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IoT-based Smartgrid System for Continuous Power Supply in Smart Cities

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***Abstract*— In today's energy landscape, there is a rising demand for stable and uninterrupted power availability, particularly in fluctuating power sources or faulty grid infrastructure. To overcome these issues with conventional power grids by regulating fluctuations in both supply and demand includes creating efficient energy management systems (EMS) by combining several techniques, such as microgrids based on renewable energy sources (RES), smart grids, and smart devices control via local area networks (LANs) or the Internet of Things (IoT). This research investigates an uninterrupted power supply model in terms of a smart grid by integrating an IoT-based microgrid system for smart cities. This case study has been investigated by creating a SIMULINK model that includes RES and IoT-enabled monitoring. The proposed work could be controlled remotely via the internet, and it would be possible to determine if any branch's failure was detected. It will notify the user using ThingSpeak in critical conditions and enable the activation of a backup power source to ensure an uninterrupted power supply. A power monitoring system would be utilized to provide the real-time status of the microgrid. The proposed simulation was completed successfully, highlighting effective outcomes in an efficient EM system to increase overall efficiency while preserving a sustainable environment.**

Keywords*— *IoT, ThingSpeak, smart grid, smart cities, EMS, control, renewable energy, continuous power supply.

I. INTRODUCTION

The current power distribution infrastructure is severely challenged by rapidly accelerating urbanization and rising energy demand in smart cities [1]. The dynamic and varied energy needs faced by modern metropolitan environments are frequently too much for traditional power systems to handle, which compromises reliability and frequently results in power outages [2]. Traditional microgrid infrastructures are being used to generate electricity and the traditional power grid has issues in energy control [3]. Firms are unable to regulate the distribution of energy once it has been released from a power plant or substation. Conventional microgrid technology is susceptible to failure because of its advanced age and inherent vulnerabilities. In 2017, the Blackout Tracker Annual Report mentioned that over 36 million people suffered blackouts in the United States and the average outage was approximately 81 minutes [4]. Power outages have a significant impact on businesses, schools, factories, and residences, as evidenced by numerous reports. Innovative solutions that make use of cutting-edge technologies are desperately needed to address these issues and improve the sustainability, dependability, and efficiency of power distribution networks in smart cities [5]. In this regard, a smart grid (SG) is an enhanced electrical system that uses digital technology to optimize, manage, and regulate the power to improve the effectiveness of the electricity supply-demand flexibility by integrating several technologies such as smart meters (SMs), energy storage system (ESS), renewable energy sources (RES) with advanced energy conservation (EC) strategies and Internet of Things (IoT)-based connectivity, which would allow to monitor, analyse, and switch to constantly changing energy demands [6]. An essential part of microgrid operation is the Energy Management System (EMS), which maximizes the integration and use of various energy sources and loads and controls demand-side management (DSM) efficiently [7]. This management system aims to reduce costs, increase efficiency, and use less energy all the while preserving a productive environment. The overall performance and operation in EMS can be optimized when an Internet of Things (IoT) technology is integrated into a microgrid [8].

A comprehensive review shows in a study [9] focused on, how IoT applications are changing for smart grids, with a focus on developments in communication infrastructure, voltage regulation algorithms, and distributed energy resources for improved microgrid performance In 2018, D. K. Aagri suggested a system [10] that investigates the possibility of integrating solar-powered microgrids into the main grid using the IoT that has a significant addition to the fields of renewable energy and smart grids which illustrates how IoT may boost microgrid flexibility and efficiency and offers a real-world example of how this technology can be applied. Information and communication technology's (ICT) role in smart grids, with an emphasis on the IoT contributions as covered in [11]. In another study, [12] authors proposed a Microgrid model that has sophisticated computerized control systems, intelligent sensors, and Internet of Things technologies that provide essential and remote grids with a dependable and safe energy supply in addition to both physical and cyber security mechanisms. There are concerns about the dependability of the security procedures that have been implemented due to the paper's extensive security plans and processes lacking in detail [13]. Though several researchers have contributed to multiple articles about microgrid systems for smart cities and remote areas, only a few articles are focused on a Smart Microgrid that is integrated with the IoT and capable of detecting branch failures and notifying users.

