Field of Tension between Energy Efficiency and Flexibility

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Abstract:
Energy efficiency measures in the industrial sector contributed to the decarbonisation over the last years. For a successful transition towards an energy system with high shares of variable energy sources it is assumed that flexibility on the demand side will increase in value /**FFE-14 16**/. This paper deals with the conflict and compliance potentials of these two goals.

The analysis is conducted from two directions. At first, the impact on the energy consumption of running industrial processes is calculated for six specific applications. For this approach the change in the weighted overall efficiency level is chosen as evaluation criteria. Secondly, the effects of energy efficiency measures on the flexibility potential are discussed. Installed overcapacities are on the one hand one of the key causes for flexibly running processes and on the other hand the reason for energy inefficiency. The different roots of overcapacities are depicted and the relating impacts of using these capacities for demand side management are assessed. The second part of the analysis shows that the influence of energy efficiency measures on flexibility potential is a slight decrease in positive demand response potential and an increase of the negative demand response potential.

Keywords: Energy Efficiency, Flexibility, Demand Response, Demand Side Management, Industrial processes

1 Introduction

The path towards a successful *Energiewende* in Germany and Europe is based on two main pillars: improvements in energy efficiency and the increased usage of renewable energies /**BMU-10 10**/. To ensure the implementation of energy efficiency measures, the German government followed the EU energy efficiency directive RL 2012/27/EU /**EU-01 12**/ by establishing a binding obligation for (non SME-) enterprises to either carry out energy audits every four years or to establish an energy management system according to ISO 50001 or EMAS. Furthermore, in order to feed in more fluctuating renewable energy to the grid, demand response measures play a continuously growing role.

In this study it is analyzed, if there are reciprocal effects between energy efficiency and flexibility, and how far this field of tension might influence the measures to be implemented within industries, in particular in electricity intensive processes and cross-sectional technologies.

Definition: Flexibilization of loads

Flexibilization of loads, also referred to as demand response, means either load shedding or load shifting compared to the regular operation of a facility. Load shifting only causes a time shift in the production. In other words the lost output can be regained at a later point of time and load shifting has therefore no influence on the amount of production, whereas load shedding induces a loss of production /**FFE-10 14**/.

2 Methodology

The study approaches the reciprocal effect of energy efficiency and flexibility from both directions. The methodology presented here was developed within the pilot project "Demand Side Management Bayern" /**DENA-01 16**/ and the project „Merit Order der Energiespeicherung im Jahr 2030" /**FFE-05 16**/.

2.1 Influence of load flexibility on energy efficiency

To begin with, the influence of demand response on energy efficiency is analyzed.

There may be positive as well as negative effects on energy efficiency. The technologies analyzed can be clustered into electricity intensive processes and cross-sectional technologies. Moreover, the demand response measures have to be differentiated into load shift and load shedding. The following operating modes are considered:

• Tendering of positive power: the provision has no impact on the regular load operation and an activation leads to reduced load operation

• Tendering of positive power: the regular load operation is increased during provision and an activation brings back the load to regular operation mode

• Tendering of negative power: the provision has no impact on the regular load operation and an activation leads to full load operation

• Tendering of negative power: the provision leads to reduced load operation and an activation brings back the load to regular operation mode

The analysis of the effects of load flexibility on energy efficiency is based on calculations of potential changes in the weighted overall efficiency per annum.

$$\Delta\eta = \frac{E_n}{E_f} - 1$$

$\Delta\eta$ change in annual overall efficiency (positive value means increase of overall efficiency, negative value means decrease of overall efficiency)

E annual electricity consumption

n normal operation mode without tendering of flexibility

f changed operation mode with tendering of flexibility

In order to determine the annual overall efficiency, following influencing factors were considered: increased or reduced specific energy consumption of electricity intensive processes, additional start-up and shut-down procedures, partial load efficiency of engines and of technologies themselves (e. g. pump, ventilator), partial load efficiency of power transmission and increased heat losses or increased heat input (cold storage).

The calculations presented in this paper are based on provision times of 7,000 h/a for all electricity intensive processes and for cross-sectional technologies when tendering positive power, and a provision time of 4,000 h/a for cross-sectional technologies when tendering negative power.

