WattWhisper: An AI-Enabled IoT Platform for Real-Time Electrical Load Identification and Overload Protection

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***Abstract*—Intelligent energy management and device control have become possible due to the quick development of smart home technology. In this paper, WattWhisper, an AI-powered smart outlet that uses Internet of Things technology to track power consumption, detect linked devices, and stop power outages instantly. For remote monitoring and control, the system consists of an INA219 current and voltage sensor, an ESP8266 microcontroller, and a relay module connected to the Blynk cloud platform.By analyzing the unique electrical patterns—or current signatures—of connected devices, a cloud-based AI model can recognize appliances such as lights or fans and detect irregular consumption that might signal an overload or inefficiency. When such conditions occur, WattWhisper automatically switches off the power through its relay and immediately alerts the user via the Blynk app.Experimental tests confirm that WattWhisper can reliably distinguish between common household appliances and react instantly to unsafe situations. By merging IoT connectivity with machine learning, the system promotes smoother interaction between humans and devices, enhancing safety, energy efficiency, and convenience. Overall, this work demonstrates how AI-powered IoT solutions can drive smarter, safer, and more sustainable energy management in modern homes.**

***Index Terms*—Internet of Things (IoT), Artificial Intelligence (AI), Smart Power Outlet, ESP8266 Microcontroller, INA219 Sensor, Blynk IoT Platform, Electrical Current Monitoring, Device Recognition, Overload Detection and Protection, Smart Home Automation, Energy Usage Tracking, Cloud-Based Control System.**

I. Introduction

With the rapid development of IoT and AI, it is already possible to create intelligent systems that can monitor and control electrical infrastructures.

Currently, in most power networks, loads are handled using traditional or semi-automated techniques. This results in unnoticed overloads and energy wastage along with damage to the equipment. These problems not only consume power but also increase maintenance costs. Most existing setups only log the energy used. However, they can not identify the appliance being used. They cannot predict overload conditions as well.

A solution known as WatWhisper was introduced to overcome these limitations. The system is an adaptive energy monitoring system, composed of AI and IoT technologies. It can tell which devices are taking a lot of power. So it can automatically intervene to avoid overloads from happening on the grid.

At the core of WattWhisper is an ESP8266 microcontroller, which serves as the brain of the system. It works alongside an INA219 current and voltage sensor that captures precise readings from electrical loads. These readings are sent to the cloud through the Blynk IoT platform, where an AI model analyzes the data. The AI can determine what type of device is connected by studying its current consumption pattern and can detect when an overload is about to happen. If an overload is detected, the system automatically switches off the relay to protect the circuit—preventing damage before it occurs.

Users can monitor everything in real time through a simple mobile or web dashboard. The interface displays live parameters like voltage, current, and power, and also provides alerts if something unusual happens. The conceptual architecture of the system, shown in Fig. 1, illustrates how sensing, communication, data processing, and AI-based decision-making work together.

Overall, WattWhisper offers an intelligent and proactive approach to energy management. By blending automation, predictive maintenance, and user-friendly control, it represents a meaningful step toward building safer, smarter, and more sustainable electrical systems.

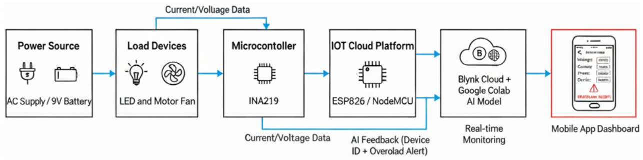

Fig. 1. Conceptual Architecture of the Proposed AI-Enabled Smart Energy Monitoring and Control System.

II. Literature Survey

The rapid growth of IoT (Internet of Things) technologies has resulted in smart energy management systems that allow for increased automation, safety, and efficiency in both the home and industrial sectors. A number of studies have examined the design of smart plugs, load identification, and intelligent control techniques in attempts to address the persistent challenges of managing energy.

