Received: 29 September 2021 | Revised: 4 February 2022 | Accepted: 28 February 2022

DOI: 10.1002/ese3.1130

ORIGINAL ARTICLE

Monitoring of renewable energy systems by IoT-aided SCADA system

Md Ohirul Qays[1] | Musse M. Ahmed[1] | M. A. Parvez Mahmud[2] | Ahmed Abu-Siada[3] | S. M. Muyeen[4] | Md Liton Hossain[3] | Farhana Yasmin[1] | Md Momtazur Rahman[5]

[1]Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, Malaysia

[2]School of Engineering, Deakin University, Geelong, Victoria, Australia

[3]Discipline of Electrical and Computer Engineering, Curtin University, Bentley, Perth, Australia

[4]Department of Electrical Engineering, Qatar University, Doha, Qatar

[5]Electron Science Research Institute, Edith Cowan University, Joondalup, Western Australia, Australia

Correspondence
S. M. Muyeen, Department of Electrical Engineering, Qatar University, Doha 2713, Qatar.
Email: sm.muyeen@qu.edu.qa

Abstract

With the rapid increase of renewable energy generation worldwide, real-time information has become essential to manage such assets, especially for systems installed offshore and in remote areas. To date, there is no cost-effective condition monitoring technique that can assess the state of renewable energy sources in real-time and provide suitable asset management decisions to optimize the utilization of such valuable assets and avoid any full or partial blackout due to unexpected faults. Based on the Internet of Things scheme, this paper represents a new application for the Supervisory Control and Data Acquisition (SCADA) system to monitor a hybrid system comprising photovoltaic, wind, and battery energy storage systems. Electrical parameters such as voltage, current, and power are monitored in real-time via the ThingSpeak website. Network operators can control components of the hybrid power system remotely by the proposed SCADA system. The SCADA system is interfaced with the Matlab/Simulink software tool through KEPServerEX client. For cost-effective design, low-cost electronic components and Arduino Integrated Development Environment ATMega2560 remote terminal unit are employed to develop a hardware prototype for experimental analysis. Simulation and experimental results attest to the feasibility of the proposed system. Compared with other existing techniques, the developed system features advantages in terms of reliability and cost-effectiveness.

KEYWORDS

energy and asset management, hybrid renewable energy system, Internet of Things, online condition monitoring

1 | INTRODUCTION

Recently the advancement and consideration of renewable energy sources (RESs) have been substantially increased. Among them, solar power, wind farms, and battery energy storage have been given much attention.[1–6] Generally, RESs are installed in remote areas or offshore and thus, a reliable condition monitoring and control system has become essential to manage such valuable assets over long distances.[7,8] Jiang et al.[9] introduced a Supervisory Control and Data Acquisition (SCADA) system and intrusion tolerance scheme to confirm the reliability of power systems. A SCADA software and hardware system have been tested in Reference[10] to manage the operation of protection relays. The proposed model has been tested on the IEEE-9 bus system. Additionally, an operative approach for assembling comprehensive and precise power production data would be essential for hybrid power systems.

A few number of papers can be found in the literature,[11–13] for enhancing the RESs effectiveness and monitoring systems. These papers recommended the essential need for future research on online monitoring systems. A biogas power plant was designed in Reference[14] using Wonderware Intouch software to vary the digester parameters safely. The parameters were displayed using MATLAB codes that represented the messages in the SCADA system. In Reference[15] a SCADA system of a power distribution network has been employed for fault detection within the network. Wonderware Intouch software was implemented to simulate the model that is associated with Arduino ATmega2560 component for experimental validation.

2 | RELATED WORK

In Reference,[16–18] IoT-based SCADA system has been presented to integrate renewable energy sources and smart grid (SG) communication protocols. In this regard, cloud computing and quality of service have been discussed. Jiang et al.[19] proposed Internet of Things (IoT) based power grid observation method with the help of dynamic thermal rating. The method was tested on a 161 kV power line that

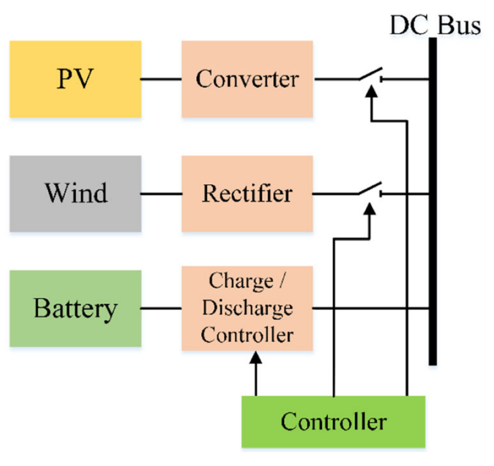

FIGURE 1 Structural diagram of the investigated hybrid power system. PV, photovoltaic

TABLE 1 Summary of the literature review

Year	References	Focus
2016	34	Concept of IoT in RESs
2017	35	Satellite services applied in SG system
2018	36	How IoT can be implemented on power systems
2019	37	IoT-aided smart metering system
2020	38	Home appliances monitoring via IoT
2020	39–41	Monitoring of RESs by controlling battery state of charge and its lifetime
2021	42,43	IoT-aided home energy management
2021	44	Energy management scheme for charging of electric vehicle by IoT scheme
2022	This paper	Monitoring of RESs by IoT-aided SCADA method

Abbreviations: IoT, Internet of Things; RES, renewable energy source; SCADA, Supervisory Control and Data Acquisition; SG, smart grid.

