Design and Analysis of IoT-Based Adaptive Microgrid System including Renewable Energy Sources for Decentralized Zones

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Abstract--- **To enhance living conditions and alleviate poverty, emerging nations require energy services that are dependable, accessible, safe, and efficient. This research study proposes an IoT-based smart microgrid system for rural areas with an enhanced control system for an efficient microgrid operation which may, in turn, solves multiple issues in the rural area. The proposed system is a combination of solar and wind power generators, diesel power stations, and backup storage, having the functionality of detecting the instantaneous fault of a branch with the help of the Bewlice lattice diagram and support vector machine algorithm and could be controlled remotely at any moment over the internet. Likewise, a power monitoring system would provide the authorities with technical attributes related to energy that would be utilized to give power to the rural area in an emergency through the Android Application, which can be retrieved and displayed using a cloud platform named ThingSpeak.**

Key Words— Microgrid, IoT, Power Monitoring, Fault analysis, Zonal fault, Relay, Busbar, Mobile application.

I. INTRODUCTION

The idea of sustainable development has created new opportunities for on-site electricity generation. Consequently, the distributed generation not managed by utility network operators demands novel design and operation. Microgrids are low-voltage, distributed energy systems that use several kilowatts from multiple sources to power a relatively small area. Microgrids have the flexibility to either feed power into a broader grid or provide power on their own. Incorporating the microgrid into the larger grid can improve efficiency and cost-effectiveness. Nevertheless, in areas with complex grid connectivity, such as mountains, islands, and isolated locales, the supply can be more regular and reliable in islanded mode. Microgrids can also be classified according to their composition, such as AC or DC microgrids. Synchronization of the grid and the requirement for reactive control are two of the various challenges of an AC microgrid [1]. On the other hand, the DC microgrid does not have these disadvantages [2]. Numerous authors [3, 4, 5] concur with the authors of this study that centralized network control cannot be used to address these growing challenges. To better accommodate distributed generation, decentralized control, and end-user market integration, the authors propose a new network design. Microgrid was first proposed by Lasseter; it is a bottom-up architectural concept that integrates heterogeneous dispersed energy generation, loads, and storage [5, 6]. Microgrid architecture can boost supply reliability, reduce customer electricity rates (lower transmission cost), transmission losses (reduce energy transport distance), and carbon footprint (replace traditional fossil fuel energy production with renewables) [7]. For the majority, microgrids have operated in one of two modes: either independently (meeting all of their own energy needs) or connected to a larger grid (importing or exporting energy as needed) [8]. Recent study has centered on the management of microgrids on islands and has focused on controlling islanded microgrids. A three-level control hierarchy is widely acknowledged [9, 10], described below:

- **Primary Level**: The voltage and current control loops of the DG unit converters use values from the primary level of control as reference values [11]. Virtual synchronous machines (VSM) and droop control are two examples of the types of control loops frequently employed at this stage [12,13].
- **Secondary Level**: Because of its role as a reference for the primary level of control, the secondary level can be used to remove voltage and frequency oscillations even at steady - state condition [14]. The system's synchronization with the wider network is simplified with this degree of control [12]. Multiagent systems [14,15] and game theory are two examples of the kinds of methods used for such control.
- **Tertiary Level**: Tertiary-level processes include P/Q import/export and network operator dispatch [16]. The tertiary level controls the microgrid's net energy import and export from the main grid. The primary level of control is used as a reference for the DG unit converters' voltage and current control loops. Set points for the microgrid's lower-level controllers can be adjusted at this level of control to achieve the microgrid's or the network's overarching goals (meeting power requirements, minimizing transmission losses, etc.) [15,16,17].

The study's primary objective is to develop a model for an IoT-based smart microgrid that will offer uninterrupted power to rural areas, having six sections. The second section addresses the regulation mechanism of microgrid system, while the third section reports microgrid-optimization. Section IV and V comprises the system Methodology and their corresponding results, respectively. Subsequently, sections VI and VII contain the conclusion of the findings and references section.

