STM32-Based Home Automation and Energy Monitoring System with TFT Display

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Abstract In our rapidly evolving technological landscape, the significance of electricity performance in our homes has become more critical than ever. With the widespread use of smart devices in our daily lives, there are both advantages and disadvantages, particularly in terms of power consumption. The lack of real-time monitoring of energy usage can lead to environmental issues and increased energy bills. To address these concerns, we propose the implementation of a comprehensive energy monitoring system equipped with a Thin-Film Transistor (TFT) capacitive touch display. This system not only provides users with immediate insights into the power consumption of their devices but also gives them control over the ON/OFF state of these devices. This innovative technology empowers individuals to make informed decisions about their energy usage, resulting in significant savings for both their wallets and the environment. With this system, users can effortlessly track and manage their energy consumption in real-time. The Thin-Film Transistor capacitive touch display enhances user experience by presenting information in a user-friendly format. This user interface allows for seamless interaction with the monitoring system, enabling users to easily understand and interpret their energy usage patterns.

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T. Senjyu et al. (eds.), *Smart Trends in Computing and Communications*, Lecture Notes in Networks and Systems 948, https://doi.org/10.1007/978-981-97-1329-5_5

Keywords Energy monitoring · STM32 Microcontroller · TFT display · Home automation

1 Introduction

In today's fast-moving tech world, we use smart devices in our homes a lot, but there is a problem—we need to manage our energy better. Most energy systems do not give quick updates about how much power each device uses. Home power consumption tends to grow in proportion to the increase in the number of large-sized electric home appliances. If we consume excess power, it is not beneficial for the environment nor for our pockets and thus can make our electric bills high. Our energy monitoring system gives seamless management. The intuitive TFT display at once offers precious insights consisting of energy intake and tool popularity. As new products emerge, our state-of-the-art era changes to satisfy converting desires. Home automation and energy monitoring is going beyond strength control and makes life more convenient and can even save you money on heating, cooling, and electricity bills. This project aims to deploy two levels, namely—power monitoring and control. By reading data from the energy meter and sending it to the STM 32 controller, real-time monitoring of power consumption of the devices will be done, and the data will be displayed on the TFT display through which you can also control the switching ON and OFF of the devices. Previously the design and implementation of the proposed system were done using a ZigBee-based wireless system, but we will be using an energy meter and designing a relay as the main component for power monitoring which will collect consumption data from the device and the collected data will be sent to the main controller (STM 32). The controller will further send the data to the TFT display where the metrics will be displayed. We also designed the graphical user interface (GUI) for the TFT display which will enable the users to control the switching ON and OFF of the devices and make it more interactive and user friendly.

Power monitoring likewise assists clients with recognizing areas of shortcomings, like pointless power utilization, so they can make a move to further develop efficient power consumption habits. Furthermore, information gathered from gadgets can be utilized to look at power yield, which can be utilized as a beginning stage to distinguish more successful arrangements for power efficiency. Besides the fact that power screens help to further develop energy effectiveness, it also assists with expanding the existence of hardware and decreasing upkeep costs, bringing about a lower generally cost of ownership. With the right infrastructure set up, users can be more aware of the extreme limits of power consumed by any device. They can better manage moves and fully utilize power in the best possible way and avoid overloading circuits or equipment.

2 Literature Survey

Several factors are crucial in determining the landscape of technologically based solutions in the areas of smart home automation and energy management. In-depth examination of the key elements covered in several research papers is done in this literature review, shining light on their importance, uses, and contributions to the area. STM32 microcontrollers, which are at the heart of smart home control, offer real-time automation and monitoring. A paper on energy-conscious multi-cloud smart home automation system with a focus on the STM32 processor for energy management [1] was made while highlighting the relevance of their suggested system's energy-saving potential and outlining similar work in the sector. The difficulties of delayed system output and reduced integration while employing numerous gateways were highlighted by the authors.

The idea of smart homes and the rising use of embedded technology to produce intelligent and linked home gadgets highlighted the significance of communication between various smart devices inside a home [2]. A comprehensive platform that integrates control operations is what the authors hope to offer. The paper describes the system's hardware, which consists of several microcontrollers (STM32 F4 and F1 series), several sensors, modules such as Bluetooth HC05, and the Anylinkin ALK8266WIFI wireless transmission module. In the paper's conclusion, it was highlighted how important it is to make homes more intelligent and to promote better communication between individuals and their homes.