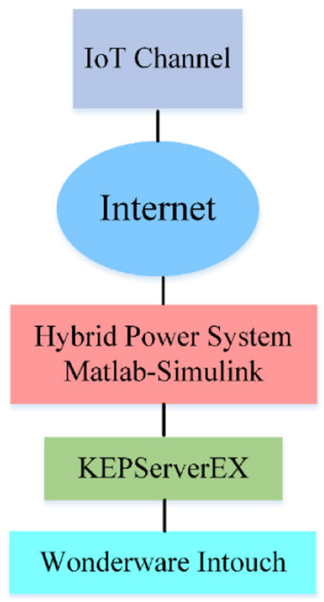

FIGURE 2 Block diagram of the proposed supervisory control and data acquisition system. IoT, internet of things

caused less than 0.8°C root mean square error on the reassembled conductor temperature. An IoT-based off-grid power supply system consisting of reversible solid oxide fuel cell, photovoltaic (PV), and battery storage was presented in Reference[20] to ensure the safe operation of oil and gas pipelines monitoring platform. PV, wind generator-based hybrid system was investigated in Reference.[21] The certain research investigated an experimental prototype and visualized the outcomes in the WEB browser.

A fast data storage system with high reliability and availability is required in the sensors data monitoring systems[22,23]. ThingSpeak web server was employed in Reference[24] to store the sensed data of PV and wind turbine-based hybrid systems. Twelve voltage and current sensors were utilized to send and store the data that performed a success rate of 94.35%. NodeMCU ESP8266 electronic component was used in Reference[25] to monitor the condition of real-time environment via the ThingSpeak website. A hardware prototype was accomplished using DHT11 composite sensor (for temperature and humidity) and the MQ7 gas sensor that can update the data every 15 s. Similarly, thermal power plant emitted data was visualized in Reference[26] with the help of ESP8266 and ThingSpeak website interfacing system. The proposed system was again extended into the Blynk App that facilitated publicizing the outcomes. Arduino ATMega2560 was interfaced with voltage, current, and water sensors: ZMPT101B, ACS712, and YF-S201; respectively, in Reference[27] to supervise the state of a microhydropower plant. A Wi-fi router was casted-off to transmit the experimental data to the ThingSpeak database every 30 s.

According to References[28] and[29] data synchronization of IoT technique is jeopardized due to the hardware limitation, environmental conditions, and limited infrastructure. A cloud and IoT-based system was developed in Reference[30] to monitor the condition of wind turbines remotely. Although the Microsoft Azure cloud computing system was applied to record the collected

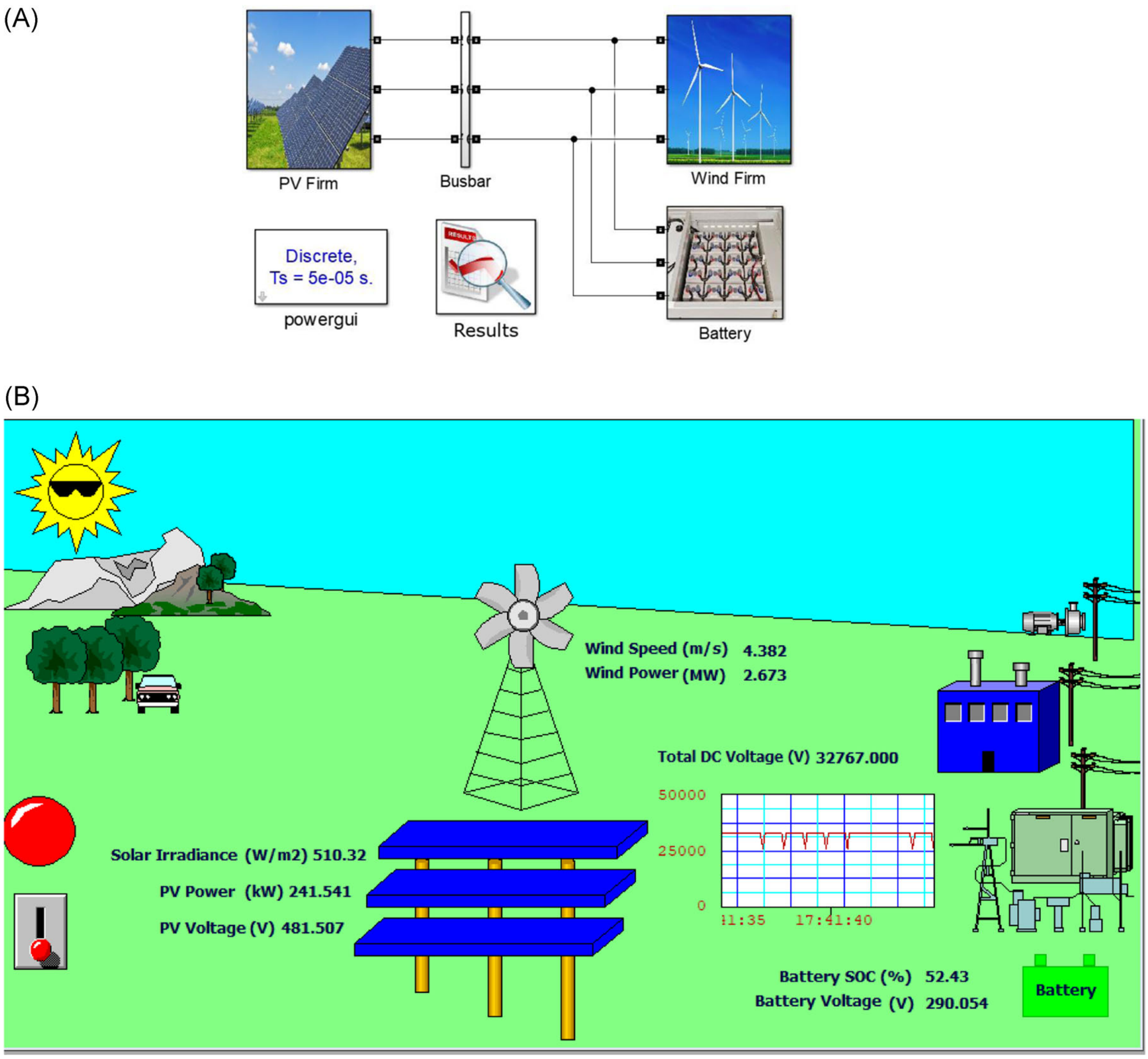

FIGURE 3 (A) Simulated model in SIMULINK software and (B) schematic diagram of the proposed model in Wonder Intouch software

