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Design and Implementation of an Energy Monitoring System for Residential Premises with Interactive Emoji-Based Language

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***Abstract*—**
Amidst technological progress and an exponentially increasing global population, it became evident that it is essential to monitor energy consumption at the customer level to sustain the technological infrastructure that supports various facets of human existence and improve its overall efficiency. It is believed that consumers become more aware of their consumption habits when the technical language—describing their energy consumption is simplified. Interactive energy monitoring systems aim to urge individuals to change their energy consumption behaviors by further exploiting the final distribution boards (FDB) that are available in every residential premise. The proposed system includes a touchscreen installed on the FDB that will alert the consumer to their real-time consumption rate. The scaled-down FDB is designed to imitate the FDB in residential premises, with loads that primarily exist in them. The loads used are LED lights, exhaust fan, and outlet sockets. The measuring system consists of an ADE9000 shield that will measure the consumed energy from the FDB by computing voltage, and current. The alerting system is represented with an emoji animation portraying how excessive the consumption is, using raspberry pi and Ionic App. The purpose of using emojis is that the system is designed to alter the consumption rate using a behavioral change approach. The emoji language was chosen due to its simplicity, globality, and the fact that its continued prevalence as modern means of communication.

***Index Terms*—Energy conservation, energy monitoring, sustainability, demand-side management, emoji**

I. Introduction

In the last decade, improving the quality of life has resulted in exponentially increasing energy consumption. Such an issue has severe consequences for the environment and the economy, which will severely impair the ability of future generations to have a decent quality of life. Therefore, to tackle such an issue and to pledge sustainability while facilitating human life, several approaches were used. Energy conservation, which can be defined as the decision to use less energy, is a crucial concept to overcome the excessive consumption of energy. In addition, improving energy efficiency proved that it decreases energy consumption, yet it will have further effects if energy conservation is comprehended. Initially, awareness must be spread to make conserving energy the individual's choice. Adopting a demand-side management approach could help; however, most consumers need to become more familiar with excessive consumption. Therefore, traditional energy monitoring appliances could not make a distinct difference.

Various energy monitoring systems were proposed in the contribution to the energy conservation literature review. Authors in [1] explore the feasibility of creating an Internet of Things Smart Household Distribution Board (ISHDB) to manage smart home devices. The established ISHDB's primary purpose is to store and make accessible information on electrical voltage, current, and power. The results demonstrate the developed system's viability for practical application in real-time residential energy management. It can also be used to monitor the current and voltage waveforms of individual appliances to spot any aberrant operation in real-time. Moreover, Cheap and easy designs were proposed by authors in [2]–[6], which required simple embedded systems and an interactive platform for users. Still, the interaction platform was proposed as a mobile app. Hence, only interested consumers interacted with it. Authors in [7] developed a project to materialize a home-scale, low-voltage electrical distribution panelboard capable of real-time load monitoring and forecasting. Voltage, current, real power, reactive power, apparent power, power factor, and energy usage were among the metrics on the Internet of Things dashboard. The panel system also includes visualization tools that may be used with cloud-based machine learning modeling.

In this paper, a demand-side management based approach is adopted to effectively change the energy consumption behavior of residential premises. The method entails the implementation of an interactive emoji-based energy monitoring. The system functions as an energy meter that computes consumed energy and exhibits a demonstrative emoji resembling the consumption rate. Emoji language was used due to its simplicity and world-wide recognition. The authors in [9] have demonstrated the wide usage of emoji language, its characteristics and detailed evolution over the years. Numerous fields have investigated the influence of emoji language, with a notable focus on sentiment analysis, particularly within the realm of marketing [8]. By selecting an adequate emoji face, the customers decision-making can be affected [10]. Using similar logic, incorporating emoji animations in energy monitoring system can provide a simple to understand means to indirectly alter the peoples' energy consumption and therefore, reduce the demand in a more of a demand-side management approach. Furthermore, emoji language has the capability to influence younger generations to indulge them further in energy conservation practices.

The rest of the paper is formulated as follows. Section II discusses the proposed system and its sub-systems. Section III discusses and interprets the outcome of testing. Section VI concludes the paper and presents future improvements.

