Data centers on ancillary markets

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Arctic DC – Arctic Datacenters project aims to strengthen the regional data centre industry's products, services, solutions and offerings to customers (parties) outside the region, nationally or internationally. This should be done by demonstrating and proving that; Investing and operating data centres in Arctic regions have low and among the lowest investment and operating costs in the world in terms of cooling and power distribution.
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1 Power grid in Sweden

There are essentially two categories of power grids, transmission and distribution grids. The power grid in Sweden is divided into three different categories, the national grid (transmission grid), regional grid and local grid (distribution grid). A good comparison for the national grid is a motorway system where large amount of electricity can be transferred over long distances with small losses. The regional grid can be compared to trunk roads where power is distributed to cities and large consumers. The last part of the grid is the local grid which distributes power to most users (1).

The national grid in Sweden is the part of the grid that operates in the range of 220 to 400 kV. The national grid is managed by the public enterprise and authority Svenska Kraftnät (SvK) which is responsible for the entire Swedish electricity system. The regional grids are owned and operated mainly by three companies: Vattenfall Eldistribution, Ellevio and E.on Elnät Sverige. The voltage level varies between 20 and 130 kV and connects the local grids to the national grid, generation plants and large electricity-intensive-industries. The local grids are owned and operated to a large part of companies with municipal ownership, in total there are 170 power grid companies where 129 are municipal companies (1).
2 Grid stability

The overall power consumption per capita is high in Sweden, this is mainly due to large energy intensive industries and the cold climate. The production and consumption are also unevenly distributed, most of the power is consumed in the south while most is produced in the north. The surplus power in the north needs to be transferred long distances to reach the consumers. Due to this Sweden has been split in to 4 different power regions, called SE1-4, these areas are based on where the bottlenecks are in the national grid. Due to these bottlenecks the price varies between the different regions, the power is in general more expensive in the south. These four regions are synchronously connected to other Nordic grids which means that the entire system has the same frequency (1) (2).

The power quality in the grid are defined by disturbances and interruptions, the most common disturbances are voltage drops, transients and flickers. These are caused by changes of load on the grid that the system does not react quick enough on. A common problem is that something which requires a lot of current to start is turned on unexpectedly. Commissioning of large machines needs to be communicated to the provider so there is enough power always supplied to the grid to avoid disturbances (1).

To have a functional grid a stable frequency is of great importance so that electric components on the grid works as intended. The Nordic synchronous system is supposed to operate at 50 Hz but is allowed to vary between 49.9 and 50.1 Hz. The frequency depends on the balance between production and consumption, if the balance is off the frequency will deviate. If the consumption is higher than production, the frequency will go down. If the production is higher than the production the frequency will go up.

The overall responsibility for the balance between production and consumption on the Swedish grid is on SvK. Under the current Electricity act an electricity supplier is responsible for supplying as much electricity as its customers consume hour by hour. The electricity suppliers may take on this responsibility themselves or transfer it to another company. Before operation the balance responsible actors on the market must disclose what production and consumption, they expect to have the coming day. If they fail to plan their balance and SvK must activate reserves to bring the frequency back to balance the actor who was responsible for the unbalance must pay what it cost to bring the frequency back. (1) (3).
3 Power system

Power sources are usually categorized into three different variants, base load, regulating and intermittent power sources. Base load power sources are those power sources who can control supply based on supply but have a relative constant production over time. Regulatory power sources are power sources that can be used to balance variations between supply and demand, this is typically a power source with a rapid activation time. Intermittent power sources are those where the production can vary a lot depending on the conditions at the time.

In Sweden the base load power is supplied by the nuclear power plants, the regulatory power mainly comes from hydro power and the intermittent power is from wind. In total around 160 TWh of electricity is used in Sweden each year. Hydro and nuclear supply about 40% each for this while wind and CHP supply 10% each.

The power system is about to go through a large change in its energy system the coming years when the nuclear power is being decommissioned. That means that the 40% it supplies to the grid needs to be replaced with other power sources if the energy consumption stays the same.

Kungliga Ingenjörsvetenskapsakademin (IVA) has made a series of report about the future Swedish energy system, where one focuses on how the future power supply might look. In this they propose four different routes the Swedish power grid can take and remain fossil fuel free.

