CHALMERS

Demand Side Management in Swedish Industry

An investigation of load management in major Swedish industries

Master's Thesis within the Sustainable Energy Systems programme

SORAN ESMAILNAJAD, JENS SUNDQUIST

Department of Energy and Environment
Division of Energy Technology
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Master's Thesis : T2014-398

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ABSTRACT

Demand side management (DSM) is a measure to reduce energy costs and stabilise the energy distribution system. The capabilities of DSM have not, so far, been utilised in large-scale in Swedish industry. DSM is particularly of interest for electricity intensive industries, where the electricity price is a large part of production cost. This work aims to investigate DSM potential in several electricity intensive industries using load management such as load shifting and shedding. Magnitude of DSM potentials in terms of power is the result of the case studies for each specific industry and branch. Economic analysis in the study shows that applying load management measures can offer financial savings.

The findings indicate a large potential of DSM capacity for total Swedish industry especially for the mechanical pulp and paper industry. Roughly the DSM potential for whole Swedish industry can be estimated to be in the range of 0.5-2 GW. However, Swedish industries are found to be very heterogeneous regarding production characteristics; similar processes behave very different even within the same category and branch. Each specific case is unique and should be analysed separately. Therefore the calculations to carry out the precise magnitude of DSM potential and its associated profits are complex. It should be noted that even if the potentials today are found to be rather large; the economic incentives are relative small to implement DSM in the Swedish industry.

Key words: Demand side management (DSM), electricity load, electricity demand, industry, load shedding, load shifting

El-laststyrning i svenska industrin

En utredning om laststyrning i större svenska industrier

Examensarbete inom masterprogrammet *Sustainable Energy Systems*
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SAMMANFATTNING

DSM är ett verktyg för att reducera energikostnader och stabilisera distributionssystemet av energi. Kapaciteten av DSM har inte blivit fullt utnyttjad i svenska industrin. DSM skulle kunna vara särskilt intressant för industrier där el är en av de stora kostnaderna inom produktion. Arbetet undersöker möjligheterna för DSM i några elintensiva industrier genom att använda laststyrningsmetoder som ”load shifting” och “load shedding”. Resultatet utav fallstudierna är den potentiella storleken (MW) av DSM för varje industri och bransch. Ekonomiska analyser i rapporten visar att implementera lastsstyrning kan leda till besparingar i särskilda fall.

Resultat från analysen indikerar på en stor potential av DSM kapacitet för den svenska industrin speciellt inom mekanisk massa framställning. Potentialen av DSM i svenska industrin kan uppskattas till mellan 0,5-2 GW. Baserat på empiriska studier och resultat kan det nämnas att svenska industrin är väldigt varierande gällande produktions karaktäristik; liknande processer kan bete sig olika även i samma kategori och bransch. Varje specifikt fall är unikt och borde analyseras separat. Därför är en exakt uträkning utav den specifika DSM potentialen och vinsten med att införa sådana åtgärder väldigt komplex. Med dagens system är möjligheterna för DSM relativt stora men incitamenten för att implementera metoder är små.

Nyckelord: Demand side management (DSM), nyckelindustrier, Shedding, Shifting, lastkurva, elpris, variationer, industri processer, massa och papper, ljusbågsugn.

Contents

Preface

This study has been done using data from several Swedish industries. The industries in the report are named by the branch, and not by the actual name of the company, according to an agreement between the authors of the thesis and contacted industries. The analysis and investigations have been discussed with each industry continuously from the beginning to the end of this study. We would like to thank all people within industries that we have been in contact with, and it should be noted that the investigations and analysis never could have been conducted without them.

This report has been carried out at Department of Energy and Environment (Division of Energy Technology) at Chalmers University of Technology. We would like to thank our examiner and supervisor Mikael Odenberger for highly appreciated advice and help during the whole study period. Finally, we would like to thank Emil Nyholm for his help with GAMS during part of the study.

Göteborg June 2014

Soran Esmailnajad, Jens Sundquist

Notations

List of abbreviations

A	Ampere
DSB	Demand side bidding
DSM	Demand side management
h	Hour
k	kilo, thousand
kA/MW	kilo Ampere per Megawatt
kSEK	kilo Swedish Krona
kWh/SEK	kilowatt hour per Swedish Krona
LPS	Load priority system
MSEK	Mega Swedish Krona
MW	Megawatt hour
MWh	Megawatt hour
PFE	Program of efficiency measure
PM	Paper machines
PVC	Polyvinyl chloride
RP	Refiners
SNG	Swedish national grid
TOU	Time of use
TMP	Thermo-mechanical-pulp
TWh	Terawatt hour
τ	Time utilization
VCM	Vinyl chloride monomer

1 Introduction

1.1 Background

In 2010, the total electricity consumption in Sweden was 147.6 TWh including losses in the transmission grid. Sweden has an industrial structure that is highly electricity intensive compared with many other countries (Worldbank, 2013), the high consumption is partly because Sweden's base industry is highly electricity intensive and demands a large amount of power to keep production running. The industry branches with the highest share of electricity demand are the paper and pulp, the steel, the chemical production and the mining industry (Swedenergy, 2012).

In 2010, the Swedish hydropower production was 65.8 TWh, which is 45% of the total annual electricity production in Sweden. The remaining electricity is generated by nuclear 40%, CHP 7%, wind 4% and small share from industrial back pressure, oil and natural gas (Swedish Energy Agency, 2012).

During time periods when demand are higher than the actual supply from base power production units, like hydro and nuclear, other sources, such as biofuel, natural gas and oil fired power units, cover the remaining demand (Swedenergy, 2012). These technologies have the advantages of being easy and quick to start, stop, and ramp up and down, but they have, on the other hand, high operation costs and environmental impact. They are, therefore, mainly used as reserve capacity in order to regulate the electricity market to maintain the balance between supply and demand. If electricity demand peaks are avoided, the higher electricity production costs and environmental impacts could be reduced, as the use of gas and oil plants decreases..

Thus, the aim of DSM in industry is to reduce peaks on electricity system and adjust electricity peak loads in order to reduce the costs. This distinguish DSM measures from energy efficiency measures which targets to reduce the amount of energy consumption. There are several DSM techniques that can be applied e.g. shifting of loads, shedding or valley filling, where the choice depends on the characteristics and aim. A description of DSM techniques and approaches will be presented in Chapter 2.2.

1.2 Aim

The main objective of this report is to investigate Swedish industry with the purpose of exploring the flexibility of the electricity use and the possibility to apply appropriate DSM measures. One aim of this thesis is to develop a method with the purpose to identify the DSM potential in Swedish industry and its distribution of the potential among different branches and industries.

Another part of this work aims to provide knowledge about existing DSM techniques in industry in order to investigate which implementations that can be part of reaching the goal of influencing and changing the load shape of in a desired way. The aim includes giving a picture of the possible adjustment of sub-loads for different industrial processes.

In this study DSM techniques are applied on case studies to investigate the potential of DSM implementation by approach and industry type.

1.3 Scope

This thesis focuses on the electricity consumption of electricity intensive Swedish industry; thus, heat demand is not within the scope of this work. The assortment of electricity intensive industries in this report has been made according to the Swedish Energy Agency definition; a company is called electricity intensive industry when electricity used in the manufacturing process is at least 190 MWh per million SEK of the company's value added (Swedish Energy Agency, 2007).

The analysis performed within this thesis only includes the industry located in Sweden and does not go beyond this national border. Some of the companies are part of large international industry groups that have a large number of facilities in several countries. However, only domestic facilities which are situated in Sweden have been taken into account.

The highest resolution of measured load data is based on hourly basis (average load over the specific hour) since it has not been possible to acquire a higher resolution of data from any of the information sources used.

This work is focused on the DSM techniques that shift and shed peak load.

1.4 Methodology

Current situation of electricity consumption within Swedish industry divided in different branches are presented based on the statistics and using electricity demand curves of Swedish industry. The annual data from Swedish Energy Agency (Swedish Energy Agency, 2012) has been used to identify the key Swedish industry and their consumption of electricity. Several industries from each of five branches were chosen by the authors of this thesis considering the size of annual electricity consumption (GWh) and power (MW) within the respective branches. Each industry has been contacted for more detailed electricity consumption data for 2012 in hourly basis. Beside power data, each industry has been asked for information about cost and opportunity cost of production, the flexibilities and difficulties in rescheduling of the production etc. These data have been analysed carefully to find out the final subjects for further investigations. Based on the previous reading and experiences, a step-by-step method has been developed by the authors of this thesis in order to find out the final subjects of deeper investigations and to assess the potential of DSM. This method together with a checklist of criteria that has to be fulfilled provides the framework of analysing the DSM potential in this report.

Finally, five industries fulfilled the conditions of that developed method. This method and its criteria are described in detail in chapter 4 of this report. Those five industries have been analysed and contacted further to get a clearer picture of the processes and their electricity consumption. Even other necessary information has been gathered from the electricity distribution companies and experts in field for that purpose.

Several simulations for each of selected case has been made to investigate the different scenarios and possibilities of the load management using the electricity spot price to investigate which hours of operation that should be regulated in order to minimize the cost. Based on the outcomes of the simulations, economical analyses have been conducted in order to find cost saving of DSM implementation.

The collected results are analysed further to investigate and reveal current potential for DSM implementation for similar industries in larger scale, both within the branches and a rough estimation for whole Swedish industry.

1.5 Outline of the report

A general introduction is given in chapter 1 and the following chapter 2 presents an overview of the context and background. Chapter 3 describes the state of electricity consumption and the current use of DSM within Swedish industry. The results from this master thesis project is given in chapter 4, which describes the method developed within the work and the results are listed in chapter 5. Chapter 6 provides a summary of the results from the case studies. The report is finalized with discussion chapter, chapter 8, and conclusions in chapter 9.

2 Demand Side Management measures

DSM is aiming to influence and change customer's use of electricity in order to create a desired structure of the consumers load shape. The objective of implementing DSM measure is to form a load shape change, but for it to be successful it has to adapt to the customer's needs, aim of keeping productivity and target environmental goals. (Gellings, 1985)

Categories of DSM measures

The different measures of DSM can be divided in different categories depending on how the demand curves are reshaped, namely: peak shedding, valley filling, load shifting, flexible load shape, strategic load growth, and strategic conservation. These are all considered as DSM measures but have different objectives on how to influence the customers load (Gellings, 1985): These five categories is briefly described below.

Peak shedding aims at reducing the peak load focusing on the specific time of use and tries to decrease the electricity costs. The amount of reduced electricity demand doesn't need to be large in order to have high impact as it targets the use of more expensive plants running at peak periods. **Valley filling** is done by building off-peak loads; that is creating a load, for example, when the electricity price is low due to large amounts of available electricity. Energy storage is one such. **Load shifting** aims to move electricity loads from peak periods to off-peak periods, thus smoothening the load curve. **Flexible load shaping** gives consumers incentive to adjust their load curve towards an increased flexible set of processes e.g. interruptible load. The last DSM category is described by Gellings (1985) as **strategic conservation**. The purpose of strategic conservation is to implement energy efficiency techniques in order to decrease the end-use of electricity. One example is to invest in more efficient electrical motors in industry in order to lower the consumption. (Gellings, 1985)

2.1 Characteristics of DSM measures

The main objective of using DSM measures is to reshape the load in order to reduce the cost and impacts of peaks on the electricity system. One can argue that changes in load in terms of using more efficient appliances or replacing old electrical devices with new ones can be counted as DSM measures. However, within this thesis these are not considered as DSM measures but as energy efficiency programs. The difference between efficiency and DSM measures is the approach of the implementation. The shift peak alternatives focus on a smaller amount of electricity during a short time interval while the efficiency measures are applied for larger amount of electricity for longer periods of time. (Jordan and Nadel; 1993)

2.2 Industrial DSM techniques

DSM measures define the choice of strategy e.g. the framework of the appropriate DSM measure. Based on the desired outcome i.e. valley filling, load shifting; of DSM there are several of existing techniques that can be used.

Dual-Fuel system

This technique aims to give more than one option of satisfying the demand of energy where the price of electricity determines whether electricity or a secondary fuel will be used as heating (energy) source. An example could be to use a dual-fuel system to supply a need of steam production for heat or production processes, where natural gas could be used when electricity price is high instead electric boilers. This system could increase the efficiency while reducing pressure on electricity supply system (Khartchenko, 1997).

A supplementary benefit for a large industrial consumer is that the duel fuel system could increase the industry's security of supply, as it wouldn't be dependent on only one source of energy.

Load priority systems (LPS)

This is a flexible load technique which makes a priority system of the specific industry's different electric loads. The aim is to identify which loads that can be turned off and for how long time, and which loads that are crucial to keep running for the productivity of the company. The objective of LPS could be to keep the industry's demand on low level during peak-load periods. It is important to include many different industries with different shapes of the load curve, to make the load demands interact with each other. One industry could have a really flat demand curve but still be able to reduce its consumption at the same time as another industry has a peak in form of a critical unchangeable load. A coordinated load priority system could flatten the total demand curve. The primary purpose of this technique is not to save energy but to reduce peaks and fill out valleys in the total load curve.

Rescheduling processes or parts of processes

One technique is to adjust the labour hours for electricity intensive processes into times with lower electricity cost. This could reduce the electricity costs, if it is possible to reschedule parts of or whole processes under condition of sufficient storage capacity. Another factor is the labour cost; if the process length will increase much with the new schedule such a system may be hard to implement. Rescheduling of processes can be of substantial benefits of industries trying to keep a constant outflow of the product. This technique could be classified as a flexible load management.

Heat, cool or media storage

For some industries it could be beneficial to implement storage of heat, cool or process media when the electricity price is low. Depending on the type of industry and production processes this could be used in different ways. This technique is mainly used for valley filling purpose, as it would increase the use of cheap electricity for example during off peak periods or at time periods when large amounts of renewable electricity is available.

Heat and power Co-generation

In industries with large demands of heat or other energy consuming processes, a steam production is often necessary to sustain parts of the production processes. With a co-generation unit this steam could, in addition to heat, produce electricity by using turbines and heat exchangers, instead of only producing heat. The produced electricity could either be used in-house, or sold on an electricity spot market. However, this is likely to be a large investment, and will probably demand large scale industries with intensive processes in order to create a steam quality that is sufficient for electricity generation. But with a successful implementation it could save cost and also be beneficial for the company from an environmental perspective. (Bjork; 1989)

Direct load control

Direct load control systems can be connected to the production related processes; and it gives a possibility to regulate the different electricity loads. The objective is to alleviate peaks and shift loads to desired hours of demand. It is mainly used by the electric power utility operator in order to match demand and supply. (Koutsopoulos; 2011)

2.3 Literature review

Moritz Paulus and Borggrefe (2011) investigate the impact of investments in DSM technologies on the spot and reserve market in Germany. The study describes DSM as an alternate replacement for investment in new tertiary reserve capacity, particularly gas turbines. (Paulus and Borggrefe; 2011)

Gelling (1985) investigates the concept of DSM for electric utilities with an objective to achieve a change in the shape of the load curve, time pattern and magnitude of utility load that is beneficial for both supply and demand side. (Gelling; 1985)

The influence of a load shifting technique on an energy intensive industry is demonstrated in a study by Ashok and Banerjee. (Ashok and Banerjee; 2000)

Jordan and Nadel (1993) describe the importance of addressing the customers concerns, to be aware of that the industry’s main concern is not to save energy but to maintain and increase productivity. (Jordan, Nadel; 1993)

The article of Klobasa shows that to provide balancing capacity, flexible demand in energy-intensive industries should be used and industry is the market with highest potential of regulating capacity. (Klobasa, 2009)

Strbac (2008) describes the benefits and challenges with DSM making an analysis on the United Kingdom’s electricity system. Strbac describes that there exists a clear possibility to use DSM as a long-term capacity reserve, given the present situation. (Strbac; 2008)

Related work and research, as mentioned above, has provided knowledge and guidelines for the framework of this thesis work. Moritz Paulus and Borggrefe (2011) conduct an analysis of DSM with a similar objective as this thesis work. The analysis is done for the same industrial branches (although in Germany) and indicates potential at the processes that are of interest for the case studies of the present thesis work. This present thesis adds a comprehensive visualisation of characteristics, constraint and load schedules of processes interesting for DSM in Swedish industry.

