Energy Flexibility Potential of Industrial Processes in the Regulating Power Market

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Abstract: Demand response is generally considered necessary for efficiently upholding grid balance with the increased intermittent production from renewable energy sources. Demand response is acknowledged to enhance the use of more renewable energy friendly technologies, such as heat pumps, electric vehicles, and electric heating in replacement of conventional technologies. To enable the use of demand response, the consumers must have economical and practical incentives without loss of convenience. This study aims to investigate the demand-response market potential of a flexible industrial process in the current electricity market structure. The Danish West regulating power market is selected in this study with an ideal process simulation of an industrial roller press. By analysing market data, the value of flexible electricity consumption by the roller press in the regulating power market is demonstrated by an ideal process simulation.

1 INTRODUCTION

Denmark has established ambitious goals for independence of fossil fuels towards 2050 (Danish Government, 2011; DK Energy Agreement, 2012) These goals imply a 12% reduction of gross energy consumption in 2020 in comparison to 2006; a share of 35% renewable energy in 2020; and 50% wind energy in Danish electricity consumption in 2020. This means that wind energy will cover more than 50 % of the total electricity consumption in 2020. A goal that is almost reached, since wind power in 2015 covered around 42% of the total electricity consumption (Energinet, 2017). Furthermore, electricity and heat production must come from only renewable energy sources in 2035. These are all milestones toward the end goal in 2050, where all energy is provided by renewable energy sources.

Traditionally, fossil-fuelled centralized and decentralized power plants covered the electricity production. The electricity production from fossil-fuelled power plants is easy to regulate compared to the consumption. The production and consumption must always be in balance to ensure a stable and functioning grid. However, when large amounts of renewable energy sources (wind and solar) are integrated into the electricity system, irregular production fluctuations will emerge. With fluctuations for both the production and consumption, challenges arise since electricity is usually produced according to the consumption demand. Hence, with the increase in renewable energy sources, it will be increasingly difficult to maintain and control the balance between electricity production and consumption.

There are different ways to deal with the above-mentioned problem. However, the transition of the electricity system requires large investments. One approach is to expand the capacity of traditional power plants to ensure balance in the electricity system by having the necessary reserve capacity disposable. According to the report 'Smart Grid in Denmark' (Energinet and Danish Energy Association, 2014), this approach requires a socioeconomic investment of approximately 7.7 billion DKK, without yielding any additional benefits for Denmark.

Another approach is to implement an intelligent and flexible electricity system, a so-called Smart Grid, which enables flexible consumption. Establishing the Smart Grid requires a socioeconomic investment of approximately 9.8 billion, according to the report. The investment includes distribution grid upgrading, equipment for metering, and control and automation of consumptions. However, the investment in a Smart Grid yields a benefit for

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Denmark of approximately 8.2 billion DKK, hence the total net cost will be around 1.6 billion DKK.

The socioeconomic benefits are divided into different categories. The first benefit is that consumers shift their electricity consumptions according to the electricity price. Thereby it can reduce the socioeconomic cost of electricity generation. The second benefit is that the electricity consumption of consumers will be more easily manageable, which makes it possible to implement energy saving and demand response solutions. This saves society the alternate capital cost that would otherwise be required if these solutions were not implemented. The third benefit is that the cost of ancillary services can be reduced by allowing more providers with lower costs access to the regulating power market. The last benefit is especially interesting in regards to demand-side flexibility.

The electricity price will to a greater extend depend on the supply, thus a behavioural change in the consumption patterns is expected to happen. However, according to the current market rules, only electricity consumers with large consumption can participate in the market for ancillary services. Therefore, a new market player is needed. This new market player, the energy service aggregator, bundles small and medium sized consumers to represent one large consumption unit in the market. This allows more demand-side flexibility to participate in the regulating power market.