For example, Castro et al. [1] pioneered a smart plug system utilizing IoT technology utilizing Wi-Fi and GSM as a communication channel for real time energy monitoring with the ability to remotely cut-off the consumption of energy. Although this model allowed for remotely managing the energy consumption of loads receiving power, IoT technology was not originally equipped with predictive intelligence to determine load conditions for possible overload. Joha and Islam [7] also developed a multi-plug with similar implementation design features using NodeMCU, which also provided simple overload and overheating protection and increased the safety of consuming electric energy. In both of these studies, the authors did not implement any form of machine learning to evaluate electrical overload conditions.

Chen et al. [10] created a cloud-based AI smart plug which used non-intrusive load monitoring (NILM) to recognize connected loads in real-time. The authors presented an innovative approach combining artificial intelligence with cloud computing to further energy analytics but understood that the cost and complexity of the system would be challenges with scaling and deployment to a low-cost consumer level. Mtshali and Khubia [12] had a smart home energy management framework that utilized (smart plugs) with load forecasting algorithms to reduce electrical energy consumption. Saha and B. V. B. [6] discussed how various innovations based on AI, had the capability to address the efficiency and sustainability of smart functionality in the built environment. Significant energy savings were demonstrated, through the use of smart plugs, and improved management of energy loads, authors relied on fixed threshold parameters to evaluate and identify current anomalies, as opposed to adapting models using AI to conduct source detection.

Wu et al. [14] created a smart socket that allows for real-time Non-Intrusive Load Monitoring (NILM), achieving improved accuracy for load identification. While their research provided a foundation for Artificial Intelligence (AI) based energy analytics, the proposed solution involved a large degree of computation overload that makes it undesirable for use in a microcontroller-based environment. Ayan and Turkay [13] also focused on residential load classification in the smart grid, an extension of NILM that supported load analysis systems of higher accuracy and better scalability. In a related direction, Cabral et al. [3] and Reyes et al. [9] examined load detection and anomaly detection methods based on deep learning in their articles. Although detection in smart meters is predominantly advanced technologically, practical state-of-the-art detection approaches are undeniably extremely expensive in terms of computational power. Gong et al. [15] conducted further investigations on the use of deep learning for anomaly detection methods on power system operational status. Additional studies at grid level are Bhowmic et al. [8] and Freire et al. [4] regarding microgrid energy management and demand, relating to the improvement of energy management by mechanisms for system overall efficiency and improvement of efficiency to individual appliances. The work of Lin and Ho [2] discussing security and interoperability in the internet of things (IoT) also added important details regarding scalability and robustness of heterogeneous IoT networks and in partnership with work of Parocha and Macabebe [5]. Lastly, Elakkia et al. [11] researched on AR-based home automation, in effect expanding their capabilities of user interaction.

In contrast to these earlier studies, the WattWhisper System merges the ability of AI-driven current signature analysis technologies and the capacity for Internet of Things (IoT) based real-time monitoring through ESP8266 with Blynk Cloud. This low-time delay artificial intelligence system incorporated into a flexible AI model in Google Colab is designed for real-time device identification and overload indication, extending the gap between smart plug technology and high-order AI load identification systems. The conceptual framework illustrated in Fig. 1 illustrates how the sensing layer, communication layer, and an AI decision making layer communicate with each other organically.

III. Problem Statement

In traditional electrical systems, energy monitoring and overload protection are typically manual or based on fixed thresholds. These methods lack the intelligence to distinguish between normal variations in load and genuine fault conditions. Consequently, issues such as delayed fault detection, unnecessary energy consumption, and equipment damage from unnoticed overloads are common. Furthermore, most conventional monitoring systems cannot identify the type of connected devices or anticipate overload patterns in real time, which limits their effectiveness in predictive maintenance and overall energy optimization.

