iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: XI Month of publication: November 2025

DOI: https://doi.org/10.22214/ijraset.2025.75869

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

Smart Metering System for Real-Time Energy Monitoring, Forecasting and Anomaly Detection

Prof. Aparna Pandey[1], Peddu Saket[2], Vibhav Bansal[3], Mukhtar Ahmed[4]
[1]Assistant Professor, [2, 3, 4]Student, Department Of Computer Science & Engineering, Bhilai Institute of Technology, Raipur, India

***Abstract:** This paper describes a fully functional smart metering system with an end-to-end flow: it collects domestic electrical parameters, stores data using MongoDB as a service, and applies machine learning for demand prediction and anomaly detection. The back end is built with Express.js and Mongoose for schema design, while the Python Flask framework hosts two microservices: one for linear regression-based one-step-ahead power forecasting and another for outlier identification using Isolation Forecast. A web interface provides form-based interaction and data visualisation. The system's flexible, modular architecture and provide a dashboard to extendible data models support a wide range of energy analytics applications.*
***Keywords:** Smart Metering, Energy Monitoring, Load Forecasting, Anomaly Detection, Node.js, MongoDB, Flask, Linear Regression.*

I. INTRODUCTION

Digitalized energy requires instant monitoring, predictive insights, and the ability to identify irregular patterns in energy consumption as soon as possible. Older utility meters have very limited programmability for collecting or analysing data. This greatly limits the decision-making capacity of the user in a proactive manner. This effort will create an integrated web-based backend and an independent ML (Machine Learning) based service that can predict the amount of energy that is likely to be used within the next few days/weeks and detect any significant anomalies that may exist in recent usage information, so that there are positive and timely feedback loops. The intended design and construction of this effort is to facilitate the use of this technology on a small scale (e.g., university) using common open-source software components while minimizing operational requirements.

II. LITERATURE REVIEW

The literature on smart meters has concentrated on two aspects of smart meter data analysis: time series forecasting for estimating energy demand (load) and identifying outliers to identify both technical and non-technical losses. For time series forecasting on a short horizon, linear methods represent a clear and transparent baseline. Tree-based methods are known to be robust when dealing with non-Gaussian noise, as is typical with smart meter data. To decouple train and inference operations from each other, industry practices have combined a transactional database for storing transactions with a stateless service for hosting machine learning operations. The same design pattern is followed by this system, using Express.js for API endpoints and Flask for machine learning endpoint services.

III. SYSTEM DESIGN & ARCHITECTURE

The entire system architecture is a composite of different elements that are specifically designed to collect data, store securely, perform predictive analysis, and provide user interaction while designed to be deployed in both distributed and scalable manners. This architecture is based on a modular design as well; it includes multiple layers (the frontend interface, backend application layer, persistent data storage layer, and AI/Analytics layer) which work together to ensure that there will always be reliable energy monitoring and forecasting regardless of environment.

Model selection and integration Machine learning model selection was based on providing fast predictive results that are easy to interpret and strong anomaly detection. Linear regression is used in conjunction with real-time forecasting of future energy demand. Isolation forest is used for detecting anomalies (abnormal usage) a timely manner. These models were encapsulated in a single ML service so they could be run as one container, compatible, scalable, and high performing. Integration was achieved via restful API endpoints, which allowed for rapid bi-directional data flow between the backend, analytics modules, and other systems for rapid low-latency feedback and coordination.

Back-end Node.js is used in conjunction with the Express framework as the back end to handle client-side requests and interface with the MongoDB database, where all energy, user, and monitoring information will be stored; APIs are also utilized to ensure secure access to data.

The machine-learning portion of the application (i.e., forecasting and anomaly detection) is handled by a microservice created using the Flask microservice framework that utilizes Linear Regression and Isolation Forest algorithms to generate predictive results that can then be returned to the main server and presented to users as additional insight into their data.

