ASSESSING ELECTRICAL FLEXIBILITY IN PROCESS INDUSTRY

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Abstract

The electricity system in Europe is changing fast. New policies and market design puts the traditional operation of the electricity grid under pressure. Classic resources like nuclear power plants and coal or gas fired plants are being closed or operate with highly reduced load factors as renewable energy resources are replacing them. Traditionally, classic thermal power plants and hydro-electric dams provided flexibility to balance the electricity system, while now grid operators need to find other balancing service providers.

The shift towards renewable energy also increases the need for balancing. Added to lower availability of the traditional balancing providers, it is expected that the volatility of energy and balancing prices will further increase.

Therefore, grid operators are reducing barriers to participate in the balancing market. Traditionally passive participants in the market such as consumers take a more active role through distributed generation. Similarly, process industry is challenged to screen its potential to provide flexibility to the electricity system. Many facilities have their own power production, and operate power intensive processes. Identifying and activating this flexibility can help to balance the grid while similarly reducing the average electricity price, taking advantage of new market opportunities due to the volatility of electricity prices and balancing markets.

This paper presents a methodology to assess electrical flexibility in process industry in order to reduce the overall electricity cost. The variety of options on how to valorise this flexibility is presented. The methods are validated using data of the Belgian electricity market.

Keywords: Virtual power plants; Microgrids, Demand side management; Process industry

1 Introduction

All over the world, the energy awareness increases. Two important factors are accountable for this raise in attention; the much debated climate change and increasing prices due to diminishing reserves of oil products. This encourages policy makers and public opinion to reduce primary energy consumption and increase energy efficiency. A large portion of the new and more energy-efficient technologies shift towards the use of electricity. To name a few: gas boilers are replaced by heat pumps and vehicles switch from combustion engines to an electrical drive train. As a result, although primary energy consumption becomes more efficient, more electrical energy is consumed.

Generation of electricity is also under pressure. As more than half of the electricity production worldwide is based on fossil fuel [1], this results in environmental and economic pressure. In Europe, the lack of large own fossil energy reserves enforces dependence on fuel imports. Also, the other large primary energy resource for electricity production, nuclear power, is causing much political and social concern. The aforementioned circumstances are the drivers for the development and installation of a large amount of new electricity producing devices like wind turbines, solar parks, combined heat and power,… Although those devices are mostly connected to the medium and low voltage grid, due to their large number they have a significant impact on the high voltage grid and hence system stability as well. To preserve the environment and increase independence of external energy sources, Europe set ambitious goals to electricity production from renewable energy sources (RES). However, this encompasses large stress on the operational stability of the electricity grid due to a lack of controllability of those sources. Virtual Power Plants (VPP), are a control concept to manage and control large amounts of relatively small energy resources and integrate them in the operation of the grid. Relatively small should be regarded from a grid perspective: all units smaller than 25 MW are considered 'small'. Combining resources within sites as microgrids and joining these microgrids in VPPs reduces the involved risks and increases the available volume [2].

In this paper, a framework is laid out in order to utilise industrial flexibility to provide balancing services to maintain a stable grid. In this way, industry can help to integrate RES without directly installing resources on their own premises. This will also help to reduce the electricity cost for industry as ancillary services are an increasing market with high potential for savings if managed well.

This paper is structured as following: in §2, a general overview is given how resources within industry are assessed. Focussing on the right resources right from the beginning will save much time and hence money later in the process. Next, in §3, the market for electrical energy and ancillary services is introduced. These are required to have an idea how to valorise flexibility. In §4, it is explained how and why modelling of flexible resources is important. Next, §5 brings §3 & §4 together in optimising the flexibility and targeting deferent resources towards different markets. Finally, in §6 a conclusion is drawn.

2 Assessing Flexible Resources

A first task is assessing potential flexible electrical resources in an industrial facility. The first screening can be made based on a load list and a process flow diagram. This will result in a fairly long list of electrical equipment, which should be filtered down to a manageable list before further measuring and modelling can start.