II. Proposed Energy Management System Design

The conceptual design proposed a system merged with the final distribution board (FDB) as shown in Figure 1. The system comprises hardware components that deal with energy measurements, data communication and software that deal with displaying the data interactively and storing it. The measurements will be taken from the three-phase incoming cables and processed and sent using an interconnected Microcontroller to Micro-Processor series. After the data is measured, it will be sent to a cloud database and displayed. The designated emoji will be displayed first to the user, and after the user interacts with the system, the energy and recommendations will be displayed.

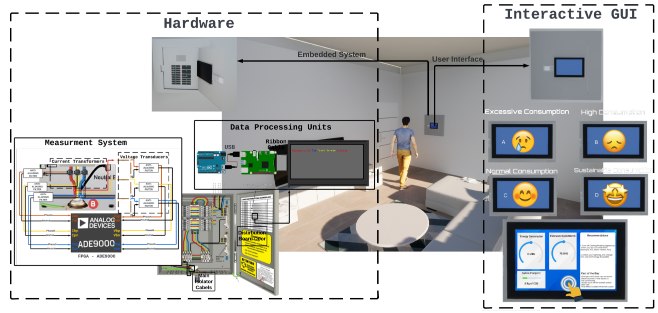

Fig. 1. System overview

A. Energy Measurement Architecture

The main components of the energy measurement system are the EVAL-ADE9000-Shield, Arduino Zero Board, and Current sensors (CTs). The ADE9000 is a Field Programmable Gate Array (FPGA) chip can provide all values, such as RMS, active, reactive, apparent powers, and energies for loads with a maximum rating of 240 Vrms and 86Arms [11]. Figure 2 shows The connection topology of the shield. The shield is compatible with the Arduino Zero board due to its 32-bit reading capabilities. Moreover, it can be inserted directly into the shield. A current sensor, shall be connected to the each phase and neutral line to read the current measurements, while the voltage can be directly be tapped using T-Tapping a crocodile wire into the line.

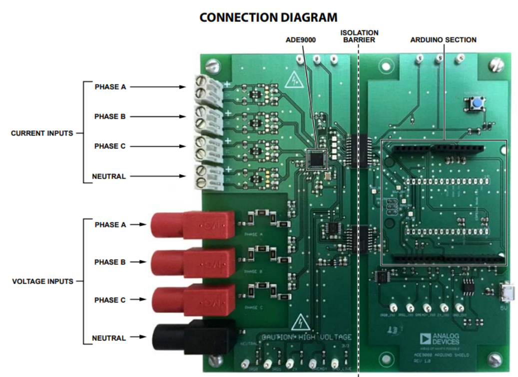

Fig. 2. ADE9000 shield connection diagram

To achieve the communication between them, the Arduino ping the required register of the chip using serial peripheral interface (SPI) interface, and hence the FPGA sent the data accordingly. The measurements of the FPGA is tuned using an external measurement device such as a multi-meter. The calibration process is achived by connecting a single phase load to each phase respectively, and comparing the received vs measured data. Afterwards, a calibration factor (CF) will be obtained Equation 1, which will be multiplied by received data to the Arduino.

$$CF = \frac{MultimeterMeasuredValue}{ADE900MeasuredValue} \tag{1}$$

The calibration was done using the HIOKI-3280-10F Multimeter as an external measurement device, the Ikon PTC Fan Heater as the single-phase load, and YHDC SCT-013-000 as the current transformer. The obtained calibration factors are shown in Table I

TABLE I
PHASES CALIBRATION FACTORS

Current Calibration Factors			
	Multi-meter Measurement (A)	ADE9000 Current Measurement (A)	Current Calibration Factor
Phase A	8.41	3126629.15	2.808559685544704e-6
Phase B	8.24	3110824.80	5.045362276666335e-6
Phase C	8.23	3106730.86	5.136440453341677e-6
Voltage Calibration Factors			
	Multi-meter Voltage Measurement (V)	ADE9000 Voltage Measurement (V)	Voltage Calibration Factor
Phase A	235	21597398	2.179773851155928e-5
Phase B	234.9	21597961.24	2.18349936326604e-5
Phase C	235.6	21643568.15	2.172789737184625e-5
Power Calibration Factors			
	Calculated Power Value (W)	ADE9000 Power Measurement (W)	Power Calibration Factor
Phase A	1976.35	502845.70	0.0078887487298347
Phase B	1935.576	499979.32	0.0074636631804773
Phase C	1938.988	500119.34	0.0075277702281163