This thesis work's aim and objective are influenced by Gellings work and description of DSM. Gelling (1985) provide an understanding of the meaning of DSM and the importance of investigating future potentials of DSM. This present thesis report contributes with an investigation of the Swedish industry based on the objectives of DSM described by Gelling.

The study by Ashok and Banerjee (2000) highlights important constraints and factors to consider when analysing DSM in industry; which has been applied when structuring the framework of the case studies performed within this thesis work. The constraints described by S.Ashok and R.Banerjee's article is used in the method of case study analysis in this thesis work, and are considered when dividing loads within the industry of the specific case study. For this thesis work it has provided important knowledge about additional constraints to be aware of when analysing DSM in industry. This thesis provides method of breaking down the analysing of DSM into step-by-step in a site specific industry.

Jordan and Nadel's report "Industrial demand side management programs, what's happened, what works, what's needed" report are interesting for this thesis work because it describes the problem that have to be overcome to be successful in implementing DSM measures in industry.

It has been great work done in the field of DSM, but still the potential of DSM in the Swedish industry is yet to be explored. This present thesis tries to give a deeper understanding about constraints and limitations, possibilities, characteristics, present and future potentials of DSM within industry in Sweden.

3 Electricity consumption in Swedish industry

The total electricity consumption in Sweden was 142 TWh in 2012. Swedish industry consumed 52.5 TWh during 2012 corresponding to 37 % of the total electricity consumption. (Swedish Energy Agency, 2012)

The industry sector in Sweden can be divided in several large branches based on their type of production. The four largest branches consist of paper and pulp, steel and metal, chemical, and mining industries. Together, this industry branches consumed 38.3 TWh in 2012, corresponding to more than 72 % of total electricity consumption of the industrial sector. (Swedish Energy Agency, 2012) Table 1 presents the annual electricity consumption for each of the four industry branches, and, as seen in the table, the paper and pulp industry is the dominating electricity user.

The power production of the electricity system varies over time, during a day it can vary between 15 GW and 25 GW (Nordpool, 2012). Power demand for Swedish industry also varies during the day, most often in the range between 5 and 8 GW, but during day times in winter, demand can peak at around 10 GW (Henning, 2005). Notable, that the electricity consumption of Swedish industry has been similar among the last decade (Swedish Energy Agency, 2012).

The price of electricity for the industrial customer may differ as it depends on agreement with electricity supplier. Agreements could be of set prices or with varying prices that follows the electricity spot market. Many industries do negotiate with electricity suppliers to secure a set price for the main share of electricity consumption. The remaining part of power varies over time and is often set by negotiating with electricity suppliers applying dynamic price setting, and it is this variable price share that is of interest when possible DSM implementation analyse.

Figure 1 shows the electricity demand for Swedish industry during two weeks in February in 2005, which indicate how the demand varies over time in the period where demand reaching its peak. Figure 1 is an example to illustrate the distribution of power consumption among Swedish industry. The demand curve of Swedish industry is based on average data and estimated to look similar to Figure 1 (Henning, 2005).

Table 1: Total electricity consumption in the major four industry branches (Sweden). Source: Swedish Energy Agency (2012)

Electricity consumption	Paper and Pulp	Steel and Metal	Chemical production	Mining
2009 (GWh)	22 305	5 962	4 462	2 423
2010 (GWh)	22 729	7 412	4 808	3 164
2011 (GWh)	22 565	7 991	4 611	3 325
2012 (GWh)	22 690	7 707	4 600	3 289

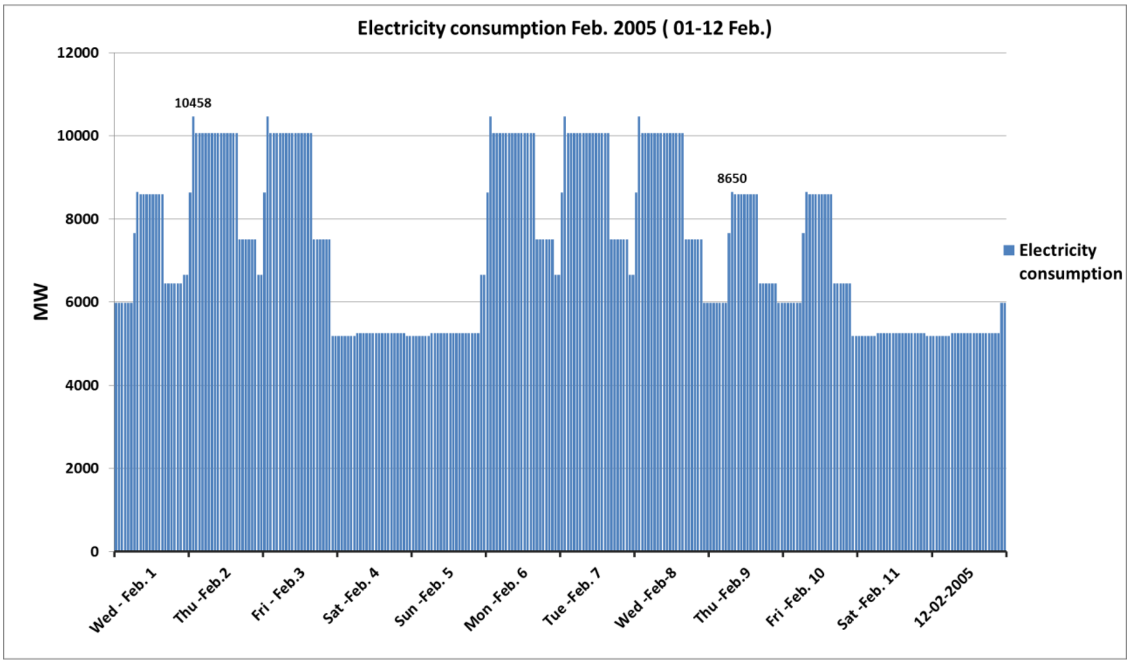

Figure 1: Approximate load curve for Swedish industry. (Numbers are extracted from Henning (2005)

3.1.1 Electricity consumption by branch

The specific electricity consumption differs between branches in the Swedish industry, largely depending on characteristics of production. One measure, which is often used to compare different branches is kWh/ (SEK value added). This measure specifies how much electricity that is used for producing one unit of production value (as measured in Swedish krona, SEK). Pulp and paper and steel and metal are the branches that have the highest electricity consumption of value added (pulp and paper industry used 0.44 kWh/SEK, steel and metal used 0.24) as compared with the rest of the Swedish industry (0.11 kWh/SEK in 2010). (Swedish energy agency, 2012)

Electricity is considered as one of the main commodities used for production in these particular industries. This indicates the large impact of electricity cost on the final cost for these goods. Figure 2 shows the electricity consumption divided by sector.

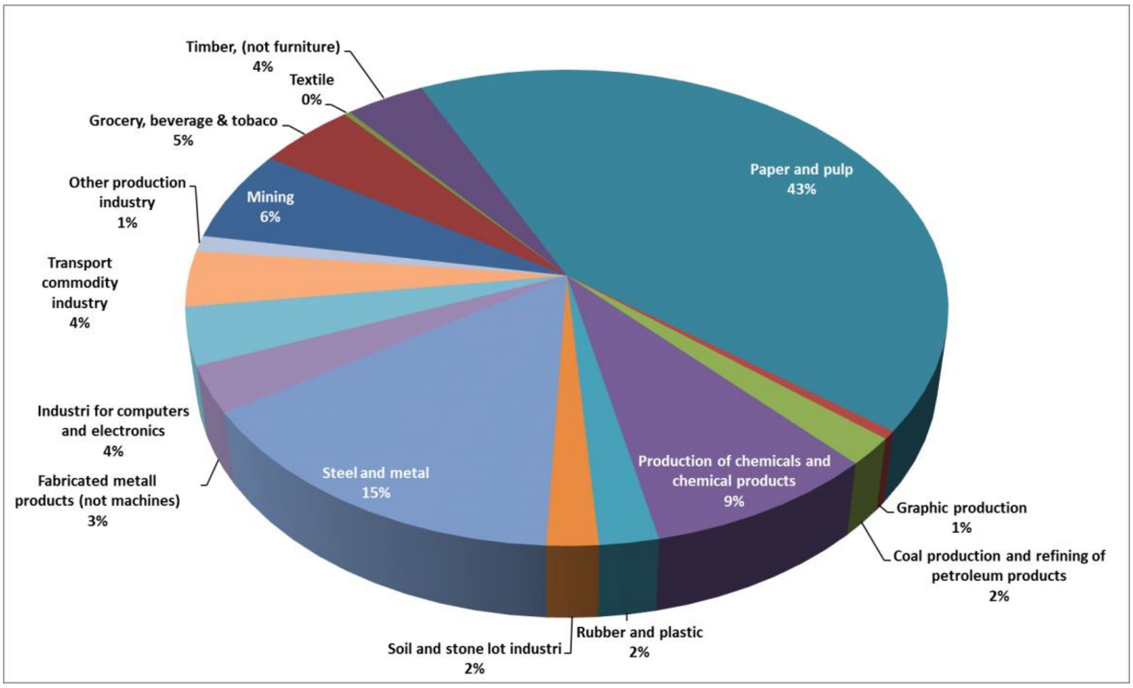

Figure 2: Electricity consumption in percentage divided by sector, 2010. (Swedish Energy Agency, 2012)

The pulp and paper industry

The pulp and paper industry is the largest consumer of electricity in Swedish industry with a share of approximately 43 % of industrial electricity consumption. The production and processes in practice differs largely between different paper and pulp production units in Sweden. The main products that derive from the pulp and paper industry are: wood; packaging; paper and hygiene products, but the industry also provides biofuel and heat to district heating system. (Skogsindustrierna, 2012)

There are two main techniques of paper production, mechanical and chemical processing. The mechanical processing was the first, and long dominating, method used for paper production, but today the chemical process is the most common one. (IVA, 2002)

In the mechanical process the fibres are grinded in large refiners. These refiners are electricity powered which makes the process highly electricity intensive. However, during this process, steam is generated. The steam is used to preheat the wood chips to 120 °C before they enter the refiners, and can also be used to satisfy other steam demand within the facility. The largest refiners have a capacity of 25 MW and approximately 70 % of electricity energy input remains in form of steam after the grinding process. (IVA, 2002)

In the chemical process the fibres are exposed by boiling the wood chips with white liquor so that part of the lignin in the wood dissolves. After the boiling process, lignin, liquor and pollutants are washed out and separated from the pulp. The lignin is used to produce thick liquor that is combusted in a recovery boiler used for steam production (IVA, 2002). Refiners and boilers are large consumers of electricity also in a chemical process mill.

Steel and metal industry

The main products from the steel and metal industry in Sweden are products like strips, rods, profiles for construction, wire, pipes and sheet metals. Many of these products are delivered to manufacturing industries to be further refined into end use goods. Rods and profiles are, on the other hand, often used directly by the construction industry (Jernkontoret, 2013). The steel and metal industry branch is the second largest consumer of electricity in Swedish industry, with a part of approximately 15 %. Roughly half this electricity is used for engine operation and lighting, while 40 % is used for heating and melting of steel, with melting as the major part. Both electricity powered and fuel powered heat treating ovens exists. However, making crude steel from steel scrap requires an electric arc furnace which, as its name indicates, is powered by electricity. (IVA, 2002)

Melting of metal scrap is a recycle steel making process; the scrap is melted by using a light arc i.e. an electric power through the air. Production is based on rest products and recycled materials of metal but is mixed with new compounds when melted. The light arc goes between the electrodes and the metal scrap, this process is highly electricity consuming and uses basically only electricity. To make the process more efficient the scrap can often be preheated by use of natural gas or coal. (SSAB, 2013)

The chemical industry

The most energy intensive production in the chemical industry is to manufacture base chemicals. These base chemicals can be divided into different production branches, for example industrial gas, organic and inorganic chemicals, fertilizers and nitrogen compounds and basic plastics. A large share of electricity consumption goes to pumps, fans, agitators and compressors for keeping required flows and pressures in the process. Heating and cooling of streams supplying the processes is another large energy consumer within the chemical industry. Chlor-alkali industry is using large amounts of electricity in its production of chlorine and alkali (through electrolysis of salt) for making for example PVC plastics. (IVA, 2002)

3.2 Current use of DSM in Sweden

One example of applying DSM in industry sector that has been taken into action is a programme called “Effektreserven” (Swedish Energy Agency, 2011).

Moreover, according to Swedish law, Swedish National Grid (SNG) is responsible to provide a reserve capacity of maximum 2000 MW. The reserve capacity is made partly by an agreement between SNG and the power production utilities and partly by agreements of reduced consumption made with consumers and distributors. This reserve capacity works as a complement to the existing generation capacity in the electricity market, showing that DSM has been used in Swedish industry to help balancing the electricity system. The industries that participate in the reserve capacity receive payment for being part of the regulating power market. Findings of new DSM potentials will help the reserve capacity to expand, thus more efficient regulating market occur. For industries to be part of it, a time limit interval of 15-30 minutes of regulating duration is required. To be a part of the reserve the limit for making a bid of reduced consumption is at least 10 MW of capacity and the facility should be connected to the Swedish national grid (Swedenergy, 2011). Loads with a ramp down time longer than 30 minutes are not qualified for being part of this regulating tool (Andersson, 2013). This is an example of DSM implementation in Swedish power market where the major consumers in industry are getting paid for reducing consumption and thereby helping the system to balance electricity demand and supply in order to avoid high system prices (Swedish National Grid, 2012).

4 Method of assessing DSM implementation

Data used as input within this thesis is collected from several major Swedish industries. Each of these industries has been contacted continuously during the study process, to collect data and information about processes. After a thorough investigation of the extensive data set, five industries from three different industrial branches were selected as case studies in order to perform an analysis of the DSM potential for each specific case. The case study selection was mainly determined by the size of industry, production type and quality of extracted data. Eventual variable costs like labour, transportation, raw material price variation and operation costs are not taken into account.

One objective of these case studies is to include the main branches of Swedish industry. Therefore one industry from Chemical, two from pulp and paper and two from steel and metal is investigated. For Pulp and paper two companies are represented, one with semi-chemical pulp production and one that only uses mechanical pulping processes. This is because there is a difference between processes and production in these types of pulp and paper mills. Mining is not a part of this study, mainly because it was not possible to get an adequate amount of data to base an analysis on.

