ECOGRID EU PROJECT – REAL TIME PRICE BASED LOAD CONTROL AND ECONOMIC BENEFITS IN A WIND PRODUCTION BASED SYSTEM

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ABSTRACT

The concept of Demand Response (DR) has been growing strongly in the last few years. Many projects have been deployed as well in an attempt to push customers and loads to participate more in the power system. One of the most ambitious projects in that area is the EU FP7 project named EcoGrid EU. In this project, it is attempted to use close to real time market prices in order to provide additional balancing resources from flexible consumption. This paper presents the work developed in that project regarding price elasticity and availability of process loads with internal relations and saturation restrictions. An industrial compressed air system, equipped with a compressed air storage unit and an electrical water heater are used as examples of flexible loads. The paper discusses how the volatility in the real time price and the quality of the price forecast consequently affects the energy costs and efficiency of this group of flexible consumer loads. Simulation results, which show the benefits of such system and possible threats to those benefits, are presented.

BACKGROUND

Governments worldwide have agreed to reduce the rates of carbon dioxide (CO_2) in the coming years. As years go by, the pressure increases for those same governments to take action and reduce their CO_2 emissions. A way to achieve the expected and agreed values is to replace polluting power production with renewable energy production. The economic incentives offered are expecting to lead to a large expansion of the renewable production. In Europe, most of the investments in renewable energy production are based on wind and sun. When connecting these energy sources, characterized by their intermittency and unpredictability, the production of power will become more variable with production peaks and dips that will challenge the balancing of production and consumption performed by the Transmission System Operators (TSOs). As more solar and wind power is connected to the network, the greater this problem becomes.

Real-time price based control models for different home appliances were studied in the small scale project GridWise in the USA [1]. The result from this study and other studies over the world [2,3] were very positive to start a large scale project integrating small- and large-scale prosumers.

This is the background for the EcoGrid EU project [4], which is initiated by the Danish TSO Energinet.dk. 16 partners from 10 countries develop and implement a new market concept that will be demonstrated on the island of Bornholm.

THE ECOGRID PROJECT

The EcoGrid EU project is developing and demonstrating a new market concept with 5 minutes time resolution aiming at incentivizing residential and commercial customers to be responsive to imbalance pricing close to operation [4]. The concept includes advanced metering and automated smart controllers that control the customer flexible loads or generation (e.g. PhotoVoltaics) based on the price signals which reflect the current system imbalance.

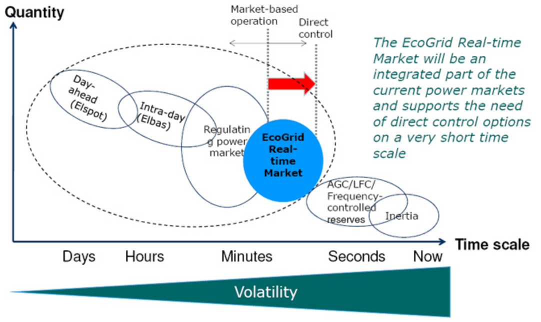

Figure 1 - The scope of a Real-time market [5]

REAL-TIME MARKET AND ITS VOLATILITY

The concept of the real-time market and flexible loads is a very good approach but requires to be well tuned so it can become a true advantage and useful for the system balancing. As Figure 1 shows, the volatility increases as the timeframe is reduced, making it hard to determine the available DR and the imbalance price. Still, the real-time market in EcoGrid EU is supported by the 24 hours Day Ahead market which gives input for the controllers on estimated hourly prices for the next day (24 hours starting at midnight, published in the middle of the previous day) [6]. This allows customers' local controllers to optimise and estimate the best working hours for their loads. The question that might be raised is how accurate can this estimated price be. The estimate is related to weather forecast (temperature and wind forecast), known for its inaccuracy, and to the expected load. This forecast inaccuracy reflects itself in the deviation between the 5 minute price that is given by the real-time market just 5 minutes before the consumption and the hourly estimated price. The expected consequence of this deviation is the incapability or uselessness of the optimization of the different process loads like the pressurizing systems described below.