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II. Regulation Mechanism of Microgrid System

Microgrids and the integration of DER units in general provide a variety of operational difficulties that must be considered when creating control and protection systems. This is to make sure that the current level of reliability is not changed too much and that all of the benefits of DG are taken advantage of. Some of these problems are caused by wrong assumptions that are usually made about traditional distribution systems, while others are caused by stability problems that were once only seen at the level of the transmission system. The most important problems in protecting and controlling microgrids are [17,18]:

• **Power flowing scheme (Bidirectional):** Since distribution feeders are built for one-way power flow, installing DG units at low voltages can reverse the direction of power. Problems with protection coordination, unwanted energy flows, fault current distribution, and voltage management can result.

• **Modeling:** It is a common practice to assume three-phase balanced conditions, primarily inductive transmission lines and constant-power loads, when modeling typical power systems at the transmission level. This is not always the case for microgrids; thus, adjustments need to be made to the models [19].

• **Stability issues:** The control systems of DG units can communicate with one another, which can lead to local oscillations. A full investigation of stability under small disturbances is necessary. If a microgrid is going to switch back and forth between being linked to the grid and running autonomously, transient stability tests are required [19].

• **Low inertia:** In contrast to bulk power systems, which have a high inertia due to their huge number of synchronous generators, microgrids may have a low inertia, especially if there are a large number of power electronic-interfaced DG units. While such an interface can improve the system's dynamic performance, the low inertia of the system can cause significant frequency changes during standalone operation if a robust control mechanism is not implemented. Despite these obstacles, the microgrid's control system must provide reliable and cost-effective operation [20,21]. Among the desirable aspects of the control system are:

DSM: The ability to control a portion of the load must be provided by suitable DSM methods, where relevant. Additionally, the active involvement of the local population may help design affordable DSM solutions that enhance load-frequency management for the electrification of remote locations with plentiful renewable resources [23,24].

• **Power balance**: The microgrid's distributed energy resource (DER) units should be able to handle abrupt fluctuations in active power, either in excess or shortage, without causing unacceptable shifts in frequency or voltage [23,24].

• **Output control:** The output voltages and currents of individual DER units need to follow their respective reference values, and oscillations need to be dampened as much as possible.

• **Transition between modes of operation**: It is desirable for microgrids to be able to switch between grid-connected and independent modes without interruption in service. There are many possible control techniques for each mode of operation; consequently, a fast-islanding detection method is required for switching between them [24].

III. Micro Grid Optimization

Table 1 outlines the variables to be utilized to explain (define) individual scenarios of power supply [21-22]. The target Micro-Grid is comprised of new and renewable energy, a load system, and an energy storage system.

Table 1. Variable definitions [21-22]

$P_{PV}[k]$	Power (kW) derived from the generation of new and renewable energy sources in time zone k.	$P_{ESS}^{chg}[k]$	Charged ESS power (kW) in time zone k
$P_{PV,ESS}[k]$	Transmission of power (kW) from PV to ESS in time zone k	$P_{g,1}[k]$	Power (kW) received in time zone k from the power grid.
$P_{PV,Load}[k]$	Transmission of power (kW) from PV to load in time zone k	$P_{g,ESS}[k]$	Power (kW) sent in time zone k from the power grid to the ESS.
$E_{ESS}[k]$	kWh amount of energy stored in time zone k	$P_{g,Load}[k]$	Electricity (kW) transmitted in time zone k from the power grid to the load.
$P_{ESS}^{dis}[k]$	Power (kW) released in time zone k	$P_{g,2}[k]$	Power (kW) transmitted in time zone k from the power grid.
$P_{ESS,Load}^{dis}[k]$	Transmission of power (kW) from ESS to load in time zone k	$P_{\mathrm{Load}}[k]$	Load power consumption (kW) in time zone k
$P_{ESS,g}^{dis}[k]$	Electrical (kW) transmitted by the ESS to the power grid in time zone k		

Although a variety of novel and renewable energy sources are already accessible, solar power generation was chosen as a typical system for simplicity. The output of the PV system will either be employed by the load or stored in the ESS. Their information is recorded in the data storage to forecast their future values, assuming that all forms of power are constant for one hour in each time zone.