The primary objective of this research study is to develop a concept for an Internet of Things (IoT) enabled intelligent microgrid designed for smart cities, to ensure an uninterrupted power supply. The main contribution of the proposed smart grid model was an analysis of an IoT-based Smart Microgrid that can be controlled remotely and a monitoring system for providing real-time status updates for more reliable demand side management with the capability of detecting branch failures and notifying responsive individuals through ThingSpeak.

As observed in Table I, the proposed work has been compared with previous studies by tabular analysis. The comparison includes essential variables such as IoT communication network integration, making it an invaluable resource for decision-makers in the sustainable energy area.

TABLE I. REVIEW OF EXISTING IOT-BASED SMARTGRID SYSTEM

IoT-based Microgrid	Power Generation Sources				Com. Network
	PV System	Wind Energy	Diegel Generator (Back Up)	H_2 Fuel	
[9]	--	--	✓	--	--
[10]	✓	--	--	--	✓
[11]	✓	--	✓	--	--
[12]	--	--	✓	--	✓
[13]	--	--	✓	--	✓
[14]	✓	--	--	✓	--
[15]	✓	✓	--	✓	--
[16]	--	--	--	--	--
[17]	--	--	✓	--	✓
[18]	✓	✓	✓	--	--
Proposed Model	✓	✓	✓	✓	✓

The above table shows that the proposed investigation includes all necessary technologies, and RETs such as photovoltaic (PV) systems, wind energy, and diesel generators. In study [9] emphasizes that a diesel generator is the main power source and that there is no network of communications to support it. On the other hand, Analysis [14] presents a hybrid strategy that combines a hydrogen (H_2) fuel and photovoltaic (PV) system, but it omits a specific communication infrastructure. By adding a PV system, diesel generator (backup), and wind energy, System configuration [19] expands on this concept, although it still lacks a dedicated communication network. Lastly, In study [20] broadens the scope even more by adding Wind Energy, PV Systems, enhanced by a Diesel Generator (Back Up) and communication network. However, This research ensures a comprehensive approach by adding IoT communication network integration, making the proposed solution ideal for both microgrids and reliable backup power [21]. This integrative approach distinguishes the proposed work as a well-rounded and forward-thinking contribution in terms of sustainable energy solutions for microgrids.

II. PROPOSED SYSTEM MODELING

The smart grid optimizes energy distribution by integrating a control panel, energy sources, and consumer units (home, corporate building, factory). Its interconnection to the main grid ensures adaptability and the microgrid provides resilience by functioning independently. This comprehensive system represents a sustainable and efficient approach to the energy management system. The smart grid optimizes energy distribution by integrating a control panel, solar panels, and consumer units (home, corporate building, factory), as seen in Fig. 1.

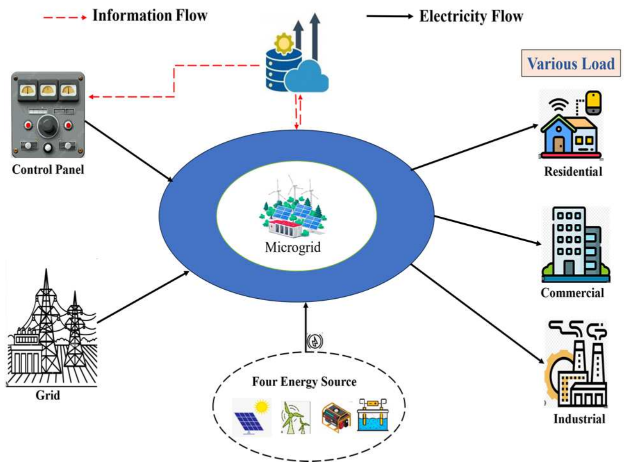

Fig. 1. Overview of the proposed smart grid model.

A. Smart Grid System for Smart Cities

A smart grid technique refers to a sophisticated and digitally combined electricity allocation network. It incorporates modern communication and information technologies to enhance the efficiency, reliability, and environmental sustainability of electrical power generation, distribution, and consumption. Also, smart grid system enables real-time monitoring, control, and optimization of the entire electricity infrastructure, enabling better management of energy resources, customer demand response, and integration of renewable energy sources. Smart cities are metropolitan regions that use ICT and IoT solutions to improve quality of life, sustainability, and the efficiency of various services. These technologies are used in industries like transportation, energy, healthcare, waste management, and public safety.