After calibrating the voltage, current, and power values, the energy was calculated manually in the Arduino. Since the power is obtained discretely, the energy in watts per hour is calculated using the following formula Equation 2. The x subscript refers to the designated phase, and T_s is the sampling time of the data, which is 5 seconds; hence the energy per second is obtained. However, in residential premises, the energy per hour is required. Therefore, the value was multiplied by the conversion factor from seconds to hours. Finally, to obtain the total value of the three-phase loads, the individual phase energy was summed using Equation 3.

$$E_{\mathrm{x}}(Wh) = \sum P_{\mathrm{x}} \times T_{\mathrm{s}} \times \frac{1}{3600} \tag{2}$$

$$E_{\mathrm{Total}} = \sum E_{\mathrm{x}} \tag{3}$$

The final hardware setup of the measurement system is shown in Figure 3. For safety reasons, an acrylic casing was designed to fit in the components.

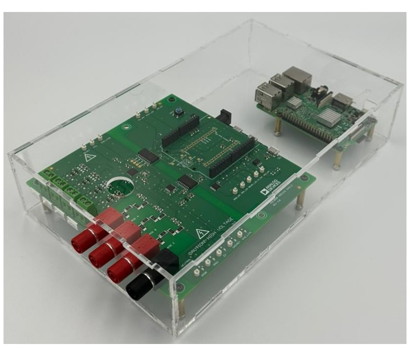

Fig. 3. Measurement system hardware design

B. Display Architecture

A web app is designed to display and store the data interactively, which will have different pages to be displayed to the user as shown in Figure 4. The user interface shows a designated emoji according to the consumption rate. Suppose the user interacts with the system's touch screen. In that case, the measurements of the energy, overall cost, and CO2 emissions will be displayed on a daily or monthly basis according to the user preference with a simple load curve. Moreover, The user can navigate to the details section of the app, which shows the individual phases energies with a simplified load schedule. A varying statement will be shown according to the largest consumed phase.

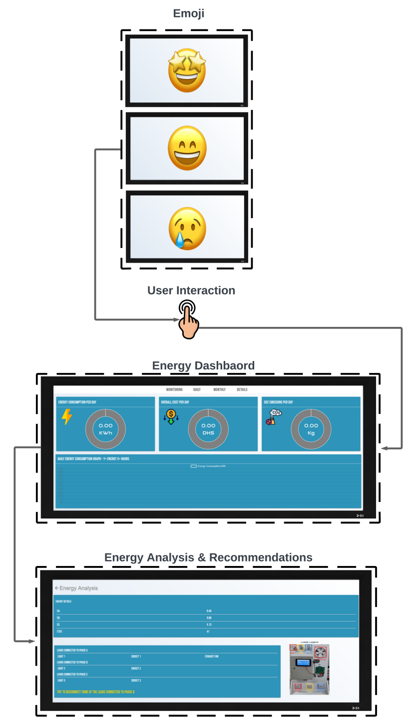

Fig. 4. Web-app overview

To send measured data from the Arduino to the app, a Raspberry Pi (RPI) was used as a linker between the two stages. Using the universal asynchronous receiver/transmitter (UART) protocol, the data was sent from the Arduino to the RPI. Afterward, the data was sent to Google Firestore as the cloud server between the two sub-systems. From there, the Energy data is sent to the web app, and the measurements of Cost and CO2 are obtained according to the following formulas: Equation 4 and Equation 5. Where Ex is the received total energy in kWh, RF is the rate factor in (fils/kWh), and EF is the emission factor in (kg/kWh). The rate factor was taken as the tariff rate in Abu Dhabi [12], while the emission factor was the CO2 emission factor of electricity in the UAE.

$$Cost = E_{\mathrm{x}}(kWh) \times RF(fils/kWh) \tag{4}$$

$$CO2emissions = E_{\mathrm{x}}(kWh) \times EF(kg/kWh) \tag{5}$$

The data will be displayed using an algorithm in Figure 5. The algorithm was designed according to ADDC expat residential consumers, where the tariff rate will increase after

20kWh daily consumption. The display has three emojis representing three consumption scenarios. The first scenario is ideal consumption, where the daily consumption is less than 20 kWh. The second scenario is the normal consumption, where the daily consumption is between 20 and 40 kWh. The third scenario is high consumption, where the daily consumption is more than 40kWh.