data, a small sort of machine was engaged to collect the produced data. In Reference,[31] ThingSpeak website was deployed to represent the IoT-aided solar power monitoring system. A Raspberry pi was interfaced to gather the signals from multiple battery sensors. A small wind turbine was simulated in Reference[32] to monitor its condition via IoT scheme. Raspberry pi and Arduino were used to manage the data of a DC generator, representing an actual wind turbine. The solar PV power was monitored in Reference[33] by dint of GPRS system and HTML file. Though the power conditioning unit of PV was revealed in the web server, the experimental validation was not presented for real-life applications.

Table 1 briefly summarizes IoT-based energy-related literature along with the focus of this paper. Herewith, the proposed IoT-based SCADA method for RESs has been presented in the paper to emphasize its key features over conventional monitoring systems. To the best of the authors' knowledge, IoT-aided SCADA system can provide a better solution to manage RESs installed in remote and offshore areas. No such investigation has been examined in the literatures formerly. Thus, the main contribution of this paper is to introduce an IoT-based SCADA system to monitor and manage RESs remotely. The feasibility of the proposed system is validated through simulation and experimental analyses using Matlab-Simulink and Thing-Speak website along with a developed hardware prototype model.

The remaining of this study paper is organized as follows.

The modeling approach of the projected hybrid power system is described in Section 3. Section 4 illustrates the simulation and experimental exploration in detail. In Section 5, key outcomes and a discussion of the projected model are presented. The conclusion of the paper is drawn in Section 6.

3 | MODELING APPROACH

The modeling of IoT-based analysis for RESs is conducted by structuring a hybrid power system and designing the proposed web SCADA system as elaborated below.

3.1 | Hybrid power system architecture

The structure of the investigated hybrid power system is shown in Figure 1.[45] The system is made up using PV plant, wind farm, and a battery storage system. The three sources are coupled to a DC bus as shown in the figure.

3.2 | Web SCADA system design

The SCADA system is implemented with the help of Wonderware Intouch software that is interfaced with Matlab-Simulink via KEPServerEX 6.0 software. In this way, the hybrid power system simulated on the Simulink environment can be accessed by the external SCADA system. The "Real-Time OPC Config" block of Simulink library can facilitate spontaneous data transfer between the above software tools. All parameters to be measured and supervised are assigned with unique tag names and addresses. The block diagram of the SCADA system is shown in Figure 2.[46] The collected data are sent to the IoT channels for precise monitoring and safe storage.

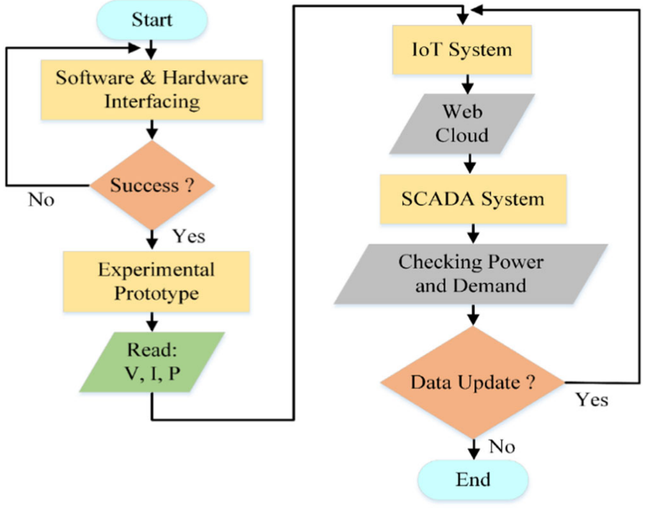

FIGURE 4 Flowchart of the proposed methodology

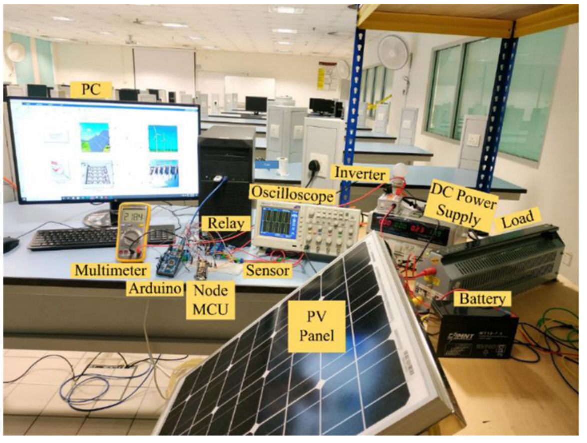

FIGURE 5 Experimental prototype of the proposed system

4 | METHODOLOGY

The proposed IoT-based SCADA system is verified through simulation and experimental analyses as described below.

