Application Note
Load Management of Industrial Systems

Tom Capiau (Agidens), Laurenz Van Daele (PowerPulse)

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Content provider(s)	Laurenz Van Daele (Power Pulse)
Author(s):	Tom Cappiau (Agidens)
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CONTENTS

SUMMARY

Load Management (LM) is the practice of actively adjusting—reducing or increasing—the consumption of electricity compared to what was originally planned.

Companies with very stable and predictable consumption profiles represent less risk and less costs to the electricity supply chain. On the other hand, companies with very unpredictable consumption profiles and large peaks in demand require a higher and costlier level of flexibility from the electricity provider. This Application Note will explain the various methods and cost structures that have been developed throughout the electricity supply chain to pass on these costs to the customer.

If a company wants to reduce its energy costs, its primary focus should be on reducing energy consumption. However, in many cases, companies can also realize significant savings by optimizing both

1. Their energy consumption profile
2. Their energy contract and purchasing strategy

It all starts at the engineering phase: operational energy efficiency can be increased by properly dimensioning installations and components. At the same time, the costs associated with an over-dimensioned grid connection can be avoided by accurately forecasting the simultaneity of electrical loads. The combined effect is a lower overall energy commodity cost and a reduction in the capacity component on the invoice.

A company can gain a better understanding of its consumption profile through energy monitoring. Once this valuable insight is in hand, it can identify both problems and opportunities in terms of time-flexible consumption. Among other things, this Application Note will discuss various ways of adjusting consumption. A company can optimize its purchasing strategy, especially for year-round, seasonal or monthly base load demand. In addition, it can flatten its consumption profile through (automated) peak shaving, thus further reducing various tariffs and peak load penalties. Such evaluations often also lead to optimized production planning. Practical examples of Load Management will be discussed in this Application Note.

Another advantage of Load Management is the ability to increase the benefits of local (renewable) electricity generation through optimized self-consumption. This helps avoid costs (or lack of savings) for injecting overproduction onto the grid.

Finally, Load Management may enable a company to valorize its flexibility of consumption on the energy market, either directly on spot or imbalance markets or through aggregated demand response.

In any case, this Application Note will clarify how Load Management is the key to reducing the cost of electricity and ensuring the necessary level of security of supply to every company.

INTRODUCTION TO LOAD MANAGEMENT

WHAT IS LOAD MANAGEMENT?

Load Management (LM) is the practice of actively adjusting—reducing or increasing—the consumption of electricity compared to how one would have operated in the complete absence of constraints. Such total freedom assumes a continuous and unlimited capacity of supply, without any price repercussions. In reality, of course, such freedom does not exist and constraints apply simultaneously to each of these parameters. As a result, choices must be made regarding load capacity, volume of consumption, time of use and unit cost. These choices must consider among others, capacity of connection, contractual peak load, contracted volume, and consumption as a function of time-of-use pricing. It will require conscious actions to manage the load at all times, hence the nomenclature of Load Management (or initialism LM).

Through LM, a company can flatten its consumption profile through peak reduction which in turn can lead to lower unit prices in the energy contract. By shifting consumption in order to keep demand below the contractual peak load (peak management), companies can avoid peak demand penalties. In addition, by avoiding, delaying or advancing planned consumption (for example, temporarily shifting utilization time) the consumer can provide the supply side a valuable—and often cheaper—alternative to increasing or decreasing electricity production to counter grid imbalance. Depending on the type of contract, such a consumption shift can also enable the consumer to benefit from lower energy prices at a later point in time. As an example within an industrial context, a cold storage warehouse is an installation with a significant temperature buffer, providing flexibility to delay electricity consumption for as long as the temperature does not surpass a certain threshold.

While this Application Note will discuss the relevance of LM in the entire electricity supply chain, i.e. from electricity production to end-user consumption, the focus will be on the value for and application at the end consumer. In this instance, LM may also be referred to as Demand Side Management (DSM).

WHY LOAD MANAGEMENT?

Most companies regard the need for LM or DSM as nothing more than an internal constraint, intended to safeguard the electricity supply at the demand side. The load on-site cannot exceed the capacity of the connection to the external distribution grid or the capacity of the internal transformers and the local distribution grid. The built-in power management system will warn the user when the power consumption approaches the maximum power capacity and will interlock switching on new consumers to avoid an uncontrolled shut down of the main circuit breaker. The goal of LM is to avoid overload and the consequential shutdown of the complete installation. This would indeed be the main purpose of LM or DSM, assuming there were no constraints at the supply side. However this is, of course, never the case.

The term Demand Side Management (DSM) was originally coined following the energy crises of the 1970s, with the first programs having been legislated in California and Wisconsin, USA, as early as 1975.[1] This period was prior to the deregulation and liberalization of the markets. The electricity supply chain at that time was a fairly simple, unidirectional model with a limited number of (semi-)monopolist players such as electricity producers, transmission system operators (TSOs) and distribution system operators (DSOs). Indeed, in some situations, a single company was responsible for all three activities. The market usually covered limited geographical areas with fairly predictable pools of residential, industrial and tertiary consumers. Electricity was produced in power plants using various conventional techniques based mostly on fossil and nuclear fuels. Coal, biomass and nuclear power plants provided base load power, while more flexible, faster-reacting gas-fired plants provided peak load power. Maintaining net balance was simply a matter of increasing production to match fairly predictable increasing demand. DSM was mostly meant to respond to a limited number of annual peaks, often climate related. In those days, peak demand was reasonably easy to predict, and utilities would call their customers one or several days ahead to request the shifting or shedding of a certain load for a certain time period. At the same time, end consumers could actively react to day-ahead price signals by selling back contracted loads.

Today, many markets have been deregulated and feature a multitude of players across the different supply chain elements. In addition, the geographical area of the grid has expanded significantly through interconnection across multiple countries and even across the seas. A problem in one country may very well spread far beyond that country's borders, as evidenced by the 2006 European blackout[2] which originated in Germany, but affected more than 15 million people across Europe.

At the same time, there has been an unprecedented increase in decentralized electricity production from various on-site production technologies such as combined heating and power plants (CHP), solar PV and wind-turbines. Growing awareness regarding global warming has spurred incentive schemes for renewable energy across the globe. In the period 2004-2014[3], global production capacity for wind power rose from 48 to 318 GW and from 2.6 to 139 GW for solar photovoltaic (PV). According to Bloomberg New Energy Finance (BNEF), renewables (143 GW) overtook fossil fuels (141 GW) for the first time in 2013 in terms of newly added global electricity production capacity[4].

While this is all good news for the environment and the renewable energy revolution created thousands of jobs, it also represents a huge challenge for the current electricity grid and its stakeholders. Renewable sources such as wind and solar are only available intermittently and cannot be turned on or off at will. Sudden heavy cloud cover on an otherwise sunny day can have immediate impact on the solar PV production on thousands of installations.

While Renewable Energy Sources have resulted in a decreased demand for power from conventional power plants, there has nevertheless been an increased need for fast-reacting, flexible production. Unfortunately, this represents a serious conundrum: the most flexible power production plants are gas-fired, but these tend to be much more expensive to run than coal-fired or nuclear plants. In recent years, many gas-fired plants were shut down, or at least mothballed, because they could no longer be operated profitably. As a result, balancing the grid has not only become much more difficult, but also much more expensive and risky.

The more unpredictable a consumer's consumption profile, the more risk and costs the supply side must bear to service this customer. In response, the supply side has reacted by transferring these risks and costs to the end consumer through tariff hikes and various levies and penalties as a direct function of the consumer's consumption profile.

This brings us to the supply side arguments for LM at the demand side. Load Management helps decrease grid imbalance risks, and helps reduce costs for peak demand penalties, as well as time-of-use pricing.

While peak demand can still be predicted to some degree, short term variance is now much greater than at any time in the past and much shorter response times are required today. As a result, automated Demand Response (DR) systems have replaced the phone call by the utilities and the manual actions by the consumer.

RISK MANAGEMENT THROUGH PEAK SHAVING

As mentioned earlier, the initial and indeed primary reason on the demand side for peak shaving is to safeguard the on-site electricity supply. Industrial sites invariably have a variety of electricity consuming installations, ranging from the very small to the very large. It is very unlikely that all of these installations or components will ever function at maximum load at the same time. The capacity of the connection to the transmission or distribution grid will therefore be dimensioned as a function of the expected maximum load on-site, rather than the total installed capacity of all consumers. While the traditional methods of sound engineering usually provides for an appropriate margin, a company's growth can require that new, additional installations and equipment be installed onsite and thereby potentially stretch the available connection capacity up to or past its limits.

At this point, the consumer has only two options: limiting consumption through peak shaving or increasing the capacity of supply. Assuming that additional capacity is available—which it must be noted may not always be the case—the decision between which of these two options to select will most likely be based on financial issues.

Reducing consumption through peak shaving may require investments in order to automate consumption monitoring and prioritized shut-down or interlocking of certain installations. In addition, companies must account for the opportunity cost of not having access to the expected amount of electricity. Not being able to produce as planned may lead to a variety of negative issues such as lost sales, penalties for delayed deliveries, unproductive labor costs and loss of product quality. In addition, the risk of black-out remains if anything goes wrong with the peak shaving system. In such an event, the financial repercussions will almost certainly be serious.

On the other hand, increasing the capacity of supply will also require significant investments. Larger connection to the grid, more/bigger power transformers and other necessary additions will usually take many months to implement. Aside from the initial CAPEX investment, such a capacity increase will usually also lead to a recurring OPEX increase for the energy or tariff component of the energy bill. Given the ever-increasing difficulty in balancing the grid, the TSOs and DSOs can be expected to face ever increasing balancing costs. These of course are ultimately passed on to the end consumer, for instance through the capacity tariff.