This paper aims to investigate the energy flexibility potential of industrial processes available to energy service aggregators for providing demand response services and its impact on market exploitation. A comprehensive review of applications of demand response in the industrial sector is provided in (Shoreha et al., 2016). The dominant electricity consuming processes and equipment in the industrial sector include machine drives, electrical heating, and electro-chemical processes (Samad and Kiliccote, 2012). The example that we consider in this paper belongs to the category of machine drives. The Danish DK-West regulating power market is selected for simulating the energy flexibility of an ideal process exemplified by an industrial roller press.

2 BACKGROUND

The Danish electricity grid is divided in two areas, DK-West (Jutland and Funen) and DK-East (Zealand). Additionally, the electricity grid is divided into production, transmission, distribution, and consumption (shown in figure 1).

The overall electricity market consists of a wholesale market, retail market, and a regulating power market for ancillary services.

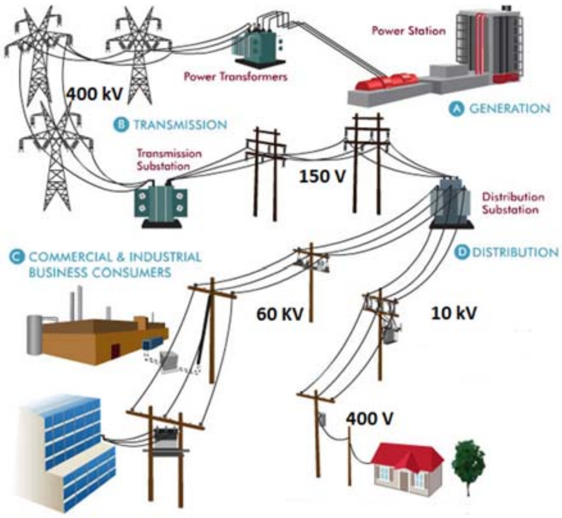

Figure 1: Overview of the Danish transmission and distribution grid (Clear Creek Networks, 2016).

2.1 The Wholesale Market

Wholesale trade of electricity in Denmark occurs primarily as either bilateral trade directly between buyer and seller or through the common Nordic electricity market - Nord Pool. In the day-ahead market (Elspot market), the electricity is traded the day before the hour of operation. A smaller part of the wholesale trade occur in the intraday market (Elbas market), with trade up to one hour before the operation hour. The day-ahead market is the major electricity market, where 70 % of the total electricity consumption in the Nordic countries is traded (Energinet, 2013). The day-ahead market is the most dominant factor for the electricity price formation of public available prices in the wholesale market.

The volume traded in the intraday market is significantly smaller compared to the day-ahead market. In 2015, the total volume traded in the intraday market in Denmark was 1.97 TWh, compared to 56.25 TWh in the day-ahead market. However, the standard deviation of the average electricity prices in the intraday market in 2015 was 105.79 DKK/MWh with a mean value of 141.06 DKK/MWh, compared with a standard deviation of 84.21 DKK/MWh in the day-ahead market (Energinet, 2016a). The high standard deviation in the intraday market indicates a potential for trading of energy flexibility in the intraday market. However, the profit that can be made here is smaller than in the regulating power market.

2.2 The Regulating Power Market

After the intraday market has close, the Transmission Service Operator (TSO) will account for all imbalances in the grid. The TSO buys regulating power from balance responsible parties, who have registered offers for up and down regulation with a given capacity (MW) and price (DKK/MW). Regulation is considered from the perspective of the production, meaning up regulation will increase the supply, whereas down regulation will decrease the supply. Manual reserves are traded in the Nordic regulating power market - the Nordic Operational Information System (NOIS).

The volume that is traded in the regulating power market is lower than the amount in the intraday market. The total amount of traded up and down regulation in Denmark in 2015 was 0.44 TWh. By comparing up and down regulation with the total electricity consumption in Denmark, there are no unambiguous tendencies during the past five years (Energinet, 2016a). A detailed description of ancillary services is provided in (Biegela et al., 2014; Lund et al., 2015).