2.2 Influence of energy efficiency on load flexibility

The potential effects of energy efficiency changes on load flexibility were analyzed and the methodology is presented in the following paragraphs.

Electricity intensive processes

In order to assess the influence of energy efficiency on load flexibility, there are two main aspects to be considered. One aspect to be evaluated is the development of electricity intensity of processes in the future. Depending if there is an increase or decrease in energy efficiency, the potential for demand side flexibility may change over time.

The second aspect to be considered relates to procedural changes within the industries. Technological advances may lead to changes of processes towards more efficient or more adaptable procedures. This may cause a boost in the amount of processes that allow load flexibilization for demand response measures.

Cross sectional technologies

The methodology used to calculate the impact of energy efficiency measures on the flexibility potential of cross-sectional technologies included four steps, depicted in Figure 2-1. First, the typical energy efficiency measures for each technology were identified, out of which the measures with highest probability of implementation were selected. Next, the impact of the efficiency measures on the installed capacity was assessed. At last, the impact on the flexible power could be determined.

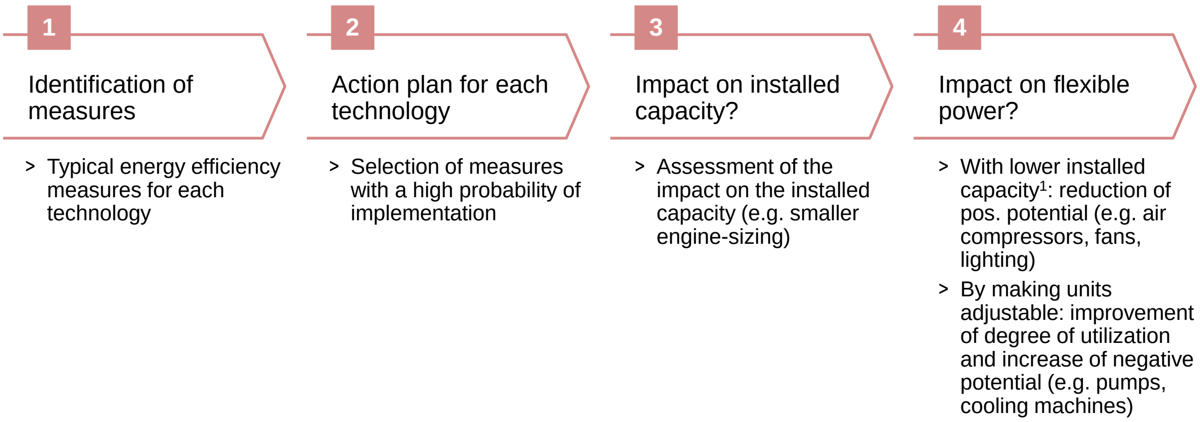

Figure 2-1: Methodology to determine the influence of energy efficiency on load flexibility (cross-sectional technologies), /**FFE-01 13**/

2.3 Reasons for flexibility

After analyzing the reciprocal effects of flexibility and efficiency, the roots of flexibility within industries are examined. The methodology, based on the results of /**DENA-01 16**/, is to investigate in how far enterprises are running their operations efficiently and, if not, whether it is reasonable to first undertake efficiency enhancements. Thus, flexibility potential emerges, when there is superfluous inefficiency within the production process or in cross-sectional technologies, allowing a decrease or increase of the load for certain periods of time.

3 Results

3.1 Influence of load flexibility on energy efficiency

The calculations of the effects of load flexibility on energy efficiency are based on the potential changes in the weighted overall efficiency of each electricity intensive process and cross-sectional technology. In the following, one exemplary calculation for each case is given and the overall results that were developed within the DSM Bayern pilot project /**DENA-01 16**/ are presented.

Electricity intensive processes – example: chloralkali electrolysis

The specific power consumption of the chloralkali electrolysis increases with an increase in partial load and decreases with a reduction of the partial load. The mere provision of flexible power does not require any change in the initial operating mode, which is typically a partial load operation. When tendering positive power, activation leads to an alteration of the operating point by reducing the specific and as well as the absolute power consumption of the process, causing an increase in energy efficiency (Figure 3-1).