The analysis follows a checklist of criteria and assessment method which are developed by authors of this thesis. The checklist is applies to divide and organise the DSM analysis in separate steps and thereby facilitate and ensure the analysis process. This method is important for showing how this thesis work has approached DSM, and is not a research method that can be expected to represent an optimal solution for every case. The case studies for different branches have been assessed according to this method to make an evaluation of possible beneficial impacts of DSM implementation. This evaluation has been made using simulations of different scenarios executed in Excel and GAMS. February is chosen for the analysis of case studies because of the large number of peak periods compared to other months. High electricity price periods are considered above 700 SEK/MWh. The different steps of the method are presented and described in words below, general for each industry of case study:

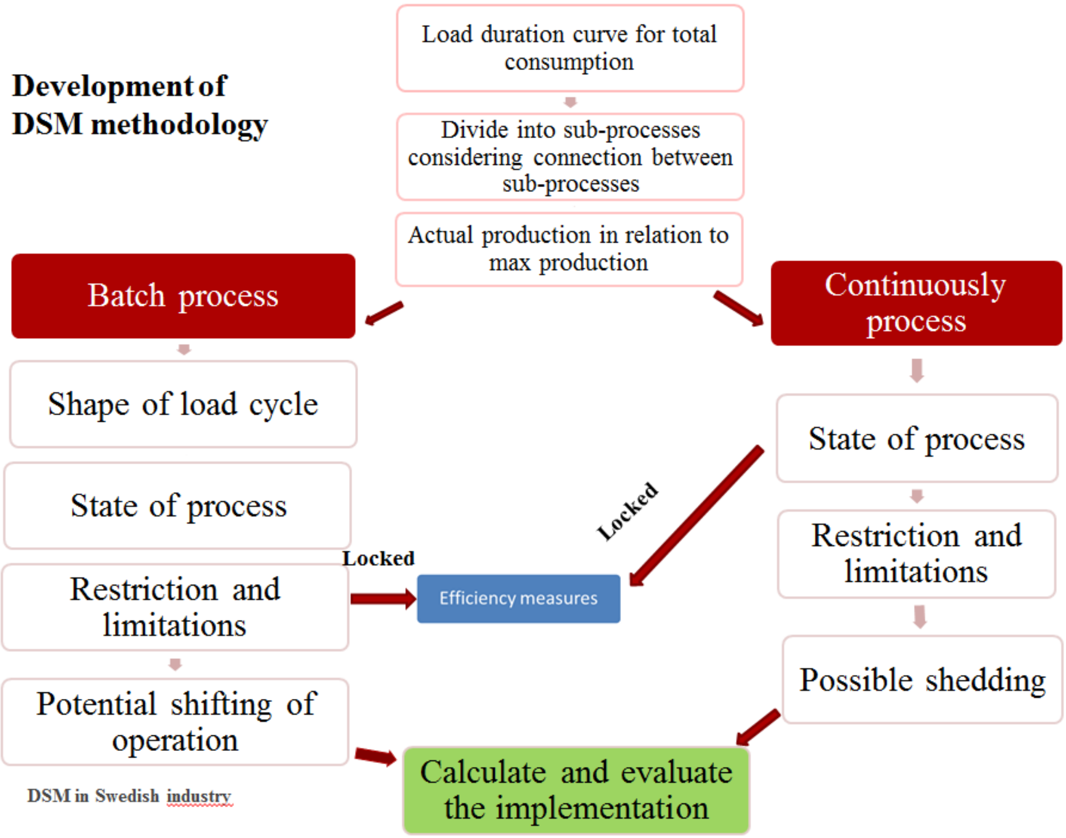

Figure 3: Method of analysing DSM possibilities and impacts in case studies of selected industries within this thesis work.

Step 1: Compiling load duration curves over total consumption of industry

Load duration curves describe the power distribution over time; and in specific, they indicate the number of hours the load demand is on a certain level. Load duration curves create the basis for analysing the variations in consumption and indicate on which DSM approach to use.

Step 2: Divide total consumption into sub-processes

A division of consumption into sub-processes aims to separate the loads and to specify the characteristics of the different sub-loads. One load could serve as base-load, and is likely to run for every hour of the year, while another process might vary over a few hours. It is important to find characteristics of sub-loads because it will determine which DSM approach is appropriate and the possibilities it implies. It is also important to get knowledge about connection between sub-processes; if loads are interconnected they have to be shifted together.

Step 3: Actual production in relation to max production

If the actual production for each sub-process equals the maximum possible production it will be difficult to implement DSM measures like load shifting. In this case, the process may be classed as a continuously run process, and measures like load shedding are more suitable than for example shifting. However, if the actual production is lower than maximum production e.g. in a batch process, other DSM measures or a combination of the measures can be used.

Making load duration curves for each process will indicate if it is of batch profile or if it is run more continuously over time. Depending on the shape of the load curve the processes are divided in two separate ways of further analyses. The loads are therefore categorised as either batch process or continuously run process. For a batch process there is four additional steps while a continuously process have three additional analysis steps, i.e. the total steps for a batch and continuously process are seven respectively six steps.

Step 4 (batch): Shape of load cycle

For a batch process it is of importance to know which hours the process operate, when it is shut down and if it is run at part load at certain times. The load cycle shape show whether the process operates at certain hours of a day or if it runs variable. The value of standard deviation of consumption indicates at how much the curve vary over time and can provide basis for further analysis of desired load shape changes.

Step 5 (batch): State of process

In this step, the constraints of the load are investigated based on whether the load is bounded to certain hours or if it is flexible. If it is a bounded process, it is not possible to implement load shifting and the load is marked for applying efficiency measures. Constraints like minimum and maximum down and up time, ramp up and ramp down time should be considered throughout whole analysis and evaluation.

Step 6 (batch): Restrictions and limitations

Restrictions and limitations for each load that have to be taken into account for DSM are;

- Minimum down/up time
- Maximum up/down time
- Ramp up and ramp down time
- Total energy used should remain the same before and after DSM
- Impacts on other processes within the production

Step 7 (batch): Calculate and evaluate the potential load shifting

For the sub-loads which fulfil the criterion of flexibility, an analysis of potential load shift is carried out. The analysis uses the electricity spot price to investigate which hours of operation that should be regulated in order to minimize the cost. The scenario with DSM implementation will be compared to the current cost of production. Evaluation and results are calculated manually or using GAMS or Excel in case of large amounts of variables.

Step 4 (continuously): State of process

In this step the constraints of the load are investigated as for the batch process, if the load is bounded to certain hours or if it is flexible in time. If it is a bounded process, it is not possible to implement load shedding and the load is marked for applying efficiency measures.

Step 5 (continuously): Restrictions and limitations

Same constraints as mentioned in step 6 for a batch process are also considered here. The only difference is that the restriction of keeping energy use is not necessary to account for when analysing a continuously process. It means that the total energy used before and after DSM could differ.

Step 6: Calculate and evaluate the implementation possible shedding

Similar method as step 7 batch process can be applied.

4.1.1 Check list

In the method developed in this study, several criteria that should be fulfilled for DSM to be possible are considered. The checklist needs to be fulfilled to be able to implement the method of DSM presented above. This represents a way of classifying different processes and what to prioritize when working with DSM. These criteria are listed as;

- Economic incentives
- No decrease of total productivity
- Flexibility of the process
- Technical feasible
- Economical beneficial considering electricity price
- Sustainable thinking
- Base and critical loads should not be interfered

Economic incentives are essential for industry to be interested in investing in DSM applications and making the effort of regulate production. Economic incentives can be in form of time-of-use tariffs (TOU) (Swedish spot market) where the price is fluctuating by the hour as it depends on demand and available supply. If there is no difference in price between time periods, there would be no incentive for shifting loads. Governments can also use other incentives for companies to be a part of a DSM schedule if the TOU doesn't give enough encouragement. This can be in form of financial support for being part of programs e.g.*"Effektreserven"*(as described in section 3.2).

Next criterion is *No decrease of total productivity* which refers to that an implementation of DSM should not interfere with total productivity. Even if a reduction in production is made, the productivity can be maintained by reducing costs. Productivity is defined as income minus costs; income could be from production sales but also from economic compensation. Productivity can, thus, be maintained by reduced costs and economical compensation. For example, with "Shedding" some production is lost; this has then to be compensated through cost savings in electricity use and in most cases by economic incentives from DSM programs.

Flexibility of the process is important for DSM study, flexibility of shifting the load in time or shedding the load at specific hours. If the load is bounded to run both at certain hours and at a specific level of power it will be difficult to implement DSM measures. It should also be *technical feasible* to connect the potential loads to operation systems e.g. direct control techniques.

In an optimal scenario it would be *economical beneficial* to invest in DSM techniques. There should be a *sustainable thinking* about implementation and impact on the electricity system. *Base and critical loads* like safety control systems should not be interfered but must be kept at same functionality as before implementation.

5 Analysis according to the method

Within this thesis work, five case studies have been carried out to assess the potential for DSM. The results of the case study analyses are presented in this chapter. For each case, the annually electricity consumption data for specific loads was provided by the company under study, thus actual consumption data for each case is used. Since actual numbers are presented, the case studies are anonymised and only the industrial branch of the case study is presented. In this thesis report, three of the case studies are presented following all the steps described in the method (see Chapter 4), while the two remaining industries are only presented by results, and descriptions and load curves for these industries are attached in appendix.

5.1 Case study 1- Chemical industry

This industry is a chemical plant that operates in the south of Sweden. The main product is PVC powder that is sold to manufacturers of end product production like pipes, floors and medicine products. The industry has an electricity demand of approximately 500 GWh/year which makes it a major industry in chemical branch of Sweden.

Step 1 Compiling load duration curves over total consumption

For this industry, data is given on hourly basis for December 2012. It is however important to note that the shape of the load curve differ compared to its normal shape. The consumption of electricity decreased in the latter part of December due to a decreased demand of PVC and thereto reduction in production. Under normal conditions, the industry is operating at full capacity all hours of the year.

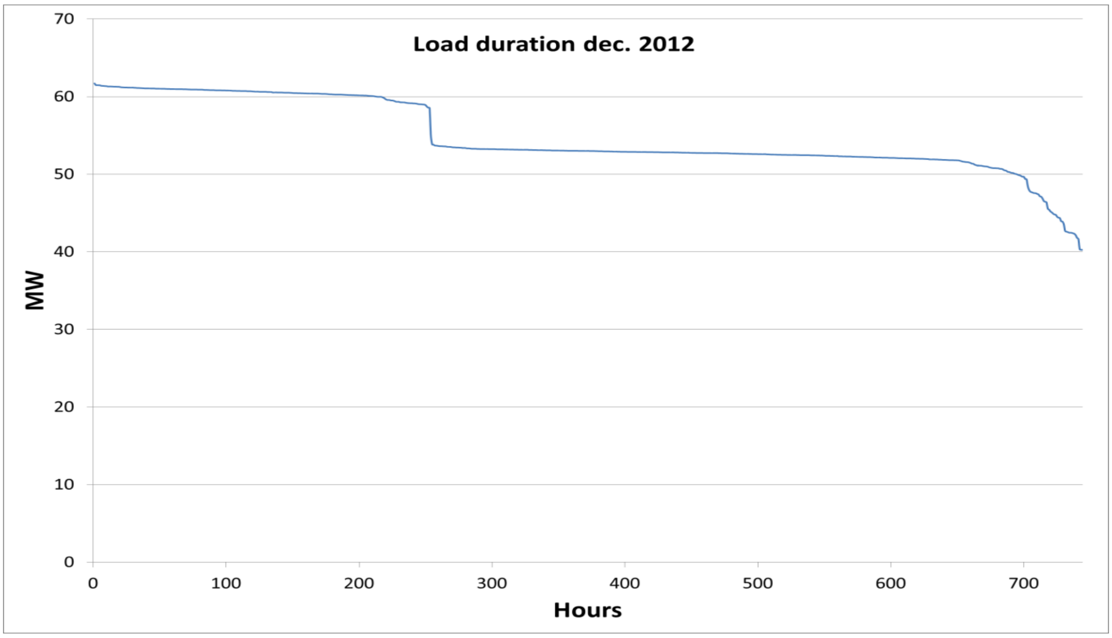

Figure 4: Actual load duration data of electricity consumption in descending order for December 2012 (case study for Industry 1 – a chemical industry)

Figure 4 presents the load curve for case study 1, and it can be seen that the company decreased its electricity demand with approximately 10 MW for about 500 hours in December. During a few hours total consumption is below 45.8 MW due to reduction in other areas of production processes. From Figure 4 it can be seen that the electricity demand decreases below 40 MW, which is the point where it is too costly to reduce the electrolysis process. This is due to the loss of heat that has to be replaced by other energy sources.

Step 2: Divide total consumption into sub-processes

The base load of 45.8 MW is never shut down because of the complexity of starting up these processes. Base load includes VCM production and manufacturing of end product PVC and parts of electrolysis. The electricity demand decreases in the electrolysis process because that is the flexible part of process which varies between 29.8 and 45 MW. The total current can be reduced from 166 kiloampere (kA) to between 100 - 110 kA but not lower than that because the cost will be too high to replace the loss of heat in the whole process. For this case 166 kA = 45 MW give the relation:

$$\frac{166\ kA}{45\ MW} = 3.69\ kA/MW$$

$$\frac{110\ kA}{3.69\ \frac{kA}{MW}} = 29.8\ MW$$

The reduction potential is thus 15.2 MW (45 MW – 29.8 MW), which may be reduced from the total consumption of 61 MW. (Company information, 2013-04-05)

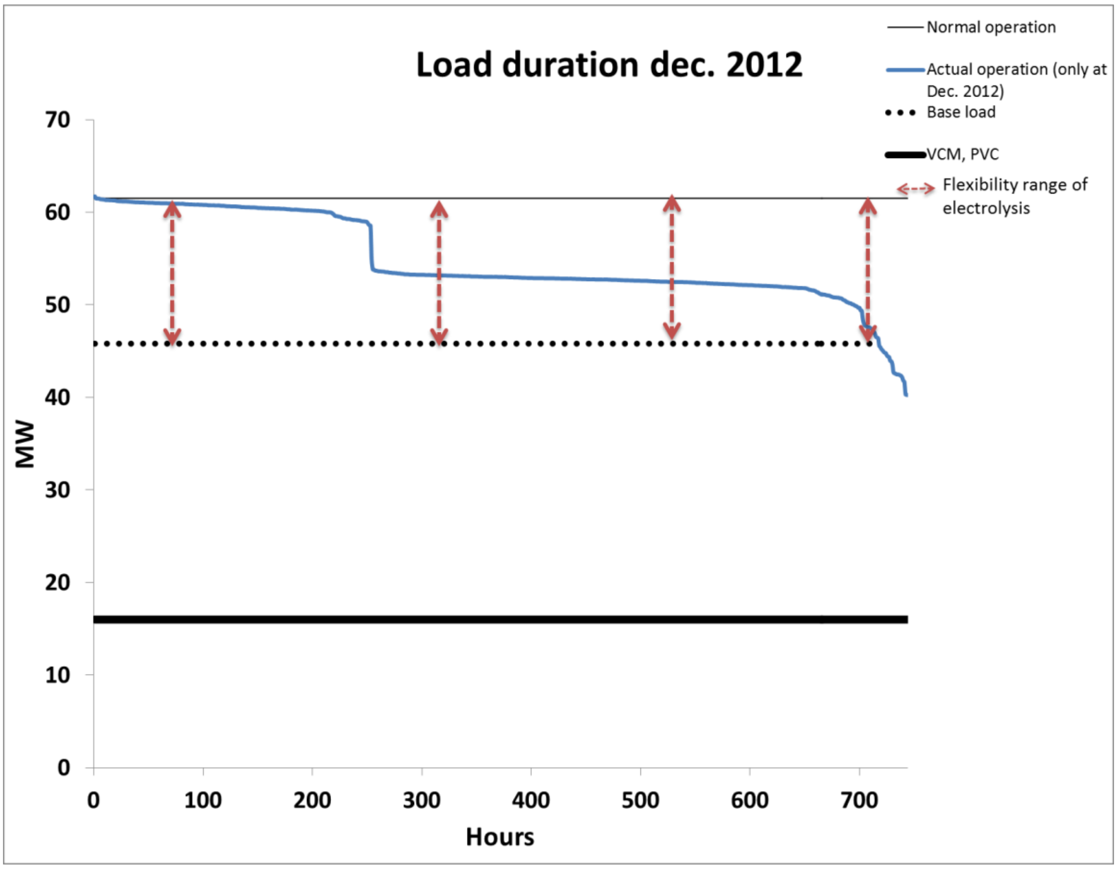

Figure 5: Divided load duration curve for a chemical industry (December 2012)

Step 3: Actual production in relation to max production

PVC and VCM production are operating at maximum over every hour during the year thus, actual production equals max production. It is complex to make changes in these processes both from a technical and economical point of view as:

- Technically it is difficult to shut down and start up those processes.
- The loss of e.g. VCM production cannot be recovered later on, since other processes will run at maximum level.

Another electricity intensive process, is the electrolysis. As shown in Figure 5 which is based on the extracted data from the company, the actual production is lower than the max capacity of this process. This process can be categorised as a continuously process. Usually this process is running at maximum capacity and it is regulated manually to respond to very high electricity prices. However, when PVC demand is low, the electrolysis process can be reduced manually by 30-40 % of the max capacity.

It should be noted that one tonne of lost VCM can't be recovered later in the factory because the other processes will run at 100 %, as also discussed above. This makes the load shifting impossible, and therefore shedding will be the chosen DSM approach.

Step 4: state of process

Because of the bounded state of PVC and VCM processes, the only option for these processes will be shedding. But this option is almost infeasible as described in step 3. These loads are therefore suggested to be analysed with efficiency measures in order to reduce energy consumption, but DSM measures would not be an efficient approach.