As a result, companies will need to carefully balance both their short-term and long-term needs for electrical supply capacity. In doing so, they will not only need to look at the direct CAPEX investments, but also at other direct and indirect effects on both costs and revenues related to their decisions.

Financial value of flexibility

When investigating the financial value of flexibility, companies need to consider what flexibility is, and how it can be provided. From the consumer's point of view, flexibility means being able to consume the amount of energy needed, whenever it is needed. At the supply side, it means being able to provide the right amount of energy as it is demanded.

In the traditional, unidirectional electricity supply chain, suppliers used their assets to respond to the demand side's needs. In doing so, the supply side incurred costs, which in turn were passed on to the consumer via invoices to generate a profit at the supply side. The flexibility demanded by the consumer was reflected in its contract with the supplier: the higher the level of flexibility demanded, and the lower the level of risk taken on by the customer, the more expensive the energy contract would become.

As noted earlier, today's electricity supply chain has become much more complex and multi-directional, with decentralized energy production, renewable energy systems (RES) and consumers becoming prosumers. The supply side now employs a multitude of electricity producing technologies in its asset portfolio, each of which has their own cost structures. This, again, has made the quest for balance between supply and demand and between cost and revenue, more complex for both sides.

In recent decades, RES have gained significant footing on both the supply and demand side. While the initial investment in RES tends to be quite high, the operational or variable costs are typically much lower than for non-RES, since no consumable (i.e. fuel) is needed to produce electricity and reduced maintenance is needed for some technologies such as PV solar power. Add-in subsidies, feed-in tariffs and other incentives, such as priority access to the grid, and it becomes clear that RES are favored to produce electricity at maximum capacity throughout the year.

Additional complexity and risk is added to the cost structure in the case of traditional, non-RES. Variable costs depend not only upon production volume or time but also upon price fluctuations for the required fuel. A high gas price at times of low electricity prices may render any production with a gas-fired plant unprofitable, regardless of other cost parameters. Fixed costs such as loans and depreciation are independent of production. If production is lowered, the fixed costs are distributed over a smaller volume of energy produced, rendering those kWh's more expensive. At the same time, increasing production will lower fixed costs/kWh, but may also require the need for additional personnel, higher maintenance costs or even the start-up of yet another production unit, which in turn again increases fixed costs. Obviously it makes no financial sense to build additional production capacity if the expectation is that it will only be needed to cover a few hours of highest peak loads per year. In absence of such an additional unit, the lack of additional production capacity to match demand may lead to significant shortages in supply that could turn into imbalance penalties which are ultimately paid by the consumer causing these imbalances.

The above illustrates why not all electricity-generating assets follow the same business logic. What works for one technology or one supplier may not work for another.

The optimal solution for the electricity provider lies in achieving a balance between flexibility in supply AND flexibility in demand. While a supplier's assets may be perfectly capable of providing the supply-side requested flexibility, it may not be the best solution from the standpoint of cost. The cost for adjusting consumption at the demand side will in many cases be significantly lower. Both sides can benefit from such an adjustment: supply side saves money on adjusting its operations, and the demand side saves money on its power invoice. By taking this approach, flexibility has become a two-way street with major win-win potential.

Peak shaving as a way to manage risk on the demand side was mentioned earlier. Clearly, this is a method which also lends itself perfectly to reducing the need for flexibility from the supplier. By reducing its peak demand, the consumer reduces the potential strain on the producer's assets.

If we take this concept further, the consumer may be able to provide flexibility to the supply side, even at times when it is not generating its own peak loads. By shifting some of its own, less-critical loads, the consumer can provide a very much needed—and therefore valuable—relief to the supplier's production capabilities. If, by doing so, the supplier manages to avoid imbalance penalties, they can use this as an opportunity to strengthen their customer relationships by sharing some of the savings with the consumers that supplied this relief.

Similarly, in times of low demand such as night shifts, weekends, and holidays and high production volumes from renewable energy, suppliers may be faced with overcapacity. It is important to note that renewable energy must often be given priority access to the grid to meet certain regulatory requirements. Likewise technologies such as coal and nuclear do not lend themselves to quick and frequent ramp-up and ramp-down. This fact must be taken fully into account since suppliers may end up in situations where they need to pay to get rid of overproduction. In such situations, it may still be cheaper to pay the demand side to increase consumption (using negative prices), rather than to face higher imbalance charges or significant costs related to unforeseen production shutdown. Take for example German wind power. In recent years, suppliers have on multiple occasions been exporting to neighboring countries at negative prices. An alternative could have been to use this cost to compensate local consumers for temporarily increasing consumption—that is to say—demand turn-up instead. This opposite approach from peak-shaving is called valley filling and was recently implemented by WPD[5].

Industrial Load Management can manage a part of the volatility of demand at the demand side. However, that is only the case if the benefits exceed the costs.

The practical implementation of this approach will be discussed later in this paper, but generally speaking, the concept is as follows: if consumption of an electric load can be shifted in time (both advanced or postponed) without causing detrimental effects on labor costs, quality, delivery times, et cetera, companies can usually afford to shift consumption. In doing so, they can receive compensation that exceeds the costs incurred by shifting consumption.

The concept of LM must represent a win-win situation for all parties involved if it has any chance of succeeding in the long-term. In addition to the financial benefits, LM and flexibility of production may have environmental benefits. This includes avoiding the start-up of additional emissions-generating production plants while at the same time improving efficiency at plants already up and running.

A recent example includes the projected imbalance tariffs in Belgium for the winter of 2015-2016. Due to various issues, several Belgian nuclear power plants were shut down, without any certainty regarding their return to production. As a result, security of supply was in jeopardy for a limited number of hours during which interconnection with other countries would not suffice to fill the production gap and cover demand. Assuming a worst-case scenario of limited supply and extreme demand in case of severe winter conditions, Transmission System Operators (TSO) pro-actively anticipated raising imbalance prices for that winter to €4,500/MWh at times when security of supply would be at risk[6].

Compared to contracted commodity prices of around €40/MWh, it made a lot of sense for suppliers to provide incentives to their customers to reduce consumption during these moments in order to avoid these imbalance penalties. At the same time, large consumers with exposure to the spot and imbalance markets could envision generating significant income by shifting consumption during these moments and selling part of their contracted capacity back to the market. Smaller consumers, whose individual volume of flexibility is not significant enough to have any significant effect upon the grid imbalance , could sell their flexibility to Demand Response (DR) aggregators, who pool together a portfolio of smaller flexible loads into a larger block of flexibility that offers significant value to a supplier or TSO.

INTRODUCTION TO ELECTRICITY TARIFFS

COMPONENTS OF THE ENERGY INVOICE

It is widely acknowledged that the invoice related to industrial electricity consumption is rather complex in most European countries. In most cases the invoice can be divided into three main components. One of the main goals of LM is to have an impact on one or more of these components:

- Commodity (energy related component)
- Grid charges for transmission and distribution
- Taxes and levies

The cost charged on the invoice for each of these components is generally related to the volume of electricity consumed, the characteristics of the connection point, geographical location of the consumption point and the maximum load over a certain period. It should be noted the importance of each of these factors varies widely from country to country.

COMMODITY COMPONENT

In most European countries, the commodity component is the most important element which can be negotiated bilaterally between the consumer and its counterparty. Negotiations tend to focus upon the price and the contractual structure. The commodity component can be a means of valorizing LM, depending upon the contractual structure. However, not all electricity consumers have a contract which allows them to engage in LM in a profitable manner. Some contracts stipulate a fixed price or a price which is calculated based upon the simple average of monthly or yearly hourly spot prices. If the price paid is the same for each hour, there is no incentive to shift consumption levels, and no way for LM to be profitable.

The degree to which a customer has an exposure to the market price can vary, but is aligned in most European countries.

An overview of the LM potential depending on the electricity contract is given in the graph below (Figure. 1):

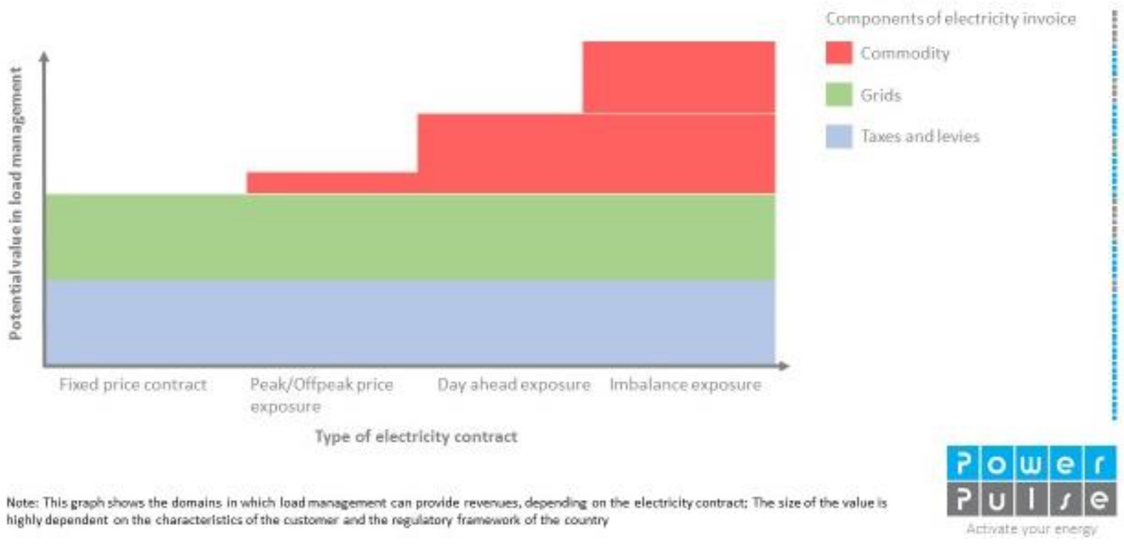


Figure 1 – Load Management potential for different types of electricity contracts.