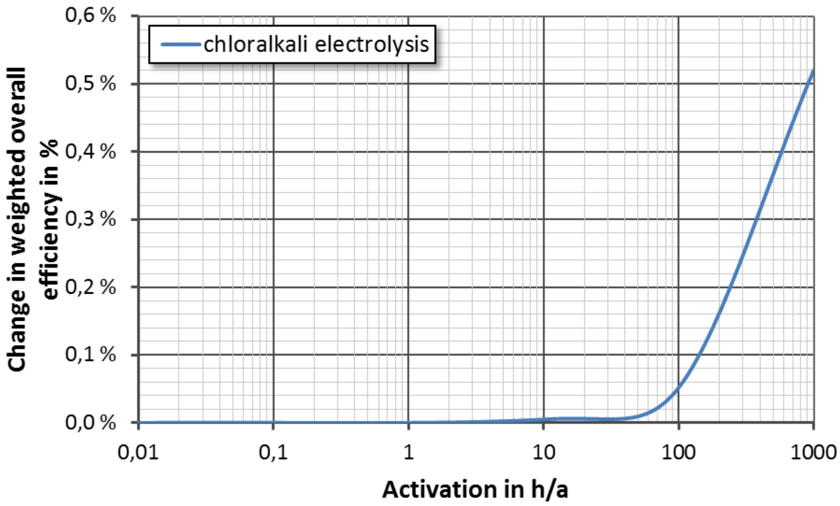

Figure 3-1: Change in weighted overall efficiency of the chloralkali electrolysis during activation caused by tendering of positive power (7,000 h provision time)

Correspondingly, when tendering negative power, the specific and as well as the absolute power consumption are increased during activation, which then leads to a decrease in energy efficiency of the chloralkali electrolysis (Figure 3-2).

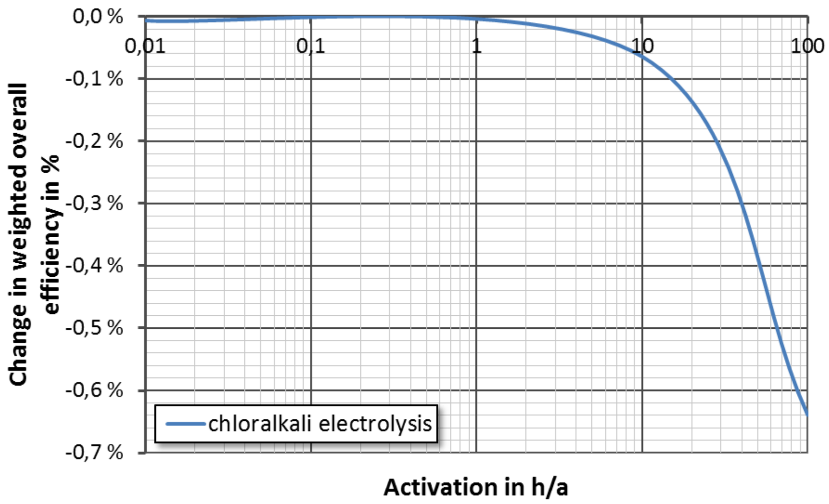

Figure 3-2: Change in weighted overall efficiency of the chloralkali electrolysis during activation caused by tendering of negative power (7,000 h provision time)

As a whole, following influences on energy efficiency of electricity intensive processes where determined, which can also be seen in Table 3-1. The energy efficiency of aluminum electrolysis is influenced by demand response measures only on a limited dimension, since the efficiency changes of about 5 % are in the range of measurement uncertainty. Within the chloralkali electrolysis, demand response may lead to small changes in the degree of efficiency; however the maximum decrease or increase is merely around one percent. The influence of tendering of negative power with the electric arc furnace is negligible, whereas tendering of positive power may result in a decrease of the efficiency degree up to 2 % because of the additional heat losses during temporary shut-down.

It is important to remark, that for manufacturing companies the output of the production process is the most significant concern. As long as the production volume and quality can be reached, tendering of flexible power can be conducted without any major resistance. In the case of not meeting the required production quantity in a certain period, the operating time of a facility is increased, so that the backlog demand can be caught up. If tendering of flexibility by any circumstance compromised the planned output volume, then it would not be carried out by the company.