3 FLEXIBILITY POTENTIAL

With the increased capacity of renewable energy sources in the future, the electricity grid must undergo modifications for a continuous effective use of these resources. One very important modification is support for demand response in the demand side. In this section, the estimation of the flexibility potential is simulated using several scenarios. The potential of increasing and decreasing the consumption, as result of changing the production in certain periods, is referred to as flexibility potential.

3.1 Case Selection

One of the leading supplier companies within the cement industry, KHD Humboldt Wedag, is selected for the flexibility potential simulation. In order for a process to deliver all flexibility demands, it must fulfil the two following requirements:

- Turn on and off instantaneously or within very short notice.
- The discontinuous operation must not affect the quality of the product from the process.

The roller presses of KHD Humboldt Wedag seem suitable for the simulation. According to the datasheet (KHD Humboldt Wedag, 2016), they have a variety of roller presses with different pressing forces and power consumptions. Since the pressing forces are not important for the simulation, the roller press with the highest power consumption (6000 kW) is chosen.

3.2 Simulation Initialisation

The market data from 2015 is selected in this study for the simulations. The regulating power market volumes and prices (DK-West), as well as intraday prices, are obtained from Energinet.dk (Energinet, 2016b), whereas Nord Pool Spot (Nord Pool Spot, 2016) is used for the intraday volumes.

Firstly, the required capacity is found that meets all up and down regulations in the different markets and areas. To find this, the maximum value of the up regulation and the minimum value of the down regulation (it is negative in the statistics) necessary at any given hour during the simulation year (2015) must be located.

The maximum amount of up regulation at any given time during 2015 was 638.9 MW, whereas it was -572.0 MW for down regulation. Since the required up regulation is larger than the required down regulation, the process capacity in the simulation is chosen as 638.9 MW. Since each roller press has a power consumption of 6 MW, a capacity of 642 MW (107 units) must be installed to cover all regulation requirements at all times in this simulation. This is not a realistic number of units in a real life scenario; however, it is used here as it suffices to demonstrate the concept.

It is assumed that the roller press adds value to the materials by pulverising it, which will further on be referred to as 'Process Income' DKK/MW. Since this value is not known, different scenarios for 'Process Incomes' will be simulated. It is not given that the process can deliver regulation whenever it is required. If the process is running in the given hour, it will only be able to deliver up regulation within that hour and not down regulation. On the other hand, if the process is turned off within that hour, it can only provide down regulation.

To determine whether the process is turned on or off, an evaluation of the 'Process Income', the hourly spot price, and the electricity taxes must be done.

Figure 2 shows the spot price (incl. electricity taxes) for an arbitrary selected day, January1st, 2015 and a 'Process Income' of 150 DKK/MW. The spot price itself fluctuates throughout the day, whereas the 'Process Income' is constant. The electricity taxes in the considered market, i.e., Denmark, relates directly to the consumed amount of electricity. In the period where the spot price with taxes is below the ‘Process Income’, it is profitable to have the roller presses running. However, when the spot price with taxes exceeds the ‘Process Income’, it is no longer profitable to have the roller presses turned on, and they will therefore be turned off.

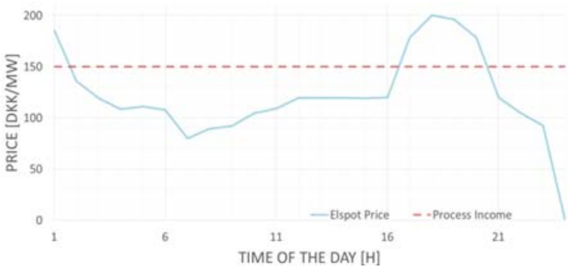

Figure 2: Example of the ON / OFF for the ideal process. The process is ON below the constant line.

3.3 Down Regulation

An IF (*condition*) function is designed in this study to determine whether alterations should be made to the ‘Initial Running Schedule’. The IF function is described below, where, if all the following conditions are met, the process will be turned on:

- Down regulation is needed.
- The process is turned off in the ‘Initial Running Schedule’.
- The income for providing down regulation and ‘Process Income’ exceeds the electricity taxes.

