Data Communication and Remote Monitoring using Raspberry Pi in a Solar-Wind-Biogas integrated Micro-grid system

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Abstract— **Micro-grid integrates the different distributed renewable energy resources such as solar, wind, and biomass. It can operate either in the stand-alone condition or in synchronization with the utility grid. Extensive research is being done on the implementation of SCADA systems for micro-grids that perform efficiently and are cost-effective. The development of effective and cost-effective real-time data acquisition and remote monitoring systems for micro-grid is essential to study the generated and consumed power quality measurement, stability, reliability, and maintenance optimization. Incomplete data and inaccurate measurement of energy output can lead to false conclusions and lost revenue. In this work, we have used Raspberry Pi for data communication and remote monitoring in a solar-wind-biogas integrated micro-grid system. Data acquisition has been done from smart meters of Elite 440-443 series of Secure Pvt. Ltd. Once the data comes to Raspberry Pi it has been used for different purposes like data display, warnings as parameters go off-limit and online remote monitoring. The operation, results and future scope of the developed data communication and remote monitoring system have been studied and analyzed in detail.**

Keywords— Data acquisition, Micro-grid, Raspberry Pi, Remote Monitoring.

I. Introduction

The increasing demand for power has led to the rapid exhaustion of fossil fuels and a dire necessity to harness clean sources of energy. Micro-grid effectively combines distributed electrical sources that use renewable energy resources such as solar, wind, and biomass as the main source of power. Micro-grids operate either in an islanded condition or in synchronization with the utility grid [1].

Data acquisition and transmission systems (DATS) in micro-grids enable continuous surveillance of the process behavior and status of the different distributed renewable energy sources connected to the micro-grid. This leads to effective monitoring of the automated system behavior with the help of real-time data through numerical and graphical visualizations. Data acquisition devices collect data from smart devices, sensors, actuators, and exchange this data with the software application that processes them [3]. Extensive research is being done on efficient and cost-effective SCADA (Supervisory Control and Data Acquisition) systems for micro-grids. The combination of several technologies such as the Internet of Things (IoT), sensors and Cloud Computing is used for the control and automation of smart micro-grids [2]. The evaluation of power quality of the generated and consumed power in micro-grids depends on the frequency, voltage and current values [4].

Major works have been done on DATS in micro-grids. An Arduino Uno based SCADA system has been developed for measuring and monitoring the PV panel temperature [5, 6]. LabVIEW based DATS for PV monitoring has been done [7, 8]. PLC and ZigBee based web monitoring DATS has been implemented [9, 10]. LabVIEW based data monitoring and control system for smart micro-grid has been implemented [11, 12, 13].

In this work, Raspberry Pi along with Elite 440-443 Modbus based smart meters are used to acquire the data of several electrical parameters in a micro-grid system for real-time monitoring. Raspberry Pi reads the digital data from the smart meters through the Modbus TCP/IP communication protocol and displays the data on a screen. Remote monitoring of these electrical data is done through the internet. The system can also send data in the cloud via the internet automatically.

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Raspberry Pi has been used for data acquisition and remote monitoring as it has multiple advantages over other embedded systems based on Linux and data loggers. It has an improved proportion of cost-benefit, a huge community of users, numerous input-output pins (40 GPIO pins for the latest versions), Python as the programming language and graphical interface [14, 18].

It is seen that most of the DATS have been implemented with the help of the LabVIEW platform being operated from a particular PC. It uses costly modules and data loggers allowing only local monitoring [14, 24]. The software of LabVIEW is large and takes a huge RAM while running. It also faces memory congestion-related issues during run time. On the other hand, Raspberry Pi is a single-board computer that is of small size and low price. It is, therefore, widely used in many real-time field applications [14]. Arduino Uno is also a low cost small-sized open-source hardware. But its clock speed is 16MHz compared to the 700MHz clock speed of Raspberry Pi. Raspberry Pi also has a larger RAM compared to Arduino Uno [15, 16].

II. EXPERIMENTAL SETUP

In this work, an integrated micro-grid system has been considered consisting of 10kWp grid-connected solar PV, 1kW wind generator 35m^3 bio-digester with 15kVA alternator installed at Centre of Excellence for Green Energy and Sensor Systems (CEGESS) located within Indian Institute of Engineering Science and Technology (IIEST), Shibpur campus. Fig 1 shows the detailed schematic diagram of the micro-grid. All the renewable energy sources namely solar, wind and bio-gas are distributed throughout the campus. The micro-grid integrates these renewable energy sources and delivers powers to the local load and the utility grid (CESC Ltd.) thorough the main control panel.