Cross sectional technologies – example: pump

For the exemplary calculation three structurally identical facilities, which are supplied with cooling water by a pump, were analyzed. In this case, the pump was equipped with a frequency converter, so that the volume flow could be flexibly adapted to the demand. The input data considered was a nominal flow rate of 400 m^3/h and a reduction to around 2/3 of the initial flow rate during activation. The results are presented in following paragraphs.

When tendering positive power, energy efficiency increases in principle, although requirements such as constant flow rate or flow and return temperatures have to be considered. Additionally, backlog demand may be needed to transport away the waste heat after the activation.

Results also include a slight reduction in the overall efficiency, which is caused by a deterioration of the individual efficiencies of transmission system and engine, whereas the efficiency of the pump stays nearly constant. On the other hand, in partial load operation significantly lower pressure losses have to be overcome, resulting in significantly lower power consumption. By tendering positive power, an activation of 1,000 h/a improves the weighted overall efficiency by about 5.6 % (Figure 3-3).

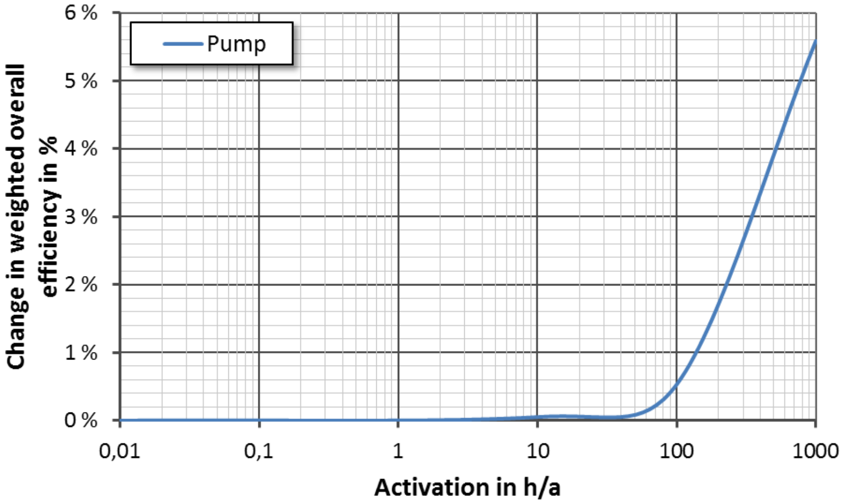

Figure 3-3: Change in weighted overall efficiency of the pump during activation caused by tendering of positive power (7,000 h provision time)

When tendering negative power, there needs to be significantly reduced power consumption during provision (e. g. only two of the three facilities running), and activation leads to a power increase to the initial state (all three facilities running). The reason for this is that the pressure drop changes proportionally to the square of power consumption, although during full load operation significantly higher pressure drops have to be overcome. In total, with an activation of 1,000 h/a, the weighted overall efficiency of the pump improves by about 40 % by tendering negative power (Figure 3-4).

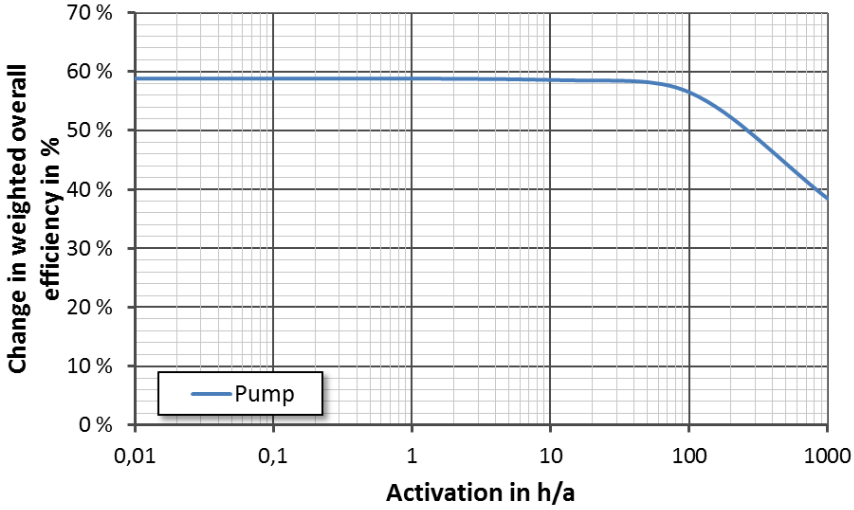

Figure 3-4: Change in weighted overall efficiency of the pump during activation caused by tendering of negative power (4,000 h provision time)