The power generated by PV is "charged to ESS" or "consumed by load" according to Equation (1).

$$P_{ESS}^{dis}[k] = P_{\mathrm{ESS,load}}^{dis}[k] + P_{E_{AS}^{dis}}^{d}[k] \qquad (1)$$

Equation (2) implies that the electricity discharged by the ESS will either be "consumed by load" or "sold to the power grid."

$$P_{ESS}^{dig}[k] = P_{ZESS}[k] + P_{PV,ESS}[k] \qquad (2)$$

Equation (3) indicates that the energy used to charge the ESS was "purchased from the electricity grid" or "produced by PV."

$$P_{g,1}[k] = P_{g,ESS}[k] + P_{g,l\,\mathrm{loal}}[k] \qquad (3)$$

The electricity received (purchased) from the power grid is "charged to ESS" or "consumed by load" according to Equation (4).

$$P_{\mathrm{S.2}}\,[k] = P_{\mathrm{ESS}\,{}^{\mathrm{dis}}_{\mathrm{SII}}}\,[k] \qquad (4)$$

The power transmitted (sold) to the electricity grid was discharged from ESS, as indicated by Equation (5).

$$P_{\mathrm{Land}}\,[k] = P_{PV,\,\mathrm{Load}}\,[k] + P^{\mathrm{dis}}_{\mathrm{ESS,Laad}}\,[k] + P_{\mathrm{g,land}}\,[k] \qquad (6)$$

Equation (6) indicates the balance between demand (right side) and supply (left side) and that load power came from PV, ESS, or grid.

$$E_{ESS}[k+1] = E_{ESS}[k] + P^{chg}_{ESS}[k]\cdot 1h - P^{dis}_{\mathrm{ESS}}\,[k]\cdot 1h \qquad (7)$$

IV. Methodology and Modeling

A. Systemic Approach

This study proposes a microgrid powered by renewable energy sources to help reduce some environmental difficulties connected with fossil fuel burning. Solar and wind energy production provides the grid with electricity. HOMER Pro was used to determine the optimal size of the PV array and battery for the BESS. In a representative scenario, the island's daily energy consumption is roughly 3,100 kWh, and its peak load is approximately 200 kW. 24 hours a day, seven days a week renewable energy penetration must be achieved with at least 750kW (3,100/4.08) of PV panels. The battery size for BESS would be excessive and uneconomical [19]. Using HOMER Pro, the optimal PV array and battery sizing for the BESS will be determined. The microgrid would be utilized to determine if the objective functions were met. Table 2.3 presents simulation results for all situations specified. For the first year, the COE is around \$0.468 per kilowatt-hour, the proportion of renewable energy is greater than 75%, and generator service hours are approximately 2,000.

Table 1. Simulation results using Homer Pro

PV (kW)	Battery (kWh)	COE (\$/kWh)	Renewable energy fraction (%)	Gen 1st yr (hours/yrs)	Gen lavg of 10yrs (hours/yrs)
750	1,000	0.460	62.09	3,906	4,931
1,000	1,000	0.467	67.44	3,420	4,447
750	1,250	0.463	65.99	3,134	4,408
1,000	1,250	0.467	72.31	2,506	3,781
1,250	1,000	0.502	70.58	3,129	4,149
1,000	1,500	0.468	76.51	2,059	3,147
750	1,500	0.469	69.22	2,671	3,926
1,250	1,250	0.480	75.95	2,158	3,400
1,000	1,750	0.476	79.33	1,911	2,743
750	1,750	0.480	71.30	2,485	3,642
1,250	1,750	0.488	83.39	1,642	2,283