A paper discussed ZigBee and Wi-Fi-based smart home monitoring and control system, with the STM32 microcontroller acting as the primary CPU [3]. By developing a wireless sensor network and a user-friendly interface for managing and monitoring home appliances, their technology overcomes common problems with smart homes, such as complicated wiring and expensive expenses. The system gives customers access to a touch screen on the gateway, terminal devices, and Ethernet-based Internet access, among other tools, to monitor and manage their smart home. Home appliances can be controlled by users, who can also get immediate feedback.

The flexibility and power of STM32 microcontrollers in coordinating numerous smart home operations are well known to researchers. These microcontrollers enable seamless device interaction, improving user experiences and enabling energy-efficient management. The method for tracking power use by home appliances was suggested, and the ACS712 current sensor is a key component [4]. The writers introduced the idea of the Internet of Things (IoT), emphasizing how it allows for the connection and communication of intelligent items. They emphasized the usage of IoT to track numerous factors, including the amount of electricity utilized by electronic equipment. The current gadgets are made to monitor electricity use and give users information. Although the current smart power meters are efficient, they have drawbacks such as high cost and difficult installation. They suggested developing a low-cost Wi-Fi-enabled electricity monitoring device. This gadget can track the electricity use of home appliances and transfer the information to a cloud server for remote access and storage. The authors discuss a system that makes use of the

ACS712 current sensor to precisely track and manage energy consumption in homes [5] in order to introduce the idea of energy consumption monitoring and emphasize the significance of managing and lowering energy usage in homes and other settings.

They included this sensor in an IoT framework, allowing for real-time monitoring, cloud data storage, online dashboard visualization, and warnings to homeowners when energy use exceeds predetermined limitations. The acquired data on power consumption is subjected to event analytics via IoT Cloud. The technology notifies the homeowners by email and Telegram if the power consumption exceeds a predetermined limit, assisting them in reducing excessive power usage.

Since the current transformer ZMCT103C [6] gives more exact information regarding energy usage than more conventional techniques, it was utilized to carefully monitor current. In light of rising urbanization and rising energy consumption, the authors emphasized the significance of energy demand management. They talked about the necessity of lowering energy use and the advantages of smart meters in doing so. They created an Internet of Things (IoT) platform for real-time remote monitoring of metering infrastructure. This platform enhanced energy management while enabling data visualization.

To investigate current studies on smart metering and energy management systems with a focus on sensors, the authors [7] conducted a literature review. To support their own research in the areas of home automation and energy management, their goal was to obtain pertinent data and insights. They came upon a report that addressed a wireless IoT-based metering system for smart cities with efficient energy use. Data on energy consumption was probably monitored and transmitted by this system using sensors. Another study focused on developing and deploying a smart meter utilizing a wireless sensor network based on ZigBee. SDM120C is employed. A cheap option for metering low Amp circuits (45 A) is the SDM120Modbus. The SDM120 series operates with a direct connection to an AC circuit with a 45 A maximum load. SDM120Modbus measures a vast range of parameters, including voltage, current, and power factor.

A paper on home automation with STM32 [8] describes a smart home control system designed to raise the level of intelligence in homes. The system is comprised an STM32 main controller, a ZigBee module, a speech recognition module, and a Wi-Fi module that uses a combination of ZigBee and Wi-Fi communication technology. The STM32 main controller uploads the ZigBee node's home environment data to the OneNET cloud platform for real-time display via the Wi-Fi module. Users can use a mobile app and voice recognition module to control ZigBee nodes remotely and voice, as well as perform environmental monitoring, security alarm, home appliance control, and other functions. The system heavily relies on ZigBee and Wi-Fi communication technology, which may not work in all environments or situations. Moreover, the system's dependence on the OneNET cloud platform for data display might raise concerns about data privacy and security.

