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Internet of Things-Based Smart Energy Meter for Monitoring Energy Consumption

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Abstract

Control and monitoring systems across all industries now include the Internet of Things (IoT) as a core component. This paper presented a smart energy meter using IoT, which measures the load voltage (V) and current (I) values as well as the phase difference (α) between V and I that are used to determine the power factor (pf). The energy consumed is calculated based on the values of I, V and P(w). ESP32 board is used to process the sensor signals as well as it acts as a server that connects to the internet and has a web page to remotely monitor the loads connected to the substation. A web page is designed for each substation so that all web pages are within a website for monitoring electrical loads connected to substations. Each webpage contains details about substation V, I, pf, frequency and energy consumed.

Keywords: Smart Energy meter, ESP32 board, Internet of Things (IoT).

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مقياس الطاقة الذكي القائم على إنترنت الأشياء لمراقبة استهلاك الطاقة

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الملخص

تتضمن أنظمة التحكم والمراقبة في جميع الصناعات الآن إنترنت الأشياء (IoT) كمكون أساسي. قدمت هذه الورقة مقياس طاقة ذكي باستخدام إنترنت الأشياء، والذي يقيس قيم جهد الحمل (V) والتيار (I) بالإضافة إلى فرق الطور (α) بين V و I المستخدمة لتحديد عامل الطاقة (pf). يتم حساب الطاقة المستهلكة بناءً على قيم I و V و P(w). يتم استخدام لوحة ESP32 لمعالجة إشارات الاستشعار بالإضافة إلى أنها تعمل كخادم يتصل بالإنترنت ولها صفحة ويب لمراقبة الأحمال المتصلة بالمحطة الفرعية عن بعد. تم تصميم صفحة

ويب لكل محطة فرعية بحيث تكون جميع صفحات الويب ضمن موقع ويب لمراقبة الأحمال الكهربائية المتصلة بالمحطات الفرعية. تحتوي كل صفحة ويب على تفاصيل حول المحطة الفرعية V و Iو pf والتردد والطاقة المستهلكة.

الكلمات المفتاحية: عداد الطاقة الذكي، لوحة ESP32، إنترنت الأشياء (IoT).

Introduction

The consumption of electrical energy must be measured to maintain it and use it as efficiently as possible. Energy consumed can be measured with energy meters and this measured data is manually gathered by employees (operators) who collect electric energy after utilizing the energy meter to calculate the amount of used energy [1]. the conventional method without the use of any contemporary technology, such as sending or receiving data, was used in the past to gather statistics on energy usage for all electrical loads [2]. In those conventional systems, it was necessary to have a designated someone who would visit the locations of electric loads, read the meter data, and then return the information to the centers for recording and distribution to energy customers [3]. however, this approach to collecting data on energy consumption and transmitting it to consumers is regarded as ineffective due to time and effort waste, additional costs associated with providing transportation, errors brought on by incorrect readings of energy meters by electricity company employees, and other factors [4].After the emergence of the electronic revolution, and specifically microcontrollers, many researches appeared on the use of microcontrollers in various industrial, agricultural, medical and other fields, microcontrollers have been used in the design of various robots that contribute to the completion of work with ease and high accuracy[14]. For example, the design of medical robots that contribute greatly to assisting in the treatment of patients, in addition to monitoring their conditions remotely through several technologies, including Wi-Fi technology [5]. An energy meter that measures energy consumption and has numerous integrated smart capabilities, such as demand side management, demand response, load control, load curtailment, etc., is referred to as a smart meter [6]. Intelligent energy metering systems are devices that shorten a lot of time, effort, and costs. Through these meters, energy consumption data is obtained without the need to move around consumers to collect energy consumption data, and to deliver this data to electric power centers to calculate a consumption bill energy, and then delivered to the user again [7]. Numerous studies have been conducted to increase the precision of the data collection process for energy consumption, with the main objective of designing smart energy meters [2] based on integrating traditional systems with microcontrollers and other communication technologies to receive and transmit data remotely, such as GSM technology [8,9] Wi-Fi and others. The GSM technology, which offers the opportunity to examine energy consumption data remotely and controls the disconnection and delivery of electrical energy to loads, is one of the most significant technologies that has been employed extensively in the construction of smart energy meters[10].The Internet of Things technology is one of the modern technologies that have contributed greatly to shortening the time and effort at work, in addition to shortening the distances in terms of placing all the areas of the world in one framework within computers. These places are accessed through smart devices such as computers, phones, and others. The Internet of Things has been widely used in the field of electric power, starting from the generation of electric power, through its transmission methods, and even its distribution mechanism. The Internet of Things technology will have an effective role in the electric power distribution process in terms of calculating the consumed energy in addition to monitoring the consumption of this energy [1].An Arduino board was used to control the reception and transmission of signals, in addition to a set of sensors and a radio frequency XBee2.4GHz.The wireless measurement and control of smart house meters using GSM has been presented by [11], this system was designed using Arduino board to read and transfer data through wireless protocol networks using GSM technology and an internet connection. Another smart energy meter equipped with a phone application and a prepaid system was presented in [1], this meter calculates the consumed energy and displays it on the application interface. With the emergence of Internet of things(IoT) technology, the development of control systems has taken on another dimension in terms of ease of access to data obtained from the work environment, as (IoT) works through the components of the control system, which are microcontrollers, sensors, etc., to process the data and display it on the internet, as well as the possibility of controlling these systems remotely, which saves a lot of time and effort in accessing this data[12]. A smart energy meter is designed using an ESP32 board to process sensor signals, and the power consumed by the load is calculated. The ESP32 board also acts as a server that provides a web page through which the value of the power consumed by this load is displayed. However, the power factor was not taken into account when calculating the effective power, as shown in equation (1), and this caused inaccurate results in calculating the consumed power[13].

