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Analysis of Electrical Energy Consumption of Accelerator Reserach Facilities

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ANALYSIS OF ELECTRICAL ENERGY CONSUMPTION OF ACCELERATOR RESEARCH FACILITIES*

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Abstract

Optimization of energy efficiency and utilization of renewable energy sources has become a major focus of political and social policies, leading to increasing energy cost not only in Germany but also in the European energy market. Simultaneously the energy demand of future accelerator projects is estimated to rise compared to existing facilities, leading to overall increased energy costs. Energy efficiency could counteract this trend by reducing energy consumption for a given research goal. This work aims to find recommendations for saving potential in existing research accelerators as well as guidelines for construction of future facilities. In order to identify and develop key figures for comparison between several international particle accelerator facilities, data has been collected by a questionnaire developed in co-operation between GSI and TUD, Darmstadt. We present the first results of it's evaluation.

INTRODUCTION

Accelerator research facilities have always aimed for ambitious research goals. Todays science frontiers demand large-scale machinery to reach highest particle energies and intensities.

These user demands lead to increasing energy consumption of the overall facilities and thus rising operation costs. In combination with increased ecological consciousness, questions by society or funding agencies about the overall energy efficiency of large-scale science facilities arise.

Single components used for constructing accelerators are usually already optimized for low energy consumption due to design constraints. Higher efficiency leads to lower amounts of waste heat, less need of cooling and might be the only way to make the component's operation feasible at all. Nevertheless there are always options to improve. Many accelerator facilities look back on long and successful operation histories. Even if they are continuously upgraded, parts of old machinery is still in use today. In general complex machinery will always be made of some parts which have been given more R&D efforts, while others were designed under time and budget restrictions or had special design criteria which did not lead to the optimal solution for today's energy efficiency demands.

We aim to break down the overall energy consumption of large-scale science facilities to subsystems to identify parts of machinery and modes of operation which are main energy consumers and such most worthwhile to investigate for efficiency improvements.

A final goal of our research is to identify potential energy consumers with a high volatility which can be used as variable load for energy network stabilization. Especially interesting are operation scenarios which can vary their loads on demand without harming their overall science output. This can be either done by energy management on long timescales, for example planning beam-times according to energy demands in the local grid, or on short timescales by direct switching between high and low consumption modes on demand, or as reaction to the energy spot market.

THE STUDY

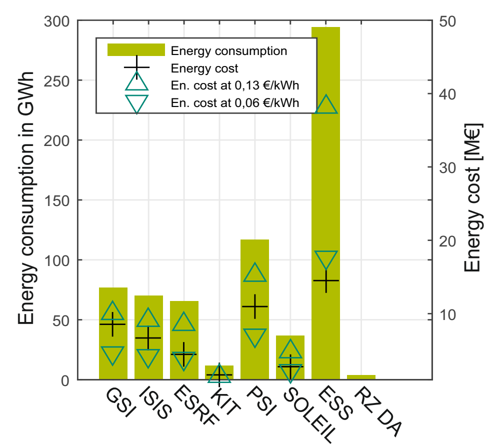

Figure 1: Energy consumption of investigated research centers and the computing center of the TU Darmstadt. All but KIT and RZ run research accelerators for different science communities. The prices range from 0.06 €/kWh to 0.13 €/kWh.

The Department of Electrical Power Supply with Integration of Renewable Energies of TU Darmstadt (E5) [1] and GSI Helmholtzzentrum für Schwerionenforschung (GSI) developed a questionnaire on electrical power consumption which was sent to fourteen institutions. The questionnaire contains general questions about energy consumption and supply as well as specific question aimed towards changing loads and distribution of the demand on major parts of the facility. The questionnaire was answered by eight research facilities, six of them operating accelerators. The others didn't answer mostly due to confidentiality obligations.

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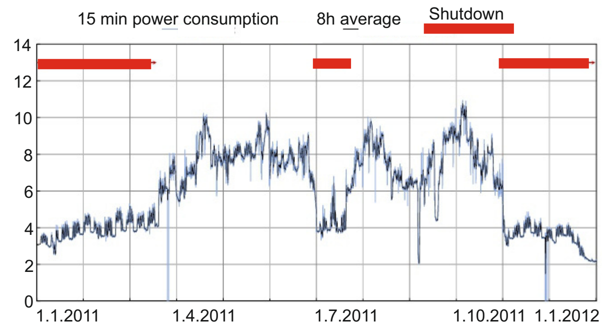

Figure 2: Energy consumption of GSI during 2011. Shown is the superposition of data averaged over 15 minutes and 8 hours. Marked in red are the shutdown times.

Figure 1 shows the total annual energy consumption of participating centers and the total energy costs. A span is given for the lowest and highest local energy price obtained in the study. The comparison with market prices shows if the supply contract is too expensive and hits if self supply would be an option. Note that ESS plans to produce and sell energy, resulting in an actual total costs below the given span.

It would be preferable to evaluate detailed energy consumption data like shown in Figure 2 by correlating it to measured consumption values of a facility's different parts.This detailed analysis has been done for GSI [2] but is not feasible within the scope of the lab survey. The questionnaire aims in getting sufficient information about variable loads and power usage directly from the facility's energy managers.

RESULTS

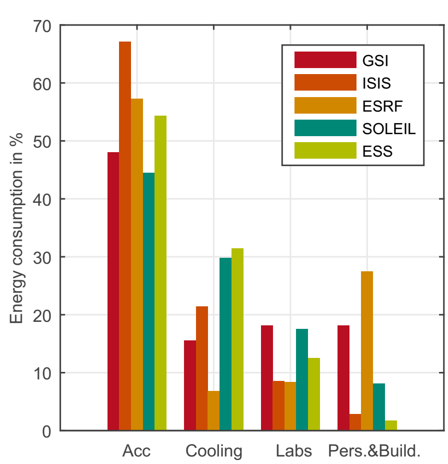

Figure 3: Shown is the distribution of the total energy consumption to four main categories. Accelerator and cooling are responsible for the major share of the consumption in the investigated cases.