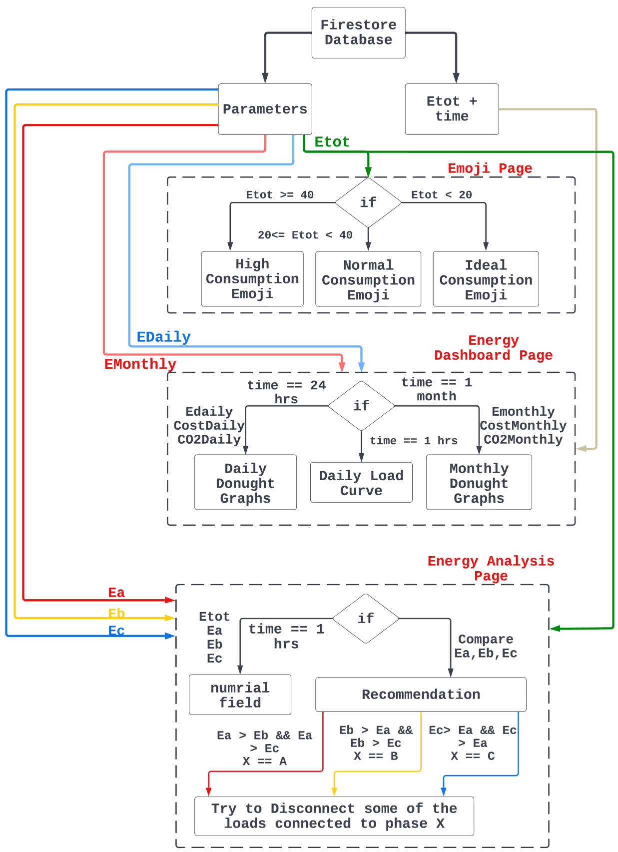

Fig. 5. Display algorithm

III. System Testing and Validation

Testing the system is carried out by imitating a simple FDB as shown in Figure 6. The FDB and the final circuits were connected using Abu Dhabi's Electricity Wiring Regulation 2020. The FDB load schedule is configured in such away that the three phases are almost balanced. Each phase is feeding a 13A socket with a lamp. However, phase A has an extra exhaust fan. The system was tested for three scenarios, where each scenario differed with the loads connected in each phase. The designed final circuits are protected using residual circuit breaker (RCD), miniature circuit breakers (MCBs), and a three-phase isolator switch.

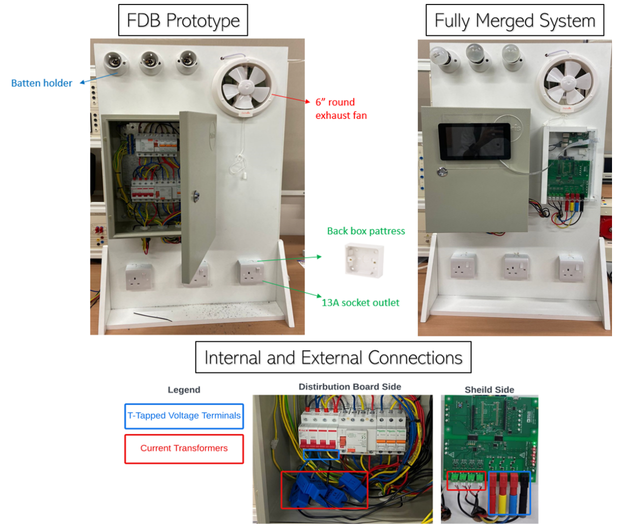

Fig. 6. Testing and validation setup

Due to the limited loads connected to the FDB, power rating assumptions shown in Table II were made for the testing environment. Moreover, each scenario was done for one hour to get the exact KWh value of the loads.

TABLE II
TESTING POWER CONVERSION RATE

Load	Real Power Rating (W)	Assumed Power Rating (kW)
Lamp	100	7.6375
Exhaust Fan	25	1.90938
Function Generator	125	9.54688

The first scenario was simulated with no load connected to any phase on the prototype. According to , this scenario is the ideal case. Figure 7 demonstrates the resulting emoji and reading of the system.

