ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Advanced Modeling and Display of International Campus Power System

Team #29

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Contents

1 Introduction

1.1 Problem

As an open and modern campus, Zhejiang University Haining International Campus has state-of-the-art infrastructure and cozy single dormitories. However, this also leads to a relatively high electricity consumption. In 2023, the Haining campus spent tens of millions of RMB on electricity. High electricity consumption is also common in campus around the world [1]. We found the following problems with the campus' electricity consumption:

- Students and faculty are not sensitive to electricity consumption and energy conservation.
- Visualization of electricity data is not intuitive enough.
- Improved responsiveness and expanded treatment options are needed to manage emergencies like over-voltage and short circuits effectively.

1.2 Solution

Our proposed solution to address the situation is to develop an Advanced Modeling and Display system for the campus power system. Specifically, we will utilize electricity consumption data from the engineering department for accurate power flow calculations. The resulting information, including current, voltage, power, and other relevant data, will be visually represented using LED strips with varying brightness and colors on a physical model.

Besides, machine learning-based algorithms such as electricity consumption forecasting and anomaly detection can be used to monitor various grid behaviors. Advanced applications like grid loss calculation and distributed wind/photovoltaic (DW/PV) power generation installation and connection are also among our considerations. In this way, we aim to visualize power distribution and usage on campus more intuitively, fostering awareness of electricity conservation among students and faculty while contributing to

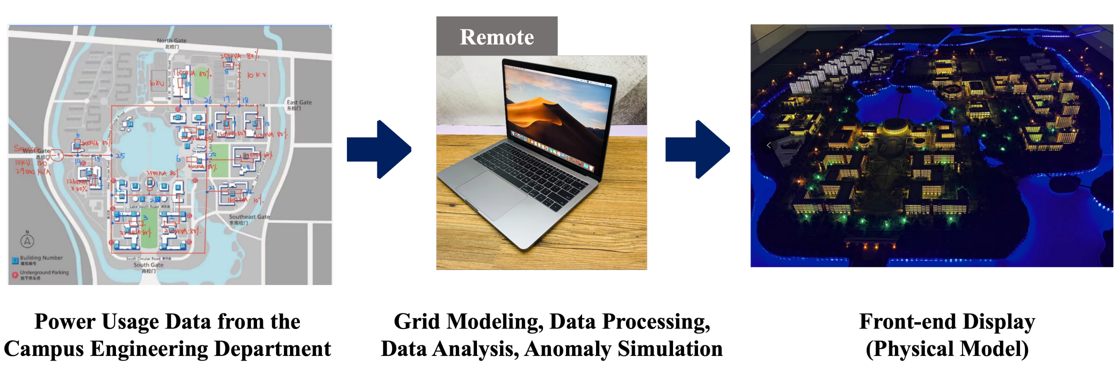

Figure 1: Visual Aid

establishing a low-carbon modern campus.

1.3 Visual Aid

The project's workflow is shown in Figure 1. The collected power data is processed using a power flow solver to extract relevant information and then visualized using the solid model. In addition, machine-learning-based data analysis and power anomaly simulation are implemented remotely and displayed on physical models accordingly.

1.4 High-level requirement list

- **Quantitative criteria for the front-end display.** The constructed physical model should be able to represent the power usage data throughout the campus visually, with accurate representations of each building (or substation). In the case of state changes, the LEDs are expected to exhibit the desired state within a delay of **2** seconds.
- **Quantitative criteria for the machine-learning model.** The pre-trained machine learning model should be able to forecast electricity consumption accurately. We expect an average error rate of **10%** or less.
- **Quantitative criteria for the event-driven power accident simulation.** For a simulated power anomaly event, e.g., simulating a two-phase short circuit to ground in North Building A, the anomaly detection module should react and trigger an alarm within **5** seconds, and the micro-F1 score is expected to be no less than **0.95**.

2 Design

2.1 Block Diagram

See Figrue 2.

2.2 Subsystem Overview

2.2.1 Data Collection Subsystem

The Data Collection Subsystem collects and stores historical electricity consumption data and real-time power usage data from each substation provided by the Engineering Department. This subsystem then transfers the collected data to the Data Analysis Subsystem for further analysis and utilization.

