PROJECT REPORT

## ANGEL Innovation Hackathon 2026

Sustainable Energy Track · Deeptech Hackathon Programme

# Industrial Energy Efficiency Copilot: An Intelligent Multi-Site Energy Monitoring and Optimization Platform


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| TEAM | **PowerTech** |
| TEAM LEADER | **Asem Ameen Qaid** |
| SUPERVISOR | **Ir. Firdaus, S.T., M.T., Ph.D., IPM** |
| PROBLEM OWNER | **PT Indmira Global Energi** |

Undergraduate Program of Electrical Engineering
Faculty of Industrial Technology
Islamic University of Indonesia


2026

## ABSTRACT

Many factories see their electricity use only as a monthly total. Without machine-level and site-level data they cannot tell which equipment uses more energy than expected, when machines run outside production hours, or when efficiency slowly degrades, and companies with several sites cannot easily decide which one to investigate first.

The Industrial Energy Efficiency Copilot is a multi-site energy monitoring and analysis platform developed for the ANGEL Innovation Hackathon 2026 challenge of the same name, with PT Indmira Global Energi as industry problem owner. It combines an ESP32-based acquisition unit with an RS485 AC energy meter, MQTT data transfer and a web dashboard. The dashboard provides multi-site monitoring, baseline-based anomaly detection, IKE analysis (energy consumed per unit produced), an initial forecasting model and an Energy Copilot that explains findings from calculated results.

The software prototype met the challenge's Prototype Alpha requirement. In a preliminary test on a synthetic dataset of 90 records covering three machines over 30 days, all three inserted anomalies were detected with no false alarms. The acquisition unit (ESP32 with a PZEM energy meter over RS485/Modbus) was designed and its firmware written; the hardware has not yet been validated. The technology readiness level reached is TKT 3 (proof of concept).

**Keywords:** energy monitoring, energy efficiency, IKE, anomaly detection, forecasting, ESP32, MQTT, PZEM, RS485

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# 1 Introduction

## 1.1 Problem Statement

Industrial facilities are a major consumer of electricity, and many of them are subject to energy-management obligations under Indonesian Government Regulation PP No. 33/2023 on Energy Conservation [1]. Yet most factories see electricity only as a monthly total on the utility bill. Without data at the level of individual machines and sites, they cannot answer basic questions: which equipment uses more than expected, which machines run outside production hours, and whether efficiency is slowly degrading. Companies that operate several sites face a further problem, because they cannot easily decide which site to investigate first.

## 1.2 Target Users

The platform is intended for energy managers, facility managers and maintenance teams in industrial facilities, especially multi-site manufacturers.

## 1.3 Objectives

- To measure electrical consumption at machine and site level with a low-cost acquisition unit.
- To bring the data of several sites into one monitoring dashboard.
- To detect unusual consumption by comparing each machine with its own normal pattern.
- To relate energy to production through IKE (energy per unit produced) and to forecast near-term consumption.
- To explain findings and rank what to inspect first, stating the evidence and assumptions rather than claiming unverified savings.

# 2 Proposed Solution

## 2.1 Concept

The platform takes an energy manager from raw measurements to a prioritised list of investigations in five steps (Figure 1): measure, monitor, analyse, predict and explain.

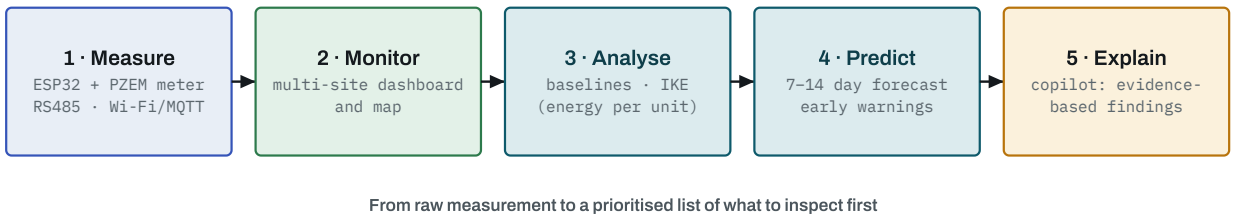



**Figure 1.** The five-step evidence-based pipeline of the platform.

## 2.2 System Architecture

The system has three layers (Figure 2). In the hardware layer, an acquisition unit measures the electrical load with a current transformer and a PZEM-series AC energy meter, which the ESP32 reads over RS485 (Modbus) and publishes over Wi-Fi using MQTT. In the data and analytics layer, the messages are received by an MQTT broker, stored, and processed by the analytics, forecasting and copilot modules. In the application layer, the results are presented in the Energy Command Center dashboard.