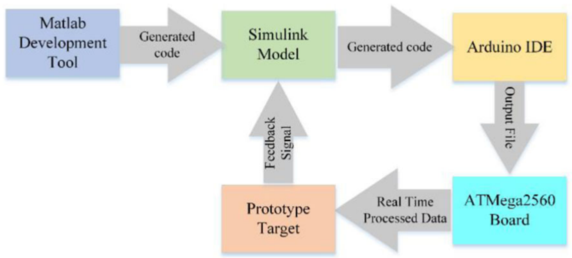

FIGURE 6 Integration of Code Generation block diagram between MATLAB and Arduino integrated development environment (IDE)

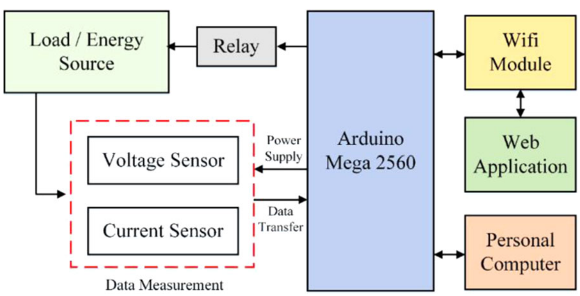

FIGURE 7 Interfacing of Arduino with other components

4.1 | Simulation model

Figure 3A shows the proposed SCADA system in which the PV plant, wind farm, and the battery bank are connected to a DC bus bar. The projected model is simulated in MATLAB/SIMULINK 2019b software. To simplify the simulation, a 240 kW PV system is simulated along with a 3 MW wind system.[47,48] In addition, a battery bank is presented as a storage system conducted with a 50 A constant load.[49] A SCADA software namely Wonderware Intouch, represents the simulated model is shown in Figure 3B.

The Wonderware Intouch software provides a graphical tool that interfaces with the SIMULINK model as a means of KEPServerEX software. The central display of the SCADA system comprises the graphical animation of the controlled hybrid power system and the monitored electrical parameters. The front-end display entails three subsystems: PV, wind turbine, and battery bank. The graphical animation displays the voltage, current, and power of each subsystem individually. In this hybrid power system, as shown in the flowchart of Figure 4, relay switches are casted-off for connecting/disconnecting the power from the DC bus. The supervision and controlling of the SCADA system is accomplished with the help of IoT technology. Since instantaneous data monitoring is the principal objective of this study, the collected data from the RESs are sent to the IoT-based ThingSpeak web server toward gathering and storing it. In this regard, a web cloud-based channel namely "Power Analysis" has been created to facilitate monitoring the investigated model's components.

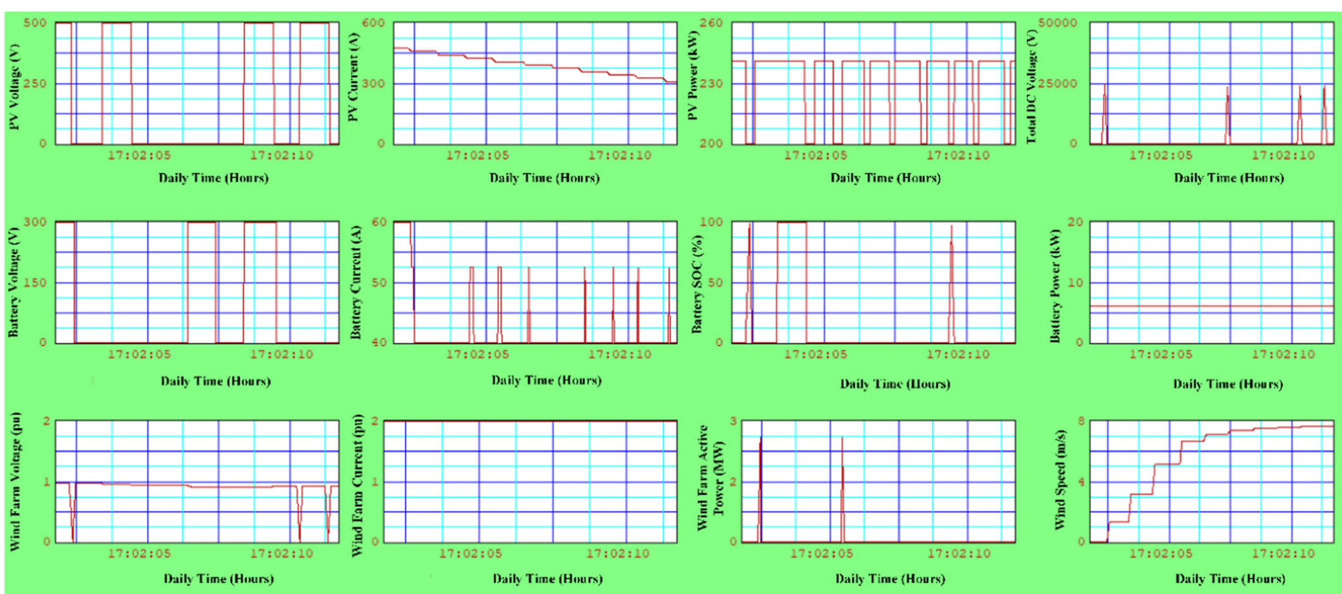

FIGURE 8 Performance of the hybrid system in Supervisory Control and Data Acquisition software