For optimal use of automation in energy management across various appliances, the paper on power consumption prediction [9] discussed the use of smart meter concept to continuously monitor energy usage and notify the consumer when it exceeds a predetermined threshold. To measure the energy used by each item in a home, estimate the monthly electricity bill, and forecast power usage for future dates, a customized mobile application and hardware module are developed. The effectiveness of the system is heavily reliant on the accuracy of the power consumption prediction model, which may not always be accurate due to changes in appliance efficiency over time.

A paper [10] on energy management focuses on the efficient automation of various appliances using IoT-based STM32 microcontrollers and various sensors. The system also continuously monitors energy consumption, providing the user with information and insights. The AWS IOT Analytics service is used to keep the information on the web up to date. The use of AWS IOT Analytics to update information on the web may result in data privacy and security issues. Furthermore, the system's performance may be influenced by the reliability of the internet connection.

Various methods for monitoring and managing electrical appliances and energy consumption are investigated in these papers. The paper "Design of Intelligent Analysis and Detection System for Electrical Appliance Based on STM32" [11] makes use of STM32 technology for real-time monitoring and Bluetooth for data transmission to mobile devices. However, there are some concerns about data privacy and the dependability of Bluetooth connections. Meanwhile, "Design and Implementation of an IoT-Based Home Energy Monitoring System" [12] focuses on IoT solutions for home energy consumption monitoring. The disadvantage here is that the accuracy of energy consumption data may be harmed because of unpredictable user behavior and changes in appliance efficiency over time. Finally, "Load Analysis and Energy Management for Residential System Using Smart Meter" [13] develops an Arduino-based system for residential energy management. Still, the limitation lies in its scalability and flexibility for larger or more complex energy management needs.

Smart homes [14] can use this energy monitoring system to manage gas and water consumption as well. As renewable energy sources such as solar and wind turbines become more widespread, energy monitoring systems can be used to monitor their performance, track their energy usage, and manage their distribution. These devices can be integrated into IoT ecosystems [15] and communicate with each other and with central systems to provide complete energy management solutions. STM32 systems can capture large amounts of data and send it to the cloud for detailed analysis and machine learning. This can be used to improve predictive maintenance, detect anomalies, and improve energy efficiency. As battery technology develops, it will be possible to use STM32 systems for battery management in a variety of applications, such as electric vehicles, energy storage systems, and mobile devices. Environmental monitoring STM32 systems can extend their environmental monitoring capabilities to include air quality, humidity, and more. This can help users make better energy and sustainability decisions.

3 Methodology

The STM32F429ZI microcontroller is at the heart of the system, managing and integrating various components. The ADE7757 is used in the energy meter circuit to continuously measure the voltage and current of the load. After completing measurement cycles, the ADE7757 sends interrupts to the STM32F429ZI. The interrupts are processed efficiently by the microcontroller, which extracts real-time power data from the ADE7757. The TFT display which is linked to the microcontroller serves as the user interface, displaying power data as well as graphical representations. The TFT display allows users to interact with the system and gain control over the connected load. Based on user input, the microcontroller commands a relay to activate or deactivate the load via a digital output pin. This relay control mechanism enables users to dynamically manage power consumption via the TFT display's intuitive interface. This whole workflow can be summarized through the block diagram shown in Fig. 1. The block diagram represents the flow of work and process that we followed to complete the project along with the simple representation of the working of our project. It mainly revolves around the STM32 controller which is responsible for controlling and sending/receiving the data hence establishing proper communication between the different blocks or components.

The STM32 controller, which serves as the primary control unit, is at the heart of our project. The load integrated into the system is wired so that the live wire is connected to a relay driver while both the live and the neutral wires are connected to an energy meter circuit shown in Fig. 2. The ADE7757 (IC) performs power consumption measurement using the configuration provided by the circuit. The circuit includes a voltage regulator, the 7805 IC (IC5), which is critical in stabilizing the voltage supply and supplying a consistent and regulated power source to the various circuit elements. This ensures that the circuit operates consistently and accurately. The MCT2E (IC4) opto-coupler also serves as an isolation component,