The Frontend is a Web Application through which users can monitor and view their Energy Data. The Frontend shows various key pages for displaying in Real-Time and Historical Metrics, Appliance Summaries, and Predictions. Users are able to provide Feedback and Queries using interactive forms. JavaScript enables the Validation of User Data and Communication between the Frontend and Backend applications so that Users can quickly and easily interact with the application. Additionally, the Frontend Architecture has the capability to support incremental updates of individual modules and integration of future features (i.e., Notifications, Advanced Analytics Dashboards)

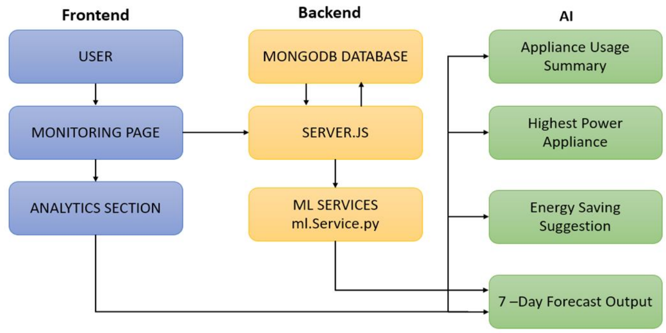


Fig 1 System Design & Architecture

IV. METHODOLOGY

Forecasting: Using recent values (i.e., time and power) in each tuple, we fit and predict using Linear Regression as follows:

$$Y = \beta_0 + \beta_1 t$$

using the model above for the very next step; this is supported by the /forecast API call, which returns JSON results for the client to use.

Anomaly Detection: We train an Isolation Forest over a window of power measurements to assign anomaly labels (-1), along with the index of readings that have been deemed anomalous for operator evaluation.

Data Handling: The server accepts JSON payload from the client, persists monitoring data, logs all contact/user data, and assigns a timestamp to each data point to allow for temporal querying and dashboarding.

Client Interaction: In app.js, we catch when the client submits a form, validate the fields, post the JSON data to our Express endpoint, and provide the client with user feedback via alerts and reset state upon successful submission.

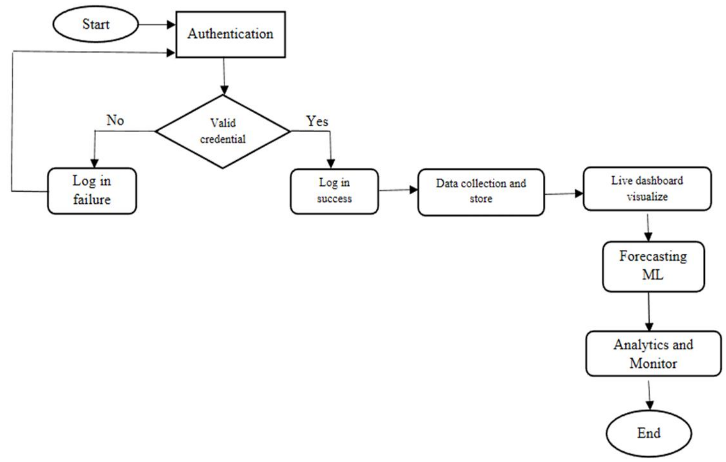


Fig 2 Complete Workflow

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

V. EXPERIMENTAL VALIDATION & RESULTS

1) Back-end: Express application running on Port 5000 using CORS + body-parser as a middleware, and a connection to MongoDB smart meter for both Compass & local workflows; contact, user, & monitoring schema definitions have been created default.
2) ML Service: Two post endpoints expose an interface for the user to input data that will be used to perform predictions; Linear Regression for next-step forecasting using sequential time index; Isolation Forest with contamination parameter to perform unsupervised anomaly detection.
3) Functional Validation: The end-to-end path is validated by creating an automated test of the full process from browser form submission through to the express application call to MongoDB persistence, and from monitoring payload to ML prediction from Flask endpoint with structured JSON output.
4) Baseline Forecasting: The linear regression model produces quick, easily understood next-step estimates, which can provide a baseline forecast for shorter time horizons; the forecasts produced by this model are deterministic, which aids explainability in academic environments.
5) Anomaly Signalling: The Isolation Forest identifies unusual segments of consumption, and may help identify potential tampering of appliances, indicate a fault in an appliance, or indicate issues with the quality of the data in the stream.