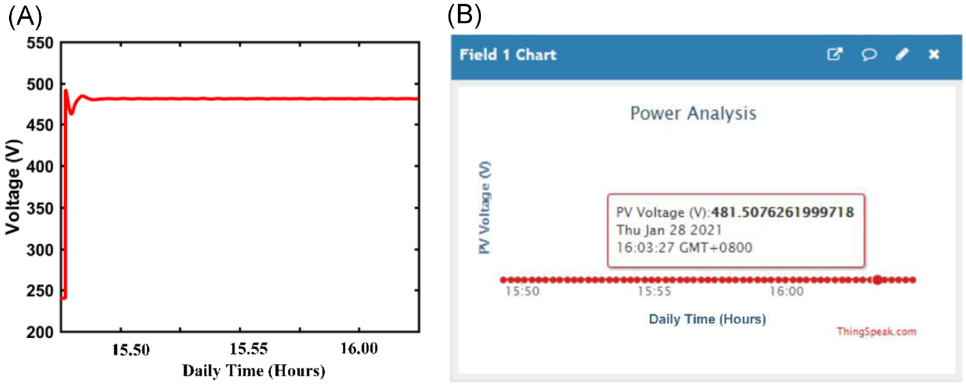

FIGURE 9 Photovoltaic voltage in (A) MATLAB view and (B) ThingSpeak website

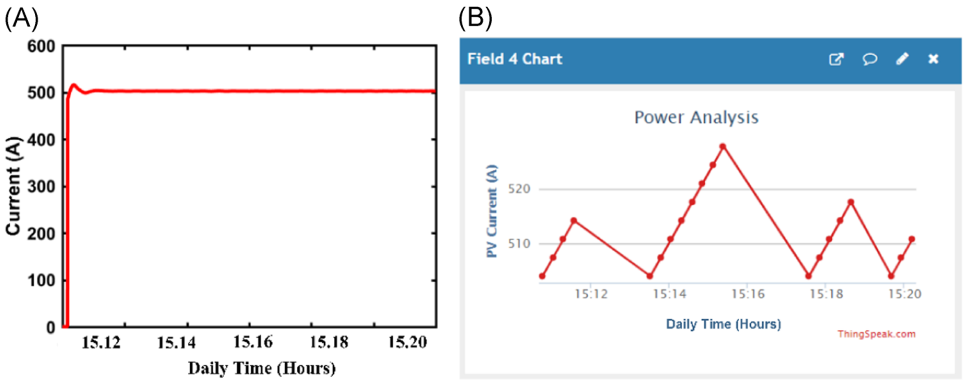

FIGURE 10 Photovoltaic current in (A) MATLAB view and (B) ThingSpeak website

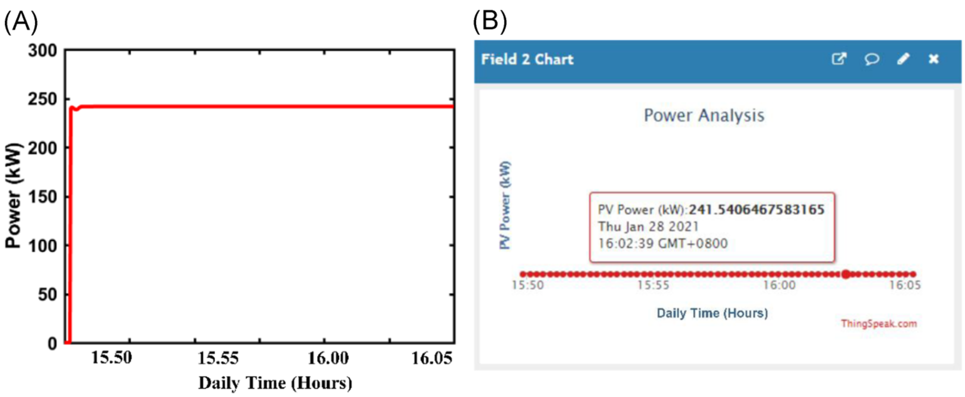

FIGURE 11 Photovoltaic power in (A) MATLAB view and (B) ThingSpeak website

The updated data of the power sources and load demand are also drawn into the Wonderware Intouch display, for further offline analysis. Thus, the SCADA system can supervise the entire system by acquiring the collected data continuously. Since the main contribution of this study is to monitor the instantaneous state of the RESs with the help of wifi or IoT-aided data acquisition, the synchronization of sending and receiving data is maintained by comparing the quantity of data seen by the MATLAB view and ThingSpeak website.

4.2 | Experimental model

As revealed in Figure 5, a hardware prototype of the proposed model has been developed in laboratory

