Development of a Multipurpose IoT based Energy & Remote Asset Monitoring and Control System

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Abstract - *In the past decade, the rise in fuel costs combined with the demand for cheap power has forced power utilities around the world to increase their tariffs. To offset this, power utilities are not only reducing their operating costs through industrial automation but also offering value added services to their end customers. The Indian power market is no exception to this change, however due to the availability of cheap labour in India, the adoption of new and innovative technologies has been relatively slower. Fortunately, this trend is changing and utilities (especially private ones) are embracing new technologies which would help them reduce cost as well as increase customer satisfaction. TATA Power, being a pioneer in adopting new and emerging technologies, has invested in multiple such technologies; one of which is Internet of things (IoT). In this paper, we address the overall development of two different projects based on the same technology; one is an IoT based energy monitoring solution for residential & commercial customers, and the other is an IoT based remote asset monitoring & control solution for Hydro Generation Plants.*

Key Words: Internet of Things (IoT), Industrial Internet of Things (IIoT), ESP-32, SIM800l, Arduino, Open Source, ESP-IDF

1. INTRODUCTION

Internet of Things or IoT as it is commonly known as, is an intelligent network which connects all things to the Internet for the purpose of exchanging information and communicating through the information sensing devices in accordance with agreed protocols. It achieves the goal of intelligent identifying, locating, tracking, monitoring, and managing things [1]. The term Internet of Things was first coined in 1999 by Kevin Ashton (while working for P&G) to attract management attention towards RIFD, a new technology at the time. However, it took another 10 years for the concept of IoT to gain some publicity [2].

1.1 Exodus from traditional M2M technologies towards Industry 4.0

It is estimated that by 2020 IoT will be a US$8.9 trillion market [2]. A big chunk of this would be from Industry 4.0 or Industrial Internet of Things. Morgan Stanley estimated in 2015 that by 2020, IIoT market will be worth US$110 billion. These estimates are not only because of the technological advantages (remote troubleshooting, predictive data analysis, scalability, etc.) that IIoT presents but also due to how easy it is to deploy. It was due to these reasons, we decided to base our solution on this technology.

1.2 Use case 1: IoT based Energy Monitoring Solution 2

Although TATA Power already has a mature AMR (Automatic Meter Reading) infrastructure in place; there was still a need for a cheaper and more compact energy monitoring solution. This would allow the end consumer to monitor room/ sub-area level (in some cases even equipment level) energy consumption. From a commercial standpoint, TATA Power intends to provide these devices as value added services to its consumers. Hence, these devices not only had to be cheap, they needed to be reliable as well. Once installed at the consumer premises, the data collected by the devices would enable the consumer to not only monitor their consumption on real time basis, but also get useful insights about their consumption pattern (both present and forecasted) and equipment health. They would also receive tips to help them reduce their power consumption.

1.3 Use case 2: IIoT based Remote Asset Monitoring & Control Solution

TATA Power has 3 hydro generation sites spread across nearly 500 sq. Km area in Maharashtra. Due to the sheer size of the hydro generation sites, it is very expensive to lay PLC infrastructure at all remote nodes to monitor various equipment and parameters. Hence, an IIoT device at these locations would prove to be a cheaper alternative to PLCs. They would not only do away with the errors associated with manual reading and conveying of various parameters, but also enable better operational decision making by provide data at real time basis. Over time they may also help in manpower optimization by making these remote locations completely unmanned.

1.4 Objectives of the Project

a) Use case 1: Design and develop a working prototype of an IoT device in a compact 25mm DIN rail mount packaging. The device should have the following features:

   i. Communication over either Wi-Fi or GSM network
   ii. Onboard data storage in case of communication failure
   iii. Handle SSL certificate or use tokens for authentication
   iv. Both electrically and programmatically fault tolerant

b) Use case 2: Design and develop a robust industrial grade IIoT device to capture various sensor data from remote hydro operational locations. The device should have the following features:

   i. Weatherproof enclosure
   ii. Redundant power supply
   iii. Communication over either Wi-Fi or GSM network
   iv. Onboard data storage in case of communication failure
   v. Handle SSL certificate or use tokens for authentication
   vi. Both electrically and programmatically fault tolerant

2. METHODOLOGY

This section deals with the path and thought process followed in designing and setting up an End-to-End ecosystem for IoT devices in Tata Power.