The income for providing down regulation (referred to as ‘Income Down Regulation’) is calculated as the product of the amount of units activated to provide the down regulation, the balancing power price for down regulation, and the power consumption of each unit (e.g. 6 MW for the roller press).

There is an electricity cost associated with providing down regulation (consisting of taxes only). However, the electricity taxes always exceed the ‘Income Down Regulation’, resulting in an economic loss for providing down regulation if it is not for the ‘Process Income’. From the companies’ point of view (the companies owning the roller presses), they can receive cheap electricity for running their processes when providing down regulation. Hence, instead of keeping the roller presses turned off, it can become profitable to turn them on.

If the ‘Income Down Regulation’ is calculated as the difference between the payment for providing down regulation and the electricity taxes, the profit of the down regulation in all markets would be zero or negative. This would provide an inaccurate picture of the value of providing down regulation in each market, as cheaper electricity from providing down regulation does hold a significant production value, especially if the ‘Process Income’ is high. For this reason, the ‘Income Down Regulation’ is calculated including the ‘Process Income’, but without taking any additional expenses for providing down regulation into consideration. The purpose of the simulations are to estimate the value of flexible consumption, and not including both the electricity taxes and ‘Process Income’ into the calculations for ‘Income Down Regulation’ would give a wrong picture of the real value in the electricity markets.

However, not all units will be activated when supplying down regulation. If there is a need for e.g. 88.3 MW of down regulation in a certain hour, only 14 units will turn on. This provides 84.0 MW of down regulation, whereas the last 4.3 MW should be supplied from elsewhere. It is obvious that, more down regulation can be supplied by the processes with smaller units (e.g. 1 MW instead of 6 MW).

There are occasions where there is a need for down regulation in a market, but it is not supplied by the processes. This is due to that conditions are not met. This lost potential for down regulation (referred to as ‘Lost Regulation Income’) is heavily influenced by the ‘Process Income’, which is why the simulations are made for different values of ‘Process Income’. The evaluation of different ‘Process Incomes’ shows a big flexibility potential in the market.

3.4 Up Regulation

For the up regulation market, the same procedure applies in this study. A similar IF (*condition*) function is made. The processes are turned off if the following conditions are met:

- Up regulation is needed.
- The process is turned on in the ‘Initial Running Schedule’.
- The income for providing up regulation exceeds the ‘Process Profit’ (which is the difference between ‘Process Income’ and electricity costs, i.e., spot price and taxes).

If the conditions are met, only the amount of units required to cover the up regulation are turned off. The remaining units continue to run. As in the simulation for down regulation, there also remains a rest for up regulating power, which cannot be covered by the processes. This is either because the unit is turned off in the ‘Initial Running Schedule’, it is more profitable to keep the processes running and not provide up regulation, or because the required up regulation is not divisible by 6 MW.

3.5 Simulation Results

The results for the DK-West regulating power market can be seen in Figure 3. Figure 3 shows that the maximum up regulation can be delivered at a Process Income of 350 DKK/MW. As for down regulation, the maximum amount is delivered at 375 DKK/MW. Furthermore, the total amount of regulating power (both up and down) that can be delivered is 154.1 GW, out of 359.6 GW, at 'Process Income' 350 and 375 DKK/MW.

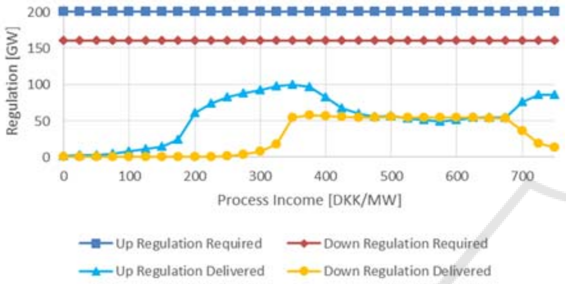

Figure 3: The flexibility potential of the 6 MW ideal process simulations for data from the DK-West Regulating Power Market.