The first step on this list is assigning categories to each resource. Often, many similar devices are present, each with a relative small power, but together adding up to a significant power level, e.g. fans of an aero cooler. By assigning devices a category based on function and location in the process / facility, similar loads are grouped together, increasing their potential further in the selection process.

Next, based on this categorised list of loads, a selection can be made which resource (groups) should be further detailed. Three factors are important: power, capacity factor and role in the process. Power is an obvious selection criterion: the larger the power, the higher the potential effect. Large units are hence more interesting to participate in the load shifting process. However, as stated above, a large group of similar small resources should also be considered.

The capacity factor is the next criterion: units which must always run at maximum power or are almost never used, might be weaker candidates for load shifting or flexibility. A moderate capacity factor might indicate a unit with some potential to shift energy. A unit working at 70% might be a candidate to shift its use a little in time.

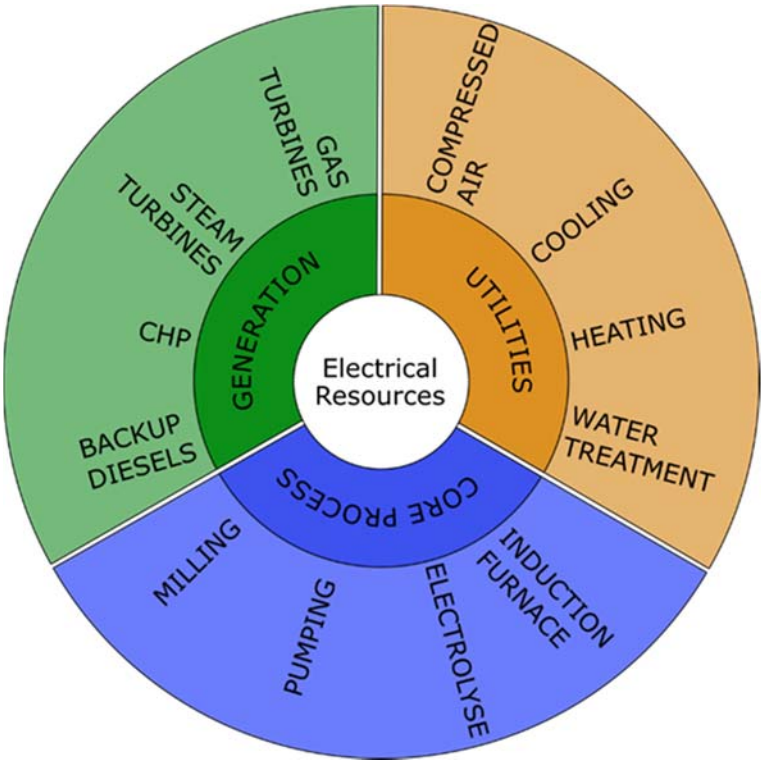

Figure 1. Electrical resources

Two examples with less flexibility potential might be an primary cooling pump in a continuous process and a fire hydrant pump. Although both might have similar power, they might not be suitable for load shifting due to their capacity factor being almost 1 for the cooling pump and 0 for the fire pump. This leads to the third selection criterion: location and purpose in the process. Electrical resources can be divided in three categories: Core process, utilities and generation. Core process resources might be critical to the production flow on the site. Shifting these resources might result in production loss, quality problems or require employees to adapt their work schedule. Therefore, core process units should be avoided or only sparingly be selected for exceptional demand response with a very high value, e.g. strategic reserve.

Utilities might be a good candidate for continuous adaptation. Often they are coupled to the core process through some kind of buffer or have a relative large time constant. Shifting these kind of resources in time might not affect the core process directly. These resources are therefore primary candidates for frequently activated demand response.

A third category of potential resources is onsite generation. Many industrial sites have backup generators, combined heat and power, expansion turbines with energy recuperation,… For most of these units, the electricity price is currently not an important factor in their operational scheduling. However, taking into account the large price variability of electricity and ancillary services might have a significant impact on their generated revenue (or cost reduction) [3].