- More solar and wind
- More bioenergy
- New nuclear power
- More hydropower

All of these come with their own fair share of advantages and disadvantages. The power grid also needs to be adapted to fit each alternative since it can either be large power sources which require distribution, as we have today, or a more distributed solution which makes the national grid less important. With all of these, except the nuclear power, it is shown that the number of intermittent renewables need to increase significantly which provides a need for more flexible demand or large-scale power reserves (4).
4 Reserve markets

To keep the balance on the grid during operation SvK procures power reserves in advance. The required volume of reserve needed is decided based around the N-1 criteria. These criteria mean that the power system should be able to remain stable even if a large production or consumption source would drop off. The system should also be able to be completely restored within 15 minutes to handle a disturbance of the same magnitude again. The reserves can be made of either producers or consumers that can either increase or decrease their energy production or consumption. In Sweden most reserves come from hydro power due to its quick and cheap flexibility. The reserves can either be upwards or downwards and are separated on the market, upwards regulation can be done with either increasing production or decreasing consumption. Downward regulation is done be decreasing production or increasing consumption (5).

To be allowed to deliver regulatory power to SvK certain technical conditions needs to be satisfied. The conditions are about the **endurance**, **response time** and **repeatability**.

- **Endurance** – Defined by how long a power reserve can contribute to the frequency containment, illustrated as $t_2$ in Figure 1.
- **Response time** – Is the time it takes for power reserve to be activated from the time that frequency deviated, illustrated as $t_1$ in Figure 1.
- **Repeatability** – Measurement for how often a power reserve can be utilized for frequency containment. I.e., the time between using the reserve and being able to use it again after recharge or recovery time.

![Figure 1. Power reserve conditions, where P is the power, t1 is the response time and t2 is the endurance.](image)

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There are different kinds of reserves procured by SvK for different events on the grid, there is the primary reserve (FCR-N and FCR-D) which are quick, then there is the secondary reserve (aFFR) which is larger but slower and used to relieve the primary reserve. Finally, the tertiary reserve (mFFR) which is the slowest of them all but used to relieve the secondary reserve. The tertiary also includes the power and disturbance reserve which are used to balance the load during winter and extreme scenarios (3) (5). An illustration of how the reserves work together is shown in Figure 2.

![Figure 2. Illustration of how the power reserves work together. Figure from Eng and Johansson 2014.](image)

### 4.1 Primary reserve (FCR-N and FCR-D)

When unbalance occurs on the grid the primary reserve is the first reserve to be automatically activated to counter the deviation in the frequency. The primary reserve consists of two automatic reserves, the Frequency Containment Reserve – Normal (FCR-N) and Frequency Containment Reserve – Disturbance (FCR-D). FCR-N is a reserve for normal operation and FCR-D is a reserve if something quickly happens on the grid, i.e. causing a larger frequency deviation. During normal operation when the frequency fluctuates between 49.9 and 50.1 FCR-N is used to contain it inside this range, if the frequency drops below 49.9 FCR-D is activated. FCR-N is used to stabilize the grid during small deviations and FCR-D is used to handle bigger deviations, such as if a power plant experiences problems (5).

An important difference between these two reserves is that FCR-N needs to handle both upward and downward regulation, due to this it is called a symmetrical reserve while FCR-D only needs to handle upwards power, making it asymmetrical. FCR-N needs to be 100% activated when the frequency is at 50.1 Hz or 49.9 Hz while FCR-D needs to be completely activated when the frequency has reached 49.5 Hz. The requirement for FCR-N is that 63% of the capacity is available within 60 seconds and 100% within 3 minutes. FCR-D has higher requirements with 50% of the power within 5 seconds and 100% within 30 seconds (5).

<table>
<thead>
<tr>
<th></th>
<th>FCR-N</th>
<th>FCR-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smallest bid size</td>
<td>0.1 MW</td>
<td>0.1 MW</td>
</tr>
<tr>
<td>Activation</td>
<td>Automatic within 49.9-50.1 Hz</td>
<td>Automatic below 49.9 Hz</td>
</tr>
<tr>
<td>Response time</td>
<td>63% within 60s and 100% within 3 min</td>
<td>50% within 5s and 100% within 30s</td>
</tr>
<tr>
<td>Volume</td>
<td>About 200 MW</td>
<td>About 400 MW</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Endurance</td>
<td>Unclear</td>
<td>Unclear</td>
</tr>
</tbody>
</table>