2.2.2 Data Analysis Subsystem

The Data Analysis Subsystem processes the power consumption data obtained from the Data Collection Subsystem, feeding the collected active power into the tidal current automatic calculation model to generate a series of desired data such as voltage and current.

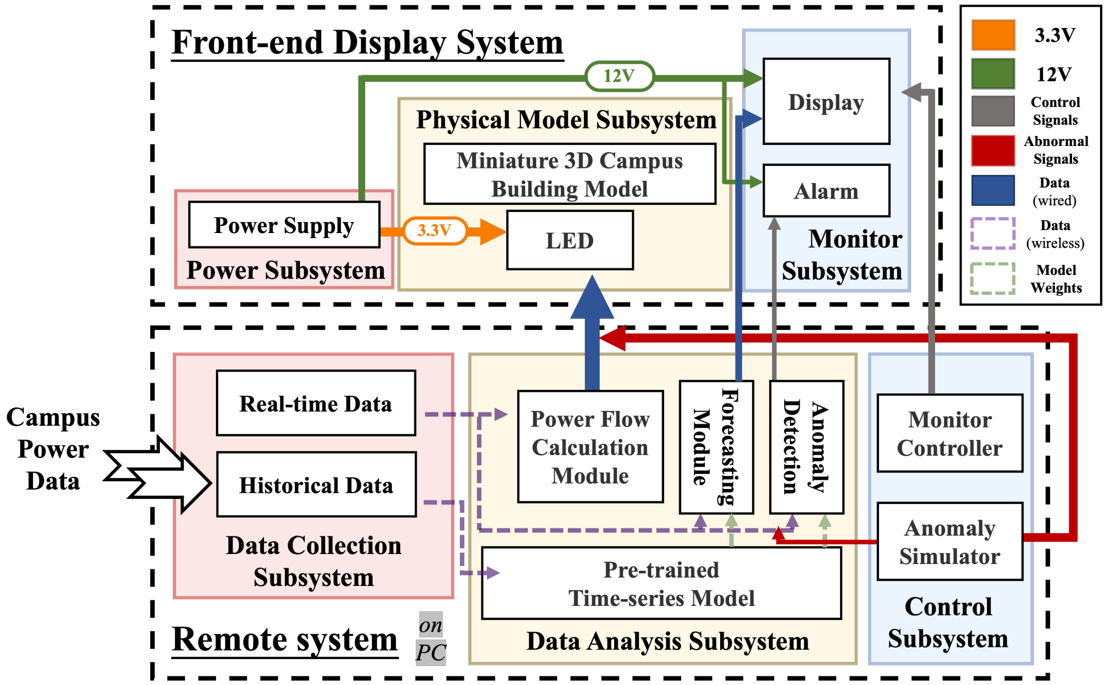

Figure 2: Block Diagram

The real-time power usage data is fed into a pre-trained model based on historical electricity consumption data, enabling the forecasting of power usage for individual buildings and the identification of anomalies. The data generated by this subsystem is then transmitted to the Physical Model and Monitor subsystems for visualization purposes.

2.2.3 Control Subsystem

The Control Subsystem enables the adjustment of data display settings on the display in the Monitor Subsystem, allowing for the selection of different time and spatial ranges. It also incorporates an Anomaly Simulator, capable of generating abnormal power consumption data to facilitate system testing and simulation of anomalies.

2.2.4 Power Subsystem

The Power Subsystem powers the Physical Model and the Monitor subsystems, providing the proper voltage to both through a transformer.

2.2.5 Physical Model Subsystem

The Physical Model Subsystem visualizes the real-time electrical usage of each building on campus. It receives display commands from the Control Subsystem and uses LED strips of various colors to display electrical data such as voltage and power.

2.2.6 Monitor Subsystem

The Monitor Subsystem responds to commands from the Control Subsystem by displaying numerical real-time or historical power data of individual buildings. It can also provide estimated future values for the power data of each building. Additionally, in the event of anomaly simulation, the Monitor Subsystem can display the specific building experiencing an anomaly event, triggering an alarm accordingly.