B. Smart Grid Power Balance

Power balance in the context of a smart microgrid refers to the balance of power generation and consumption within the electrical network. Maintaining a power balance is critical concern for management of a consistent and dependable electricity supply. A smart microgrid uses advanced monitoring and control mechanisms to optimize power generation, manage energy storage, and match real time electricity demand with supply power, resulting in a stable and resilient power system.

C. Real-time Monitoring and Control:

Power generation, transmission, and distribution can all be continuously observed through the IoT-based sensors incorporated all around the grid. In order to guarantee a steady supply of electricity, this real-time data enables proactive management of grid functions, such as load balancing and problem detection.

D. IoT system for Smartgrid System

In this study, the model was developed by MATLAB Simulink optimizer model encompassing renewable energy sources, IoT-enabled monitoring, and continuous power supply control mechanisms within a smart microgrid. Below Fig. 2 represents a schematic diagram of our circuit, illustrating the interconnectedness of all its components. There are four main energy sources in the microgrid system that is being described: a diesel generator, an H_2 fuel cell stack, wind energy, and PV sources. Together, these energy sources provide the microgrid with power, which powers loads of all kinds—commercial, industrial, and residential.

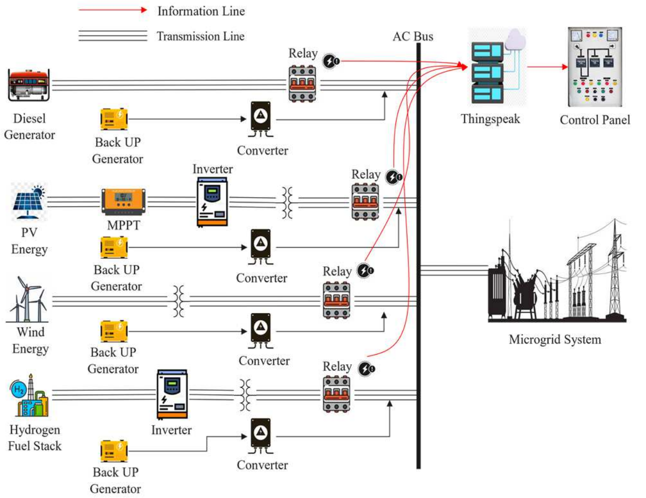

Fig. 2. Proposed model of IoT-based smart grid system.

Every energy source has a busbar that connects it to the microgrid; at each busbar, a relay switch with sensors to identify abnormalities or faults is located. These sensors provide real-time information on the performance and status of the microgrid and energy sources by continuously monitoring their state. These sensors are interfaced with a microcontroller board, which gathers information on defect detection and system performance. The information gathered from the sensors is transmitted by this microcontroller board through processing of the sensor data and communication with an IoT server, such ThingSpeak interface. ThingSpeak acts as a cloud-based platform designed for both the storage and analysis of data. The proposed work could be controlled remotely via the internet and would be able to detect if any branch fails. Initiating data from various sensors, including the relay module, and three-phase fault detector, which includes monitoring voltage, current, and power parameters. The real-time data monitoring system improves the ability of operators and stakeholders to properly monitor the microgrid's performance, allowing them to make educated decisions and respond quickly to any developing issues or concerns. This feature is critical for maintaining the microgrid's reliability, efficiency, and stability during real-time operations.

A smart grid system optimizes power flow using an ordered approach as well as the working principles are described in Fig. 3. The system continuously scans for defects, starting with the capture of data from microgrid sensors, including voltage, current, and power measurements. When a fault arises, the developed algorithm starts a decision-making process to decide what to do in the next step depending on the capabilities that are available according to the load demand. This algorithm can start backup energy sources, like diesel generators or batteries, to turn on to ensure vital loads are receiving power continuously. At the same time, the system can alert the appropriate individuals, isolate the impacted area, and, after the issue is fixed, return to regular operation. Within the smart microgrid, this automated process ensures dependable and effective power transmission in the energy management system.