One possibility of gaining exposure to different market prices lies in having a contract in which consumption during off-peak hours (generally weekend and night time) is charged at a different rate than peak hours. This is the most basic way of enabling LM possibilities, although the potential value of LM coming from this type of contract is generally also the lowest.

Another contract type enabling LM of electricity as a commodity involves exposure to the hourly day-ahead spot price. In this type of contract, consumption levels for each hour are charged at the corresponding price on the power exchange. The calculation for this is carried out automatically by the electricity supplier and requires no extra effort on the part of the consumer. Day-ahead prices exist in the vast majority of EU countries, and prices are published the day before delivery. This means that load changes can be planned several hours in advance.

The final possibility of valorizing LM through the commodity component is by being exposed to the real-time market. In most countries this is the imbalance market. This market is organized differently in each country, but generally involves more volatile prices than the day-ahead market. Because actions need to be taken very quickly, that is within minutes, this market is generally only accessible to a small number of industrial users that implement automated responses to price signals on these real-time markets.

Having a day-ahead price exposure is a prerequisite for this type of contract. Moreover it is also necessary to make daily consumption forecasts to be eligible for access to the real-time market.

The value of load shifting in the commodity component is largely driven by price volatility. Price volatility drives corresponding price differences throughout the different hours of the day, days of the week and/or periods of the year. If price volatility is sufficiently high, customers can create value by adapting load levels to price levels. Price volatility is expected to increase in most European countries in the upcoming years as the penetration of intermittent renewables increases. When evaluating investments in LM capabilities, the greatest difficulty for companies will be to accurately take into account the risks related to this evolution in price volatility.

In some countries it is possible for grid users to also actively participate in the balancing or reserve market. The power consumer is effectively committing to the grid operator to change consumption levels whenever such a signal is sent to the consumer. Reserve products have vastly different characteristics from one country to another. In some countries a variety of reserve products are available to end consumers, with different requirements regarding reaction time, number of maximum activations per period and total accumulated activation time over a specified period.

Clients are remunerated based on the availability of the capacity offered to the grid operator (EUR/MW), potentially complemented by an activation fee (EUR/MWh). The different options are discussed in greater detail in the chapter entitled ***Valorization of flexibility on the energy market*** in this **Application Note**.

GRID COMPONENT

Unlike the commodity component, grid charges are calculated rather differently across European countries. The calculation of grid tariffs is mostly based on two principal components, the power component and the energy component. The chart below shows the extent to which the power component is important in the average transmission tariffs across Europe.

- The power component is generally based on one or more of the following elements: MW peak consumption level over a certain point, size of the connection point or maximum contractual capacity as agreed with the grid operator
- The energy component is directly related to the volumes of MWh that are being consumed.

Note that in North-Western Europe the power component is in general a more important element of the transmission tariff than in the South-Eastern European countries. The current trend within grid tariff structures is to put more emphasis on the power component. This is mainly driven by the increased penetration of renewables that are generated locally, leading into lower levels of net volumes consumed. A power-based methodology generally seems to be more reflective of the costs that grid operators are facing.

As the map in Figure 2, below, shows, there are significant differences in the proportional share of the transmission tariff in the overall energy bill. These differences are mainly based on the regulatory framework within which the TSOs determine their tariffs. While not all differences can be explained analytically, they seem to have developed historically, often in line with the level of liberalization of the market. Many of the darker colored countries represent largely liberalized markets with high levels of market liquidity. In these countries, the market regulators tend to have focused on the power component as it is the most representative cost component.

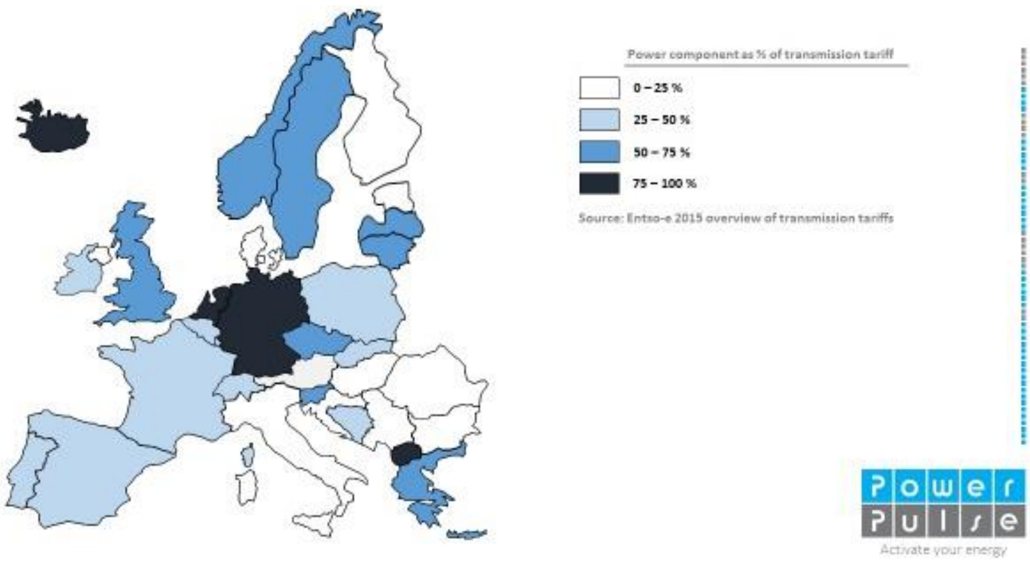


Figure 2 – Importance of power component in transmission tariff.

Power-based methodologies typically encourage LM actions that are related to peak shaving and load shifting, thus enabling consumers to avoid the high fees related to maximum consumption. Moreover they can avoid fees connected to surpassing the contractually maximum connection capacity agreed with by the TSO. If load peaks are particularly well-managed, it is sometimes possible to save costs by lowering the contractual maximum reserved capacity.

Power-based tariff methodologies could have a negative impact on the profitability of certain types of load shifting. If commodity prices encourage additional consumption at a certain time during the day, this could lead in a peak in consumption at that point in time. Peak-monitoring systems can be enabled to overrule LM actions that were made for the purpose of commodity price optimization, thus eliminating the risk of net negative effects of load shifting actions. This illustrates that power-based tariff methodologies can be a potential barrier for load shifting driven by commodity prices.

Other grid tariff designs partly can ameliorate this barrier. This is achieved through the means of time-of-use power-based grid tariffs. In this approach, grid tariffs are lower during times of low grid demand. This can be done through specifying fixed timeframes; for example calculating annual peak loads only in the period of November to March and only between 5pm and 8pm. This disincentives peak consumption during winter evenings and does not punish high peak consumption at other moments throughout the year. Other designs apply a more dynamic principle of seasonally changing definitions of peak periods, which change depending on renewable availability and peak grid demand.

TAXES, LEVIES AND INCENTIVES COMPONENT

The component related to taxes, levies and incentives such as green energy certificates is the most fragmented component throughout Europe. Some countries have been very creative in adding specific taxes within the energy bill. Even on a country level, some provinces or regions can have different taxes than others.

Due to this high cross-border diversity, this paper will not go into detail about LM opportunities within the taxes and levies component.

One case example can serve as an illustration. In Belgium CHP (combined heat and power) units receive certificates that are related to the output of the plant. CHP plants could reduce output levels when electricity prices are very low, and import cheap electricity from the grid while producing steam with backup boilers. The CHP certificates are however, not linked to the power prices valid at the moment of generating electricity. Given that these certificates generate a significant revenue stream, load shifting based on commodity prices is significantly reduced. Europe is now taking measures to ensure no day-ahead market prices are below 0 EUR/MWh. The Netherlands will for instance adopt this methodology for its 2016 SDE+ support mechanism.

INTERFERENCE BETWEEN THE INVOICE COMPONENTS

Depending on the country specific situation, there can be interference between the different components of the electricity bill. If the LM actions that are taken are driven by a single invoice component, the impact on other invoice components should be monitored. The impact of power-based transmission tariffs on LM has been mentioned above. Another concrete example is related to the utilization time of consumers. The graph below shows that in some European countries, transmission costs are determined based on the utilization time of the consumption process. Utilization time calculation is used as a proxy to define how stable a consumption process is, particularly in relation to base load. The calculation is often made by dividing the overall consumption volumes during a year (MWh) by the maximum consumption level (MW). The result is a hypothetical number of hours in which maximum consumption is consumed. The higher this number, the more stable the consumption is considered to be, and the lower transmission costs (EUR/MWh) will be.

The graph below (Figure. 3) illustrates the differences across Europe, with a strong utilization time effect in countries such as Slovak Republic, the UK, Ireland and Germany.