2.3 Subsystem Requirements

2.3.1 Remote System

Data Collection Subsystem

The Data Collection Subsystem relies on substantial power data from the Engineering Department to ensure accurate modeling. Therefore, obtaining a minimum of **3** years' worth of historical data for each substation is essential. Furthermore, a backup mechanism must be established to safeguard data integrity in the event of a system failure. Additionally, for the real-time display of power data for each building on campus, the data acquisition subsystem must be capable of collecting real-time power data from each substation at a frequency of no less than **once per second**. Moreover, strict adherence to data privacy and security regulations is necessary to prevent any potential data breaches.

Data Analysis Subsystem

Since the Data Collection Subsystem collects the electricity consumption of each substation on campus, the Data Analysis Subsystem first needs to preprocess these data into the active electricity consumption of each building. It also needs to screen out some special cases of data to ensure the accuracy of the model construction. In addition, the time series modeling needs to consider the seasonality and periodicity of electricity consumption to make the data analysis more complete and accurate. The data model needs to process data from all buildings simultaneously and update the model with tidal stream calculations on a minute-by-minute basis. The constructed electricity time series model has a prediction accuracy of at least **90%**. It is imperative that the reprocessed data is transmitted to other subsystems within a maximum latency of **1** second upon receiving new data.

Control Subsystem

In order to ensure convenience, the Control Subsystem incorporates a user-friendly interface that enables manual control of the front-end display system. This control interface facilitates the selection of different time and spatial ranges to showcase various power situations. This includes historical, real-time power consumption data, power data predictions, and anomaly simulations. By transmitting control signals to the Monitor Subsystem and the Physical Model Subsystem, the Control Subsystem swiftly switches the power data display, with a response time of less than **100** milliseconds. Additionally, effective communication with other subsystems is established through standardized protocols.

Remote System Overall Requirement List

- For power usage data, historical data must be accessible for at least **3** years, and real-time data must be collected at a frequency of no less than **1** second at a time.
- To fulfill the high-level requirements, the time series model must achieve a minimum accuracy of **90%**.
- To meet the overall time delay requirements, the remote system must maintain a data update response time of less than **1** second and an operation update response time of less than **100** milliseconds.

2.3.2 Front-end Display System

Power Subsystem

The Power Subsystem is responsible for supplying power to the LED strips of the Physical Model Subsystem and the monitor subsystem through transformers in order to obtain different required voltages. First of all, for the light strips of the Physical Model Subsystem, the LED strips must be supplied with a continuous current of at least **500**mA and a stabilized voltage of about **3.3**V to ensure the stability of the LED strips. An overcurrent protection device is also required to prevent damage to the LED strips. For the monitor subsystem, a stabilized voltage of around **12**V must be provided for the monitor and alarm. In addition, the power provision subsystem needs to be equipped with a backup power supply in case the main power supply fails. It also needs to provide status signals to indicate the health of the power supply so that it can be serviced and handled in a timely manner.

Physical Model Subsystem

The Physical Model Subsystem needs to receive display commands from the Control Subsystem within **500** milliseconds to ensure the timeliness of the visualized power data presented. The subsystem should also be equipped with at least three different colored LED strips to display voltage, power and other parameters. The campus building model needs to be as realistic as possible to facilitate real-time troubleshooting and processing. The use of LED strips to display power data makes it more intuitive for individual buildings and areas, but the exact power data values are not directly visible. In addition, the Physical Model Subsystem needed to include fail-safe mechanisms to deal with issues such as LED strip failures in a timely manner.

Monitor Subsystem

The Monitor subsystem is required to receive display commands from the Control Subsystem within **500** milliseconds while displaying real-time power data at a refresh rate of at least once per second to ensure real-time power data. In anomaly simulation, the subsystem needs to trigger an alarm within **5** second after detecting a power failure and record the time of the failure, so as to facilitate timely handling of power failures and post-inspection. At the same time, the Monitor subsystem needs to provide a user interface for manual control and monitoring, which can be used by the observer to obtain the required or more accurate power data.

Front-end Display System Overall Requirement List

- The LED voltage must be **3.3V**, while the display voltage should be **12V**.
- To meet the overall time delay requirement, color changes to the LED on the physical model and display on the monitor must maintain a response time of less than **500** milliseconds.
- The physical model needs to include all the **26** significant buildings on campus that are electrified.
- Voltage, current and active power information for each building is clearly displayed by LED strips of at least **3** colors or brightness.

