T.C.

KIRSEHIR AHI EVRAN UNIVERSITY

INSTITUTE OF SCIENCES

DEPARTMENT OF ADVANCED TECHNOLOGIES

A Cheap and Easy-Controllable Energy Measurement System for Smart Homes in Micro and Smart Grid Infrastructure

Husham Sakeen Farhan

MASTER'S THESIS

KIRŞEHİR / 2022

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Supervisor
Assist. Prof. Dr. Mehmet GÜÇYETMEZ

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THESIS STATEMENT

I declare that all the information in the thesis is obtained and presented within the framework of ethical behavior and academic rules, and in this study, which is prepared in accordance with the thesis writing rules, all kinds of statements that do not belong to me are fully cited to the source of the information.

Husham Sakeen Farhan

20.04.2016 tarihli Resmî Gazete ’de yayımlanan Lisansüstü Eğitim ve Öğretim Yönetmeliğinin 9/2 ve 22/2 maddeleri gereğince; Bu Lisansüstü teze, Kırşehir Ahi Evran Üniversitesi’nin abonesi olduğu intihal yazılım programı kullanılarak Fen Bilimleri Enstitüsü’nün belirlemiş olduğu ölçütlere uygun rapor alınmıştır.

PREFACE

Whoever enters the road without a guide will take a hundred years on a journey that only takes two days. (**Jalal Uddin Rumi**)

I offer my highest thanks and gratitude to **Assist. Prof. Dr MEHMET GÜÇYETMEZ**, who kindly accepted the supervision of my master's thesis and who gave me his precious time and his vast knowledge and experience, which constituted a great addition to my research work. As his guidance and valuable advice that I used in my entire research work, I ask God Almighty to reward him well. In addition, thanks to my family who have always supported me financially and morally.

Yola rehbersiz giren, sadece iki gün süren bir yolculuğa yüz yıl çıkar. (**Celal Uddin Rumi**)

Yüksek lisans tezimin danışmanlığını kabul eden, değerli zamanını ve araştırma çalışmalarıma büyük katkı sağlayan engin bilgi ve deneyimini bana ayıran **Dr. Öğretim Üyesi MEHMET GÜÇYETMEZ'e** en içten teşekkürlerimi ve şükranlarımı sunuyorum. Tüm araştırma çalışmalarımda kullandığım rehberliği ve değerli tavsiyesi olarak Cenab-ı Allah'tan kendisini hayırla mükafatlandırmasını niyaz ederim. Ayrıca maddi ve manevi her zaman yanımda olan aileme teşekkür ederim.

October, 2022 **Husham Sakeen Farhan**

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SYMBOLS AND ABBREVIATIONS

Abbreviations	Explanation
SM	: Smart Meter
SG	: Smart Grid
IoT	: Internet of Thing
SMS	: Short Message Service
AMI	: Advanced Metering Infrastructure
KWh	: Kilowatt-hour
HAN	: Home area network
MDMS	: Meter Data Management Systems
SQL	: Structured Query Language
KPI	: Key Performance Indicators
API	: Application-programming interface
RPC	: Remote procedure call
ML	: Machine learning
AI	: Artificial intelligence
MCU	: Controllers or microcontroller units
ADC	: Analog/Digital converters
DAC	: Digital-To-Analog
I2C	: Inter-Integrated Circuit
SPI	: Serial Peripheral Interface
RDBMS	: Relational database management system
SSA	: Singular Spectrum Analysis

ABSTRACT

MASTER THESIS

A CHEAP AND EASY-CONTROLLABLE ENERGY MEASUREMENT SYSTEM FOR SMART HOMES IN MICRO AND SMART GRID INFRASTRUCTURE

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Electricity is one of the most significant gifts that science has bestowed on humanity, and with rapid growth and development, as well as growing concern about global warming, concern about greenhouse gas emissions is growing by the day. The energy crisis has become a very big issue. For this reason, the scientific community has increased the scope of its intervention in the field of energy production by shifting electricity production to renewable energy sources and regulating electricity consumption.

Because of the rapid growth in the population and development, and the dependence of millions of people on electricity in their daily lives, the problem of energy consumption has become one of the major problems that are given great attention by governments, especially in the case of energy production being less than required. To maintain the continuity of energy without stopping, it is necessary to regulate electricity consumption, and that requires providing real-time data to consumers. At the present time, there is no real-time data for the consumer about the amount of energy consumption, as well as no information about the

appropriate period of consumption. This is in addition to the fact that the data is read manually at the end of each month for the purpose of providing monthly bills, which requires a workforce for the purpose of completing this work, in addition to what goes along with human intervention from errors.

Even while traditional electromechanical meters are still commonly used today for residential users, despite being a well-known technology, they have a number of restrictions because of their constructive qualities. In general, electromechanical meters are not very accurate, and various technical issues, like waveform distortions or imbalance load, operation temperature, among others, may have an impact on the measurement. Additionally, this class of energy meters solely measures the cumulative active power component and essentially takes unidirectional energy usage into account.

The emergence of limiters in electromechanical meters necessitated a new idea for power metering and control, leading to the recent appearance of the smart grid (SG) and the smart meter (SM). A SG system is a type of intricate and highly developed technology that not only enables the flow of power in both directions but also has a number of additional features like availability, effectiveness, accuracy, controllability, economics, flexibility, interoperability, maintainability, measurability, optimality, reliability, sustainability, stability, security, and scalability.

It is clear that the issue of electrical energy consumption will become a preoccupation in the near future due to limited natural resources, in addition to the population increase and its dependence on electrical energy in all industrial aspects as well as in the details of daily life.

In order to maintain the continuity of electric power generation, it is necessary to rely on new sources in power generation in addition to rationalizing consumption by users, and this is what the research focuses on by building an integrated system that leads to rationalization of consumption by users by providing a mechanism to automatically read data by A system built on the Internet of things and storing energy consumption data for each consumer on an external database and providing information to the consumer about the amount of energy consumed per hour, day and month, in addition to informing him of the best time for energy consumption, as well as alerting him in case the amount of money for the amount of energy consumed exceeds the amount of money amount for the estimated energy By the user, in addition to providing data analysis to the user to inform him that the current use of electricity is beneficial or harmful for him in relation to the financial cost, the system also provides the

possibility for the electricity producing company to directly provide a mechanism for communication with the user in case of emergency or to send a message to the user.

Keywords: *Smart Energy Measurement System, Internet of Things (IoT), Smart grid (SG), Smart meter (SM), stored energy, structured query language (SQL), SqlServer*

ÖZET

YÜKSEK LİSANS TEZİ

MIKRO VE AKILLI ŞEBEKE ALTYAPISINDA AKILLI EVLER İÇIN UCUZ VE KOLAY KONTROL EDILEBILIR ENERJI ÖLÇÜM SISTEMI

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Danışman: Dr. Öğretim Üyesi MEHMET GÜÇYETMEZ

Elektrik, bilimin insanlığa bahşettiği en önemli armağanlardan biridir ve hızlı büyüme ve gelişmenin yanı sıra küresel ısınma ile ilgili endişelerin artmasıyla birlikte, sera gazı emisyonları endişesi de her geçen gün artmaktadır. Enerji krizi çok büyük bir sorun haline geldi. Bu nedenle bilim camiası, elektrik üretimini yenilenebilir enerji kaynaklarına kaydırarak ve elektrik tüketimini düzenleyerek enerji üretimi alanındaki müdahalesinin kapsamını artırmıştır.

Nüfusun ve kalkınmanın hızla artması ve milyonlarca insanın günlük yaşamlarında elektriğe bağımlı hale gelmesi nedeniyle, enerji tüketimi sorunu özellikle devletler tarafından büyük önem verilen önemli sorunlardan biri haline gelmiştir. Enerji üretimi gerekenden daha az. Enerjinin durmadan sürekliliğini sağlamak için elektrik tüketiminin düzenlenmesi ve bunun için tüketicilere gerçek zamanlı verilerin sağlanması gerekmektedir. Şu anda, tüketici için enerji tüketimi miktarı hakkında gerçek zamanlı veri olmadığı gibi, uygun tüketim süresi hakkında da bilgi bulunmamaktadır. Bu, hatalardan insan müdahalesine ek olarak, bu işi

tamamlamak için bir işgücü gerektiren aylık faturaların sağlanması amacıyla verilerin her ayın sonunda manuel olarak okunmasına ek olarak .

Geleneksel elektromekanik sayaçlar günümüzde hala konut kullanıcıları için yaygın olarak kullanılsa da, iyi bilinen bir teknoloji olmasına rağmen, yapısal nitelikleri nedeniyle bir takım kısıtlamaları vardır. Genel olarak, elektromekanik sayaçlar çok hassas değildir ve diğerlerinin yanı sıra dalga biçimi bozulmaları veya dengesizlik yükü, çalışma sıcaklığı gibi çeşitli teknik sorunlar ölçümü etkileyebilir. Ek olarak, bu enerji sayaçları sınıfı yalnızca kümülatif aktif güç bileşenini ölçer ve esas olarak tek yönlü enerji kullanımını hesaba katar.

Elektromekanik sayaçlarda sınırlayıcıların ortaya çıkması, güç ölçümü ve kontrolü için yeni bir fikri gerektirdi ve son zamanlarda akıllı şebekenin (SG) ve akıllı sayacın (SM) ortaya çıkmasına yol açtı. Bir SG sistemi, yalnızca gücün her iki yönde akışını sağlamakla kalmayıp aynı zamanda kullanılabilirlik, etkinlik, doğruluk, kontrol edilebilirlik, ekonomi, esneklik, birlikte çalışabilirlik, sürdürülebilirlik, ölçülebilirlik, optimallik, güvenilirlik, sürdürülebilirlik, kararlılık, güvenlik ve ölçeklenebilirlik.

Elektrik enerjisi tüketimi konusunun, sınırlı doğal kaynaklar, nüfus artışı ve günlük yaşamın tüm detaylarında olduğu gibi tüm endüstriyel yönleriyle elektrik enerjisine bağımlılığının yanı sıra yakın gelecekte bir meşguliyet haline geleceği açıktır.

Elektrik enerjisi üretiminin sürekliliğini sağlamak için, kullanıcıların tüketimini rasyonelleştirmenin yanı sıra elektrik üretiminde yeni kaynaklara güvenmek gerekir ve araştırmanın odaklandığı şey, tüketimin rasyonelleştirilmesine yol açan entegre bir sistem inşa etmektir. Nesnelerin interneti üzerine kurulmuş ve her tüketici için enerji tüketim verilerini harici bir veri tabanında saklayan ve tüketiciye saat, gün ve ay başına tüketilen enerji miktarı hakkında bilgi sağlayan bir sistem tarafından verilerin otomatik olarak okunması için bir mekanizma sağlayarak, Enerji tüketimi için en uygun zamanın kendisine bildirilmesinin yanı sıra, tüketilen enerji miktarı için para miktarının tahmini enerji için para miktarını aşması durumunda uyarılmasının yanı sıra, kullanıcı tarafından veri analizi sağlamanın yanı sıra, kullanıcının mevcut elektrik kullanımının finansal maliyetle ilgili olarak kendisi için faydalı veya zararlı olduğunu bildirmesi, sistem ayrıca elektrik üreten şirketin, acil durumlarda kullanıcı ile doğrudan iletişim kurmak veya kullanıcıya bir mesaj göndermek için bir mekanizma sağlama olanağı des.

Anahtar Kelimeler: Akıllı Enerji Ölçüm Sistemi, Nesnelerin İnterneti (IoT), depolanan enerji, Akıllı şebeke (SG), Akıllı sayaç (SM), yapılandırılmış sorgu dili (SQL), SqlServer

1. INTRODUCTION

Electricity is one of the most important blessings that science has given to mankind, and with rapid growth and development, and with fear of global warming mounting over us concern for greenhouses emissions is rising day by day, energy crisis has become a very big issue. For that the scientific community has narrowed down its intervention to these two approaches:

1. Shifting Electricity production to renewable energy source.
2. Regulating electricity consumption.

While greater emphasis is being given to the first solution, there is little awareness on second alternative [1]. According to a research, the units of electricity power consumption used in enlightening buildings is around 40% in which the energy wastage is about 10-15%. This energy wastage is due to the irresponsibility of the humans because they are unaware of how much amount of energy has been wasted in a day [2].

Demand Response (DR) is one of the techniques used to regulate electricity consumption, where exploit electricity consumers flexibilities by giving them particular incentives, in order to achieve some services to the grid like reducing: peak demand, generation, transmission and distribution costs or increasing renewable energy insertion. In DR programs, the aggregated energy demand is a key metric and an aggregator interacts with active consumers willing to minimize their electricity bill or maximize their utility to optimize this demand profile. In such a framework, energy can be viewed as an asset demanded by customers, and which has a cost that depends on total demand and the time of demand [3].

With changing power consumption according to demand period (Peak, Standard and Off-Peak demand), this will help in regulating power consumption, beside that the consumers should know their instantaneous consumption and grid power price. Traditional electromechanical meters still today widely used for residential consumers, although it is a well-known technology, but it has several limitations due to its constructive characteristics. In general, electromechanical meters are not highly accurate and its measurement may be affected by many technical factors, such as waveform distortions or imbalance load, operation temperature, among others. In addition, this category of energy meter can only measure e a cumulative active power component and basically considering unidirectional

power flow. Other important factor effected of this technology is the human factor where the energy measurement typically requires manual or human reading what is certainly more susceptible to reading errors. Besides that, the operating cost is high because reading all electromechanical meters need many workers, that such process represents a high operational cost for the utilities, which tends to increase energy tariffs [4]. For that, both grid companies and consumers could not get benefit from using electromechanical meter if they want use DR technique.

These days we see a big development public electric system, where energy flow becomes bidirectional due to increasing in distributed generation plants. Electricity is shared among the several nodes of the power grid, named micro grids [5]. This development in power system required new concept of power metering and control, for the new concepts appear in recent years, which are smart grid (SG) and smart meter (SM). A SG system is a kind of complex and high advanced technology that allows not just bidirectional power flow but it also has several different features like as availability, effectiveness, accuracy, controllability, economically, flexibility, interoperability, maintainability, measurability, optimality, reliability, sustainability, stability, security, and scalability [6]. Electromechanical become not suitable for micro grid also, so for that and to get benefit from DR technique a Smart Meter is used. The smart meter is a vital evolution in SGs. The smart meter has been introduced to the public as an alternative to conventional electromechanical. Conventional electromechanically must be separately inspected by metering workers from the energy provider companies. Many solutions are given for the problems related to the traditional meter. On the other hand, smart meters that employ the Internet of Things (IoT) technology gave the consumers the ability to monitor and regulate energy consumption remotely and get accurate automated meters. Smart meters can give opportunity for customers to participate on large scale and economically in the electric power sector, thus will enhancing the role of the end user in energy conversion [7].

1.1. Purpose and Importance of the Research

It is clear that the issue of electrical energy consumption will become a preoccupation in the near future due to the limited natural resources, in addition to the population increase and its dependence on electrical energy in all industrial aspects as well as in the details of daily life.

In order to maintain the continuity of electric power generation, it is necessary to rely on new resources in power generation in addition to rationalizing consumption by users, and this is what the research focuses on by building an integrated system that contains

- Providing the ability for the user to see the amount of instantaneous consumption of electrical energy,
- Determining the amount of consumption according to the amount of money specified by the user,
- Providing the possibility to benefit from the low-price processing hours for operating electrical appliances,
- Providing the power supply company with the ability to know the users who consume a lot of energy now,
- Send alerts to the user in the event of a power outage and when the cost of consumption exceeds the user's estimated cost,
- Provide the possibility to predict the future energy consumption of the user using prediction through machine learning,
- Provide charts showing the user's monthly, daily, and hourly consumption in order for the user to be aware of his energy consumption pattern.

1.2. Literature Survey

Many researchers proposed different methods and algorithms to reduce power consumption using SM and data analyzing:

Present system contains a smart home technology with SG facility, System interfaced with cloud application is used for controlling or monitoring home appliances. I spite of the authors take into their account sent feedback to customer to warning them when the power consumption pass the limit of preen setting limit which was set by the customer but they did not tell the customer which the best time to consume the power (peak off period) [8].

In proposed algorithm in which, the device will generate the rate of units and send it to the user's smartphone along with the bill at the end of each month. The android application was connected to the same server where the SM is connected. The bill sent on a monthly basis on the user Smartphone and the user can set his limit of consumption as per his requirement. The application will be having the option of online payments via credit cards or the specific ID card. The meter will send both units and bills to the user. The user can also check the units on a daily basis. The application will also have the option to optimize the bill based on his usage. In addition, the user can control the connected appliances with the help of Smartphone. The algorithm did not ensure that the user will know the optimum time for power consumption and did not take care of reactive power consumption [9].

In present a consumption pattern-based energy theft detector (CPBETD) where the total consumption of each neighborhood is measured by transformer meters and is compared with the total amount of usage reported by the SMs. If at this level a nontechnical loss (NTL) is detected, customers in the area with abnormal patterns will be selected as suspicious users. This show the importance of using SM [10].

In the total cost of geo distributed data centers and EVs in SG was minimize by scheduling data center workloads and EV charging demands in real time without violating heterogeneous EV charging delays and peak power limits, where the cost consists of electricity bill. This work could be expanded to include the energy storage system for residential using where the system will enable the customer to charge the energy storage system at peak off period and using the stored energy or sell it at peak demand period [11].

In algorithm approach has been proposed for home automation and metering system to increase the efficiency and reliability of power consumption control and supervisory. First

all data is collected from the sensors and organized where dynamic analysis is done using Apriori algorithm. Based on the algorithm criteria, the common rules are generated to control the connected devices. The pivotal benefit of these rules is to train the system for upcoming events. An IoT embedded appliance and other electronic devices at home can be controlled from any part of the world in a reliable manner by web portal, which is designed and developed for this purpose. Consequently, the electricity consumption can be determined, and the automated billing can also be generated with the help of the web portal. In spite of that but the system did not take in its account the effect of the storage system, which it can be used to enhance the performance of the SG [12].

