that the PV-production is taken up by the storage system for later self-consumption and could aid in automatically preventing curtailment.

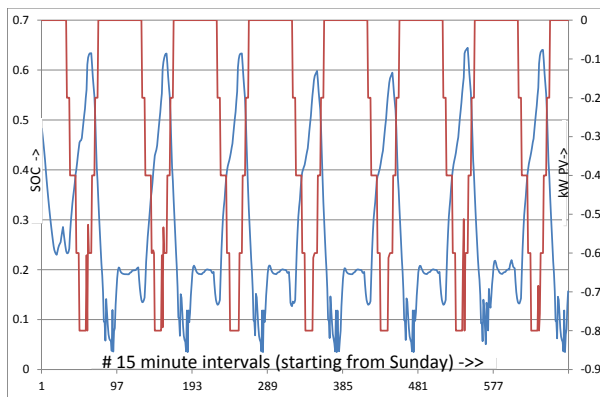


Figure 8 State-of-charge for home battery charging

CONCLUSIONS

Introducing a bid ladder model, additional to PowerMatcher operation, offers a light-weight and fast solution to mobilize demand and generation response in case of automatic grid congestion relief and self-healing operations. Stability improvement for a particular segment in the grid can be supported following the DREAM architecture using hierarchies. The mechanism is able to evenly distribute the consequences of a power shortage or abundance to a number of connected device types in a way, that can be configured at the home level. The mechanism simultaneously satisfies the requirements from an overarching commercial, portfolio optimizing perspective as well as from a local, grid topology bound real-time operational perspective.

The mechanism was verified in a number of use cases. The cases pertained to winter and summer situations with a high DG-RES grid. They showed the synergy of the devices to optimize simultaneously for the overarching commercial portfolio objective and the local grid operation distribution system congestion prevention objective.

ACKNOWLEDGEMENTS

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