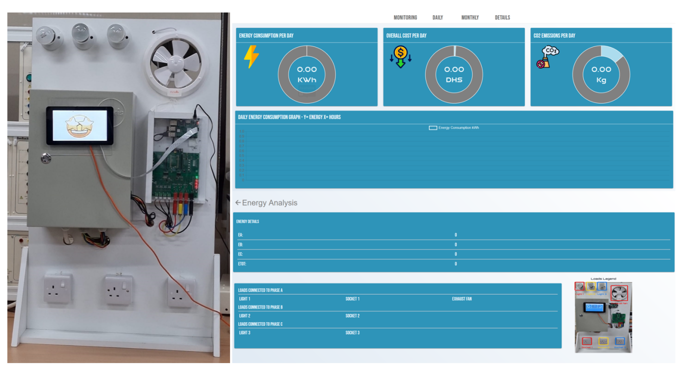

Fig. 7. First scenario results

The second scenario was simulated by turning on the three lamps with the exhaust fan. This scenario is the normal consumption case. Figure 9 demonstrates the resulting emoji and reading of the system.

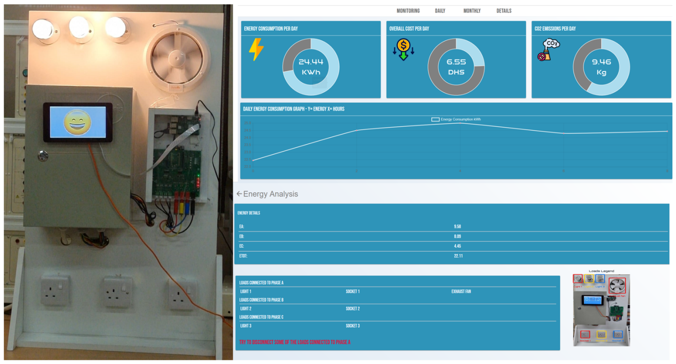

Fig. 8. Second scenario results

The third scenario was simulated by turning on the three lamps with the exhaust fan and loading the three sockets with function generators. This scenario is the high consumption case. Figure 9 demonstrates the resulting emoji and reading of the system.

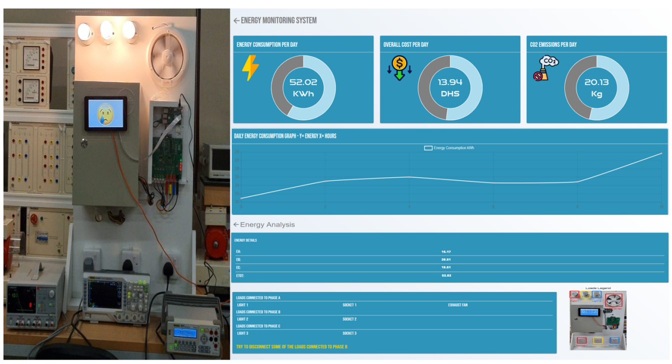

Fig. 9. Third scenario results

For all cases, the chosen emoji were displayed to the user first, and after the touch screen interaction, the dashboard and recommendation pages were displayed. The system functioned as expected from Figure 5, and the measured data were reasonably accurate.

IV. Conclusion

This paper presents the design and implementation of an interactive energy monitoring system for residential premises using emoji language. The main objective of this implementation is to spread self-awareness using demand-side management and construct the consumer's life to be more accessible from the side of dealing with electricity bills utilizing emoji communication. The system consists of integrating two subsystems, which are the energy measuring system and the Interactive user interface system. The energy measuring system is responsible for measuring accurate daily and monthly energy values using an ADE9000 shield integrated with an interactive user interface that displays the energy consumption, cost, CO2 emission, and a simplified load curve for the user. Furthermore, a prototype that imitates the FDB in residential premises was built to test the functionality and accuracy of the system. Generally, this system can be readily modified to assist consumers in managing their consumption depending on the premise type and power consumption allowance. According to the system capabilities mentioned, it can be integrated with peak hours shaving algorithms, which will lead to reducing the spikes in consumption from the consumer side effectively.

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