FlexLast: An IT-Centric Solution for Balancing the Electric Power Grid

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Abstract—How can energy from renewable sources be integrated in large quantities into the power supply without overwhelming the grid? A collaboration between BKW, the electric utility in the Canton of Bern, IBM, Migros, Switzerland’s largest retailer and supermarket chain, and Swissgrid, the national grid operator is creating a unique solution that applies advanced algorithms to data on the state of the grid and large freezer warehouses to optimize and manage the consumption of power for cooling to help balance the grid. In this paper we describe the architecture of the system and examine the business case required to make this approach feasible.

Keywords—smart grid; demand response; balancing power; energy data analytics; ICT for grid management;

I. INTRODUCTION

Renewable energy sources are becoming increasingly important in the supply of electricity. For example in 2012 Germany was a net exporter of electricity, producing its largest surplus in the last 4 years in spite of the fact that eight nuclear power plants have been taken offline since March 2011 [1]. Underlying this remarkable result is a successful transition to renewable energy sources, in particular wind and solar power [2]. While this transition will bring benefits to society in terms of safety and low CO2 emissions it creates a problem for the electricity grid since although it is possible to forecast the energy that will be produced by renewable sources, it is not possible to control this production. The result is a need to increase the ability to balance the production and consumption of electric power.

The question for the network operator and energy provider is twofold. First, how can demand for electricity be met when power from renewable sources is unavailable or scarce? Second, what can be done with excess power from these sources when they supply more than is needed? One solution is to create a buffer between power suppliers and consumers to help keep power flowing when supply is low and absorb power when it is high. Many possible solutions exist for achieving this, including:

- Storage: Excess energy can be stored, for example by using pump water reservoirs or large batteries. Pump water reservoirs play a key role in the management of the supply of electricity today, but in general if additional capacity is required these solutions are capital intensive, and therefore need to be augmented.
- Flexible production: Production from other sources can be regulated to help accommodate for the variable production from renewables. This option may also be capital intensive if sufficient sources of flexible production do not exist and new plants are required. Furthermore as the percentage of renewables increases, this becomes less feasible.
- Demand Response: This is a widely studied mechanism to adapt consumption based on supply. Providing demand response for example using smart homes requires a capital investment to enable appropriate monitoring and control. Demand response based on industrial loads may prove to be more cost effective and quicker to accomplish since infrastructure changes are required at relatively few places. The existing control systems for these loads need to be adapted using indirect control (e.g., temperature set points) to participate in demand response schemes.

One especially promising form of industrial demand response is to use the significant energy storage available in industrial refrigeration warehouses as a buffer for renewable energy production. Advanced algorithms use logistics planning information and warehouse temperature-sensor data, along with near-real-time energy data from the grid operator, to help optimize the balance between energy production and consumption for cooling. Simply put, when the sun shines and the wind blows, renewable energy powers the cooling units in the warehouse. When renewable energy is not available, the units will run less or shut down until cooling is required. Optimization benefits both the warehouse owner, who maintains the required temperature range while reducing energy costs, and the grid operator and energy producers through improved balancing.

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In this paper we describe FlexLast, a solution developed to exploit demand response in an industrial setting. FlexLast is derived from the words “flexible” and “Last”, the German word for (electric) load. The technology underlying FlexLast has been developed over a number of years in projects focused on a wide range of flexible loads:

- EDISON: The purpose of EDISON was to provide balancing power for wind-generated electricity through the use of electric vehicles [5].
- EcoGrid: This project is focused on the introduction of market mechanisms that make it possible to achieve significant balancing power from participants including smart homes [6].
- iFlex: The use of flexibility from domestic hot water boilers as a source of tertiary balancing power [7].
- Smart buildings: Although not yet supported by the system, studies focusing on IBM buildings in Zurich (as one example of many) have shown that they are also a significant potential source of balancing power by exploiting available hot and cold water storage [8].

The focus with FlexLast is on exploiting demand response in the large freezer warehouses of the Migros distribution center in Neuendorf, Switzerland (MVN). Compared to other sources of demand response the MVN freezer system are very attractive since they offer a relatively large energy buffer from each source. For example, the main freezer building “TKL3” has a peak capacity of over 1MW and, thanks to good insulation and processes, the system can go without any consumption of electricity for several hours while remaining in the allowed temperature range. During the initial project phase the system is limited to using a single freezer building, TKL3, for providing balancing power. TKL3 is subdivided into 4 halls which can be individually monitored and controlled as explained below.

In Section 2 of this paper we describe the architecture of the FlexLast solution. The business case for running a system like FlexLast commercially is discussed in Section 3. Initial results of our work to date are presented in Section 4 followed by conclusions in Section 5.

II. FlexLast SOLUTION ARCHITECTURE

Previous studies have investigated using industrial refrigerated warehouses for demand response [3]. In those studies the systems were automated so that demand response could be obtained without manual intervention. A signal was provided by the electric utility to indicate its needs and used by the refrigeration control systems in order to decide autonomously when to reduce consumption. However there was not any planning, scheduling, or advance commitment of specific amounts of balancing power. The systems reacted on a best effort basis to provide balancing power.

