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FIRST YEAR OF DATA TAKING WITH THE ELECTRICITY METER NETWORK FOR SUSTAINABLE OPERATION OF THE KIT ACCELERATOR FACILITIES FOR THE KITTEN PROJECT *

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Abstract

In times of climate change and with increasing challenges of the power grid stability due to unstable renewable energy sources, it is not sufficient to know the electric energy consumption of accelerator facilities. In order to optimize the operation of the research infrastructure in terms of stability, reliability and sustainability, the knowledge of the dynamics of energy consumers and generators is mandatory. Since a few years, KIT's accelerator teams collaborate with its Energy Lab 2.0, Europe's largest research infrastructure for renewable energies, within the KIT test field for energy efficiency and grid stability of large-scale research infrastructures (KITTEN). At the research accelerators KARA and FLUTE a dense network of power meters, more than 100 sensors of different kind, is used to monitor the load of individual components to infrastructural components and central electricity distribution. With more than one year of data taking of the sensors, we are already able to quantify implemented energy-savings measures.

INTRODUCTION

KIT has two large research infrastructures, KARA and Energy Lab 2.0, that joined in KITTEN to investigate different aspects of running accelerators sustainably in a power grid that might be stressed by changes caused by the transition to renewable energies; namely: KIT's accelerator team that operates the two research accelerators KARA and FLUTE and the Energy Lab 2.0, Europe's largest research infrastructure for renewable energies. Together we investigate the influence of the accelerator onto the power grid [1] and vice versa, as well as the power consumption of the accelerators. KARA, the Karlsruhe Research Accelerator, is a storage ring and accelerator test facility and a synchrotron operated in ramp-up mode [2] for the KIT Light Source. The accelerator is operated from Monday afternoon to Saturday morning and at different beam energies, ranging from 0.5 GeV up to the usual photon science user operation mode at 2.5 GeV. FLUTE, a short-bunch electron linear accelerator [3, 4], hosts multiple different experiments involving lasers, RF, and clean rooms. Within KITTEN, the Energy Lab 2.0 is developing an electrical digital twin of KARA and going to validate it with the Power Hardware In the Loop (PHIL) setup [5]. For that, the basic model is being developed with data acquired at a rate of multiple seconds and more than 100 sensors. The full model combines that with a fast-data acquisition system for the detailed studies of 16 measurement points at important locations. It is currently being installed. For details see [1]. In this paper we will focus on the multi-second acquisition network and power consumption aspects.

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Table 1: The column "Usage" lists the components that are connected to the corresponding transformers. Transformer 1 and 2 are connected in parallel to each other. Transformer 3 and 4 are connected directly to one RF station each.

Transformer	Usage
1 and 2	Accelerator, beamlines and labs
3, 4	RF system
5	Cooling plant
6	Further labs, beamlines, their cooling and a solar power plant
No	FLUTE and clean rooms

EXPERIMENTAL SETUP

The KARA infrastructure is connected to six dedicated transformers T1-6. The FLUTE infrastructure including a clean room for the driving laser of a future laser plasma accelerator [6] are connected to a sub-distribution. The transformers are operated by the electricity supplier, here KIT central facility management, which provides power readout values for every quarter of an hour. The mapping of the transformers to our infrastructure is shown in Table 1.

We measure at central points like the transformer for the cooling plant (T5) and the distribution line to the ring (T1 and T2) with a power analyzer (model: Janitza UMG96RM-EL). Two of these power meters are placed at FLUTE and at the clean room. In the following we will refer to these as Janitza power meters.

Besides these centrally placed power meters, we also measure at distribution points for sub-components, i. e. parts of the accelerator, parts of the cooling plant, beamlines and labs.

For the main devices of the accelerator itself, we use 85 Siemens Sentron 7K1661 and 7K1665 in combination with current transformers. 64 units are installed at the main storage ring and 21 units for the booster synchrotron. These devices are read out through MOXA boxes and Modbus/TCP. This happens at a rate of approximately 10 s.