In a microcontroller Atmega328P based is used for detection and controlling the energy meter from power theft, when a theft is detected the service (line) of a particular consumer will be remotely disconnected. Where SMS will be sent automatically to the utility central server through GSM module whenever unauthorized activities detected and an action message will send back to the microcontroller for disconnecting the unauthorized supply. A unique method is implemented by interspersed the GSM feature into SMs with Solid-state relay to deal with the non-technical losses, billing difficulties, and voltage fluctuation complication. The authors did not discuss the database that will be used in the utility system and did not discuss the cost of GSM communications [13].

A methodology is implemented for monitoring the power quality parameters using Ethernet based smart energy meter. Energy consumption data is sent to server by the smart energy meter and stored there. Graphical programming of LabVIEW is utilized to fetch data from server and then various power quality parameters are calculated using the virtual instrumentation created. Additionally, at household level, smart energy meter identifies appliances as capacitive, inductive and resistive, where automated method is developed to schedule loads such that the reactive power is cycled within the loads. This diminishes the need for higher dependency of reactive power from utility, which improves the power factor, and defeat the usage of high cost Power Factor Correction (PFC) circuits for households. The authors did not discuss the price policy of power utility [14].

In authors proposed smart energy meter controls and calculates the energy consumption using ESP 8266 12E, a reading is uploaded to cloud server "Thingspeak". Therefore, energy analyzation is done by consumer becomes much easier and controllable. Thus, this SM helps in home automation using IoT and enabling wireless communication, which is a great step

towards Digital Word. The authors did not discuss the price policy of utility and did not discuss how generating electricity bills [15].

A prototype of electrical power SM that was designed to be included in a WM-Bus 169 MHz based AMI "Advanced Metering Infrastructure" was presented, the radio module of the SM can work as repeater thus helping network designers in optimal siting of gateways in urban areas. The authors did not discuss the electricity bill generator for customers and did not discuss power consumption analyzation for customers [16].

IoT-based SM has been developed and its performance has been explained by authors, a reading are uploaded to cloud server "Thingspeak" which is used to collect and store data in the cloud and develop further IoT applications, all readings including, voltage, current, power, energy, and power factor can be displayed in tabular form in the browser, for having a better view of the pattern of consumption and related signals, graphical representation is preferred. The authors did not the price policy of utility and did not discuss how generating electricity bills [17].

An end-to-end IoT solution (i.e., from the hardware to software development) has been we designed and implemented which is used for a smart energy monitoring system that is capable of monitoring and controlling devices in a real time. The prototype of smart sockets developed its firmware and deployed a real-time platform in order to collect and store data for research purposes has been built. However, the authors did not work on the data analyzing and power metering to generate bills for customers [18].

In the hardware was designed using a microcontroller PIC16F877, current and voltage transformer, voltage regulator 7805, solar panel, solar charge controller and inverter. The author's discus the hardware design only without consideration the data base of the utility and generating the bills [19].

Authors proposed smart energy meter with which the consumer will be notified the amount of power consumed by the end of the day depending on message send by GSM such that he can plan the consumption of power. In addition, the power consumed by the consumer will be notified to the distributor as well as consumer such that no manpower is necessary for meter reading. The system cannot depend on it if the price of the power is change with daytime [20].

Authors proposed Voltage Ampere Power Smart Meter (VAPSM), which provides utility providers an efficient way to collect data for billing and save the costs of the trips to the physical location of the meter by sending message using GSM system. The authors did not discuss the database of the utility, they did not explain how the bill would be generated, and they did not take care about hourly power consumption, which is very important to consumers as to the grid companies [21].

Authors proposed technology collects the data from meter and transfer that data to central database for storing data, analyzing and monitoring the safety related issues. Moreover, it also includes the module which has provision of on demand units loading facility from the energy provider company by just sending a request SMS. The authors did not discuss the timing of sending message to the providers and they did not take care of hourly consumption, which is very important issue to the customers as to the providers [22].

ZigBee wireless technology-based data acquisition system is designed. Starting from hardware and software, the networking and data transmission of ZigBee are introduced. Where, the data is sent to PC for data processing and storage. The authors did not discuss the pricing policy or how database will be generating the bills [23].

Authors proposed energy meter could measure the real-time consumed energy and store this data into an SD card. Different electrical parameters such as AC voltage, the current, phase angle is measured against real-time which is used for determining the consumed energy. It can be implemented in both the prepaid and postpaid billing system. A GSM modem is integrated with the system that allows the vendor to inquire about consumed energy and making digital billing without errors. The main power passes through a relay to the consumer. The vendor can cut off or on the consumer's power supply by triggering relay via SMS [24].

Authors proposes the design and fabrication of SM. The information of power consumption is send to vendor by GSM. The system offers consumer to set consumption limit with SMS alerts and turn ON/OFF the supply of electric energy. The whole consumption details of each appliance are also sent to utility with consumption date and time via SMS for billing purpose. The utility also has access to the SM for power cut off in case of bills not being paid. The author did not discuss how the database would generate bills [25].

FPGA-based smart energy meter is introduced. A power quality analyzer capable of performing remote monitoring of electric power systems operating under sinusoidal, non-

sinusoidal, balanced and/or unbalanced conditions was done by implementing the power quantities definitions of the IEEE 1459-2010 Standard. In order to ensure portability, the digital signal processing algorithms implemented on the FPGA device were entirely coded in hardware description languages, and all equations of them are fully described to be applied to any digital signal-processing environment. The authors focused on the signal processing side and they did not discuss the mechanism of generating smart bills [26].

SM depending on Power Line Carrier was introduced, as the transformer cannot transfer high-frequency signals without adding noise in the original signals and hence not useful for PLC, the proposed system was designed to collect the data of SMs using plc in low level, low voltage side, and send by local server to venders using internet, the authors did not discuss the process of generating smart bills [27].

2. ELECTROMECHANICAL ENERGY METER AND SMART METERS

2.1. Electromechanical Energy Meter Mechanism

Over a century, traditionally electricity has been measured by the use of electromechanical meters. It is capable of measuring only the active energy, which is typically displayed on a mechanical counter in kWh. Energy consumption calculation in electromechanical meter is done with the help of both mechanical and electrical circuits. It may be three or single-phase power meter. It consists of four subsystems: measurement system, moving system, breaking system, and recording system. The measurement system comprises of current and voltage system, the moving system consists of an aluminum disc, the permanent magnet acts as the braking system and the gear train and counter act as the recording system.

The current system mainly consists of current coil which is connected in series with the main circuit while pressure coil (voltage coil) connected in parallel with the main circuit to form voltage circuit. So, the electromechanical power meter work in the same way as induction motor. The fields of the meter are generated in proportion to current of the load and the voltage of the source. Both field cause disk to rotate which make pivot rotate, pivot spindle rotates recording display gear, the rotation of recording display gear is proportion to power consumption. The gear system of the recording display is consisting of several cogs that are associated with sub counters that record total consumed power. The recording display is composed of four, five, or six sub counters, each one corresponding to a digit. So, the type of electromechanical power used will depend on the utility specification. The recording display may directly express consumption, or it may be needed to multiply the values obtained from the recorder by a coefficient. To eliminates unnecessary acceleration or nonstop events associated with the disk inertia when there is increasing or cutoff in current, the magnetic brake rotor will produce an opposite force to the disk rotation that controls its speed in relation to the energy used [28]. In Figure 2.1, schematic of a single-phase electromechanical energy meter is shown. In Figure 2.2, the phasor diagram of the single-phase energy meter is given.

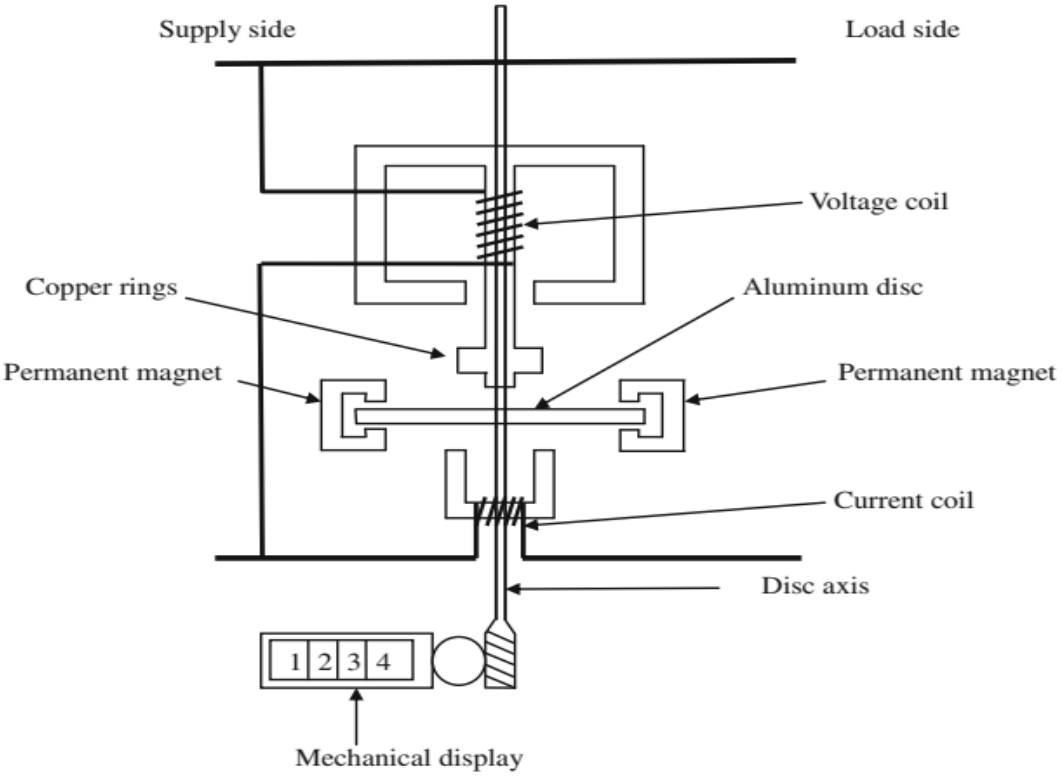

Figure 2.1. Schematic of a Single-phase Electromechanical Energy Meter

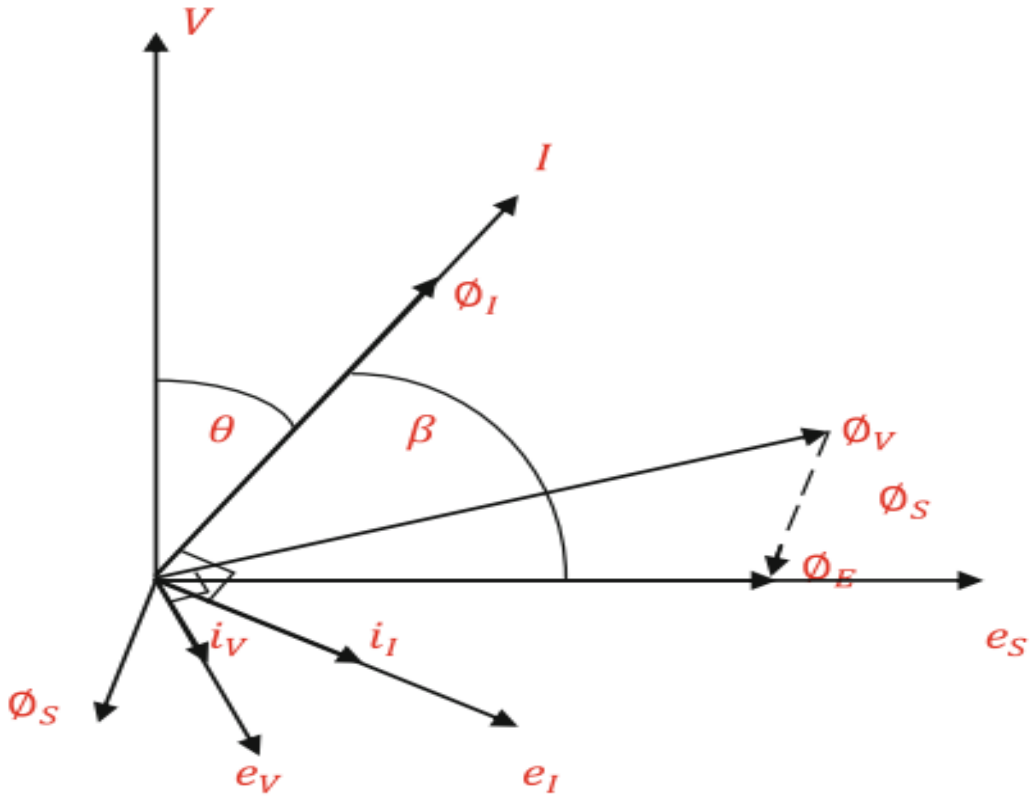

Figure 2.2. The Phasor Diagram of the Single-phase Energy Meter

where;

$\emptyset_I$ Is the flux due to current coil

$\emptyset_S$ Is the flux due to quadrature band

$\emptyset_V$ Is the flux of the voltage coil

$\emptyset_E$ Is the effective flux ($\emptyset_S + \emptyset_V$)

e_s Is the induced e.m.f. due to $\emptyset_E$

e_I Is the induced e.m.f. due to $\emptyset_I$

$\dot{I}_v$ Is the current in the rotor due to e_v

i_I Is the current in the rotor due to e_I (neglecting the rotor resistance)

I Is the current through the series coil

V Is the supply voltage

θ Is the phase angle between the current and the voltage (load connected to meter).

The energy calculation inside an electromechanical energy meter is described as follows. The average driving torque acting upon the disc can be written as

$$T_{d(av)} = k_d\,[\,\emptyset_E\; i_I \cos(\theta) - \emptyset_I\, i_V \cos(180 - \theta)] \tag{2.1}$$

Where;

$T_{d(av)}$ is referred to average driving torque,

k_d is a constant for the meter,

Since

$$\emptyset_E \;\propto \frac{V}{\omega} \rightarrow \emptyset_E \;=\; k_1 \frac{V}{\omega} \tag{2.2}$$

$$\emptyset_I \;\propto I \rightarrow \emptyset_I \;=\; k_2 I \tag{2.3}$$

$$\emptyset_I \propto I \rightarrow \emptyset_I = k_2 I \tag{2.4}$$

$$i_V = k_1 \frac{V}{Z} \tag{2.5}$$

where; Z is the eddy current path impedance (the phase angle is assumed to be zero), k_1 and k_2 are constants, x is the angular frequency. Substituting terms in (2.1), using Equations (2.2) – (2.5)

$$T_{d(av)} = k_d \left[k_1 \frac{V}{\omega}\, k_2 \frac{I\omega}{Z} \cos(\theta) - k_2 I k_1 \frac{V}{Z} \cos(180 - \theta) \right] \tag{2.6}$$

$$T_{d(av)} = \frac{k_d\ k_1 k_2}{Z} [VI.\cos(\theta) + VI.\cos(\theta)]$$

$$T_{d(av)} = \frac{2\ k_d\ k_1 k_2}{Z} [VI.\cos(\theta)]$$

$$T_{d(av)} = \acute{k}\ P \tag{2.7}$$

where $\acute{k} = \frac{2\ k_d\ k_1 k_2}{Z}$ and P is the active power

From (2.7) we can see that the driving torque is directly proportional to the active power. The breaking torque is produced by two permanent magnets mounted in opposite directions.

$$T_{d(av)} = k_b\ \emptyset_b\ i_b \tag{2.8}$$

$$T_{d(av)} = k_b\ \emptyset_b\ \frac{e_b}{R_e}$$

$$T_{b(av)} = k_b\ \emptyset_b\ \frac{N\emptyset_b}{R_e} \tag{2.9}$$

$T_{b(av)}$ is referred to the average breaking torque

i_b is the eddy current due to $\emptyset_b$

e_b Is the induced e.m.f. due $\emptyset_b$

k_b Is a constant of proportionality,

$\emptyset_b$ Is the flux produced by permanent magnets,

N Is the rotational speed of the aluminum disc and

R_e Is the resistant of the eddy current path.

At steady state,

$$T_{b(av)} = T_{a(av)} \tag{2.10}$$

Therefore, using Equation (2.7) and Equation (2.9);

$$k' P = k_b \frac{(\emptyset_b)^2}{R_e} N$$

$$P = \frac{k_b (\emptyset_b)^2}{k' R_e} N \tag{2.11}$$

From Equation (2.11), we can clearly see that the active power is proportional to the rotational speed of the disc.

The disk axis will transmit the disc rotation to a mechanical counter. This system continuously accumulates the disc displacement with the time. Therefore,

$$\alpha = \int N \, dt \tag{2.12}$$

$$E = \int P \, dt \tag{2.13}$$

where;

α is the disc displacement

E is the active energy and

t is the time

Using Equations (2.11)–(2.13)

$$E = \int \frac{k_b (\emptyset_b)^2}{k' R_e} N \, dt \tag{2.14}$$

$$E = \frac{k_b \ (\emptyset_b)^2}{k\acute{}R_e} \int N \, dt$$

$$E = \frac{k_b \ (\emptyset_b)^2}{k\acute{}R_e} \ \alpha \qquad (2.15)$$

According to Equation (2.15), the displacement is proportional to the active energy. Therefore, the counting system can be calibrated accordingly with the active energy to display the energy consumed.

2.2. Electromechanical Energy Meters Demerit

Electromechanical meter suffers from many drawbacks, which are as follow;

1. Electromechanical meters have many susceptible errors; some of the common causes of errors are listed below.
    - Dirt (on the disk and the air gap)
    - External magnetic fields
    - Broken jewels
    - Dirty and improperly adjusted bearings
    - Vibration
    - Creep (which mean disk of a meter may move, either forward or backward, when all loads are disconnected)
2. Overload or internal short circuit
3. Presence of harmonics will make recording watt-hours incorrectly. Error caused by the quality of the power being supplied and load power factor.
4. Power theft cannot be detected directly with these meters**.**

2.3. Electronic Meters

Electronic meters are capable of measuring electric power consumption with other electric parameter such as phase currents, phase voltages, power factor, frequency active power, reactive power, apparent power, maximum demand, and power quality measurements using digital technology. They have also the capability of sending the measured data through a communication link.