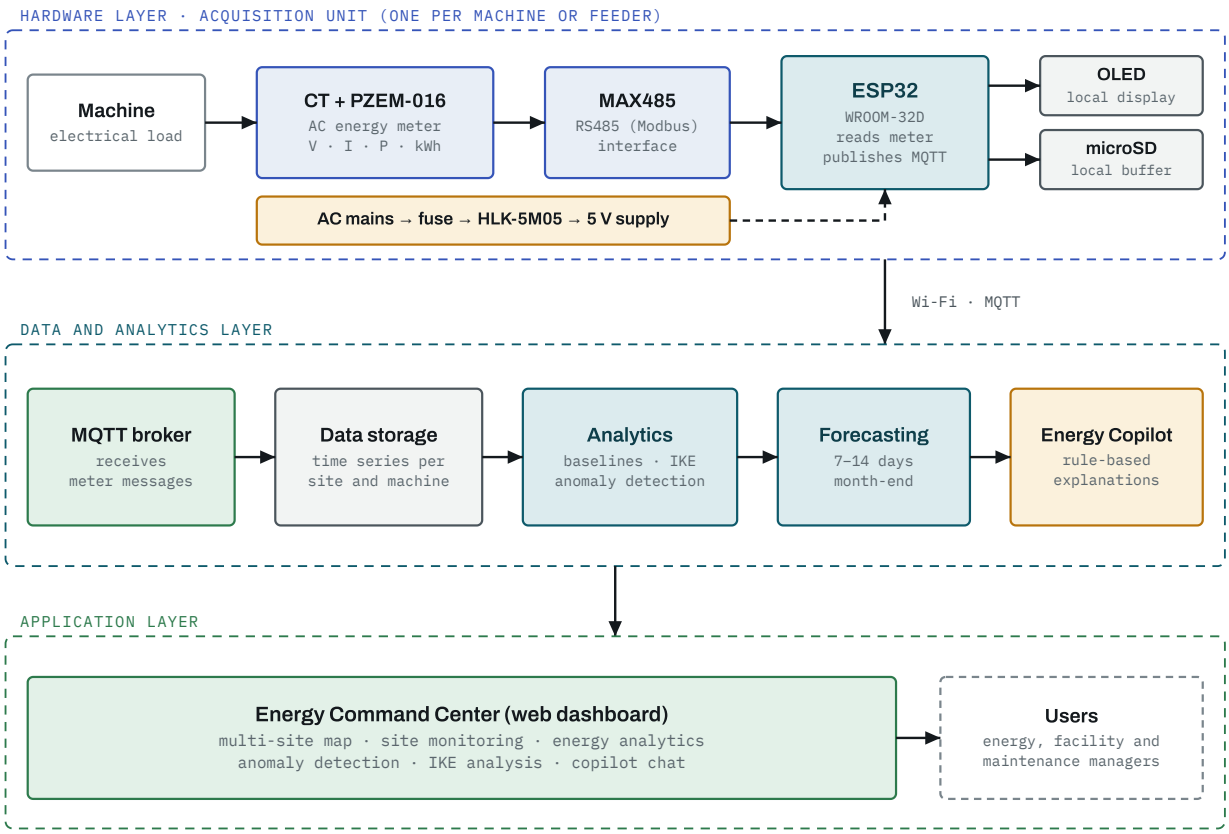



**Figure 2.** System architecture: hardware, data and analytics, and application layers.

## 2.3 Advantage over a Consumption-Only Display

A conventional energy display shows how much electricity was used. This platform instead compares each machine with its own normal weekday pattern, links findings to IKE and to forecasts, and ranks what should be inspected first. Every result is traced to measured data and shown with its evidence, and the platform states its assumptions instead of presenting estimated savings as fact.

