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Increasing Economic Benefits by Load-Shifting of Electrical Heat Pumps

Joannes I. Laveyne*[a], Brecht Zwaenepoel[b], Greet Van Eetvelde[c],
Lieven Vandevelde[b]

[a]Ghent University, Power-Link, Wetenschapspark 1, 8400 Oostende, Belgium
[b]Ghent University, Electrical Energy Laboratory, Sint-Pietersnieuwstraat 41, B-9000, Gent, Belgium
[c]Ghent University, Center of Mobility and Spatial Planning, Vrijdagmarkt 10-301, B-9000, Gent, Belgium
joannes.laveyne@ugent.be

Electrical heating is still widely used in the process industry. While the use of immersion heaters for the production of hot water or steam is declining, the adoption rate of electrical heat pumps is increasing rapidly. Heat pumps show great flexibility and potential for energy savings, e.g. through low temperature waste heat recuperation. In combination with thermal storage they also allow for load shifting. Because their main power source is electricity, which up to now cannot be stored efficiently, heat pumps can transpose their thermal load shifting ability to the electrical grid. Today, more and more industrial electricity consumers are adopting energy supply contracts with variable pricing parameters strongly coupled to the energy trading market. Some large consumers even buy and sell on this market directly. In this paper it is proven that for customers with (hourly) variable electricity pricing, the use of electrical heat pumps can lead to additional cost savings without influencing the industrial process. The yield of the heat pumps can be increased during hours with low energy cost, with the thermal buffer absorbing the heat surplus. During hours with high energy cost the heat pump yield is lowered and stored heat is used by the industrial process.

Considering that heat can be stored much more efficiently than electricity, the load shifting ability of heat pumps can also be utilised to provide stability on electrical smart grids and to increase electrical self-consumption on microgrids. This paper will also explore the potential of thermal storage through heat pumps for these electrical smart grid applications.

1. Introduction

Heating is a fundamental component in many industrial processes, especially in manufacturing. Depending on the type of process or application, different types of heating methods and fuel sources are used. Slow processes with a constant heat demand, e.g. dehumidification of wood, will require a different approach than short burst processes, e.g. plastic cap sealing.

According to the U.S. Department of Energy (2004), most key industrial processes requiring external heat are gas fired. Coal is used for processes requiring slow and constant heat such as calcining. Electricity is used in some metallurgical processes such as melting, or chemical processes like curing.

The performance of a heating process is typically based on its ability to deliver a certain product quality in a given time constraint. Most companies focus on these productivity related parameters because process output and product quality are economically important. With rising energy costs, the Industrial Heating Equipment Association (2001) demonstrates that companies are also starting to consider the ‘energy use per product’. More efficient heating systems can therefore lead to a competitive cost advantage. In some cases however, the heating system cannot easily be changed due to process constraints, or because of the most efficient heating system is already used.

An alternative way of achieving cost savings is by lowering the cost per energy unit. The liberalisation of the energy market has opened up perspectives for cost savings by exploiting variable energy prices. The market for electrical energy is especially interesting because of its significant price fluctuations, with

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sometimes only a few hours between peak and bottom price levels. This can make electrical heating attractive, e.g. as an addition to a conventional gas fired heater or by employing efficient heat pumps powered by available waste heat streams as shown by Matsuda et al. (2012), even low temperature as demonstrated by Keil et al. (2008). It has been shown by the U.S. Department of Energy (2003) that heat pumps can be used in industrial processes, or in large scale residential and commercial applications by Dejanović et al. (2010) or Sarbu and Sebarchievici (2014). Research by Lund (2005) and Martínez-Patiño (2012) has already proven that heat pumps can offer potential for balancing (renewable) energy production, even in small scale applications such as described by Pagliarini and Rainieri (2010) or Becker et al. (2012). This paper will expand those findings by using this potential to benefit from the price volatility on the wholesale energy markets.