The primary reserves are procured one to two days before. The suppliers leave offers on what capacity they can offset. The offers are then activated in order of price and the suppliers are paid for the capacity they have quoted. For FCR-D the suppliers are only paid for the capacity they have quoted while FCR-N are also paid for the energy they have supplied. To be allowed to provide reserves on the FCR market the suppliers first need to go through a pre-qualification in collaboration with SvK to make sure that all conditions are satisfied (5).
4.2 Secondary reserve (aFRR)

The secondary reserve consists of the Automatic frequency restoration reserve (aFRR). The goal of aFRR is to relieve the primary reserve after it has stabilized the frequency from the previous deviation, so it is available later. This reserve has multiple technical requirements that needs to be satisfied. The smallest bid volume for aFRR is 5 MW and it needs to be completely activated within 120 seconds (5).

<table>
<thead>
<tr>
<th>aFRR</th>
<th>Smallest bid</th>
<th>5 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Response time</td>
<td>100% within 120 s</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>150 MW</td>
</tr>
<tr>
<td></td>
<td>Endurance</td>
<td>At least an hour</td>
</tr>
</tbody>
</table>

aFRR was introduced in 2013 to improve the frequency stability and thereby the quality on the Nordic grid. The reserve is procured once a week for the coming week and the bids are activated in order of price like FCR. A supplier of aFRR is paid for both the power quoted and for the energy supplied if it was activated. The reserve only needs to work either up- or downwards. The endurance needs to be at least an hour. Currently the aFRR market is only national for each Nordic country (5). There are however plans that in the future to use a mutual market (7).

4.3 Tertiary reserve (mFRR)

The third type of power reserve used on the market is the tertiary reserve which consists of three different manual reserves, the Manual Frequency Restoration Reserve (mFRR), power reserve and disturbance reserve. The tertiary reserves are activated manually on request from SvK. The purpose of mFRR is to relieve aFRR in the same way that aFRR relieves FCR. mFRR is procured for each hour on the reglerkraftmarknaden (RKM) which is a market hosted by the Nordic TSOs. On RKM bids on up- and downwards power is placed by the suppliers from 14 days before and up to 45 minutes before the operational hour. The smallest bid for mFRR is 10 MW except for SE4 where it is 5 MW. The reserve needs to be fully activated within 15 minutes of signal from SvK.

<table>
<thead>
<tr>
<th>mFRR</th>
<th>Smallest bid</th>
<th>10 MW (5 in SE4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Response time</td>
<td>100% within 15min</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Endurance</td>
<td>-</td>
</tr>
</tbody>
</table>
The disturbance reserve is an extra reserve to support the system on a short time basis during large unforeseen events. This has been procured by SvK and consists today of gas turbines that can balance the system if something happens (8).

The last tertiary reserve is the so-called power reserve which is used to balance supply and demand during the winter peak hours when electricity demand is very high. SvK is the one who provides this reserve by making deals with power providers and large consumers between November and March. This can either be a reduction of consumption or an increase in production to balance the load (8).

4.4 Inertias (FFR)

Another important service on the power grid is inertia, this is created by synchronous generators connected to the grid. These create an inertia which helps to stabilize quick frequency deviations that can occur. With the current direction on the Swedish power grid where nuclear is being decommissioned, a large part of the inertia on the grid is also going away. Renewable power sources as wind and solar does not have a synchronous generator and does not provide any new inertia, this has opened a new market for quick power reserves.

The Nordic TSOs are as this report is written preparing for a new reserve on the Nordic power grid to handle situations when the inertia on the grid is too low. In some situations, the current reserves are not quick enough to stabilize the power system. The proposed new reserve to resolve this is called Fast Frequency Reserve (FFR) and it’s planned to put in use from the summer 2020 (9).

From the report, specifying the technical requirements (10), there are two different FFR providing entities:

- Long support duration FFR – with support duration of at least 30 seconds
- Short support duration FFR – with support duration of at least 5 seconds

The two different support durations have different requirements on the speed of deactivation, the provider can freely choose which support duration to prequalify for, given the different deactivation requirements.

There are three different combinations for frequency activation level and maximum full activation time, the FFR provider can freely choose the most suitable combination for each specific providing entity.