Additionally, the overall system can be operated by an IoT system to add its robustness and user-end manipulation, and this project uses a diesel generator as an energy source. Solar, wind, and diesel generators generate electricity independently and add it to the grid. The microgrid is safeguarded with three-phase circuit breakers. The complete technique for this project is shown in Fig. 1. This microgrid system, however, is coupled with a power monitoring system. The display and the cloud server are constantly updated in this setup with the most recent power usage ratings. The current power status, Fault Status, Branch Status etc., are all displayed in this monitoring interface. The controller device monitors and displays the power ratings. In addition to functioning as an internal microgrid interface, it regularly uploads data to the ThingSpeak Server. The principal authorities can view the microgrid's status at any time and from any location. Fig. 2 displays the accompanying block diagram.

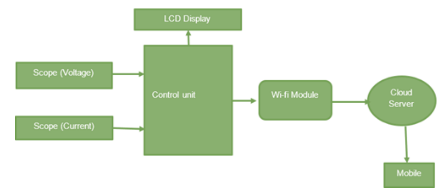


Fig. 1. Block Diagram of Cloud Communication System

B. Simulation diagram of the overall system

The proposed model uses a diesel generator, PV system, and wind energy. The diesel generator converts fuel into electricity and supplies the diesel generator bus with power. The electricity is then transferred to the relay, where an electrical defect can be identified. On the contrary, solar power generates electricity using sunshine and transmits it to the grid system. MPPT controller and Boost Converter are utilized to improve results. In this line, a 250V/25 KV transformer and a relay are employed to detect faults automatically. In the Control unit, the authority can view the voltage, current, power, fault, and branch status. Fig. 2 represents the overall scheme.

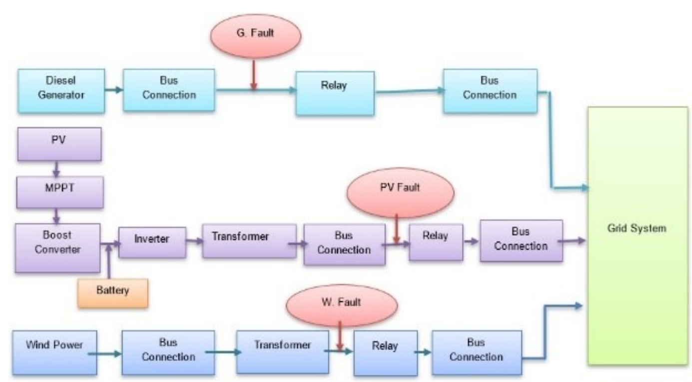


Fig 2. Simulink model for overall Grid System

This layout illustrates the connectivity between the Electrical element and the Cloud Server (given in the following Fig. 3). This transmission has only one message. The cloud will only get information from the Wi-Fi device. For communication reasons, the Wi-Fi device will serve as the Microcontroller's Auxiliary Protocol, receiving data from the Microcontroller and delivering it to cloud storage.

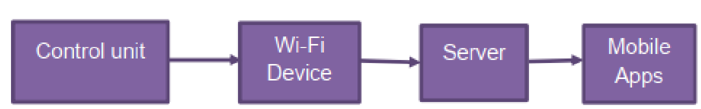
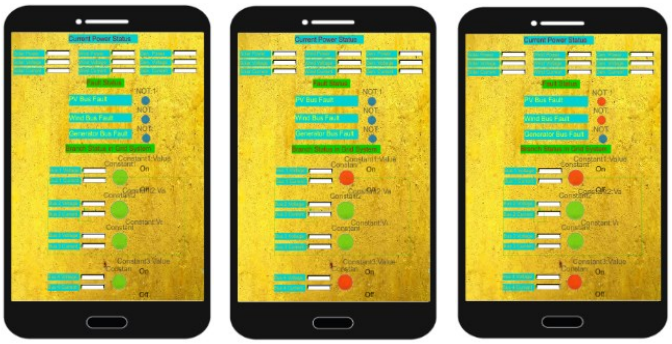


Fig. 3. Block diagram of the Architecture of the cloud Communication with Electrical system

C. Control Unit

The design of a control unit to control the microgrid system from the control room includes the addition of various status fields to display value and control as shown in fig. 4. Any branch can be turned on or off at any time by the authorities. The interface is augmented with the current, power, voltage, fault, branch current, and branch voltages as illustrated in fig. 4.