The use of electrical heating, combined with sufficient thermal buffering, also offers opportunities for peak shaving or demand side management applications. Essentially, the thermal storage capacity of the buffer is transposed to the electrical grid with the electrical heat pump functioning as converter.

This paper will elaborate on the cost savings achievable in heating processes by buying energy directly from the market, and on the use of electrical heating for balancing applications on the electrical grid. The paper is structured as follows. First the mechanism of wholesale energy trading is detailed, with the Belgian market as a study case. The following sections give some examples on how participating on this energy market can lead to cost savings. Finally, the conclusions and some considerations for further research are given.

2. Wholesale energy trading

In this section of the paper, the process of wholesale energy trading is discussed. A detailed look is given on two wholesale trading platforms: one for electrical energy and one for natural gas. The concerned platforms are Belgian, but are representative for other trading platforms elsewhere in Europe.

2.1 Electrical energy

The electrical energy markets in Europe are more or less partitioned alongside national borders. Some larger nations have a domestic electricity trading platform closely coupled to national grid infrastructure. In the presented case of Belgium, Sharma (2007) describes the domestic ‘Belpex’ trading platform as a part of a collaborative platform between France, Belgium and the Netherlands made possible by strongly interconnecting each nations electrical transport grids in 2006. In 2010 this collaboration was expanded with Germany and Luxembourg, resulting in what Elia (2012a) now calls the Central Western European Market Coupling (CWEMC). In unconstrained situations this collaboration leads to price convergence between each participating nations’ domestic trading platform. However, this convergence is limited by the power exchange capacity in the tie points between national grids. There are plans to expand the CWEMC to the Nordic region and the UK, resulting in a unified Central- and West-European market coupling.

There are multiple possibilities for trading parties to buy and sell electrical energy on the wholesale market. Historically, mainly bilateral Over The Counter (OTC) contracts were used in which both parties agree to buy and/or sell a certain volume of energy on a certain date for a certain price. These contracts remain outside of the wholesale trading platform and there is little to no oversight on contract contents. Additionally, all credit and delivery risks rests with the two parties.

A second option, made possible by the trading platforms, is the exchange of standard contracts on an exchange market. The contracts contain buy or sell orders for a specific volume of electricity delivered on a specific date. Two types of contracts are identified: futures trading and spot trading. Futures trading is the trading of contracts of which the delivery date is well in the future. This allows parties to ensure a certain baseload for a well determined price. Spot trading is the trading of contracts of which the delivery date is during the same or the next day. The Day-Ahead Market (DAM) is the most used spot trading market. Parties place their buy or sell orders (hourly nominations) for the next day, the trading platform matches the individual orders and a price is determined. The price movements on the DAM are much more erratic than on the futures market, but this opens up perspectives for parties which can quickly ramp their energy use or production up and down. A second spot market is known as the Continuous Intraday Market (CIM) and allows for energy trading with very close delivery dates, sometimes up to a few minutes. Because of the imbalance implications of such real-time trading on the electrical grid, according to Elia (2012b) access to the CIM is very limited and it is only used in emergency situations.

A main difference between OTC and trading platforms is that the platforms act as clearing houses, thereby mitigating credit risks to market participants. The clearing house buys energy from the seller, and sells to the buyer. Seller and buyer remain anonymous, and the clearing house is responsible for payment and delivery.

2.2 Natural gas

Trading of natural gas is a relatively new phenomenon in Europe. Historically, natural gas was produced and consumed regionally and pricing was set by the local government and/or the state-owned utility company. Where gas transport grids were connected, regional pricing structures started to develop. Starting from the 1960s, Melling (2010) describes the coupling of natural gas pricing to the oil price index becoming the dominant market mechanism throughout much of the world.

However, in the United States, hub trading emerged as a competing market mechanism. In this mechanism, buyers and sellers form individual pricing arrangements and notify the gas hub to exchange the agreed upon volumes on agreed upon dates.