# 3 Hardware Design

## 3.1 Acquisition Unit

The acquisition unit was designed in Cirkit Designer (Figure 3). Mains power enters through an AC inlet and a fuse to a terminal block and is converted to 5 V by an HLK-5M05 module. A Peacefair PZEM-series AC energy meter measures voltage, current, power and energy and communicates through a MAX485 RS485 interface with an ESP32-WROOM-32D. An OLED display shows local readings and a microSD module provides local storage. Screw terminals are used for the field connections.

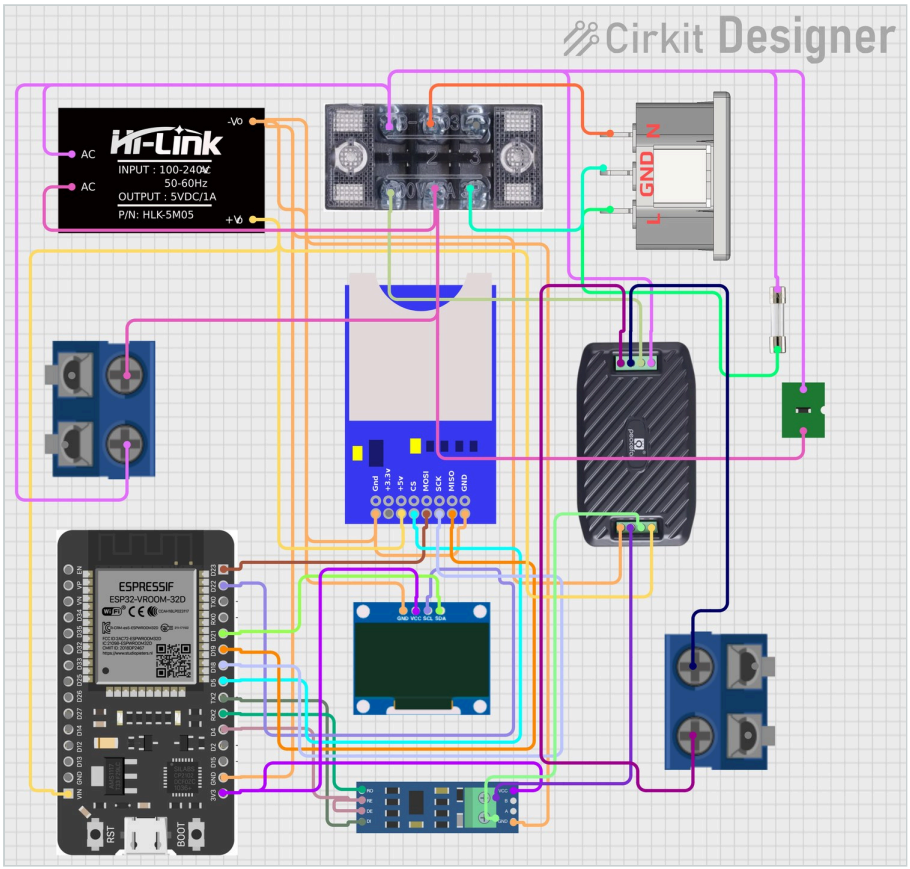



**Figure 3.** Electrical schematic of the acquisition unit (Cirkit Designer).

**Table 1.** Main components of the acquisition unit

| Component | Function |
|---|---|
| AC inlet, fuse, terminal block | Mains input and protection |
| HLK-5M05 | AC to 5 V DC power supply |
| Peacefair PZEM-series meter with CT | Measurement of voltage, current, power and energy |
| MAX485 | RS485 (Modbus) interface between meter and ESP32 |
| ESP32-WROOM-32D | Reads the meter and publishes data over Wi-Fi/MQTT |

| Component | Function |
|---|---|
| OLED display | Local display of readings and status |
| microSD module | Local data storage |

### 3.2 Firmware

The ESP32 firmware reads the energy meter over RS485 and publishes the measurements to the MQTT broker, with a design update interval of about 0.5 s. The firmware was written; it has not been integrated with the physical meter, and the hardware has not yet been validated.