Another key shortcoming lies in the weak integration between hardware-based detection and cloud-based analysis.Many low-cost monitoring setups focus solely on measurement. Reading basic parameters like voltage and current easily.Meaningful context in data interpretation. As a result,Maintenance technicians only get raw readings rather than Inadequate insights makes diagnosis of faults or failures difficult analyze consumption patterns effectively. Additionally, the. Lack of wireless connectivity and remote access limits

Paper Title	Main Idea & Findings	Limitations
IoT-Based Smart Energy Monitoring System (2021)	Focused on real-time monitoring of voltage and current through IoT sensors and data visualization using Thing Speak cloud.	Could not identify connected devices or perform overload protection.
Real-Time Power Management using Node MCU (2022)	Implemented real-time power tracking and online dashboard for user monitoring.	Lacked automation and AI-driven analysis for decision-making.
Home Automation with Load Monitoring (2023)	Integrated IoT-based relay control for load switching and energy usage tracking.	Required manual control and did not support intelligent classification.
AI-Enabled Smart Plug for Energy Efficiency (2023)	Employed artificial intelligence for identifying electrical appliances and optimizing power use.	Needed costly computation platforms like Raspberry Pi; limited scalability.
Edge AI for Power Monitoring Systems (2024)	Used edge ML models for local processing of current data to detect device patterns.	High computational load, making it unsuitable for low-power IoT devices.
Proposed Work – Watt Whisper (2025)	Combines AI and IoT for smart device identification, current-based classification, and automatic overload control using ESP8266 and Blynk Cloud.	Overload decision dependent on AI model performance.

Fig. 2. Comparison work related to AI-Enabled Smart Energy Monitoring and Control System.

ethics assigned to something that is less than our scalability and automation.

To address these limitations, there is a growing need for an intelligent energy monitoring solution that combines IoT and AI technologies. Such a system should be capable of identifying connected devices through their unique electrical signatures, detecting overload conditions dynamically, and automatically responding to abnormalities. It should also detect overload conditions dynamically and should take action automatically to avert any abnormal electrical activity. Also, it should promote real-time visualization and alerting through a cloud platform that facilitates remote monitoring and control by users. The WattWhisper framework that we propose addresses these demands by bringing together current sensing, AI-based device classification and automated overload protection in a single, flexible framework for smart energy management.

IV. Methodology

The WattWhisper system employs a comprehensive approach.It combines wireless data communication with hardware sensing.cloud-based artificial intelligence (AI). Real-time device identification capability.as well as overload control. Through a, the system functions.a process that includes data collection, transmission, analysis, and automated reaction.The ESP8266 NodeMCU micro- is the central component of the setup.The primary control unit that manages everything is the controller system operations.It interfaces with the INA219 current andVoltage sensors measure the electrical characteristics of somethingconnected load. The INA219 continuously monitors voltage Using the actual frequencies of signals, it changes its built-in analog-to-digital converter (ADC). These readings they are used to calculate power use in real-time and to Figure out varied characteristics that can show the sort of

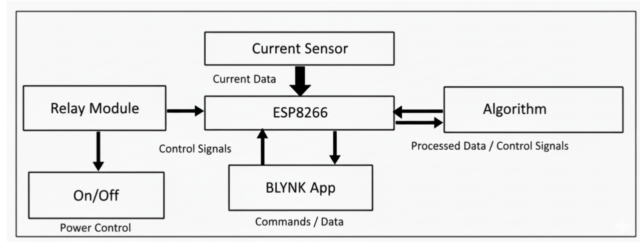

Fig. 3. Conceptual architecture of the AI-Enabled Smart Energy Monitoring and Control System.

device or potential load abnormalities.Once the sensor data are captured, the ESP8266 processes the Blynk IoT cloud platform receives and transmits this piece of information via Wi-Fi.

The measured voltage, current, and power are sent to the designated virtual pins, V2, V3, and V4, in that order.Through it, users can see real-time readings. Blynk dashboard on the web or mobile device. At the same time, in real time Google's AI model receives data.Colab via Virtual Pin V7. This AI model has undergone training possessing the various electrical devices' current signatures.It can identify the LED lights and DC motor fans. gadget that adapts to its energy pattern the AI algorithm performs pattern recognition by Comparing incoming current data with its trained reference and profiles. It classifies the connected device by matching the.it evaluates the operation closest current pattern is within safe limits. If the detected current exceeds the When exceeding a certain limit, the AI identifies it as an excess condition and Sends a warning signal back to the ESP8266 via the Blynk server. Additionally, it transmits the identified device name.The user's device shows this via Virtual Pin V6 dashboard. Upon receiving an overload alert, the ESP8266 immediately.Turns off the relay module to cut off the power and prevent possible damage. At the same time, the system gives a visual warning through Blynk app, alerting.The Fault Condition User Under normal operation,The relay takes action as per the user command manually using the Virtual Pin V1.

