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Applying IoT Platform to Design a Data Collection System for Hybrid Power System

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***Abstract*—For monitoring the energy supply from the hybrid small-scale wind turbine generators and rooftop solar power systems, this paper presents the design of a management program for the studied system based on the Internet of Things (IoT) technology. The proposed system consists of digital power meters that communicate wirelessly to the Programmable Logic Controller (PLC) through the ZigBee communication standard. Using a free cloud platform will greatly facilitate the Supervisory Control and Data Acquisition (SCADA) interface design work for a Human Machine Interface (HMI) or mobile phone. This system configuration may be easy to be fit to collect electrical information such as voltage, current, power, frequency, and energy extract from the designed system to be monitored.**

Keywords— ZigBee; IoT; SCADA, hybrid power system, wind turbine generators, rooftop solar power systems.

I. INTRODUCTION

Clean energy types such as wind power, solar power ... are increasingly being used in many installations with severe geographical features, far from the management area. This leads to more difficulties in managing according to the old method. Furthermore, problems arising in the manual record database easily lead to errors and misplacement.

Most of the self-sufficient and self-sufficient electric energy projects of households use small hydroelectricity, solar, or wind power systems. The management of this energy source is even more strict for reasons of maximum saving but cannot always have enough time to check monitoring parameters, the status of the electrical system [1-3].

A solution is necessary to apply and improve the quality of management and monitoring of power supply systems. To ensure a sustainable energy source in the future, the integrated electrical system between solar and wind energy with different modes and configurations is introduced in [4-7].

When science and technology in Vietnam had not developed and had many practical applications, the collection and management of electricity data were mainly done by manual methods. Power companies or transmission and distribution units need a large number of employees, covering all areas to monitor and check the grid parameters.

Problems arising in manual data collection are becoming more and more difficult and inadequate. Clean energy types are increasingly being used in many installations with severe geographical features, far from the management area such as wind power, solar power... This leads to more difficulties in managing according to the old method. That is the driving force that drives us to research and creates a product that controls and monitors electrical parameters with a new way of reducing time, reducing costs and errors, releasing labor. That method is remote monitoring via mobile devices, namely smartphones with internet connection. The integrated electrical system between solar and wind energy with different modes and configurations is introduced in [8-9].

This paper is organized into the following sections: Section I is the introduction. Section II will show the proposed system configuration, The designed hardware and software are shown in Section III and Section IV, respectively. Some of the experimental results are illustrated in Section VI. Conclusions are discussed in Section V.

II. SYSTEM CONFIGURATION

Since electricity generated from solar and wind resources is intermittent and unpredictable, higher penetration of its power system could cause and create high technical challenges, especially to a weak grid.

By integrating the two renewable resources into an optimum combination, the impact of the variable nature of solar and wind resources can be partially resolved, and the overall system becomes more reliable and economical to run.

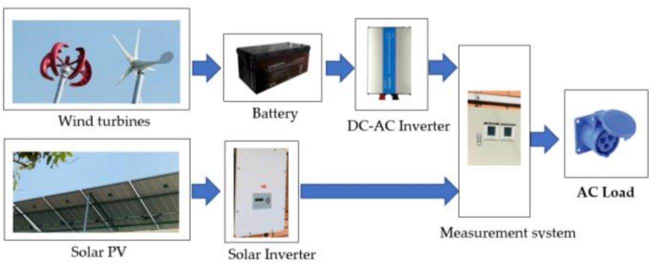

Figure 1. Block diagram of the studied system

Figure 1 shows the block diagram of the hybrid power system integrated into the power grid. In which, the central processing unit is a Programmable Logic Controller (PLC) that processes signals from the input blocks that collect data and transmit data to the control and display unit including Human Machine Interface (HMI) and connectable IoT.

With a project on monitoring specifications, the measurement is extremely important. The selection of a measuring device for the project is also extremely necessary to create the suitability of technical requirements and investment costs.

Observing parameters, as well as all ratings, are displayed on the HMI device Users can compare data simply.

Based on these basic requirements we choose the metering device as the Selec MFM383A mini measuring meter. This multi-function meter has the function of measuring parameters such as V, A, Hz, PF, kVA, kW, kVAr, total kW, total kVA, total KVAr, and kWh.

Besides, the selection of HMI screens is also based on the important factors that are compatible with control devices, which means that communication between control devices such as PLCs and HMI is supported. Using Haiwell's PLC will direct us to an HMI monitor developed by the company. Another reason for choosing Haiwell devices is that its research and development towards industrial IoTs has made great strides. The C7-W HMI monitor device fully supports the basic features while supporting higher features than the HMI versions from other industrial control equipment manufacturers, which is the ability to connect. The internet network combines cloud technology to provide a remote control solution "SCADA - CLOUD".

