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OPTIMIZATION OF THE ENERGY USAGE AT CERN

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Abstract

Some of the efforts of CERN to optimize its energy usage are presented. Work is proceeding in several areas: campus and infrastructure, accelerators and beam lines, as well as R&D for future accelerators. The existing building stock is being renovated and new buildings apply an integrated energy concept. The energy efficiency of the accelerators and beam lines can be further enhanced by powering more equipment dynamically only during the time it is really needed. For designing new accelerators novel approaches are being investigated to re-use energy which in today's installations gets dumped thermally.

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INTRODUCTION

Big research facilities are often atypical in terms of energy use: they need substantial amounts of energy for unconventional installations and processes. Together with the technical knowledge available this opens the possibility for developing new ways of using and saving energy, which subsequently cannot only be applied by other institutions but can also be used in standard industrial and domestic applications.

The European Laboratory for High Energy Physics CERN in Geneva, Switzerland, operates a chain of particle accelerators and several high energy physics experiments. The total electrical energy consumed amounts to 1.2 TWh for a year of full operation of the installations. 82% are needed for the accelerators, 12% for the experiments, 3% for the computer centre and 3% for the campus infrastructure. About 1 TWh gets dissipated in cooling towers. This paper describes some examples of the efforts made by CERN to optimize its energy use by increasing the efficiency, re-using “waste” energy, and using renewable energy where possible.

The first section describes the recent upgrade of the cooling system of the computer centre which led to considerable savings in operation costs. The next section deals with the CERN campus in general and with energy aspects of new buildings under construction. Also, the operations of the accelerators and experimental areas have potential for energy savings. As an example the planned modernisation of an experimental facility is given in section three. Novel technologies can be used in the design of new accelerators as shown in section four.

UPGRADE OF THE COOLING SYSTEM OF THE COMPUTING CENTRE

Non-optimal cooling methodology can badly affect the overall power efficiency of large computer installations. In old data centres the power used for cooling sometimes exceeds the power needed by the computing equipment itself. The main data centre of CERN was built in the early 1970s. It has been the object of several upgrades and has recently been modernised to reduce cooling cost.

Most of the servers of the CERN data centre are located in one main room, which is air-cooled by a legacy ventilation system. Powerful chillers produce the chilled water needed to provide cold air which is blown into the room from a false floor. The warm air is extracted at the ceiling of the room and is either re-cooled or blown out of the building. The air flow rate is about 10^6 m^3/h. In order to ensure an average ambient air temperature of maximum 25°C for each server in the room, the chillers were running most of the time at full capacity in order to produce chilled water of 5°C allowing the ventilation units to provide cold air of 14°C.

In order to be able to cool more servers and to decrease the cooling cost, CERN IT and cooling experts have reviewed the cooling methodology; the most important steps taken to increase the cooling efficiency of the data centre have been the following:

1. Strict separation between the cold air provided to the servers and the hot air returned. This has been achieved, at a marginal cost, by creating cold corridors in which the servers are installed face to face (Fig. 1);
2. Modification of the ventilation units and their control system in order to take automatically and whenever possible fresh air from outside rather than to recirculate and cool down the hot air returned from the servers (so-called ‘free-cooling’);
3. Increase of the maximum allowed inlet server temperature from 25°C to 27°C.

Figure 1: Cold corridor in the CERN main data centre

These modifications have several consequences which, together, resulted in a major increase of the energy efficiency. First of all, the moderate increase of the inlet server temperature combined with the strict separation of cold and hot airflows has allowed increasing the temperature of the cold air produced by the ventilation units from 14°C to 21°C. This in turn enabled increasing the set point of the chilled water circuit from 5°C to 7°C, allowing the chillers to work at higher efficiency and thus reducing their power consumption.

In addition, the use of the free cooling principle in the air management requires the use of chillers only when the outside temperature exceeds 21°C. For example during the whole year 2009 this temperature has been exceeded for only 119 days and, often, only for a few hours per day.

The implementation of the above mentioned modifications decreased the yearly power consumption of the chillers from 6.3 to 1.2 GWh in 2012.