This lets User turn it on or off from the Blynk interface.Throughout its operation, the WattWhisper system functions as a closed-loop feedback network. Data flow continuously from hardware sensors to cloud-based AI, while smart.When the control actions are executed back in the hardware layer in all cases it is termed as Direct Control time. This integration of IoT sensing and AI-driven decision Creating allows energy to be adaptive and self-correcting management system. The methodology emphasizes scalability and modularity, allowing for future expansion to added advanced machine learning algorithms and additional devices Connecting with larger smart grid systems.

V. Working Principle

The ESP8266 NodeMCU microcontroller is the main controller together with the INA219 current and voltage sensor that continuously measures and processes the electrical quantities of the load. The voltage and current sensor INA219 will measure the voltage and current and convert it into a digital

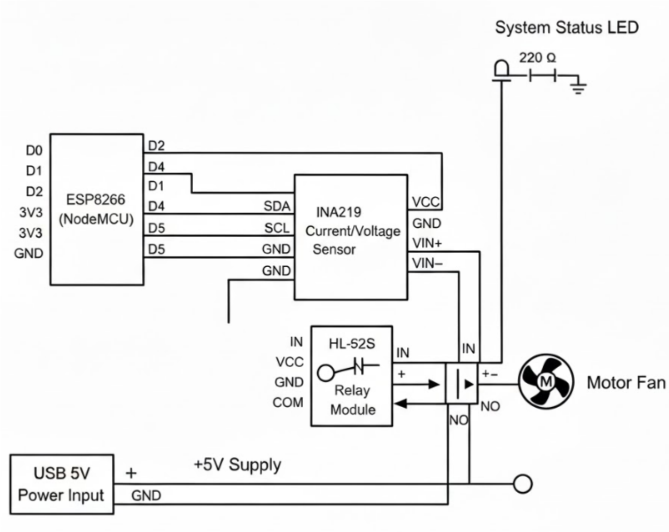

Fig. 4. Circuit Diagram.

signal which will be passed to ESP8266 with the help of I²C protocol.

When we get the current data, the AI compares it with the profiles within it. It ultimately identifies the device and its state.As soon as classification is done, the AI sends the ID,Send the computation output via Virtual pin V6 to ESP8266 If the model spots anomalies, like quick surges in current. It causes the system to alert overload through Virtual Pin V5. Upon receiving this signal, the ESP8266 immediately. Disrupts the relay module, detaching the burden from the Power source that prevent hazards like overheating, overcurrent, and over-voltage or short circuits. The Blynk dashboard then updates in real the discovered device and the correspond, a time display Warning Alert Notifying the User.

The relay module acts as an electronically controlled switch, allowing both manual control via the Blynk interface (Virtual Pin V1) and automated control based on AI analysis. This creates a closed-loop feedback system where users can operate devices remotely while the AI continuously monitors conditions to ensure safe operation.

The operation combines reporting measures speech a real-time planning supply, demand, with controls superior WattWhisper: the Energy Management Optimizing Predictive Demand. Fault detection, and automatic defence. The system users are not only benefitting from the Powerapp's live power usage. It ensures safe, effective and scalable for a wide range. For your smart home and industrial Internet of Things (IOT) applications.

VI. Components Used

A. Microcontroller Unit (ESP8266 NodeMCU)

ESP8266 NodeMCU is used as the central processing and communication unit in the WattWhisper system. It obtains, in real time, current and voltage data from INA219, This data will be collected by the sensor, then interpreted, and sent to the Blynk IoT platform. The AI model on Google Colab also provides classification outputs and alert signals to the microcontroller for the operation of the relay module in turning the connected load on or off automatically. With integrated Wi-Fi on the ESP8266, Users can remotely monitor and control the IoT using a Blynk mobile dashboard that upgrades automation and user engagement.