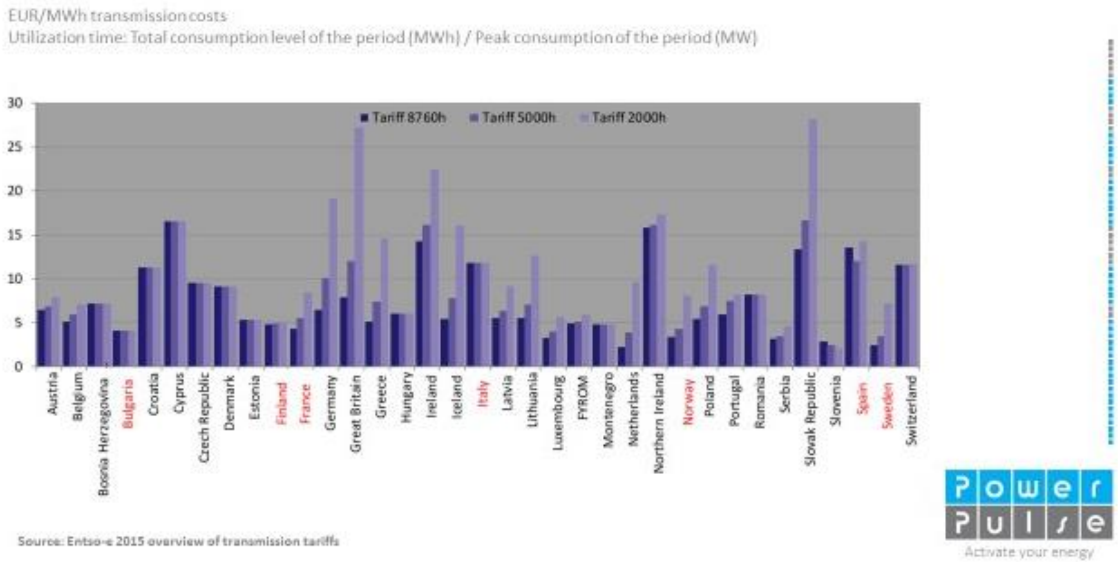


Figure 3 – Differentiation of transmission tariffs.

If LM measures are taken, it could have important implications on the utilization time of the consumption process. At times of low (or even negative) electricity prices, LM practices might favor increasing consumption, for instance by shifting planned consumption in order to take advantage of these low prices. However, doing so may raise the annual maximum consumption level, which in turn will result in lower utilization time for the year. As a result, the temporary savings from consuming low-priced electricity may lead to a higher transmission tariff. A trade-off therefore needs to be made to verify that the cost savings from LM (e.g. conservation mode) are larger than the potential increase in the transmission cost due to the lower utilization time. On a more positive note, peak shaving as a LM measure is aimed to lead to a lower level of peak consumption. This in turn will increase the number of hours in the calculation of utilization time, thus potentially lower transmission costs. Other tradeoffs and mutual reinforcing behavior between invoice components exist in the different European countries.

OPTIMIZING THE LOAD PROFILE

FROM THE ENGINEERING PHASE OF THE PRODUCTION LINE

Most companies have implemented some degree of LM without actually defining it as such. After all, not all electricity consuming equipment is ever run simultaneously at maximum loads. In reality, the installed capacity of all electrical equipment combined is often a multiple of the actually available capacity of the connection to the grid. During the engineering phase, the engineers will calculate the expected loads of a new installation or equipment. While doing so, they will make assumptions regarding time of use, expected load, simultaneity of loads, et cetera. Depending upon their results results, they may opt for a different technology in order to avoid overloading the available capacity on-site, or they may determine that the capacity of the existing connection must be increased. As mentioned earlier, the first goal of LM is to ensure security of supply. If these principles are not followed, and no system is in place to monitor and control the demand on-site, there is a risk that the actually available capacity may be exceeded. In such a case, the overcurrent relay of the main circuit breaker will be triggered, resulting in a site black-out.

Even this elementary form of LM illustrates the need to understand the flow of energy throughout the site. The more that detailed monitoring is available, the less need there is for assumptions and perhaps unnecessary safety margins in calculating and engineering capacity. The more detailed the insight into consumption, the easier it gets to link consumption to activities and processes. In turn, this enables better forecasting of expected consumption as a result of planned activities.

Realistic consumption estimates, based on experience or temporary measurement campaigns, are used instead of the equipment's official nominal load. A basic level of automated LM could involve the use of a PLC to calculate current consumption and available capacity for additional loads. For this calculation, available consumption data can be gathered from automated equipment such as lighting, electrical heat tracing and variable frequency drives on pumps, compressors and fans. In addition to this live data, a safety margin based on calculated values can be included to cover non-automated and non-measured consumers.

One example includes an industrial site whose expansion plans required increasing transformer capacity to 23 MVA. Given that the connection capacity to the grid was limited to just 4.2 MVA, the initial reaction was to request an increase in connection capacity. However, this request was denied by the TSO because no additional connection capacity was available on this particular transmission loop. In addition, the existing connection had never even come close to its limits, and an expansion seemed therefore unnecessary.

In order to safeguard the security of supply, the engineers assigned priority levels to the various activities using automated equipment. A PLC calculates current consumption, using live data from all automated consumers and drives. The calculated consumption is then compared against the total consumption, measured at the main connection to the grid, and against the capacity of that connection. The difference in consumption is indicative of the consumption of the smaller, non-automated installations, and of power losses throughout the on-site power distribution grid. For these smaller, non-automated systems and the overall power-losses, a realistically appropriate amount of power (in this case 0.5 MVA) is reserved as unavailable for the automated systems. Throughout operations, the system monitors total consumption and visualizes it using color codes. Green signifies total consumption below 3MVA, with no operational restrictions. Orange indicates total consumption between 3 and 3.5MVA, which means that there is no more unlimited operational freedom to increase power consumption. Red, the final color, is triggered when total consumption has surpassed 3.5MVA. At this point, the system will prevent additional consumption, as a function of the expected load and priority. If large loads with high priority need to be started, other, lower priority loads will be shed automatically.

This example of basic LM was implemented purely for the sake of security of supply. However this approach can serve equally well to prevent exceeding the contractual peak, even if plenty of connection capacity is still available. Companies seeking to implement LM in order to optimize energy contracts and to valorize their flexibility of demand on the energy market will need to gain a much more detailed insight into their energy streams. Automated energy monitoring and structural energy management will prove to be essential for such companies.

THROUGH OPTIMIZED ENERGY MONITORING

As mentioned earlier in this Application Note as well as in the Application Note ***Energy Management***[7], insight leads to improvement. A good energy audit will identify waste of energy as well as potential for improvement that may require investments. But an energy audit is only a momentary snapshot of the situation, and may not be representative for operations throughout the year. For continuous, up-to-date insight, companies need to turn to energy monitoring and structural energy management.

Companies can best gain continuous insight into how much energy is used by the various processes and equipment on-site via energy monitoring. The consumption volume can obviously be translated into a cost, and by linking production data to consumption data, more accurate cost models can be developed. While monitoring itself does not save energy, the insight gained from monitoring usually leads to energy savings. After all, it will become evident when certain equipment is unnecessarily consuming energy. Likewise, it will be easier to calculate the savings from investing in more energy efficient equipment. By taking energy-efficiency measures, the base load consumption can be lowered. Generally, the same goes for peak loads.

The most important result of energy monitoring and energy management in relation to LM is understanding how much energy is actually used by the various processes and activities and then being able to predict fairly accurately how much energy will be consumed at what time, as a function of planned production.

THROUGH OPTIMIZED PRODUCTION PLANNING

Once there is a clear understanding of the energy consumption related to the activities on-site, it is important to identify which loads are flexible and which aren't. Flexible loads are those that can either be shifted in time or whose load can be modulated or interrupted without affecting the quality of the end product or the safety of the production process. Chemical industries, for instance, may have production processes that cannot be interrupted due to necessary safety measures. At best, the start of the process can be shifted in time, but the process itself may offer limited or no optimization potential. In the food industry, cooked foods may need to be cooled down in a very short period of time. Because of food safety regulations, there is no flexibility in slowing down the cooling process in order to save energy. Cold storage on the other hand is an industry which typically has a significant level of flexibility. Given the thermal inertia of a warehouse full of frozen products, these installations usually have hours of flexibility to run the cooling systems, as long as the temperature in the warehouse remains within an acceptable range.

In continuous production, time shifts are, logically speaking, less relevant (short of stopping the process entirely) but flexibility will be more likely to come from modulating the load, changing settings, et cetera. In some industries, multiple types of energy are used for heat production and companies may switch from natural gas or diesel to electricity and back, depending upon the prices for each fuel. Some processes can proceed at a slower pace in return for lower consumption. Other processes, such as steel production or electrolysis, can even be stopped altogether without significant quality, safety or economic considerations. Other continuous processes, such as glass production, cannot be interrupted without causing significant maintenance costs to the installations.

In batch production, time is an intrinsic part of the process, with a start and a stop to each batch. Shifting the batch in time is therefore easy to achieve, at least in theory. Load Management in batch production may look at avoiding simultaneity of peak demand of various processes across multiple batches. In line with the concepts of energy management, the different steps in the process can be analyzed for their load profile and this may lead to changes in the process or the batch size. If batch set-up, start-up and shut-down processes are very energy intensive steps in the production process, it may make more sense to increase batch size.

While technical and safety-related elements help determine whether or not flexibility is possible, other elements must be investigated to determine whether or not flexibility can be profitable. The optimized manner of working in terms of flexibility must be compared to the business as usual way of working, not only in terms of expected energy consumption and related costs, but also taking into account planned operational costs (OPEX) for labor, lost raw materials, opportunity cost in terms of non-produced goods and increased delivery times, et cetera.

Only a proper life cycle analysis can help identify the best measures to take in order to maintain net balance.