Electrolysis process is interesting for further DSM analysis due to conditions mentioned in step 3. When chlorine production is at maximum during long periods, the company compares the marginal cost of chlorine production with electricity prices. Company practice is that they decrease production by 15.2 MW during time periods with high electricity prices. During periods with low PVC demand, the electrolysis load is more flexible and the shedding part can be optimised. This is due to more flexibility of choosing the appropriate hours for shut down or running at part load.

Step 5: Restrictions and limitations

Limitations of shedding are associated with max/min up/down time, ramp up/down time together with interconnection with other loads. Following data is for electrolysis process:

Max up time (MAXUT) = ∞
Min up time (MINUT) = 3 hours
Max down time (MAXDT) = 24 hours
Min down time (MINDT) = 3 hours
Min ramp up (MRU) = 1 hour
Min ramp down (MRD) = 15 minutes (negligible)

As electrolysis is a continuously process and only load shedding is considered, the amount of energy is not bounded to be constant before and after the implementation of DSM. Time of shedding is connected to the electricity price and the marginal price of production value. The electrolysis load is reduced when the price of electricity is higher than 700 SEK/MWh. This corresponds to the marginal production value. A regulation of 15.2 MW is activated and operated when electricity price is higher than marginal production value. By regulation means that the load is operated at either 61 MW (max) or 45.8 MW (min), due to the limitation described in step 2.

Step 6: Calculate and evaluate the possible shedding

Before DSM implementation, the total electricity cost for the industry was 19 MSEK in the analysed period of February 2012. This estimation is based on actual spot market electricity prices for February 2012 and the production level is assumed run constant at max level without shedding. February was chosen to show the shedding possibility since the electricity peak and off-peak prices differ largely during this period. For the rest of the year, the prices are seldom higher than 700 SEK/MWh, thus no shedding will occur.

However, the total electricity cost after optimising was 17.5 MSEK, thus a reduction in cost of 1.5 MSEK. The value of corresponding lost production during this period is estimated to 0.9 MSEK which is calculated based on 700 SEK per each MWh loss in production (total reduction of 1327 MWh electricity). The final result shows a potential saving of 0.6 MSEK for the month analysed (February 2012).

One aspect of implementing load shedding in this particular industry is the recovery capacity of production. The electricity consumption is in direct relation to production, in other words one unit of reduced electricity equals one unit of lost production output. It can be beneficial to shed load when electricity prices are high, but there is a limit for how much shedding that can be made. The production has to be kept at a certain level in order to maintain its position in a competitive market. The key is to find the optimal time of hours to shed, when both aspects are taken into consideration.

There are several other factors that will have an impact on how to manage the shedding procedure. Raw materials like saltine and ethane, transportation costs and customer demand are examples of those factors. This together with electricity price will have to be combined to determine if the time of shedding is appropriate or not. For example, the price of raw materials can be low when electricity price is high. In such a scenario it is important to evaluate which alternatives, shedding or continuously production is the most beneficial.

Figure 6 presents the results of a model run for case study 1, it can here be seen that shedding occurs when electricity price peaks during analysed period of February 2012. The shedding of the load curve accounts for the limitations specified above. Even though electricity price seldom is higher than 700 SEK/MWh this shows that there is a possibility of regulating the electricity consumption according to electricity prices or generation deficits in the electricity system. Although 15.2 MW might not significantly impact electricity prices in general, this could, aggregated together with several other industries' potential, be of importance of balancing the electricity supply demand system.

The steps described above for case study 1 has also been done for the remaining four case studies. The steps of restrictions and limitations together with the simulation findings are presented in the main report. In order to make the report easier to follow for the following case studies, the first four steps are attached in the report's appendix.

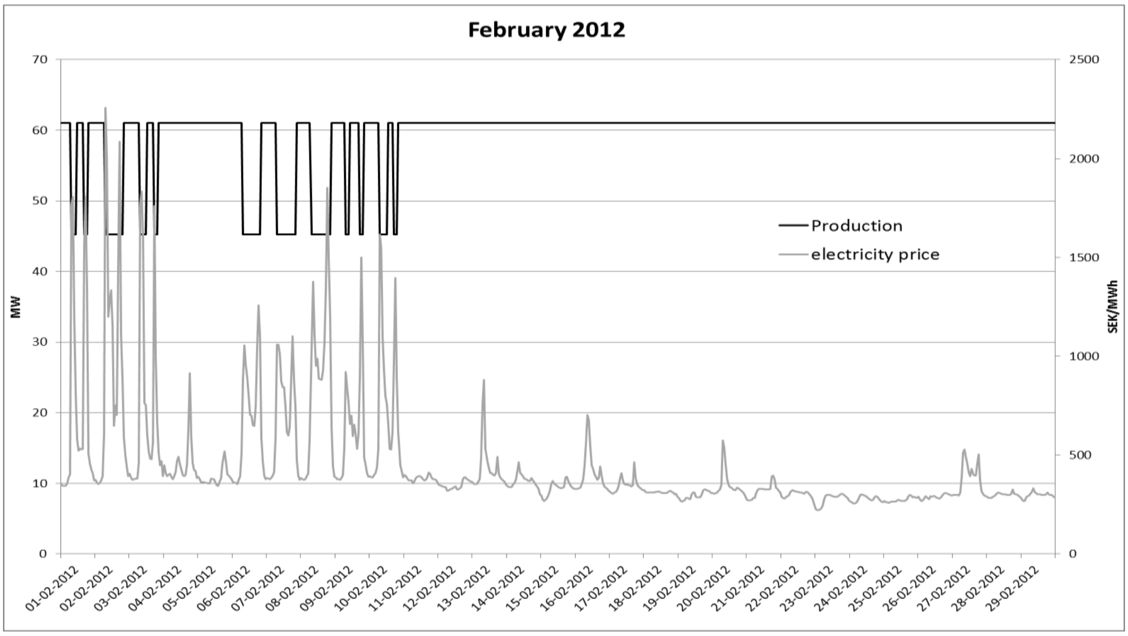

Figure 6: Load cycle of electricity consumption for chemical industry (Case study 1) with shedding implementation.

5.2 Case study 2- Steel and metal A

Steel and metal A produce stainless material construction tools, special alloys, titanium and other high performance materials. In 2012, the electricity consumption of the company was approximately 500 GWh which makes it a major industry in the steel branch.

The electricity consumption is mainly related to of a number of furnaces that are used for melting and moulding of steel scrap. When melting steel scrap an electric arc furnace is used, and it is the largest of the furnaces in term of power capacity.

The analysed processes for this industry are the arc furnace and six ovens that are used for moulding the melted steel scrap after the arc furnace is used. There are also two electric boilers of 15 MW each that produce steam for heating of buildings and steam demanding production processes. There are no hourly consumption data available for the electric boilers but they are assumed to be running at max power during winter. In summer, steam demand is lower; thus, electric boilers would run on part load as there is always a need for steam to supply specific processes within the production. There is a backup system consisting of an oil boiler unit for these boilers.

Restrictions and limitations

Melting and moulding are interconnected processes which make DSM slightly more complicated. This interconnection must be considered and if shifting or shedding is made, both processes will be affected.

The optimal operation of the arc furnace is at high level at all time, to maximize the production output. But the production will vary according to the demand of products from customers. When production is running, a load of 75 tonnes of metal scrap is charged to the furnace, one charge is running between 60-90 minutes before ejected from the furnace. Usually one load is followed by another (as shown in Figure 7) to keep production going. When one charge is completed it is possible to choose to keep arc furnace at melting mode alternative shut down the process. It is crucial for this process to not be regulated when it is charged; a down regulation in power will cause large damages to the furnace and probably result in a need of replacement of the unit. The arc furnace is thus a batch process and is considered interesting for load shifting. Load shifting can only be done by changing start time of charging to desired hours. There is also load flexibility in smaller furnaces working with heating of components, these are however small in power and are not regarded in this report’s scope.

The electric boilers that supply the industry with steam have the highest flexibility in this production facility. These boilers are easily regulated without causing additional high cost. However, the potential cost savings from electricity consumption is low because of the additional fuel cost of oil for the replacement boilers. The electric boilers are a continuously process and considered interesting for load shedding.

Findings of simulations

Load shifting of the arc furnace is a possible option with planning in advance, the “must run if start” constraint has to be considered and is the most important limitation of the process.

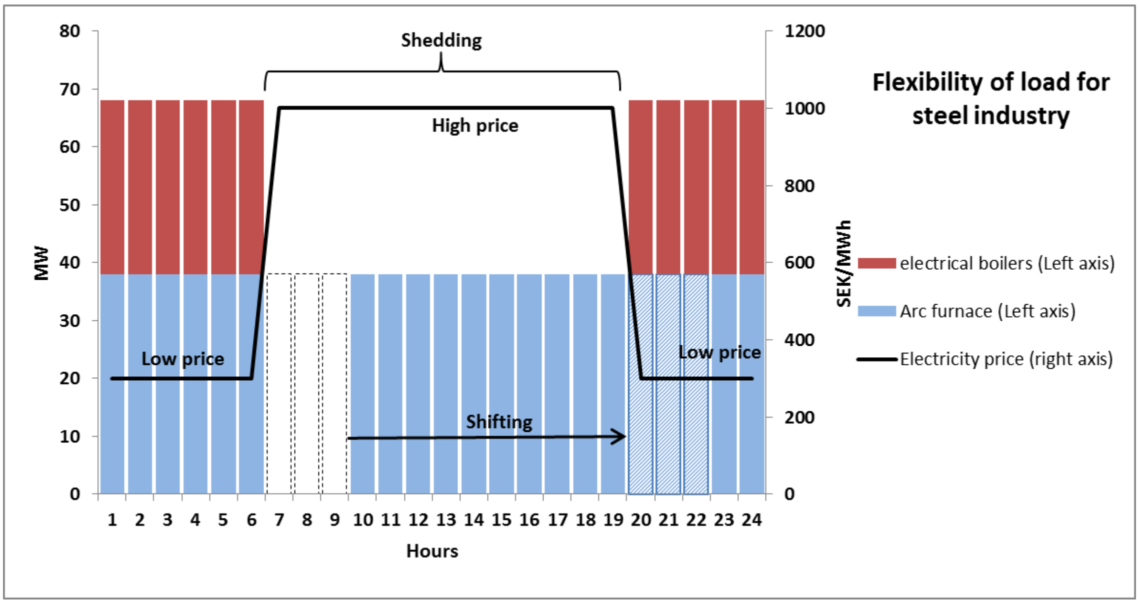

Figure 7: Illustration of theoretical response to electricity price for the arc furnace and electric boilers in Steel and metal A. The x-axis shows time (h) and y-axis to the left indicates power of Electric boilers and Arc furnace (MW) and y-axis to the right shows electricity prices at each hour illustrated with a price curve (SEK/MWh). Source: information from company

Normally the price of electricity is negligible compared to the production value in the arc furnace. This makes the shift of running hours as a response to electricity price just costly and unprofitable due to the additional costs related to reschedule the production. However, during periods with very high electricity prices (peak hours) the shift of production cycles from peak- to off-peak hours may be motivated. This is because of the very large price difference between those periods and relative large amount of power needed in the arc furnace. Empirical findings show that rescheduling has been done in reality during very high price periods and low demand.

A calculation example for shifting two loads of arc furnace the 3rd of February from 7:00-10:00 AM (Peak hours) to 13:00-16:00 PM (off-peak hours) at the same day, shows a potential cost saving of 0.15 MSEK. The calculation concerns only electricity consumption excluding other additional costs related to reschedule of production.

Even if the economic saving during peak price periods is relatively large; the required compensation in order to make such regulation in the arc furnace is much higher than the actual saving. The company needs a compensation of 150 to 200 times the average electricity price (app. 400 SEK/MWh) for each MWh of down regulation. (Company information, 2013)

Electric boilers

Electric boilers are more flexible compared to the arc furnace in terms of response time. During peak periods the boilers could shut down immediately and oil fuelled boilers are available to replace the electricity fuelled boilers. The flexibility of these electric loads (2 x 15 MW) could provide a potential for load shedding both within company planning scheme and as a capacity reserve in a DSM program in larger scale e.g. the ”Effektreserven” scheme. However, electric boilers can’t be shut down at extreme cold outdoor temperatures, because then the capacity of the existing oil boilers is not sufficient to cover demand.

The fact that Electric boilers are replaced by oil in a dual-fuel system might be seen as an unsuitable solution since the magnitude of energy used at the moment is constant.

But it is important to notice that oil boilers are used only to produce steam for heating and not electricity. The efficiency of an oil-fired steam boiler is, in general, above 82% (U.S. Energy Department, 2012) compared to oil-fired power plant with an efficiency of maximum 44% (Khartchenko, 1997).

5.3 Case study 3- steel and metal B

Steel and metal B is also active in the steel and metal business and consumes approximately 250 GWh of electricity on a yearly basis. The company takes part in ”Effektreserven” meaning that consumption can be regulated on short notice. The main consumption of electricity takes place in one arc furnace for melting steel scrap and in a couple of smaller furnaces for after treatment of the melted steel. The smaller furnaces use natural gas as their primary source of energy but use electricity for fans, pumps and compressed air.

Restrictions and limitations

Melting and moulding are interconnected with each other which make implementation of DSM more complicated. This connection between processes must be considered and if shifting or shedding is made both processes will be affected. The loads do not follow the same pattern in terms of power consumption. When the arc furnace reduces its power demand, the remaining furnaces are still running close to maximum load. However, the supply of melt steel from the arc furnace has to be sufficient for the moulding furnaces to keep running at all times. Keeping the moulding furnaces running at all times are critical for not losing in quality in products.

The power variations of the arc furnace indicates an over production capacity compared to moulding furnaces. Thus, the arc furnace is operating at a high capacity divided upon short time periods. The flexibility at site here might be the start-up of the processes, for example after a maintenance stop, trying to manage the time interval of start and stop cycle of arc furnace considering the moulding furnaces. During a day there are changes in the type of metal that are produced, in these times the process are shut down and raw material is switched. When this is done there are some flexibility in postpone start up again. This is all depending on the customer demand of product type and amount of demand.

The electricity use of the arc furnace can be reduced but is controlled by limitations, for this investigated industry, one charge takes between 30-45 minutes to complete. A down regulation of 25 MW (arc furnace) can be done in the time of 15 minutes but the limit of shut down time is maximum 3 hours. In addition, this down regulation can only be done at six different times during a winter, and between activation times it has to be a minimum of six hours. This is a costly change of production schedule and electricity price peaks do not provide enough incentive to make such a change.

Findings of simulations

The load shifting and shedding potentials for the investigated steel industry 3 are shown below, limitations are considered such as not violating any constraints. Moreover, the short shut down time of 15 minutes makes the arc furnace flexible and thus subject for load shedding as well as shifting. Shedding is however limited to a maximum of 3 hours to avoid harming the furnace. This means that the arc furnace can be used for load shifting with careful planning but also for shedding in specific cases.