2.1 Project Plan Flow Chart

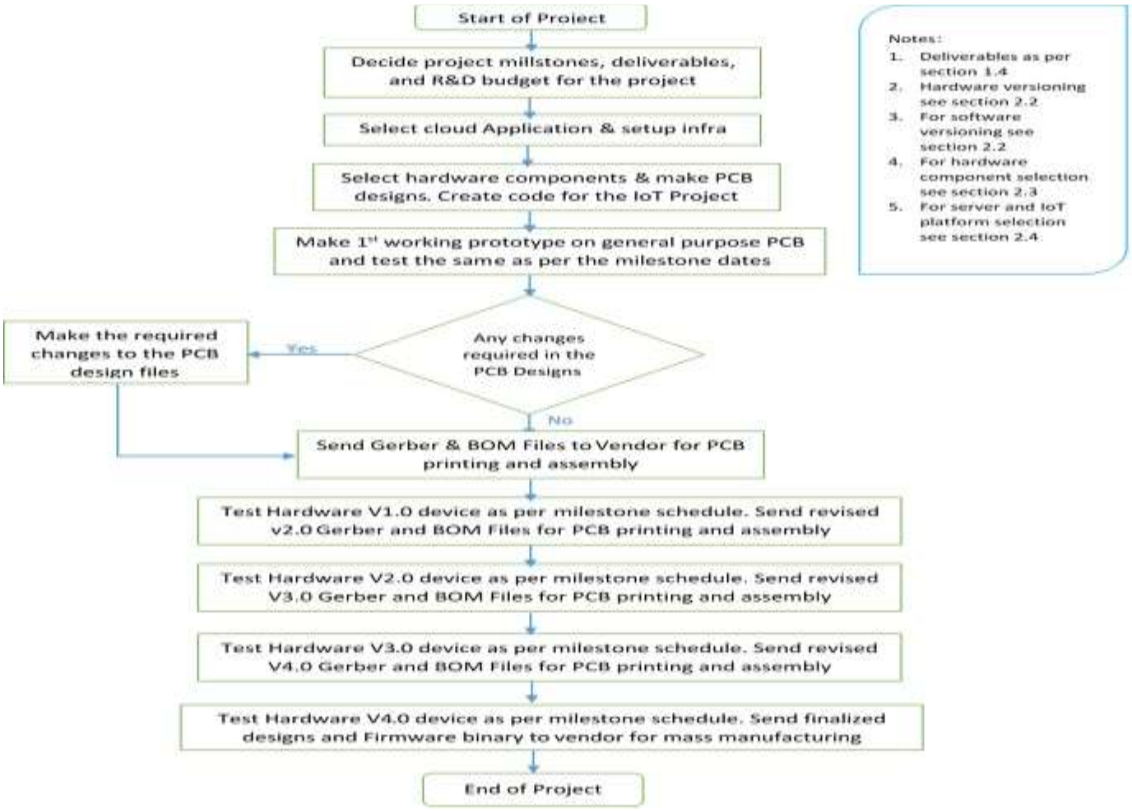


Fig -1: Project plan flow chart

2.2 Hardware & Firmware Version Methodology

While finalizing the milestones for this project, it was decided to approach the hardware and software development in stages. This would enable the management to quantifiably measure the work done for each milestone. It would also ensure an MVP (Minimum Viable Product) was available early in the project. The following H/W (Hardware)& F/W (Firmware) versioning was finalized:

a) H/W v1.0 & F/W v0.9 to v2.1:
  i. Different PCB designs for the Wi-Fi & GSM Devices with separate RS485 module
  ii. The power supply was not integrated with the device
  iii. The devices were only capable of reading the energy meter and sending the data to the MQTT broker

b) H/W v2.0 & F/W v2.2 to v3.5:
  i. The power supply was integrated with the IoT device
  ii. The devices now maintained the timestamps on the devices side as opposed to the server side on the previous versions
  iii. The devices were now tolerant toward connections drops
  iv. Wi-Fi manager integrated with the Wi-Fi devices

c) H/W v3.0 & F/W v3.6 to v4.5:
  i. Common PCB for both Wi-Fi and GSM devices with integrated RS485 module
  ii. Onboard data storage in case of communication failure
  iii. Two-way secure communication using X.509 certificates

d) H/W v4.0 & F/W v4.6 to v5.0:
  i. Reduced the PCB footprint to fit a standard 25mm DIN rail mount IP58 case
  ii. Added dual colour status LED
  iii. Optimized the design files for mass manufacture
  iv. Added RPC call activated FOTA on Wi-Fi devices