3 Electricity Trade

The industrial flexibility can be valorised in two different ways. The first is pure as energy. Processes can be planned in order to utilise the cheapest electricity possible and selling onsite generated electricity at the highest possible price. Flexibility is used to shift energy from one hour to another. Participating in the energy markets however also implies the requirement to submit a profile day-ahead. This profile should be maintained in real time in order to avoid fines. These fines are based on the price of the ancillary services. The last reserve to be activated in order to correct for system imbalances determines the fine for imbalance in the energy market.

The second way is selling the flexibility to the transmission system operator (TSO), Access Responsible Parties (ARP) or flexibility aggregators. As has been explained in §1, the traditional providers of flexibility (combined cycle gas turbines) are shut down due to lower margins and reduced operation hours. At the same time, RES increases the requirement for demand response due to the inherent variability and unpredictability. This drives the high demand for new balancing resources and the increasing prices paid for them.

3.1 Energy markets

Trading in wholesale energy markets has certain implications. First, a precise power profile is required. This profile needs to be submitted to the TSO at the latest the day before actual delivery. In order to actually profit from the wholesale markets, a company need to send the 15 minutes profile and keep to this profile in real time.

As a result, this requires a precisely predictable process or some form of near real time load and/or production management. If the profile in real time differs from the submitted profile, an imbalance fee will be applied by the TSO. This fee can be positive or negative, but is generally encouraging BRPs to follow the submitted profile. In [4], it was proven however that in certain cases profit could be made by submitting a false profile.

Knowing the electricity requirement of each production step is a prerequisite to estimate the total load profile. This profile can then be used as well to reschedule certain process steps in order to take advantage of better prices in the day ahead market.