2.3.1. Construction of Digital Meter

The main part of the electronic electricity meter in Figure 2.3 is the measuring transducer that converts the measured power to standardized voltage or current. The converter consists of transformers (1,2) that convert the currents and voltage to the values suitable for multiplier, analogue multiplier (3), and low pass filter (4) that separates the DC output voltage component proportional to the active power of load. After amplification (5), the output voltage is converted into frequency -pulses (6). This procedure is managed by a special controller unit (7). The number of pulses over time is proportional to the energy ***W=Pt***. The impulses are brought to the counter (8) and the output contacts (9).

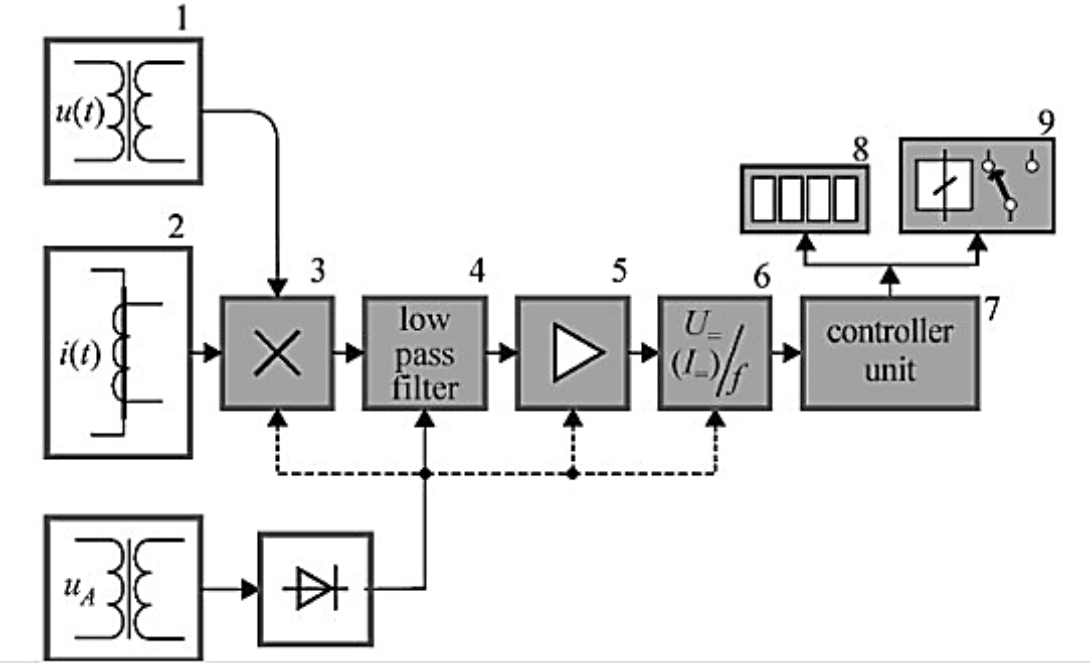

Figure 2.3. Principal Circuit of Electronic Meter

2.3.2. Advantages of Electronic meter:

1. They have small error limits below 0.1%.
2. Lower consumption, less dependency on changes in voltage and frequency, and insensitivity to the position of the installation.
3. They can store data, and support various automatic meter reading and SG technologies, which is good feature when reading many meters in one large building is required [29].

2.4. Prepaid Meter

A consumer's outlay for using a commodity or service before consumption is referred to as a prepayment system. In the case of electricity, the prepayment system is a reversion of the traditional commercialization system: whereas in the latter, consumers have a consumption credit because they pay their energy bills on a regular basis and after consumption, such credit is not available in the prepayment system because energy is purchased and paid for before consumption. Prepaid systems, on the other hand, allow customers to consume energy only while they have credit in their power account, as supply is cut off once that credit is depleted.

Figure 2.4. Prepaid Counter

2.5. Smart Meter (SM)

A SM is an solid state electronic device that incorporates technologies of communication directed to the execution of tasks remotely, enabling the exchange of information between consumers and utility, and the interaction with other devices involved in SG environments. Besides that, a SM must use methodologies and algorithms that allow carrying out power quality analyses with the ability to differentiate the effects due to the service provided quality and the installed loads' behavior in the system [30].

2.5.1. Architecture of SMs

In fact, SMs can read real-time energy consumption data from customers, such as voltage, frequency, and phase angle values, and securely transmit the data to control centers. SMs can collect information about the electricity consumption values of customer premises

utilizing bidirectional data transmission. SMs capture data using a mix of parameters including a unique meter identifier, data timestamp, and electricity consumption figures. SMs can monitor and operate all home devices and appliances at the customer's premises remotely as well as locally based on the information. SMs can also communicate with other meters within their range via the home area network (HAN) to collect diagnostic data on appliances at the customer's location as well as the distribution grid. Furthermore, SMs can be designed to bill just power consumed from the utility grid, ignoring power consumed from distributed generation sources or storage devices owned by customers. As a result, they can set maximum electricity consumption limits and remotely disconnect or restore power to any consumer, A SM architectural model is shown in the Figure 2.5.

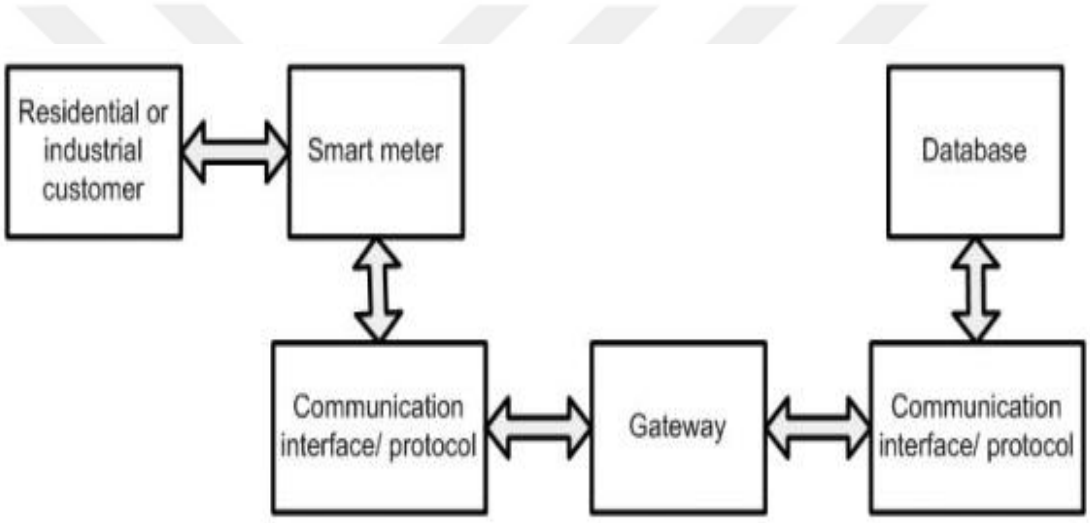

Figure 2.5. Architectural Model of SM.

The greatest benefit of using SM is the ability of using Dynamic Pricing. As observed, the customers increase its energy consumption when power price cheap and reduce it when power price is expensive [31]. Utilities offer fixed price or dynamic price. In fixed price case the power price doesn’t take care to the demand, while in the second, while in the second, the per unit rate of electricity will be depend on power demand where the price will increase when the demand is low and increase when the demand reach to high levels. However, the operating costs of generation for peak demands are higher than costs of generation to meet off-peak demand, since most peak time generating units have higher operating costs than base load units. Thus, the abovementioned electricity prices do not reflect the true costs of generation and distribution. Dynamic pricing can offer better results than flat pricing, where the price will increase as the demand be close to peak limit of generation, this will make

customers reduce their consumption at peak periods [32]. Advanced metering infrastructure, which collects and analyzes data from SMs and provides intelligent management of various power-related applications and services based on that data, is one of the fundamental components to putting this notion into action.

2.6. Advanced Metering Infrastructure (AMI)

Is multi technologies configured to achieve its goals. AMI includes SMs, communication networks in different levels of the infrastructure hierarchy, Meter Data Management Systems (MDMS), and means to integrate the collected data into software application platforms and interfaces. The customer is used advanced solid-state electronic power meter that collects time-based data. These meters can transmit the collected data to AMI host system via commonly available fixed networks, such as Broadband over Power Line (BPL), Power Line Communications, Fixed Radio Frequency, as well as public networks such as landline, cellular and paging [31]. In Figure 2.6, overview of AMI is given.

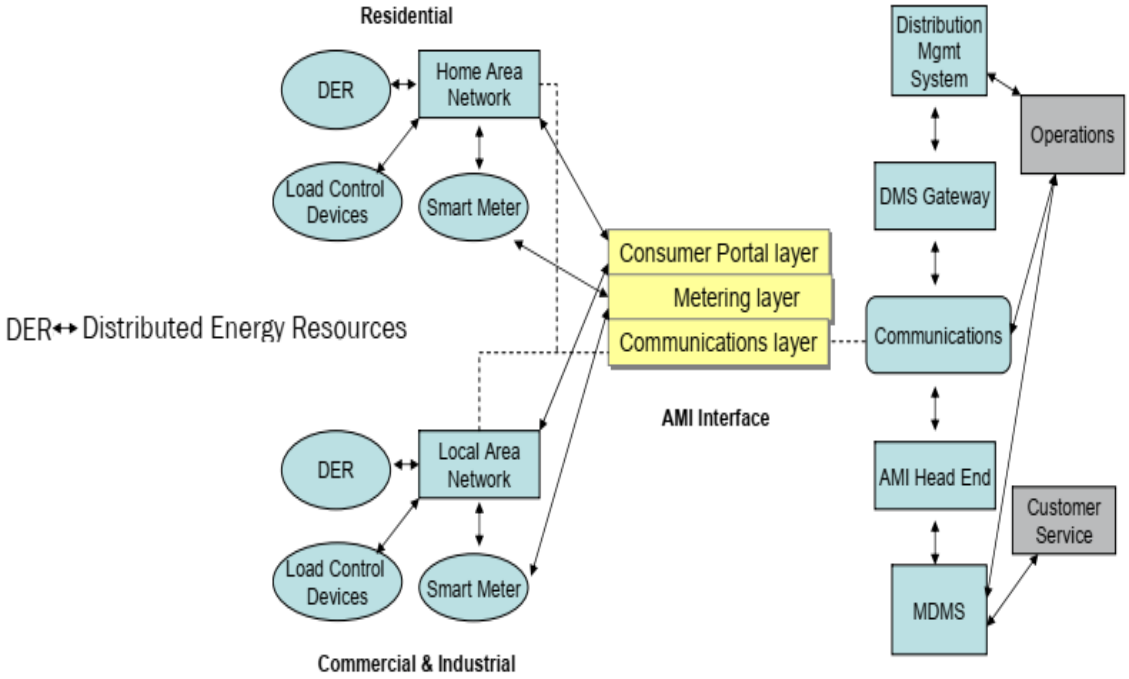

Figure 2.6. Overview of AMI

2.6.1. Database in AMI

The use of SMs will lead to the production of a huge amount of data, which will lead to the emergence of a problem in the storage, transfer, and management of data efficiently, so it is necessary to use a database to support all user requirements in addition to simplicity,

durability, flexibility, scalability, and performance, in addition to processing and analyzing requests, collecting, storing, and processing data, and creating report [33].
A database can be defined as a set of organized data. The system that manages this data, transactions, problems, or any aspect of the database is a database management system (DBMS), which uses the Structured Query Language (SQL). Data is stored in rows and columns in a tabular form such as MYSQL, SQL SERVER, and ORACLE.

A new type of modern database is NoSQL databases: NoSQL follows a non-relational data model. The non-relational model supports schema-free storage of data in various forms, such as documents and graphs [34].

2.7. Real-time Data

Real-time data is data that is available once it is generated and collected. They are paid to users as soon as they are collected, making them immediately available immediately, which is important for real-time decision support. This data runs in nearly every life, from banking to GPS to the many COVID19 maps that took place during the pandemic.

The real-time data is of particular value to the enterprise. Companies have focused on accelerating this process as it has become easier to collect large amounts of big data and extract insights from datasets. Enterprises use enterprise-wide real-time data to improve customer service, manage products, and streamline operations. However, one of the most valuable uses of real-time data is to help monitor and maintain IT infrastructure. Real-time data gives organizations greater visibility and insight into how complex networks work. [35].

2.7.1. Advantages that Real-time Streaming

- **Real-time KPI Visualization-** CEOs are faced with a sense of need for flexibility in decision-making, with the huge amount of data made up by sales channels has become more complex and data-driven decision-making so companies need to monitor their KPI (Key Performance Indicators) On the basis of real time to know the performance of the business and the immediate status of things.
- **Enhanced Market Competency-** Because of real-time KPI visualization, the decisions formed are more cost-effective and successful, and this helps the organization improve its position in the market and helps increase growth, business managers can rely on real-time data to gain insight into the growth of the business and this helps the organizations to maintain competitive advantages in the market.

- **Accurate Customer Profiling-** Customers today have changing spending habits. These habits are not only dependent on prices, but also on many other factors. Real-time data helps organizations to know the factors that prompted customers to make purchases at a certain time more than at another time, which helps to know the characteristics of customers accurately and target pricing for products.
- **Speed and response time-** The most obvious advantage of real-time data is the short response time. Changes happen constantly, and unexpected changes can have a multiplier effect in markets where changes occur within seconds, such as aircraft movements and stock markets [36].

2.7.2. Real Time Techniques

1. **Firebase**

   Firebase is a backend platform for building web, Android, and iOS applications. It provides a real-time database, various APIs, multiple authentication types, a caching platform and more. Firebase allows developers to focus on creating great user experiences. Users do not need to manage the server. A user does not need to write any API [37] .

2. **Pusher**

   A Pusher is a real-time layer between the server and client. The Pusher maintains persistent connections to the client over Web Socket where possible and reverts to a connection based on HTTP when necessary [38] .

3. **SignalR**

   SignalR is an open source library released by Microsoft in 2013 for ASP.NET and rewritten in 2018 for ASP.NET Core. SignalR provides real-time functionality in applications and where the latest information is always wanted without having to poll the server for updates; the server side can instantly send content and data to different clients. SignalR supports "server push" functionality, where the server code can call client code in the browser using a remote procedure call (RPC), instead of the request-response pattern common on the web today [39] .

4. **OneSignal**

   The customer engagement platform is used by over 1 million developers and marketers and is the fastest and most reliable way to send mobile and web push notifications, in-app messages, email and SMS [40] .

The use of the system for relatively long periods of time will lead to the provision of special data for each user that reflects his energy consumption pattern, and for the purpose of making the most of the data, machine learning is used to predict the user's consumption based on the data collected.

2.8. Machine Learning

Over the past years, machine learning has become one of the main pillars in information technology, and due to the increasing amounts of data, there is a belief that intelligent data analysis will become more prevalent as a necessary part of technological progress. Machine learning (ML) can be defined as the process of using a mathematical model of data to allow a computer to learn without direct instruction. It is considered a subset of artificial intelligence (AI). Machine learning uses algorithms to identify patterns in data and use those patterns to build data models that can make predictions. The more data and experience, the more accurate machine learning results will be. This is very similar to how humans improve with more practice.

The adaptability of machine learning makes it suitable for selection in scenarios where the data is constantly changing, the nature of the query or task is constantly changing, or the coding of the solution is virtually impossible [41].

2.8.1. Types of Machine Learning

As with any method, there are different ways to train machine-learning algorithms. Each has drawbacks and advantages. To understand the pros and cons of each type of machine learning, we must first note the type of data. There are two types of data.

- Labeled data
- Unlabeled data

Labeled data contains input and output parameters in a fully machine-readable format, but requires a lot of human labor to label the data to begin with. Unclassified data contains one or no parameters in a machine-readable form. This negates the need for human intervention but requires solutions that are more complex.

There are types of machine learning algorithms that are used in very specific cases, but today three main methods are used [42].

2.8.2. Supervised Learning

Supervised learning is one of the most basic types of machine learning. In this type, the algorithm is trained on classified data. Supervised learning is extremely powerful when used in the right conditions.

The ML algorithm is given a training dataset to work with. This data provides the algorithm with a basic idea of the problem, the solution, and the data points that must be dealt with. Then the algorithm finds the relationships between the parameters provided and the cause and effect relationship between the variables in the data set. Finally, the algorithm has an idea of how the data and the relationship work between input and output. After that, the solution is deployed for use with the final data set in the same way as the training set is learned from. This means that the supervised machine-learning algorithm will continue to improve and discover new relationships and patterns as it is trained on the new data, which can be broadly divided into two main categories as in Figure 2.7.

- **Classification**: It is the process of classifying a specific set of data into categories, and it can be performed on both structured and unstructured data. For example, “dog” or “cat”.
- **Regression**: A target prediction value based on independent variables is mostly used to discover the relationship between variables and prediction. For example, “price”, “geographical location” [43].