## 4 Software Prototype

### 4.1 Energy Command Center

The software prototype is a web dashboard called the Energy Command Center (Figure 4). It shows an organisation-level summary of total energy, monitoring coverage, anomaly findings and energy above baseline; a site map with the status of each site; and a list of sites needing attention, ranked by severity and data availability. Further pages provide site monitoring, energy analytics, anomaly detection, IKE analysis and the Energy Copilot. The prototype runs on a simulated demonstration organisation, not on data from physical meters.

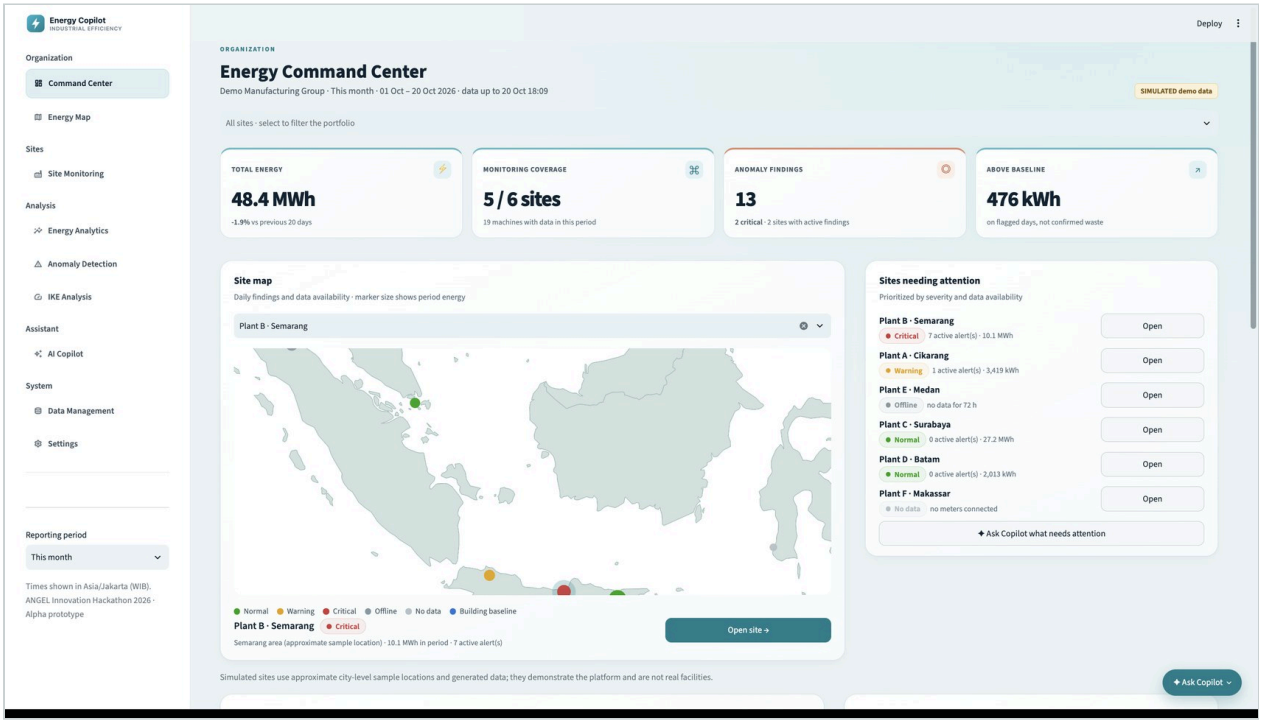



**Figure 4.** Energy Command Center dashboard, shown with the simulated demonstration organisation.

### 4.2 Analytics and Energy Copilot

The analytical functions are organised in four capabilities (Table 2). An initial version of each was implemented and tested on simulated data.

**Table 2.** Copilot capabilities (initial version, tested on simulated data)

| Capability | Initial version (implemented, simulated data) |
|---|---|
| **Observe** | Site status from data freshness and findings; live MQTT path tested with a simulated meter |
| **Detect** | Each machine compared with its own weekday baseline; energy per running hour and per unit |
| **Predict** | 7–14 day energy forecast with expected range; month-end projection; efficiency early warning |
| **Recommend** | Rule-based recommendations with evidence; data-based chat assistant |

### 4.3 Role of the System Integration Work

As team leader and system integration lead, the author was responsible for the dashboard, the data pipeline (MQTT and storage) and the integration of the system, and for coordinating user tests and feedback with industry users.