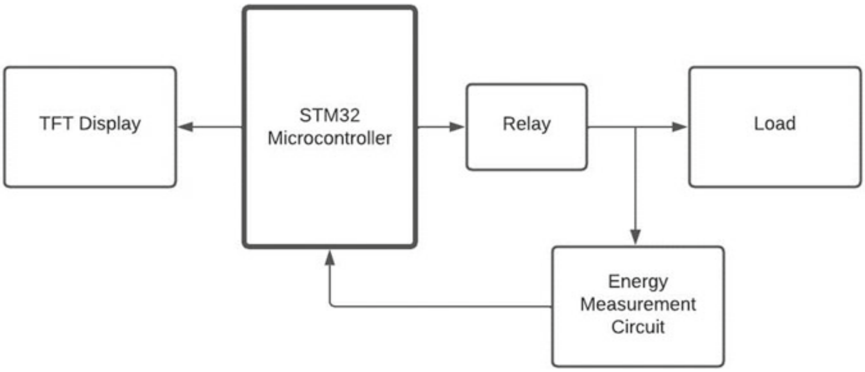


Fig. 1 Block diagram of the system

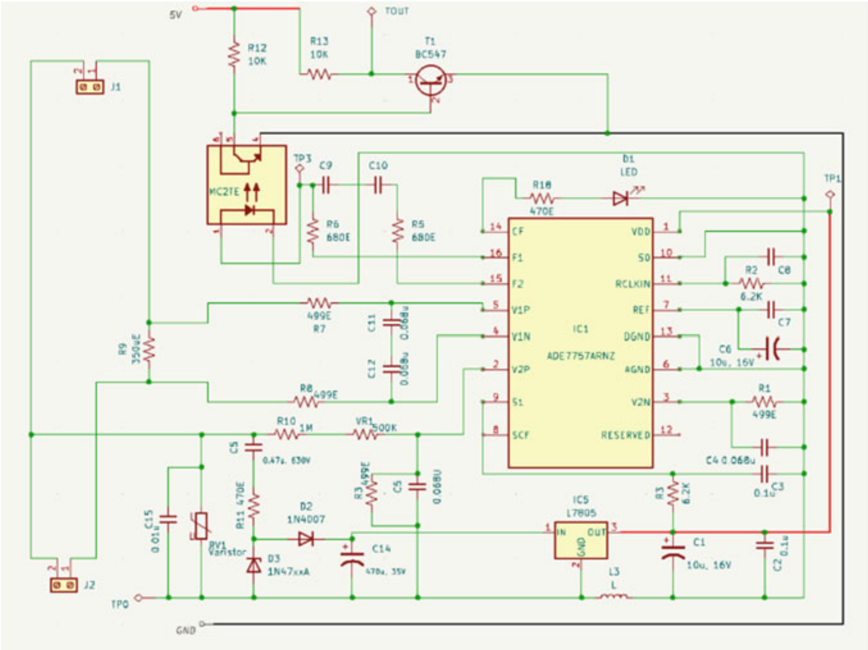


Fig. 2 Schematic of the energy meter circuit

electrically separating different parts of the circuit while allowing them to communicate optically. The opto-coupler is critical for electrical safety and data integrity. Together, the voltage regulator (7805) and opto-coupler (MCT2E) contribute to the circuit's stability and safety, ensuring that it accurately measures electrical energy while mitigating errors associated with data transmission.

Once the cycle for calculating the power is completed, the calculated power consumption data is sent to the microcontroller. It has a reference circuit and a fixed DSP function for calculating real power. The chip's required clock is provided by an internal, highly stable oscillator. Any counter can count the pulses to determine the meter's capacity of 100 pulses/kWh. This indicates that one unit of energy is used up by 100 pulses. At the calibration frequency (CF) pin, the ADE7757 produces a high-frequency output. Using the capacitor divider network, the power supply for IC ADE7757 is directly obtained from the mains. When connected to a device, it will give the energy consumption data directly to the TFT display through which the energy can be monitored.