Types of load management/flexibility in production

Mapping the characteristics of the production process is crucial. For LM, the boundaries of each process will determine the potential for flexibility. The following parameters are important to assess:

- Marginal cost of activation: Costs related to lower output levels of industrial processes driven by reducing power demand. Industrials that produce very expensive end-goods are typically less interested in flexibility if this leads to lower output levels. It is crucial that the revenues from flexibility are higher than the potential costs related to lower production output. Not all companies are necessarily faced with lost output. When production is merely delayed by shifting loads, the marginal costs of flexibility activation is drastically reduced.
- Storage/buffer capacity: The marginal cost of activations can be very low in the event there is a buffer or storage capacity within the process. This results into lower risk of lost production volumes since it can be shifted in time thanks to the storage or buffer.
- Reaction time: The time it takes for a process to ramp-up or ramp-down after a signal is given. The activation speed is an important parameter which drives the value of flexibility. Processes that can provide flexibility in seconds are eligible for more flexibility options such as primary or secondary reserves, while slower flexibility is excluded from these products.
- Maximum duration: The maximum length during which flexibility can be activated during a single activation cycle. This can range from minutes to hours.
- Frequency: The number of times a given flexibility can be activated over a period of time. If flexibility can only be activated at widely spaced intervals, this will typically result in a lower value.
- Flexibility volume: The volume of flexibility can be important in the event that there is a minimum amount of capacity that needs to be offered for a specific product. In the past, this used to be a more important barrier for industrial flexibility. Now aggregators can build up large capacities existing from a compilation of smaller end-users.
- Technical impact on the process: The impact of flexibility actions on the rest of the process needs to be assessed in detail. Certain instances need to be taken into account in the marginal cost of flexibility. These include the activation of flexible sub-processes that result in bottlenecks elsewhere in the process streams.

In the charts below (Figure. 4-6), an overview is given of typical LM actions. Examples are provided of processes that could benefit from each type of LM, together with the main advantages and drawbacks. The X axis of the graphs represent the hours in a day while the Y axis represents the demand level of the end-user (MW). A short summary of the different LM actions:

- Peak shaving: Reducing peaks is a mostly inward looking LM action, in the sense that market factors play little or no role. Process-driven peaks are being managed in order to reduce the costs related to them, often in transmission and distribution tariffs. Companies typically set a maximum load value. If these levels are being approached, either an alarm is given to the operators or automatic action is taken to reduce load levels.

- Load shifting: Market prices or the need to reduce the peak demand level drive the modification of the normal consumption pattern linked with the standard production planning. Shifting from one hour to another during production may not work for processes that tend to run on maximum load. It is better suited for processes that run at varying loads or batch processes.

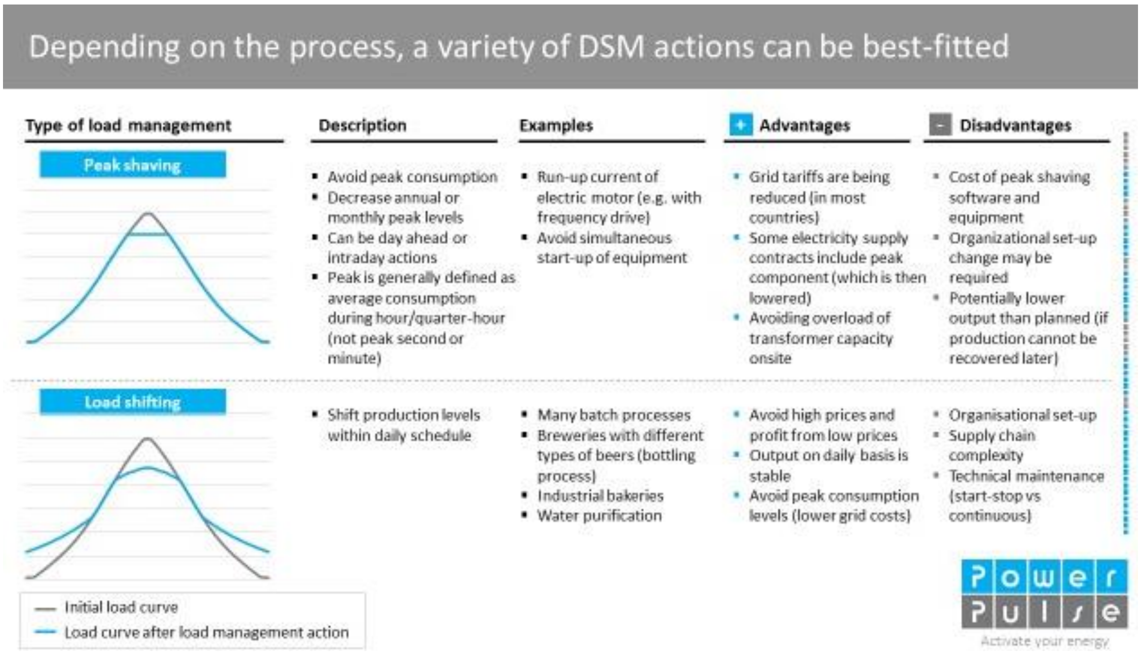


Figure 4 – Peak Shaving and Load Shifting.

- Load reduction: Reducing load levels is a type of flexibility that is generally utilized in periods with extended high market prices. Either the high market prices to which a client is exposed results in financially loss-making production or the incoming order level is rather low and the client can choose when to produce its orders. On days with expensive prices, production could be on the minimum level with the expectation to produce more on days with lower power price such as weekend days.
- Load increase: Increasing load levels is the opposite of load reduction. Companies could choose to produce more units on days with cheap power prices if they have limited orders in their books or a large buffer to store their produced goods.
- Base load lifting: Increasing base load demand is a flexibility approach in which lower power prices are used as a trigger for more production. This is possible for companies with a buffer. Companies lacking such a buffer will opt for load shifting rather than base load lifting.

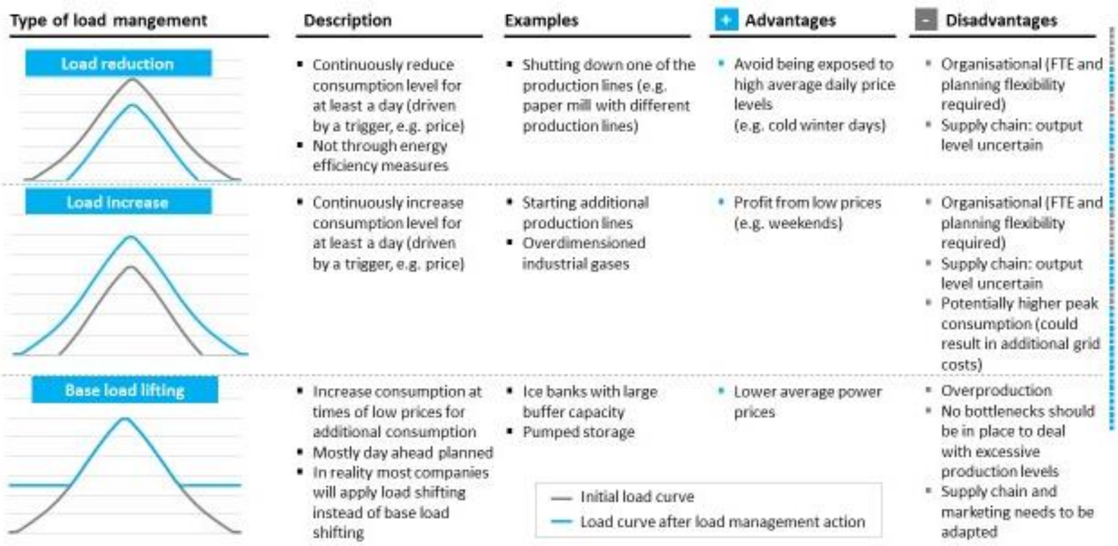


Figure 5 – Load Reduction, Load Increase and Base Load Lifting.

- Ripple shaped profile: Flexible processes that have an exposure to real-time prices can make use of shorter periods of low prices to increase production output, or high prices to reduce production output. Operators have to actively monitor these real-time markets in order to be able to react with appropriate quickness. Corporate culture and KPIs often need to be adapted to make this a successful approach.
- Saw-shaped profile: Very flexible processes can go one step beyond the ripple-shape profile approach by automatically reacting to all price swings in the real-time market. This results into many smaller swings in production output. If companies choose to offer primary reserve to the TSO, the resulting consumption profile would often look similar to the saw-shaped profile as frequency control is automatically changing consumption output on a quite regular basis.

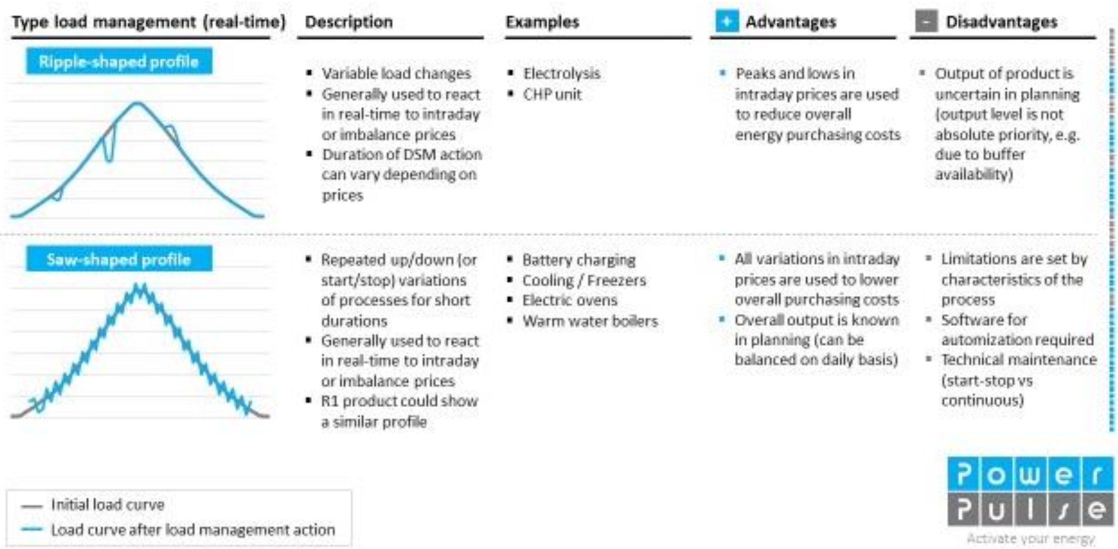


Figure 6 – Ripple-shaped profile and Saw-shaped profile.