This means that around 43 % of the total regulating power needed throughout the year can be delivered, when using roller presses of 6 MW. However, this is an ideal scenario and illustrates the total potential of flexible consumption within the current regulating power market. The remaining 57 % must come from other sources, such as power generation or other types of demand response.

The figure also shows that it is not profitable to provide either up or down regulating power for low value of 'Process Income' (e.g. 0-150 DKK/MW). The electricity taxes were 498 DKK/MW, which means that the balancing power price needs to be high for it to be profitable to provide down regulating power. The graph for 'Down Regulation Delivered' shows that the balancing power price does not compensate for the high electricity taxes. Only a small amount of down regulating power was delivered until the 'Process Income' reached 350 DKK/MW. From this point, the down regulation delivered was almost constant until the 'Process Income' reached 675 DKK/MW afterwards it slowly decreased. The reason for this plateau of constant 'Down Regulation Delivered' between 375-675 DKK/MW is due to the electricity taxes. The electricity taxes make a restriction to the amount of down regulating power that can be delivered by the ideal process.

The reason why 'Up Regulation Delivered' is also small at low values of 'Process Income' is indirectly caused by the electricity taxes. The electricity taxes have huge impact on the 'Initial Running Schedule' resulting in the processes being turned off at most occasions. However, as the 'Process Income' increases, the processes are turned on more often in the 'Initial Running Schedule'. Since it is only possible to provide up regulation when the processes are already on, this can cause the increasing amount of 'Up Regulation Delivered'. At 'Process Income' 375 DKK/MW, the 'Up Regulation Delivered' starts to decline, because the income for providing up regulation (referred to 'Income Up Regulation') no longer exceeds the 'Process Income', and it is more profitable to keep the processes running instead of turning them off to provide the up regulation. The 'Up Regulation Delivered' remains almost constant until the 'Process Income' is as high as 675 DKK/MW. The 'Process Income' is so high that the processes keep on almost all the time in the 'Initial Running Schedule'. It allows much more up regulating power and much less down regulating power to be delivered.

Figure 4: The total regulation income of the 6 MW ideal process simulations for data from the DK-West Regulating Power Market.

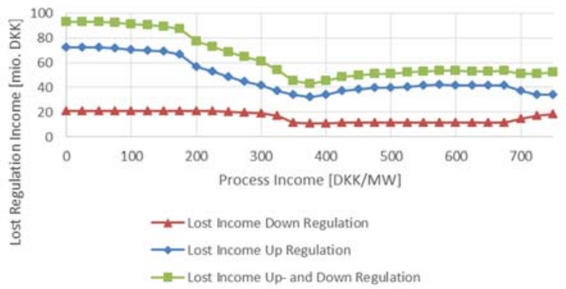

Figure 5: The lost regulation income of the 6 MW ideal process simulations for data from the DK-West Regulating Power Market.

Figure 4 shows the total income for both up and down regulation is highest (50.6 million DKK), when the regulation potential is at its maximum, at a ‘Process Income’ of 375 DKK/MW.

Unsurprisingly, as figure 5 shows the ‘Lost Income Up and Down Regulation’ (defined as the ‘The Lost Regulation Income’) is at its lowest when the ‘Process Income’ is 375 DKK/MW. It is because the total regulating power and the income are at the peak point.

In this study, a roller press of 6 MW has been used in the simulation. In theory, it should be possible to increase the amount of regulation capacity delivered by using more but smaller processes. The smallest roller press in the datasheet (KHD Humboldt Wedag, 2016) is 280 kW. It is possible to alter the power consumption of the ideal process to study how it can affect the amount of regulation provided. Replacing the 6 MW roller press with a 280 kW roller press in the simulation looks almost identical to the 6 MW process, as shown in figure 6.