CERN CAMPUS

CERN has a building stock of about 600.000 m^2, of which about a third are offices and laboratories. The rest are mainly industrial buildings. As more than 80% are older than 30 years, continuous renovation is on-going, however at quite a slow pace due to the very limited funds. The main measures being taken are improving the thermal insulation and the implementation of new heating regulation systems for the individual buildings.

All newly constructed buildings include a coherent energy concept. They are either connected to CERN's internal district heating system or use air-water heat pumps for heating. A study is underway to also use water-water heat pumps, taking as primary energy source the waste heat of accelerator equipment. This waste heat is available normally around 30°C, in some special cases up to 50°C.

The most recent building presently under construction also uses renewable energy. It has a surface area of about 4000 m^2 for mixed use (offices, laboratories, computing equipment, and public areas) and it includes a solar field of 250 m^2 on the roof. This is composed of novel thermal solar collectors, a spin-off from CERN. Technologies developed for the accelerators – like high vacuum, surface treatment, and welding techniques - have been used by a spin-off company [1] to design these panels and they are now industrially produced. Thanks to vacuum insulation they have extremely low thermal losses, resulting in high efficiency and the possibility to reach very high temperatures in excess of 300°C. In the present case they will be operated in summer at a temperature of about 90°C in order to drive an absorption cooling unit of 90 kW output at 10 °C for cooling computing equipment and offices. In winter the solar field injects its energy into the heating system. A simulation of the solar field predicts a total energy of 160 MWh and 60 MWh for summer and winter, respectively. As solar energy is not continuously available, standard sources for heat and cold – the district heating system and compressor cooling – serve as fall-back. A priority scheme will ensure that solar energy is used first. During times when heat is needed the waste heat from either the absorption or the compressor system is used by the heating system. In this way the energy required from conventional sources is minimized.

UPGRADE OF EXPERIMENTAL AREAS

The East Area at the PS has been operating in various configurations since the 1960s and the latest implementation dates from the late 1990s [2]. A primary proton beam of 24 GeV/c is extracted from the PS into one of several branches. It can be sent to two primary beam users (DIRAC and an IRRADiation facility) or be used to produce three secondary beams (Fig. 2).

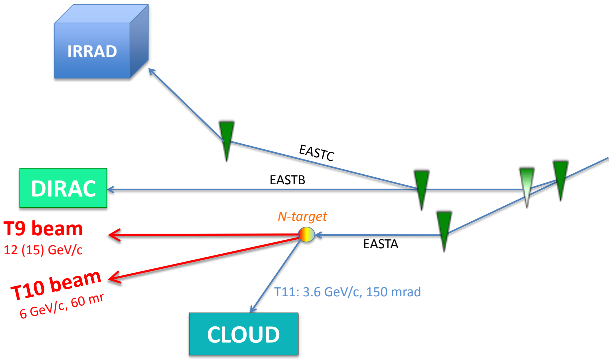

Figure 2: A schematic layout of the East Area

The protons are slowly extracted during a flat top of typically 0.4 seconds, several times over the 45 second long machine cycle. The overall duty cycle of the primary beam is of the order of 6-7%, and for the individual branches it is even lower. Many of the magnets in the primary lines and all magnets of the secondary beam lines are operated in DC mode, as many of these magnets have massive yokes and cannot therefore be ramped quickly.

The age of the equipment and the design-related high radiation doses in the primary areas cause equipment failures that lead to long down times and significant radiation exposure of personnel. Therefore, a renovation and consolidation program is underway. In a first phase during 2013-2014 the completed DIRAC experiment will be dismounted and replaced by a modern combined proton and mixed field irradiation facility. In a second phase, tentatively planned for 2018-2019, the beam lines will be redesigned and rebuilt to improve equipment reliability, maintainability, radiation containment, and down times.

It is proposed to also use this occasion to improve the power economy by energizing the magnets only when the beam is on, i.e. to ramp them down for the parts of the super-cycle without beam. This requires replacing the massive magnets by laminated ones, either to re-build them completely or to replace only the yoke re-using the existing coils. Instead of reducing the coil size following the reduced effective current, it is preferred keeping the old design in order to lower the current and hence the power consumption.