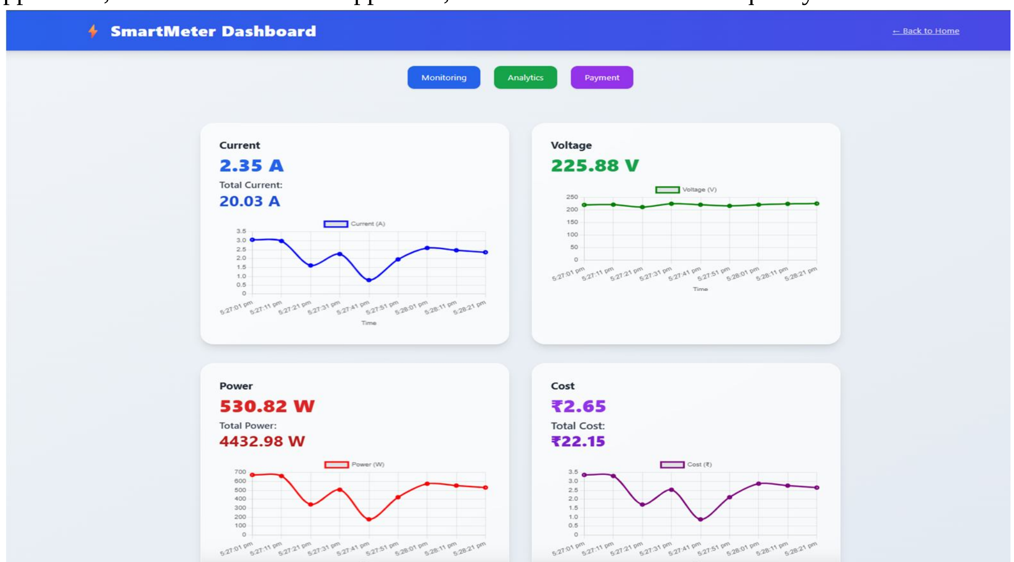


Fig 3 Result

VI. CHALLENGES & LIMITATIONS

1) Smart Meter Costs are High in Relation to Installation and System Upgrades.
2) Connecting smart meters to older systems is difficult.
3) Processing Large Volumes of Smart Meter Data Requires Complex Processes.
4) There is a Risk of Privacy and Security Issues due to the Amount of Smart Meter Data being collected and stored.
5) Poor Network Reliability Can Result in Gaps in Data Collection or Delays in Processing the Data.
6) Many Users Have Difficulty Understanding How Smart Meters Work, and Many Resist Using Them.

VII. FUTURE SCOPE

Future of Smart Metering will be to integrate new and emerging technologies (such as Artificial Intelligence, Blockchain, IoT Devices) for enhanced energy insight and automated processes; additionally, increased use of 5G and Edge Computing will provide the means for rapid, real time analytics that are scalable; also expected is a significant increase in the level of Cybersecurity provided for smart metering systems, the development of user centric dashboards, and increased support for Renewable Energy Systems and Microgrids; ultimately, continued innovation will result in greater consumer and utility control and transparency regarding their energy management and greater sustainability in the management of their energy resources.