$$Power\ (W) = V_{rms}\ (V) \times I_{rms}\ (A) \quad \text{……………………………………. (1)}$$

Therefore, this research presents a design for a smart energy meter based on the Internet of Things (IoT) to calculate the consumed energy, taking into account the calculation the power factor to be used in calculating the consumed power. In addition, the design presented in this research provides the process of monitoring the energy consumed for several electrical loads (homes). Through web pages that were designed and connected to the server (ESP32) to display readings of the consumed energy in addition to reading the current and voltage.

Block Diagram of the Smart Energy Meter Control System

Figure 1 shows the Block diagram of the smart energy meter presented in this paper. The Block diagram shows the system's inputs, outputs, and the processing and control unit. The processing unit (ESP32) receives electrical signals through the sensors, while the system outputs are transferred to the graphical user interface to display them.

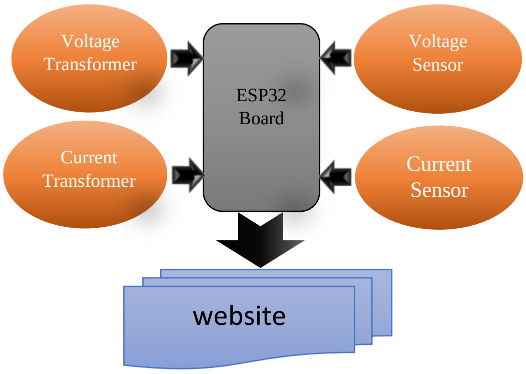

Figure 1: The block diagram of the proposed smart energy meter.

Proposed system architecture

The smart energy meter presented in this paper is a monitoring system based on Internet of Things technology. This meter reads the voltage (*V*) and current (*I*) of the load connected to the transformer substation, in addition to calculating the power factor(*p.f*), active power (*P*), as well as the frequency (*f*) of the voltage source and the consumed energy. These readings are displayed on the web page of the substation to which the electrical load is connected. The smart electric energy meter as shown in Figure 2, mainly consists of ESP32 board which is the heart of the system circuit, this board receives signals from voltage and current sensors, in addition to the signals received from the voltage and current transformers, and then process these signals to calculate *p.f*, *P* and consumed energy, and display these values on the web page of each station.