An important consideration while assessing flexibility potentials of cross-sectional technologies is that volume flows of pumps and fans can be adapted to demand by two means: throttle control and speed control. Whereas the power consumption of the partial load operation is maintained relatively high through throttle control, it can be reduced significantly when utilizing a flexibly controlled frequency converter. Since the volume flow is proportional to the cube of power consumption, this means that during partial load operation the power consumption can be considerably reduced through speed control, thus causing an improvement of the energy efficiency of the unit. The relation of power consumption and volume flow depending on the type of volume flow control is displayed in Figure 3-5.

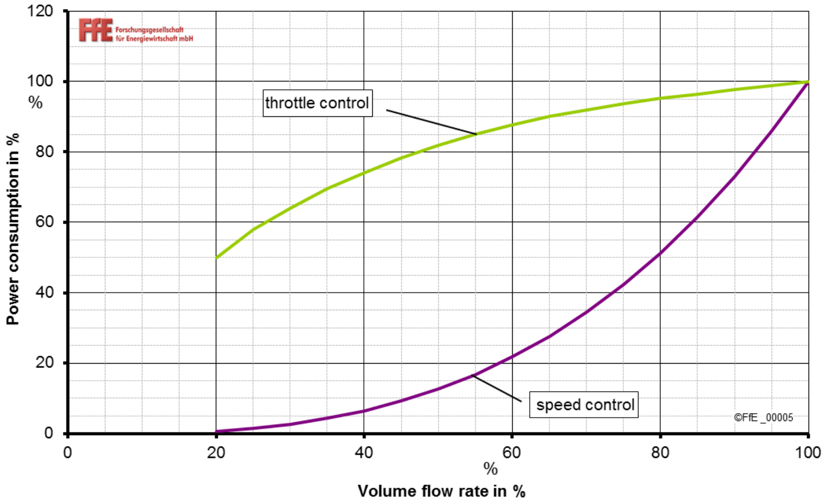

Figure 3-5: Power consumption subject to volume flow rate in throttle control and speed control

As a whole, demand response measures with cross sectional technologies may lead to slight negative changes in overall energy efficiency of the technologies. Nevertheless, the decreasing effect of speed controlled volume flows on power consumption significantly surpasses the small efficiency decline of transmission system and engine, and results in a substantial enhancement of the energy efficiency of pumps and fans. The results of the calculations are displayed in Table 3-1.

The following table shows how different activation frequencies (10, 100, 1,000 hours per annum) of the demand response potential have impact on the efficiency level. The analysis differentiates between positive demand response potential (reducing the load and providing a positive contribution to the system balance between generation and consumption) and negative demand response potential (increasing the load and providing a negative contribution to the system balance between generation and consumption).

Table 3-1: Change of overall efficiency by tendering of flexibility

provision: 7.000 h/a pump & compressed air: 4000 h/a		activation in h/a					
		10		100		1000	
		influence on					
allocation	technology	pos. potential	neg. potential	pos. potential	neg. potential	pos. potential	neg. potential
electricity intensive process	aluminium electrolysis	< -0.1 %	< -5 %	< -1 %	< -5 %	0 %	< -5 %
electricity intensive process	chloralkali electrolysis	< 0.1 %	0 %	< 0.1 %	0 %	< 1 %	< -0.1 %
electricity intensive process	electric arc furnace	< -0.1 %	0 %	< -1 %	0 %	< -5 %	< 0.1 %
cross sectional technology	fan (ventilation system)	< 0.1 %		< 1 %		< 5 %	
cross sectional technology	pump	< 0.1 %	< 60 %	< 1 %	< 60 %	< 10 %	< 40 %
cross sectional technology	compressed air	< -0.1 %	< -10 %	< -0.1 %	< -10 %	< -1 %	< -5 %

- = decreasing overall efficiency

+ = increasing overall efficiency

In most applications and activation frequencies the impact on the efficiency level is less than 1 % and therefore below typical measuring accuracy. Considerable efficiency changes can be assessed for pumps, ventilation systems and compressed air with yearly activation times of more than 1,000 hours.