The communication is facilitated through interrupt spikes between STM32 and the ADE7757. This approach is vital for ensuring efficient and swift data transfer between the STM32 and the ADE7757 semiconductors. The use of interrupt spikes serves as activation signals, prompting rapid responses from the microcontroller to both data and events generated by the ADE7757 microprocessor. This dynamic communication strategy is indispensable for the accurate collection and processing of electrical energy measurement data. The incorporation of interrupt spikes not only improves overall system performance but also enables the precise retrieval of power consumption data. This pivotal phase in the procedure underscores the seamless collaboration between the ADE7757 chip and the microcontroller, facilitating the effective management and retrieval of essential information related to electrical energy measurement. Regarding cloud integration, we have thought of this as a prospective feature. In the future, we envision the use of a Wi-Fi module, such as the ESP8266 or ESP32, to facilitate the transmission of data received by the microcontroller to a cloud platform, such as ThingSpeak. This would enable further data analysis and the potential implementation of artificial intelligence algorithms.

TouchGFX, a sophisticated graphic software framework especially designed for STM32 microcontrollers, was used to create a graphical user interface (GUI) for a TFT display [16]. We started out by carefully reviewing the project's specifications and requirements. This stage demanded a thorough comprehension of the key attributes and capabilities that the TFT Display's user interface must offer. These included presenting dynamic graph data, providing navigation controls, enabling on/off control, and displaying startup information. A dynamic graph was painstakingly created for the statistics page in order to enable real-time data visualization. To create and update this graph, data sources were seamlessly integrated into the user interface. It was necessary to include pertinent libraries and functions for this. Figure 3 shows the landing page of the project once it is booted up.

4 Implementation

The widespread usage of smart devices in daily life has benefits and drawbacks, particularly in terms of power consumption and the lack of real-time energy. Concerns with consumption that frequently result in environmental problems and a surge in power bills. To deal with these problems, we have presented a thorough energy tracking system using a touch screen using a TFT that not only gives customers quick access to information about their device's power as well as providing control over the ON/OFF state of these gadgets. This inventive generation empowers individuals to make informed decisions about their energy intake, leading to saving money and the environment at the same time.

As previously discussed, we have used the STM32 microcontroller as the main component in our project for energy monitoring as it efficiently processes data and schedules tasks precisely in complex energy monitoring applications. STM32 microcontrollers are suitable for applications that call for continuous monitoring of energy use and quality because they can handle real-time data collecting and processing.

The circuit shown in Fig. 4 is intended to accurately measure the energy consumption of a connected load. It is an implementation of the schematic shown in Fig. 3. It makes use of the ADE7757 IC, which is a single-phase energy metering chip known for its high accuracy, wide dynamic range, low power consumption, and small size.

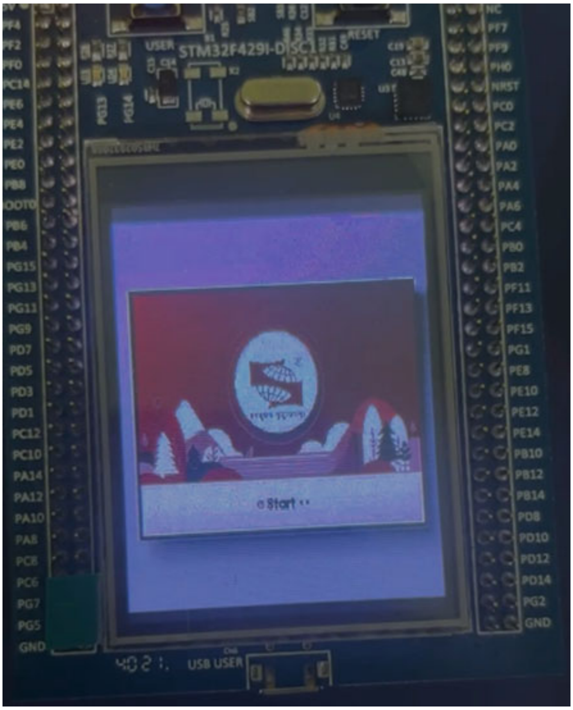


Fig. 3 GUI on the TFT display

The circuit is made up of several components, each with a specific function: resistors for voltage division and current measurement gain adjustment, capacitors for noise filtering and power supply stability, diodes for reverse polarity and overvoltage protection, a transistor for LED indication, and a trimpot for fine-tuning the current measurement gain. These components work together to ensure ADE7757's proper operation and precise energy consumption readings.