The existing power converters are obsolete and it is foreseen to replace them anyway. The new ones can thus be designed to allow pulsed operation. This additional investment will not only lead to direct energy savings but also to reduced need for power cabling and general power and cooling infrastructure.

First estimates of investment cost and potential savings have been made recently for the East Area, building up a methodology that can also be applied to other projects such as a future North Area consolidation. Data are based on the year 2011, which was a typical year of operation.

The overall electricity consumption of the East experimental area for the year 2011 was just over 15 GWh. Out of this 12% was used for the water-cooling and 4% for the air-cooling systems. In the case that all magnets are pulsed, the cost of the power consumption could be reduced to less than 10% of the present consumption, excluding the DIRAC magnet. However, 23 out of 55 magnets cannot be pulsed, because their yoke is not made of laminated steel. Replacement of these yokes by laminated ones requires a certain investment. In this study, savings have also been identified for the electrical distribution and water-cooling systems, which can be optimised for the much lower power consumption. As an example, most of the electricity connections can be reduced from 630 to 125 A or even to 32 A. However, the cost of the power converters will increase if designed for pulsed operation.

The outcome of the estimate is that the additional investment could be amortised in about 5-6 years, assuming present energy prices and not counting the reduced infrastructure needs. Further investigations are planned to minimise the types of new magnets needed and hence the overall cost and to define the global strategy, also keeping in mind other experimental areas. These studies will include detailed changes to the beam layout.

RECUPERATION OF RF ENERGY

In synchrotrons, usually only a fraction of the RF power delivered from the generators is finally transferred to the beam. This fraction is practically zero in coast and may be around 50% during the acceleration ramp. Even with a very energy conscious design a certain amount of RF power must be dissipated in RF power loads where it is usually converted to low grade heat. The use of such loads is unavoidable due to beam stability issues as well as for robustness of control and for operation aspects.

Three different technologies for recuperating RF energy have been studied at CERN. One concept implies the use of an array of solid-state rectifier modules for direct RF-to-DC conversion with efficiencies beyond 80% [3]. The DC power obtained could be fed back to the utility grid by commercial units like those in use for photovoltaic solar systems. This looks at a first glance like the most elegant and promising solution. However, RF power rectification can presently only be done with a fairly large number of medium size (300 Watt/unit) diodes leading to rather complex RF signal splitter structures. In addition, a conventional dummy load connected via a circulator must be provided in case the DC power cannot be delivered to the grid and thus the RF energy would be reflected. The concept described looks technically feasible, but its financial viability still has to be verified.

The second approach is to raise the outlet temperature of the cooling water. In this context, mechanically robust structures operating as low Q resonators have been investigated. For particle accelerators the RF power is usually fixed to a very narrow frequency range thus allowing for narrowband load design. Ferrite powder containing silicon rubber coatings, which can stand temperatures in excess of 220°C in operation, is one example of an absorbing material placed onto water-cooled metallic surfaces. This technology has been adopted from the “crisp plates” used in consumer microwave ovens and thus is easy, cheap and uncritical to implement. Another more demanding possibility is plasma sprayed ferrite layers on metal, probably better suited for vacuum applications [4].

A further approach is an air-cooled load at a very high temperature of up to 800°C using ceramic foam inside a metal enclosure [4]. This porous block serves both as microwave absorber and as heat exchanger at the same time. It is essentially a hot air blower with a ceramic heating element that absorbs and converts the RF energy.

SUMMARY AND CONCLUSION

CERN has always tried to be economical in its use of energy. Already in the 1960s one of the first accelerators at CERN, the PS, has included a big rotating wheel assembly to re-use the 12 MJ of energy stored in the magnets every cycle of 2.4 sec. This has helped to reduce the total amount of energy needed as well as to smooth out the load on the electricity grid. Whenever purchasing energy-intensive equipment, both the investment and the operational cost over its lifetime are taken into account.

New technologies enable a further reduction of the energy consumption. CERN has increased its efforts in this field, as shown by the examples described in this paper. This may lead to innovations which can also be applied in other areas.

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