2.3 Description Hardware components

a) Main controller:
  i. For hardware versions 1 & 2, ESP8266 was used for the Wi-Fi variant and ATMega328p was used for the GSM variant
  ii. For hardware versions 3 & 4, ESP32 was used as the main controller
b) GSM Modem:
  i. SIM800L was used as the GSM Modem in all H/W versions
c) MODBUS to Serial (5V TTL) Converter:
  i. For hardware versions 1 & 2, an off the self RS485 module was used for both variants
  ii. For hardware versions 3 & 4, the RS485 circuit was integrated on the PCB itself

d) Power supply module:
  i. For hardware versions 1 & 2, an off the self HLK-PM05 AC-DC converter was used for both the variants
  ii. For hardware versions 3 & 4, the AC-DC converter circuit was integrated on the PCB itself

2.4 Selection of Firmware Development Environment

For H/W versions 1 & 2, Arduino IDE was selected as the firmware development platform as an MVP (Minimum Viable Product) needed to be quickly developed. For H/W versions 3 & 4, ESP-IDF was chosen to be the development environment; however, shortly after development H/W v3.0 started, it was decided to go back to Arduino. This decision was taken as it would take a long time to develop the competency level of each member of the development team in ESP-IDF. This in turn would cause issues in maintaining continuity in case any separation from the team/company. Moreover, as the previous development was already done on Arduino, further development would be sped up too.

2.5 Selection of Energy Meter for Use Case 1

Eastron SDM120 Single-phase energy meter and Eastron SDM630 Three-phase energy meter were selected for this project due to their form factor, cost and ability to communicate over MODBUS protocol.

2.6 Selection of IoT Platform and Server

Initially, Thinger.io was used to demonstrate data transfer from the meter to the main controller and unto the IoT application (via MQTT protocol). However, Thinger was found to be very restrictive in terms of dashboards and configurable parameters; hence, three other platforms were tested. Finally, Thingsboard was chosen (over Ubidots and Grafana among other) as it provided the right balance between cost and features.

Next, it was decided to deploy Thingsboard on AWS (Amazon Web Services), as deployment options only included AWS and Azure at the time and AWS was the lower cost option.

2.7 Development of IIoT based Remote Asset Monitoring & Control Solution (Use Case 2)

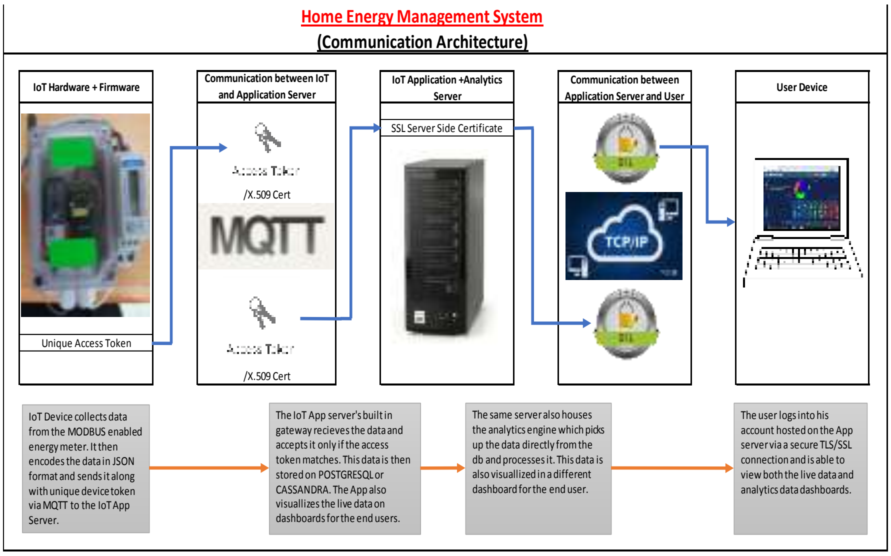
All develop for use case 2 (IIoT based Remote Asset Monitoring & control Solution) was done after completion of H/W v4.0 and F/W v5.0 of use case 1. Hence, its hardware and firmware are mostly based on that of use case 1 (with the exception of redundant power supply, onboard status display and IP68 casing).