The European situation started to shift in the 1990s when the United Kingdom liberalized the natural gas market and utility companies started adopting the American market mechanisms. When the UK natural gas transport grid was connected through the Interconnector pipeline to Belgium in 1998, Interconnector UK (2014) states the hub trading mechanism gained a foothold in mainland Europe as well. The liberalization of European energy markets increased the popularity of the hub trading mechanism, but oil indexing still retains a not to be underestimated market share.

Natural gas trading is not as centralized or transparent as electrical energy trading discussed in the previous paragraph. The most important trading platform is hosted by the Dutch company ICE ENDEX . Parties can engage in futures or spot market trading, similar to the way electricity is traded. However, because of the greater flexibility of the natural gas transport grid provided by gas storage and flexible pipe pressure limits, the CIM is much more active. Nominations can be made up to one hour before delivery time.

Nonetheless, a lot of day-to-day natural gas trading in Europe happens in the form of OTC contracts and through brokers. Brokers are intermediate parties who receive buy or sell orders from their client portfolio and try to match them. They function similar to a trading platform, but provide no anonymity or clearing services. When a match between supply and demand is found, the broker arranges an OTC contract to be signed between the selling and buying party and informs the hub of the required volumes to be exchanged.

Because of the more decentralized nature of the natural gas market, it is less transparent and regional pricing differences exist. It is in some aspects similar to the electricity trading market before the establishment of the CWEMC interconnected zone.

3. Economics

In this section of the paper an example is given how participation on the energy trading market can result in lower energy costs without influencing the process the energy is delivered to. Only energy costs are discussed, A reference case is compared to two additional cases in which the process operator buys electrical energy at trading prices.

The cost comparison is made between three set-ups:

- Heat delivered exclusively by gas fired boiler
- Heat delivered by gas fired boiler and electrical immersion heater
- Heat delivered by gas fired boiler and electrical heat pump

The process heat demand is identical and constant in each case. In the first case, the heat is delivered exclusively by the gas fired boiler resulting in an energy cost dependent on a gas price fixed on a monthly basis. In the second case, heat is delivered by a gas fired boiler combined with an electrical immersion heater, with the energy cost depending on the monthly gas price and hourly electricity price. The immersion heater is only activated during hours when producing heat with electricity has a lower energy cost than producing heat through the gas fired boiler. During these times, the boiler is shut down.

The third case is similar to the second, but with the immersion heater replaced by an electrical heat pump.

The immersion heater is considered to have an efficiency of 100 %. The heat pump is considered to have a constant COP, e.g. by connecting the evaporator to a waste heat stream.

The cost comparison is made for a period of one year. The hourly electricity prices are taken from the Belgian power exchange (Belpex) DAM of the year 2012, the corresponding natural gas prices are monthly averages from the Dutch ENDEX gas trading platform.

Figure 1 shows the relation between heat pump COP and cost savings for different boiler efficiencies. For a plausible case with a boiler efficiency of 85 % and a heat pump COP of 3 a cost saving of 13.63 % can be achieved if the heat pump is activated rather than the gas fired boiler during times when generating heat with the heat pump results in lower energy cost. When the COP of the heat pump is lowered to the minimum value of 1, the gain drops to 3.16 %. This case is the same as when using the immersion heater. In the worst case, with a heat pump COP of 1 and a boiler efficiency of 95 %, the cost saving is 2.78 %. In the best case, with a heat pump COP of 6 and a boiler efficiency of 75 %, cost savings can be as high as 51.08 %.

4. Energy balancing

Distributed Renewable Energy Systems (DRES) have known a rapid increase in both number of installations and combined power generating capability throughout Europe. In the case of Flanders, the northern part of Belgium, this was especially the case for PhotoVoltaic (PV) installations. The main driver for this growth were the plentiful subsidies provided by the Flemish government combined with tax breaks from the federal Belgian government. According to data supplied by VREG (2008) this resulted in yearly increases of total installed PV power generating capacity as high as 488 % (in 2007).