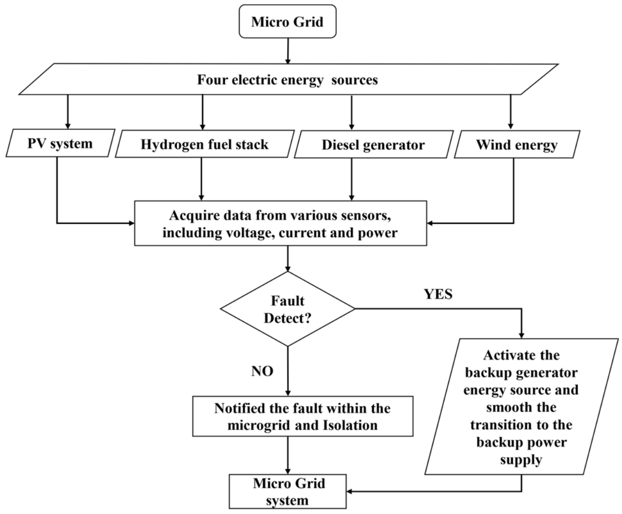

Fig. 3. System control diagram of Smartgrid system.

III. Modeling of Smart Microgrid

A. PV System

PV systems can effectively transform solar energy into electrical power. In this proposed model, the simulation of the system runs at 500 V and produces 5 A of current with 650 kW of power production by PV system. The solar irradiation physical representation on an inclined surface is provided by eq (1), where I_d represents diffused solar irradiance and I_b represents normal solar irradiance. The tilt factors for the reflecting and diffuse portions of the solar irradiation are represented by the parameters R_d and R_r. One major element affecting the overall solar irradiance is the sun's location in the sky [22].

$$I_{Total} = I_d R_d (I_d + I_b) R_r + I_b R_b \quad (1)$$

B. Diesel Generator

Diesel generators are essential for supplying steady electricity, particularly when the source of renewable energy is inconsistent. In our proposed model, the diesel generator provides a significant current of 104 A and a voltage of 480 V to the microgrid. Its apparent power, which represents the sum of its reactive and actual power components, approaches 50 kVA. The diesel generator's (DG) mathematical model in power generation includes several important components in the proposed model. The diesel engine produces mechanical power (P_m) by eq (2) [23], which is based on engine speed (ω) and torque (T). Also, the generator efficiency (η) is used to determine the electrical power output (P_e). Controlling the generator's voltage (V) and frequency (f), which are controlled by the governor and excitation system, is essential to sustaining a steady power output [24]. Power generation and specific fuel consumption (SFC) are related to fuel consumption (F_c). The governor system, the excitation system, and the dynamics of the diesel engine are considered in the design of the overall model.

$$P_m = \omega . T \quad (2)$$
$$P_e = \eta . P_m \quad (3)$$
$$F_c = \frac{1}{SFC} . P_m \quad (4)$$

C. Wind Power

A useful renewable energy source in the microgrid is the wind power system, which has a voltage output of 480 V and a current of 31 A. The systems 120 kW power output demonstrates itself as an effective power source in the proposed system. The primary determinants that have been considered for output power are the wind turbine's height and speed characteristics. The power-law eq (5) provides the relationships. The wind speed determines the output power of the turbine generator at the hub as V_z, wind speed at reference V_i, hub height Z, and reference height Z_i [25].

$$V_z = V_i \left[\frac{Z}{z_i}\right]^x \quad (5)$$

D. H_2 Fuel Stack

The H_2 Fuel Stack provides 30 kW of electricity in microgrid system while running at 400 V and 75 A. This section displays the use of hydrogen cells as a sustainable energy source. Fuel cell (FC) characteristics are usually shown as a polarization curve that shows the voltage-current density relationship. The current per active area, denoted by i is the definition of the current density. When fuel cells are stacked in sequence, the stack power is determined by P_{at} and the total stack voltage is determined by $V_{st} = n \times V_{cell}$. Fuel cell losses or overvoltage are subtracted from the fuel cell open circuit voltage E, to get the FC voltage: $V_{fc} = E - V_{act} - V_{ohm} - V_{conc}$. Different sections in the polarization are affected by the concentration overvoltage (V_{conc}), ohmic overvoltage (V_{ohm}), and activation overvoltage (V_{act}) which is determined by eq (6), (7), and (8) [21].