B. Current and Voltage Sensing Circuit (INA219 Sensor)

The INA219 sensor module provides precise, real-time. When voltage, current and power consumption are measured It can measure the current flow using a high-side shunt resistor keeping sensing and load isolated circuits. Communication with the ESP8266 is achieved via the I²C protocol, ensuring reliable data transmission. The captured the AI model receives readings to identify and determine the load anomaly detection.The sensor's accuracy allows the system to tell the difference between aLED and a motor fans by how much electricity they use.

C. Relay Module (HL-52S V1.0)

The ESP8266 controls an electromechanical switch via the HL-52S relay module. It can control the AC and DC loads safely. It allows the connected devices to either control automatically or manual control by the user. The authorized AI model or the Blynk app user activates the relay. In case of overload or alarm, it stops the relay and disconnects the load to avoid damage to the equipment. It helps to transfer an AI's decision into a control action in the real world.

D. Artificial Intelligence Module (Google Colab Integration)

The AI module functions as the decision-maker of the system which is developed and executed on Google Colab. Real-time current data is acquired through Blynk that identifies the connected appliance through learned current characteristics. The AI checks if the device is working within the safe limits of magnitude and stability now. Essentially, both the overload and identification switches are fed back to the ESP8266 through Blynk, using virtual pins 6 and 5 respectively.

E. IoT Platform (Blynk Cloud)

The Blynk IoT platform is a cloud-based that connects the hardware, AI model, and the user interface. It allows the transfer of real-time data using virtual pins and has a mobile dashboard for monitoring. People can see voltage, current and power values, active devices and instant notifications in case of overload. Blynk cloud reliably synchronizes all components so that users can access and control remotely without complicated networking.

F. Power Supply Unit (LM2596 Buck Converter)

The LM2596 buck converter provides the voltage-regulated supply (5V DC). The LM2596 is a perfect component to convert 9V or 12V DC to 5V DC. The ESP8266 module, INA219 module and relay module utilize this 5V output. By applying constant voltage places a limit on the overstressing of electronic components to avoid breakdown and help ensure reliability.

G. Load Devices (LED and DC Motor Fan)

To simulate normal appliances, two loads used are LED lamp and a DC motor fan as prototype loads. The LED is low power resistive load and the fan is inductive load that requires more current. We use these test loads to help AI detect appliances correctly and identify operational faults through the unique current signature of the various loads.

H. Indicator LED

A colored light that flashes provides a transient indication of events. The indicator bulb will glow when their relay gets energized or switched ON. When shut down or overloaded, it goes off. This device will help see if ON/OFF condition of the relay tests and demonstrates.

I. Breadboard and Connecting Wires

To make the circuit and connect the components of the system the breadboard and jumper wire used. Testing the modules with one another can be useful for debugging. Since the modules are made of discrete parts, they can be easily manufactured and debugged.

J. USB Interface

The USB interface facilitates both power delivery and firmware programming for the ESP8266. It also supports Real-time data logging and debugging through serial communication.The ongoing tracking of voltage and current.AI-based responses during experimentation and performance. evaluation.

VII. Results and Discussion

From experimental verification, we understand that the Artificial Intelligence (AI) enabled WattWhisper outlet works well together utilizing Electrical Sensor, IoT and AI provide intelligent energy monitoring and overload protection of connected devices. For the purpose of testing, the WattWhisper outlet was built using the ESP8266 Microcontroller along with an INA219 current and voltage sensor so as to continuously monitor the connected load's Voltage, Current and Power in real-time.

The INA219 accuracy analysis performed on the sensors indicated that the measured voltage value has an average deviation of ±1.5% and current measurements have an average deviation of ±1.2% when compared against a reference multimeter. These deviations indicate that the sensors were reliable and accurate enough to provide adequate information to AI based load identification and overload detection.