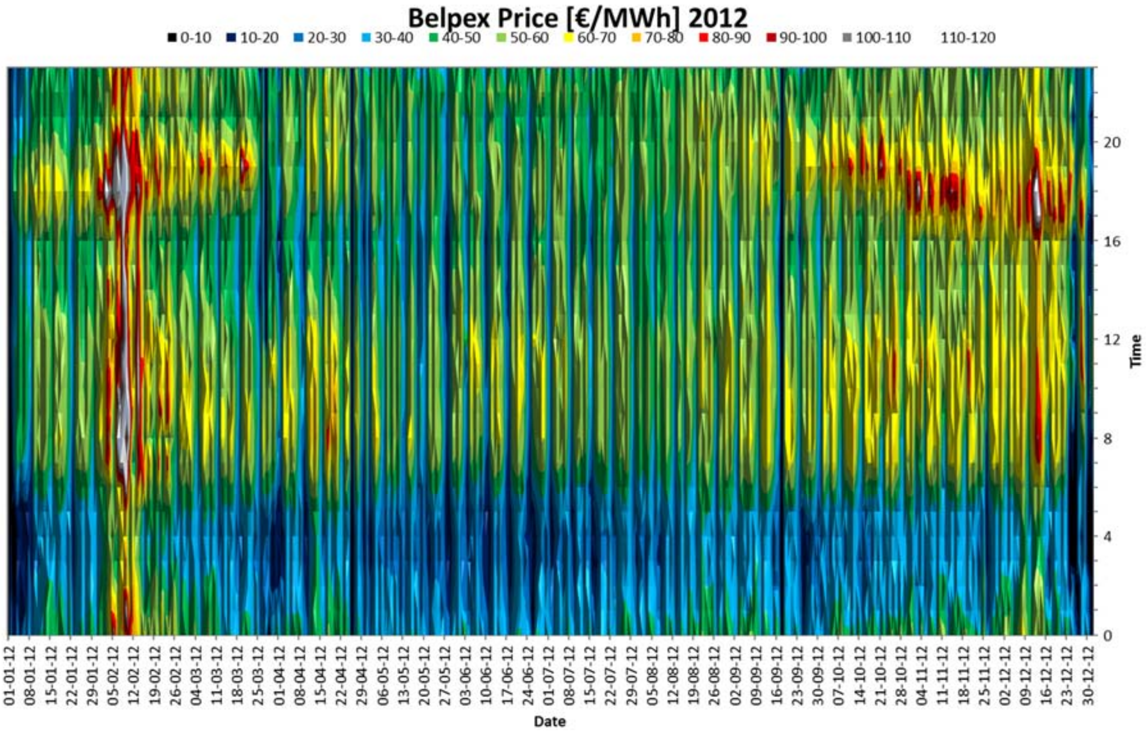

Figure 2. Belpex Day Ahead price

Although many options exist for trading electrical energy, the main market applicable to plants willing to apply load shifting is the day ahead market. In Fig. 2 one year of the day ahead market prices in Belgium is shown. On the horizontal axis the day of the year is shown, whereas on the vertical axis the hour of the day is denoted. The colour represents the price. In this figure, several patterns can be observed. The seasonal patterns are out of scope of this paper, but the evening peak is clearly changing by the time of the year. Of more interest are the daily changes in price. In these, a pattern can be discovered as well. In the night, the prices are generally the lowest. During the morning hours, the prices rise to lower a little during noon. The highest peak is often observed during the evening and after 20h the prices fall again to their lowest level. Using this daily variations could save a company a significant amount of money.

3.2 Ancillary services markets

In order to keep the energy balance on the grid, the frequency is used as the main measure. A surplus of energy will rise the frequency, a shortage will decrease it. The frequency control is divided in several levels. The primary control is in place to limit the deviation of the frequency from the nominal value (50 Hz in Europe). The secondary control then takes over in order to restore the nominal value. Tertiary reserve is used to free the secondary reserves.

In Fig.3 [5], the timing sequence for the activation of these reserves is shown. In [5], primary reserve is stated to be a joint action of all involved parties following a frequency deviation within seconds. This is to maintain a balance between generation and consumption and to prevent the system frequency from drifting away from its nominal frequency. This primary reserve is activated within seconds of a measured deviation.

Secondary control replaces primary control over minutes and is put into action by the TSOs [6]. The secondary control will restore the primary capacity after its activation. Whereas primary control is activated all over the synchronous zone, secondary control will only be activated in the control zone which caused the deviation.

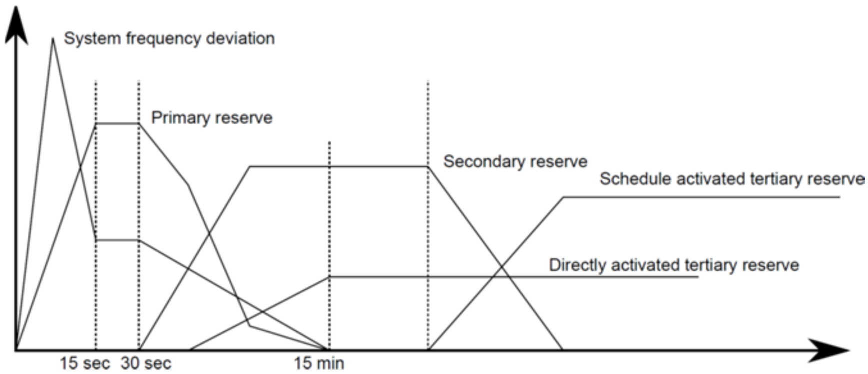

Figure 3. Timing of reserve markets

Tertiary reserve is mainly used to replace secondary reserve. It can be manually activated by the TSO in the follow up of an incident. Schedule activated control reserve is operated according a predetermined time frame.

4 Modelling Flexibility

Based on the list of potential resources presented in § 2, these resources should be evaluated in depth. Some units are relative simple to evaluate: generators for example have known efficiency curves, require service after a determined (running) time and have a more or less fixed fuel cost. Hence a minimal run cost can easily be determined. Many units in the generation group have similar, relatively easy determinable cost structure.

Generation type units are often redundant or have large operational headroom. Therefore, they can easily be rescheduled or shifted in time according to the signals of the energy market or sold as ancillary service providers. Optimising these units according to the electricity prices can bring extra value compared to fixed energy price contracts by benefitting from the price volatility in the day ahead or ancillary services market. Combined Heat and Power (CHP) units are on the edge between generation and utilities as they provide process heat next to electricity.