- 0.7 s maximum full activation time for the activation level 49.5 Hz
- 1.0 s maximum full activation time for the activation level 49.6 Hz
- 1.3 s maximum full activation time for the activation level 49.7 Hz

The FRR reserve is asymmetrical and only needs to be able to regulate the power upwards, meaning that it is used in underfrequency situations. It can thereby reduce consumption or increase production. The resource can be a generation based, load based, energy storage based or an aggregated resource. A maximum of 50 MW of FRR can lie behind a single point of failure.

For the long support duration FFR there is no limitation in the rate of deactivation, it can be stepwise. For short support duration FRR the rate of deactivation can be a maximum of 20% of the prequalified FFR capacity per second. FFR providing entity must be ready for a new activation cycle within 15 minutes.

4.5 Compensation for providing reserves

The prices for primary reserves are supposed to be available on the Mimer platform (11) but due to a switch of data source it was not available when this report was done. Historical data was found in a presentation from Damsgaard (12).
Figure 3. Prices for FCR-N and FCR-D during 2017 and 2018. From Damsgaard (12)
5  Projects about future tools for frequency reserve

5.1  Svenska Kraftnät - Pilots

SvK has done two studies about using flexible consumption and energy storages on the FCR market, the first pilot was done on Swedish households with hot water tanks. The system could buy and sell reserves on the market and react on SvK’s signal on up- or downwards regulation. The system connected 100 households and combined it with hydropower to reach the needed power requirement to be allowed to offer bids on the FCR-N market. This test was done in 2017, the main take away was that there is potential for this kind of system, but both the control of the water tanks and the signal system from SvK needed to improve (13). This kind of aggregation system of smaller energy sources has been discussed further by the Nordic TSOs in a discussion paper called *Unlocking Flexibility* (14).

The second study conducted by SvK was to use the UPS system in a data center to operate on the FCR-D market. The reasoning to this was that the battery in the UPS is mostly unused and thereby is an unused asset inside the data center. The energy storage could in theory operate on both the FCR-N and FCR-D market but for the pilot FCR-D was used due to the criteria of symmetrical requirement on FCR-N. The way the system worked was that the data center ran of the batteries if the frequency deviated, thereby it was lower load on the grid temporarily. If the batteries are big enough, they could supply to the grid as well. Both central and local control was tested and local gave the best results. One problem that was observed during the pilot was that the recharge of the batteries caused unbalances, since the load became higher when both the data center and energy storage needed power after the activation. Further research on when to charge the batteries needs to be done according to the study.

5.1.1  Projects in use

Fortum operates a virtual battery on the finish grid containing both hot water tanks and data centers (15). Bahnhof is also awaiting green light from SvK to start operating on the reserve market with a data center in Sweden (16).

5.2  Data centers on the reserve market

The power grid is transitioning to include more renewables which come with intermittency. The electricity consumption in the world is increasing, both with industries and electric vehicles. Data centers are a growing power intense industry. To help and increase renewable penetration on the power grid their shortcomings need to be handled, and to get off fossil fuels which often are used for ancillary services on the grid. With even more intermittency on the grid the flexibility and number of services needed to keep the grid stable will thereby increase. Since data centers are large energy consumers and is a rapidly growing industry, it is of great interest to see if there is potential for these to help stabilize the grid and make it easier for renewable penetration.

There has been quite a lot of research in this area on how data centers can contribute to a more stable grid and make it easier for renewables to enter the market. In a survey by Wierman et al (17) they propose that these challenges are in fact symbiotic. Data centers are large loads, but also flexible meaning that data center loads can be shifted in time or geographically. The load in the data center can be shifted in two main ways:

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1. **UPS with batteries and/or backup power** – By running the datacenter on batteries or backup generators, the power draw from the grid can momentarily be reduced.

2. **Workload scheduling** – Reducing power draw from the datacenter, which in practice means workload shifting, this method is very dependent on what the operation of the datacenter is. Some workload is better suited for this method.

The main difference between these is that the service from the data center is affected in the later but remains constant in the first.

### 5.2.1 UPS with batteries and/or backup power

Data center UPS are designed to meet the peak load of the data center if there is a blackout, the equipment is however rarely used. Meaning that there are large, underutilized energy resources in the form of backup generators and batteries that can be utilized to provide services to the grid and extra income. There has been experiments in Sweden (8) and Norway (18) where the UPS system in the DC has been modified to be able to operate on the FCR market. Both pilots showed promising results and that the system reacts quick enough to work on both the FCR-N and FCR-D market. The Swedish pilot tested both local and central control, the conclusion was that with the current central signal system the local control was preferred. The central control failed to activate all times it should have. It was also observed that the recharging process caused disturbances on the grid, so further work needs to be done on when to charge the batteries.