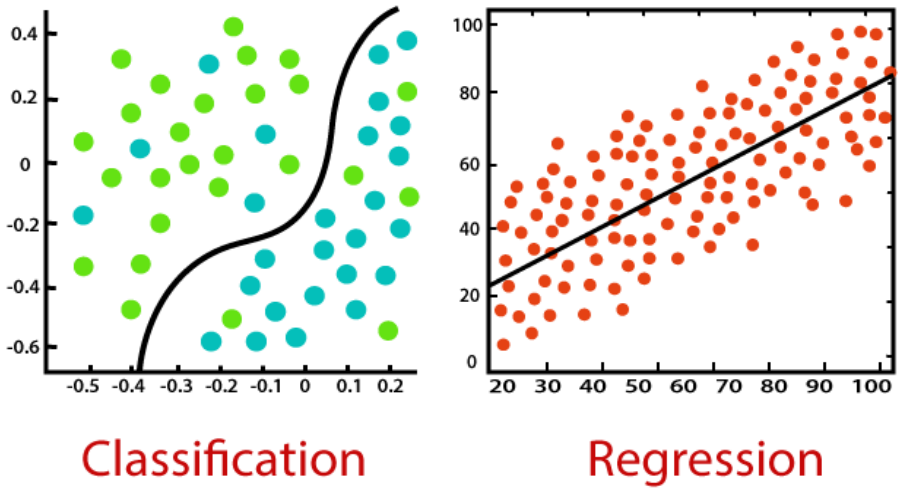

Figure 2.7. Supervised Learning [44]

2.8.3. Unsupervised Learning

Unsupervised machine learning has the advantage of being able to work with unlabeled data and find hidden patterns from a given dataset. This means that no human factor is required to make the data readable, allowing much larger datasets to be used. Unsupervised learning algorithms can adapt to data by changing hidden structures dynamically, much like the human brain when it learns new things. The unsupervised learning algorithm in Figure 2.8 can be further categorized into two types of problems:

- **Clustering**: Clustering may be a strategy of gathering the objects into clusters such that objects with most similitudes remains into a bunch and has less or no likenesses with the objects of another gather. Cluster investigation finds the commonalities between the information objects and categorizes them as per the nearness and nonattendance of those commonalities.
- **Association**: An association run the show is an unsupervised learning strategy, which is utilized for finding the connections between factors within the huge database. It decides the set of items that happens together within the dataset. Affiliation run the show makes promoting procedure more viable. Such as individuals who purchase X thing (assume a bread) are too tend to buy Y (Butter/Jam) thing [44].

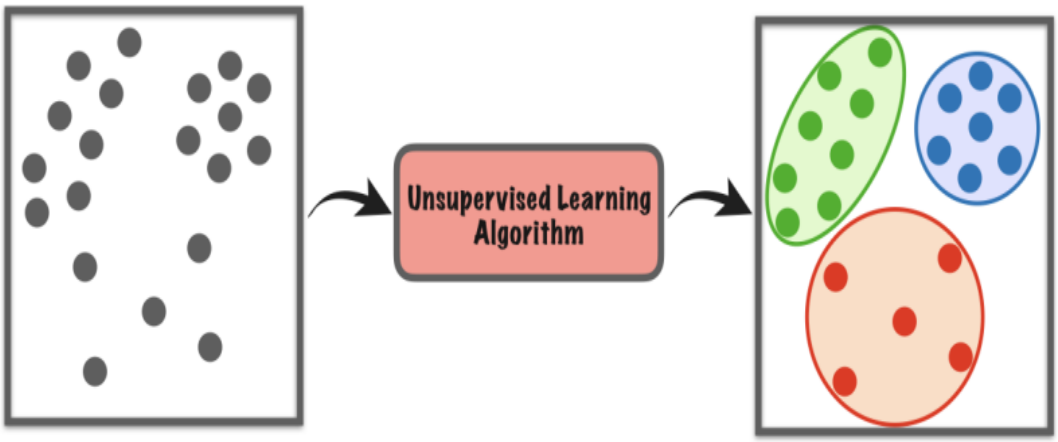

Figure 2.8. Unsupervised Learning [45]

2.8.4. Reinforcement Learning

In this type of learning, the machine's algorithm interacts with the surrounding environment and detects errors on its own, as this method is based on the idea of reward and punishment as given in Figure 2.9. Where the algorithms learn by negative and positive interaction with which reaction the machine should take in a given situation, the machine takes steps and executes them, and through the reaction coming from the surrounding environment, it can determine whether it is wrong or right, and develop itself. There are mainly two types of reinforcement learning.

- **Positive Reinforcement:** Positive reinforcement learning means adding something to increase the tendency for the expected behavior of the algorithm to occur again. It increases the strength of the behavior and positively affects the behavior of the agent.

  This type of reinforcement can sustain changes for a long time, but excessive positive reinforcement may increase the burden on states that can reduce the consequences.
- **Negative Reinforcement:** The negative reinforcement learning is opposite to the positive reinforcement as it increases the tendency that the specific behavior will occur again by avoiding the negative condition. It can be more effective than the positive reinforcement depending on situation and behavior, but it provides reinforcement only to meet minimum behavior [44].

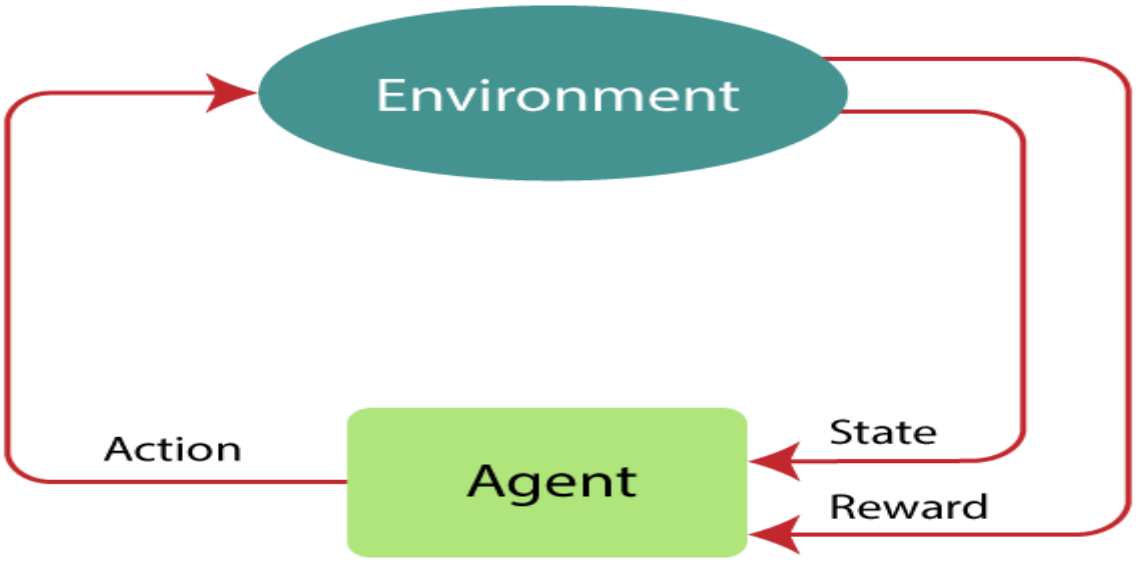

Figure 2.9. Reinforcement learning [46]

3. MATERIAL AND METHOD

The block diagram of a smart energy meter system is shown as shown in Figure 3.1 whose hardware and software architecture includes devices consisting of a SM, a SQL Server database, and an API. The SM will measure the instant and gained energy consumed for a specified period (Tminute) and send the information online to the SqlServer database. SqlServer will be used to store and analyze the received information, calculate the generated amount of consumption per hour, day, and month, and generate an electricity bill.

Consumption information is sent to the customer's mobile phone or website via an application programming interface (API). The data is sent in real time without any delay. The data generated for each user is used to predict future consumption by knowing the user's consumption pattern by means of a machine learning (ML) algorithm. The details of the proposed system are explained as follows:

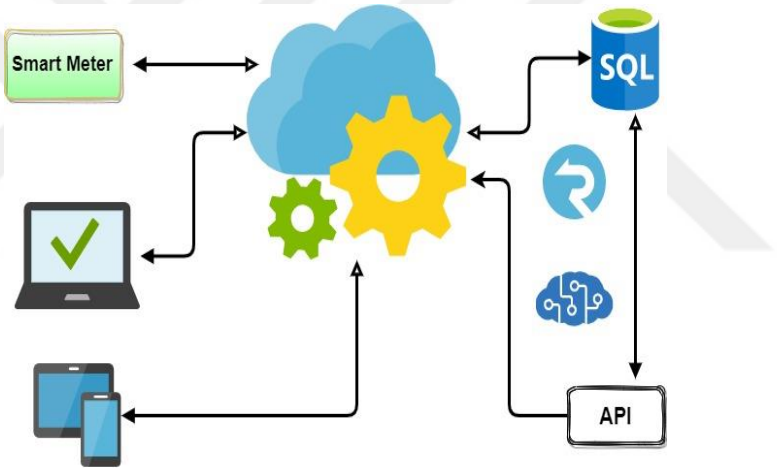

Figure 3.1. Proposed Smart Energy Meter System Architecture

3.1. Smart energy meter

The designed energy meter is illustrated in Figure 3.2 and the prototype is illustrated in Figures 3.3 and 3.4 where two prototypes were made, respectively.

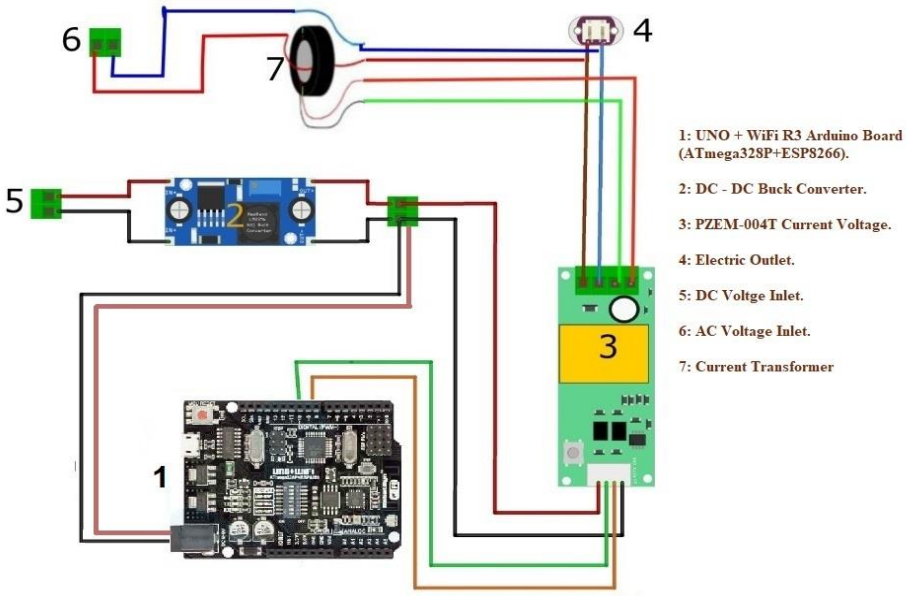

Figure 3.2. Smart Energy Meter Design

3.1.1. Microcontroller

An embedded system's microcontroller is a small integrated circuit that controls a single process. On a single chip, a typical microcontroller houses a CPU, memory, and input/output (I/O) peripherals.

Microcontrollers, also known as embedded controllers or microcontroller units (MCU), can be found in a variety of devices, including vending machines, robotics, office equipment, medical devices, and office machines. They are essentially straightforward mini-personal computers (PCs) built without a sophisticated front-end operating system to control specific details of a bigger component (OS).

To control a single device function, a microcontroller is integrated into a system. It accomplishes this by utilizing its core CPU to evaluate data that it receives from its I/O peripherals. The microcontroller receives temporary data that is stored in its data memory, where the processor accesses it and employs program memory instructions to interpret and apply the incoming data. It then communicates and takes the necessary action using its I/O peripherals. Numerous gadgets and systems make use of microcontrollers. Devices frequently employ a number of microcontrollers, which cooperate to carry out the device's many functions.

A microcontroller is a programmable integrated circuit capable of executing the orders recorded in its memory. A microcontroller has inside it three main functional units: a central

processing unit, memory, and input and output peripherals. The microcontrollers are different from the processors because, besides the logical components and usual arithmetic of a general-purpose microprocessor, the microcontroller integrates additional elements into its internal structure, such as memory read and write for data storage, read-only memory for storage of programs, EEPROMs for permanent data storage, peripheral devices such as analog/digital converters (ADC), digital-to-analog (DAC) converters in some cases, and data input and output interfaces. They are generally used in automation and control of products and peripherals, such as automotive engine control systems, remote controls, office and residential machines, toys, supervisory systems, etc. Microcontrollers are an efficient alternative for controlling many processes and applications because they reduce the size, cost, and energy consumption when compared to the way conventional microprocessors are used, as well as the ease of application design and low price [47].

The main microcontroller board of our system is the Arduino Uno Wi-Fi R3 (ATmega328P+ESP8266). It receives the current, voltage, and consumed power from the measurement unit system (PZEM-004T), does the required calculations, and the useful results of the calculations are sent to the SQL Server database using the Wi-Fi Shield (ESP8266).

3.1.2. Arduino Microcontroller Board

Arduino is a very widely used platform for building projects. The reasons for this are hardware that can be plugged into the main panel, code libraries, and information found in books, tutorials, videos, DIY projects, and the e-community. The main feature that makes the Arduino platform accessible to everyone is that Arduino's developers have decided to hide most microcontroller technical details behind library functions and expansion boards. These functions and boards take care of all the implementation and configuration details needed to run a sketch (application program) on the microcontroller and translate these tasks into simple program commands.

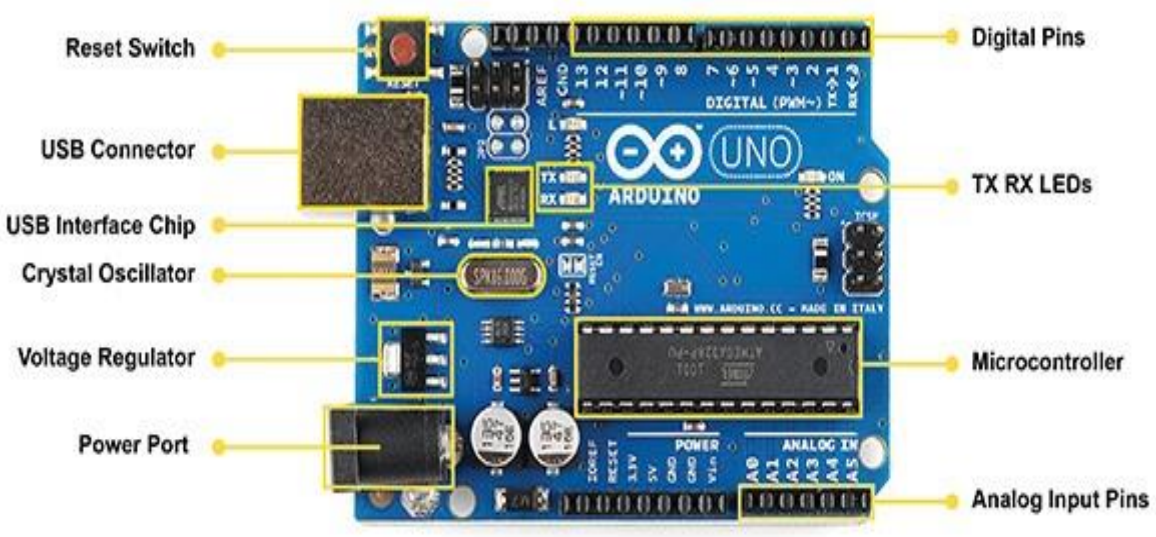

Figure 3.3. Components of Arduino UNO Board

3.1.2.1 Arduino Board Components

Arduino board components are shown in Figure 3.3 which are consist of:

- USB connector
- Power port
- Microcontroller
- Analog input pins
- Digital pins
- Reset switch
- Crystal oscillator
- USB interface chip
- TX RX LEDs

USB connector:

This is a printer USB port used to load a program from the Arduino IDE onto the Arduino board. The board can also be powered through this port.

Power port:

The Arduino board can be powered by an AC-to-DC adapter or a battery. The power source can be connected by plugging a 2.1mm center-positive plug into the power jack of the board. The Arduino UNO board operates at a voltage of 5 volts, but it can withstand a maximum

voltage of 20 volts. If the board is supplied with a higher voltage, a voltage regulator (it sits between the power port and the USB connector) protects the board from burning out.

Microcontroller:

It is the most prominent black rectangular chip with 28 pins. Think of it as the brains of the Arduino board. The microcontroller used on the UNO board is the Atmega328P by Atmel (a major microcontroller manufacturer). The Atmega328P contains the following components:

- **Flash memory** of 32KB. The program loaded from the Arduino IDE is stored here.
- **RAM** of 2KB. This is the runtime memory.
- **CPU**: controls everything that goes on within the device. It fetches the program instructions from flash memory and runs them with the help of RAM.
- **Electrically Erasable Programmable 1 KB of Read-Only Memory (EEPROM)**: This is a type of nonvolatile memory, and it keeps the data even after the device restarts and resets.

The Atmega328P is pre-programmed with a bootloader. This allows the user to directly upload a new Arduino program into the device without using any external hardware programmer, making the Arduino UNO board easy to use.

Analog input pins:

The Arduino UNO board has 6 analog input pins, labeled "Analog 0 to 5." These pins can read the signal from an analog sensor like a temperature sensor and convert it into a digital value so that the system understands it. These pins just measure voltage and not current because they have very high internal resistance. Hence, only a small amount of current flows through these pins.

Although these pins are labeled analog and are analog inputs by default, they can also be used for digital input or output.

Digital pins:

These pins are labeled "Digital 0 to 13." These pins can be used as either input or output pins. When used as an output, these pins act as a power supply source for the components connected to them. When used as input pins, they read the signals from the components connected to them. When digital pins are used as output pins, they supply 40 milliamps of current at 5 volts, which is more than enough to light an LED.

Some of the digital pins are labeled with a tilde (~) symbol next to the pin numbers (pin numbers 3, 5, 6, 9, 10, and 11). These pins act as normal digital pins but can also be used for Pulse-Width Modulation (PWM), which simulates analog output like fading an LED in and out.

Reset switch:

When this switch is clicked, it sends a logical pulse to the reset pin of the microcontroller, which now runs the program again from the start. This can be very useful if the code does not repeat but the user wants to test it multiple times.

Crystal oscillator:

This is a quartz crystal oscillator, which ticks 16 million times a second. On each tick, the microcontroller performs one operation, for example, addition, subtraction, etc.

USB interface chip:

Think of this as a signal translator. It converts signals in the USB level to a level that an Arduino UNO board understands.

TX – RX LEDs:

TX stands for transmit, and RX for receive. These are indicator LEDs that blink whenever the UNO board is transmitting or receiving data.

