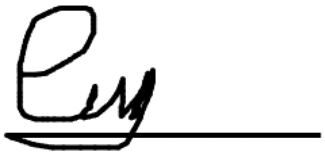
Software Requirements Specification

Slab Guardian, Real Time IoT Energy Threshold Monitor for Karachi Households

UBIT, University of Karachi | Final Year Project

Version 1.0

Prepared based on our hardware build, live testing, and dashboard readings
July 2026



1. Introduction

1.1 Purpose

This document specifies the software and hardware requirements for Slab Guardian, a real time IoT energy monitoring device built to help Karachi households track their monthly electricity consumption against K Electric's 200 unit protected slab. It reflects the requirements we defined at proposal stage and updates them based on what we have actually built and tested on the bench so far. It is meant to guide the remaining development work and to serve as the reference document for our supervisor's evaluation of the project.

1.2 Scope

The system covers a physical sensing unit built from an ESP32 microcontroller, a PZEM-004T V3.0 energy metering module, and an SCT-013-000 non invasive current clamp, connected wirelessly to a backend that stores readings and serves them to a live dashboard. It covers real time voltage, current, power, and cumulative energy readings, a running total of units consumed in the current billing cycle, and threshold based alerts as the household approaches the 200 unit limit. Appliance level detection (identifying which specific device is consuming power) is documented as future scope in Section 8 and is not part of the committed V1 deliverable.

The system is intended for a single household's main electrical line. It does not extend to solar/net metering setups, three phase supply, or direct integration with K Electric's own billing systems, unless explicitly stated as future work.

1.3 Intended Audience

- Final Year Project development team (hardware, backend, and mobile developers)
- Project supervisor and evaluation committee
- Household users who would install and rely on the device day to day

1.4 Definitions, Acronyms and Abbreviations

Term	Definition
KE	K Electric, the electricity utility serving Karachi
NEPRA	National Electric Power Regulatory Authority, the federal regulator governing KE's tariff structure
Protected consumer	A residential customer billed at a subsidized rate for staying at or under 200 units per month for six consecutive months
Slab breach	Crossing the 200 unit limit in a billing cycle, which reclassifies the bill and revokes Protected status for six months
CT clamp	Current transformer clamp, a non invasive sensor that measures current by clipping around a wire
RMS	Root Mean Square, the standard way of expressing an effective value for an AC voltage or current waveform
MQTT	A lightweight publish and subscribe messaging protocol used to send sensor data from the device to the backend
LittleFS	A filesystem built into the ESP32's own flash memory, used here to persist the running unit count through power cuts

2. Overall Description

2.1 Product Perspective

Slab Guardian is a new, standalone device. It does not replace or modify the existing KE meter in any way. It sits entirely on the household's own side of the meter, inside the distribution board, and provides a real time view of consumption that the monthly KE bill cannot. At the time of writing, we have the full sensing chain wired and tested (ESP32, PZEM-004T, SCT-013) and are seeing live voltage, current, power, energy, and power factor readings on a working dashboard when a low voltage test appliance is connected, as shown in our current build.

2.2 User Classes and Actors

Actor	Description
Household user	Views the live dashboard, tracks daily and monthly usage, receives threshold alerts
Installer (team member or electrician)	Physically installs the CT clamp and enclosure inside the DB box, sets the billing cycle start date
System	Reads sensor values, calculates cumulative units, publishes data, triggers alerts, persists state through power loss

2.3 Operating Environment

The sensing unit runs on an ESP32 connected over Wi-Fi to a local or cloud hosted MQTT broker (Mosquitto), which feeds a Node.js backend and an InfluxDB time series database. The user facing dashboard is currently being validated through a lightweight web view served directly from the device during bench testing, with the final version intended as a Flutter mobile app. Specific hosting choices for the backend, whether a low cost VPS or a locally run server, are implementation decisions to be finalized as we move past the bench testing stage.

2.4 Assumptions and Dependencies

- The household has a working Wi-Fi connection reachable from the distribution board, or within reasonable range of it.

- The specific KE meter's pulse rate and billing cycle start date will be confirmed for each installation rather than assumed.
- The team has already sourced and validated the ESP32, PZEM-004T, and SCT-013 as the core sensing hardware, as documented in our earlier component research.
- Karachi's frequent load shedding is treated as a normal operating condition, not an edge case, which is why local persistence through LittleFS is a core requirement rather than an optional feature.