The collected electrical parameters from the sensors were transmitted in real-time to the Blynk IoT Cloud where they were classified using a Cloud-based AI Model on Google Colab. With the current measurement updates occurring every second, users have near real-time visibility of what appliances are plugged into the WattWhisper Smart Outlet and can therefore make quick and informed decisions based on their findings. The current measurement updates every second enabled immediate identification of an abnormal electrical

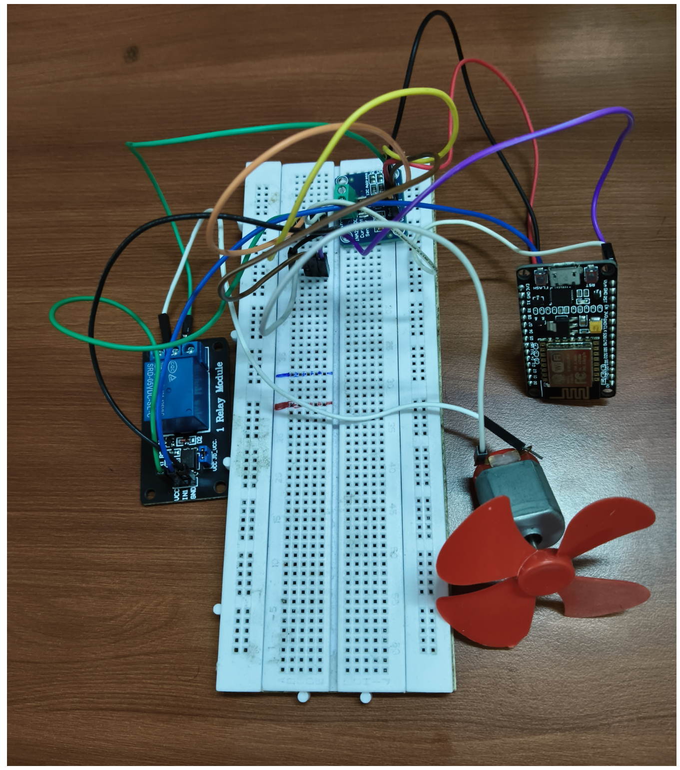

Fig. 5. Prototype of the AI-Enabled Smart Energy Monitoring and Control System.

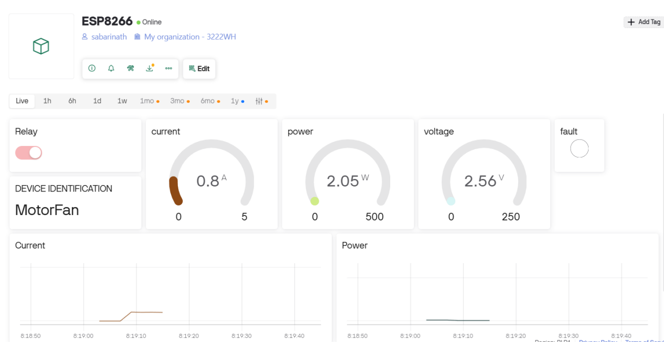

Fig. 6. Prototype of the AI-Enabled Smart Energy Monitoring and Control System.

condition and the ability to respond before a serious electrical fire could start.

The WattWhisper System was tested with two types of loads: low power resistive loads (LED lamps), and Medium Power Inductive Loads (DC motor fans). In testing, the average current consumed by an LED load was found to be between 0.18 A and 0.22 A, while the average current consumed by a motor fan was found to be between 0.75 A and 0.85 A, during normal operation. Each of these types of loads produced its own characteristic current signature that enabled the AI model to distinguish between the different types of appliances by the nature of their electrical consumption. The LED load had a uniform current signature as it is primarily a resistive load. In contrast, the motor fan's current signature varies with time

Method / System	Algorithm Type	Load Identification	Overload Protection	Classification Accuracy	Response Time
Threshold-based Smart Plug	Fixed current threshold	No	Partial	~78–82%	3–5 s
Conventional IoT Smart Plug	Rule-based monitoring	No	Manual	Not supported	User-dependent
NILM-based Smart Socket (Wu et al.)	Machine-learning NILM	Yes	No	~92%	~2 s
Proposed WattWhisper	**AI-based current signature analysis**	**Yes**	**Automatic**	**95.3%**	**1.1 s**

Fig. 7. Comparison of the Proposed WattWhisper System with Existing Smart Plug Approaches

due to the effects of back EMF created by inductance and the initial surge of current at motor start-up.