There has been multiple studies on the area, mainly with the goal to use the UPS for ancillary services and lower the cost of energy by participating in i.e. peak shaving (19) (20) (21) (22) and also in improving the penetration of renewables (23) (24). The results from these studies show that there is a possibility to lower the energy bill, but it is of great importance to factor the cost of each cycle of the battery. There is also the problem that the batteries might be low on charge after participating on the grid and a blackout occurs, then the UPS cannot do its primary purpose.

Fortum operates a Virtual battery in Finland under the name Fortum Spring. This aggregated service contains both hot water pans and an Ericsson data center (15). Bahnhof is awaiting green light from SvK to start operating on the FCR market with its data center in Sweden (16). There is also the Aurora DC in Finland which is operating on the market right now (ref: Mattias Vesterlund).

> “Each datacenter represents millions of dollars’ worth of unused fast-response storage-equivalent capacity” – Wierman et al (17)

### 5.2.2 Workload scheduling

The other alternative is to time shift the load on the DC, meaning that the work that was planned to a certain time is shifted forward and the server is either downclocked or put into idle. There are three features that make datacenters especially attractive candidates for real-time demand response (25):

- Fast power ramp rate
- Large Dynamic range
- Finely tunable power consumption
Figure 4. An example of a datacenter demand response application from McClurg (25).

How this is used in practice is covered in a survey about the strengths and weakness of workload scheduling by Wierman et al (17):

- **Capacity right-sizing**
  - Attention to algorithms that can adapt energy usage do create power proportional systems that use power in proportion to the utilization of the computing system. Such designs focus on speed-scaling, power-capping, moving servers into and out of power saving modes and many other features.

- **Load shifting**
  - Data centers typically have a mixture of workloads. Some are inflexible, i.e. delay intolerant, but many are delay tolerant. For delay-tolerant workload, it is possible to shift work in time to run when renewable or cheaper energy is available among other things. Many algorithms have been proposed to accomplish this sort of load shifting over time in different circumstances.

- **Quality degradation**
  - In addition to load shifting, another flexibility data centers have is “load shedding” which is typically associated with quality degradation of some form, with possible consideration of quality-of-service (QoS) requirements and service-level-agreements (SLAs). E.g. when serving ads, a data center can use less energy by targeting adds less effectively. This tradeoff can be exploited to reduce energy costs or reduce brown energy usage, among other things.

- **Geographical load balancing**
  - Many internet-scale systems depend on several geographically distributed data centers. Thus, in addition to flexibility within a data center, there is also geographical flexibility for a data center location at which they can serve a given workload. This so-called “geographical load balancing” has been shown to be effective in reducing energy costs and improving the efficiency of local renewable energy at data centers, among other things.

An important factor to consider is that many of these approaches can be implemented without impacting the QoS. Some of these do however certainly impact it. For instance, moving unused servers into power saving modes or rescheduling delay tolerant workloads may impact response times.

McClurg has studied how demand response in datacenter can be implemented and shows that not all loads are applicable for use with demand response. McClurg recommends workloads as video transcoding as perfect candidates, but the properties of a workload should look like the following according to the study:

- They are CPU or GPU intensive (CPU throttling reduces server power)
- They always have useful work to do (reduction in CPU throttle increases performance)
- Part of the workload is insensitive to small latency increase
Since the load and type of workload can vary in a DC it is possible that a DC at a specific time might not be able to apply demand response. In these situations, aggregation of multiple DC can offer a more resilient solution (25). This could also be included in a VPP with multiple different consumers to get varied sources (26). Geographical distribution has also been suggested for large cloud operators to promote renewables by moving the workload to places where renewable power is available at the moment (27).

There have been many studies that show how workload scheduling can be used for ancillary services where the common thread is that datacenters can increase their profit and at the same time help the grid maintain service quality and reliability (28) (29) (30). There is a balance between flexibility and QoS which needs to be thoroughly examined for each workload and use-case to see if the decrease of computational power is worth it compared to the energy price and compensation for the ancillary service.