VIII. CONCLUSION

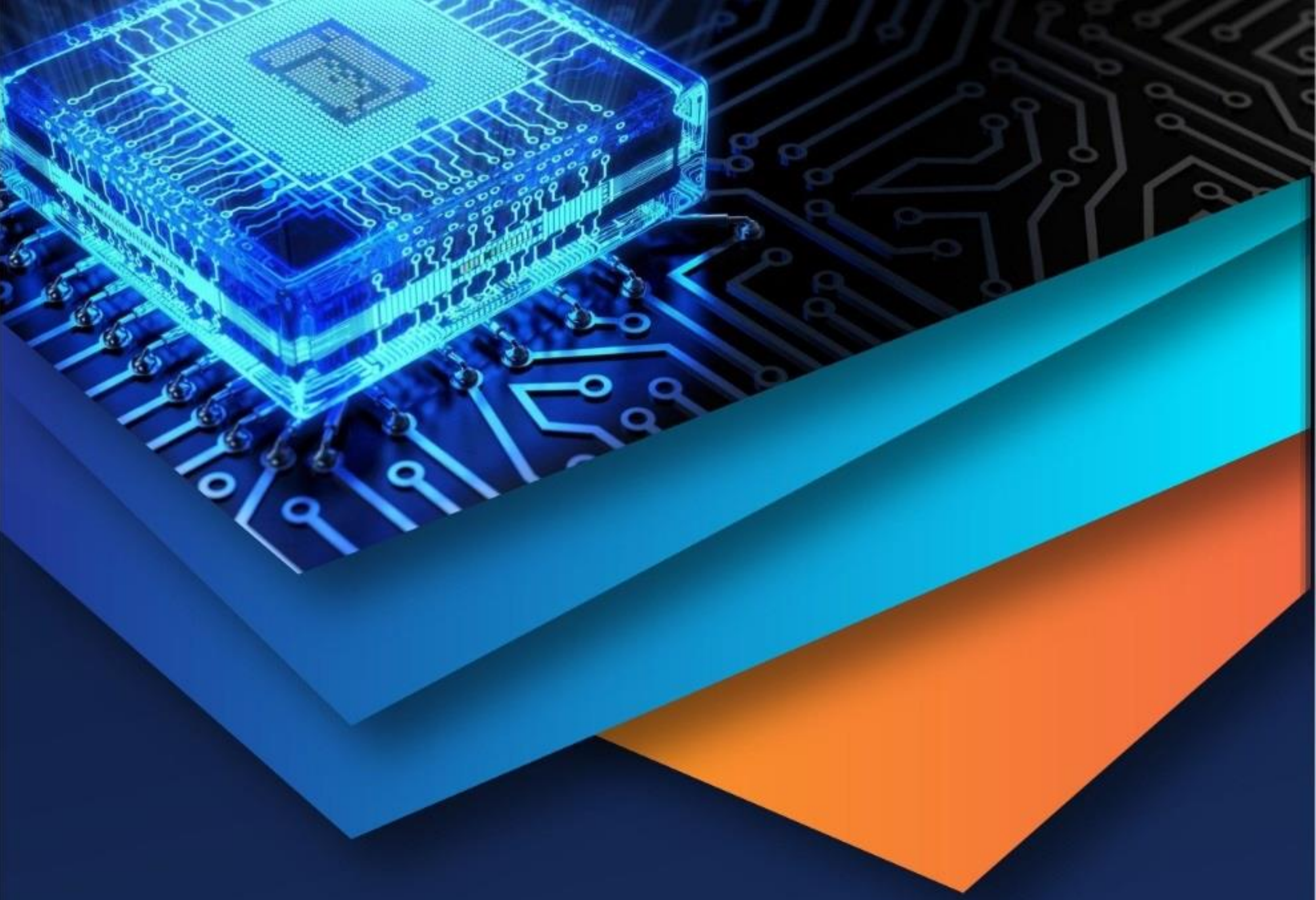
The smart energy management system being developed will incorporate web-based monitoring capabilities, a secure back end, as well as machine learning (ML) based analytical tools to enable an integrated platform for energy use management that can meet the needs of today's energy users. The proposed system is designed to provide utility providers and consumers with timely and useful information (real-time usage, predictive load forecasting, anomaly detection) to optimize their energy use and ensure reliable service. The system has been designed to be easily scalable to accommodate both residential and institutional applications by using a modular design, which also ensures accurate data collection and transparent operations. The development of this system is to serve as a foundation for future predictions in smart energy management systems

IX. ACKNOWLEDGEMENT

We cannot accomplish the successful completion of this Smart Metering System Project without the help of our mentorship group, our project guides, and the encouragement from our college staff, because they assisted us with their expertise in the development process through providing constructive criticism and suggestions to improve this project. We are grateful to fellow students that we worked with on this project for their teamwork, input, and the motivation they provided to assist us in the development of this project; and we thank those who helped either directly or indirectly toward the accomplishment of this new technology.