$$v_{act} = v_0 + v_a(1 - e^{-c_1 i}) \quad (6)$$
$$v_{ohm} = i . T_{ohm} = i \frac{t_m}{\sigma_m} \quad (7)$$
$$v_{conc} = i \left(c_2 \frac{i}{i_{maz}}\right) \quad (8)$$

TABLE II. SPECIFICATION OF THE POWER SYSTEM

Source	Voltage	Current	Power
PV System	500V	5A	650kW
Diesel Generator	480V	104A	50kVA
Wind Power	480V	31A	120kW
H_2 Fuel Stack	400V	75A	30kW

The power generation systems are shown in the table as an overview taken during a particular time period using a simulation. It provides information on the performance parameters of several energy sources, such as wind power, solar energy, diesel power, and hydrogen fuel stacks. The PV system operates at 500 V with a current of 5 A, demonstrating a noteworthy power output of 650 kW. On the other hand, even though the diesel generator runs at the same voltage of 480 V, it produces less power 50 kVA and requires a larger current 104 A. Wind energy produces 120 kW at 31 A with a 480 V operational voltage. Operating at a lower voltage of 400 V, the H_2 fuel stack generates 30 kW at a current of 75 A. In order to facilitate decision-making processes about the deployment and utilization of these diverse power production technologies in various scenarios, this data offers a comparative overview of their performance and efficiency. It is important to remember that these data points are simulation-derived and might not accurately represent the real-life situation.

IV. RESULT ANALYSIS AND DISCUSSION

A. Output of PV System Bus

The voltage and current characteristics of a PV bus with a filter inside a microgrid are shown in Fig. 4, represented by the graph. Approximately 800 volts has been recorded as peak-to-peak voltage, which represents the range of the voltage waveform's maximum and minimum values over a specific period. At the same time, the current waveform's amplitude difference between its highest and lowest points is measured at 10 A, which is known as the peak-to-peak current. The power provided by the PV source bus is reflected in this data, and around 600 kW power output has been recorded. The interaction of the voltage and current waveforms, as well as the unique features of the PV system, such as the effectiveness of energy transformation and any filtration mechanisms used, is represented in this power output.

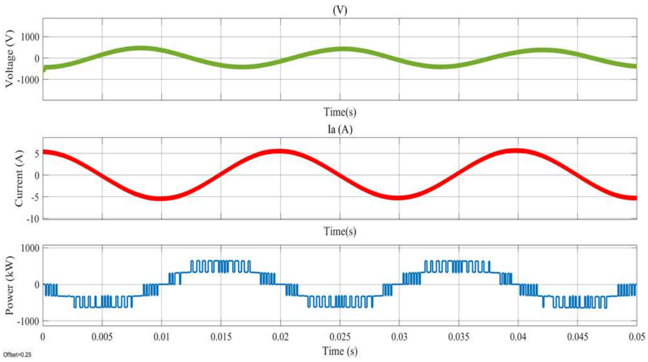

Fig. 4. Measurement of output voltage, current and power from solar PV.

B. Output of Wind Energy Bus

The wind energy bus in the proposed microgrid system produces 100 kW of power with a peak-to-peak voltage of 50 V and a peak-to-peak current of 20 kA, as shown in Fig. 5. This statistic represents the contribution of the wind source, which affects the energy mix and capacity of the microgrid. The large peak-to-peak current highlights the requirement for a strong infrastructure to manage surges, and the unpredictability of wind energy calls for sophisticated control systems to maintain grid stability. Wind intermittency impacts the microgrid's considering dependability, requiring energy storage and grid support systems.

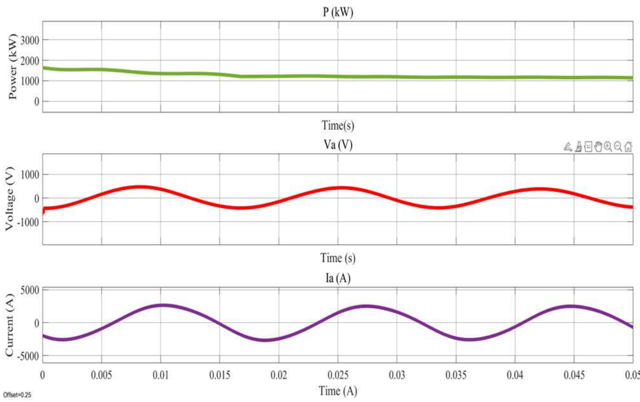

Fig. 5. Measurement of outpot voltage, current and power from wind turbine.