The main control panel has four Elite 440 multifunctional smart meters. These meters measure and display the various instantaneous electrical parameters [17]. Ethernet modules (TCP/IP to Ethernet converter) that are fitted to the smart meters transmit data to a Raspberry Pi through Ethernet cables and an 8-port Ethernet switch. Modbus TCP/IP protocol based on the master-slave model establishes communication between the Elite 440 smart meters and the Raspberry Pi [19]. The smart meters connected are the slave devices that transmit data to the master Raspberry Pi via Rj-45 cables. The data corresponding to any electrical parameters is stored in designated registers of the smart meter in digital form. Python codes have been written and run in the Raspberry Pi operating system that is Raspbian for accessing these 16bit holding registers from the stack of registers through the Modbus protocol.

The Raspberry Pi model used here is Raspberry Pi 3 Model B+ which has a 1.4 GHz 64-bit quad-core processor, dual-band (2.4GHz and 5GHz IEEE 802.11.b/g/n/ac) wireless LAN, Gigabit Ethernet over USB 2.0 [18]. This ensures the faster acquisition of data to the Raspberry Pi from the smart meters and transmittance of data from Raspberry Pi to other users via the internet. The Raspberry Pi is connected to an HMI display by an HDMI cable for displaying the collected data. Fig 2 shows the detailed schematic of the data acquisition system from smart meters using Raspberry Pi for the smart micro-grid system.

VNC Connect which is an open-source IoT platform following the client-server paradigm has been used in this work for the multi-user remote monitoring purpose [20]. VNC Server is installed in the Raspberry Pi whereas VNC Viewer (Client) is used in other devices for accessing the acquired data in the VNC Server through the internet.

Python codes have been written and run in the Raspbian for streaming data in the Google Cloud platform [21]. The data is stored in the online cloud storage platform and accessible as charts and tables. ThingSpeak Viewer which is a free software IoT application has been used to retrieve this data using HTTP over the Internet [22]. Fig 3 shows a detailed schematic of the remote monitoring system using Raspberry Pi for the smart micro-grid.

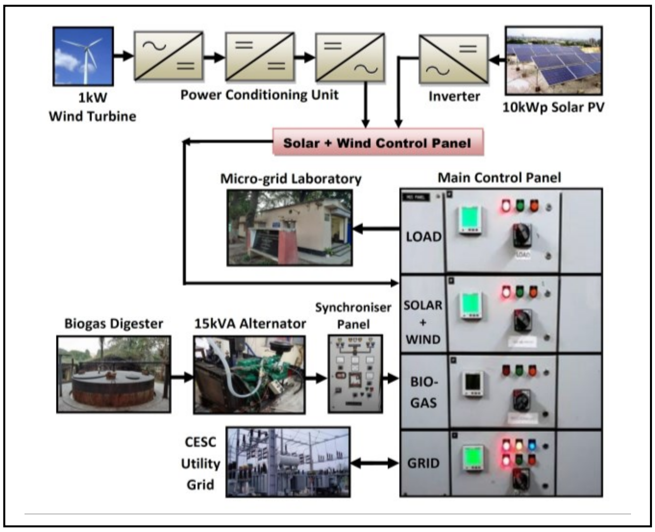

Fig 1: Schematic diagram of the micro-grid installed at IIEST Shibpur.

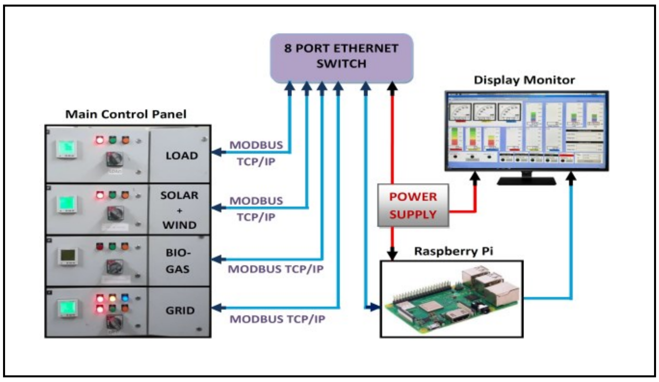

Fig 2: Schematic of the data acquisition system from smart meters using Raspberry Pi.

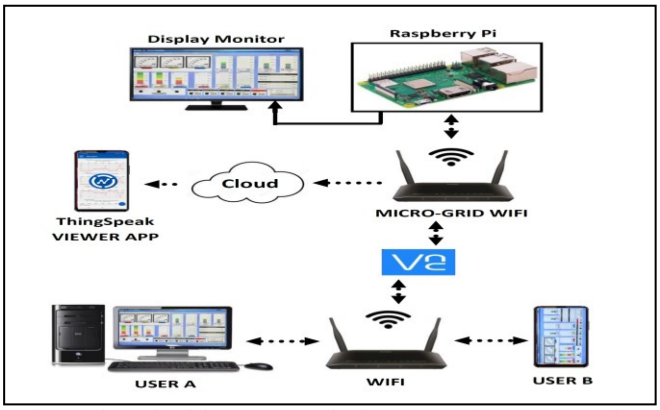

Fig 3: Schematic of the remote monitoring system using Raspberry Pi.