3. ARCHITECHTURE

This section tries to highlight the architectures (only high level) used in various components in the IoT ecosystem.

3.1 Use case 1 final architecture (Data flow/ communication)

To ensure secure two-way transport encryption between the IoT devices and application servers without hardware gateways in between, the X.509 certificate is stored on the SPIFF memory of ESP32 and the Public RSA Key is stored on the server side within the IoT application.



IoT Device collects data from the MODBUS enabled energy meter. It then encodes the data in JSON format and sends it along with unique device token via MQTT to the IoT App Server.

The IoT App server's built in gateway recieves the data and accepts it only if the access token matches. This data is then stored on POSTGRESQL or CASSANDRA. The App also visuallizes the live data on dashboards for the end users.

The same server also houses the analytics engine which picks up the data directly from the db and processes it. This data is also visualized in a different dashboard for the end user.

The user logs into his account hosted on the App server via a secure TLS/SSL connection and is able to view both the live data and analytics data dashboards.

Fig -2: Use case 1 final architecture. This figure shows the flow of data from the end-point device to the server and finally to the end user dashboards

3.2 Use case 2 final architecture (Data flow/ communication):

In use case 2, the same secure communication architecture is followed as above. Additionally, the main control unit acts like a gateway for various peripheral units such as the I/O modules, sensor hubs, etc. This architecture saves costs as only one gateway can handle 32 such MODBUS capable modules.

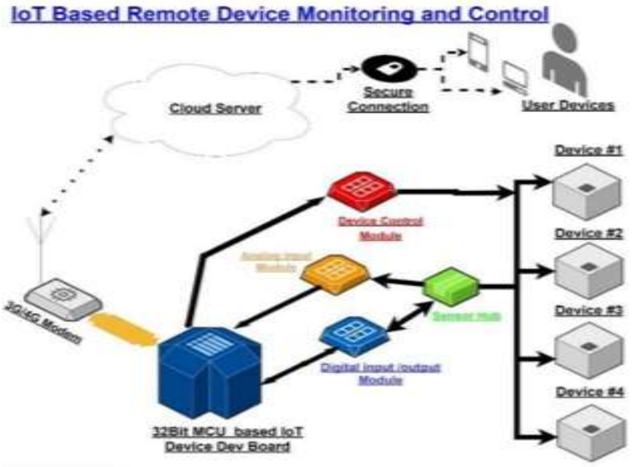


Fig -3: Use case 2 final architecture. This figure shows the flow of data from the end-point device to the server and finally to the end user dashboards

3.3 Use Case 2 Application Example

This sub section describes an example application for the IIoT device to be deployed for monitoring and control of remote assets. In this example, the IIoT device is controlling and monitoring 3 water pumps. The control is established via a group of SPST relays which act as pilot relays for main replays controlling the input supply to the motors. In the initial version, Bus PTs and clamp on CTs are used (via a sensor hub) to monitor the pumps; but in the later versions, SDM630 3 phase power analyzer was used as it is more accurate. All safety measures like overcurrent relays, thermal cut off relay, etc. were wired in parallel with the IIoT device.

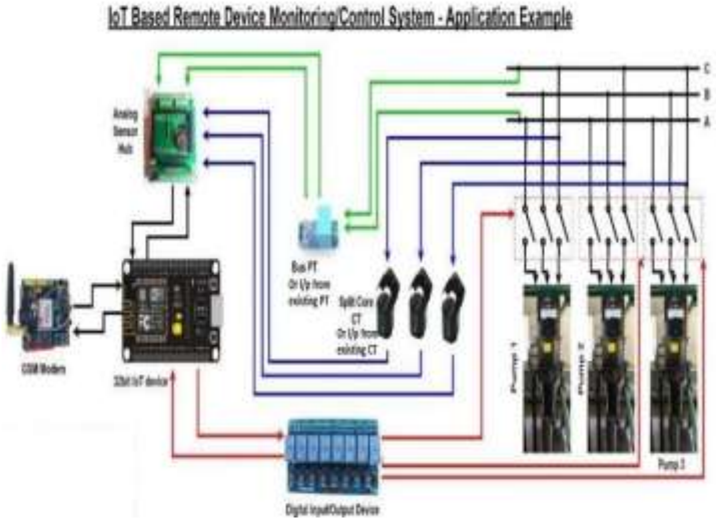


Fig -4: Use case 2 application example

3.4 Server side (IoT Application) Architecture

a) High Level Architecture:

The IoT application (ThingsBoard) contains set of core services that allow managing the following entities:

- Devices and their credentials
- Rule Chains and Rule Nodes
- Tenants and customers
- Widgets and Dashboard
- Alarms and Events

Rules can invoke a certain subset of this APIs. For example, a rule can create an alarm for certain device.