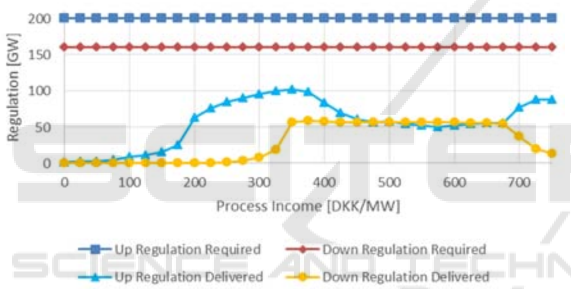

Figure 6: The flexibility potential of the 280 kW ideal process simulations for data from the DK-West Regulating Power Market.

The total amount of regulation delivered is 158.3 GW, instead of 154.1 GW, which constitutes 44 % of the regulation required in 2015. It is only an increase of 4.2 GW of regulation delivered, but it illustrates the principle that more regulation can be delivered with more but smaller processes. The optimal values for the ’Process Income’ are the same as with the 6 MW process, but the ’Regulation Income’ has increased from 50.6 to 51.7 million DKK. However, it is questionable if this relatively small increase in profit is enough to justify the additional cost and effort of aggregating and administrating smaller loads.

4 DISCUSSION

The simulation in this study is based on an ideal process of the roller press of 6 MW, which is able to deliver both up and down regulation instantaneously without affecting the quality of the product from the process. In the simulation, the ideal process can deliver all required regulating power and the results are the ’best-case scenario’. The ideal process is associated with a ‘Process Income’. Different values of ‘Process Income’ were simulated, to compensate for the fact that the ‘Process Income’ for the roller press process is unknown. By changing the ‘Process Income’ in the simulation makes it possible to evaluate, if an industrial process is likely to be profitable for providing demand response in the regulating power market.

This study takes the DK-West regulating power market as example, because the balance responsible parties are charged for their imbalance, and this is the business potential for aggregators to enter the market for regulating power. Meanwhile, more regulating power is traded in the DK-West, due to the fluctuating production from a large installed capacity of wind turbines.

The roller press has functioned as the ideal process for the simulation in the study. However, it is an ideal scenario and the results would be naturally difficult to achieve in practice, because the majority of industrial processes link to certain operation hours during a working day. In addition, some industrial processes like the use of artificial lighting in commercial greenhouses depend on external factors like the weather forecast, and the decision to turn the processes on or off requires more consideration than just the ‘Process Income’ (Zheng and Jørgensen, 2016). Other examples of flexible consumption are given in (Biegela et al., 2014). Here the examples of households, supermarket refrigeration systems, and Battery storage are used. The first two examples address intrinsic flexibility in thermal capacity, and the second electrical storage. Other examples on energy storage technologies, including services provide by electrical vehicles, are given in (Lund et al., 2015). The case of compressed air for manufacturing processes is considered in (Beier et al., 2015). Our example differs from this previous work in the field by focusing on flexibility provided by a mechanical production process based on machine drives.

5 CONCLUSIONS

To leverage the imbalance between supply and demand in an electrical grid with a large penetration of fluctuating renewable energy sources, there is a need for marketization of energy flexibility in the demand side. Due to a larger amount of power being traded in the intraday market, the total value of energy flexibility in the intraday market is much higher compared to the regulating power market. However, due to market regulations the value of trading energy flexibility is higher per unit in the regulating power market compared to the intraday market. It means that consumers can gain more income by delivering energy flexibility into the regulating power market.

It is demonstrated that the ideal process is able to deliver both up and down regulation, depending on whether it is initially turned on or off and according to the expenses of electricity taxes. An economic statement of an aggregation company is not assessed in this study, and it would be too complex to specify actual expenses and determine how an aggregator can regulate its income. An economic statement of individual consumers is also out of the scope for this study.

This study only addresses industries with a high potential for delivering energy flexibility through simple processes based on machine drives. To limit the scope, small electricity loads related to industrial site personnel, such as lighting, cooling, heating, ventilation, and office equipment, are not considered in this study, since the incentive of aggregating small loads to perform demand response appears to be too small compared to the impact on user inconvenience.

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