ENERGY EFFICIENCY IN THE NORTH EXPERIMENTAL AREA AT CERN

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Abstract

The North Experimental Area at CERN is a versatile experimental facility that provides proton, hadron, electron, muon, and ion beams to over 2000 users annually for detector R&D and fixed-target experiments. Currently, this facility, which is more than 45 years old, is undergoing a consolidation program to enhance availability and reliability and to prepare for new experiments and test beams in the coming decades. In this context, and within the framework of ISO 50001, energy efficiency was assessed, potential energy-saving opportunities were identified, and various strategies for sustainable operation were evaluated. This contribution summarizes the results and outlines planned measures for future implementation.

CERN EXPERIMENTAL AREA NORTH

The North Experimental Area at CERN, commonly known as the “North Area”, was constructed in the 1970s at the CERN Prévessin site. It features a complex of three experimental halls, service buildings, and underground tunnels, comprising approximately 7 km of beamlines. The total surface area of the North Area facilities is 60 000 m^2. With a primary beam provided by the Super Proton Synchrotron (SPS), the North Area offers particle beams across a broad energy spectrum and various particle types for fixed-target experiments and R&D test-beam programs for collaborations. Over the last fifty years, the North Area has been one of the most frequently utilized experimental areas at CERN. Figure 1 illustrates the range of beamlines, experiments, and test facilities available. Due to its unique characteristics, the North Area remains the only place in the world where such physics studies can be performed.

To secure the availability of this facility for the physics community in the future, the North Area Consolidation (NA-CONS) project was approved in 2021. This project aims to enhance the North Area’s reliability, safety, and scientific capabilities in the next decade through infrastructure renovation, beamline upgrades, safety improvements, and the modernization of scientific equipment.

Energy Consumption in the North Area

The North Area has an average annual electricity consumption of 104 GWh during a Run year[1], representing approximately 8 % of CERN’s total electrical energy use. In Shutdown years, the electricity consumption of the North Area drops to less than 20 % of that in a Run year. Magnets account for a large share of the North Area’s total power consumption. In 2024, a typical Run year, they used 57.6 GWh: The 154 DC beamline magnets consumed 19.8 GWh, while the 396 cycled beamline magnets used 22.9 GWh. Additionally, the five large experimental magnets, all operated in DC, used 14.9 GWh of electricity. Figure 2 illustrates the distribution of electrical energy consumption for the North Area magnets in 2024.

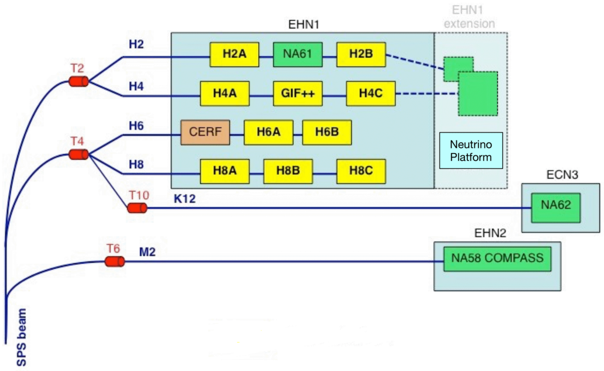
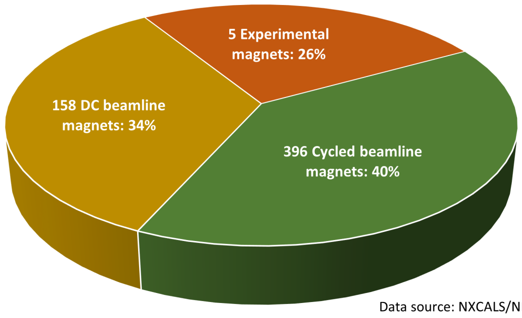


Figure 1: North Area beamlines, with targets (red), experiments (green), and test-beam areas (yellow).

Power Metering

For a reliable assessment of present and future power consumption, a sensible power metering system is key. Today, CERN manages around 500 energy meters across its electrical distribution network, organized by load type and zone via *WebEnergy* [1]. However, the metering in the North Area has a limited monitoring granularity. Planned upgrades to the North Area electrical distribution system will introduce finer metering, fostering a more accurate evaluation of future power consumption. Despite these improvements,



Data source: NXCALS/NEAT

Figure 2: Distribution of electrical energy consumption amongst the North Area magnets in 2024.