The second type of readout devices are based on Siemens PLC. The Siemens SIMATIC ET 200SP AI Energy Meter 480V AC ST is used in combination with Janitza KUW1/40-

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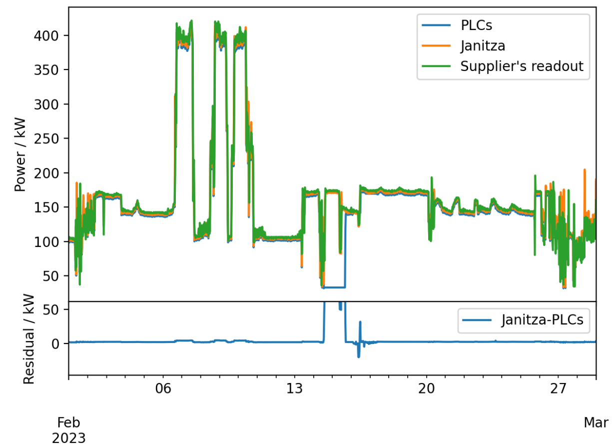

Figure 1: Comparison of PLC based power readout and the Janitza based readout measurements with data provided by the energy supplier's readout system for T5 over one month. Besides a readout error for two and a half days, the difference between the two data sources is below 5 %.

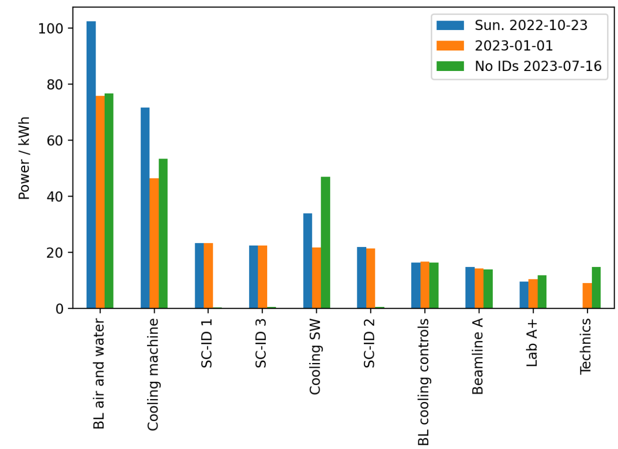

Figure 2: The ten highest power consumers at the KIT Light Source during three different kinds of "no operations." The regular Sunday between usual weeks (2022-10-23), a full shutdown during the winter break (2023-01-01) and a summer shutdown with IDs heated up (2023-07-16).

250/1A, KUW2/40-500/1A, and KUW4/60-800/1A as measurement transformers. These systems are used for auxiliaries in the hall, cooling systems and cooling plant (28 units), and for power distributions to beamlines and laboratories (33 units). To this setup we will refer to as PLC in the following.

The sensors are placed in the (sub-)distribution cabinet for the respective devices, i. e. close to the load.

The voltage transformers are of class 3 (3 % deviation at 100 % to 120 % nominal current) and the PLCs of class 0.2.

All the measurements are fed into the EPICS control system and the power, current, voltage and frequency values are archived in the Cassandra database [7] onsite.

DATA ANALYSIS

Comparison of the Devices

One important step of the data analysis was to compare the different power meter setups, and cross check the energy supplier's values. We did this in different ways. Firstly, we use a mobile three phase power quality analyzer (model: FLUKE 1777 [8]) for comparison with the supplier's readout data at a sub-distribution used for FLUTE, and to the readout data by the Janitza power meter. The averaged power does agree within the device's uncertainties. Furthermore, we can cross-check the PLC data with the Janitza data and the supplier's readout data at the T5 for the cooling plant. Figure 1 shows the power of the cooling plant measured by the supplier at the transformer, by the Janitza power meter directly after the transformer and the sum of the individual measurement points of the PLCs inside of the power plant. In the middle of the month the readout failed for 2 days and was restarted. The data acquisition was integrated into the alarming system to prevent future failures. Besides that, the difference between the Janitza and the PLCs, shown in the lower part of the plot, is below 5 %.

Operation Modes and Main Consumers

As mentioned earlier, KARA is operated in ramp-up mode, is turned off during the weekends and has different operation modes. The three days photon science user operation at a beam energy of 2.5 GeV are also clearly visible in Fig. 1 as the three peaks in the cooling plant's power consumption. The other typical operation modes can also be recognized by their power consumption scheme. Given the overall energy consumption during the different no-operation modes has been between 25 % and about 40 % compared to user operation with electron beam, it is important to save energy in the "no-operation" modes. Measures to do so can be: fully turning off the booster synchrotron during the normal operation of the storage ring, by turning off data acquisition and archiving infrastructure during longer shutdowns. During user operation, one effective way to save energy is reducing the beam energy if that would be acceptable for the beamline users, e. g. operating at 2.3 GeV with one RF station instead of two for the 2.5 GeV operation. When looking into the no operation modes, which are either just a short time over a weekend, or a long shutdown where most of the machine and also additional components can be turned off, it is clear, that the cooling and the superconducting insertion devices are by far the most significant intakes, as can be seen in Fig. 2. That figure shows the ten top consumers during these two scenarios, indicated as "Sun." for a Sunday between two weeks of operation, and January 1st during the winter shutdown. Firstly, the "No IDs 2023-07-16" data shows the impact of heating up the insertion devices, which do not show up in the graph, and secondly, the effect of summer versus winter in the cooling loads.