## 5 Testing and Readiness

### 5.1 Software Test on a Synthetic Dataset

The software was tested on a synthetic dataset, without hardware, to check that the analysis pipeline behaves correctly (Table 3). The dataset contained 90 records covering three machines over 30 days, with three anomalies deliberately inserted.

**Table 3.** Preliminary software test

| Item | Value |
|---|---:|
| Records processed | 90 |
| Machines simulated | 3 |
| Period | 30 days |
| Anomalies inserted | 3 |
| Anomalies detected | 3 (100 %) |
| False alarms | 0 |

This test demonstrates the functionality of the software on simulated data. Detection and forecast accuracy on real measurement data have not been evaluated.

### 5.2 Technology Readiness

Figure 5 summarises the readiness of each part of the system. The project reached TKT 3 (proof of concept: a designed system with core software working on simulated data). The hardware has not yet been validated.

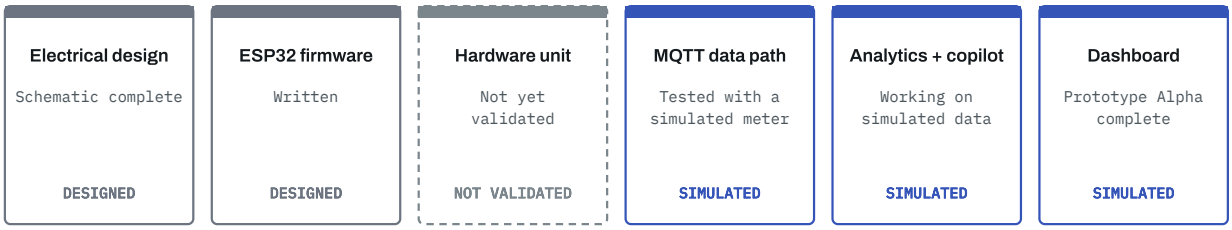



**Figure 5.** Readiness of each part of the system.

## 6 Team

Team PowerTech consists of one lecturer and four students with expertise in electrical engineering, informatics and business management (Table 4).

**Table 4.** Division of tasks and responsibilities

| Member | Role | Responsibilities |
|---|---|---|
| **Asem Ameen Qaid** Electrical Engineering | Team leader; system integration; user-validation coordinator | Dashboard, data pipeline (MQTT, storage), system integration; user tests and feedback with industry users |
| **Ir. Firdaus, Ph.D.** | Supervisor | Academic and technical supervision; quality review of test methods and reports |
| **Fawaz Abbaker** Electrical Engineering | Technical coordinator; standards | Electrical design, metering hardware, ESP32 firmware, measurement validation; electrical safety and standards |
| **Abdullah Al-Hamid** Informatics | AI and data lead | Anomaly detection, forecasting, copilot (LLM integration), data quality and evaluation |
| **Yasmin Mohamed** Business | Business and downstreaming coordinator | Market and user validation, business model, TKDN and HKI preparation, commercialisation and partner relations |

### 6.1 Project Management

- A weekly progress meeting reviewed a shared task board in which every task had an owner and a deadline.
- Code and firmware were managed in Git with peer review, and hardware and data tests were recorded in written test logs.

- The supervisor reviewed progress, risks and test results every two weeks, and a risk register with a fallback for each risk was kept.

## 7 Conclusion

The Industrial Energy Efficiency Copilot addresses a practical gap in industrial energy management: the step from raw consumption data to a clear, evidence-based decision about what to inspect first. The software prototype demonstrated multi-site monitoring, baseline-based anomaly detection, IKE analysis, forecasting and rule-based explanations on simulated data, and detected every inserted anomaly without false alarms in a preliminary test. The acquisition unit has been designed and its firmware written.

The system reached TKT 3 (proof of concept). The hardware has not yet been validated, and detection and forecasting have not been evaluated on real measurement data.

## References

1. Ministry of Energy and Mineral Resources (ESDM), "Implementasi Manajemen Energi Tahun 2023 Mampu Hemat 10,42 Juta SBM," esdm.go.id, summary of Government Regulation (PP) No. 33/2023 on Energy Conservation.