There is a difference in operation characteristics for the arc furnace in steel industry B compared to industry A. The charge processing time is 30-45 minutes and there is a possibility of shutting down the process in the early phase of operation. This arc furnace is also smaller in terms of power compared to steel industry A.
According to the company an economic compensation of 300 - 600 kSEK/period of regulation is required for making such regulation economic feasible. This is equivalent to 4-8 kSEK/MWh. (Company information, 2013)

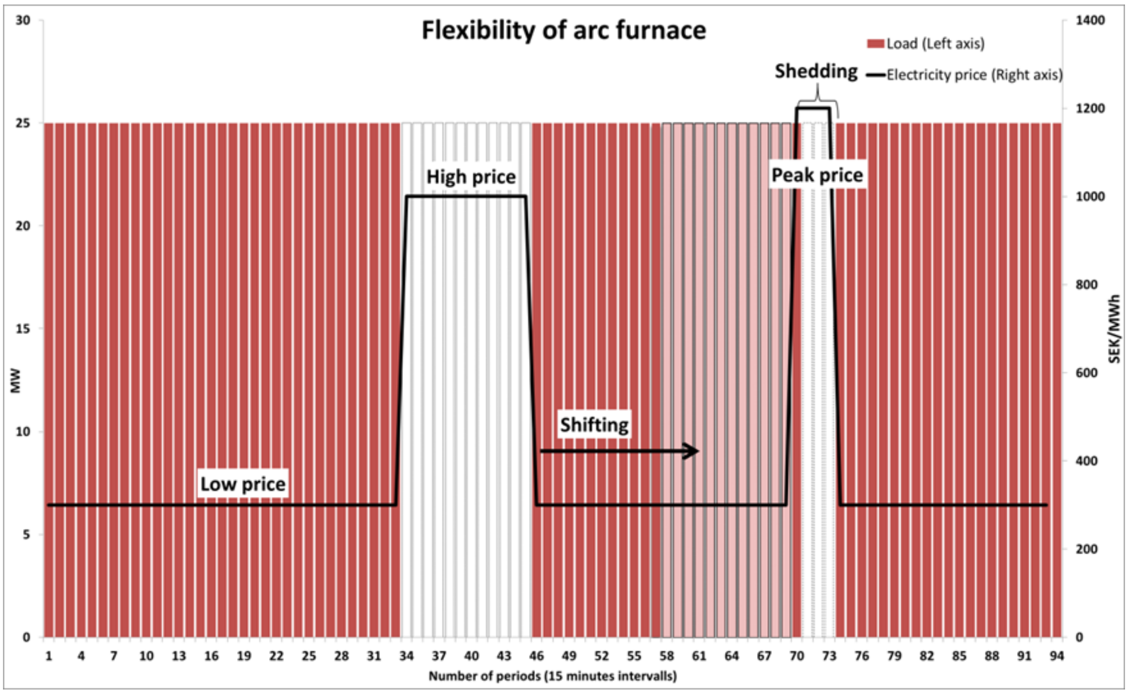

Figure 8: Flexibility of electricity load of arc furnace in steel industry B. The x-axis shows time (h) and y-axis to the left indicates power of Arc furnace (MW) and y-axis to the right shows electricity prices at each hour illustrated with a price curve (SEK/MWh). (Case study 3)

5.4 Case study 4- pulp and paper A

This industry produces pulp and paper and has an annual electricity consumption of 700 GWh. The industry is a semi-chemical pulp and paper producer, meaning that fibres of the wood are exposed through a combination of chemical and mechanical treatment. The largest share of electricity consumption derives from sulphate pulp production, which mainly operates at a capacity of approximately 28 MW. The mill also generates electricity in a steam turbine which provides approximately half of the in-house electricity demand. The steam is produced by combusting rest products from the wood room in form of bark from the trees.

The market pulp production machines are used to dry the pulp and press into pulp rolls that are planned for shipping or transporting to other paper mills. (SodraCell, 2013)

Restrictions and limitations

The market pulp production machines has to consider the surplus of pulp, i.e. it is limited to only be down regulated as long as there is no surplus of pulp. Start up and down time is less than an hour meaning that the regulation is easily done.

The only restriction to consider for the wood room is the amount of wood chips. There has to be sufficient amount of wood chips to supply the system in order to maintain the production. Start up and down time of wood room is even faster than the market pulp production and can be regulated without any problem.

Both wood room and market pulp are usually operated either on full capacity or shut down, and not on part load.

Findings of simulations (Wood room)

Shedding is evaluated by regulating the electricity consumption according to electricity prices. After applying shedding as a DSM measure for the wood room, its annual consumption can be reduced by 221 MWh. This corresponds to the reduced amount of electricity consumption during high price periods i.e. the 82 hours when electricity prices are higher than 700 SEK/MWh (based on 2012 prices). If the actual shedding would be activated 82 times during a year, this results in a decreased cost of electricity by 231 kSEK, which should be balanced against additional costs and loss of production as a result of shedding.

The analysis indicates at a shedding capacity of 2.7 MW which can be activated either as a measure at the company level or as part of reserve capacity in a national large scale DSM programme. This shedding capacity is rather small in terms of power, but it has the advantage of high flexibility of the process.

Findings of simulations (Market pulp production)

The load shifting potential of the market pulp production is evaluated by shifting loads from high price periods to low price periods. Shifting is limited to 3.3 MW. The savings in electricity costs when shifting loads are 13 kSEK for the month of February 2012; once again this is not actual profit of load-shifting. February is chosen because of the large number of peak periods compared to other month. The electricity consumption is kept constant since only shifting takes place. Therefore the outcome in production is maintained. There is currently limited knowledge of the time intervals of pulp surplus in the pulp production system as current practice is that the Market pulp production is started up by workers on site when considered necessary.

5.5 Case study 5- pulp and paper B

This industry is a pulp and paper industry with a consumption of over 1000 GWh/year. Production of pulp consists of two main parts, pulp recycle production and mechanical production of pulp. The focus in this study will be on mechanical production. Mechanical production consists of grinding the wood material into pulp, which is a highly energy intensive process. The industry also manufactures paper which takes place in a number of large paper machines. The difference between this industry and the previous pulp and paper industry investigated (Industry A) is that Industry B only uses mechanical treatment of pulp where Industry A also uses chemical treatment. This makes the processes different in characteristics but also in electricity demand.

Restrictions and limitations

There are interconnected processes and the main objective is to keep the level of production at a continuously level. If sufficiently pulp is produced, the thermo-mechanical pulp (TMP) could be shut down. However, this requires an overcapacity in pulp production together with available storage capacities. This limitation is also valid for the grinding mill; there has to be a sufficient pulp surplus in the system to enable regulation. In this case study, the TMP process is analysed for shedding possibilities. The remaining processes will mainly be concerned by implementing efficiency measure options which is not evaluated in this work.

Findings of simulations (Grinding mill)

Figure 9 shows the variation of load for the grinding mill measured during February 2012. The pattern is similar for all month and can thus be considered representative for the whole year (the annual load cycle for year 2012 is found in the Appendix). For the grinding mill process, there is a considerable capacity operating during short time periods, which could allow for load shifting.

The estimated cost decrease due to the reduction in electricity consumption before and after shifting is 1.8 MSEK for February 2012. The total electricity consumed are kept constant, thus production output remain the same. This saving do not represent cost decrease potential for every month, though electricity price peaks in February are high compared to rest of the year.

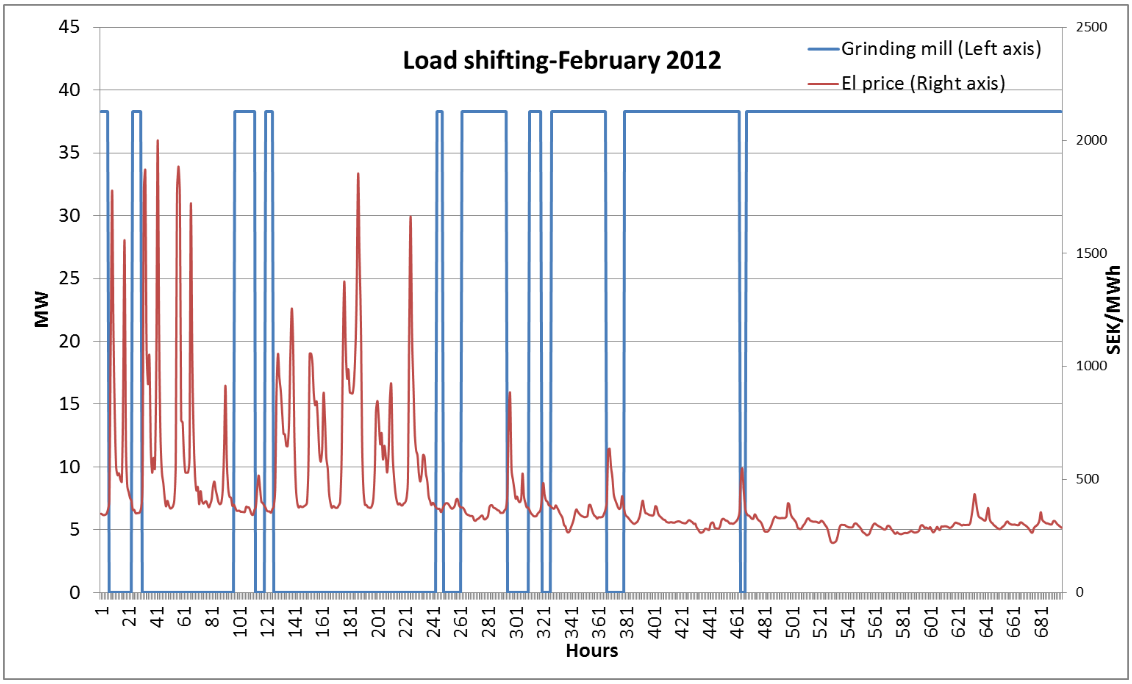

Figure 9: Load shifting of grinding mill for Case study 5. The x-axis shows time (h) and y-axis to the left indicates power of grinding mill (MW) and y-axis to the right shows electricity prices at each hour (SEK/MWh). (Pulp and paper industry)

Findings of simulations (Thermo-mechanical-pulp; TMP)

The load cycle of the TMP process is shown in Figure 10 for February 2012; the pattern is similar for all month and can thus be considered representative for the whole year. The magnitude of possible DSM adjustment is large because the high amount of power that can be regulated. Complexity of collaboration between productivity and shedding is although present and has to be considered. It is of importance of keeping the level of pulp constant to avoid productivity decrease.

The load is shed during hours when electricity prices is higher than 700 SEK/MWh and kept on maximum level at lower price levels. The results show that about 15 GWh is shed during 198 hours for the investigated year 2012. This corresponds to a cost reduction for electricity of 10 MSEK. However, when production is down regulated it must be kept down for a minimum of 24 hours, thus this DSM action will not be appropriate to only use for peak hour reduction.

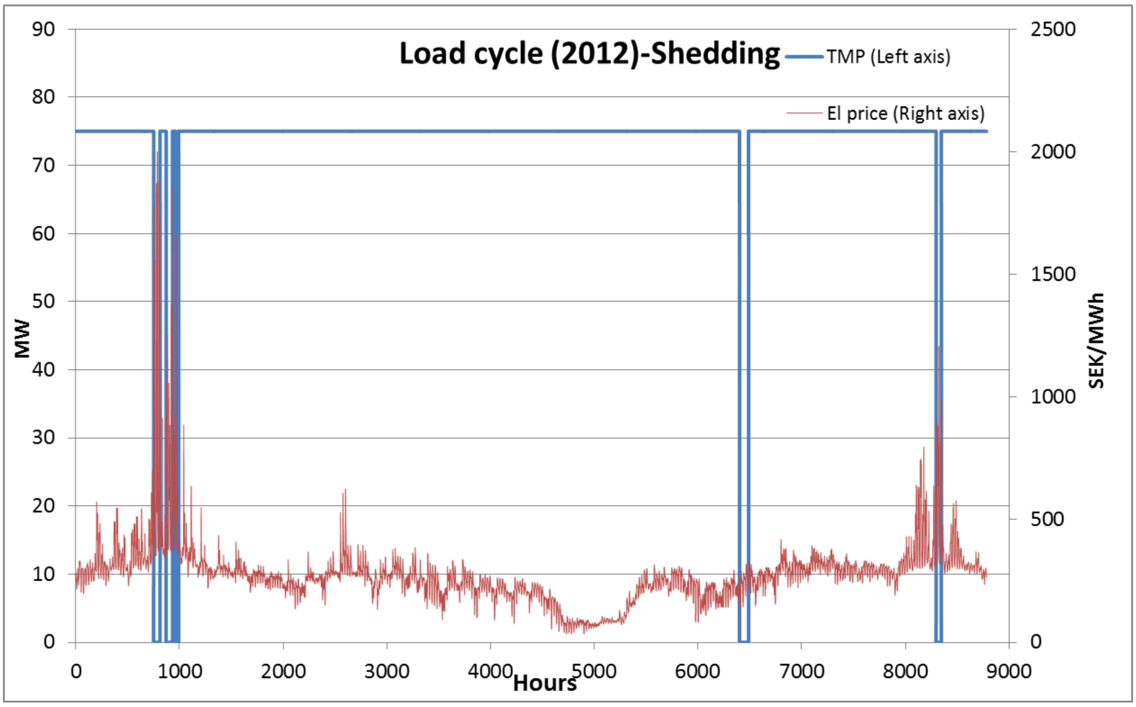

Figure 10: Shedding scheme of the load for Thermo-mechanical-pulp "TMP" (Case study 5). Period with 0 loads between hours 6000-7000 is the annual revision stop. The x-axis shows time (h) and y-axis to the left indicates power of TMP (MW) and y-axis to the right shows electricity prices at each hour.

6 Result

In this chapter a summary of the results from the performed case studies are presented, see Table 2. The numbers are calculated according to the case study method and present the estimated DSM potential for each case study based on findings and calculations. The investigated industries in this report represent roughly 7% of the total annual electricity consumption in Swedish industry. In total, the estimated DSM potential for the analysed industries is, in total, 147.9 and 104.6 MW for load shedding and load shifting respectively.

Table 2: Summarised results of the five case studies performed within this thesis work. For each case study the potential of load shifting and load shedding stating capacity, ramp down and ramp up time, minimum and maximum down time.

Industry	Type of DSM	Capacity (MW)	Ramp Down Time (minutes)	Ramp Up Time (minutes)	Minimum Down time (Hours)	Maximum Down time (Hours)
Chemical industry	Shifting	0	0	0	-	-
	Shedding	15.2	15	60	3	24
Steel and metal A	Shifting	38	0-90	0	DD*	DD*
	Shedding	30	0	0	0	∞
Steel and metal B	Shifting	25	15	15	DD*	DD*
	Shedding	25	15	15	Undefined	3
Pulp & Paper A	Shifting	3.3	15	15	DD*	DD*
	Shedding	2.7	0	0	DD*	DD*
Pulp & Paper B	Shifting	38.3	0	0	DD*	DD*
	Shedding	75	60	60	24	24

* DD = Demand dependent (production output)

6.1 Estimated DSM potential

Swedish Energy Agency lists companies according to their main activities in an efficiency program called PFE; The Programme for improving energy efficiency in energy intensive industries (Swedish Energy Agency, 2011). Industries with similar activities are placed in the same branch and more specific similarities in production are gathered in the same division[1]. This classification in PFE lists has been used in this thesis to assess a potential of DSM in Sweden. The PFE is not listing all active industry within each industry branch, but only the industries that participate in the program. It may, therefore be more industries with potential which are not listed in the PFE. The estimated DSM potential for divisions are based on data from PFE list, thus there are eventually larger potential within divisions since all industries are not listed.

The estimated DSM potentials for each division are presented in Table 3. Each of investigated industries in this report belongs to one of these divisions with same SNI code[2]. Estimations are based on the assumption that industries within same division have the similar characteristics. To avoid significant error, large parts of industries for each branch are not accounted for the estimation i.e. divisions with same SNI codes are only a small part of the branches (Third column in (%) Table 3). These divisions stand for approximately 15 % of total electricity consumption in Swedish industry. Total estimated shedding potential for those four divisions together is 285 MW and the estimated value for shifting is 205 MW. Roughly the DSM potential for whole Swedish industry can be estimated to be in the range of 0.5-2 GW.

Table 3: Estimated DSM potential for case study division of Swedish industries.

Division of industry based on SNI code	Associated branch	Share of electricity consumption of the division within the branch (%)	Estimated Shifting potential (MW)	Estimated Shedding potential (MW)
Chemical plants	Chemical industry	20	-	30
Steel production	Steel and Metal	22	122	106
Pulp & Paper (Semi-Chemical)	Pulp & Paper	11	12	10
Pulp & Paper (Mechanical)	Pulp & Paper	11	71	139

[1] Division means the aggregated industries with the same production type.
[2] SNI (Svensk Näringsgrensindelning): "*Swedish Standard Industrial Classification is based on EU: s recommended standard. It is primary an activity classification. Production units as companies and local units are classified after the activity which is carried out*". (SCB; Statistics Sweden, 2007)

7 Discussion

The analyses of the case studies of Swedish industry indicate that there exists a potential for implementing load shifting and load shedding in industry. This potential can be used either in purpose of decrease cost of electricity or to help the electricity system to balance supply and demand during peak periods. However, only 7 % (5 industries) of total electricity consumption of Swedish industry is covered by this study. That said there is a large share of industries that still may be objects of future investigation. The results show that there is a large capacity of flexibility in power demanding processes. Roughly the DSM potential for whole Swedish industry can be estimated to be in the range of 0.5-2 GW. This can be compared with the analysis made of Moritz & Borggrefe (2011) there report identifies a process based DSM potential of 2660 MW in German industry that can be used as balancing power. This potential is based on a number of industrial branches, including mechanical pulp production, aluminium production (electrolysis), Steel (electric arc furnace) and cement mills.