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Table 2: Power consumption of the superconducting insertion devices with and without powered coils.

ID	Power/kW @0 T	Power/kW @Max Field
SC-ID 1	21.0	23.8
SC-ID 2	21.6	31.3
SC-ID 3	22.3	25.3

Table 3: Pearson's correlations of the power consumption and one of the magnet field/applied current, beam energy, or beam current.

ID	Current	Beam Energy	Beam Current
SC-ID 1	0.17	0.19	0.18
SC-ID 2	0.90	0.62	0.57
SC-ID 3	0.93	0.59	0.54

Superconducting Insertion Devices

As the superconducting insertion devices are substantial power consumers, it is of interest to investigate their contributions to the operation modes. We are looking at two superconducting wigglers and one undulator. All three superconducting insertion devices — SC-ID 1-3 — are cooled by four cryo-coolers each. When their coils are not powered, the respective power consumption is up to 10 kW lower as shown in Table 2. However, as they continue to consume energy when the accelerator is not operating, they then become one of the dominant factors. Therefore, it is preferable to schedule fewer long shutdown periods over multiple shorter ones, so that the cost and time of heating the IDs up and cooling them down again is cheaper than the energy savings.

The Pearson's correlation [9] of the power consumption with the field is evident for the SC-ID 3 and SC-ID 2 as shown in Table 3. With values between 0.5 to 0.62, the consumed power and the electron beam energy as well as the power and the current are slightly correlated. However, the correlation to the applied current of the magnets, or the magnetic field respectively, is stronger with values above 0.9. That might be caused by the devices being used during these operation modes and thus implicitly being correlated to the magnetic field, whereas the latter one is a direct correlation.

An exception is the SC-ID 1 for which the Pearson's correlation does not show a strong correlation for any of the considered cases.

Savings

In 2023 the summer shutdown was scheduled to be longer than usual, so that the superconducting insertion devices could be heated up. That was one measure that was taken to reduce the power consumption by more than 60 kW during no operation. Furthermore, replacing parts of the microtron and its power supply enabled us to fully turn it off during long shutdowns and to reduce its operation power by 7 kW.

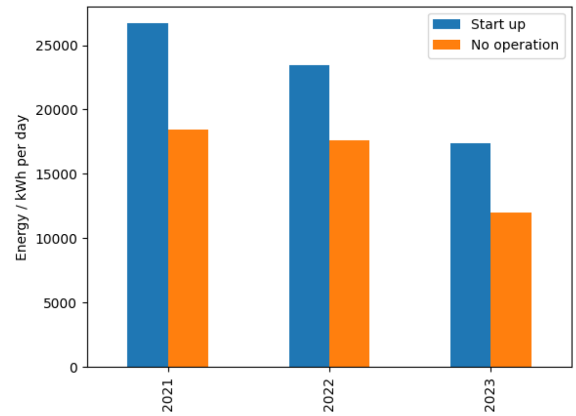

Figure 3: Energy savings since actively reducing the power are shown for the startup of KARA and the shutdown including weekends.

Figure 3 shows the effect of the efforts to minimize the consumption. In comparison to the year before installation of the power measurement devices and observability of effects of individual measures on a component level, the baseline energy consumption decreased, visible in the "no operation" and the "start up" mode data. The averaged energy per day in the "no operation" mode was about 1/3 smaller in the year 2023 than in the year 2021.

OUTLOOK

Currently we are installing 10 kHz current and voltage meters to create an electrical digital twin of the accelerator facilities. With this, we aim to investigate the influence of fluctuations in the power grid onto the beam quality and the loads of the machine onto the grid, in addition to optimizing the power consumption by simulating different usage scenarios. Also we continue the efforts to minimize the power consumption by further analysis of the already gathered data.

SUMMARY

Different power measurement equipment was successfully installed and cross validated. We fixed some issues that showed up during that process and were able to find measures to decrease the energy consumption by identifying the main consumers and quantifying the effects of actions taken. We plan to further investigate individual components and the reliability of both the power grid and the machine operation in the future.

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