C. Output of Diegel generator Bus

The microgrid's Diegel generator bus supplies around 1600 kW of total power. The generation rating of 400 V peak-to-peak voltage and roughly 100 amperes current have been recorded from the generator's output (See Fig. 6). The microgrid is greatly impacted by this large power contribution, which affects its overall energy capacity and supply reliability.

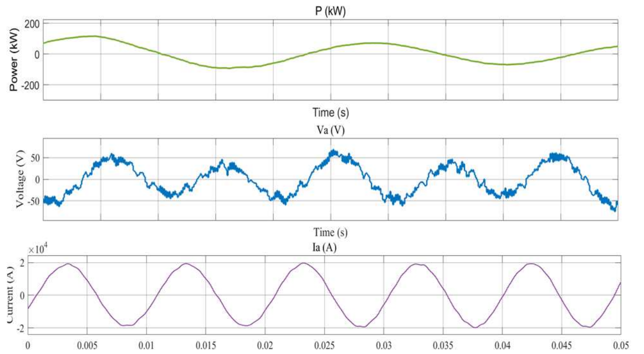

Fig. 6. Measurement of outpot voltage, current, and power from diesel power generator.

D. Output of H_2 Fuel cell stack Bus

Based on the evaluation of the H_2 Fuel cell stack, we get the following results that are shown in Fig. 7, but it becomes important to control their intermittent nature and adapt to changing power requirements. To maintain stability, a control algorithm has been designed for microgrid control systems.

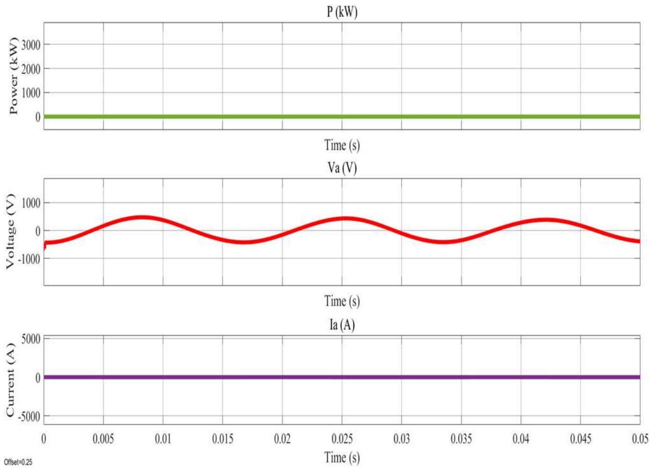

Fig. 7. Measurement of outpot voltage, current, and power from H_2 Fuel cell stack.

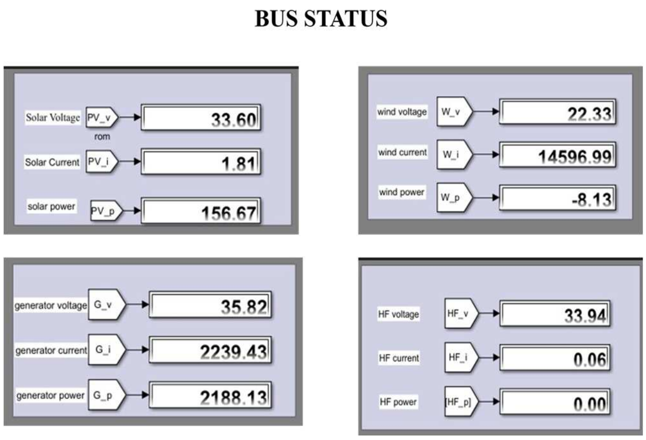

Fig. 8. Monitoring panel of proposed IoT-based Smartgrid system.

E. Real-Time Data Monitoring

In the control panel, a power monitoring unit or system would be utilized to provide the real-time status of the microgrid. Different sources of clean energy have been integrated into smart grids which makes the microgrid more efficient over traditional grids. Fig. 8 represents a sequential presentation of the simulation findings for each section.

