System optimization through co-operation
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Abstract

Until now, much of the work for energy efficiency has been concentrated on raising the effectiveness of single components. More attention should be given to the whole system, as this can allow radical improvements in energy efficiency. Pumping applications present a good example on the importance of systems approach, as they consume up to 15–20 percent of electricity both in the US and Europe. A pump is the second most widely used type of mechanical equipment in the world as only the electric motor outnumbers it.

This paper focuses on three themes: reliability and energy efficiency boost of pumping systems with the systems approach, consortium-based development work that this requires and practical application of the obtained knowledge during energy appraisals for existing systems.

So far reliability studies have mainly been carried out for fixed-speed pumping systems. For variable-speed-driven (VSD) pumps, the traditional recommendation of driving the pump at its best efficiency point (BEP) may not be the most feasible approach, if the pump can alternatively be driven at a lower rotational speed. The latest research suggests that the concept of best efficiency area (BEA) should be used with the VSD pumping systems in addition to the pump BEP information. The best efficiency area can be determined according to the specific energy consumption $E_s$ of the pumping system.

A concrete methodology to decrease the amount of energy used in e.g. pumping applications is introduced. With these energy appraisals a company can determine the anticipated savings from given applications.

The successful realization of the systems approach requires a wide knowledge that individual companies do not typically possess. Instead, a co-operative model is needed to gain the expertise of several companies into the same research project. This paper presents a program that has the goal to realize radical improvements in the system energy efficiency with the co-operation of device manufacturers, system designers and academia.

Introduction

The world is becoming ever more dependent on electric energy. More and more industrial processes rely completely on electric motors. Also residential usage of electricity is rising steadily. This ongoing increase in demand makes a compelling case for energy efficiency.

If energy efficiency of whole system is observed instead of individual components, significant savings can be made. Alike individual companies do not generally alone have the required information for system improvements. Thus it can be advantageous if companies join forces in a consortium. This enables them to pool resources and share research results, which is both faster and more cost effective than each company trying to resolve the problems by themselves.

As a case of point, attention is drawn to increasing the energy efficiency in pumping applications. Here the concepts of best efficiency operating point (BEP) and best efficiency operating area (BEA) are introduced.

Energy appraisals are a pragmatic way towards realizing the energy saving potential in industrial installations and applications. When the system approach is taken into consideration, even bigger savings can be reached.
System approach combines efforts

Many innovations have been the product of a specific research program or team, or even individuals. Today, however, it is becoming ever more commonplace that industry, research institutes and universities work together. Thus joint project planning and new joint research programs will considerably facilitate the development of the whole innovation chain and the development of globally competitive technology and service products. (Tolvanen, 2011)

Close co-operation between suppliers and customers has been commonplace in energy intensive Finnish industries. Today, however, this has been lifted to a new level, where even research and development work is pursued in a joint manner.

In Finland this kind of work has been pioneered in a consortium called CLEEN Ltd. CLEEN is one of six Finnish Strategic Centres for Science, Technology and Innovation. These competence clusters concentrate on research on the most important areas of business and society. CLEEN focuses on energy and environment.

The ownership of CLEEN is divided between private companies, research institutes and universities. The funding of its research activities, i.e. research programs, is provided by the participating companies. Significant contribution comes also from non-shareholders and Tekes, the Finnish Funding Agency for Technology and Innovation.

The objective of CLEEN is to create value to the participants through its operations by offering the most competitive environment for joint knowledge building of the best industrial and academic competences. The national aspect is that the hub and access into the network of world class energy and environmental core competences would be found from Finland. Therefore it is crucial that Finland holds its competitiveness and reputation as a place for trustworthy and flourishing environment for open innovation. (ABB Review, 1/2011)

Consortium work advantages

One of the major advantages in the systems approach is that the research will be concentrated on generic energy intensive applications instead of industry specific ones. For example, the research topics include future industrial separation, low temperature heat recovery and pumping, ventilation and mixing systems.

Participating in a CLEEN program can be very advantageous for the company or research facility. If, for instance, a research initiative costs one million euros, and the research were decided to be performed by only one participant, the costs could be reimbursed maximally by 30 percent by the Finnish Funding Agency for Technology and Innovation, Tekes.

If the research were carried out in the consortium of CLEEN, one half of the costs would be taken care of a participating university. The other half would be divided by the participating companies. This means a significant contribution to the R&D budget.

Mutual trust is, of course, an important element of the consortium work, but Intellectual Property Rights (IPR) are of such importance to the whole idea that participants are required to share the results of their work. This cornerstone is cemented through IPR agreements. Many participants also have such projects that they want to develop alone. Thus they will have to consider carefully, which projects they want give in the public domain. Usually the answer lies in the applicability and competitive edge of the project. The companies obviously want to keep this kind of strategic projects to themselves. Hence, an ideal CLEEN project encompasses such knowledge that is of generic value to the whole industry.
Efficient Energy Use Program EFEU
CLEEN has already produced research results in its first programs. Now the EFEU program has also started its work. The work is based on the finding that power losses through each stage in the power consumption process add up to significant amounts (Figure 1). If energy can be saved in some stage of the process, the gain in primary energy savings can be significant. (CLEEN, 2010)

When the working groups in CLEEN are composed in such a way that a problem is looked at from various angles, it is more probable to come up with a solution that alleviates the whole process instead optimizing just a small part of it. The latter can occur more easily, if the development work is done by an individual company.