The objective of FlexLast is to provide balancing power in a predictable fashion to maximize the value to the power networks and markets. FlexLast will determine how much balancing power is available from a given configuration of flexible loads in a known state and offer this to an electricity market or other system that exploits the balancing power. The external system will indicate the required consumption levels to FlexLast, which will schedule operation of the MVN freezer systems appropriately to match the request.

A. Predictive Analytics

The MVN freezer warehouses are divided into a number of halls. There are separate evaporators for each hall with a common refrigeration system behind the evaporators supporting each warehouse (common condensers, separators, etc.). Each hall is always in one of the following 4 states:

- Cooling (evaporators active)
- Fans running (evaporators not active)
- Ready (nothing running)
- Defrosting

A thermal model of the halls was created to relate the state to the evolution of temperature in the hall. The thermal model is a linear state-space model with two states per hall. The dynamic states in the model are a single air temperature and a single temperature of the solids in each hall. All of the solids, i.e., the dynamics of the walls, building, and goods are thus aggregated. The inputs to the thermal model are the states of the evaporators. In addition to the thermal model, a cooling system model that maps between evaporator states and electric power consumption was created using historical data. Detailed data with a 10 second time granularity was available to support this process. System identification techniques were used to estimate the parameters of the model to achieve a close fit between measurements and model outputs.

The thermal model is being further refined by considering the two primary factors that impact energy loss in the halls:

- Logistics: Incoming goods that are warmer than the current internal temperature will result in energy consumption in order to maintain the temperature in the hall. Logistics data specifying the volume and weight of incoming goods along with the expected temperature is available for 15 minute intervals.
- Outside weather (including temperature, solar irradiance, humidity, wind): Clearly more energy will be lost through the walls and doors when the temperature is high with direct sunshine, compared to a cold, relatively dark day.

Forecasts of the incoming goods are available from MVN. Although delivery times may vary by several hours from the forecasts, for long-term models this does not have a significant impact. Forecasts for the weather are also available. The accuracy of detailed weather forecasts decreases with the length of the period being predicted; however the weather forecasts are well suited to the problem at hand. They are very accurate for the short term, thus supporting accurate energy forecasting for the coming hours and days. For longer periods, the trends (especially the outside temperature) are good enough to support (less accurate) forecasts.
Given the cooling system and thermal models, along with forecasts for logistics and weather, it is thus possible to produce good forecasts for the temperature evolution and thus the energy and power consumption of each hall. In Figure 1 we show the temperature forecasts made using our model, compared to measured values. This example and our results in general indicate that it is possible to model the systems adequately.

![Temperature forecasts and measurements](image)

Fig. 1. Temperature forecasts and measurements

For purposes of FlexLast control, the MVN freezer systems are allowed to operate within a temperature range of -24 degrees Celsius to -28 degrees. By using the maximum (minimum) allowed target temperature of -24 degrees (-28 degrees) with our models, a forecasts for the minimum (maximum) energy consumption can be obtained. The flexibility is given by the difference between these minimums and maximums. This is illustrated in Figure 2.

![Conceptual flexibility offered by FlexLast](image)

Fig. 2. Conceptual flexibility offered by FlexLast

In the pilot system the flexibility is offered to BKW as a time series comprised of the minimum and maximum power levels of the system for a 2 week period. Once additional freezer warehouses have been added into the FlexLast system, the aggregate flexibility will be computed and provided.

Defrost events can be scheduled at regular intervals, and the start of a defrost event can be delayed. In this way the impact of defrosting on the overall system can be accounted for (in aggregate) while minimizing the short-term impact. At this stage of the implementation and testing these events are ignored, and thus they are a source of potential error.

### B. Indirect Control

To influence the energy consumption of each hall, the MVN control systems allow FlexLast to specify a temperature set point for each hall. The set point must always be in the range allowed by MVN. FlexLast can also issue a command to the control system to initiate or stop cooling immediately, in order to overcome the internal hysteresis of the system. This capability significantly improves the responsiveness of the system. There is a limit however of 4 changes in the set point for each hall in one hour. Given that TKL3 has 4 halls, this limits the overall system to 16 control events per hour. Clearly this restriction on control events precludes the system from being able to provide secondary balancing power on its own. Thus our goal in the initial phase of the study is to understand the capabilities of FlexLast when using a single source of balancing power. As the system is extended (e.g., by adding monitoring and control of additional freezer building) these capabilities will be extended.

In response to the flexibility offered by FlexLast, BKW provides a signal that requests a specific power level within the limits specified. We have developed a model to map the requested power levels into the necessary state of one or more of the halls (cooling, fans running, ready, defrosting as described above). A separate model was developed which allows us to determine the temperature set point needed to achieve the desired operating state for each hall. Thus in two steps we are able to map the requested power into a temperature set point for each hall, which can then be provided to the MVN freezer control systems.