(a)Voltage, Current and power status at output end

(b) Bus 1 and bus 3 gets disconnected as per the user command

(c) PV bus and Wind bus Fault Status showing at GUI

Fig. 4. Control unit GUI

D. Mobile Application

To display the output results on mobile phones, an Android application has been developed as shown in fig. 5. There are three distinct platforms for three sources of energy. The real-time power of the microgrid system can be examined via this platform. This application is restricted to authority only. The mobile application's primary user interface is as follows:

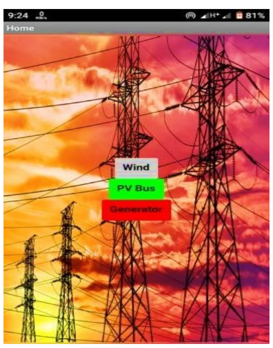


Fig. 5. Interface of Mobile Application

E. Zone-busbar fault detection and controlling

This research introduces a new fault zone identification system for busbar based on support vector machines (SVMs) and the bewlice lattice algorithm, which can distinguish between faults inside and outside the busbar's protective zone. One cycle after a fault, current signals on all lines are used as input to a support vector machine (SVM) in the proposed technique. Controlling multiple busbars simultaneously and automatically for exact power flow is likewise something that the authority can supervise

V. Results & Output Analysis

In this section, the specific results of each project component are detailed. The results of each section are listed here.

A. MATLAB Result Analysis

1) PV Bus Voltage and Current Without and With Filter

It is possible to obtain the voltage and current with and without the Filter. The first graph displays the voltage graph, while the second exhibits the current signal after filtration. In contrast, the signal without a filter is represented by the third graph, shown in fig. 6. The PV bus output power is shown in fig. 7. Because the sun does not always deliver consistently concerning the azimuth and tilt angle, and clouds continuously affect the feed-in from photovoltaic systems, renewable energy generation also produces a significant amount of frequency fluctuations in the grid.

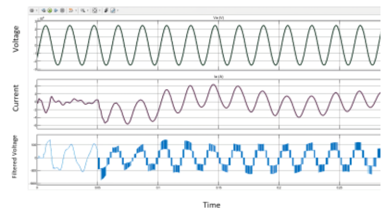


Fig 6. PV Bus Voltage and Current with & without filter

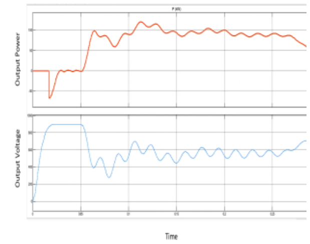


Fig 7. PV Bus Output Power & Voltage (found as 100 KW)

2) Wind Bus Output Voltage, Current & Power

Nearly 5000 kW of output power was found from the Wind Bus. Fig. 8 below shows the output graph accordingly. Maximum power for the wind turbine designed in this research is 580 kW when the wind speed is 12 ms^{-1} and higher, and that's because of the pitch angle position control. For less wind speed, the position control works to increase the output power by changing the pitch angle to a certain value so the fan rotates faster and vice versa.

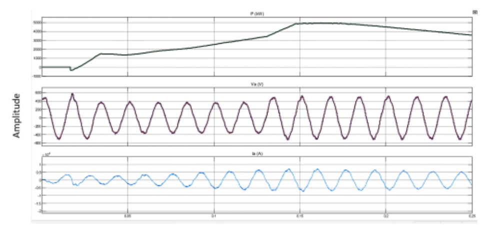


Fig 8. Wind Bus Output Voltage, Current & Power

3) Diesel Generator Bus Output

The study of the generator bus yields a value of over 16000 kW, with a voltage of nearly 2000 V and a current of 4000 A as illustrated in Fig. 9. In this event, when the load is disconnected for some instance, some reactive power is created, primarily to meet the needs of all the choke filters in the AC/DC/AC converter, resulting in a large discrepancy.