The EFEU program is divided into three working packages (WPs). WP1 contains the management of the project, communication with partners and dissemination of results through workshops, seminars and related organisations.

WP2 concentrates on energy system level. There is a single project Energy Efficiency of Energy Chains. In the project the energy efficiency of different energy chains will be studied and optimal energy chains are found by using different criteria, such as energy efficiency, cost-effectiveness and potential to reduce emissions. This work package pursues comprehensive understanding of energy efficiency and CO₂ emissions in energy chains.

In previous studies the focus has been in the emissions into air, not in the efficient use of energy. Often the specific energy consumption or energy efficiency is rather only one of the input variables in the environmental assessment than a main interest. However, in this work package the focus is in energy efficiency of wide energy systems, i.e. energy chains.

WP3 focuses on industrial systems in three projects: Energy Efficient Process Sites, Energy Efficient Separation Methods and Integrated Fluid Handling Systems. In the first one the focus is on reducing primary energy consumption of industrial process sites by developing and improving system analysis tools and their capabilities to integrate the most potential upgrading, recovery and conversion technologies into processes. Likewise, the main objective of Energy Efficient Separation Methods is to improve the separation efficiency by 25 percent compared to the current best available technology. (CLEEN Efficient Energy Use Program Plan 2011–2015, 2010)

Best efficiency point vs. Best efficiency area
Pumping applications represent a good example of the importance of the systems approach, as pumping systems consume up to 15–20 percent of electricity in the US and Europe. A pump is the second most widely used type of mechanical equipment in the world as only the electric motor outnumberes it. There are literally millions of them in service in every conceivable application.

Pumping applications bear a clear connection to the previously mentioned work in the CLEEN consortium as they are one of the focus areas in WP3. Integrated Fluid Handling Systems concentrates on pumping, mixing and ventilation systems that represent the most consumed energy in industrial applications. According to preliminary analysis, up to 60 percent savings in primary energy could be reached in pumping systems. (CLEEN Efficient Energy Use Program Plan 2011–2015, 2010)

Most of pumps are typically operated (relatively) near their best efficiency point, with the pump efficiency around 70–90 percent. Because of this high efficiency rating, it is easy to dismiss the potential energy savings that can be reached by optimizing pumping systems for instance based on their specific energy consumption \( E_s \) (kWh/m³). (Livoti, 2011)
A pump is very sensitive to how it is operated, which is why the pump controlling device has a great influence on the pump energy use together with the characteristics of the surrounding system: a centrifugal pump can be very efficiently designed, yet it can be operated in an inefficient manner. As a result, many pumping systems operate at efficiencies far below their best efficiency point (BEP). Since energy costs can account for as much as 75 percent of a pump’s total cost of ownership, inefficient pump operation can have a substantial effect on the pump usage costs. If the pumping system is installed, operated or sized incorrectly, also the maintenance and downtime costs can be higher than anticipated. For these reasons, a fixed-speed pump should be selected and normally operated at or near its best efficiency point.

**Best efficiency area (BEA)**

As the severity of pump vibration, cavitation, and flow recirculation phenomena are greatly affected by the pump rotational speed, guidelines given for centrifugal pumps should more clearly recognize the effects of variable speed operation on the pumping system energy efficiency and reliability. So far, reliability studies have mainly been carried out for fixed-speed pumping systems. For variable-speed-driven (variable-speed) pumps, the traditional recommendation of driving the pump at its best efficiency point may not be the most feasible approach, if the pump can alternatively be driven at a lower rotational speed. Researchers of Lappeenranta University of Technology (LUT), Finland, suggest that the concept of best efficiency area should be used with the VSD pumping systems besides the pump BEP information. Figure 2 shows how the BEA can be determined according to the relative specific energy consumption $E_s$ of the pumping system at different operating conditions, which also considers the effect of surrounding process on the system energy efficiency. (Viholainen & al, 2011)

**Energy appraisals**

It has been shown in practice that a service-oriented approach towards energy savings brings good results. This means that an industrial facility and/or industrial application(s) are audited in terms of their energy efficiency. According to this appraisal, the appropriate systems are taken into use.
Energy appraisals lead to significant savings

Only some industrial systems are optimally dimensioned from the point of view of energy efficiency. Designing an optimised plant with hundreds of actuators, valves, pumps, fans, etc. for a complex process that involves multiple parameters from varying demand to ageing equipment is a challenging task. The investment cost for both the (re)design and for the selection of control equipment technology still remains a major decision criteria, even if it only represents less than five percent of the plant life cycle costs.

In order for a company to reduce energy costs, it needs to evaluate how it uses energy. An energy appraisal is a systematic examination of key pump and fan applications both theoretically and computationally. Besides replacing the existing control mechanism with a VSD-based control system, the calculations often justify having new energy saving motors with IE3 or IE4 efficiency class.