Concrete examples of load shifting, saw-shaped profile and peak shaving are given below.

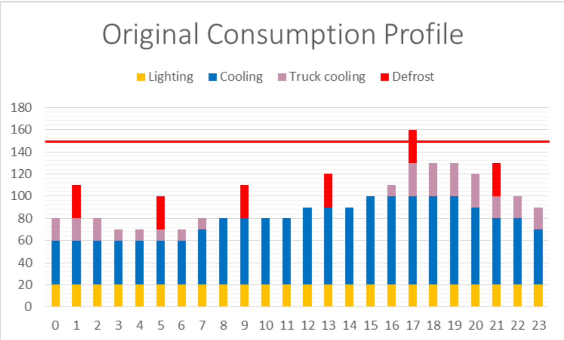
PRACTICAL EXAMPLES: LOAD SHIFTING ON HVAC

Heating, ventilation and air-conditioning typically offers a significant LM potential of around 1/3 of the electrical load for office buildings. Adjusting temperature settings or even turning off the AC altogether can offer a significant load reduction. However, the comfort of the users should at all times be guaranteed. While temperatures may deviate a little from the ideal settings, air quality must never be compromised.

Among industrial HVAC users, the cold storage sector has traditionally been very active in LM. Several factors contribute to the success of LM in this sector. First of all, there are few if any complicated production processes, just cooling of a building and the products contained therein to within a specified temperature range. Given the typical temperature ranges in which these products may be stored, and the temperature buffer created by a well-insulated building and the products, there is usually quite a lot of potential for load shifting by periodically turning off the cooling compressors and fans. The larger the temperature range and the greater the buffer available, the greater the available flexibility. Companies active in the food supply chain that specialize in frozen goods typically have a high level of flexible demand.

More passive companies in this sector tend to select tertiary reserve (aka Replacement Reserve) as a way to valorize this flexibility. In this approach, they receive a fixed sum from the TSO or an aggregator to provide the option to reduce their demand remotely several times during the year. The drop in electricity demand does not impact the quality of the deep-frozen goods provided their buildings are well-insulated and their goods can cope with a specified temperature range. This is one of the most accessible ways for companies to valorize flexibility as it provides a fixed income and very little additional work, apart from installing the device that can remotely steer their demand. Since the lost consumption volumes are often compensated after the flexibility activation, this can be regarded as load shifting.

The graphs below (Figure. 7) show the example of a cold storage warehouse that was facing high costs for energy consumption as well as for peak demand penalties for consistently breaching contractual peak load. This was mainly due to the simultaneous peak demand of the cooling installation, its defrost cycle, and the cooling of the freezer trucks at the end of the day shift.



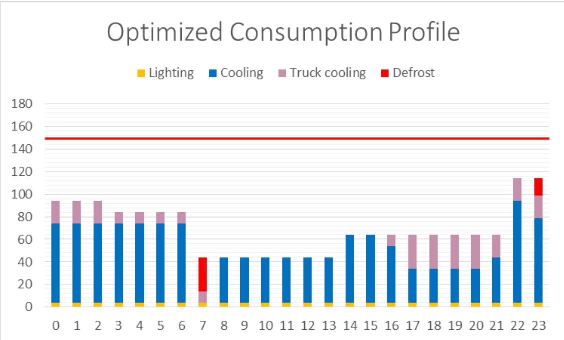


Figure 7 – Optimizing the cold storage consumption profile.

By replacing the old, always-on, gas discharge lighting with high efficiency LED lighting with motion detection, the company was able to reduce the base-load of lighting consumption by more than 80%. This in turn reduced the heat load on the cooling system, thus further reducing base-load consumption.

An additional investment enabled the time-based defrost cycle of the air coolers to be optimized, reducing both base-load and peak load consumption.

Finally, by applying demand side management techniques, the company was able to shift consumption of the cooling installation towards the off-peak hours by taking greater advantage of the acceptable temperature range, as shown in the temperature profile graph below.

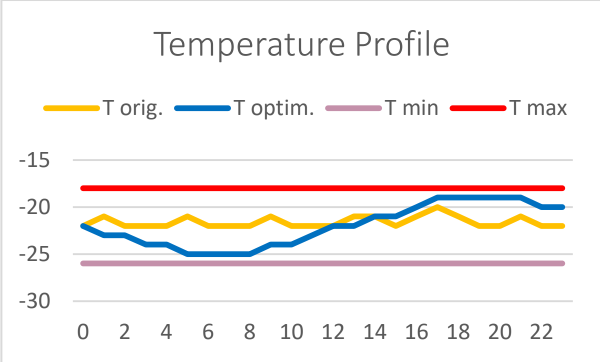


Figure 8 – Temperature profile before and after consumption optimization.

In doing so, the cooling installation could be run at much lower output when the freezer trucks returned from the day shift and needed to be cooled down again from positive temperatures to their safe operational temperatures. These combined actions resulted in lower overall consumption, eliminating peak demand penalties, and a flatter and less costly consumption profile. In addition, the cold storage's consumption profile now offered more flexibility that could be valorized through a demand response aggregator.

There are other companies in the deep-frozen goods sector that go further and apply active management of their demand. They buy electricity at day-ahead prices based on their expectation of what would be the lowest cost hours. They then carry out most of their cooling during these hours, while avoiding cooling during expensive hours. Some companies in this sector go as far as changing the positions they bought in the day-ahead market by reacting to price volatility in the real-time balancing markets. If imbalances prices are high, these companies reduce their consumption vis-a-vis what was planned on the day-ahead market, thereby selling back a share of the volumes they bought in the day-ahead market into the imbalance market if the imbalances prices are high.

On the other hand they consume additional volumes when imbalance prices are low. This is typically the most highly valued way of monetizing flexibility, with the drawback that it requires a more active approach. The resulting profile is often one that resembles the ripple-shaped profile or even the saw-shaped profile when this approach is automated and all peaks/lows are being valorized. Markets need to be followed in real-time and the temperature range needs to be respected in order not to damage goods. Electricity costs represent a high share of total costs of companies in this sector, sometime more than one third of total costs. Therefore this is a sector which is at the forefront of utilizing the flexibility inherent to their processes.

Practical examples: automated peak shaving concerns

Peak shaving is now a rather common maneuver used by industrial consumers to manage their load. It is usually undertaken in order to reduce the distribution and transmission costs since this portion of the overall invoice is usually based on the highest peak within a certain period (typically month or year). Hence, this type of LM (peak shaving) is based purely on internal factors within the processes of clients without taking into account market price elements. Customers can set a maximum level of load. When the load is approaching this maximum, an alarm signal can be given to the employees responsible for operations. Moreover it is also possible to actively manage assets, for example by automatically stopping non-crucial sub-processes in order to avoid exceeding the preset peak level. The principle of active management is often integrated into the start-up control of an electric motor,, for example a frequency drive.

Implementing peak shaving goes well beyond simply turning off some equipment in order to receive some financial benefit.

First priority should always be safety: can a piece of equipment or a process be turned off or shut down instantly or is a ramp-down process needed? Similarly, are certain other actions needed, possibly by an operator, before being able to start up again? If the equipment can start-up without intervention, can it do so without creating a hazard for those employees working in close proximity?

Other concerns include product quality and waste. Does interrupting the production process affect quality, and if so does this create unnecessary waste? Will an interruption require more raw materials during restart? What are the related costs? What about maintenance? Do frequent start/stop sequences increase equipment wear and tear? Does this increase maintenance requirements? If production is slowed down, or even halted, will this cause other bottlenecks throughout production and will delivery times be impacted?

These are all issues of considerable importance that need to be part of evaluating the potential benefits of this approach to LM.

LOCAL ELECTRICITY GENERATION AND OPTIMIZED SELF-CONSUMPTION

Many companies have invested in local, decentralized electricity generation on-site, employing various dimensions and technologies. Diesel generators are often bought in combination with a UPS system to provide sufficient back-up power in case of a power black-out. These systems may be sized to enable a controlled ramp-down of essential processes, with special attention to safety requirements. Some systems may even offer sufficient redundant capacity to keep the entire site up and running for as long as necessary. Other technologies, such as CHP plants, are part of normal operations and provide some or all of the required electricity on-site. Finally, many companies have invested in renewable energy installations, as will be discussed below.

Consumption on the same site as where production takes place generally results in a local advantage. Lower grid costs and taxes can be achieved when locally generated production is consumed on-site. This is in contrast to injecting locally generated electricity into the grid and importing the same volume again from the grid at a later time. In order to make maximum use of this local advantage that RES or CHP on own premises may offer, it is generally profitable to consume as much as possible of the generated electricity onsite. Load Management is essential in facilitating this result. Moreover, additional costs can be avoided if peak consumption occurs at times when electricity is generated locally. These peak volumes are then partially offset by local production, and will result in a lower level than the situation that does not employ renewables. This enables the reduction of grid costs related to peak consumption. The Application Note ***Wind Powered Industrial Processes***[8] investigates how maximum benefit can be gained from self-consumption of on-site wind power.