### III. BUSINESS CASE

The future demand for flexible regulation power will be driven by the increasing feed-in of volatile energy production coming from wind and solar plants. For the case of Germany the future demand in regulation power is calculated to increase by 34% in 2020 compared to the situation in 2010 as shown in Figure 3.

![Development of balancing power provisioning without primary reserve from 2010 to 2050](image)

Fig. 3. Development of balancing power provisioning without primary reserve from 2010 to 2050 [9]
The major expected increase from 2010 to 2020 is driven by the massive increase in renewables until 2020 whereas the only slight increase beyond then and the decrease in 2050 compared to 2030 results from advancements in forecasting renewable production. In numbers, the need for secondary and tertiary reserve power together would account for 12 GW in 2020 compared to 9 GW in 2010.

Today only a small number of pools are prequalified for the German balancing power market of which an even smaller number is prequalified for both secondary and tertiary balancing power. In spite of the fact that the total number of pools is small, already a handful of major players in the heavy and chemical industries are prequalified, mostly for tertiary balancing power and in few cases also for secondary and even primary reserves. The current overall potential for providing balancing power from industrial sources in Germany is approximately 2.8 GW [10] without knowing the fraction of this that would be suitable for secondary and tertiary reserves. Thus one immediately sees that the additional German need for balancing power could come almost entirely from flexible industrial loads.

The ultimate decision regarding investment in industrial load flexibility vs. flexible power plants depends on a number of technical, financial and regulatory issues.

From a manufacturing industry's point of view the business value of demand response will be driven by two technical parameters that will be investigated as part of the FlexLast pilot project:

- The goodness of forecast of flexibility in consumption.
- The timing constraints on the provided flexibility.

These parameters will determine how this flexibility can be exploited in existing balancing power markets.

From an aggregator's or utility's point of view the business case for demand response is driven by the advantages of incurring operational expenditures compared to capital-intensive investments such as in new pump storage stations. One of the largest Austrian pump storage stations today has a capacity of 0.5 GW. Six times this capacity would have to be installed in Germany in order to meet the additional need of 3 GW of balancing power by 2020. At the same time, the capital expenditure budgeting for the proposed pump storage station Grimsel III has been suspended since profitable operation does not seem feasible at present. Similar arguments hold for other ongoing and planned pump storage projects in the D-A-CH region. Therefore, focusing on flexible operation of industrial loads seems promising and focusing on large, already installed industrial capacities seems to be beneficial compared to investing in a multiplicity of individual household loads.

Depending on the regulatory framework additional benefits from demand side management solutions can probably be exploited. For example, as soon as it is beneficial for the owner of a photovoltaic plant to self-consume the produced energy instead of feeding in, the full potential of flexible loading can be exploited.

Fig. 4. Initial Flexibility of Energy Consumption for TKL3.

The time resolution is 15 minutes for 48 steps (12 hours). The future flexibility depends on the state of the system at the time of the computation (i.e., time zero in the figure). For this case the air temperature was -27 degrees Celsius (°C), and the temperature of the stored goods -25 °C. The following constraints were used for the computation:

- maximum allowed air temperature = -25.5 °C
- maximum allowed goods temperature = -24 °C
- minimum allowed temperature for air and goods = -28 °C

The lower line shows the minimum possible energy consumption required for maintaining the allowed temperature range as forecast by our model and the upper line shows the maximum possible consumption. The total flexibility for this period, given by the area between the maximum and minimum energy lines is approximately 11,000 kWh². Thus on average in this scenario 920 kWh of power are available to be shifted every hour. If the system were required to deliver balancing power for a longer period of time, of course the available balancing power would be reduced. For example if the system is required to consume energy at the lowest possible level, eventually the minimum energy consumption will be limited by the level required to preserve the maximum allowed temperature. Conversely if the system is required to consume energy at the highest possible level, eventually the maximum energy consumption will be limited by the minimum allowed temperature. In Switzerland tertiary balancing takes over from secondary balancing after approximately 15 minutes, so the 12 hour period shown is relatively long.
V. CONCLUSIONS

The FlexLast system is currently in its testing phase where the capabilities and limits of the system will be approached step by step. The responsiveness of the system is limited by the physical cooling process of the refrigerated warehouse. The flow of coolant through the system cannot be changed quickly due to physical limits. A greater number of refrigerated warehouses or other flexible loads contributing to a bigger pool could alleviate this constraint by enabling scheduling of specific loads taking into account individual constraints. Expanding the FlexLast solution to support a wide range of flexible loads in a single instance to maximize the value of the FlexLast system is therefore the logical next step.

From a business case point of view pooling industrial loads in order to participate in balancing power markets could be beneficial compared to investing in new power plants. However this will only be successful if balancing pools of sufficient size can be achieved. Pools of 50 MW and above have the best chance to gain a bigger market share in balancing power markets since TSOs have an intrinsic interest in filling up their balancing power requirements from a small number of sources. Therefore, even if the winning bids are assigned in order of merit, it is unlikely that the complete balancing power need can be filled by minimum bids of 5 MW. Larger pools, therefore, have the chance to be accepted at higher prices than minimum pools.

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