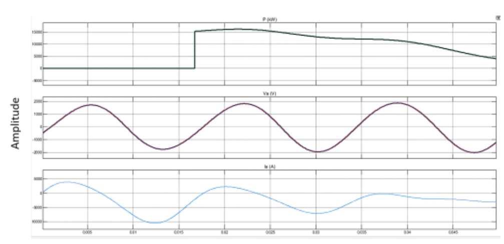


Fig 9. Diesel Generator Bus Output

4) Fault analysis at PV and Wind bus

When a generator bus electrical fault occurs, the system immediately shuts off that power source. Different sorts of electrical problems were executed. As illustrated in fig. 10, a three-phase to ground fault is applied to both the PV and wind bus at 0.051 seconds, and the power supply is immediately interrupted. Similarly, the situation concerning the grid is supplied by backup power. A considerable amount of fluctuations is visible due to the harmonics of the grid-connected at the time of the arc; later, it again stabilizes after a certain level.

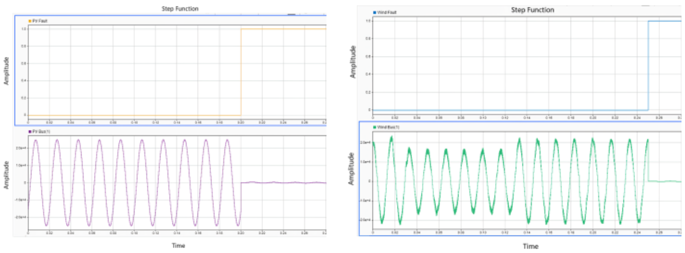


Fig. 10. Fault clearance and backup power supplying to grids

B. Zone identification for fault monitoring

A theoretical derivation and simulation approach is used to examine HVDC transmission line voltage transients and variation rates during in-zone and out-zone faults. Results reveal that in-zone fault maximum voltage variation rate occurrence time is different from out-zone fault, allowing them to be distinguished demonstrated in fig. 11.

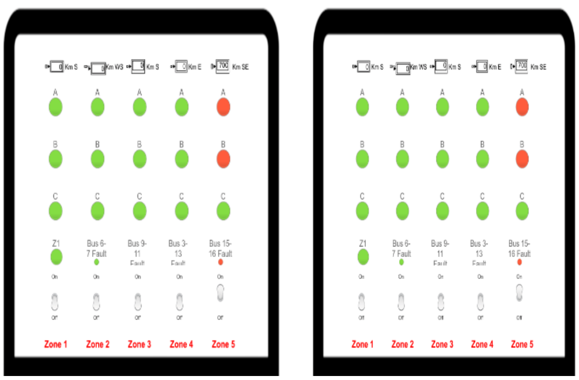


Fig 11: Identification of fault location at different zones and busbar controlling

C. Output Results in IoT platform (ThingSpeak)

As suggested by the author, the microgrid system is IoT-based, and the authorities can access real-time data using ThingSpeak Server. Using a login and password, they can log in to this server from anywhere at any time. Below, in order, are the results for the individual's section.

1) PV Branch

For this study, two field sections were developed. The first is PV voltage, whereas the second is PV power analysis. the planned PV system outputs a voltage of 278.58 kV to the ThingSpeak server and provides 100.36 kW of power as shown in fig. 12.