Companies invest in these electricity generating systems because they reduce costs and because they reduce risks. However, most companies have yet to fully realize that these systems also offer opportunities to generate income. Diesel generators used for back-up require maintenance and usually need to be tested on a frequent basis. During such a test, the generator will most likely run for at least an hour, producing electricity that is then consumed on-site. In many cases, these test runs are scheduled according to a fixed calendar plan, for instance every first Monday of the month. In this case diesel fuel is used to generate electricity which is consumed on-site, whether or not grid-delivered electricity is cheaper at that time. If these generator tests are performed at times of high peak demand, the company can benefit from high spot or imbalance prices by selling back to the market some of its contracted volume being covered by the generators. Such actions could be automated through a power optimization algorithm provided by an external service provider including among others, a demand response aggregator. (Figure. 9)

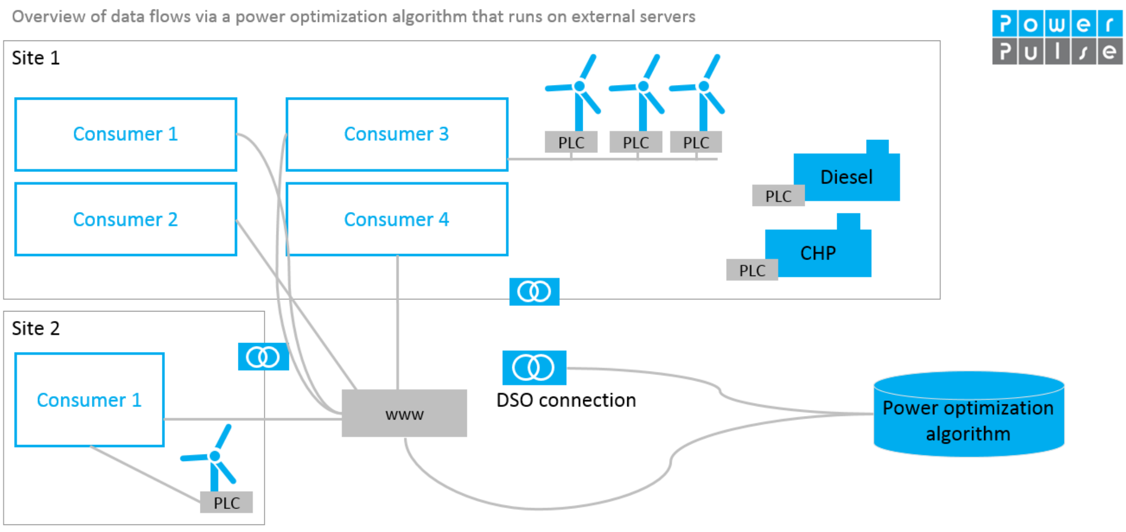


Figure 9 – Simplified overview of technical set-up: data flows (illustrative).

Impact of renewable energy systems (RES)

One of the most common domestic applications for renewable energy is solar PV. Unfortunately, much of this energy cannot be consumed at the point of production, for the simple reason that the sun only shines during the day, when most people are at work. As a result, only a portion of the energy produced is self-consumed while the rest is injected into the grid. Most homes with solar PV are in effect using the grid as a virtual battery.

However this adds to the complexity of balancing the grid because of the more or less synchronized intermittence of PV production. Cloud cover affects not just a single PV unit but rather all PV installation in the same region at the same time and in the same manner as a lack of wind affects wind turbine generation. Recent developments however, such as the Tesla Powerwall, signal a new drive towards decentralized storage. Not only can these systems be used to store renewable energy, thus avoiding injection into the grid, they can also recharge from the grid during lower-cost off-peak hours and provide electricity during peak hours at off-peak rates, while relieving the grid of this demand.

These same issues come into play in industrial applications, but at a larger scale. It is certainly true that industrial scale renewable energy comes in a greater variety of technologies and scales than those normally employed for residential energy. While solar PV can play an important industrial role, currently the greatest volumes tend to come from wind turbines. In industrial applications, there is also great potential for thermal renewable energy, including solar thermal, geothermal, biomass and biogas combustion. Some of these thermal technologies may reduce electrical loads for boilers, heating applications, et cetera but will more often replace (or reduce) the use of fossil fuel in combustion. In some cases however, the thermal renewable technologies can provide not just heat but also electricity and even cooling.

Trends in energy storage

Energy storage can be an efficient way to absorb day-to-day differences caused by intermittent renewable energy sources. However, this technology cannot yet cope with seasonal differences in renewables output. The current commercial business cases for most storage projects, based on arbitrage between less expensive and more expensive hourly power prices, are still showing negative returns. This is caused by, among other reasons, low peak/off-peak spreads in the oversupplied Western-European markets. Currently the price difference between moments of cheap electricity, during which storage systems are loaded, and moments of expensive electricity, during which storage systems are used for additional power, is generally rather low. The US market however is already showing greater potential for large scale battery-based energy storage[9].

Certain consumer situations can make a positive business case however. Some consumers have over dimensioned renewable generation capacity on their site. If these consumers face high grid charges and taxes for electricity offtake from the grid, storing electricity to consume at a later moment can generate greater benefits.

Due to the negative business case of many new storage projects, subsidies are under consideration in some countries while in others, including Belgium, specific grid tariffs are being considered for storage. Also, energy arbitrage is just one of several valorization avenues. There are currently profitable business models based on participation in multiple markets, notably to FCR (primary reserve)[10]. In addition, technological advances in battery technology, as well as effects of economy of scale may signal a turning point for battery technology. Tesla's mega-factory, currently under construction, is expected to double annual world-wide lithium-ion battery production, which could help decrease the cost for battery storage projects.

Taking into account the continued increase in renewable energy production, including China's plans to triple solar power capacity by 2020 to as much as 143 GW[11], the interest in energy storage, and its role in optimizing LM, can only be expected to increase.

Valorization of flexibility on the energy market

DR in Europe today

Until recently, reserve products and balancing activities were typically the domain of power generators. These services were often imposed by law. The only demand side management came from interruptibility contracts, which were available to large industrial consumers and which enabled a limited number of activations. The majority of large consumers were exposed to forward products rather than hour-by-hour day-ahead prices. This left most end-users without any incentive or practical possibility of applying LM for commodity or reserve purposes.

There are several ways to valorize flexibility. But be aware that these differ from one country to another. As an example the different ways to valorize flexibility in the Belgian market are depicted in the Figure below.

Traded exchange markets provide levers for day-ahead and intraday flexibility. Industrial users can buy and sell electricity and set maximum or minimum prices through a market platform. In the day-ahead market, the exchange finds a counter-party in case the participant's bid is matched in the clearing. An industrial client could for example set a maximum price, meaning that if prices rise above this level the industrial will no longer consume a share of its initially planned electricity. The intraday market is based on continuous trading with a much lower liquidity level than the day-ahead market. Currently, very few industrial customers have access to the intraday market.

Bilateral deals are also mentioned as a way of valorizing flexibility. This is a channel utilized most commonly by utilities rather than industrial users. This encompasses a wide variety of contracts that two parties can agree upon, which could be either standard or non-standard trading products.

TSO interactions provide an important way to valorize flexibility. Reserve products are mostly opened up for industrial end-users. Tertiary reserve requires the slowest reaction time compared to the faster primary and secondary reserve. The imbalance market is a way for end-users to react to price signals in the balancing market. The prices in the imbalance market are generally related to the activation costs that TSOs pay for activating reserve volumes.

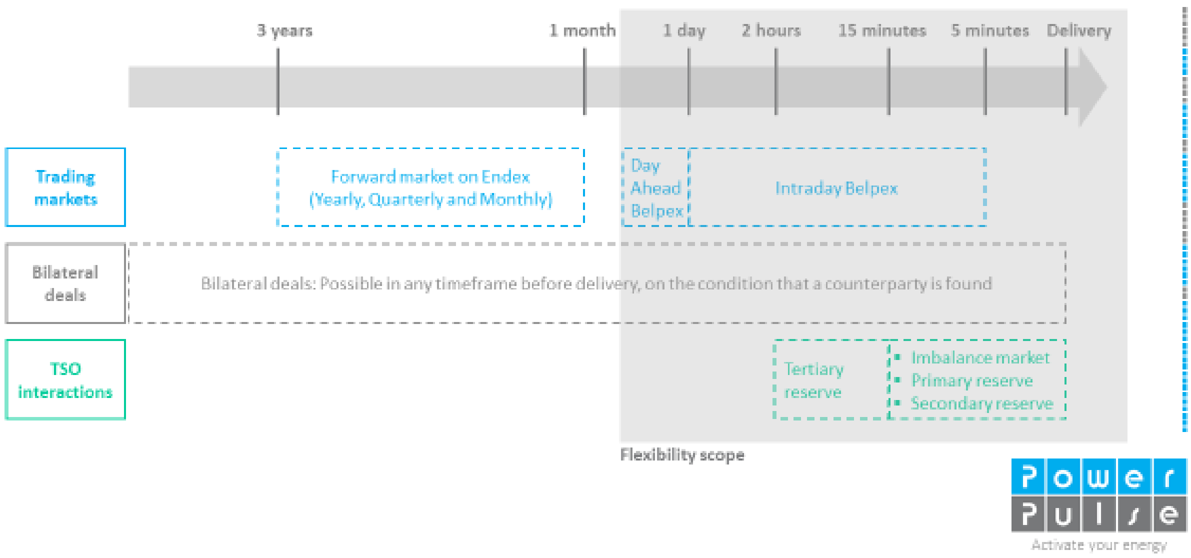


Figure 10 – Example—How to source electricity and valorize flexibility in Belgium.