Although industries are classed within the same category of production these industries are rather heterogeneous. Generally the main factors that make industries heterogenic concerning implementation of DSM are as follows:

- Production pattern
- Size of power
- Duration of operation
- Flexibility of sub-processes
- Interconnection between sub-processes
- Production demand related to productivity of company
- Additional cost related to DSM implementation
- Ratio of electricity price in production value

The variation of the listed factors creates a complexity of estimating the net savings of DSM implementation. Some industries are running continuously for long period during the year, while other industries have more of a periodic appearance in pattern. With difference demand of power in similar processes the characteristics can be completely diverse e.g. for the use in arc furnaces. This is because of variations of technical appliances used for specific processes. In relation to demand, the operation time will differ from case to case, which is especially of interest for batch processes. Furthermore, flexibility of the processes is crucial when implementing DSM measures. Flexibility is limited by constraints as ramp up/down time, min up/down time and max up/down time which varies a lot among industries. The complexity of estimating net savings of DSM implementations is additionally increased due to different types of interconnections between processes. Strong connectivity between processes makes DSM more costly and complicated. The influence of a load shifting technique on an energy intensive industry is demonstrated in the study of Ashok and Banerjee (2000). It is here mentioned that inter-locked processes and storage capacity are important constraints for load shifting. By inter-locked processes means that one load can be strictly connected to another load and both loads must therefore be shifted together in order to maintain functionality. (Ashok and Banerjee; 2000)

In comparison with the work of Moritz and Borggrefe, they also conclude that it is the large-scale and energy-intensive processes based on a single source of demand that has the highest potential of DSM in the industrial sector. Energy intensive industries bundling of small sources of industrial demand makes it difficult to apply DSM due to individual characteristics of underlying processes, according to Moritz and Borggrefe (2011).

Demand of products differs between industries and type of produced unit. From an economical point of view, production has to follow demand of goods in order to keep productivity at the desired level; demand of goods also varies over time and global economic situation. A final factor which makes industries heterogenic is additional costs related to DSM measures. Appropriate choice of technical appliances differs depending on process and objective of DSM measure. Any alternative fuel cost as a DSM measure is considered and investment costs of new equipment and other variable cost are important for each separate case. Additional costs related to factors like labour, transportation, raw material etc. varies between industries depending on size, activity and pattern. For certain products electricity is a large share of total production cost. In general, with a larger share of electricity cost there will be a larger potential for making regulation according to electricity prices.

All together, these factors will have to be considered and will affect future DSM development and implementation in industry. In the future, it is likely that the possibilities of DSM will increase due to more frequently fluctuations of electricity prices (see Figure 3), since more fluctuations will raise the incentives for DSM. With today’s prices of electricity there is a need for additional economical compensation programs for industry to respond to a deficit on the supply side. For those industries with flexible processes e.g. electrolysis, grinding mills and electric boilers, there will be a larger incentive to regulate only based on electricity prices in the future. The cost of regulation of loads e.g. arc furnace and semi-chemical based pulp, is often too high to make such change only depending on electricity price, both currently and probably also in the future. With more research within the field of DSM, techniques will develop making measures cheaper and easier to implement.

The report of Strbac is describing, that it is only beneficial to implement DSM in an inflexible power production system; it is harder to make DSM competitive in an already flexible production system. (Strbac; 1985)

Depending on the characteristics of the loads considering ramp up and down time some of the loads could suit as a negative reserve capacity. Loads can be categorized as primary, second or tertiary reserve depending on down regulation time. Utilization of these potentials of reserve capacity calls for a need of a program to organize these loads. There is already a reserve capacity program in Sweden called ”Effektreserven”, but there is still unutilized capacity within industry. An expansion of reduction capacity reserve would increase the power of influence for the ”Effektreserven” in Swedish electricity market.

If there would be a free market of demand side bidding (DSB) the competition would be quite uneven between branches. Characteristics of processes and factors discussed earlier will impact the price of bidding for different industries. An arc furnace cannot compete with a wood room or electrolysis in terms regulation cost. If the situation would call for a regulation of arc furnace it will be to a high price for the regulating market. This price is in fact much higher than the actual marginal price of present regulating market (natural gas). Therefore it’s reasonable to assume that mechanical pulp and electrolysis based industries are the first industries to join this type of market. For example, the result of Moritz and Paulus shows that the only significant load shifting takes place in wood pulp production and has a low opportunity cost due to its high flexibility of catching up loads. Electric arc furnaces are described as only interesting for load shedding, but with high costs. (Moritz and Borggref, 2011)

Today the demand of product controls the production level for pulp and paper, which excludes a focus on the electricity price. A future scenario could create a case where it would be beneficial to move present production pattern towards a production with an over capacity. Storage together with an over capacity would make loads more flexible and more subject for DSM. A large investment cost is probably needed but opportunity of cost saving could make it beneficial in a long term perspective. For pulp and paper, which generates large amount of steam, there could be beneficial to invest in a low pressure steam turbine when DSM incentives are high enough. That kind of change would make the load shape more flexible, thus the company can switch between steam and electricity generation as a response to market price.

In case of shutting down the loads of electric boilers, generation is replaced by oil-fired boilers. This could be a short term solution to reduce the peak in the electricity system with quick notice. However, this replacement is not sustainable since the site boilers are fired by oil where the largest part of electricity generation in Sweden comes from hydro and nuclear.

8 Conclusion

- Swedish industries are heterogeneous regarding production characteristics. Similar processes behave very different even within the same category and branch. Based on the performed case studies and the results obtained it can be concluded that for each specific process there has to be a separate investigation. Therefore it is complex to carry out the accurate amount of DSM potential only based on similar cases. While an estimation of DSM potential can be drawn from the result for similar cases. Estimation for large scale potential is rather rough, but it can indicate areas of interest among Swedish industry.

- There is an estimated potential of DSM in the range of 250 MW for investigated industries in this report. Those five industries stand for 7 % of the total electricity consumption of Swedish industry. That indicates a large potential of DSM capacity since the power demand are between 5 and 8 GW for whole Swedish industry DSM implementation in industries could be beneficial in terms of reducing the peaks and the costs, both in industry and system level.
-
- The largest DSM potential is found within the Mechanical pulp and paper industry. These mills are large in power, and have inert loads but can often be regulated at some extent. Cost of regulation depends much on possibility of over production and storage of pulp.

- Semi-chemical pulp and paper often consists of large power consuming processes, but these loads are to large extent interconnected which makes the potential of DSM limited. The loads that are flexible and suitable for DSM are rather small in power.

- Chemical industries are found to be relatively small in power within the processes that are flexible. However, the flexible loads are easy to regulate and can be of interest for shedding or shifting with no high additional cost of regulation.

- Steel and metal industries based on melting of metal scrap, have processes with large power loads e.g. arc furnaces. The regulation of these loads is limited and there exist an inter-connection with several of the remaining processes. Although with the right approach, concerning limitation and constraints as well as planning the production, DSM would be possible to implement. Arc furnaces can have different characteristics and limitations depending on size and production type, making the approach of DSM changeable between furnaces. Possibilities are not only locked to arc furnace but can be of other sources as well, this has to be separately investigated for each industry.

- There is a need of economical compensation program for making DSM competitive; the incentive of today's fluctuating electricity prices is not enough for DSM to be fully integrated. The cost of electricity for production is too low compared to other factors and has a small impact when evaluating productivity for most companies. Shedding of load in absence of other incentives will not be beneficial with exception of extreme cases of price peaks and for certain industries. Load shifting has greater potential to develop as a voluntary measure based on the incentive of fluctuating electricity prices. Load shifting has to be done considering constraints and limitations and should be carefully planned for.

- There are several factors to keep in mind when analysing the potential of implementing DSM in an industry. This report can be seen as a framework for future working on DSM but it has to be further developed.

- Cost of DSM implementation is complex to calculate, thus depending on many other factors. Conclusions and calculations should be made with carefulness considering any assumption that has been made during the way. Shedding differs from shifting as well from other DSM approaches. Results show that there are large electricity costs for certain industries and processes that can be avoided with DSM. Opportunity costs and other additional costs are not considered to full extent.

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Appendix

Application of method (Step 1 to 4)

Case study 2- Steel and metal industry A

Step 1

Load duration curve (Figure 11) for total industry is sloping, indicating that load varies during hours over the year.

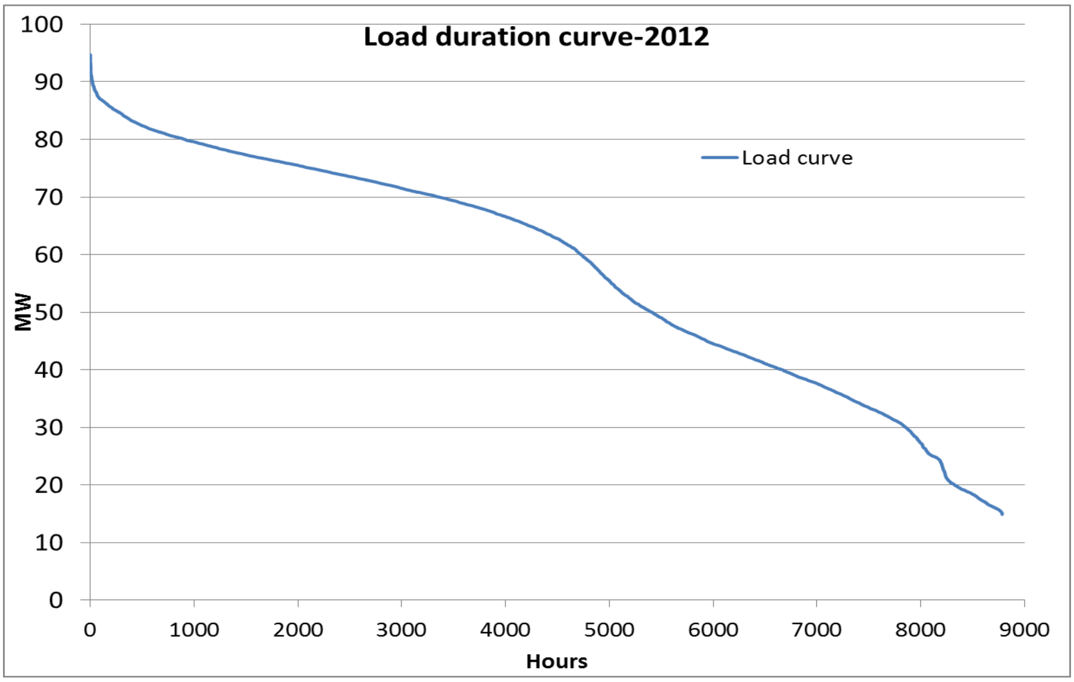

Figure 11: Load duration curve total consumption

Step 2

Load duration curves for sub processes of the industry can be seen in Figure 12 with the largest consumers of electricity as the arc furnace and the oven 6105. The arc furnace looks like it varies in load with a drop of consumption in approximately 550 hours of the month, where it is shut down for the remaining time. There are six ovens working in other parts of process named 3552, 3553, 3557, 3573, 6006, and 6105.

The moulding ovens of 3552, 3553 and 3554 have peaks of consumption for about 48 hours during a month but has considerable less power than arc furnace and oven 6105. Oven 6006 and 6105 have flat load curves and seems to run with a continuously level during the year.

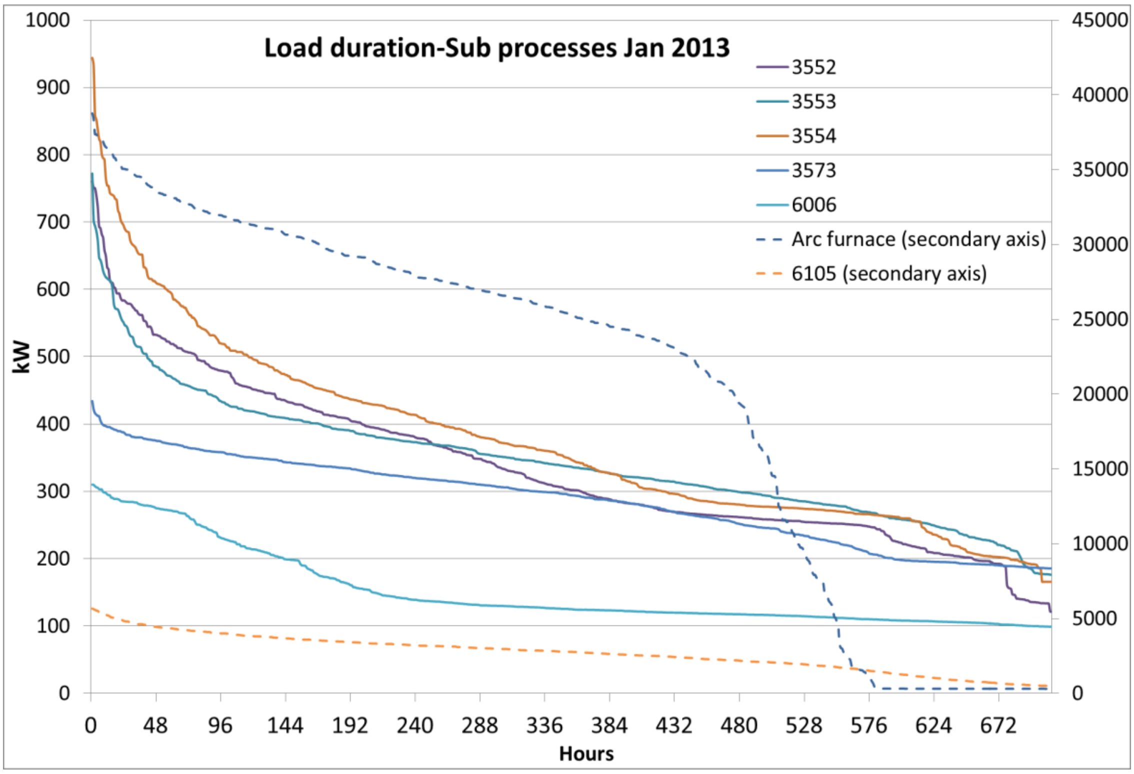

Figure 12: Load duration of sub-processes

Step 3

For furnace 6006 and 6105 the actual production is close to maximum production, arc furnace does not work for full load all the time but is varying over time. Furnaces 3552, 3553, 3554, 3573 do have peaks of consumption for certain hours of duration and will not be in the category close to its maximum production.

Step 4

Arc furnace and unit 3552, 3553, 3554, and 3573 are batch processes and works with high load and low loads varying over time. Oven 6006 and 6105 have flat load curves and are considered continuously processes.