The second group of resources, the utilities, are more intertwined with the production process. Although often, these resources have some buffer in between: thermal inertia, product storage, … These processes are more difficult to use as flexible resource as they are somehow related to the production process. Therefore, a more detailed study is required. Due to their direct or indirect linkage with the process and the production schedule, a dynamic model should be made. This dynamic model should reflect the time a certain unit can deviate from its target setpoint without disturbing the production process by using the larger time constants of the unit. These dynamic models should reflect the inertia often found in utility processes. As has been shown in [7, 8], thermal systems like CHPs, pipe tracing, cooling units,…

are typical examples where the time constant of the thermal side is much larger than the time constants of the electrical grid and many types of ancillary services.

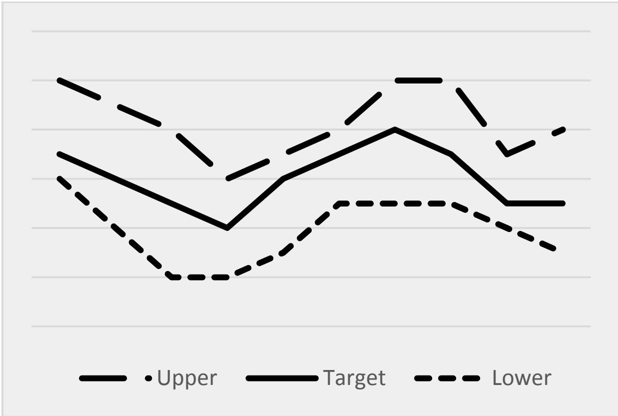

Figure 4. Flexibility band

As shown in Figure 4 the dynamic model should provide an upper and lower limit of the power as consumed by the process. Together with the time constants of the process, this gives the amount of flexibility and the duration the process can deviate from its original target.

Combining these models will result in a flexibility model of the process, plant and site. Knowing the power levels, the time constants and the control margins, these combined models can then be used to decide how to valorise the flexibility.

5 Optimising Flexibility in the Market

After the flexibility is estimated, the best methodology to sell it should be determined. As has been explained in §3, there are multiple options to valorise flexibility. However, both energy market access and ancillary service provision are targeted at large resources. A VPP can aggregate enough units to create a critical mass in order to have a strong market position and spread the risks. 10-25 MW is regarded as the target flexibility volume for a viable VPP.

First, flexibility can be used to optimise the energy profile of the site or cluster (VPP) in order to take advantage of the dynamics of the day-ahead market. Loads can be shifted towards the cheaper hours whereas generation is started as much as possible during the expensive hours. As this is a multi-hour operation, this is most suited for units with some operational headroom or standby/backup units. Also, a control margin should be maintained in order to react to unexpected changes in order to avoid high imbalance fines.

A second option is to sell flexibility as ancillary services. This is a highly dynamic market. Prices can vary from a few cents per MWh to well above €500 per MWh (price cap on € 4500 / MWh). As is shown in Fig. 5, not all price levels are occurring equally. As the grid operator will select the best bids first, setting the price of the service is of utmost importance: to high and selection is unlikely, to low will result in to frequent activation and depletion of the control band.

Flexibility is remunerated via a bid-ladder. For a given regulation volume, the TSO will first select the cheapest resource. For upwards activation, this is the lowest price offered by a provider, for downward reserve it is the highest price offered. The flexibility provider receives its submitted price, not the price of the latest activated resource. This is an important factor as a cheap upward regulation action might be selected quite often, but generating a low revenue. A high offer might be selected less and will hence also generate a low revenue. In Fig. 5 the price-duration curve is shown for February 2017 for the different Belgian reserve markets. R2+ and R2- are respectively secondary upwards and downwards activation. DC and IC are respectively downward and upward non-contracted regulation capacity on coordinable power plants. DLC and ILC are downward and upward non-contracted regulation capacity on limited coordinable power plants, subjected to real time constrains. ICH is pre-contracted upward reserve (sheddable consumption) from industrial clients and R3std represents pre-contracted upward tertiary reserves.