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[1] During a **Run** year at CERN, machines operate and physics data is collected, with magnets and power converters fully active, resulting in the highest energy consumption. During a **Shutdown** year, most machines are offline for maintenance and consolidation, leading to significantly lower energy use.

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monitoring individual magnet circuits remains a specialized need.

To address this need, a new software tool called *NEAT* (North Area Energy Analysis Tool) has been developed. It largely benefits from operation parameters recorded in NXCALS, a logging system based on Hadoop Big Data technologies. The new framework, based on PySpark, features realistic models of powering cycles and power converter efficiencies. It allows reading and processing data directly from NXCALS to calculate power and energy consumption for any period and individual circuit. Additionally, it can identify power consumption when there is no beam in the beamlines, helping to pinpoint potential energy waste. The development of a web-based user interface is underway.

PROPOSED ENERGY-SAVING MEASURES

Methodology

To study potential energy-saving opportunities in the North Area and to synchronize the efforts of all stakeholders, a North Area Energy Efficiency Task Force was formed [2]. The work was divided into four phases:

- Identify, evaluate, and recommend potential energy-saving measures in the North Area, considering future scenarios for physics operation.
- Assess the energy consumption and associated financial savings for each action.
- Develop a strategy with an implementation plan, estimated costs, and required resources to present to CERN management for approval.
- Suggest effective methods to monitor and verify the efficiency of the measures after they are implemented.

The following sections describe several energy-saving measures that have been identified as relevant and proposed for implementation.

Power Converters

The existing power converters in the North Area date back to the 1970s, have reduced reliability, and possess limited control capabilities. As part of the NA-CONS project, all current power converters will be systematically replaced in the coming years by new, water-cooled, state-of-the-art power converters. The new converter design [3] incorporates an energy recovery technique for cycled magnets, enabling reactive energy exchange between the energy storage and the magnet. The future converter rating will match the actual power required by the load based on the operating current, not the magnet's nominal power. Finally, the new converters will facilitate optimization of the powering cycle and the implementation of various economy modes.

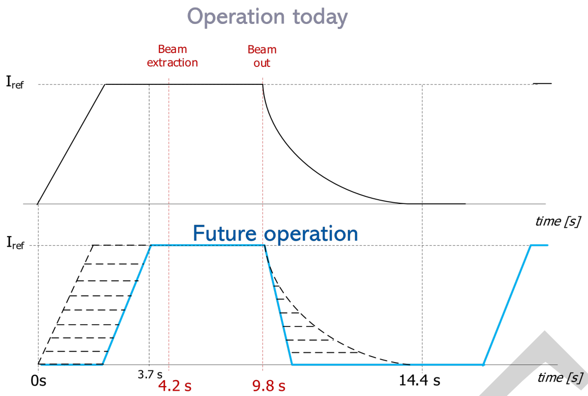

Figure 3: North Area operation cycle today (top) and in the future (bottom). "Beam out" corresponds to the moment when the total beam has been extracted from the SPS.

Optimization of Powering Cycles A new converter control system will enable the optimization of the powering cycle for pulsed magnets. Instead of starting the magnet powering cycle for all magnets simultaneously and in sync with the magnetic cycle of the SPS, which causes an idle period until the extracted beam passes through the North Area beamlines, the start of the cycle can be delayed so that a stable flat-top of the magnetic field is achieved just before extraction begins. Ramp-up and stabilization times can be individually set for each magnet based on load parameters. Figure 3 compares the present and future operation modes. The hatched areas in the lower image indicate the savings from the new operation cycle, which are in the range of 32 % for cycled beamline magnets.

Another effective method to reduce power consumption in an accelerator facility is to implement economy modes. These modes involve shutting off or reducing power to beamline components when no beam is present. This can happen during planned stops for technical work, scheduled machine developments or access periods, or unexpected outages due to failures. The main difficulty is predicting how long the no-beam period will last during failures. Since magnets and power converters are the biggest energy consumers, they are prime targets for this strategy. Different economy modes can be identified based on the length and reason for the beam stop.

Stand-by Mode This mode can be manually activated by the SPS Control Center for long physics stops of known duration, and sets selected power converters to stand-by.

Full Economy Mode Like the previous mode, it can be manually triggered by the SPS Control Center, but for short physics stops of unknown duration, ranging from minutes to hours. It reduces the power converter currents to a low setting (typically 10 A) and affects all beamline magnets.

Dynamic Economy Mode This economy mode automatically activates when a beam intensity threshold in the SPS is reached, especially if the injectors unexpectedly do

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not deliver beam for one or multiple cycles. It then reduces the currents in the cycled beamline magnets to a low setting.