The appraisal defines where energy can be saved and quantifies how much energy can be saved with the installation of variable speed drives and new high efficiency motors. These figures are then translated into a possible annual saving, the amount of money that will be saved in energy bills alone, if the equipment is installed.

Figure 2. Relative $E_r$ of a pumping system including the drive train efficiency at different operating conditions. BEA is determined here to be the region with relative $E_r$ below 1, and it is affected by the applied rotational speed.

Figure 3. Required and wasted energy with different control mechanisms. When smaller flow ($Q_2$) is needed part of the energy is wasted (to frictions and heat) with throttle control, but with variable speed control just needed speed of the pump can be used without wasted energy. (Application guide No. 2, 2006)
It is not unusual for users to dismiss the promise of 50 percent energy saving on a 20 percent speed reduction as the exaggerated claims of a manufacturer. (Sustainability Guide No. 1, 2008). However the savings can be verified and the best way to start is with an energy appraisal.

The advantage of using VSD control can be seen from Figure 3. Throttling control leads to high loss in the pump and in the valve when the system is running at a reduced flow rate. In VSD control, the operating point follows the system curve, which can be optimal for the pump efficiency in closed-loop systems. In general, based on affinity laws, the energy consumption drops dramatically, when speed is reduced. The energy savings with VSD control are thus significant. (Application guide No. 2, 2006)

Identification of typical process functions

Another study by the Institute of Energy Technology at LUT, Finland, looked into the process system where a centrifugal pump works. In practice, the surrounding process system dictates how the pump operates. Therefore, it is important to understand the characteristics of the process in which the pump is located, since they determine the minimum possible energy consumption of a pumping system. For instance, a small closed-loop pumping task typically requires less energy than the distribution of water with a constant pressure reference. By identifying typical (and ideal) process functions and tasks set for pumping systems, models can be formed for each process function concerning the locations of pump operating points and the energy consumption of the pumping system. These models may provide new tools for energy appraisals, and also move the prime focus of energy appraisals from a single pumping system to the complete process. (Ahonen & al, 2011)

In Table 1, four generic classes of process functions are introduced with examples of pumping applications belonging to each class.

If the emphasis in energy appraisals can be moved more towards evaluating whole systems as compared to auditing individual components or applications, the results can be more far-reaching in terms of anticipated savings. Also the energy saving measures can be dimensioned accordingly.
Energy appraisal put to practice

ABB has used energy appraisals in various countries all over the world. To this date – April 2012 – several thousands of appraisals have been made, which present a good background for evaluation of the process.

When the customer has decided to have an energy appraisal, usually some three to five pumps and fans are selected for closer scrutiny. Information, including power and annual usage times are gathered for calculation together with the customer. The information is fed in the appraisal tool, from which the customer gets a detailed report of the energy usage of the present solution as well as a proposition based on the use of VSDs. With this method the customer gets engaged in the process as the measurements are done together with the appraisal team. It is not unusual – after the first VSDs have been installed and after having compared the energy consumption figures of before and after – that the customer orders new appraisals.

The following calculation exemplifies a possible appraisal output:

- A pump with a 100 kW motor uses control by throttling of 20 percent. The nominal flow of the pump is 1,100 m³/h and the nominal head 25 meters (max head 35 meters). The efficiency of the pump is 85 percent and the static head 5 meters. The annual time of use is 8,046 hours (seven days a week and 48 weeks) and the price for electric energy is 0.1 euros/kWh (=100 euros/MWh). With throttling the annual consumption of electricity goes up to 685.3 MWh and with VSD control to 452.6 MWh. Thus the annual savings amount to 233.7 MWh or approx. 23,000 euros (34%). Because most industrial sites have more than just one pump, the potential savings are obvious.

Conclusions

First the model of doing joint research was introduced. This kind of work has been pioneered in Finland in the consortium of CLEEN. The participants of CLEEN come from companies and academia, who share the same interest in resolving complex problems. By joining forces the participants gain a wide knowledge that individual companies do not generally have. The CLEEN research program have looked at several areas within electrical engineering. In the context of this paper, the EFEU program was taken into closer consideration.

As a case of point for the energy efficient use, pumps were mentioned because they use more energy than any other industrial application. It is therefore of great relevance that the pumping process is made more energy efficient. To this end the concepts of best efficiency point and best efficiency area were introduced. If pumps were run at their $E_s$-determined best efficiency area instead of the best efficiency point, significant amounts of energy could be saved by the pumping system operation with lower $E_s$. Also the pump service life would be most probably prolonged with the energy efficient system operation.

A practical way of applying the knowledge gained in the work of CLEEN and in the study of pumps is the use of energy appraisals. These audits convey the accumulated knowledge to the factory floor. The appraisals give recommendations for energy saving measures with which significant savings can be reached. The payback times are dependent on the kind of investment that is taken into use.

The research consortium and energy appraisals strive for the same goal: to optimize the system through co-operation.
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