The number of PV installations in Flanders is more or less evenly divided between small installations (P<10 kW) and large installation (P > 10 kW). Of the latter, around two-thirds are very large installations with more than 250 kW power.

Again according to data supplied by VREG (2012), as of 2012, PV power accounts for more than 33 % of the total renewable energy production in Flanders. The large amount of DRES can cause balancing problems on the electrical grid. DRES power production is more unpredictable than conventional controlled power generation and, in Flanders, DRES have priority over conventional power plants. Grid operators are therefore promoting the increase of synchronism between local energy consumption and production. This is also reflected in the energy pricing: the buy price of electrical energy is higher than the sell price, encouraging the increase of synchronism.

Energy storage offers interesting perspectives for increasing synchronism between local energy consumption and production as described by Krajacic et al. (2011) and Soderman and Pettersson (2004). Electrical energy storage is however relatively expensive an often suffers from low efficiencies. Desrues et al. (2010) states that heat storage is often much more feasible. This section of the paper explores the effect of thermal storage, e.g. of heat produced by electrical heat pumps on total energy cost of a process.

In Figure 2 the measured energy consumption of an electrical heating system for the months July to December is depicted, together with the energy production of a PV installation on the same site. The average power demand of the heating system is 11.8 kW and the half-yearly energy demand totals 51 MWh. The PV installation is sized to cover the energy use of the heating process. In the considered months, the 90 kW PV installation produces 53 MWh. Energy is bought at hourly variable price, which is taken from the Belgian power exchange (Belpex) DAM of the second half of the year 2012. Surplus energy is sold at a fixed price of €35 /MWh.

While the total energy production of the PV installation cancels out the total energy consumption of the heating process in the considered time frame, the energy demand profile seldom matches the energy generation profile. This lack of synchronism is depicted in Figure 3, which shows the demand and generation profile of a single day in August. PV power generation peaks while energy demand from the heating process remains stable.

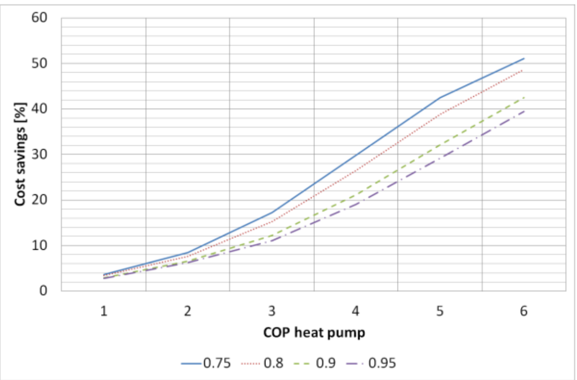

Figure 1: cost savings related to heat pump COP for different boiler efficiencies

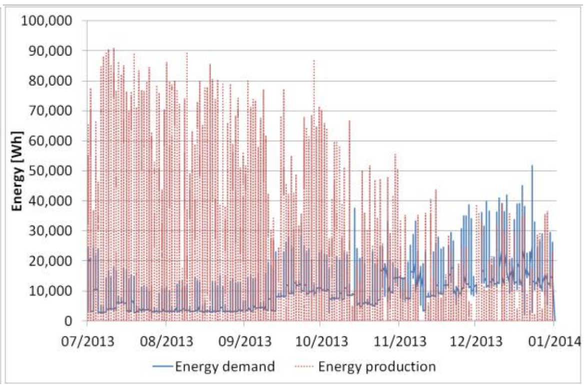

Figure 2: energy demand and production for July 2013 to December 2013

Increasing the synchronism between energy demand and energy production can result in additional cost savings. When there is a surplus in energy production, e.g. during noon, this surplus is sold on the grid for a price typically lower than the price at which energy is bought at market tariff when there is a shortage, e.g. during the night. If the energy surplus can be stored it (partly) removes the need for buying energy at market tariffs.