Case study 3- Steel and metal industry (industry 3)

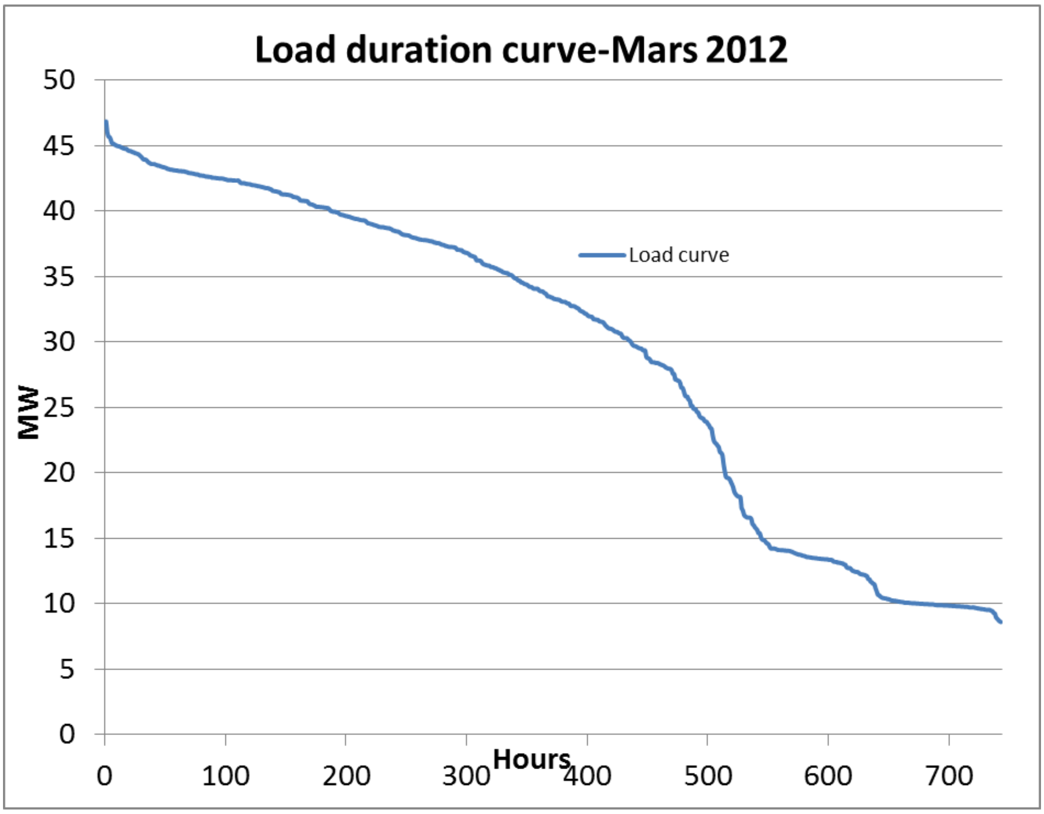

Figure 13: Total Load duration curve-Mars

Step 1

The total load duration curve for Mars is not typically flat and indicates of processes that are of the batch characteristics.

Step 2

A division of the total load curve into sub-processes gives an overview for the different characteristics of the production processes. The arc furnace is more of a batch process where the furnaces at Moulding are running continuously. Then there is a sub process named “Mediasystem” that contains control system and electrical devices. Mediasystem is also running continuously with exception for a few hours.

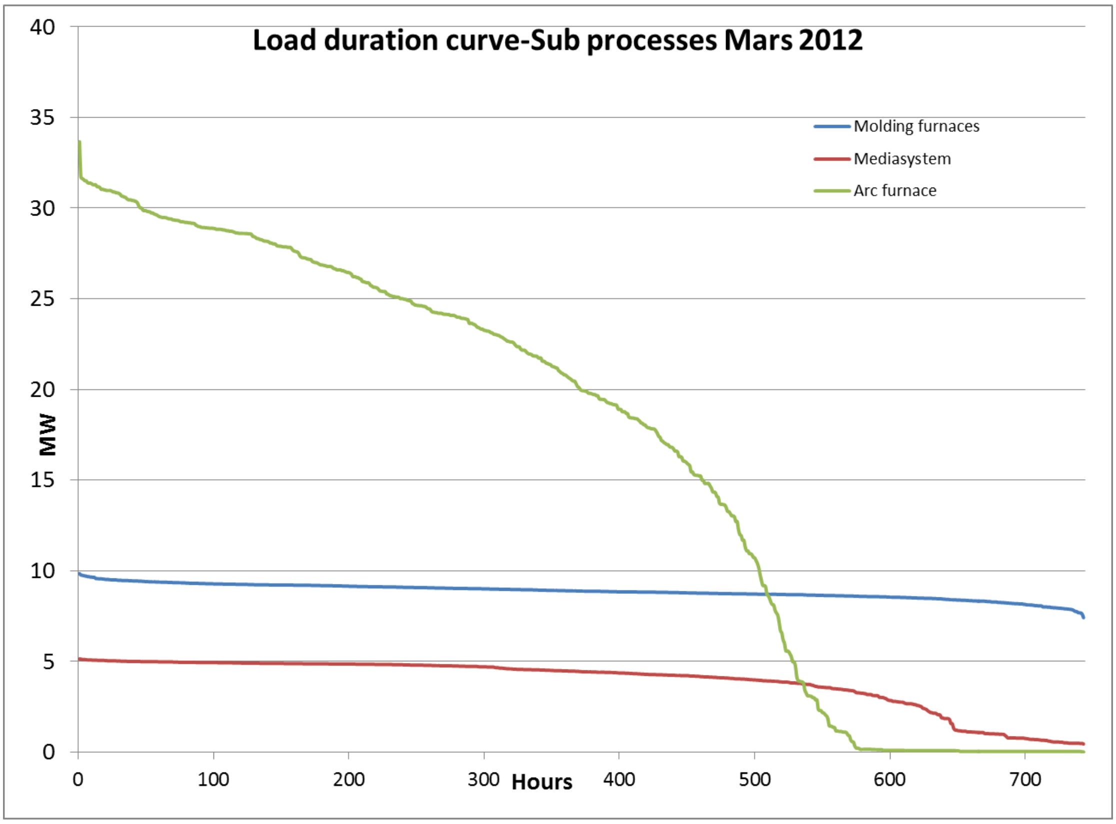

Figure 14: Load duration curve sub-processes for Mars.

Step 3

Furnaces of moulding are working at its full capacity close its maximum possible production capacity. Also mediasystem is close to reach its max, this is not of typical load that are investigated in this report and of small power and therefore not considered for DSM. Arc furnace is the largest process in use of power and it is not working at full capacity during all of the hours, actual production is less than maximum production.

Step 4

The arc furnace is categorized as a batch process and furnaces of moulding is categorized as continuously processes. Mediasystem is probably locked and considered as a critical load and should not be interfered; this has to be considered in further analysis.

Case study 4- Pulp and paper industry A; semi chemical

Step 1

The consumption of electricity is kept on a continuously level for most of the hours during a year. The drop in the end of the year depends on maintenance hours of the machines. This shows that most of processes in the production are of the characteristics of continuously processes. Because own production of steam is related to demand of electricity the shape of the curve of generation from intern turbine looks similar as the demand curve. The study is based on data for 2012.

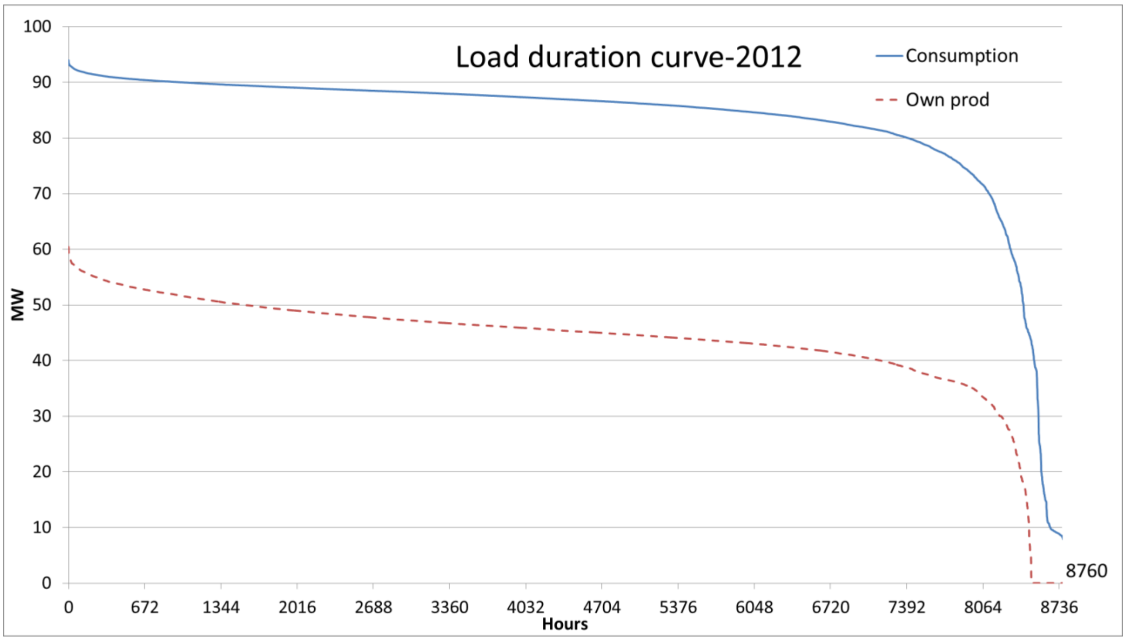

Figure 15: Load duration curve of pulp and paper industry 2012.

Step 2

It can be seen from Figure 16 that the only process that doesn't run continuously for full hours of the year is the Market pulp production. This data is calculated and is not based on actual data on hourly basis. The duration and running hours are based on discussion with staff on site giving information about total consumption and maximum power output. Running time of all processes except for Market pulp production is given as maximum time disregarding maintenance. Running time (τ) of Market pulp production is calculated:

Max power = 3.3 MW
Total consumption = 20 000 MWh

$$\tau = \frac{20000\ MWh}{3.3\ MW} = 6061\ h$$

The Market pulp production is used as a regulator for wood chips production contra paper machines. There is an overcapacity of pulp production, when there is more pulp than capacity of making paper the dryer is used for the overproduction thus connected with the pulp production. This means that the Market pulp production is locked to the criteria of having a buffer of pulp. When there is a buffer of pulp in the production the dryer is turned on and run as long as there is an extra amount of pulp. The start up and down of this dryer is really quick (less than 1 hour) but when it is started up it has to be operated as long as there are pulp available. This is because the pulp production needs to operate at full capacity at all times and kept on a regular level, it will be very expensive to shut down pulp production. Paper machines are more easily regulated. In certain occasion "paper lines" are shut down to match the pulp production.

Wood room, the start and stop time is less than an hour and can easily be regulated. There are storage capacities and there are no certain constraints more than there should not be a deficit of processed wood chips.

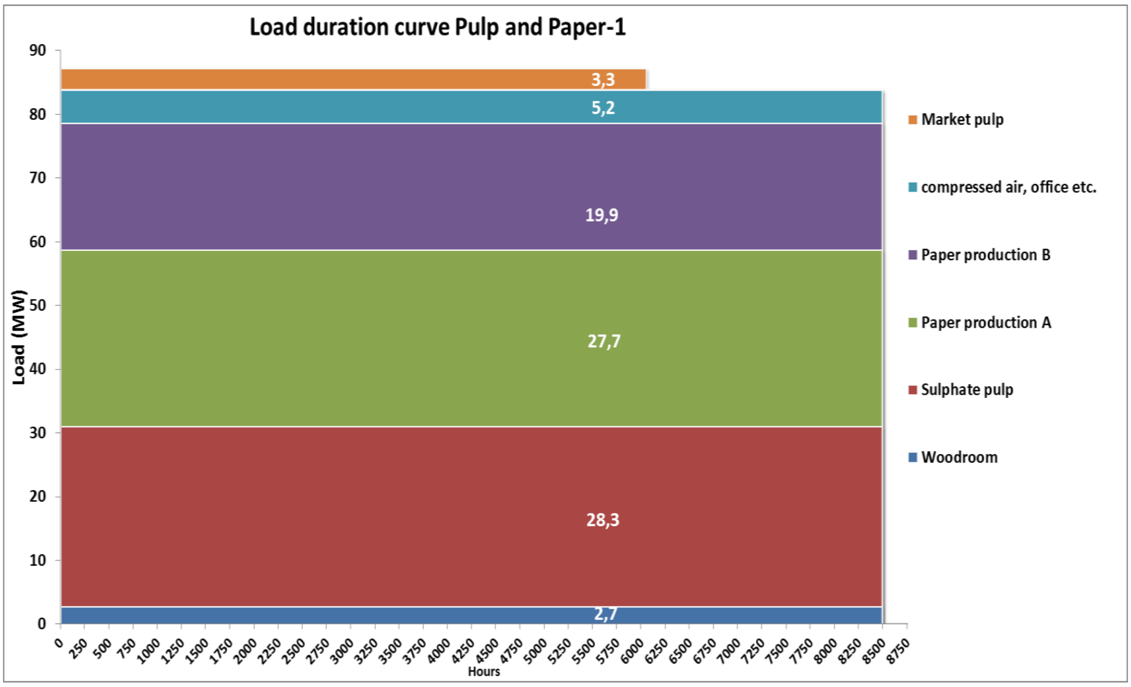

Figure 16: Load duration divided by processes semi-chemical pulp and paper (case study 4).

Step 3: Actual production in relation to max production

Sulphate pulp process is the process that is most important to keep on a continuously production. Paper production A, paper production B, wood room and compressed air are also operated at maximum hours but are not as critical in terms of retaining operation. These processes are although connected with each other which make it complex in DSM point of view. Wood room are connected to the other processes but are more flexible because of storage capacities an easier start and stop functions. Every process except the Market pulp production is operated on its maximum production, disregarding the maintenance stop. The Market pulp production runs for about 6000 hours during a year but are locked to the hours where it is a surplus of pulp within the production.

Step 4: state of process

Paper production A, paper production B, wood room, sulphate pulp process and compressed air are all of the characteristics of continuously processes. Sulphate pulp process needs to be run for all of the hours, because of the complexity and cost of start and stop this process. The objective for the Market pulp production is to make it possible for the pulp process to run for every hour, thus Market pulp production is connected to the pulp process. Because the pulp needs to be operated at all times the paper machines also need to operate as long as the pulp is running, to not cause bottlenecks in the system. The Market pulp production can be categorized as a batch process but is locked for certain hours of operation. The rest of processes are continuously and connected to each other and locked for full operation time except the wood room. The wood room are a continuously process but it is flexible in terms of start up/down and the fact that it's not that critical of being interconnected to rest of the production. The wood room are however the smallest process in power consumption, but can be of options of shedding. The Market pulp production is also small in power but could be considered as a load shifting alternative, with this has to be taken into account the connection with the pulp production surplus. Following the method Paper production A, paper production B, sulphate pulp process and compressed air goes to the step of efficiency measures. Market pulp production goes the load shifting evaluation and wood room goes to shedding analysis.

Case study 5- Pulp and paper B; mechanical

Step 1

From the load curve (Figure 17) it can be seen that the consumption is continuously and the production is constant during most of the hours. The internal generation of electricity follows the same pattern.

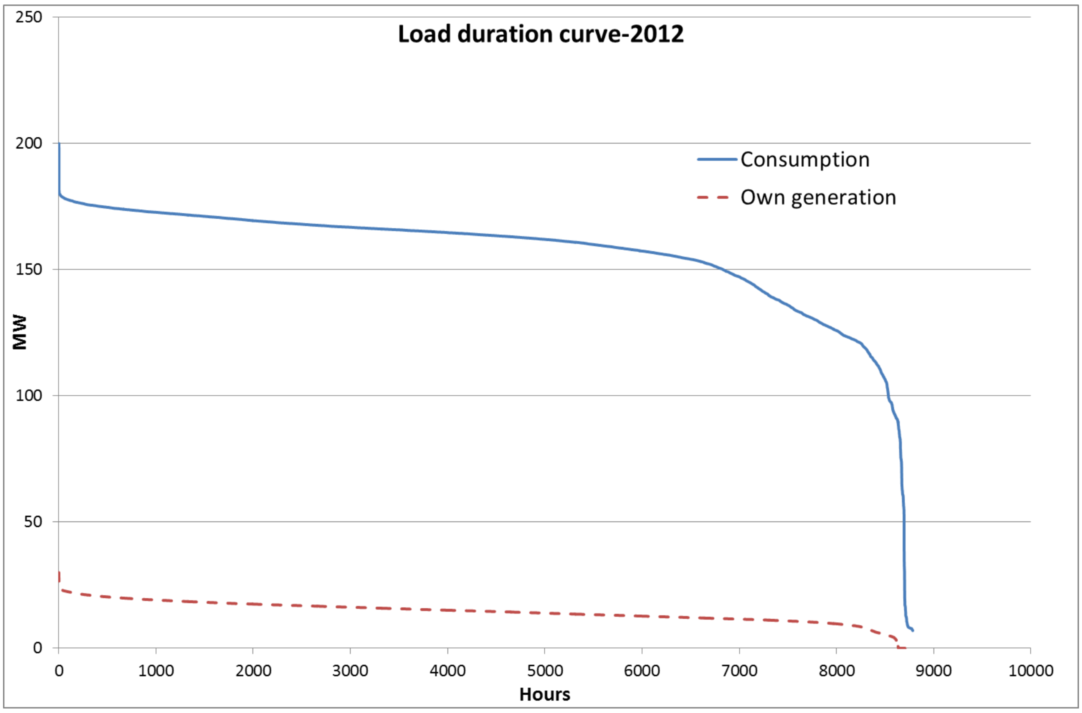

Figure 17: Total Load duration curve 2012

Step 2

From dividing the total load curve into sub processes (Figure 18) it can be seen that most of processes are operating at a consistent high level during most of the hours. The only process that varies significant is the grinding mill; the rest of the processes have really flat curves. Paper machines (PM1-PM4) is stopped for maintenance every 6th week, that's why there is a drop in the load curve the last hours of the year. Refiners (RP) where the wood chips are threated to pulp are stopped ones a month for maintenance. The largest processes in terms of power are thermo-mechanical pulp (TMP) and the grinding mill; both are handling the manufacturing of wood chips into pulp. Energy and environment is assumed to be handling ventilation, lighting and control system and has a flat curve, which is a result of importance of keeping function of those systems.