It includes a power supply section, a voltage measurement section, a current measurement section, and an energy measurement section. The power supply section provides a regulated 5 V supply to the ADE7757. The voltage measurement section measures the voltage across the load using a resistor divider network. The current measurement section measures the current through the load using a shunt resistor. The energy measurement section calculates the energy consumption of the load based on the voltage and current measurements. It outputs the energy consumption on the F1 and F2 pins of the IC.

The numerous resistors, capacitors, regulators, and transistors in the circuit are necessary to ensure that the ADE7757 operates properly and provides accurate energy measurements. For example, the resistors are used to divide down the voltage and current signals to a level that is safe for the ADE7757 to measure, and the capacitors are used to filter out noise on the signals. The regulators provide stable power supplies to the ADE7757, and the transistor drives the LED indicator.

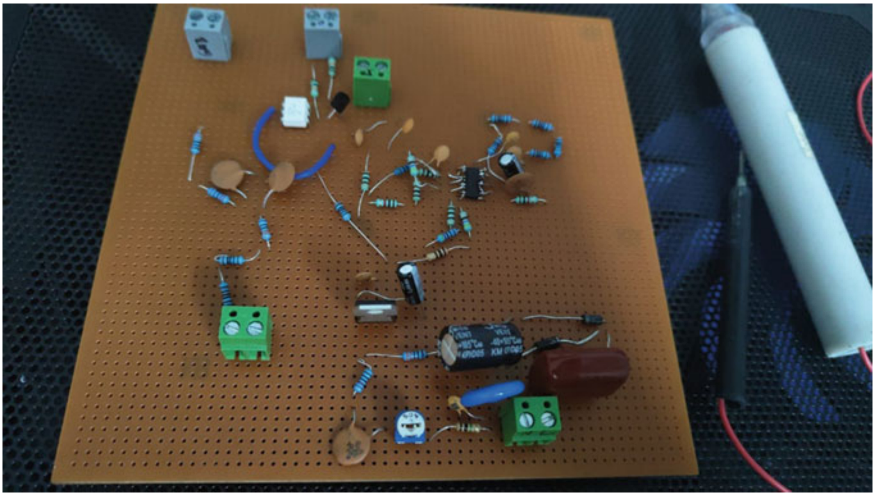
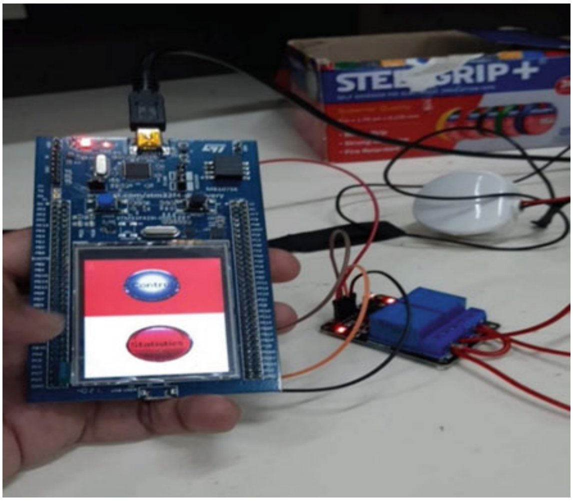


Fig. 4 Energy measurement circuit on a universal PCB

To control the connected load, we used 5 V relays in our home automation setup shown in Fig. 5. These relays act as bridges between our STM32 microcontroller and the appliances, allowing us to safely manage their operation. The low-voltage coil of the 5 V relay is connected to the STM32, and when we use a GPIO pin to energize or de-energize the coil, it controls the power supply to the appliances. This configuration allows us to manage various devices remotely and efficiently, improving the functionality of our smart home system while ensuring electrical safety.