REFERENCES

[1] L Ashok Kumar [a], V. Indragandhi [b], R Selvamathi [c], V. Vijayakumar [d], Logesh Ravi [e],Design, power quality analysis, and implementation of smart energy meter using internet of things Available from: https://www.sciencedirect.com/science/article/abs/pii/S0045790621001993
[2] Jonathan Gumz [a b], Diego C. Fettermann User's perspective in smart meter research: State-of-the-art and future trends 1 April 2024 Available from: https://www.sciencedirect.com/science/article/abs/pii/S0378778824001415
[3] Konark Sharma, Lalit Mohan Saini Performance analysis of smart metering for smart grid 18 May 2015 vol. 50, 2021 Available from: https://www.sciencedirect.com/science/article/abs/pii/S1364032115004402
[4] A lessandro Piti 1, Eleonora Bettenzoli 2, Marco De Min 2, Luca Lo Schiavo 2 Smart metering: an evolutionary perspective Available from:https://erranet.org/wp-content/uploads/2017/09/Highly-Acknowledged-Paper_PitiTeam_Paper_Award_2017.pdf
[5] Advanced Smart Metering Infrastructure for the Modern Grid J. S. Thomson, IEEE Transactions on Smart Grid, vol. 13, no. 2, pp. 1001-1014, 2022. Available from: https://www.workongrid.com/blog/smart-metering-trends-for-2025
[6] Research advancements towards existing smart metering system IJACSA, Vol 8, Issue 5, May 2021. Available from: https://thesai.org/Publications/ViewPaper?Volume=8&Issue=5&Code=IJACSA&SerialNo=11
[7] Smart Electric Meter Market: Global Trends and Leadership Genus Power, Market Report, 2025. Available from: https://genuspower.com/smart-electricity-meter-market-global-trends-and-genus-powers-leadership/
[8] IoT based prepaid smart energy meter S. Satpathy et al., Sathyabama University, 2023. Available from: https://sist.sathyabama.ac.in/sist_naac/documents/1.3.4/1923-b.tech-biomedical-batchno-14.pdf
[9] Smart Electric Meter Market: Global Trends and Leadership Genus Power, Market Report, 2025. Available from: https://genuspower.com/smart-electricity-meter-market-global-trends-and-genus-powers-leadership/
[10] Smart Metering for Rural Electrification: Challenges and Opportunities S. Patel, Kimbal Blog, 2025. Available from: https://kimbal.io/blog/blog-tile-smart-metering-the-critical-building-block-to-empower-utilities/
[11] GSM Based Energy Meter Reader and Billing System P. Singh et al., 2023. Available from: https://www.ijraset.com/research-paper/design-and-construction-of-a-gsm-based-energy-meter-reader
[12] Research advancements towards existing smart metering system IJACSA, Vol 8, Issue 5, May 2021. Available from: https://thesai.org/Publications/ViewPaper?Volume=8&Issue=5&Code=IJACSA&SerialNo=11
[13] The impact of smart meter programmers on household water consumption in Auckland F. O'Sullivan et al., Sustainable Cities and Society, 2025. Available from: https://www.sciencedirect.com/science/article/pii/S2214804325000771
[14] Smart electricity meter market 2024: Global adoption landscape IoT Analytics, 2024. Available from: https://iot-analytics.com/smart-meter-adoption/
[15] Smart Metering in India: A work in progress Prayas (Energy Group), 2025. Available from: https://energy.prayaspune.org/power-perspectives/smart-metering-in-india-a-work-in-progress
[16] ESP32-Based Prepaid Electricity Energy Meter with Remote Monitoring and Control J. L. Balingit et al., 2025. Available from: https://www.scitepress.org/Papers/2025/135855/135855.pdf
[17] Smart Metering Momentum: Progress, challenges and the road ahead Powerline, August 2025. Available from: https://powerline.net.in/2025/08/04/smart-metering-momentum-progress-challenges-and-the-road-ahead/
[18] Time Series Forecasting Analysis for Automated Smart Meter Reading System SSRN, 2025. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5252530
[19] Transition and Impact of Smart Meters on Renewable Energy Integration in India IJFMR, 2025. Available from: https://www.ijfmr.com/papers/2025/5/55075.pdf



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)