3.2 Influence of energy efficiency on load flexibility

The results of the study „Merit Order der Energiespeicherung im Jahr 2030“ /**FFE-05 16**/ are presented in the following paragraphs.

Electricity intensive processes

Energy efficiency implies a long-term reduction of the energy intensity of processes. Several studies assume a decrease of electricity intensity for individual processes up to 5 % until 2030 (business as usual scenario, /**ISI-06 11**/). A reduction of electricity intensity has a diminishing effect on the positive flexibility potential.

On the other hand, energy efficiency measures may lead to procedural changes in electricity intensive processes, resulting in an increase or decrease of positive or negative flexibility potential. An example is the replacement of the inflexible diaphragm process in chlorine production by the flexibilized membrane process, which can then participate in demand response.

Cross sectional technologies

Two effects of energy efficiency on the potential of load flexibility for cross-sectional technologies were identified /**FFE-01 13**/. First, a lower installed nominal power leads to a general reduction of the positive flexibility potential. Second, an increase in the negative potential can be achieved by making units adjustable. This is due to the improvement of the degree of utilization when units can be adapted to the demand, therefore leading to an increase in the overall negative potential.

3.3 Reasons for flexibility

In the study DSM Bayern /**DENA-01 16**/, two main reasons for flexibility were identified: oversizing and redundancy of units.

Redundancy means that there is an additional and functionally equivalent unit, which is not needed in normal conditions. Therefore, redundancy is primarily caused by the need for intentional security within the production process. It was found that technologies with redundancies are mostly pumps, boilers, cooling machines and air compressors.

Redundancies are an important source for potential offering of flexibility. To that effect, redundant units may be switched on to enable tendering of negative power. An important prerequisite is that the increased power has to be either immediately used or temporarily stored. Moreover, it must be ensured that no redundant unit compensates the shutdown of a regular unit during activation of positive power.

Oversizing occurs when the installed power capacity of a unit exceeds the maximum requirement. There are different reasons for intentional or unintentional oversizing. Within industrial enterprises, oversizing may be planned for future expansion of production or for increase of production output. From the perspective of the planner of the unit, there might be an intentional oversizing characterized by a larger dimensioning of units in order to guarantee supply in any case. On the other hand, the engineering of the facilities is often based on reference data rather than plant-specific needs, causing unintentionally oversized units. From the producer´s perspective, there are often only certain power classes available, which results in an unintentional but conscious oversizing.

When technically feasible and economically advantageous, the oversizing of units is reduced and will therefore no longer be available to provide flexibility potential for demand response. In the event the enterprise has already implemented demand response measures with other units, the utilization of the additional oversized units for demand response might be considered.

4 Summary and Conclusion

First, this study analyzed the influence of the utilization of load flexibility on energy efficiency in the industrial sector. For this, the changes of the weighted overall efficiency of some relevant electricity intensive processes and cross-sectional technologies were calculated. The results show that the effects are usually negligible, since they are in the range of measurement uncertainty. Exceptions are technologies with variable speed control or a deviation from the optimized operating point.

Second, the influence of energy efficiency on the flexibility potential was determined. A reduction in the installed power leads to a reduced positive flexibility potential. It was also found, that by making units adjustable, an increased negative potential and a higher degree of utilization can be reached.

Third, the two main causes for flexibility of the industrial load, oversizing and redundancy, were evaluated. While the first step taken by enterprises is to reduce oversizing of units as far as economically and technically possible, the second step is to take intentionally oversized and redundant units into consideration for flexibility measures.

Finally, it was concluded that the analyzed field of tension merely comprises marginal reciprocal effects between energy efficiency and load flexibility. But further research is necessary to find out how these two pillars of the future energy system work together if they are considered in a comprehensive planning process right from the beginning.

5 Literature

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