3.1.3. Arduino Ethernet Shield

Arduino board can connect to the internet by Arduino Ethernet Shield as shown in Figure 3.4. Arduino Ethernet Shield is based on W5100 Ethernet chip, this chip provides network (IP) enabled on both TCP and UDP. It supports four simultaneous sockets, uses the ethernet library to write a sketch that connects to the internet through the shield. The ethernet shield is connected to the Arduino board via a long wire wrap header.

Figure 3.4. Arduino Ethernet Shield

Use the Ethernet library to write a sketch that connects to the internet through the shield. Ethernet shield connected to Arduino board with long wire wrap headers. Extends through the shield. This keeps the pinout the same and allows another shield to be stacked on top. The shield provides standard RJ45 Ethernet jacks. The reset button on the shield resets the W5100 and the Arduino board. The logo contains a number of information LEDs: [48]

- PWR: The board and shield are powered, as indicated.
- LINK: flashes when the shield sends or receives data, indicating the existence of a network link.
- FULLD: denotes a full-duplex network connection A 100 Mb/s network connection (as opposed to a 10 Mb/s connection) is indicated by the prefix 100M.
- RX: when the shield gets data, it flashes.
- TX: flashes when the shield sends data
- COLL: flashes when network collisions are detected.

The Arduino Ethernet Shield enables users to connect Arduino to the internet quickly and easily. This shield allows the user to send and receive data from its Arduino from anywhere on the globe that has an internet connection. In our system, it sends data to the SQL Server database**.**

3.1.4. Communication between Sensors and the Arduino

To make the transfer of digital data between microcontrollers and sensors like the Arduino simple, the SPI (Serial Peripheral Interface) and the I2C (Inter-Integrated Circuit) standards were developed. It is simple to use both the I2C and SPI protocols thanks to the Arduino libraries.

The devices that want to connect typically make the decision between SPI and I2C. A device or chip typically supports either one or the other standard, while some devices offer compatibility for both.

I2C has the benefit of requiring just two signal connections to connect to Arduino, making it simple to use multiple devices on those two connections and to receive confirmation that signals have been appropriately received. The drawbacks include a slower data rate than SPI and the limitation to one-way data flow, which further reduces the data rate when two-way communication is required. To ensure reliable signal transmission, pull-up resistors must also be connected to the connections.

The benefits of SPI include its greater data rate and independent input and output connections, which enable simultaneous sending and receiving. If there are multiple devices to be linked, more connections are needed because it takes one extra line per device to pick the active device.

The majority of Arduino projects use a single SPI device for high data rate applications like Ethernet and memory cards. I2C is more frequently utilized with sensors that do not require much data to be sent [47].

3.1.4.1. I2C (Inter-Integrated Circuit)

Philips Semiconductor invented the I2C communication standard in 1982, and since 2006, programmers and embedded engineers have been able to use it without having to pay any license fees.

I2C is a two-wire communication protocol that is frequently used in embedded systems to link low-speed peripherals like A/D, EEPROMs and D/A converters, I/O interfaces, and microcontrollers. The clock signal is transmitted over one of these wires, designated SCL (Serial Clock), while data transmission between slave and master devices on the bus is permitted over the other wire, designated SDA (Serial Data). The I2C protocol enables the connection of multiple slave devices to a single master device or the control of one or more slave devices by several masters [47][49].

3.1.4.2. SPI (Serial Peripheral Interface)

Early SPI microcontrollers were based on the Motorola 68000 microprocessor, which was widely used in early Macintosh computers, arcade games like the Atari ST, and laser printers. Motorola created the SPI protocol in the middle of the 1980s.

A/D and D/A converters, temperature and pressure sensors, memory devices, LCDs, and other devices can all be connected to microcontrollers using the four-wire SPI communication protocol. A highly natural strategy for facilitating data transport over the serial bus is the four-wire setup. There are four wires, and each one corresponds to a different logic signal.

The SPI protocol was created to enable quick initialization of peripheral devices on the same integrated circuit as the microcontroller. Generally, projects where speed is more important than lowering production costs and when using additional wires needed to support SPI communication are best suited for the SPI protocol [47][49].

3.1.5. PZEM-004T Current Voltage

In Figure 3.5. PZEM-004T Current Voltage card is seen. That electronic module measures all the voltage, power, current, energy, frequency, and power factors. It is used in our system as a measuring power source for electrical consumption [50].

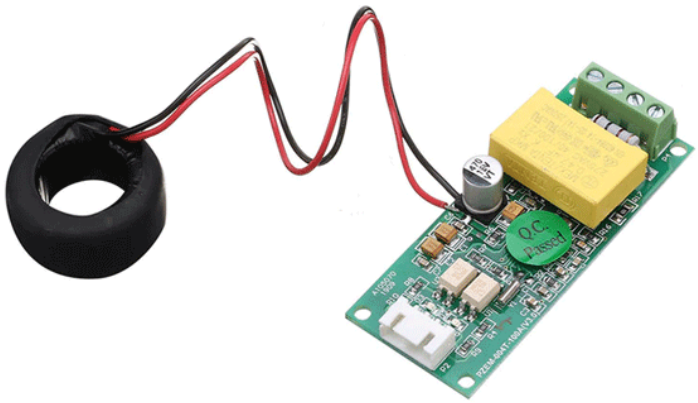

Figure 3.5. PZEM-004T Current Voltage

3.1.6. DC-DC Buck Converter

DC-DC Buck Converter in Figure 3.6. is used to reduce the DC voltage source from greater than 5V to 5V, which is the required voltage to run Arduino and PZEM-004T.

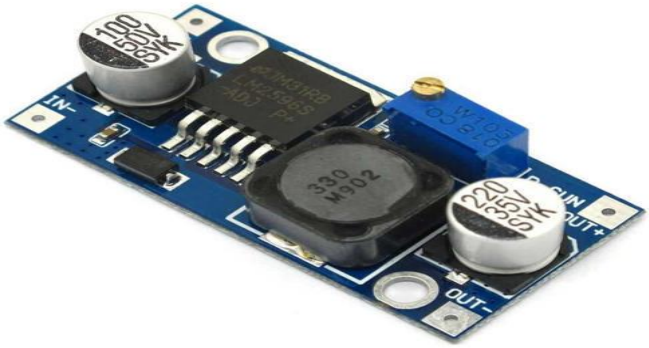

Figure 3.6. DC-DC Buck Converter

3.1.7. Electric Output

It used to connect AC electric source to loads.

3.1.8. DC Voltage Input

It used to connect DC voltage source in our system.

3.1.9. AC Voltage Input

It used to connect AC electric source to measurement system.

3.1.10. Current Transformer

It is a kind of transformer used to increase or decrease alternating current (AC). It generates a secondary current that is inversely proportional to the primary current. A current transformer is utilized with PZEM-004T for high current loads.

The consumed power is measured using PZEM-004t modules as electrical sensors to measure the voltage and current and using the sensed values to calculate power and energy. The modules gave measured results in digital codes having a resolution of three digits via a universal asynchronous receiver/transmitter (UART) interface. The measured results were the values of voltage, current, power, and energy having the units of volts, amperes, watts, and kilowatt-hours, respectively [51]. The instantaneous data is received by Arduino and accumulated for a specified time, and then is sent by ethernet shield to SQL Server via the internet. The size of received data in SQL Server decreases as the amount accumulated grows. The DC buck converter is used to step down the DC voltage to 5 volts; the 5V will

be used to run the Arduino and PZEM-004T. Two prototypes of Smart Energy Meter are shown in Figures 3.7 and 3.8, respectively.

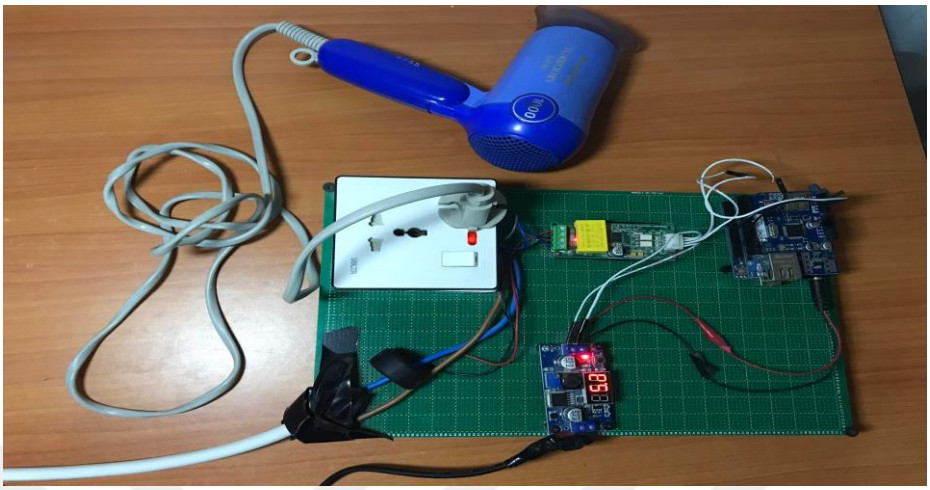

Figure 3.7. Smart Energy Meter Prototype 1.

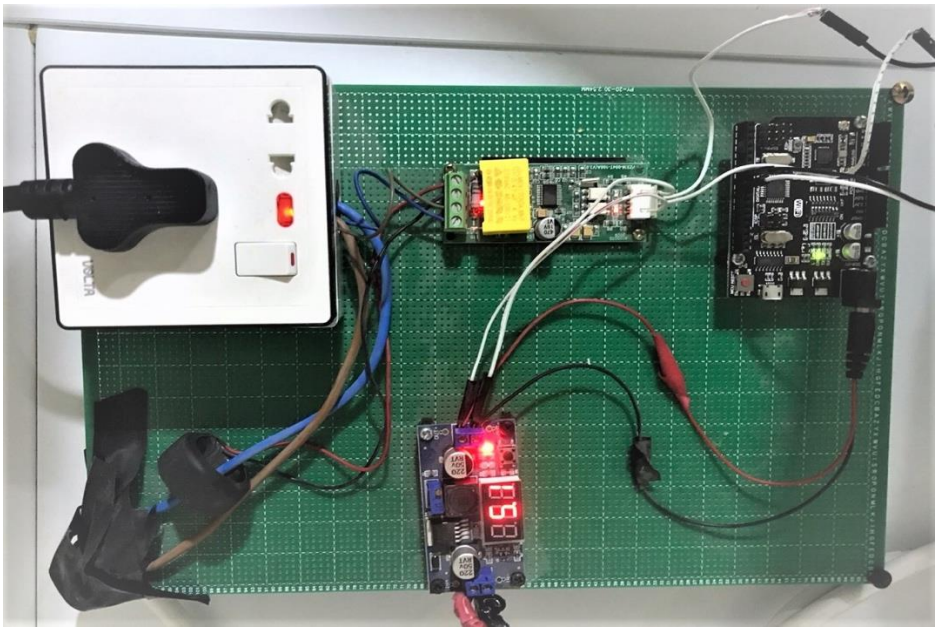

Figure 3.8. Smart Energy Meter Prototype 2.

3.2. SQL Server Database

SQL Server is a relational database management system (RDBMS) built and marketed by Microsoft as a database server. The primary function of SQL Server is to store and retrieve data used by other applications. It works exclusively on the Windows environment for more than 20 years, and in 2016, a version was built that runs on Linux [52]

The Arduino project is connected to the SQL Server via an API that sends the data received from the Arduino to the SQL Server database. The flowchart of the SQL server flag is shown in Figure 3.9.

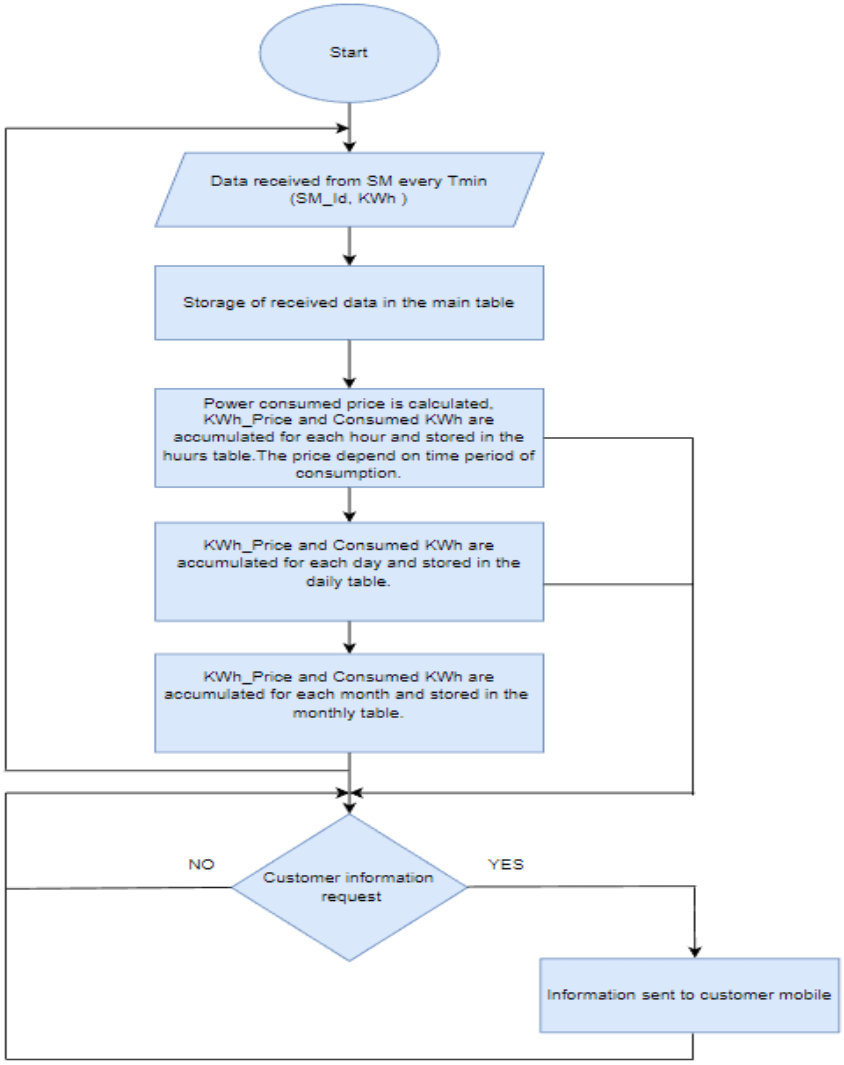

Figure 3.9. SQL Server Flowchart

The received data is the device ID and the accumulated power consumed. The received data is first stored in the master table, and then, according to the innovative identifier, the energy consumption calculated for T_{minute} is multiplied by the energy price and accumulated for 1 hour in the stored hour's table. Each energy consumed and the cost for 1 hour is grouped with the other previous hours and stored in the daily schedule. Each day is grouped with the other days and stored in a monthly schedule for each device. The price depends on the time of consumption, and the day can be divided into three or more periods: "peak," "standard,"

and "off-peak." The highest price is at the peak, and the lowest price is at the off-peak, while the normal price is in the standard period.

3.2.1. Database Tables

The database consists of a number of tables for storing the data coming from the Arduino.

3.2.1.1 Main Table

The main table contains the data coming from the Arduino directly, the data coming from the Arduino contains the device number, the amount of data consumed, and the storage date and ID are added to each row of the database.

The table contains a trigger that stores the data in the total hour's table by checking the total hour's table by the device number and stores the data in groups of hours for each device.

Table 3.1. Main Table

Main	
PK	**Id int NOT NULL**
	DeviceId int NOT NULL
	KWh float NOT NULL
	DateTime datatime NOT NULL

3.2.1.2. Total Hours Table

It is the table consisting of the data sent from the main table in addition to the consumption price. The table consists of the device number, consumption quantity and price per hour in addition to the storage date. The date is determined at the hour level, for example “20-09-10 20:00:00**."**

The amount of consumption is calculated by the database operator, it calculates the amount of consumption times (×) the price in the price table that contains the consumption price per hour distributed over specific time intervals according to the degree of consumption, and also by the database operator the price and the amount of consumption for each device is stored in a table Total days.

Table 3.2. Hours Table

totalhours	
PK	**Id int NOT NULL**
	DeviceId int NOT NULL
	Total int NOT NULL
	InsertDate datatime NOT NULL
	Price float NOT NULL

3.2.1.3. Total Days Table

In this table, the amount of consumption and the amount of money formed from the consumption are collected for each day. The device number, the amount of consumption, and the amount of money for consumption are stored every day. The data comes from the hours table after calculating the price. Through the data in the daily total table, the monthly consumption amount and the amount are stored. Monthly financial data in a table for each device.

Table 3.3. Days Table

totaldays	
PK	**Id int NOT NULL**
	DeviceId int NOT NULL
	Total int NOT NULL
	InsertDate datatime NOT NULL
	Price float NOT NULL

3.2.1.4. Total Months Table

Data is collected for each month and for each device in the month table. The data contains the amount of energy consumption, the amount of consumption, and the date of the month of consumption. This table is used to find out the amount of monthly consumption and the amount of money made up of consumption for each month. The data comes directly from the day's table by the trigger database. The trigger fetches the new data from the day's table

and the date of the day is checked if the current month exists. The data is added to the data within the month. In the absence of the current one, a new entry is added for the new month.

Table 3.4. Months Table

totalmonth	
PK	**Id int NOT NULL**
	DeviceId int NOT NULL
	Total int NOT NULL
	YearMonth int NOT NULL
	InsertDate datatime NOT NULL
	Price float NOT NULL

3.2.1.5. Price Table

The price table contains the hourly price of electrical energy consumption and is divided Hours are divided into groups according to the nature of consumption, such as the time of peak consumption, the natural time of consumption, and other times determined according to the nature of consumption.