Worst case scenario is if the real-time market 5 minute price is the day maximum when the controller was expecting a very low forecasted hourly price. Depending on the flexibility of the load, this can be solved by the controller with a postponing of the load to an actual low price period. In case the flexibility of the load is limited, a load start-up in a high price period will result in an increased loss for the customer and a contribution to aggravate the balancing problems in the network.

WORKING WITH FLEXIBLE LOADS

Although it can be understood that flexible loads are, as its name says, flexible on its consumption periods and that such can bring benefits for the network and customer [7], the reality is that flexibility itself on these loads may have limits. For example, one can choose to put his washing machine to work now or 5 hours later, offering load flexibility, but once the decision to start the washing machine is made, it can't be stopped during the washing process. On the other hand, thermal loads like space heating and water heaters can consume for 5 minutes periods and stop without any consequence to the equipment and/or customer, being the most suitable appliances for the market type proposed by EcoGrid EU.

Being able to use the flexibility of the loads in the EcoGrid EU market context implies the use of optimizing controllers capable of determining the right time to start and stop loads according to the real time market price. Obviously, these flexibility limitations presented by some of the loads need to be considered by the controller in its optimization (the controller will seek to optimize the use of the load but always guaranteeing equipment safety and customer satisfaction first).

In this paper, the flexible load used as an example in the simulation and results, is an industrial compressed air system, equipped with a compressed air storage unit. The use of a compressed air storage unit gives the load extra flexibility but it will still have some limitations due to safety reasons connected to the storage unit.

The industrial compressed air system is responsible for delivering compressed air at a certain pressure and with a predetermined air flow as demanded by the system user. Although the air compressed system is a complicated system to represent, the system used in this paper was simplified with a simplified compressed cycle and no specific compression type. The motor is also considered as being only able to be ON and OFF. The compressed air system has also constant air losses in time that result in loss of general system pressure and air flow usage for a period of 8 hours per day (representing industrial air flow usage for a normal work period).

The dynamic behaviour of the air flow in the compressed air system can be simply described by variations of air flow, pressure and time with the following equation:

$$\Delta q = \frac{\Delta p}{P_{atm}} \times \frac{V_s}{\Delta t} \tag{1}$$

Replacing the Δ, the air flow balance equation of the compressed air system is given by the next equation.

$$Q_{out} - Q_{in} = \frac{P_{initial} - P_{final}}{P_{atm}} \times \frac{V_s}{T_{final} - T_{initial}} \tag{2}$$

Where:

Q_{in} [m3/s] is the air flow provided by the air compressor; Q_{out} [m3/s] is the air flow required by end-user; $P_{initial}$ [Pa] is the initial system pressure; P_{final} [Pa] is the final system pressure; P_{atm} [Pa] is the environment pressure; V_s [m3] is the storage unit volume; T_{final} [s] is the time for P_{final}; $T_{initial}$ [s] is the time for $P_{initial}$

Additionally, the compressed air system used in the simulations presented in this paper was also subdued to flexibility restrictions related to its physical limitations regarding its internal pressure. For safety reasons, the compressed air storage unit has maximum and minimum pressure values allowed (as it would have in a real system). The result of this safety restriction is that the system can only postpone consumption for a limited amount of hours (until the pressure drops to the minimum value) or consume to a limited value as well (until the pressure reaches its maximum value). The flow diagram for this load is resumed in Figure 2.

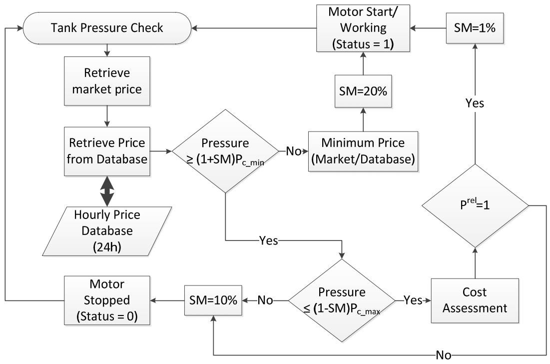

Figure 2 – Flow diagram for compressed air system

The control of the load is done by a controller that receives the input with the real time price and the input with the 24 hours day ahead price. The controller uses the information from those inputs to determine if the real time price received for those 5 minutes is beneficial considering the expected prices for the rest of the day. The algorithm used by the controller to determine a beneficial situation is:

$$x = \frac{RTM - FP_{av}}{\sigma_{FP}} \tag{3}$$

Where:

RTM is the real time market price (5 minute price) given to the controller every 5 minutes; FP_{av} is the average value of the forecasted hourly prices expected until the end of the day; σ_{FP} is the standard deviation of the forecasted hourly prices expected until the end of the day; x is the relative price result

The value of x defines how good the 5 minute price given is compared with the upcoming forecasted prices. In case x is a positive number it means the forecasted prices in the future are lower and load should be postponed if possible. In case x is negative, it means forecasted prices in the future will be higher and consumption is recommended for the period of that 5 minute price.

Another load used in simulation was the electric water heater shown in Figure 3. The water heater has the function of maintaining the hot water temperature within comfortable limits. The electrical consumption of this load depends on the ambient (room) temperature and inlet temperature of cold water, the thermal characteristics of the water heater and the comfort settings of the end-user.

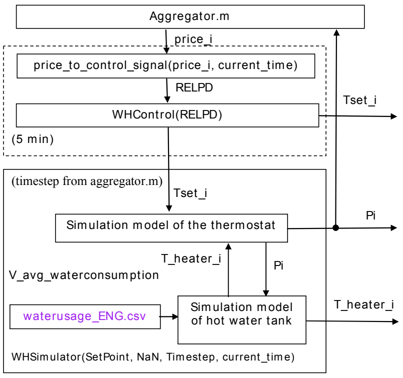

Figure 3 Overview of the simulation model

The model provided schedules for the load consumption of water heating system over a specified control period (e.g. 24 hours) according to real-time electricity prices in order to minimise heating costs while maintaining a trade-off between costs and living comfort. The living comfort is defined as the maximum number of degrees that the end-user allows to increase/decrease the temperature set-point.

Dynamical and different control models of water heater are described on different papers as [1-3, 8]. Depending on water consumption pattern, temperature set-points according to comfort settings the different strategies have different advantages. Many of these have well saving result only with lower comfort settings (the deviation between lower and higher temperature limits is higher) [3]. In the EcoGrid EU project, it was used a modification of control strategy described by D. Hammerstrom[1], which has better savings in higher comfort demand scenarios.

The control algorithm used is described with the following equations:

$$T_{s,i} = \begin{cases} p_{rd,i} = 0, T_s \\ p_{rd,i} \neq 0, \begin{cases} T_{s,i} \geq T_{m+}, T_{m+} \\ T_{m-} < T_{s,i} < T_{m+}, T_s + k_{c,i} \cdot (p_{ra,i} - p_{r,i}) \cdot \dfrac{|T_{m-} - T_s|}{p_{rd,i}} \\ T_{s,i} \leq T_{m-}, T_{m-} \end{cases} \end{cases} \quad (4)$$

Where:
$k_{c,i}$ is comfort setting at time step *i*, defined by customer for next 5 minutes or more; $p_{ra,i}$ is moving average (mean) price, calculated from last 24 hours real time prices; $p_{r,i}$ is real time (clearing) price at time step *i* (for next 5 minutes); T_{m-} is minimum temperature limit; T_{m+} is maximum temperature limit; T_s is temperature set-point, defined by customer; $T_{s,i}$ is modified temperature set-point for next 5 minutes; $p_{rd,i}$ is standard deviation of price, calculated from prices of last 24 hour.

The minimum and maximum limits are changed according to comfort setting, pre-heating and allowable temperature deviation as follows:

$$T_{m-} = T_s - k_{c,i} \cdot \Delta T \quad (5)$$

$$T_{m+} = T_s + x_i \cdot 0{,}5 \cdot k_{c,i} \cdot \Delta T \quad (6)$$

Where
X_i is pre-heating variable; ∆T is allowable temperature deviation

REDUCING COSTS WITH REAL TIME MARKET CONCEPT

Using the load described previously, simulations were run for a week period (7 days) with and without using the optimization controller in the market concept of the EcoGrid EU. The used prices, as the 24 hours day-ahead prices (always provided in the day before as described in the market concept) and the real-time market prices (5 minutes period given at the moment) are shown in Figure 4.