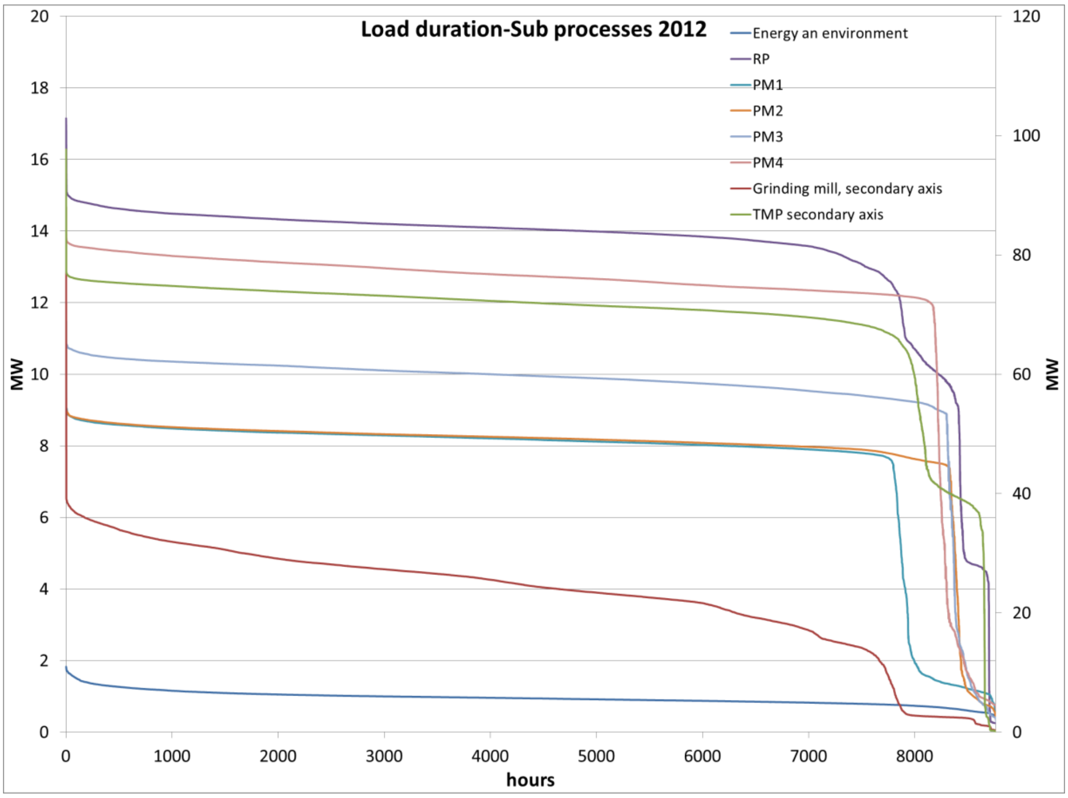

Figure 18: Load duration sub-processes 2012

Step 3

PM1-PM4, energy and environment and RP are at its maximum production output disregarding maintenance stop for a number of hours. Grinding mill does vary over time and has been a process for regulation in power within the company. Grinding mill does not work at full power for all the hours of the year. TMP is operating at a high level for most hours of the year but can be down regulated for 24 for hours if necessary and the production of pulp is enough.

Step 4

Grinding mill is categorized as a batch process and is further analysed with shape of load cycle. TMP is categorized as a continuously process with flexibility of regulation. Both processes are connected to the other processes and this has to be taken into account as one of the restrictions to keep in mind.

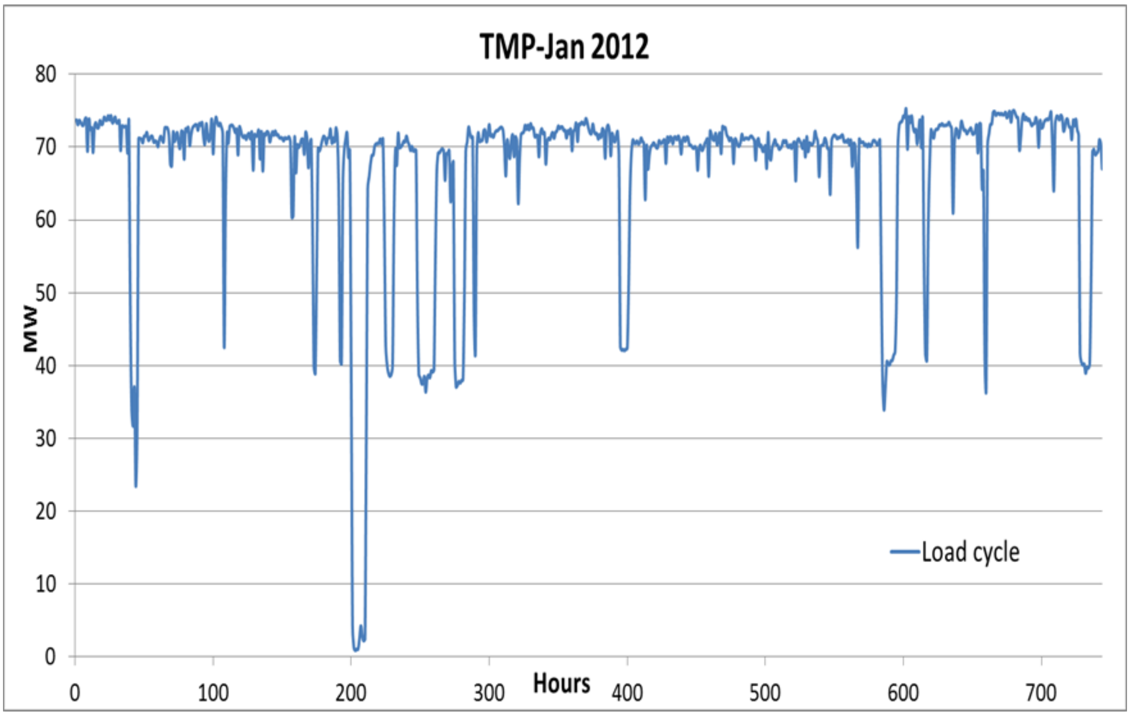

Figure 19: Shape of load cycle TMP 2012.

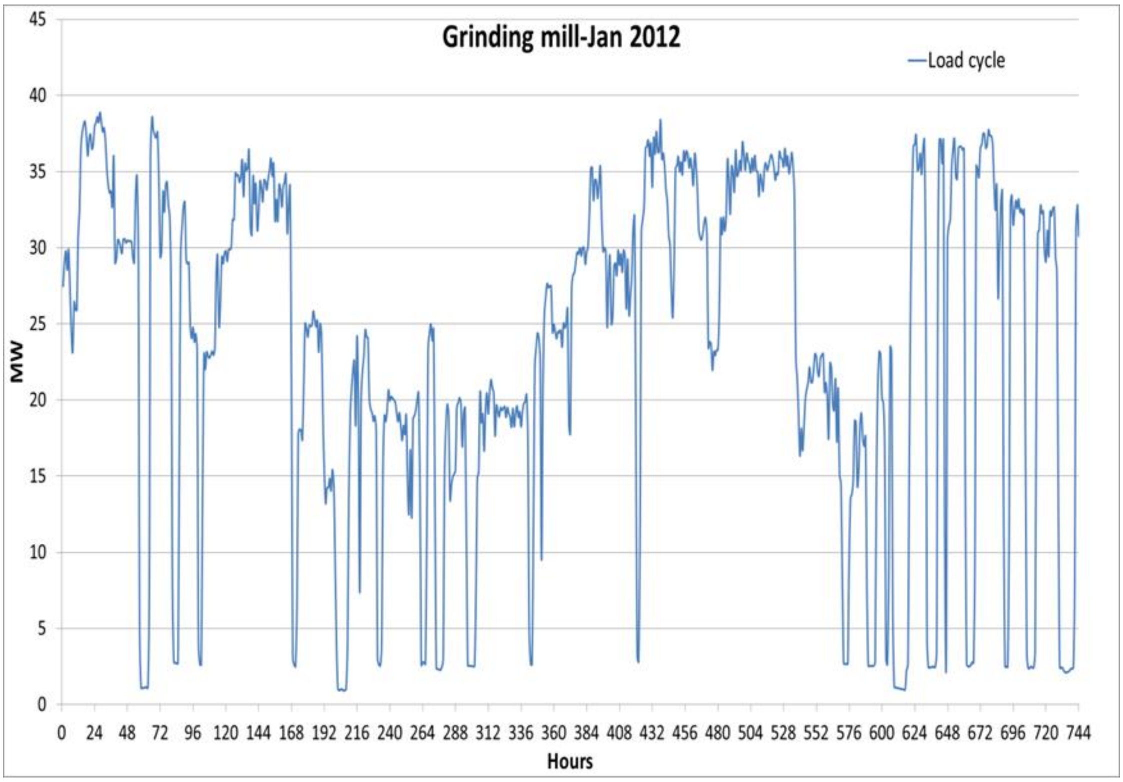

Figure 20: Shape of load cycle Grinding mill Jan 2012.

Example of electricity demand curve for Swedish industry

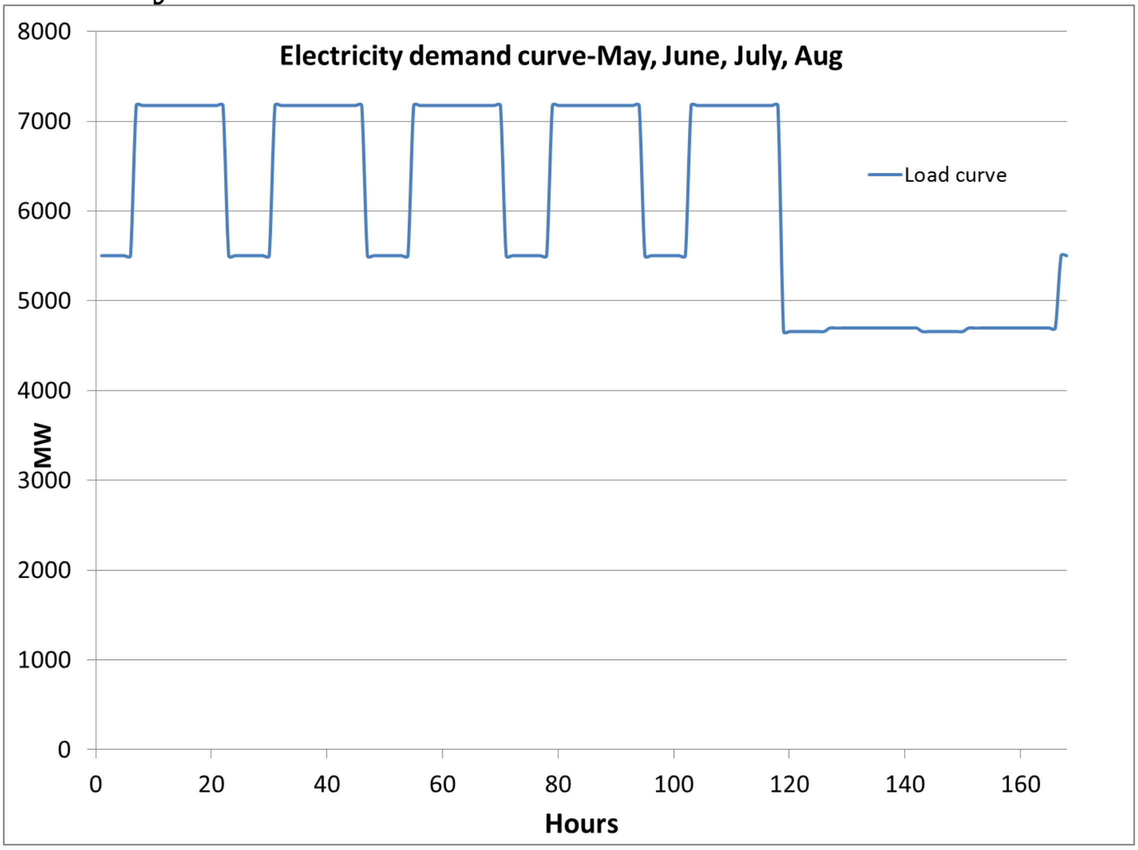

Figure 21: Electricity demand within Swedish industry May, June, July and Aug.

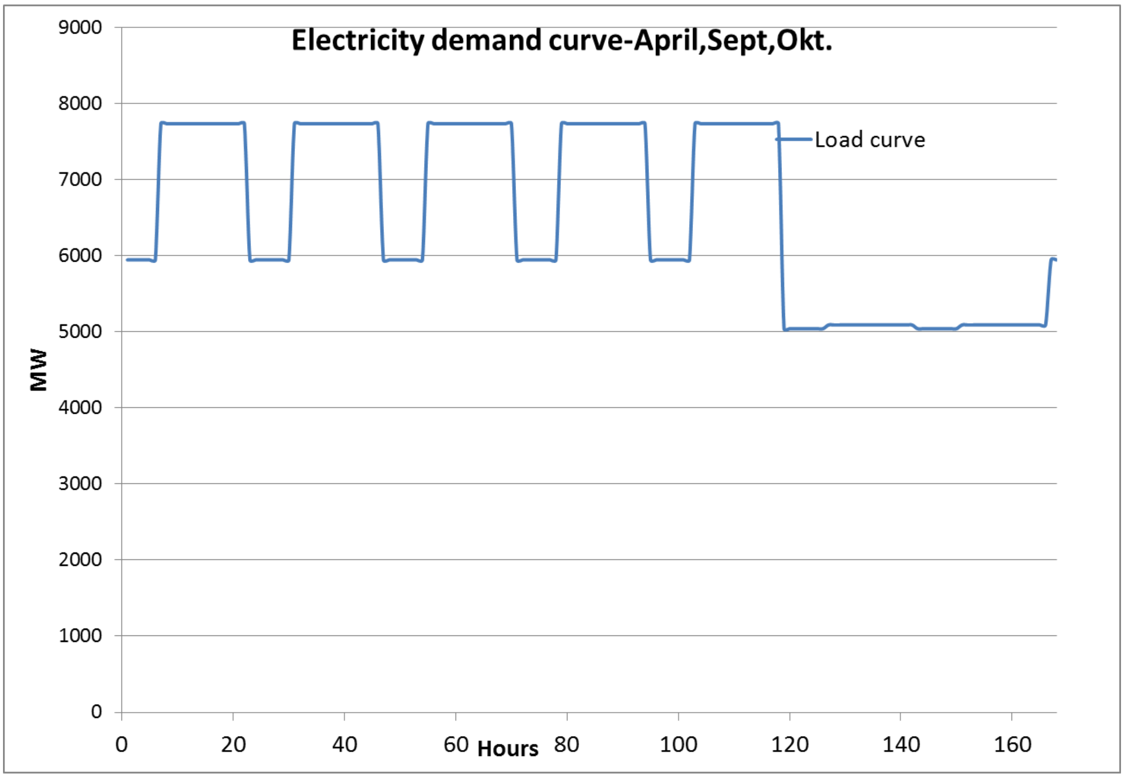

Figure 22: Electricity demand within Swedish industry April, Sept, and Oct.