III. RESULTS AND DISCUSSION

The study of electrical parameters in any power plant is essential to determine the generated power quality, total plant efficiency and reliability of the power plant.

Fig 4 shows an overview of some electrical parameters of the micro-grid. The RYB phase voltages, Power Factors, Voltage THD (Total Harmonic Distortion) of Grid, instantaneous power generated from Solar + Wind and Biogas, instantaneous power consumed by the load and instantaneous power consumed or delivered by Grid, date and time has been shown in fig 4. The grid power has been considered as the difference of the generated power of (Solar + Wind + Biogas) and the power consumed by the load. The option of "Generate CSV" allows the user to download the required data for a particular time in a ".csv" file. The fault indicators give warning if any parameter goes off-limit in the RYB phases. The obtained power is integrated to calculate the generated energy and the corresponding carbon footprint.

The Solar + Wind and Bio-gas energy sources are connected to the utility grid via the control panel. Hence the voltage of all the four meters is almost constant. Fig 5 shows the instantaneous phase voltages, phase currents, active power and three-phase active power of individual meters. Fig 4 and fig 5 show the display pages on the HMI display monitor which can also be remotely monitored on other devices.

ThingSpeak Viewer has been used for accessing data in Google Cloud. Fig 6 shows a part of the data in the Google Cloud that is displayed in the ThingSpeak Viewer. Fig 7 shows the flowchart of data communication and remote monitoring using Raspberry Pi for the solar-wind-biogas integrated smart micro-grid system at IIEST, Shibpur.

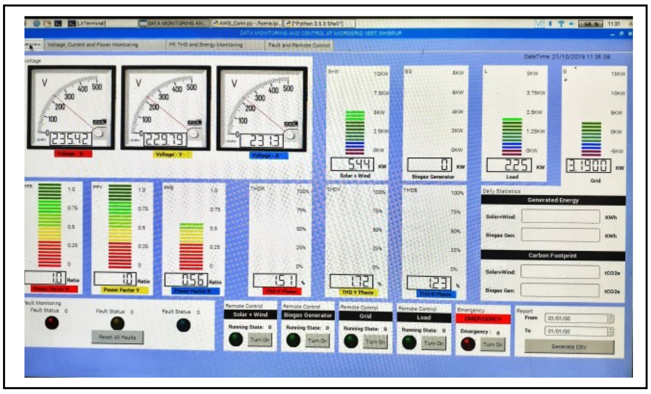

Fig 4: An overview of some electrical parameters of the micro-grid system.

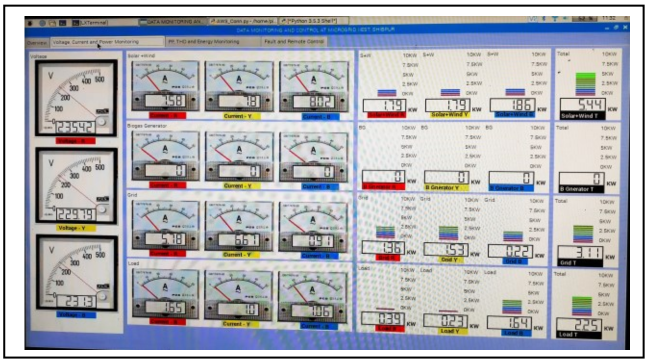

Fig 5: The instantaneous phase voltages, phase currents, active power and three-phase active power of individual meters.

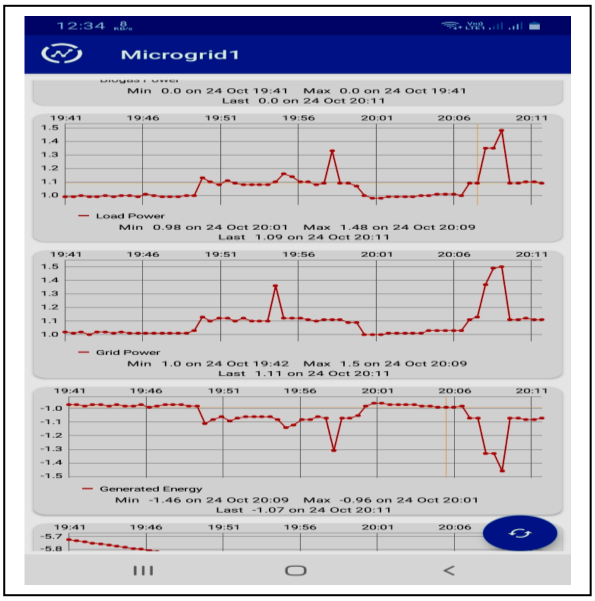

Fig 6: Data in the Google Cloud displayed in the ThingSpeak Viewer.