Destination Economy Mode This mode acts on magnets of specific beamlines that do not receive beam due to access issues or local faults. It can be automatically triggered by beamline safety devices.

All these economy modes, except for the Destination Economy Mode, are already in operation and have been accounted for in the total North Area energy budget.

Magnets

A specific focus was on magnets that stay continuously powered during nearly the entire physics run. These are DC beamline magnets and large spectrometer magnets used in experiments.

From DC to Cycled Beamline Magnets Cycled operation provides current to the magnets only when needed and can lower power usage depending on the duty cycle. However, it requires magnets with laminated iron cores to reduce eddy currents induced by changes in magnetic flux. In the North Area today, 154 out of 550 beamline magnets still have non-laminated yokes and therefore can only operate in DC. Replacing these magnets would require a substantial investment. A CapEx-OpEx analysis showed that the return on investment would only be achieved after 30 years of operation, which was not considered economical.

Energy Management for Experimental Magnets In 2024, experimental magnets accounted for 26 % of the total energy dissipated by North Area magnets. Energy consumption can vary significantly across experiments, depending on the number of operational days per year. When not in use or if no beam is available for physics, the spectrometers should be set to stand-by by the user, thus relying on the user's discipline. Potential average (2022–2024) savings were around 20 % of the experimental magnet's power consumption. Considering only the three most powerful magnets (SM1, SM2, and MNP33), this corresponds to 3.1 GWh/yr.

A survey indicated that implementing an automatic economy mode is not feasible because the magnet and detector equipment must be declared "safe" before changing the magnetic field. Moreover, these large magnets take more than an hour to reach stable operating conditions, so only stops exceeding two hours can be taken into account.

Water Cooling

Effective water cooling requires a low coolant flow rate and a large temperature difference between the water inlet and outlet. Currently, the opposite is true in the North Area, and the cooling system operates at its maximum capacity with a very high coolant flow and a low return water temperature because the water flow in the magnets, which are the primary cooling consumers, cannot be adjusted. Additionally, the cooling systems run at full capacity year-round, regardless of actual cooling requirements, which can fluctuate over time depending on the equipment in operation. Therefore, two improvement strategies have been suggested:

Cooling Flow Optimization Installing regulation valves in the North Area secondary beamlines during the coming Shutdown will enable the adjustment of the cooling flow rate to match the real power dissipation in the future. These regulation valves will be configured to optimize coolant flow in the beamline magnets based on the permitted temperature increase (typically 25 °C) and the maximum specified operation current, rather than the nominal magnet current. Calculations indicate that the flow rate can be reduced by as much as 74 %. A more conservative reduction of 60 % would still yield annual electricity savings of up to 5.6 GWh with a reasonable investment. Positive side effects include increased reliability, improved cooling efficiency, and a reduced risk of erosion due to lower coolant velocity.

Economy Modes for Water Cooling The implementation of cooling economy modes, similar to powering economy modes, has been studied. While it was deemed beneficial to temporarily reduce the flow rate and thus the cooling power during periods when Stand-by Mode or Full Economy Mode are active, the Dynamic Economy Mode and the Destination Economy Mode were discarded because they were considered either too short or too complex to provide reasonable savings. If the cooling economy modes are activated, the flow rate is reduced to 50% but not completely stopped. This allows for a quick restart when exiting the economy mode and maintains a minimum flow in the cooling circuits, preventing problems caused by stagnant water.

Compared with today's operation, the Stand-by Mode for cooling could save up to 2.3 GWh/yr, especially during hardware commissioning at the beginning of the year, when the power converters and magnets are operated only sporadically for testing. The savings during Economy Mode are more difficult to predict: For an assumed total time of 500 hours in Full Economy Mode per year, savings in the range of 0.7 GWh could be expected. Cooling economy modes will require modifications to the control and interlock infrastructure to ensure that all related power converters are in economy mode and that flow-monitoring systems do not trigger an interlock when the cooling economy mode is activated. These modifications will be implemented as part of the NA-CONS project.

CONCLUSION

Various opportunities for energy savings in the North Area have been identified. Several measures can be realized through intelligent operation of the facility without requiring large budgets or resources, such as the economy modes discussed in this article. The proposed measures yield in electricity savings of at least 21 GWh/yr, which corresponds to more than 20% of the total annual electricity consumption in the North Area. Reference measurements before and after implementation shall validate the efficiency of each measure.

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