F. Control Unit and Alert Notifications

Since the proposed microgrid system is Internet of Things (IoT) based, real-time data monitoring via a cloud server is made possible. In Fig. 9, the green indicator represents the normal operations of any branch and red indicates the faulty branch. In the control panel, If any faults occur a backup generator will operate for emergencies.

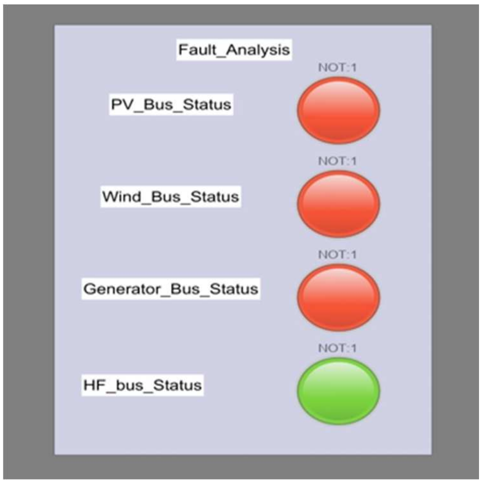

Fig. 9. Real-time bus status monitoring and control system.

Real-time electrical fault diagnosis is made easier in the microgrid system by Thingspeak adaptable warnings where the administrator can choose thresholds for voltage, current, and other variables to indicate a critical condition. With a secure login and password, authorized personnel can access this server from anywhere, as seen in Fig. 10, where ThingSpeak is the host of the prototype server used for demonstrations.

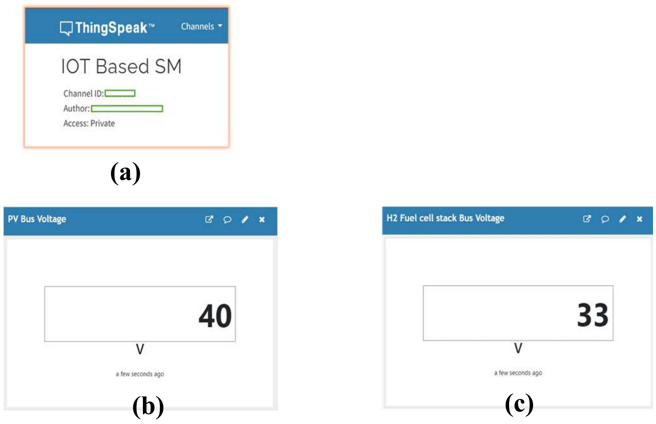

Fig. 10. Visual representation of ThingSpeak alert system.

In terms of detecting an abnormal condition, ThingSpeak promptly notifies the relevant authority through diverse communication channels, including email alerts, SMS messages, and other designated channels. This robust notification system ensures swift communication, promptly informing responsible personnel and facilitating an organized and timely response to the identified abnormality within the microgrid system. Upon detecting an issue, the system autonomously initiates corrective measures, simultaneously notifying the user via ThingSpeak. Additionally, it can trigger the activation of a backup power source, ensuring an uninterrupted power supply throughout the identified problem-resolution process.

V. CONCLUSION

The primary objective of this study is to investigate a case study to design, plan, test, and monitor using the Internet of Things of an efficient EMS. In this regard, a smart grid system is simulated on the MATLAB Simulink optimizer platform using hybrid renewable energy sources, such as solar and wind power, hydrogen fuel cells, and battery storage. The research outcome suggests that implementing an IoT-based smart grid can be a productive and efficient EM system in smart cities. Furthermore, the utilization of renewable energy sources can effectively mitigate the environmental impact. Various sustainable energy sources can ensure a continuous and uninterrupted provision of electricity, with the ability to store surplus power during power outages. Future EMS will be able to enhance their performance and billing by sharing energy quality and consumption data with power grids using IoT-based smart energy meters. Nevertheless, there is still much space for development in areas like communication protocols, safety rule reform, incoming big data control, and grid infrastructure in smart grid systems, especially among developing nations. To further improve EMS, machine learning and deep learning techniques can be used for consumer-side data measurements and analysis of power consumption behaviours to forecast efficient power grid configurations for productive power distribution.

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