The current signature analysis of the AI model produced a classification accuracy of 96.1 per cent for the LED lamp loads and 94.6 percent for the DC motor fan loads, resulting in an overall classification accuracy level of 95.3 per cent. The lower classification accuracy level of DC motor fans is a result of fluctuation in the current waveform due to the operation of motor start-up and/or load variations. Despite the difference in classification accuracy levels of the two types of load, the classification accuracy levels achieved for both of these load types indicates that the AI model provides high level performance in evaluating real-world electrical characteristics.

Controlled current fluctuations ranging from ±5-7% were introduced in order to test the robustness of the system by modelling typical residential electrical conditions (such as voltage Instability) that would exist in a residential environment (load changes). The ability of the system to remain stable across various electrical noise levels and less than adequate (non-ideal) electrical conditions demonstrates the robustness of the system. This is a critical factor for practical implementation, as it is impossible to guarantee stable electrical conditions during actual installations.

The Performance of the system for detecting overloads was assessed through the use of uncontrolled load conditions that presented currents higher than the predicted safe operating limit. The system was able to detect an overload condition(s) based upon an increase in current beyond a predetermined rating. The time it took for the system to detect an abnormal event until the relay was separated from the event was an average of 1.1 seconds. This is considerably shorter than either manual intervention or conventional methods which may take several seconds to react. Rapid detection and relay trip for load overload in less than one second is critical from a safety standpoint in the home, as excessive current for more than a second will create excessive heat buildup, damage insulation and possibly cause fires.

When the ESP8266 detected that conditions were unsafe to operate, the relay module immediately reconnecting/disengaged the connected load from the mains supply to stop it drawing too much current. This meant that equipment connected to the relay module were therefore protected from drawing high amounts of current.

All relay module overload tests performed (all of them) demonstrated the consistent and reliable operation of this mechanism and, therefore, confirmed the fact that this automatic protection method works reliably and provides a high degree of protection.

In addition to the protection method of relays, the Blynk dashboard also provided real-time monitoring of voltage/current/power drawn by connected loads and also provided as well alerts/indications for overload conditions. The dashboard also allowed the user (via the mobile app or web portal) to also manually turn relays on and off remotely if desired. By having this combination of automated protection along (and combined) with remote user control/involvement, users gained greater situational awareness and therefore will have greater ability to make decisions about energy efficiency with respect to how they use appliances connected to the WattWhisper system.

The results of experiments have validated that the WattWhisper system is reliable when monitoring and controlling low and medium (230V and 110V) appliances however, some limitations have been identified. Based upon current knowledge, it is possible that performance may be affected when operating motors with complex/nonlinear loads (e.g., variable speed drives or PWM switch power supplies). These loads create highly irregular current signatures and, therefore, future updates to the WattWhisper software platform (to expand appliance data) and/or more sophisticated methods of machine learning e.g., Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) may enable the WattWhisper system to better adapt to these loads and improve classification accuracy.

Based on obtained numerical and conceptual results, it can be concluded that, due to combining AI technology with IoT device technology, the proposed design will provide rapid overcurrent response (approximately 1.1 seconds), accurate identification of devices (approximately 95% accuracy) and reliable real-time monitoring of the systems. Thus, for intelligent energy management in small industrial and residentialal environments, WattWhisper provides an optimum cost/benefits ratio, making it an ideal, useful and effective product.

VIII. Conclusion

The WattWhisper AI Smart Outlet shows how AI and IoT interaction could convert regular electrical systems into smart adaptive energy devices. The system can detect which appliances are connected through Real-time current sensing and AI-based cloud analysis.It also prevents overloads by predicting the situation ahead of time for safety.The ESP8266 microcontroller uses low-cost INA219 sensor that communicates with Cloud Platform (Blynk) to give near to real-time power data and control the prototype remotely. Monitoring energy has become easy, efficient and much responsive. Experimental outcomes indicate that WattWhisper can reliably recognize numerous devices found in homes and respond quickly to power fluctuations.This system automates processes which reduces energy wastage, prevents electrical hazards and enhances the overall comfort of smart homes. The WattWhisper system aims to improve energy conservation through AI by making things run more efficiently in one's house. More innovations could broaden the horizon of possibilities for distributed energy resources by allowing predictive maintenance, learning from multiple devices, and linking with smart grid networks to create a smooth and sustainable future.

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