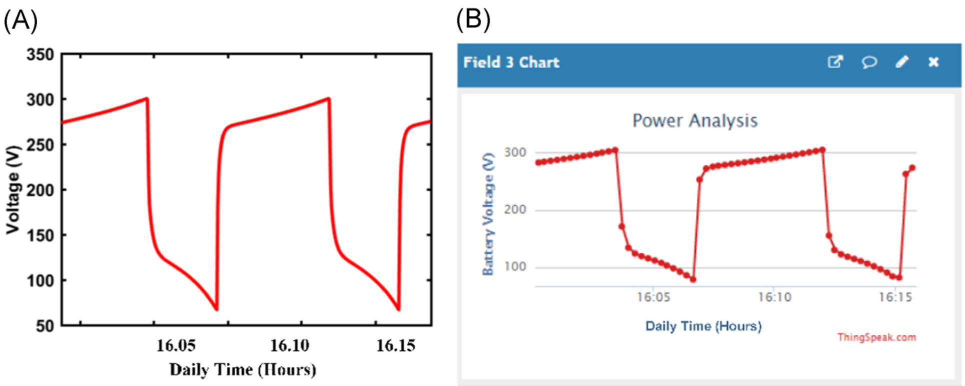

FIGURE 12 Battery voltage in (A) MATLAB view and (B) ThingSpeak website

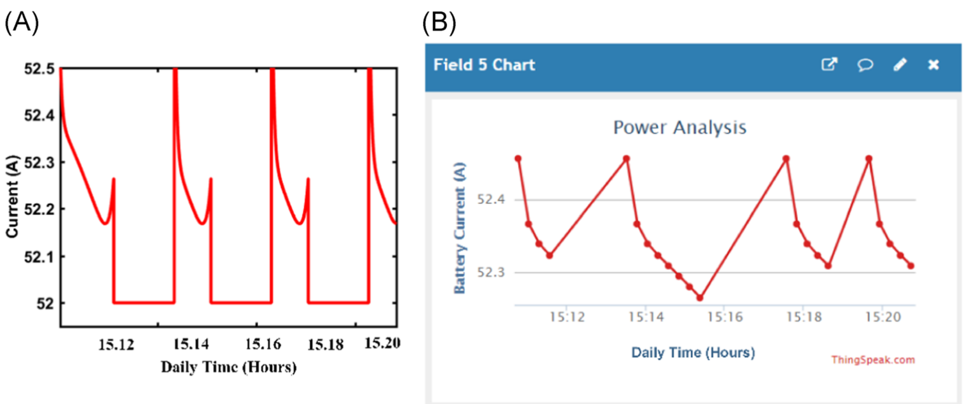

FIGURE 13 Battery current in (A) MATLAB view and (B) ThingSpeak website

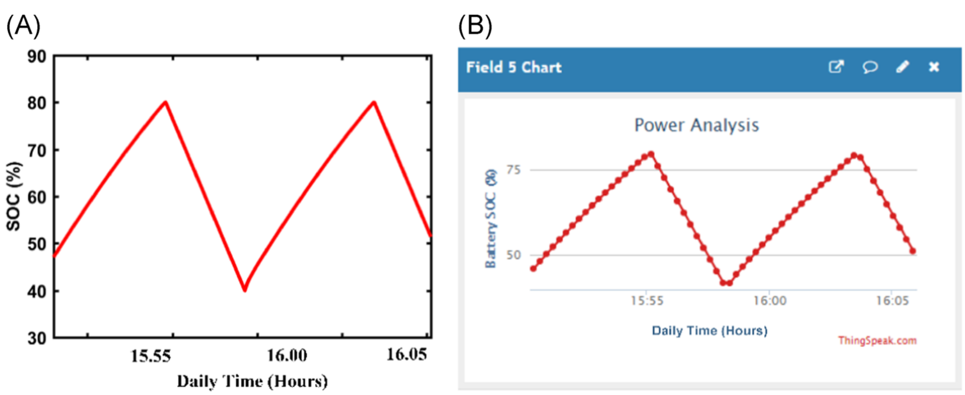

FIGURE 14 Battery SOC in (A) MATLAB view and (B) ThingSpeak website

environment. A PV solar panel with nameplate date, $V_{OC} = 21.5$ V, $I_{SC} = 3.50$ A, and $P_m = 55$ W is installed with a 12 V, 7 Ah lead-acid (LA) battery and an AC bulb (5.5 W, 240 V, and 50 Hz) as a load. A SUVPR power inverter is attached to the AC bulb to convert the DC into AC voltage. The PV panel, LA battery, and load are linked through fuse and circuit breaker (CB) and the MATLAB/SIMULINK 2019b software is interfaced together with the Arduino integrated development environment (IDE) ATMega2560 remote terminal unit (RTU) controller on Windows 10 (professional operating system) using a personal computer (PC). RTU is the field device that reads data from the sensors and refers commands to the actuators. The integration of MATLAB and Arduino IDE code generation block diagram is illustrated in Figure 6. Voltage and current data are