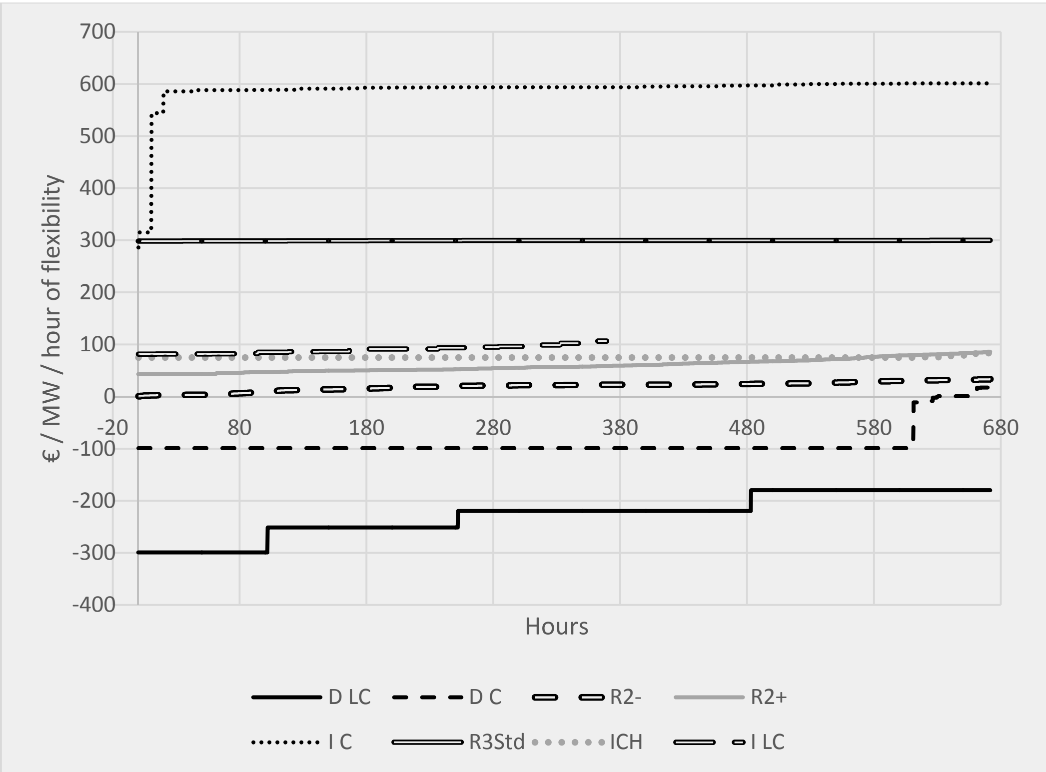

Figure 5. Price duration curves of ancillary service markets in Belgium (Feb 2017)

This shows the very different prices, their occurrence and the different value of each product. Each of these products has its own requirements regarding reaction time, time to maintain a setpoint and number of activations. Careful allocation of a flexibility resource within this market and the price offered is therefore critical to the success of the VPP.

6 Conclusion

In this paper, an overview is given of the steps required to get started with industrial demand response. First, resources should be listed and selected on their potential. Large resources with some headroom are the most interesting to further investigate. Based on this list, dynamic models should be made. These models are required to predict the flexibility band of the resource, depending on the requirements of the surrounding processes. Industrial flexibility relies on operational headroom (e.g. generators), redundancy (e.g. turbines and expansion valves) or the difference in time constants of the electricity market and the process. Processes with relative short time constants could be used to deliver frequency control, whereas processes with large flexibility margins could be used to utilise the dynamics of the day-ahead market.

Combining resources of industrial flexibility in a Virtual Power Plant remains a big challenge. Although aggregators are an expanding business, most only utilise the low hanging fruit, e.g. cooling cells or CHPs. Much more flexibility can be found in industrial plants, however, in order to actually activate it, detailed dynamic models are required. These models will be used to predict the power and maximum duration a process can deviate from its planned profile.

The final step for an industrial VPP is to determine the best value for the flexibility. Depending on the specific characteristics of a (group of) resource(s), this can be the short term primary reserve market or the multi-hour day-ahead market. Selecting the best bid price, according to the process planning, resource cost and grid state will finally determine the profitability of industrial VPP.

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