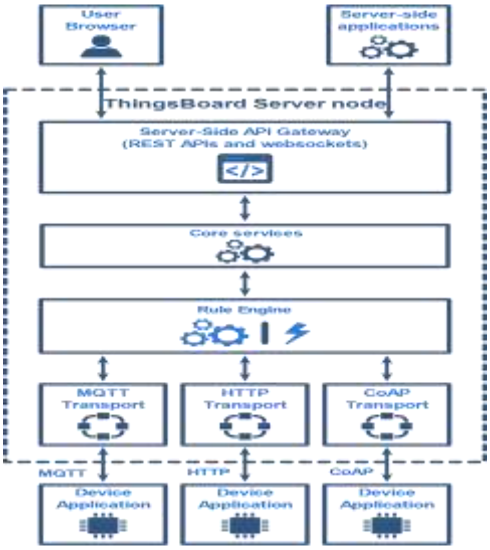


Fig -5: ThingsBoard High Level Architecture [3]

b) Actor Model:

Actor model enables high performance concurrent processing of messages from devices as long as server-side API calls. ThingsBoard uses Akka as an actor system implementation with following actor hierarchies.

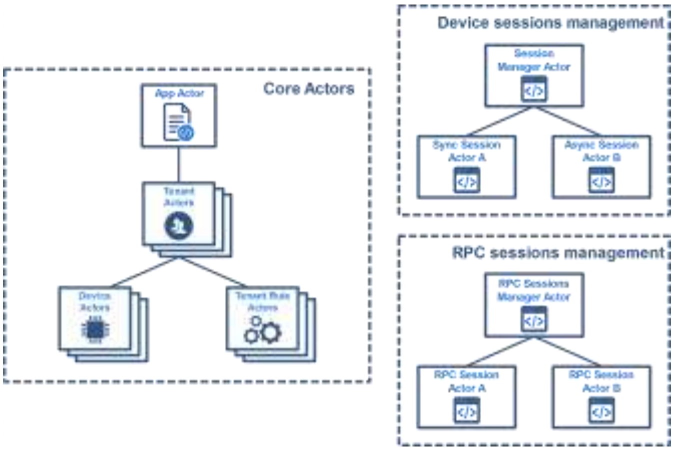


Fig -6: ThingsBoard Actor Model Architecture [3]

4. DEVICE HARDWARE AND FIRMWARE

This section describes the final hardware and firmware of both use case 1 and use case 2 devices.

4.1 Use Case 1 final hardware block diagram (v4.0)

The main controller and all other peripherals draw power from the onboard 5V 2.5A SMPS. The AC input of the SMPS comes from the line out of the energy meter.

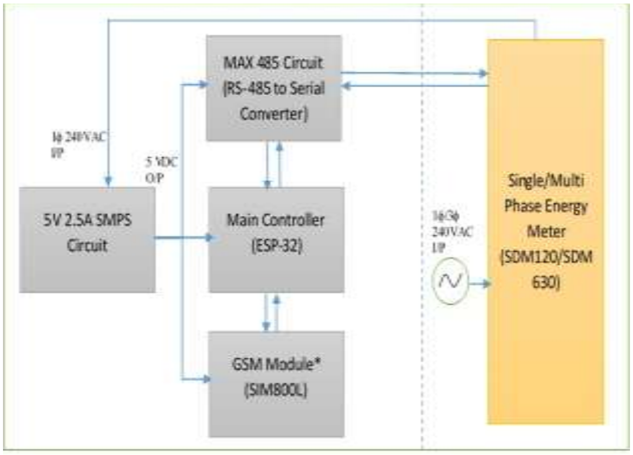


Fig -7: *Use case 1 final hardware block diagram*
**GSM module disconnected in Wi-Fi only devices*