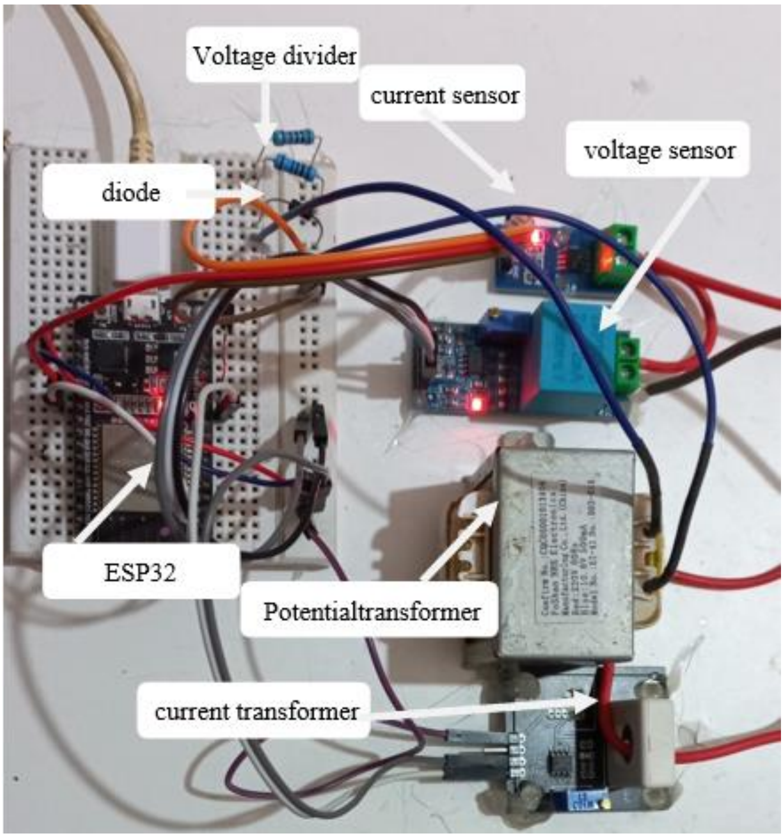

Figure 2: Hardware prototype connection.

ESP32 is a small-sized board that has GPIO pins that can function as an interrupt request. The power factor or phase angle between voltage and current must be known to calculate the active power(w), so phase difference has been determined programmatically using interrupts. the phase difference between the voltage and the current is represented by the interval between the moments when the maximum value of the voltage signal and the maximum value of the current signal emerge. Both the voltage transformer and the current transformer are linked to GPIO pins that can function as interrupts. Through these inputs, the ESP32 board receives the sinusoidal voltage and current signals as depicted in Figure 3, allowing the maximum values of voltage and current to be calculated.

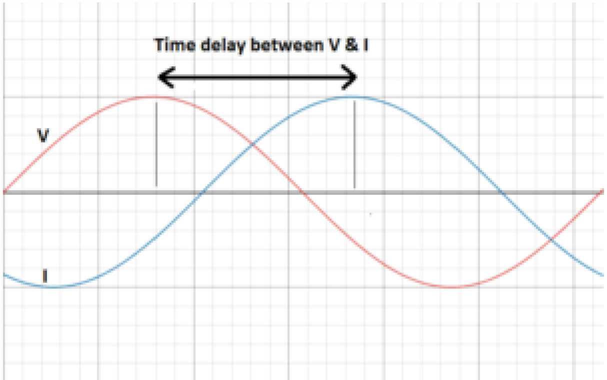

Figure 3: Sinusoidal voltage and current signals.

The software design of the smart energy meter

The code for the smart energy meter control system was written using the Arduino ID. A website for displaying the energy meter readings remotely and from any location in the world was created using the html language. The home page of this website is depicted in Fig.4.

Figure 4: The main interface in the website of the proposed smart energy meter.

The home page contains links referring to pages that contain information about energy meters connected to electrical loads (houses) as illustrated in Figure 5, where the smart energy meter is connected on each load supplied by the substation, and thus all data of loads for this substation are displayed on one page. Several pages can be included in this website shown in Figure 5 as needed and according to the expansion of the distribution substations.