3. Functional Requirements

3.1 Sensing and Hardware Module

ID	Requirement description	Priority
FR-1.1	The system shall measure RMS voltage, RMS current, real power, apparent power, power factor, and cumulative energy using the PZEM-004T module.	High
FR-1.2	The system shall sense current non invasively using the SCT-013-000 clamp, clipped around a single live wire only.	High
FR-1.3	The system shall communicate between the PZEM-004T and the ESP32 over UART using the standard TX to RX2 and RX to TX2 wiring.	High

3.2 Data Communication Module

ID	Requirement description	Priority
FR-2.1	The system shall publish sensor readings from the ESP32 to an MQTT broker at a regular interval.	High
FR-2.2	The system shall format published readings as a structured JSON payload including voltage, current, power, and cumulative energy.	Medium
FR-2.3	The system shall reconnect automatically to Wi-Fi and the MQTT broker after a network interruption without requiring a manual reset.	High

3.3 Local Persistence Module

ID	Requirement description	Priority
FR-3.1	The system shall write the cumulative unit count to the ESP32's internal flash (LittleFS) whenever it crosses a whole new unit.	High
FR-3.2	The system shall read the last saved unit count from flash on boot and resume from it rather than resetting to zero.	High
FR-3.3	The system shall survive at least 20 simulated power interruptions in testing without losing the running unit count.	High

3.4 Backend and Storage Module

ID	Requirement description	Priority
FR-4.1	The system shall subscribe to the MQTT topic and write incoming readings into a time series database (InfluxDB).	High
FR-4.2	The system shall expose a REST API providing the latest reading and historical readings over configurable time windows (7, 10, and 15 days).	High
FR-4.3	The system shall calculate the household's position against the 200 unit budget relative to their own billing cycle start date, not the calendar month.	High

3.5 Dashboard Module

ID	Requirement description	Priority
FR-5.1	The system shall display live voltage, current, power, and cumulative energy on a dashboard, as already demonstrated on our bench build.	High
FR-5.2	The system shall display units consumed this hour, today, and per day average, alongside a projected monthly usage figure.	High
FR-5.3	The system shall present a clear indicator of days remaining under the current 200 unit budget in plain language rather than requiring the user to interpret raw numbers.	High

3.6 Alerting Module

ID	Requirement description	Priority
FR-6.1	The system shall trigger an alert when cumulative consumption crosses 50, 75, and 90 percent of the 200 unit budget for the current cycle.	High
FR-6.2	The system shall avoid repeating the same threshold alert more than once per cycle.	Medium

3.7 Non Intrusive Load Monitoring Module (Future Scope)

The Non Intrusive Load Monitoring (NILM) module, covering appliance level detection, is discussed as a desirable enhancement rather than a firm V1 requirement, and is scoped separately in Section 8.

4. Non-Functional Requirements

ID	Requirement	Priority
NFR-1	Accuracy: the device's reported energy consumption should stay within roughly 2 units of the official KE meter over a full test cycle.	High
NFR-2	Reliability: the running unit count must never reset to zero due to a power interruption.	High
NFR-3	Safety: all wiring must remain non invasive, with no cutting or splicing of the household's main service wire.	High
NFR-4	Responsiveness: dashboard readings should reflect a change in load (an appliance switching on or off) within a few seconds.	Medium
NFR-5	Usability: the dashboard should communicate the household's status at a glance, without requiring the user to interpret raw electrical values.	Medium
NFR-6	Availability: the device should continue operating and buffering data locally during Wi-Fi outages, publishing once connectivity returns.	Medium

5. Business Rules

- A household is classified as Protected by KE if monthly consumption stays at or under 200 units for six consecutive months.
- Crossing 200 units in a single month reclassifies that month's bill at the higher Unprotected rate and revokes Protected status for the following six billing cycles.
- The daily consumption budget is calculated as 200 units divided by 30 days, approximately 6.67 kWh per day, and is used as the baseline for pacing alerts.
- Current sensing must always use a non invasive clamp around a single live wire, never a cut or spliced connection, and never both live and neutral clamped together.

- The billing cycle used for all budget calculations is anchored to the household's actual KE meter reading date, not the calendar month.

6. Key Data Entities

Entity	Key attributes
Device	device ID, install location, firmware version, last seen timestamp
Reading	timestamp, voltage, current, power, power factor, cumulative energy
Billing Cycle	household ID, cycle start date, cumulative units so far, projected monthly usage
Alert	household ID, threshold percentage, timestamp fired, acknowledged status
Calibration Log	date, KE meter reading, device reading, deviation, notes

7. Constraints and Open Questions

The following points are still open and should be confirmed with our supervisor or through further field testing before the design is fully finalized.

- Should the field test target a single household over a full billing cycle, or multiple households in parallel, given our current timeline?
- Is the mobile Flutter app expected to fully replace the current web based bench dashboard by final submission, or can both coexist for the demo?
- What exact accuracy tolerance will the evaluation committee consider acceptable, our stated target is within 2 units of the KE meter, but this has not been formally confirmed with the supervisor.
- Should NILM be attempted in any limited form for this submission, or fully deferred to future work as currently planned?
- What level of enclosure and safety documentation is expected for the final hardware submission versus the bench prototype currently working?

8. Future Scope

Beyond the core V1 scope defined in this document, the following enhancements are being considered as recommendations for future work rather than committed deliverables.

- Non Intrusive Load Monitoring for appliance level detection, once a labeled dataset of local Pakistani appliance signatures is available.
- An optical pulse counter reading the KE meter's own LED as a secondary, independent validation source against drift.
- Support for solar and net billing households under NEPRA's Net Billing framework.
- A Demand Side Management integration allowing KE to send voluntary curtailment signals to the device in exchange for billing credits.