A simulation was made by adding a thermal buffer to the heating process. When there is a surplus of generated PV energy this is converted to heat, e.g. by raising the COP of the heat pump, and stored in the thermal buffer. When generation of PV energy falls below the energy demanded by the process, heat is taken from the buffer until it is empty or generated PV energy again rises above the energy demand.

Figure 4 shows the relationship the size of the thermal buffer, expressed relatively to the average energy demand of the process, and the calculated cost savings. When a thermal buffer the size of 25 % of the average energy demand is used, the cost saving amounts to 8 %. When the buffer size is doubled to 50 %, the cost savings rise slowly to 8.6 %. At 100 % around 11 % costs can be saved. Cost savings max out just below 18 %, but this requires a thermal buffer of five times the average process energy demand.

5. Conclusions

This paper explored some practical opportunities for additional cost savings in electrical process heating by employing the hourly variable pricing options provided by wholesale energy trading platforms and flexible electrical heating systems such as heat pumps. First, a short overview of the technical aspects of heat pumps were given, and some previous research into the use of heat pumps for balancing and storing of energy consumption was presented. Then the energy trading markets were discussed, with some similarities but also some discrepancies highlighted. Finally, two simulations were presented showing how variable energy pricing can lead to cost savings without influencing the process.

Most energy savings are modest but can reach levels as high as 51.08 % when high performing electrical heating systems are used, e.g. heat pumps with a high COP. With an installation with more feasible parameters, such as a heat pump with a COP of 3, 15.3 % savings still represent an interesting opportunity.

In a second simulation it was shown how thermal storage can be used to balance local energy production and consumption. By bridging the spread between higher energy buying prices and lower selling prices additional cost savings can be achieved. In the considered heating process, up to 18 % cost savings could be realized.

This paper only discussed potential energy cost savings. A complete economic analysis would also require hardware and installation cost. Also, electrical heating cannot be applied to all heating processes or process plants. E.g. for the sensible use of a heat pump, a waste heat stream is required.

Additional research can be done into more optimal use of the thermal buffer. In the above simulation, heat was transferred from the buffer to the heating process when local energy production did not meet the heating process' energy demand, independent of current hourly energy price. Additional cost savings could be realized if the stored heat is released during hours with high energy price.

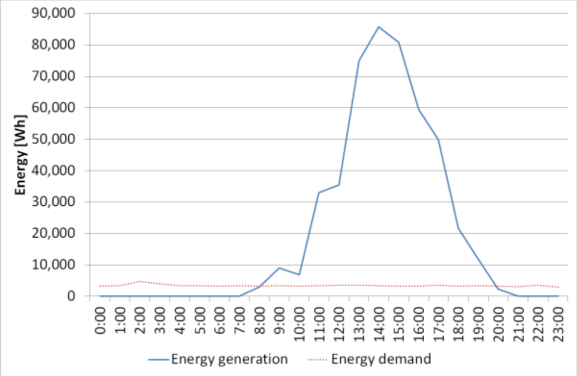

Figure 3: energy consumption and production for 20/08/2013

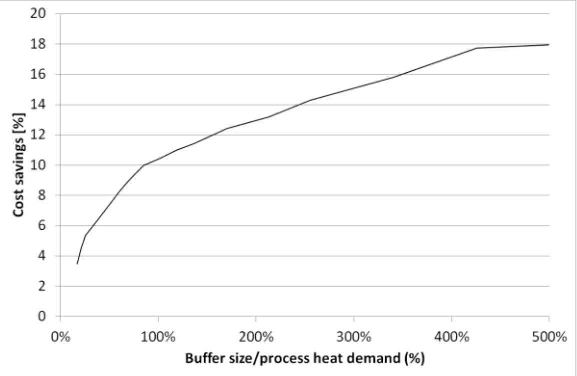

Figure 4: cost savings related to buffer size

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