Fig. 5 Relay control using the STM32



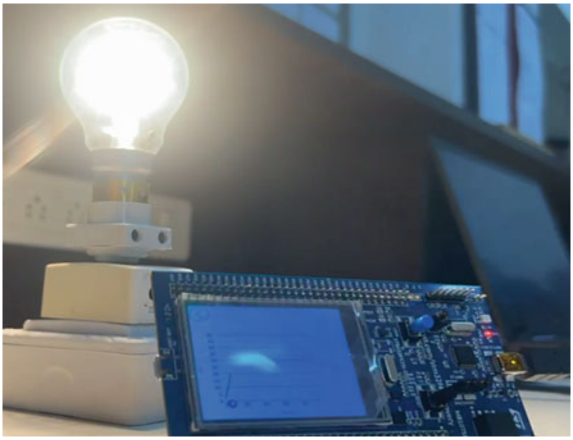


Fig. 6 Energy consumption graph being plotted in real-time

Finally, once the data from the output to the microcontroller is received, a graph can be plotted. The STM32 microcontroller counts pulses generated by the energy meter IC. The pulses are received as interrupts by the microcontroller. The energy meter reading is calculated, and a cumulative energy consumption graph is plotted based on these interruptions and how frequently they occur. The x-axis in the graph represents time, and the y-axis represents total energy consumption. It keeps a running total of power consumption, allowing users to see overall energy consumption trends. The graph for a 60W bulb is depicted in Fig. 6 as an example of the implementation.

5 Costing and Scalability

This project encompassed a variety of components, including a resistor, IC ADE7757, opto-coupler, voltage regulator, capacitors, screw terminals, varistor, BC547 transistor, diodes, and the soldering of the PCB. The STM32, featuring an integrated TFT screen and a relay module, constituted the remaining components of the project. The estimated cost for the entire project from the assembly to the installation is approximately Rs. 5000. The major cost is for the microcontroller and the ICs involved. Exploring alternatives, such as using an STM board without a built-in TFT and connecting an external larger TFT display, coupled with enhancements to the energy meter circuit, can potentially reduce costs and enhance affordability.

In terms of scalability to date, our system is developed for serving domestic households operating on a single-phase power supply. However, there is potential for broader applications by integrating this circuit into complex power systems commonly found in industrial settings, which operate on a three-phase power supply. To accommodate three-phase power measurement, the implementation of the ADE7758 IC is recommended, given its increased capabilities and specific design for polyphase energy measurement applications. Nonetheless, the project's adaptable architecture allows for future enhancements such as multi-device support, improved user interfaces, and overheating protection mechanisms. Our energy monitoring project's journey continues, with exciting possibilities for more robust and accessible energy management solutions.

A potential idea and a prospective future scope for using this project in a building would be to have a network of such devices connected to a main device which is connected to a cloud. Each device acting as a single node in the network would have its own TFT display and will be sharing the data a device acting as the main node. This main device could serve as a centralized hub, collecting and aggregating data from individual nodes within the network. The networked devices, each equipped with its own TFT display, would function as individual nodes, continuously collecting and processing relevant data. This information would then be transmitted to the main device, which is connected to the cloud. The main device, acting as a gateway to the cloud, could facilitate real-time monitoring and analysis of energy consumption patterns throughout the building. This interconnected system would provide a comprehensive overview of energy usage, enabling more informed decision-making for energy optimization and efficiency. Additionally, users could remotely access and monitor the energy data via the cloud interface, offering a convenient and accessible means of managing power consumption in the building.

6 Conclusion

The widespread use of smart gadgets in present society creates a huge issue for energy resource management. The lack of real-time energy consumption data results in financial and environmental costs, which emphasizes the importance of finding proactive solutions. We have responded by releasing a thorough energy monitoring system that includes a TFT capacitive touch display. Users can regulate the operational state (ON/OFF status) of numerous devices using this technology, which also offers immediate insights into how much energy they are using. Our energy monitoring system relies heavily on the STM32 microcontrollers, which provide accurate and real-time data handling capabilities. They act as the main mechanism for gathering, processing, and displaying data. This energy monitoring system has endless scope in the future such as remote integration and cloud facility. The data can be sent on the cloud to enable remote access and usability to the user which the user can access anywhere and anytime with a mobile application.

In conclusion, in the age of smart homes and developing technologies, our energy monitoring system answers the vital requirement for efficient energy management. It gives consumers the power to limit their energy use, which saves money and contributes to a more sustainable future. Our system directs us toward a future characterized by energy efficiency and environmental responsibility through continual innovations.

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