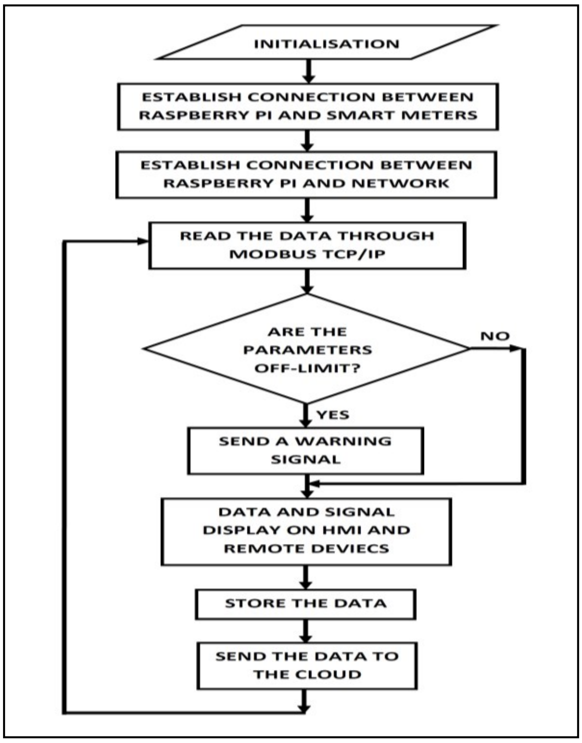

Fig 7: The flowchart of data communication and remote monitoring using Raspberry Pi.

The Elite 440 smart meters used in this work have push buttons on the front panel that is used to navigate through the various instantaneous electrical parameters [17]. Nevertheless, data acquisition and remote monitoring when done through Raspberry Pi have some advantages.

1. An overview of the important electrical parameters and fault conditions can be displayed simultaneously. This makes the maintenance of the micro-grid easier.
2. The data acquisition is faster than other IoT platforms. Hence decisions made based on the acquired data such as relay tripping, grid islanding will also be executed faster. This will make the protection system of the micro-grid more reliable.

3. The data being acquired can be stored for future analysis and study.
4. Remote monitoring has been done through open-source IoT platforms such as VNC Connect and ThingSpeak. The cost of a Raspberry Pi 3 Model B+ kit is very less compared to the total cost of the micro-grid. Hence data acquisition and remote monitoring in a micro-grid can be done effectively and efficiently by Raspberry Pi without any significant increase in the capital investment of a micro-grid.
5. The remote monitoring can be done even at faraway places from the site of the micro-grid. Hence data acquisition can be done even for the micro-grid located at the remotest places.

IV. FUTURE SCOPE

The future scope and further improvement of the designed data communication and remote monitoring system for a solar-wind-biogas integrated micro-grid system are discussed below.

1. By studying and analyzing the data obtained, prioritization of the operation of the different renewable energy sources according to the load and generation may be done in the future [1]. This will help in the generation side as well as the load side management.
2. The decrease in the efficiency of solar panels due to the accumulation of dust, sand, dry leaves, and twigs poses a major challenge for solar photovoltaic plants [23]. In the future panel temperature and panel efficiency of the installed solar photovoltaic plant may be measured and the data can be acquired and displayed through this data communication and remote monitoring system. The amount of incident solar radiation and the amount of solar energy harnessed by the solar panels may be measured and calculated and accordingly cleaning systems may be operated to maximize efficiency.
3. For better analysis and further improvement, in the future, the amount of biogas flow may be measured and the data may be acquired and stored with the help of the developed system. This can lead to further study and analysis.

V. CONCLUSION

Data sensing, monitoring, and control play an important role in the operation of a smart micro-grid system. Sensing of data has to be done for different locations of micro-grid and the acquired data has to be sent to the control unit for the efficient operation of a smart micro-grid. In this work, the data communication and remote monitoring system in a micro-grid by Raspberry Pi has been summarized. The applications and future scope of the developed system have been discussed.

Micro-grid integrates the various distributed renewable energy sources and is increasingly finding a strong foothold in the power generation sector. By impregnating digital intelligence, the micro-grid will reformate the way electricity is produced, transmitted and consumed.

VI. ACKNOWLEDGMENT

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