4.2 Use Case 1 Final Hardware Schematic (v4.0)

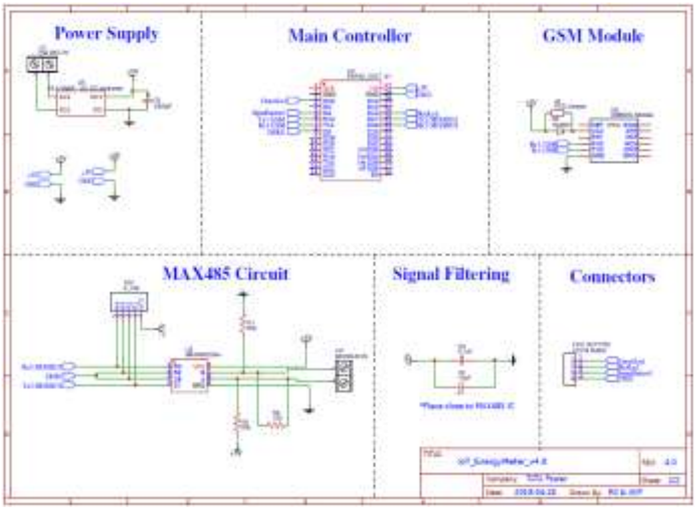


Fig -8: *Use case 1 final hardware schematic*

4.3 Use Case 2 final hardware block diagram

The main difference between the hardware in use case 2 and that of use case 1 are the integrated backup power supply system and the onboard 3G/4G Wi-Fi dongle.

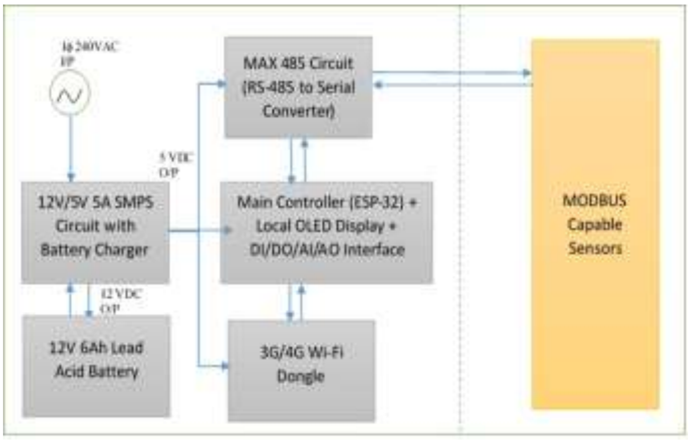


Fig -9: *Use case 2 final hardware block diagram*

4.4 Use Case 2 final hardware schematic

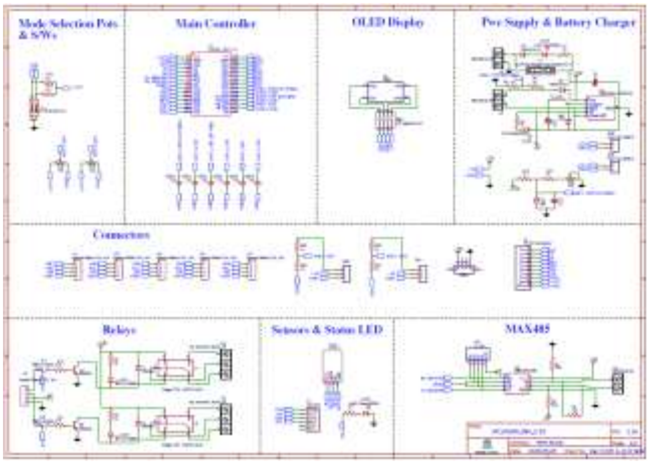


Fig -10: *Use case 2 final hardware schematic*

4.5 Final Firmware Flow Chart

The figure below is the flowchart of the final firmware version of the devices in both use case 1 and 2. It has 4 separate routines namely: Data acquisition routine (MCU Reset/Reboot), GSM/Wi-Fi connection routine, Data save routine, and OTA routine. The last two run on Core 0 and the rest on Core 1. Working of the program can be understood from the flowchart below:

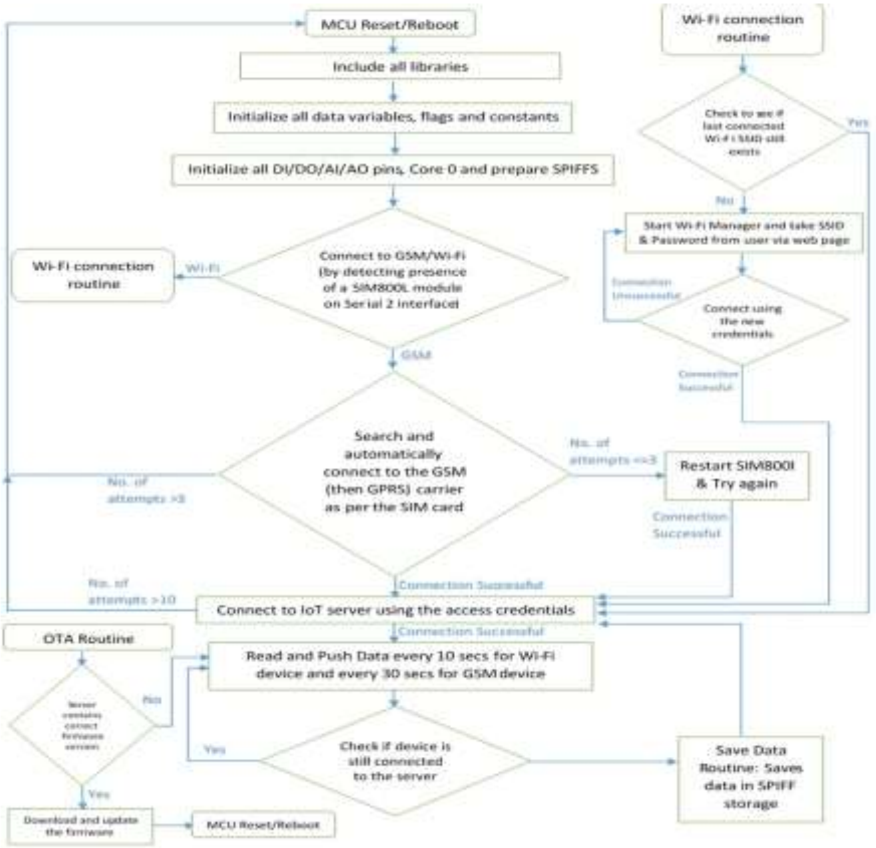


Fig -11: *Final firmware flow chart*

5. CONCLUSIONS/END PRODUCT

During the developmental period of this project, many learnings, in form of bug fixes on the firmware, PCB layout issues, server setup/config setbacks, etc., were made. As these learns are now part of TATA Power's knowledge matrix, they cannot be covered under this publication. However, the images of the end user dashboards and IoT devices has been added in this section as a testament of the quality and robustness of the final product of this endeavor.

5.1 End User Dashboards

The end user dashboards have been designed to be both insightful and easy to understand. The navigation to various dashboard and dashboard states can be done easily using the standard ThingsBoard GUI. As described in section 3.4 b, the same dashboard is assigned to various users; however, they can only see the data from the devices linked to them via the role assignment module. This enables the system admin to only make a few standard dashboards and assignment to the appropriate end users.

Fig -12: *Live data Dashboard for Single Phase Meter IoT Device*

Fig -13: *Dashboard showing consumption data from a device*

Fig -14: *Dashboard showing tabulated data from a device*

Fig -15: *Main dashboard for Asset Monitoring Device*

Mulshi Dam Parameters Monitoring System - TATA Power - Bhira Division

Fig -16: *Dashboard showing live data from Asset Monitoring Device*

Mulshi Dam Parameters Monitoring System - TATA Power - Bhira Division

Fig -17: *Dashboard board showing all historical and live wind related data from an Asset Monitoring Device*

5.2 End Point Devices

Fig -18: IoT device with a *Single-Phase Meter*

Fig -19: *Hardware v4.0 IoT device (assembled)*

Fig -20: *Hardware v4.0 IoT device (rear view)*

Fig -21: *IoT device for Use Case 2*

Fig -22: *IoT device for Use Case 2 inside weatherproof IP68 enclosure*

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BIOGRAPHIES

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Rex has been working on utility scale digitalization projects like UAV based asset monitoring, IoT for energy monitoring, Switch Yard Inspection Robot, etc. for the past 4 years. Although he has authored multiple technical document, this is his first publication in an international journal.

Amitkumar Patel
Amitkumar has worked in the power utility industry for the past 10 years. During this time, he has pioneered multiple automation projects at TATA Power. He also holds an Indian patent for "Robotic Painting for High Rise Structures".