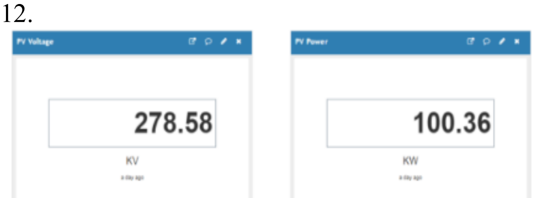


Fig 12. PV Results in Thingspeak Server

2) Wind Branch

In this analysis, wind voltage and wind power are presented. This wind module was determined to have a 30.60 kV output voltage and 136.14 kW of power. The output is displayed below in fig. 13.

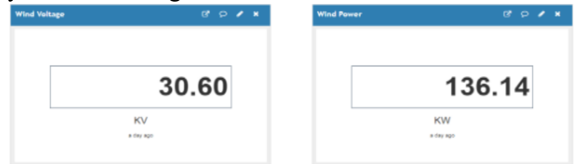


Fig 13. Wind Results in Thingspeak Server

3) Generator Results

In this section of the Generator analysis, two measurement fields for voltage and power have been established. The author obtained 279.52 kV as voltage and 2222.76 kW as owner after executing our Simulink file. The picture shown below is the output:

Fig 14. Generator Results in Thingspeak Server

The deterministic output for fault analysis and zone location identification is demonstrated in the table 3 below:

Table 2. Zone identification and fault clearance

Fault time (sec.)	Delay to clear the fault (sec.)		Zone-occurring fault	Zone-identification by model	Power fluctuation
0.06	Single phase	0.01	A (30 km)	A (28.1 km)	No
	Two phase				
	Three phase				
0.5	Single phase	0.06	B-A (42 km)	B-A (39 km)	Yes
	Two phase				
	Three phase				
2.5	Single phase	0.32	D (85 km)	D (81 km)	No
	Two phase				
	Three phase				

D. Fault Analysis

The author devised three notification lights to signify a branch's electrical issue. The occurrence of a solar energy fault implies a problem with the solar energy bus. Similarly, the wind and the generator perform identical actions on the ThingSpeak Server. This field appears below is the output viewed in fig. 15:

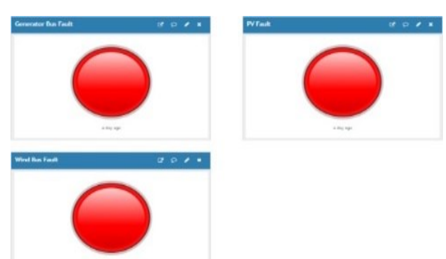


Fig 15. Fault Notification in Thingspeak Server

E. Mobile application based monitorization

The output showed the exact results that the author got in Thingspeak Server. If the branch encounters any fault, the authority will get the exact information about the occurrence, as shown in fig. 16.

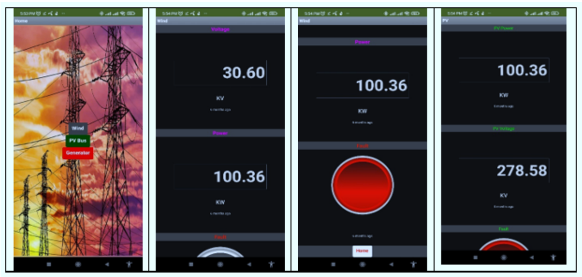


Fig 16. Results visualization in Mobile Application

VI. CONCLUSION

This research describes the primary characteristics of IoT-based micrograms and their usefulness for rural electrification. In the new context, rural electrification in large nations is a formidable obstacle. It is not cost-effective to supply rural areas with electricity from huge traditional systems. The proposed research study provides with a solution that microgrids are simple to implement and offer long-term viability. The primary objective is to demonstrate how the study can solve a real-world issue. Researchers are resolving real-world problems to benefit humanity as a whole. To improve the functionality of the grid system, various researchers have worked on a variety of microgrid efforts. In contrast, this study suggests a smart microgrid system that can be remotely monitored at any time. Additionally, using renewable energy sources can aid in reducing environmental impact. Multiple renewable energy sources can provide a continual supply of electricity, and any excess power can be stored for use in the event of a blackout.

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