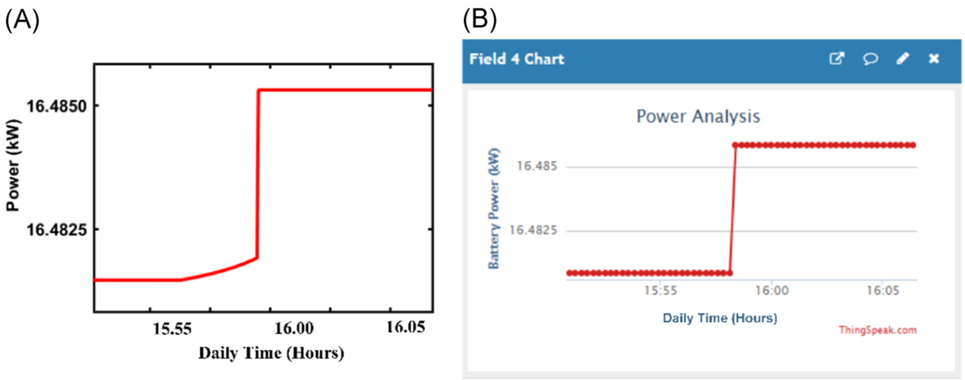

FIGURE 15 Battery power in (A) MATLAB view and (B) ThingSpeak website

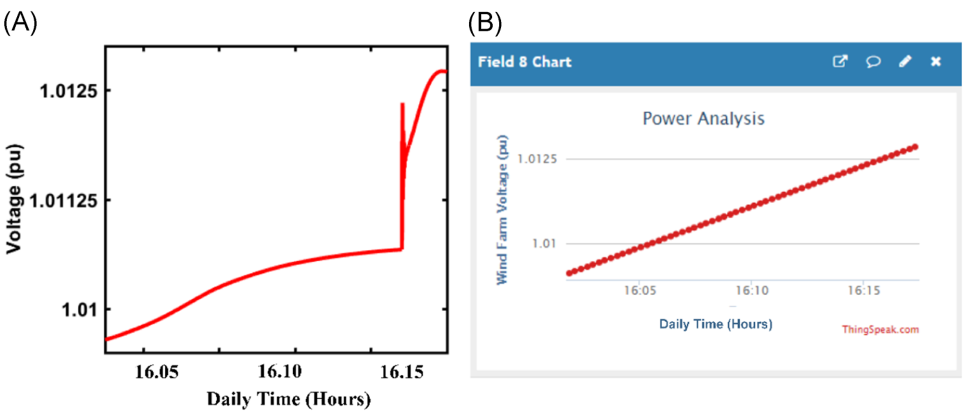

FIGURE 16 Wind firm voltage in (A) MATLAB view and (B) ThingSpeak website

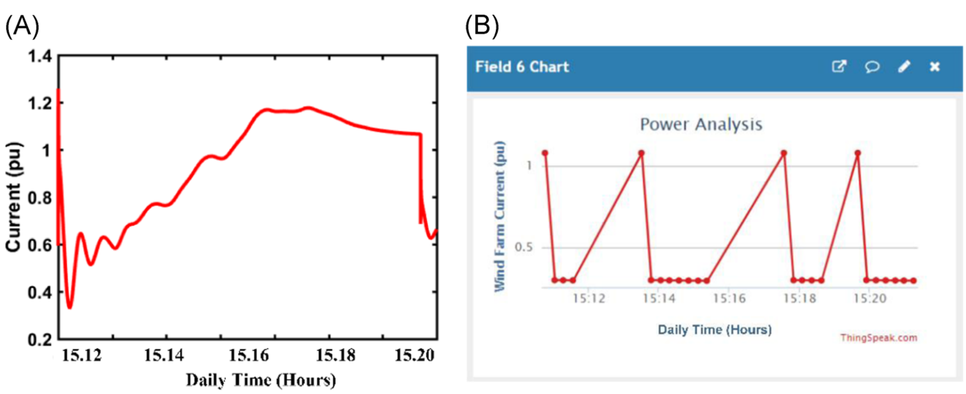

FIGURE 17 Wind firm current in (A) MATLAB view and (B) ThingSpeak website

measured by dint of voltage and current sensors and are provided to the PC model via ATMega2560 electronic board.

The SIMULINK model analyses the received data and estimates the generated power for a particular period. As shown in Figure 7, a Wi-fi module, namely NodeMCU and ESP8266 is introduced with the ATMega2560 electronic board to transfer and receive the real-time power sources/load data in the ThingSpeak web server. Voltage and current signals are sensed with the ACS712 sensors. The control system is aimed at connecting or disconnecting the power sources from the DC-bus to optimize the energy supply. The Wi-fi module connected to the SCADA system through the RTU device delivers the signal to control the operation of the CBs connecting these sources to the DC bus bar.

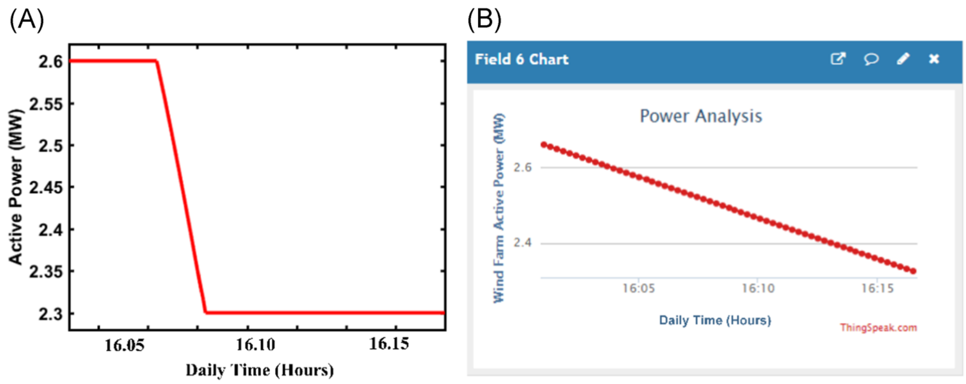

FIGURE 18 Wind firm active power in (A) MATLAB view and (B) ThingSpeak website

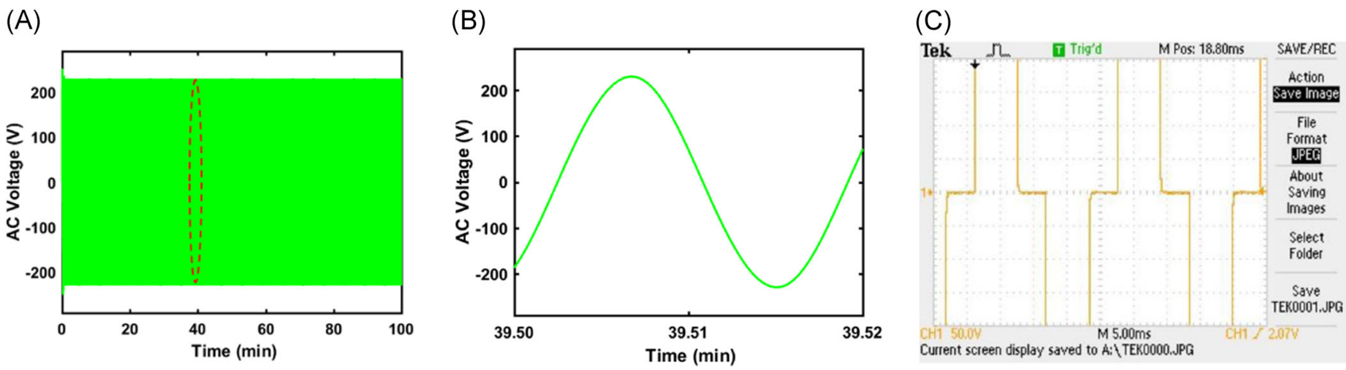

FIGURE 19 (A) Density of AC voltage production, (B) pure AC sine wave, and (C) modified AC sine wave view in oscilloscope

TABLE 2 Comparison of proposed model with other existing models

Year	References	Energy resources	Simulation	Experimentation	Data synchronization
2019	52	Wind	Yes	No	Not presented
2020	31	PV	Yes	Yes	Not presented
2021	53	PV	Yes	Yes	Not presented
2021	54	Wind	Yes	Yes	Not presented
2022	Proposed model in this paper	PV, battery, wind	Yes	Yes	Presented

Abbreviation: PV, photovoltaic.