Table 3.5. Price Table

price	
PK	**Id int NOT NULL**
	PeriodForm time(7) NOT NULL
	PeriodTo time(7) NOT NULL
	Price float NOT NULL

3.2.1.6. Device id Table

This table contains the device number stored in the Arduino and the device number consisting of a group of numbers containing County number

- City number
- Zip code
- Street number

- Building number
- No. device

Through this number, we can follow the network outages and find out the source of the defect and whether the defect exists in one house, building, street, or area.

Table 3.6. Device id Table

deviceid	
PK	**Id int NOT NULL**
	DeviceId int NOT NULL
	DeviceNo int NOT NULL
	DeviceLocation string NOT NULL
	UserId int NOT NULL

3.2.2. ASP.NET Core Identity

Asp.net Core Identity was used for providing authentication and authorization to use the site. Asp.net core identity is a membership system that allows users to register and log in to the site. The system handles authentication and authorization issues. Authentication is concerned with who can access the site. Authorization means what the user is allowed to do. Therefore, authentication is a prerequisite for obtaining permission [53].

Asp.net core identity was used because it is open source and provides great security in password encryption for users' identities. It also supports external login providers such as Twitter and Facebook. Membership data is kept in the website's database. In Figure 3.10, identity tables of ASP.NET is shown.

Login functionality is another crucial process for proposed smart meter and is given in Figure 3.11.

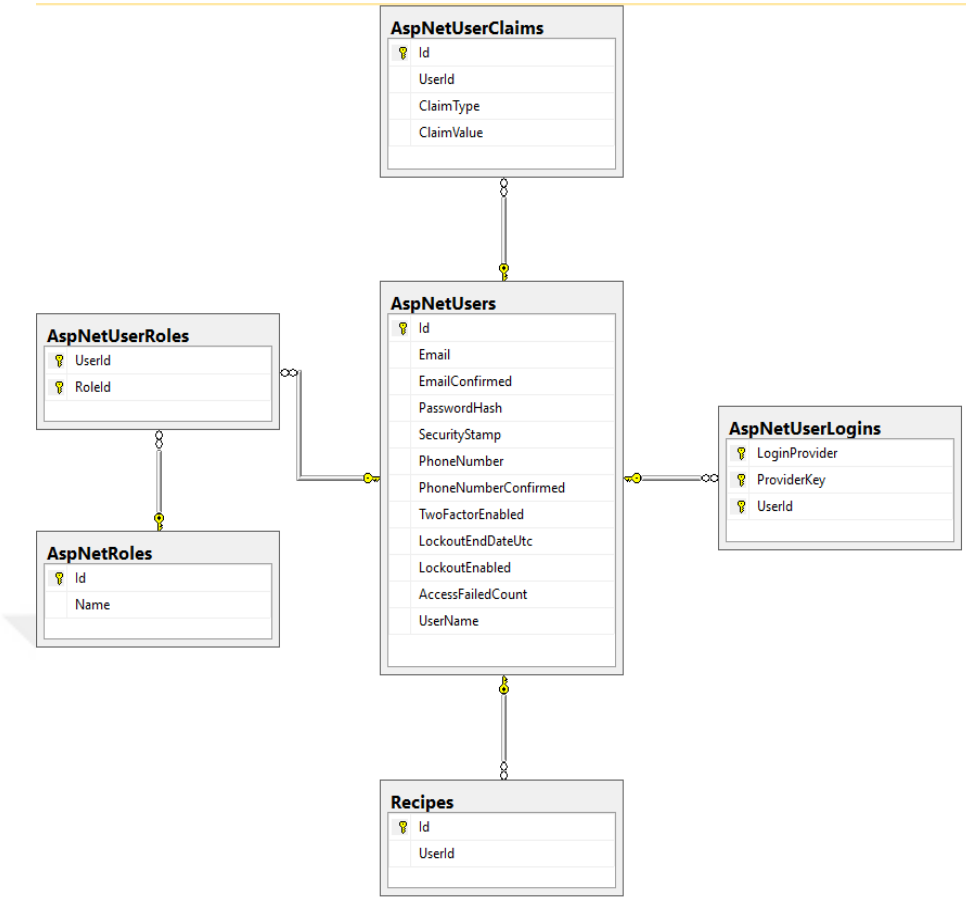

Figure 3.10. ASP.NET Core Identity Tables

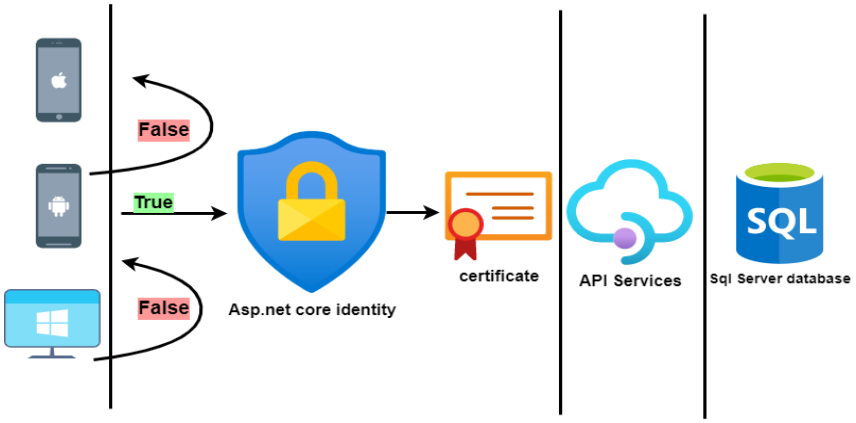

Figure 3.11. Conceptual Architecture of the Login Functionality

3.3. API (Application Programming Interface)

Application programming interfaces (APIs) provide operational signatures to create, read, update and delete data, related to business (or logical) entities, managed in software

applications, without revealing the software implementation that supports the, managed in software applications, without revealing the software implementation that supports the operations [29]. APIs are essential to many modern software architectures, as they provide high-level abstractions that simplify programming tasks, support the design of distributed and modular software applications, and allow the reuse of code [54].

The API is built using a technology (Asp.net core6) where it connects to the database SQL Server and provides data to users. It provides device data for each user, including hour usage, daily and monthly usage, and total bills for each month as shown in Figure 3.12.

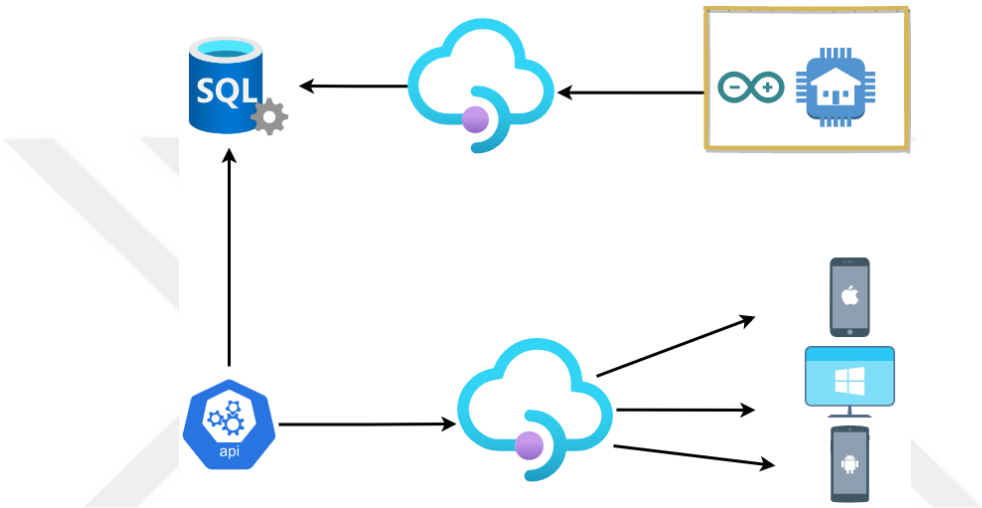

Figure 3.12. API Function in the System

3.4. Real-time

Today's web applications are not only expected to function properly, but they need to do so through a great user experience. In addition to the speed of applications, applications are also expected to provide information in real time, without the need to update the browser [55], so Microsoft's signalR technology was used to fetch data from SQL Server database in real time. When the IoT device sends the data to the database, the data is shown directly to the user without demand in order to facilitate the process of monitoring energy consumption.

The technology that was used in the project is SignalR ASP.NET Core, which is an open-source library. SignalR technology gives flexibility in using multiple types of databases, as well as gives the possibility to use the project in internal networks without the need for the Internet.

When the user enters the system, he can follow the results directly without delay, and this provides the user with the ability to know the amount of energy consumed as well as the amount of money resulting from the monthly and daily use without waiting for the electricity bill at the end of the month. Real-time process of the device is shown in Figure 3.13.

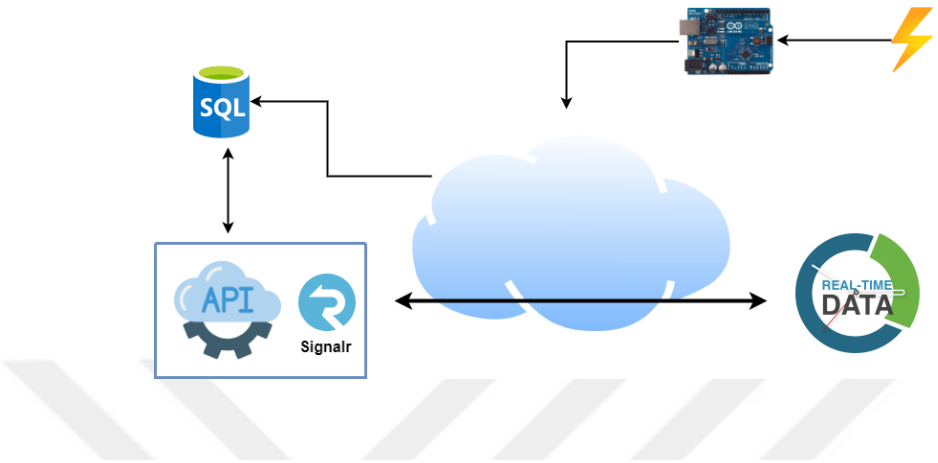

Figure 3.13. Real-time

3.5. Forecasting by ML.NET

Predicting energy consumption is the first step to conserving energy [3], [56]. In addition, since the system provides data on energy consumption for each user, it was necessary to exploit the existing data, which reflects the daily, weekly, and monthly energy consumption patterns of the user. In addition, because the urgent need for the user requires knowing the number of amounts resulting from the amount of energy consumed, the forecast feature was added using time series and using the ML.net library, which is an open source framework from Microsoft, which provides security and scrutiny of the code [57], [58]. The contribution of ML.net to the smart metering system can be seen from the Figure 3.14.

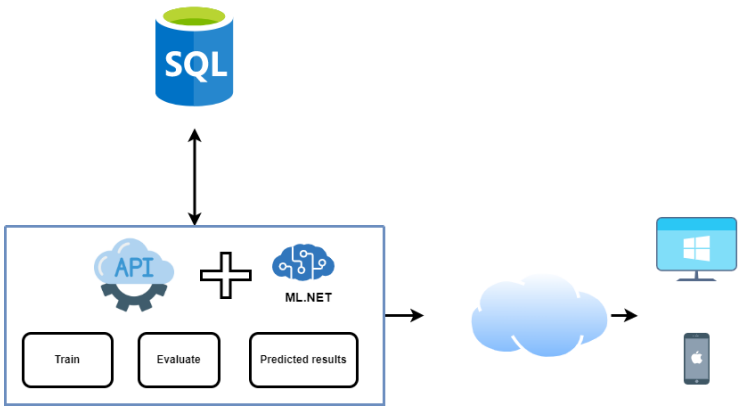

Figure 3.14. Forecasting by ML.NET

The system provides the possibility of predicting energy consumption and the amounts of consumption by using the time series forecast provided by the ml.net framework using the Singular Spectrum Analysis (SSA) algorithm.

3.5.1. Singular Spectrum Analysis (SSA)

Singular Spectrum Analysis (SSA) is a technique analyzed by Golyandina [59] and used by combining 5 segments in time series: The elements of five classical time series analysis, multivariate statistics, multivariate geometry, dynamical systems and signal processing.

The method can be briefly explained with some basic mathematical operations and formulas as follows:

The method basically consists of decomposition and reconstruction stages. The decomposition is done by splitting into embedding and singular value decomposition steps.

Embedding Step

The trajectory matrix which is a lagged version of the original series of

$y = [y_{1} \ldots y_{n}]$' and defined as

$$Y = \begin{bmatrix} y_{1} & y_{2} & \cdots & y_{k} \\ y_{2} & y_{3} & \cdots & y_{k+1} \\ \vdots & \vdots & \ddots & \vdots \\ y_{I} & y_{I+1} & \cdots & y_{I+(\kappa-1)} \end{bmatrix} \quad (3.1)$$

With $k = n - 1 + 1$

Each vector $\boldsymbol{yi} = [\boldsymbol{yi} \ldots \boldsymbol{y1} + (\boldsymbol{i} - \boldsymbol{1})]$ is referred as a window. Where *l* is the window length, defined by the user.

Step of Singular Value Decomposition

The eigenanalysis of *YY'* gives the $\lambda_1 \geq \cdots \geq \lambda_d$, where d=rank (*YY'*) denoted by the corresponding left and right singular vectors, w_i and v_i, respectively.

Through the decomposition made in this step *Y* can be obtained approximately through

$$Y = \sum_{i=1}^{d} \sqrt{\lambda i} wiv'i \quad (3.2)$$

After the decomposition step, reconstruction can be applied as a second phase of the method which includes the grouping and diagonal averaging.

Grouping

In this step, the first *m* leading eigentriples associated to the signal and exclude the remaining *(d-m)* associated to the noise are selected. So, a proper selection of *m* is performed to disangle *Y* into,

$$Y = \sum_{i=1}^{m} \sqrt{\lambda i} wiv'i + \varepsilon, \tag{3.3}$$

where ε is error term, and the remainder summands represents the signal. This is a readjustment method to select the b number of principal components.

Diagonal Averaging

In this step the main idea is reconstructing of the deterministic component of the series. The process is reversed which is done so far, returning to a reconstructed variant of the trajectory matrix, and thus the deterministic component of the series. An optimal way to do this is to average over all the elements of the several 'antidiagonals'. Formally, consider the linear space $M_{1,k}$ formed by the collection of all the $1 \times K$ matrices , let $\{h1\}1^n = 1$ denote the canonical basic of R^n and consider the matrix $x = [x_{i,j}] \in M_{1\times k}$ The diagonal averaging procedure is hence carried on by the mapping $\overline{D} : \widetilde{M}_{1\times K} \to R^{\tilde{n}}$ defined

as $\overline{D}(X) = \sum_{w=2}^{k+1} h_{\omega-1} \sum_{(i,j)\in A_w} \frac{x_{ij}}{|A_\omega|}$ (3.4)

where |.| denotes the cardinal operator, and $A_\omega = \{(i,j) : i + j = \omega\}$ Now, the deterministic component of Y can be written as

$$\tilde{y} = \widetilde{D}\left(\sum_{i\in 1} \sqrt{\lambda_i w_i v'_i}\right) \tag{3.5}$$

3.6. Fault Detection

The development of the SM provides great potential benefits for the planning, management, and operation of the power network. The benefits are derived from integrating smart metering and outage management to reduce the duration of power outages, provide statistics on outage periods, and provide feedback to customers affected by outages. Outage management is one of the important operations in the management and operation of the electrical network [60].

One of the features added to the system is the ability to monitor the flow of data from the SM and try to deduce the type of errors that occur and their cause. One of the problems with

mechanical meters is power outages and the user's lack of knowledge of the interruption if it is outside the house or the place where the electricity meter is located, so the electricity meter was added The feature of monitoring the continuous access of data to the system and alerting the user by sending a text message in the event of a power outage in the house, as well as knowing the state of the interruption if it is in the house or for all the electrical transformers that equip the area.

It was used in Hangfire, an open-source framework that helps create, manage, and manipulate our back-end jobs [61]. Figure 3.15 shows the fault detection stage in smart metering environment.

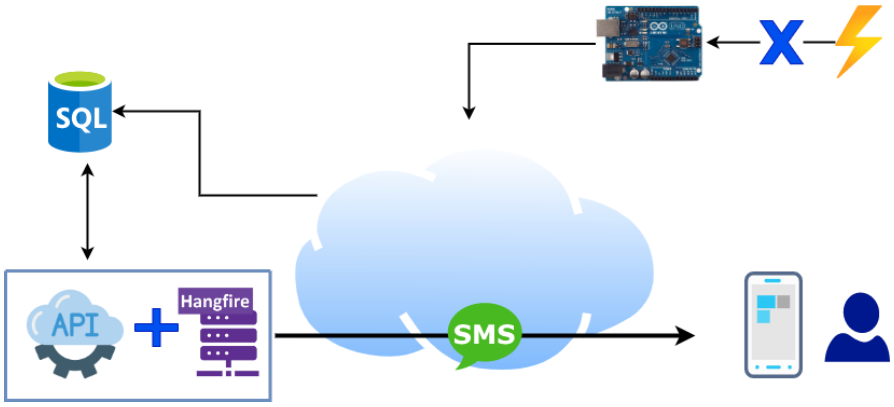

Figure 3.15. Fault Detection

3.7. Geolocation Data

Internet devices sense what is around them and facilitate the services they provide. One of the main features of IoT enabling technologies is the ability to determine the geographical locations of devices in order to provide services. The geolocation of devices has become an important matter. Therefore, changing the locations of the devices or their disappearance is a real risk to the continuation of any work, so checking the geographical location information is an important solution from a security point of view [62].

One of the problems facing electric power supply companies is the problem of electrical energy measuring devices malfunctioning, determining the time of failure, locating the measuring device in addition to changing the location of the device. In the proposed smart measurement system, for locating the device in the event of a malfunction, the device's location data must be available and be via:

- The location data is entered manually and, in this way, it is possible to know the location of the device, but it is not possible to track the location of the device if it is transferred to another place,
- Locating the device by GPS Module, which is an expensive method because a GPS Module must be available for each SM,
- Locating the device by Geolocation with Google Maps, which is what we use in this smart system.