2.4 Tolerance Analysis

Timing Synchronization. Since power data needs to be collected and processed before display, the real-time nature of power data displayed on the front-end may be difficult to ensure. Ideally, the Data Collection Subsystem collects real-time power data at a frequency of once per second with a time tolerance of ±100 milliseconds. This includes network latency, substation reporting time variations, and system clock synchronization. The Data Analysis Subsystem processes real-time data with a tolerance of ±50 milliseconds. This includes pre-processing, model building, and providing data to other subsystems. Any delay outside of this range may affect the real-time responsiveness of the system. Also, the Control Subsystem must control the display and switching of real-time and historical data. It coordinates with the other subsystems with a time tolerance of ±20 milliseconds. This is critical for seamless switching and real-time monitoring. Exceeding this tolerance may result in inconsistent or delayed displays. In the face of possible delays, we can build mathematical models of data synchronization and processing times and use statistical analysis to determine the impact of time variations on overall system performance. Alternatively, network time protocols can be implemented to achieve accurate clock synchronization.

Power Supply Reliability. The power supply needs to provide continuous power to the LED strips of the Physical Model Subsystem and the monitor subsystem. Any failure or interruption of the power supply may result in the loss of the visual display and alarm functions. At the same time, the voltage and current supplied to multiple LED strips after passing through the transformer may be unstable, which may lead to damage or malfunction of the strips. Therefore, we need to have a backup power supply in case the main power supply fails. When a mains failure is detected, the backup power supply should be activated within 1 second, which ensures a seamless transition and avoids interruption of the LED strip operation.

Errors in the Forecasting Model of Power Usage. In accordance with the common setup of the state-of-the-art (SOTA) model in the domain under consideration [2], we choose to employ the Mean Squared Error (MSE) loss as a metric for quantifying the dissimilarity between the predicted values and the corresponding ground truth data. By aggregating and averaging losses for each individual channel, we are able to derive an overarching target loss, which serves as a comprehensive measure of the model's performance.

$$\mathbf{L} = \frac{1}{M}\sum_{i=1}^{M} \left|\left|\hat{\mathbf{x}}^i - \mathbf{x}^i\right|\right|_2^2$$

By minimizing the loss function, the model's parameters can be adjusted, enabling it to more accurately approximate the actual outcomes.

3 Ethics and Safety

Privacy. The data displayed by our system should not reflect any individual's electricity usage, as we highly value the data privacy of each individual. Thus, our system takes each building as our measuring object, to exclude any sensitive personal data while maintaining the purpose of displaying meaningful power usage data of the campus.

Social Benefits. According to IEEE Code of Ethics, we are obligated to prioritize the safety, health, and well-being of the public [3]. Furthermore, we should make diligent efforts to adhere to ethical design principles and promote sustainable development practices. Our system is designed to achieve two main goals. Firstly, it monitors the power usage of the campus to provide a safe and efficient electricity system. Secondly, it also plays a role in educating people about the value of electricity we use every day. With the model we built, we can vividly display how electricity power runs inside our campus, which urges us to use it appropriately.

Data Safety. The power usage of each building can be highly sensitive data, especially for those involving experiments. To realize our goal of power usage model display and power usage data analysis, we will preprocess the data before displaying it with our model, thus making sure that no one can reverse engineer the model to get the sensitive data. Meanwhile, the data we collected will be carefully stored to avoid any information leaks. In our project, we adhere to high standards of integrity, responsible behavior, and ethical conduct, ensuring the use of legal data sources and preventing harm to others according to [3].

Electricity Usage Safety. As our system uses a large number of LEDs to display the power consumption of the campus, it's important to monitor the functionality of the circuits and avoid potential safety issues such as fire hazards. The LEDs we use should be capable of not only long-term functioning but also smooth voltage adjustment. We will also add monitoring components for our system, in case of any unpredicted accidents.

References

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[3] *Ieee code of ethics*, Online, Visited on 03/07/2024, IEEE, 2016. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.