5.2.3 Opportunities and challenges for data center participation on demand response market

Data center demand participation in demand response programs has the potential to be a “win-win”: data centers provide a significant service to grid operators and demand response programs provide a significant revenue source. There is despite this “win-win” opportunity barely any interaction from data centers on the demand response programs. This is according to Wierman et al (17) not by accident, there are several significant challenges.

One of these is the risk management for the data center which typically are in the business of maximizing uptime and performance. Energy issues are certainly secondary to maintaining strong guarantees about the primary measures. However, participation in demand response programs always comes with some risk. This risk may purely be financial, but it might also have the possibility of uptime/performance degradation. As a result, risk management is a crucial issue for data center participation in demand response programs. Taking a huge financial/performance hit because the TSO sends a price/control signal at the same point as the data center is heavily loaded is a serious concern that limits data center participation in current programs. For exactly this reason data centers prefer to negotiate long term energy contracts with fixed usage prices (17).

There is also the fact that many data centers are colocations where space is rented to many different tenants. In such situations, the data center operator does not have control over the computing resources. So, when there is a demand of response directly they must find a way to encourage the tenants to respond appropriately (17).
6 Discussion/conclusion

The energy system is going green, the amount of intermittent energy sources is going to increase. Nuclear power in Sweden is shutting down, what will replacing it is unclear, but IVA shows in a report about the future power system in Sweden that despite what direction the Swedish power grid takes the amount of renewables will increase, except if new nuclear is built (4).

The integration of renewables on the power grid requires changes in the grid, both in how it is built and the markets. Renewables like wind and solar produce intermittent power, meaning it is not always available, which has not been the case with the traditional power system. Large consumers have been passive on the market, so if the consumption has increased the production has been increased too. If the consumers are supposed to be kept passive on the market when renewables are introduced to a larger degree LARGE amounts of energy storage needs to be installed.

The world is at the same time consuming more electricity, vehicles are electrified, industries like SSAB are electrified and the data center industry is growing rapidly. There is however a way to integrate these loads on the grid to promote the use of renewable energy sources. This can be done by demand response to either stabilize the grid or utilize power when it is available.

Data centers are perfect candidates for this due to their flexible load and UPS with batteries and/or generation power (17) (25). The batteries in the data center UPS systems are rarely used and thereby is a large, underutilized energy storage solution that can be used on the reserve market. There is also possible to move the load on the data center to a later time and thereby provide a flexibility that can be sold to balance providers.

In Sweden there are currently six different power reserves in use for grid stability, FCR-N, FCR-D, aFRR, mFRR, power reserve and disturbance reserve. The later three are not of large interest for the data center case due to the amount and response time required. The FCR-N, FCR-D and aFRR are quickest markets, but aFRR has higher requirements on power and slower response time then FCR-N and FCR-D. What is best is depending on the data center and what battery capacity it has and possibility to move the workload. There is also a new market coming with high requirements on response time to handle the situation of decreased amount of inertia on the grid. This will be called FRR and the time needed to respond is in the range of 0.7-1.3 seconds and with short amount active time, between 5-30 seconds. This might be a perfect candidate for the UPS systems, few sources have the possibility to work in these time ranges.

The possibility of workload scheduling would need work with the data center on how to control the load. Ideas have been shown in practice by McClurg (25) but there is work to be done in how to do this with varying workloads. How this would work in colocation data centers is unclear. But these solutions may be tethered to certain data centers with applicable workload. But by utilizing workload shifting a data center would be able to promote that they are helping renewables to enter the market. There is a case that this might be an economic problem if the reward for not using energy is higher than the profit. By doing a computation profit driven datacenter might make the move.

Currently the datacenter industry is all about stability and availability. To provide this to their customers they negotiate long term energy contracts with fixed usage prices. To match the future power system, power consumers need to become flexible.
7 Bibliography


8. **Svenska Kraftnät.** *Slutrapport pilotprojekt inom förbrukningsflexibilitet och energilager.* 2018.


11. **Svenska Kraftnät.** *Mimer - Primärreglering.* [Online] https://mimer.svk.se/PrimaryRegulation/PrimaryRegulationIndex.


14. **Statnett, Energinet, Fingrid, Svenska kraftnät.** *Unlocking flexibility - Nordic TSO discussion paper on third-party aggregators.*


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