4. RESULTS AND DISCUSSION

4.1. Electricity Measurement

The system is started by measuring the electrical energy consumption using PZEM-004t, where it calculates the current energy consumption and collects the results every 5 minutes. Then, by connecting to the Arduino, the results are sent to the wireless (esp8266), which in turn sends the consumption value to the database via the API route is built with (asp.net core 6 API) technology. It was uploaded to an external server that is connected to the Internet.
It is possible to increase or decrease the consumption calculation time as needed. Five minutes were chosen to obtain quick results. Figure 4.1 shows the smart metering measurement diagram.

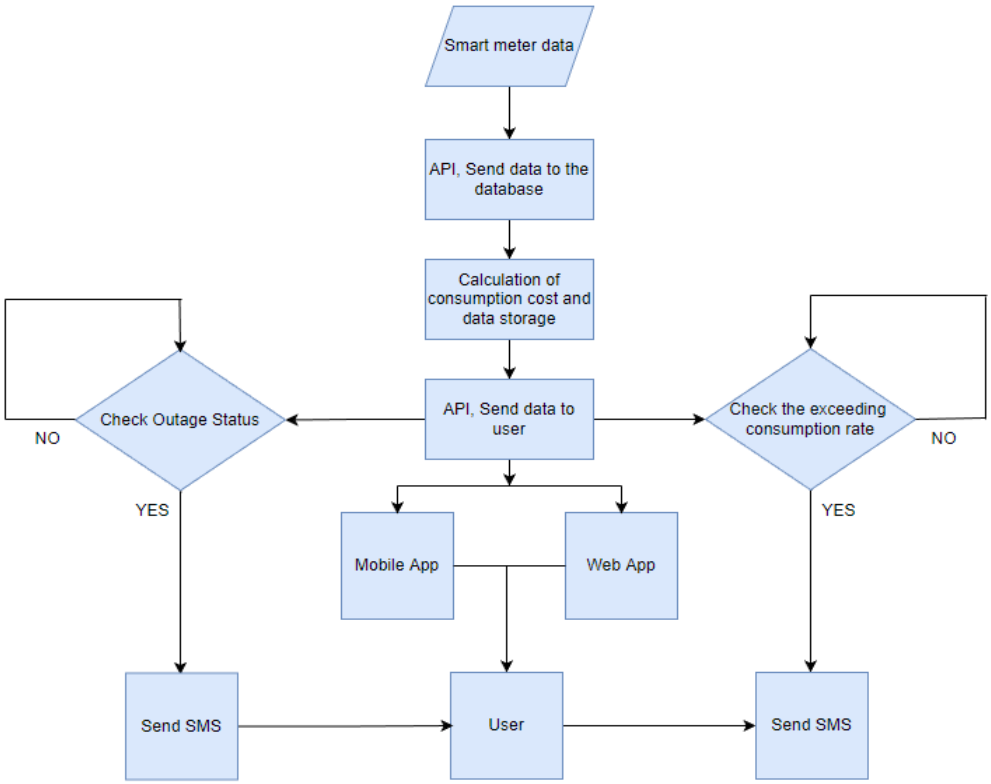

Figure 4.1. System Diagram

4.2. API Server

The consumption amount is sent to an API server, which in turn sends the data to the SQL server database. The data sent contains the device number and the consumption amount. The consumption history is stored directly in the database.

4.3. Database Server

The SQL Server database was used. The consumption data for each device is stored every 5 minutes, and the financial amount for consumption is calculated through the price table, where the cost is calculated according to the consumption in each period of time. Quantity and price data are stored in the hours table, days table, and months table as shown from Figures 4.2 to 4.6.

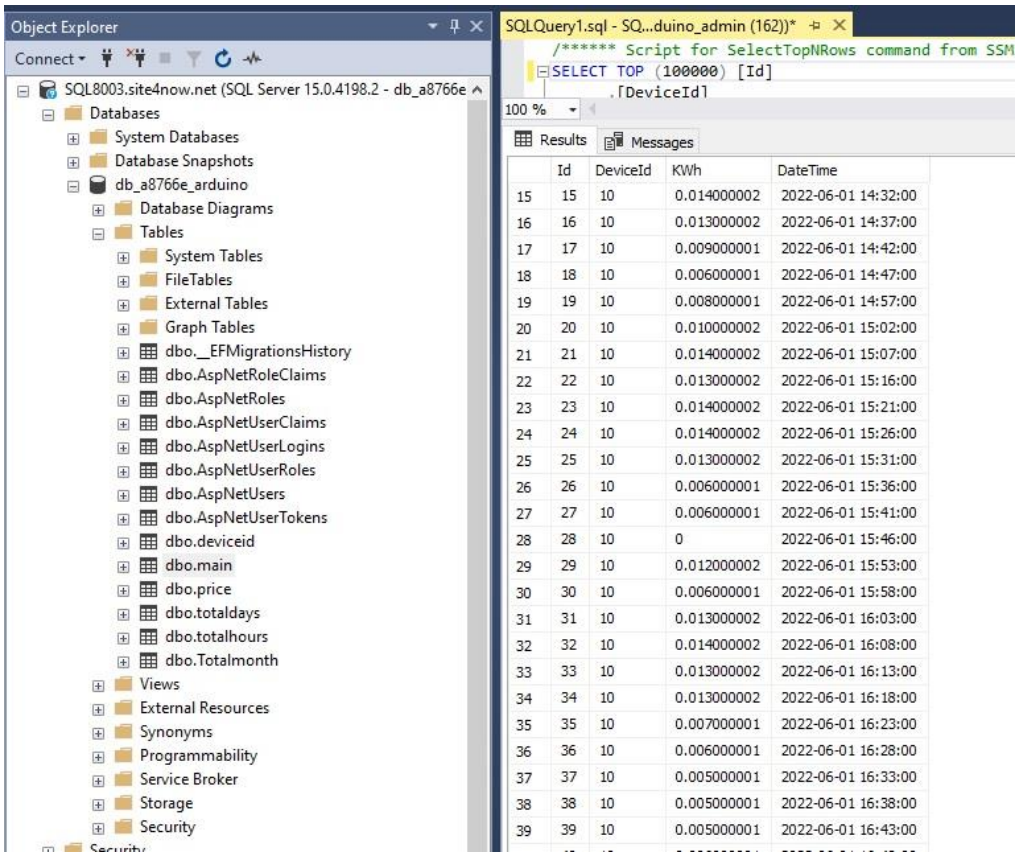

Figure 4.2. Main Screen

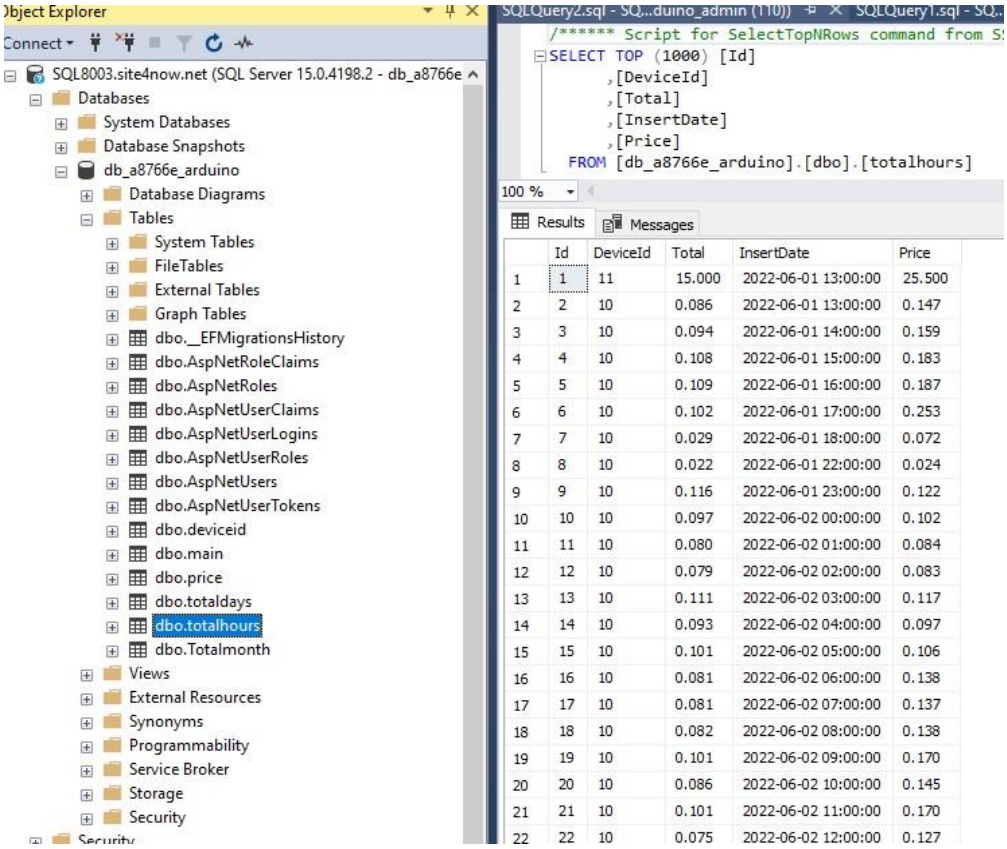

Figure 4.3. Hour's Screen

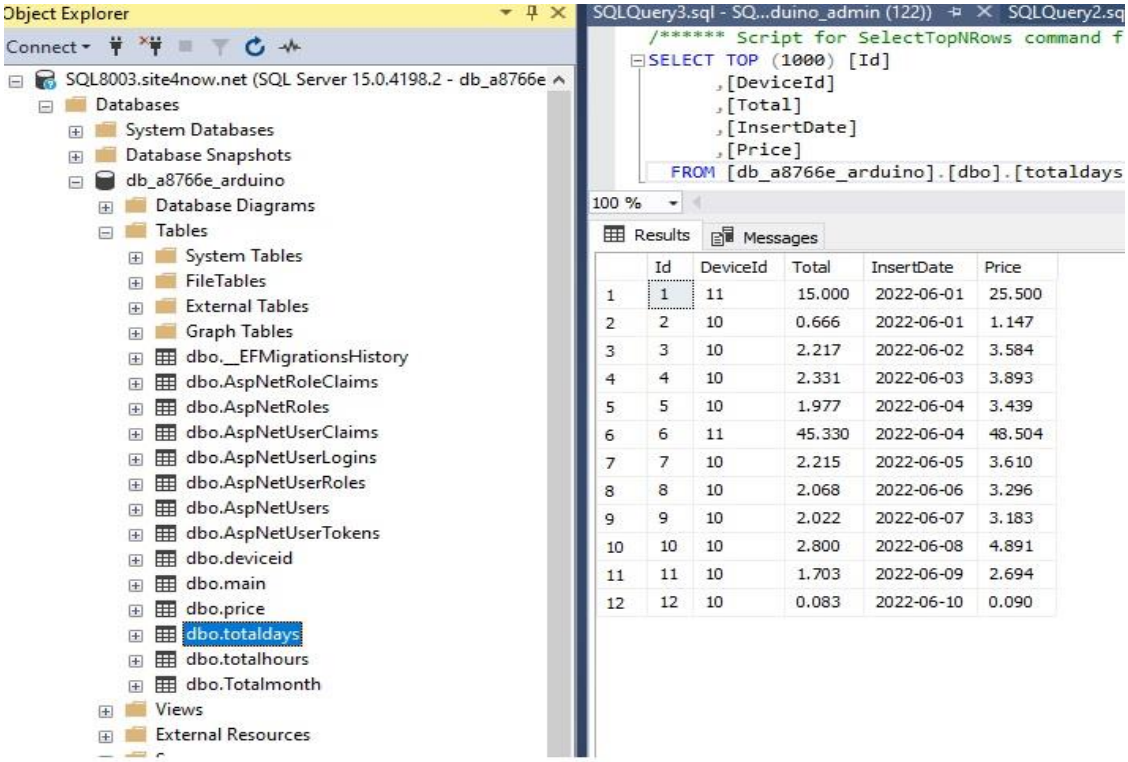

Figure 4.4. Day's Screen

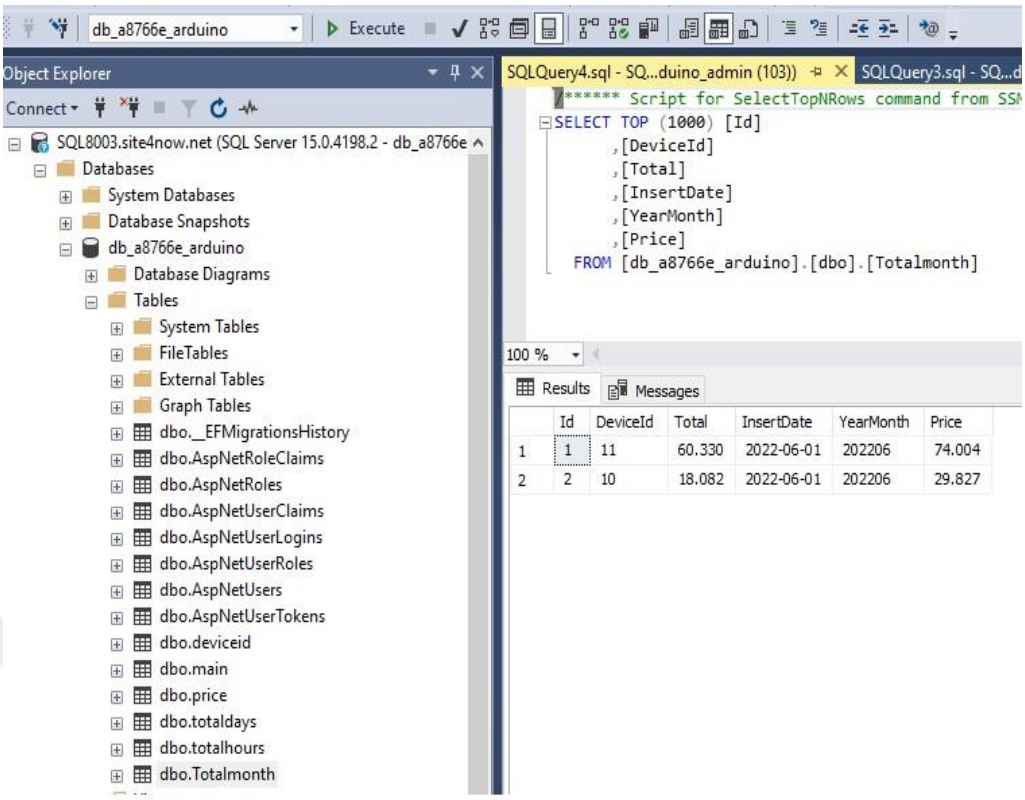

Figure 4.5. Month's Screen

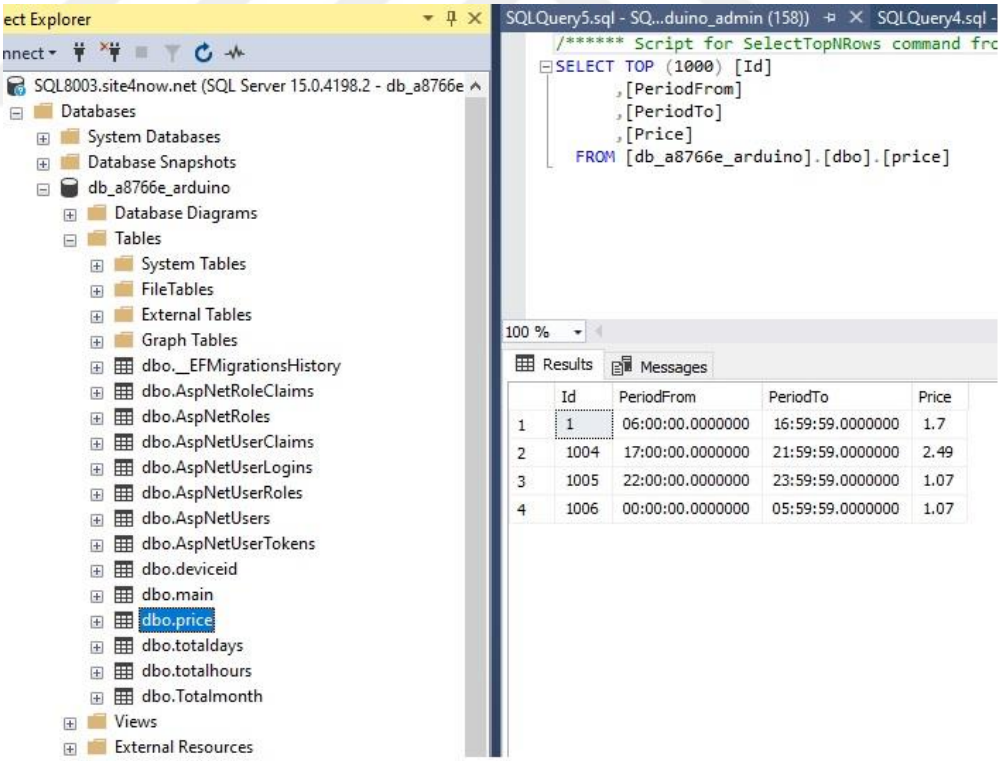

Figure 4.6. Price Screen

4.4. System Interfaces

The system interfaces are built using asp.net core 6 blazor web assembly technology. The system is entered through a login interface with a username and password. Interface for the web application login is shown in Figure 4.7.