Two important trends have taken place in recent years which have increased the feasibility of LM commercially and its practically:

- The increase of exposure to variations in prices throughout the day and week have helped to create the incentive to react either to extreme prices or to shift loads from expensive time blocks to less expensive time blocks. An ongoing trend is the access of industrial consumers to so-called limit orders on the day-ahead markets. This enables customers to, for example, define a maximum price at which consumption would be dropped to a lower level.
- The emergence of aggregators has provided market access for a much larger group of end-users in Western-European markets. These aggregators typically build up a portfolio of flexibility consisting of several end-users with different characteristics. Aggregators consequently offer this portfolio in an aggregated way to transmission operators in reserve or balancing auctions. Generally, aggregators get a share of the reserve revenues contractually agreed upon between themselves and the consumer.

Current demand-related reserve products have rather limited number of activations, with the most common exception being primary reserve, which is regularly activated. Additional steps will need to be made to accommodate future power system with ever higher degrees of intermittent renewables. The future system will need a more continuous balancing from demand both intraday and across larger time periods. The existing reserve products for demand are not designed for that; they provide rather for sporadic reductions in demand. Real-time power markets can also play an important role here with demand reacting to short-term volatility in prices and thus absorbing intermittency in the grid.

The characteristics and boundaries of the process can be matched with the requirements of each demand response product. We make a distinction between two important ways to valorize flexibility: reserve products and electricity markets.

Reserve products have different characteristics which vary widely by country, but they are showing signs of convergence in Western-Europe. Consumers can directly participate in reserve auctions organized by the transmission grid operator or choose to participate through an aggregator who bundles a portfolio of consumers.

A typical breakdown of different reserve products in European countries includes the following:

- FCR (R1): Frequency Containment Reserve (formerly Primary Reserve)
  - Automatic and very fast response time (seconds) required
- AFFR (R2): Automatic Frequency Restoration Reserve (formerly Secondary Reserve)
  - Fast response time (minutes) required
- MFFR and RR (R3): Manual Frequency Restoration Reserves and Replacement Reserves (formerly Tertiary Reserve)
  - Slower reserve products with varying reaction times and generally longer activation times

Replacement Reserves are managed in the so called balancing market, on the basis of economic merit and technical profile. Usually demand can participate to this market although it is still not yet possible in some countries. Usually only delivered energy is remunerated.

FCR and FRR have more stringent requirements. Power made available is often remunerated (capacity payment), as is the energy actually delivered. Participation of demand to these reserves is often not permitted. However, upcoming market design reforms should systematically open participation of consumers to these markets.

Along with the reserve products, flexibility can also be valorized through different markets on the condition that the consumer has the right contractual exposure. The most important electricity markets to valorize flexibility are the day-ahead market and the real-time balancing market.

The pros and cons of reserve products versus market mechanisms is summarized in the chart below (Figure. 11).

Reserve products tend to have strict requirements for flexible assets to be available during the contracting period for providing increased or decreased consumption levels whenever the TSO asks for them. The availability of these volumes is crucial and non-compliance generally results in penalties. For example when an industrial client has agreed to provide primary reserve to the TSO using an electrolysis installation during one month, penalties are typically imposed when the electrolysis is facing an outage during this period. The advantage of reserve products is that they come at a fixed remuneration, assuming full availability of the assets.

Market solutions on the other hand typically do not guarantee a fixed fee for flexibility since commodity price volatility is not a certainty. Monthly income from market-based flexibility valorization could thus be rather variable. The advantage of market solutions is that end-users only make use of them when their assets are available to do so. Given that the most important market-based flexibility is either on the day-ahead or real-time timeframe, the availability of most assets can be assessed rather accurately.

	Reserve mechanisms	Market solutions
+	▪ Guaranteed minimum income ▪ Limited number of activations ▪ TSO provides signal for activation	▪ Full control over process ▪ Number of activations decided by customer based on availability ▪ No risk of fines ▪ Potential for high revenues when processes are very flexible
–	▪ Lower control over processes ▪ Fines when not adhering to signals ▪ Same revenues for all levels of flexibilities	▪ No guaranteed minimum income ▪ Price signals need to be closely monitored ▪ Real-time prices hard to anticipate

Power Pulse
Activate your energy

Figure 11 – Advantages vs. disadvantages of reserve and market mechanisms.

CONCLUSION

Load Management (LM), as discussed in this Application Note, is the practice of actively adjusting the consumption of electricity compared to what was originally planned. The most important justification for undertaking LM is risk management regarding net balance.

At a micro-level (i.e. for a single commercial site), LM is implemented by the consumer to keep power demand below the maximum available capacity on-site. This avoids the risk of a local shut-down and guarantees the security of supply. It is also used to avoid penalties for surpassing contractual peak demand.

While a site's power supply installations were once engineered for a certain load, the demand onsite may have grown over time. Such growth may have stretched the available capacity to a point where the consumer is no longer able to run operations as desired, because it is limited by the available capacity of supply. At this point, the consumer will need to decide whether to cap demand (and thus limit operations) or increase the supply capacity in order to enable operations as desired.

When choosing to limit demand, the consumer will apply techniques such as peak shaving and load shifting in order to keep demand below critical capacity limits. Doing so may require investments in automating load monitoring and management of individual consumers. In addition, operations may face an opportunity cost for reducing or shifting production. The alternative to demand reduction is increasing the capacity of supply. This will often require significant investments, both financial and time wise. In addition, such an increase will have an impact on electricity supply contracts and transmission and distribution costs.

This brings us to the second reason for implementing LM: saving money. Each consumer has a contract with a supplier which stipulates a certain forecast of expected volume of consumption over a certain time. The supplier has a responsibility to safeguard net balance across its entire portfolio of consumers. Each consumer added to this portfolio can add or reduce the risk to the supplier, based on the consumption profile of said consumer. The more predictable and stable the consumption profile of the consumer, the lower the risk to the supplier. ***A consumer that can optimize its consumption profile by making it more predictable and by reducing the variance between base load and peak load consumption, will be in a favorable position to negotiate more advantageous contracts than a consumer whose consumption is totally unpredictable.***

A consumer that can properly manage its consumption profile will also be more capable of optimizing on-site consumption of locally produced renewable energy. By having a clear understanding of its consumption and production profile, a consumer may choose to charge the batteries of the fork lift trucks on Saturday and Sunday, using the free solar power generated during these days, rather than charging them immediately following the Friday afternoon shift, during peak demand hours. In addition, such a consumer will be less likely to require significant investments in a supply capacity increase, which may not be used to its full potential and which, in turn, may lead to unnecessary charges based among other things upon utilization time.

A third, more advanced reason for implementing LM, is to generate income by valorizing flexibility of consumption. Consumers can get paid both for reducing consumption or even providing production at times of high demand, as well as for increasing consumption at times of low demand. Depending on the agreements with other supply chain stakeholders, consumers can even get paid just for having flexible capacity available on-call, even if that capacity is never actually called for.

For all parties involved, it all comes down to what action offers the most value. In short, what saves or generates the most money: starting up an additional production plant vs. paying consumers to reduce consumption; opportunity cost from reducing consumption vs. peak demand penalties for maximum production, et cetera.

For the consumer, the main question is really how to get started with Load Management.

The number one prerequisite for LM is to have a proper understanding of, and insight into, the consumption of electricity on-site. A company needs to understand with a high degree of confidence which installations consume how much energy, when, and why. Typically, such insight is gained through an energy audit and by implementing a temporary (or better yet, permanent) monitoring system. The first result of such an audit and monitoring campaign is likely to be an improvement in energy efficiency. After all, energy audits enable the identification of energy waste. Investing in energy efficiency upgrades such as relighting, frequency drives and energy efficient motors and fixing compressed air leakage not only reduces overall consumption but often also provides additional capabilities in controlling and managing total consumption. Another benefit of gaining accurate energy consumption profiles is that it often leads to additional insights that can have secondary benefits in terms of operational efficiency. For more information regarding energy audits and energy management, check out the ***Energy Efficiency Self-Assessment in Industry***[12] and ***Energy Management***[13] **Application Notes** or contact a consultant specialized in energy audits.

The second step is to take this insight into the consumption profile to identify which loads offer flexibility. The crucial part is to identify whether a certain load is time-critical (i.e. whether or not it can be shifted in time) and whether or not the load itself can be reduced or increased. Next, one will need to investigate how fast a certain load can be adjusted to provide flexibility. Depending on the reaction time, the load may offer value for primary, secondary or tertiary reserve products. In addition, it is important to understand what the time constraints are on this time shift. In some cases there may be a direct impact on labor costs (i.e. idle time for personnel) while in other cases there may be secondary regulatory restrictions (e.g. maximum allowed temperature in a cold storage warehouse). All these findings can be used to compile a flexibility portfolio. For more information on flexibility audits, check out the ***Flexibility Audit*** section in the ***Wind Powered Industrial Processes***[14] **Application Note** or contact a consultant specialized in flexibility audits and energy contracts.

Once there is proper insight into the consumption profile and the available flexibility has been mapped, the next step is to investigate the potential of LM within the context of the current energy contracts. Top management needs to understand the current invoice's price share for the energy component, charges for transmission and distribution (T&D), taxes and levies, et cetera. Based on the consumption profile and ability to properly forecast consumption, the purchasing methodology and time frame (for instance, a three year contract with annual volume vs. intraday contract) will need to be reviewed. A company that is very much budget-driven may prefer a more long-term methodology, foregoing short-term profits for long-term stability. Such companies may benefit from selling their flexibility to a demand response aggregator. Others may choose a much more active, albeit more short-term approach, both in terms of purchasing contracts and selling flexibility back to the market. All in all, it will always be an exercise in evaluating potential profits vs. opportunity costs and risk.

Once the first steps are taken into Load Management, consumers will start to include requirements from LM into the engineering phase of new projects, as well as into production planning, maintenance planning, et cetera. Over time, LM will become an integral part of operations and risk management, enabling consumers to not only save money on their energy invoice, but generating additional income by managing consumption in a more intelligent and efficient manner.

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