Figure 3 shows the distribution of the total power consumption to categories of main consumers. Note that cooling includes load on air, water and cryoplants by the accelerator(s) but not office air conditioning or other cooling. The order of the labs is from older to younger (red to green). Modern labs seem to use less energy on personnel and buildings due efficient infrastructure, but demanding experimental communities lead to high energy consumption in laboratories at modern user facilities like SOLEIL and planned ESS.

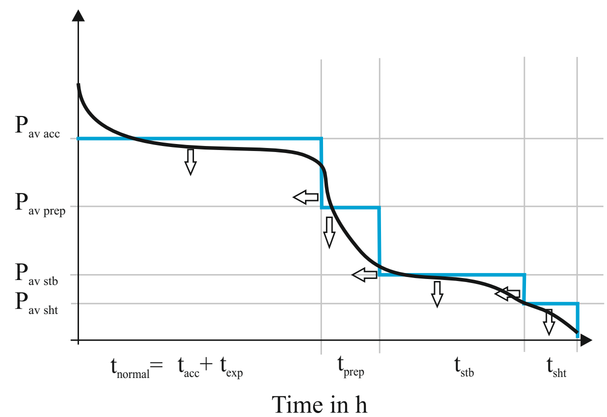

Figure 4: A generalized annual load curve for an accelerator facility. t_{normal} is the energy consumption during full experiment (and obviously accelerator) operation. t_{prep} is the energy consumption during setup, machine development or testing operation. t_{stb} is standby or normal shutdown and t_{sht} represents a deep full or holiday shutdown. Obviously by investigating gross data one only obtains a superposition of all machines if the facility runs several independent accelerators.

Figure 4 shows a generalized annual load curve for an accelerator facility. Of course there could be more steps if there is more than one accelerator operated independently. There can be extra steps if there are special modes of operation which cause lower or higher loads over long periods of time. We try to fit our data to those general curves to draw conclusions on the mode of operation and potential for energy saving and management. Points of interest are the steps between modes of operation. They can be used to determine the load balancing potential by long term energy management, for example scheduling shutdown periods during times of high Energy demand like winter shutdown at CERN [3] to compensate electricity demand by private heating.

Another extractable information is the existence of strong fluctuations within a single mode of operation. Those offer possibilities for short term load balancing by deliberately switching between different operation scenarios.

The area below the curve equals the total power consumption. Large areas indicate high potential for energy saving measures. A very high base load, for example, might lead to a decision to invest in modern technology to lower the overall consumption while long setup periods demand better setup and operation tools.

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The fluctuations during operation vary strongly, depending on the type of the facility. Large user facilities like neutron- and light sources tend to have very stable operation over long periods of time. Radioactive beam accelerator facilities which have very differing experiment requirements among their users like GSI have large variations even during time of beam operation. Energy consumption of a cycling machine with normal conducting magnets increases during high energy operation with long flattop times. In contrary to that a synchrotron with superconducting magnets like SIS100 of the future FAIR facility [4] has the highest energy consumption while operating with high repetition rate due to dynamic losses caused by fast magnet ramps which have to be cooled by the helium cryo-plant.

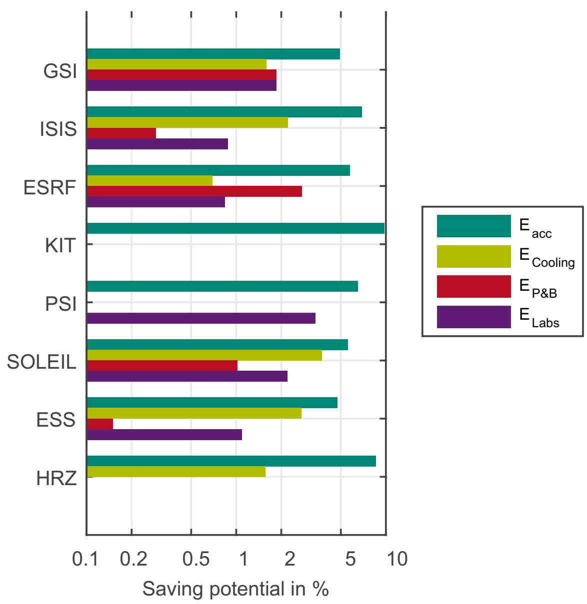

Figure 5: Potential savings in the areas of Figure 3 by reducing or optimizing operating time and power (for details see [5]).

The evaluation of the study in [5] tries to find saving potentials by optimizing operation times, identifying suitable candidates for investments in energy efficient modernization or switching to self supply. Figure 5 shows the predicted saving potential in different areas according to our data evaluation if the facilities optimize their operating times and mode of operation.

CONCLUSION

The facilities participating in our study have rather different research goals whichleads to different accelerator concepts and modes of operation. Despite the diversity some general trends could be detected, like potential of energy efficient modernization or standby and setup times between full operation and deep shutdown. Pointing out areas with highest leverage for modernization investments can be used to convince funding agencies. The overall environmental impact of future facilities will be part of a project's evaluation and hard data can only be gathered from existing facilities.

Due to the experimental and high-tech nature of accelerator science facilities in combination with their high power demand, they might be ideal test-beds for smart-grid technologies aiming on dynamic load balancing. The overall complexity of the research accelerators will expose many technological problems encountered in general application of smart-grid technologies in industrial facilities.

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