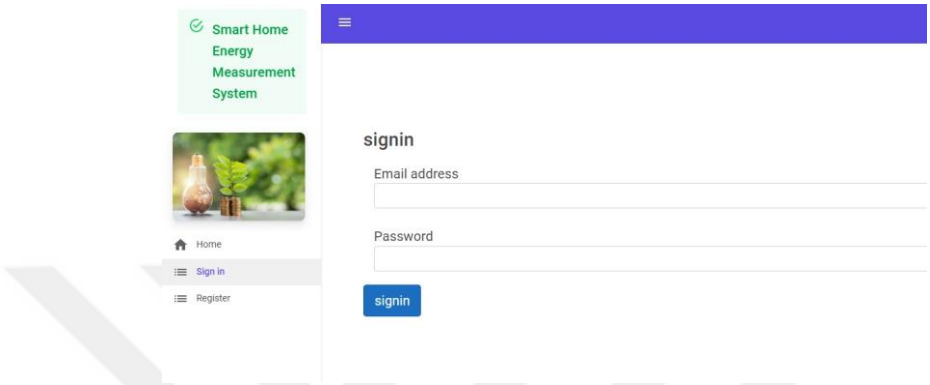

Figure 4.7. Web Application Login

4.4.1. Total Month

The monthly consumption and the monthly consumption amount are displayed in addition to the ratio of the consumption amount to the amount specified by the user. In addition to displaying a consumption chart for the previous months, with the amount of consumption and the amount of money for consumption. Monthly consumption can be seen from the Figure 4.8.

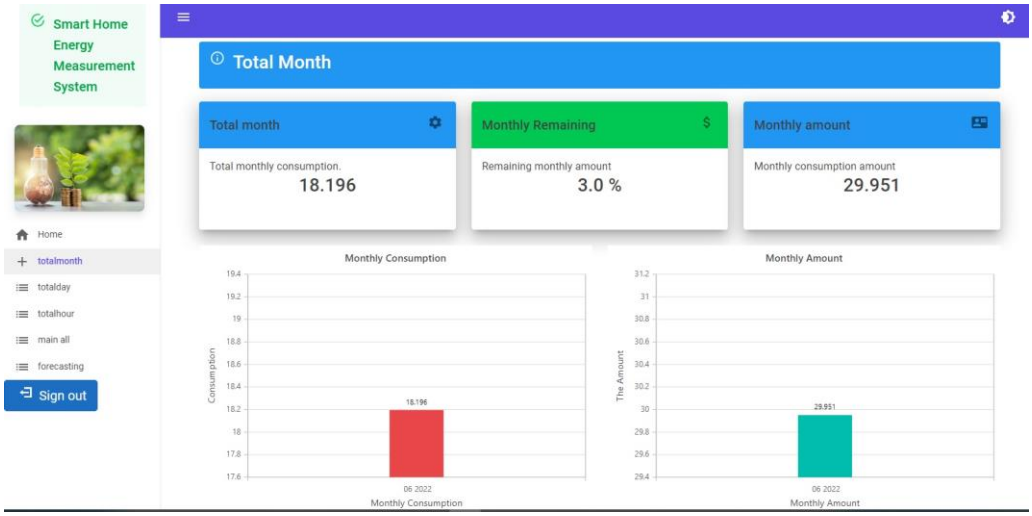

Figure 4.8. Monthly Consumption Page

4.4.2. Total Day

The daily consumption and the amount of money for daily consumption are displayed. The data update is in real time due to the use of real-time techniques to display the data, which provides the ability to display the data directly without any delay. In addition to displaying the consumption amount chart for the previous days with the amount of money for consumption. Daily consumption can be seen from the Figure 4.9.

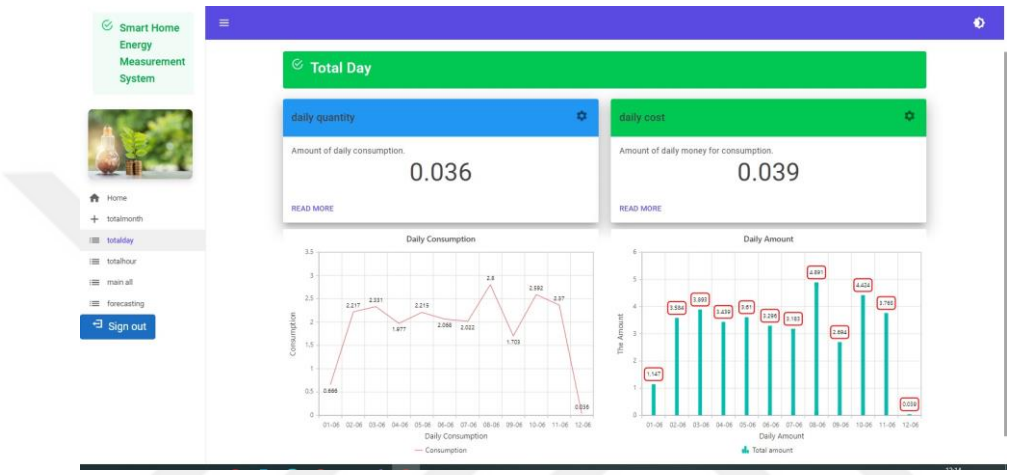

Figure 4.9. Daily Consumption Page

4.4.3. Total Hour

The consumption per hour and the amount of money for consumption per hour are displayed. The data is updated in real time due to the use of real time technologies to display the data, providing the ability to display the data directly without any delay. In addition to displaying the graph of the amount of consumption in the previous 24 hours with the amount of money for consumption. Hourly consumption can be seen from the Figure 4.10.

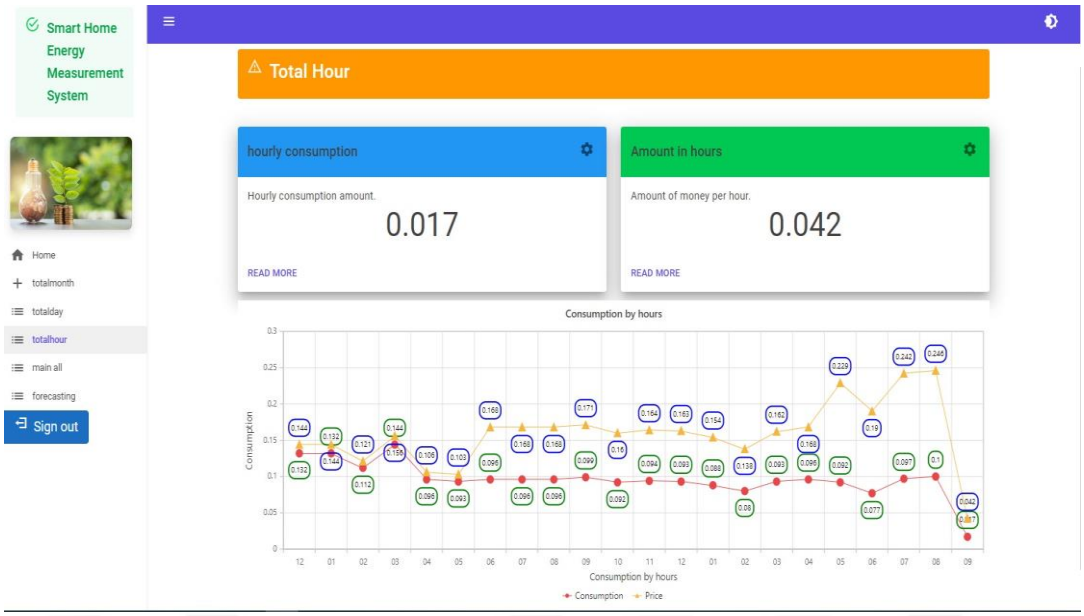

Figure 4.10. Hourly Consumption Page

4.4.4. Data Usage Stats

For the purpose of making maximum use of the data that was stored in the database, which reflects the nature of the user's consumption, the possibility of displaying percentages of consumption according to days and hours has been added so that the user can know which day more money is consumed or which hour of the day more money is consumed as shown in Figure 4.9 and in Figure 4.10, respectively.

Figure 4.11. Percentage of Money for Consumption by Days of the Week

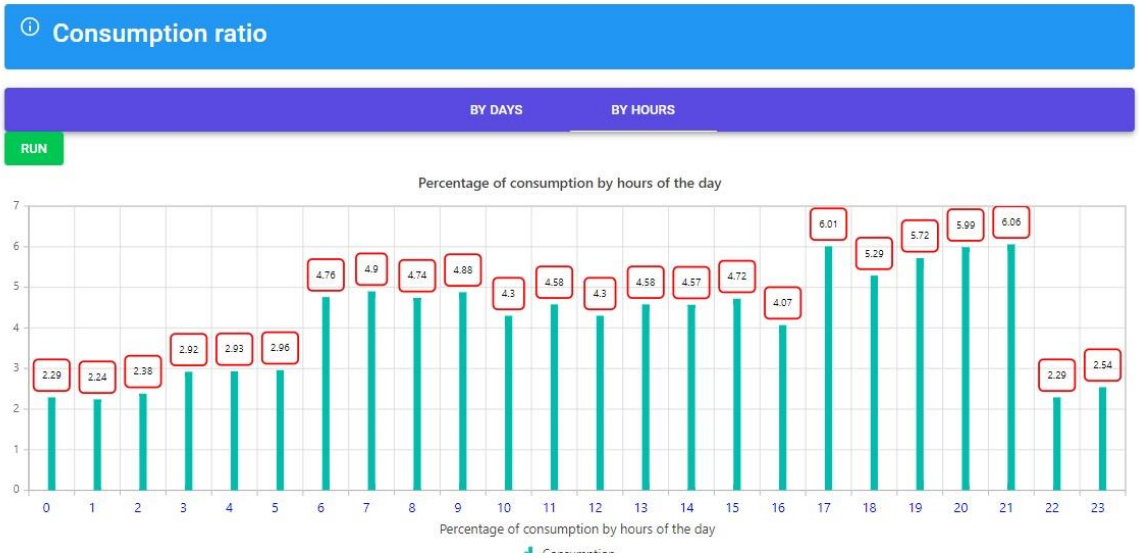

Figure 4.12. Percentage of Money for Consumption by Hours of the Day

4.5. System Alert

In the system, alerts were provided for the purpose of alerting the user to any emergency event that occurred outside of expectations and to enable the user to take the appropriate action. From these alerts, text messages were relied on for alerting to ensure that the alert reached in the event of an internet outage. The Twilio API was relied on for the purpose of providing text messaging service.

4.5.1. Power Outage Alert

Continuing the supply of electricity is important for the user, and therefore the user must be alerted in the event of a power outage in the house. A text message is sent to the user about the occurrence of a power outage. The alert mechanism is by checking the data sent to the system every 20 minutes. Alerts are sent from the system without the user having to enter the system interface. Power outage alert will be seen as in Figure 4.13.

Figure 4.13. Power Outage Alert

4.5.2. Over Consumption Alerts

One of the things that the user cares about regarding the consumption of electrical energy is the electricity bill, which sometimes comes with amounts of money that are outside the user's expectation, so one of the alerts that was provided in the system is the warning that the percentage of the specified amount of money from the user for the consumption of electrical energy is exceeded. This warning is once in a day as in the Figure 4.14.

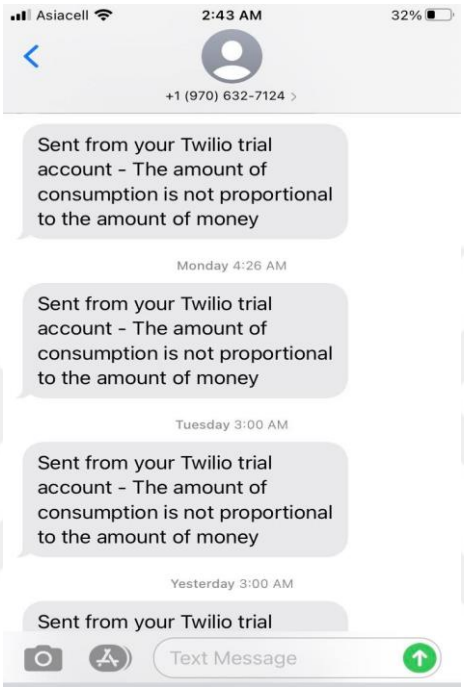

Figure 4.14. Over Consumption Alerts

4.6. Mobile App

A mobile application was built in order to enable the user to monitor his energy consumption and know the amount of money for consumption. The application was built using the ionic framework. The application provides the ability to follow the monthly, daily, and hourly consumption. In Figure 4.15 and Figure 4.16, two interfaces are given as login and application screens of mobile applications, respectively.

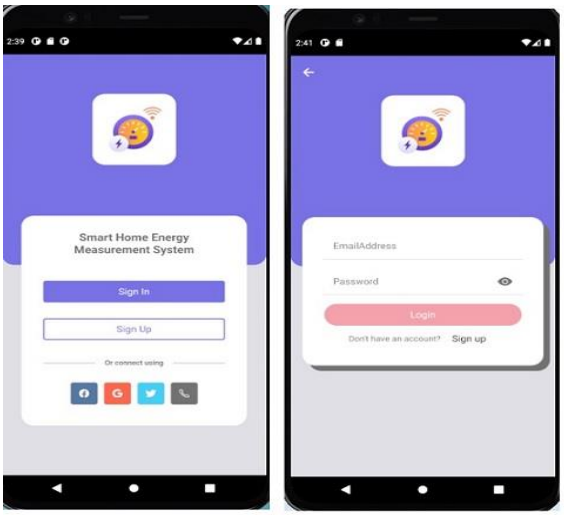

Figure 4.15. Mobile Application (1)

Figure 4.16. Mobile Application (2)

4.7. Geolocation Data

4.7.1. Show stopped working devices:

The devices that stopped sending data to the central database are searched, and in the case of a device that stopped sending data, the location of the device is displayed on the map, so the company can know the idle devices and locate them, which facilitates the process of directing maintenance cadres to repair the device.

4.7.2. View devices whose location has been changed:

The device's geographical location data is sent twice a day, the new geographical location is compared with the old geographical location, and in case there is a difference, an alert is sent to the company that a device has changed its geographical location. Figure 4.17 shows the geolocation screen.

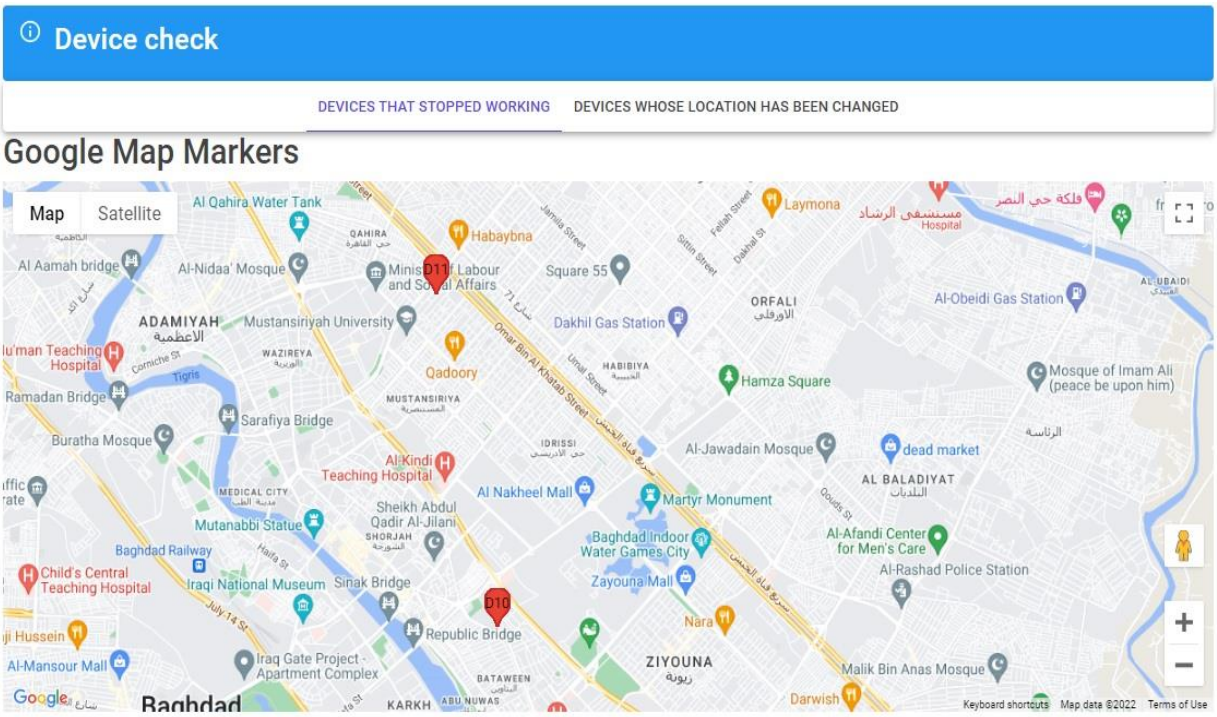

Figure 4.17. Geolocation Data

5 . CONCLUSION AND RECOMMENDATIONS

Due to the increase in population growth and the rapid development in the industrial and technological fields, the demand for electrical energy has increased, and to maintain the continuity of electrical energy, new and cheap alternatives to energy must be found and energy users must rationalize their energy consumption.

The research tries to find a solution to rationalize energy consumption for users by building a smart system based on IoT to measure energy consumption, store data in a cloud database, display data to the user in real time, and try to regulate its energy consumption by sending alerts. In case the amount of money for consumption exceeds the amount set by the consumer, as well as sending alerts in the event of a power outage, the user will be able to regulate his energy consumption, he will not be surprised by the amount of the consumption bill at the end of each month. The system will also provide the user with the ability to know which times he consumes more energy and causes the financial bill to rise, which will help him to distribute his consumption over time periods to reduce the financial cost of consumption, as well as the system will provide.

The user has the ability to predict his energy consumption based on his detected consumption pattern from the data. The data provided by the system and the use of prediction by machine learning and time series. Helping the user to regulate his energy consumption will help reduce his energy consumption, which leads to the maintenance of electrical energy production. Currently, no matter how much information is available that helps the user rationalize their energy consumption, the issue still needs human intervention from the user to turn on and turn off electrical appliances according to their urgent needs and peak times. Therefore, we recommend that a system based on artificial intelligence be built to regulate the user's consumption of energy by determining the daily bill that the user can pay and trying to organize the operation of electrical appliances according to the importance and peak times so that the amount of money for consumption does not exceed what has been determined by the user.

In order to solve the problem of the internet stopping and the inability of the SM to send the amount of consumption, we suggest storing the data in the SM until the internet service is restored and sent back to the server.

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RESUME

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