5 | RESULT AND DISCUSSION

The proposed SCADA system is instigated with a hybrid power system, as well as several simulations and experimental analyses are conducted. The investigations cover the power sources, the functionality of the SCADA system, and IoT features for a short daily period (hours). The performance of the proposed hybrid power system is shown in Figure 8 by SCADA-based Wonderware Intouch software. It is to be noted that in Figure 8 through Figure 18, the parameters are analyzed using the same unit, for instance, PV and battery voltage is in volt (V), PV and battery current is in ampere (A), PV and battery power is in kilowatt (kW), battery SOC is in percentage (%), wind turbine voltage and current is in per unit (pu), while the wind power is shown in megawatt (MW) over a daily time (hours).

To confirm the control functions of the SCADA system, the monitoring and control tasks presented on the simulation results of MATLAB/SIMULINK software are observed and compared in real-time via ThingSpeak website. Figure 9 shows the PV output voltage as 481.50 V in Matlab and ThingSpeak website. Albeit the slight fluctuation that can be observed in the measured PV current as depicted in Figure 10, around 241 kW power has been produced within this duration (Figure 11).

Figures 12–14, show the parameters of the battery storage. A fluctuation of the battery voltage can be noticed in Figure 12 that results in fluctuated current and state of charge (SOC) (Figures 13 and 14, respectively). The fluctuation is occurred due to the irregularity of environmental situation and switching condition. However, as depicted in Figure 15, approximately 16.48 kW of power can be maintained during this period. Although as shown in Figure 16A, the initial terminal voltage of the wind turbine increases irregularly, a sudden escalation is noticed after few moments. Nevertheless, only the steady incremental trend is shown in Figure 16B owing to the discrimination of wifi or data synchronization. According to References[50] and[51] the manufacturing differences of the devices raise a slight data discrepancy in the clock oscillators that affects the synchronization of frequency. The atmospheric conditions and internet issues are further revealed in Figures 17 and 18. From Figure 17 within a period of nearby 10 min, roughly 1.02 pu current is provided and approximately 2.6 MW active power is generated as shown in Figure 18 that again decreases gradually. This is attributed to the intermittent characteristics of wind speed.

To improve the reliability of the proposed model, the produced DC voltage is rehabilitated into AC voltage as displayed in Figure 19. Figure 19A shows the created AC voltage from which the pure AC sine wave is obtained as shown in Figure 19B. Figure 19C reveals the modified AC signal attained from the experimental measurements of low-powered components.

A brief comparison of the proposed model with other systems recently published in the literature is depicted in Table 2. Previously, IoT-aided PV or wind turbine has been investigated alone without certifying the data synchronization for sending and receiving place. In the proposed system, data synchronization is confirmed by delineating the two individual displays on MATLAB and ThingSpeak website. The proposed technique can be particularly adapted to observe the instantaneous status of power converters,[55] as well as different pliable ac transmission systems.[56]

6 | CONCLUSIONS

This paper illustrates a monitoring technique for hybrid renewable energy-based power sources through Wi-fi. An IoT-based SCADA of PV-wind-battery combined system has been introduced to monitor and control the individual components remotely. The monitored data of the simulated model are transferred to the online platform via experimented condition in real-time. The key conclusions of the obtained results can be drawn in the following bullet points:

- The proposed method can monitor the electrical data of multiple energy sources installed in remote locations through SCADA system in real-time.
- The proposed methodology to combine the SCADA software Wonderware Intouch and simulation model using Simulink can transfer data via IoT-based scheme.
- The proposed SCADA system is further developed by including the experimental ambience to independently monitor and control the hybrid power system situation.
- The RESs can be effectively monitored via a cost-effective online-based ThingSpeak website.
- A comparison with other standard techniques reveals the effectiveness of the proposed method.

In the future, the proposed system can be extended to tackle the low latency and network security issues of the IoT-aided overhead-communication networks. Also, the economical and user-friendly prototype will be developed for commercialization.

ACKNOWLEDGMENTS

The publication of this article was funded by Qatar National Library. This study was supported by the Ministry of Higher Education (MHE), Malaysia and Universiti Malaysia Sarawak (UNIMAS) for Funding Project entitled by *Simulation of Smart Grid-based Two-Way Communication Framework for the Wide Area Measurement,* Project No: FRGS/1/2019/TK04/UNIMAS/01/1.

ORCID

Md Ohirul Qays http://orcid.org/0000-0003-1949-7160
Musse M. Ahmed http://orcid.org/0000-0001-5132-5743
M. A. Parvez Mahmud http://orcid.org/0000-0002-1905-6800
Ahmed Abu-Siada http://orcid.org/0000-0002-2094-3036
S. M. Muyeen http://orcid.org/0000-0003-4955-6889
Md Liton Hossain http://orcid.org/0000-0001-9393-6534
Farhana Yasmin http://orcid.org/0000-0001-7377-0688
Md Momtazur Rahman http://orcid.org/0000-0001-9688-5074

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How to cite this article: Qays MO, Ahmed MM, Parvez Mahmud MA, et al. Monitoring of renewable energy systems by IoT-aided SCADA system. *Energy Sci Eng*. 2022;10:1874-1885. doi:10.1002/ese3.1130