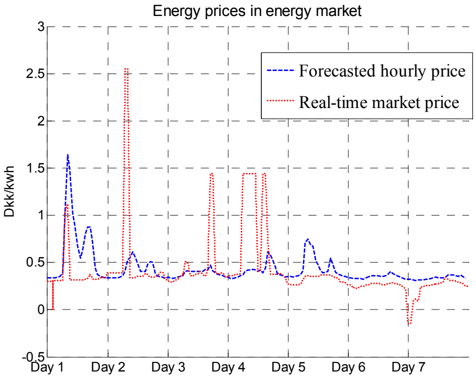

Figure 4 – Forecasted hourly prices and real-time market (5 minute period) prices used in the simulation (values supplied by DTU)

Conditions applied to the simulations for both situations, with and without the optimization controller, are identical in every way (same air flow consumption was given as well as pressure loss, starting conditions, etc).

RESULTS AND CONCLUSIONS

Total costs results for the situation with and without optimization controller can be seen in Figure 5.

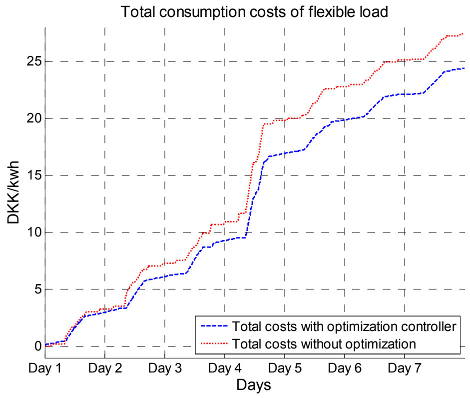

Figure 5 – Total consumption costs of the compressed air system for optimized and normal consumption in a real-time market

Results show that the use of an optimization controller helps to generate savings in energy costs. Although the costs might not look significant, it is important to remember that values are per kWh which means that a simple compressed air system that consumes a total of 1 MWh every week results in a gain of over 2000 DKK (over 250 €) every week. Depending on the comfort settings and used load pattern, an electric water heater that consumes from 3.5 MWh in year results in a gain up to 83 €. In an apartment building with 20 apartments the total annual savings could reach up to 1660 €.

The efficiency of the optimization is, as it was written before, connected to the reliability of the forecasted hourly hours. Looking at Figure 4 and Figure 5, it is possible to notice that on the first days, when there is more imprecision between the forecasted prices and the real time market prices, the costs of both situations are very similar if not the same. At the end of Day 4, when forecasted prices and real time market prices become similar, the costs with the optimization controller are much smaller than the ones without optimization controller.

On a balancing perspective, the flexibility of the load was without a doubt valuable on the last half (after Day 5) on helping the system balancing since the controller work actually moved the load consumption to periods with cheaper prices and more energy availability in the network. Regarding the first half of the week, the controller work was not so effective and might have pushed some load consumption periods to more critical times when energy was scarce and more expensive. This is partially reflected by the fact that, even though there was load postponing for later periods, the total cost of both situations was very similar. This means that there were periods where load consumption was done when prices were actually higher due to the controller postponing load consumption as much as he could (until he was overrun by the safety requirements of the system and load could not be postponed anymore), always expecting to find a lower price in the future that did not come. Further work is being developed in the Ecogrid EU project regarding load and distributed energy resources forecasting models.

In conclusion, the use of optimization algorithms and controllers to take full advantage of flexible loads in a real-time market scenario like the one described in the EcoGrid EU project brings clear advantages. The advantages can be economical and operational.

Economically, the paper shows a reduction of consumption costs when the forecasted prices meet the real-time market prices and even when the forecasted price fails to meet the real-time market price, the consumption costs are about the same for the situations with and without optimization.

Operationally, wrong forecast of prices can push loads to periods where there is already a high demand and low production which can aggravate the network operational conditions while good forecasted prices will help balancing the network operation.

The EcoGrid EU project is working on deploying the work presented in this paper in its pilot test at Bornholm, Denmark.

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