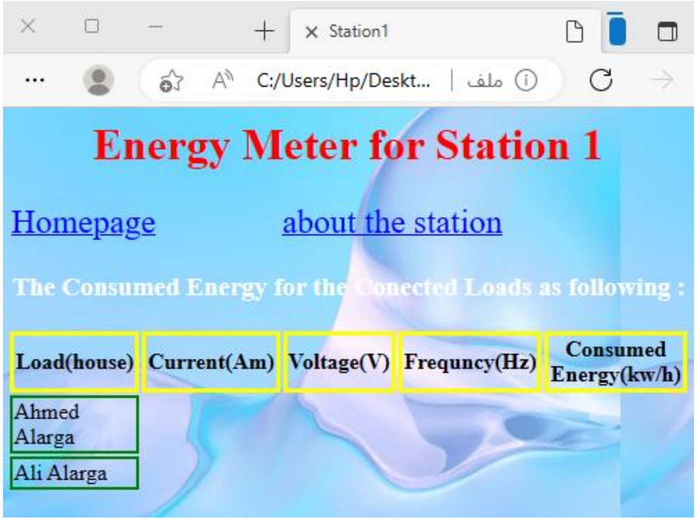

Figure 5: The page of a substation.

Calculation of energy consumed

the amount of energy consumed by households is expressed in kWh, and it can be calculated by (2):

$$Energy\ (kw/h) = \frac{Power\ (W) \times Duration\ (hours)}{1000} \quad (2)$$

And the active power in watt (W) can be calculated by multiply the RMS voltage with RMS current as in [3].

$$Power\ (W) = V_{rms}\ (V) \times I_{rms}\ (A) \times p.f \quad (3)$$

In order to calculate the effective power P, it requires finding the value of the power factor (*p.f*) = cos(α). Where *p.f* is found by determining the time period t_d between the maximum value of the voltage and the maximum value of the current. The value of the period t_d is determined programmatically using interrupts, and the phase angle between voltage and current is calculated through (4) [14]:

$$\propto = t_d * f * 360 \quad (4)$$

Results and discussion

Practical results of the smart energy meter proposed in this paper will be discussed in this section. The web page of the transfer Station1 is shown in the figure 6 which illustrates the readings obtained from the meter connected to the first load, which is Mr. Ahmed's house, as well as readings obtained from the meter connected to the second load, which is Mr. Ali's house. The readings obtained from the meters are shown in the figure 6 and they are I, V, P(w), f, p.f and energy consumed values.

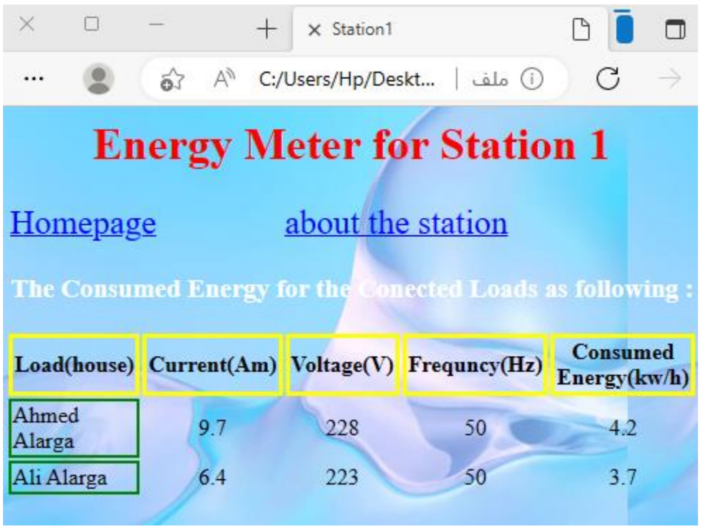

Figure 6: The obtained meter data displayed on webpage.

Conclusion

In this paper, an intelligent energy meter based on the Internet of Things was designed that monitors the values of voltage, current, and energy consumed. This system allows data to be collected remotely without having to go to the user's location and display it on a web page. Through this feature, a web page was designed for an electricity distribution station, so that the electrical energy consumption of users connected to this station was monitored. Through this system, illegal energy consumption can be monitored so that the users' total energy consumption is compared with the total consumption of the distribution station, thus determining the presence of illegal consumption or not.

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