The C7-W HMI screen is integrated with many communication protocols such as ZigBee, EtherNet, Modbus ... These communication protocols are also integrated on the PLC, but the choice of communication methods for these two devices is special. Paying special attention to the communication stability and quality. Therefore, the Ethernet method is chosen.

A. The PMSG-based wind turbine model

The p.u. d-q axis equivalent circuit model of the studied wind PMSG, where the q-axis is fixed on the machine rotor and rotates at rotor speed, can be expressed by [10-11]

$$v_{qs} = -r_s i_{qs} + \frac{p\psi_q}{\omega_b} + \frac{\omega_r}{\omega_b}\psi_d \tag{1}$$

$$v_{ds} = -r_s i_{ds} + \frac{p\psi_d}{\omega_b} - \frac{\omega_r}{\omega_b}\psi_q \tag{2}$$

in which $\psi_q = -(X_{mq} + X_{ls})i_{qs} = -X_q i_{qs}$ (3)

$$\psi_d = -(X_{md} + X_{ls})i_{ds} + X_{md}i_m^{'} = -X_d i_{ds} + X_{md}i_m^{'} \tag{4}$$

where Ψ is the p.u. flux linkage, v_s is the p.u. stator-winding voltage, i_s is the p.u. stator-winding current, X_m is the p.u. magnetization reactance, X_l is the p.u. leakage reactance, i_m' is the p.u. magnetization current, ω_r is the p.u. rotational speed, and ω_b is the p.u. base speed.

The power converter of each wind PMSG consists of a voltage-source converter (VSC) and a voltage-source inverter (VSI) as shown in Fig. 2. In this figure, six insulated gate bipolar transistors (IGBTs) are used to convert AC voltage to DC voltage.

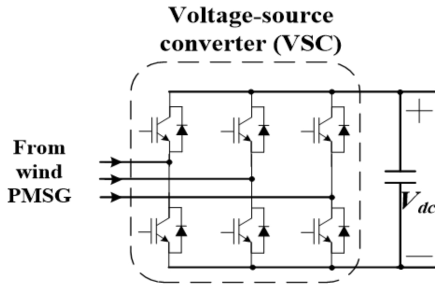

Figure 2. Model of the power converter of the studied wind PMSG

The input dq-axis p.u. voltages of the VSC-converter of a wind PMSG can be expressed by:

$$v_{cond} = km_{cond}V_{dc} \tag{5}$$
$$v_{conq} = km_{conq}V_{dc} \tag{6}$$

where V_{dc} is the DC-link voltage
km_{cond} is the d-axis modulation index of the VSC
km_{cond} is the q-axis modulation index of the VSC

B. Model for PV System

Each practical PV panel of the studied system has the rated power of 530Wp monocrystalline module of Jingko PV with the Current-Voltage and Power-Voltage curves are illustrated in Figure 3. To obtain the required voltage and power, some modules are connected in parallel to form a PV array.

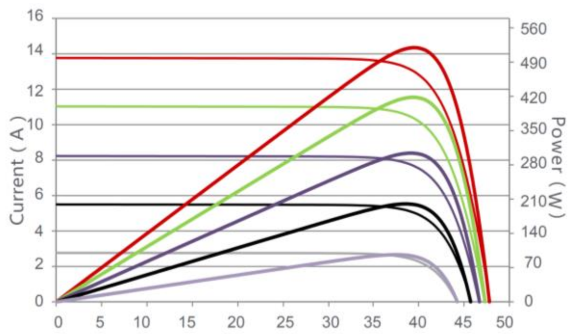

Figure 3. C-V and P-V curves of Jingko 530 kWp PV panel

Figure 4 shows an equivalent circuit diagram of a PV array including an equivalent short-circuit current source I_{SC} in parallel with a diode and a shunt resistor R_{sh}, where N_s is the number of cells in series, N_p is the number of modules in parallel and R_S is a series resistance.

The equivalent-circuit model of the PV array shown in Figure 4 can be expressed by the following equations [12-14]:

$$I_{PV} = N_p I_{SC} - N_p I_D \left\{ exp\left[\frac{q}{AkT}\left(\frac{V_{R\_PV}}{N_s} + \frac{R_S I_{PV}}{N_p} \right) \right] - 1 \right\} - \frac{N_p}{R_{sh}}\left(\frac{V_{R\_PV}}{N_s} + \frac{R_S I_{PV}}{N_p} \right) \tag{7}$$

where V_{R_PV} is the output voltage of the PV array, q is the charge of an electron (q = -1.602×10-19 C), k is Boltzmann constant (k = 1.38 ×10-23 J/K), T is the temperature in K, A is the quality factor which is a constant, I_D is the reverse saturation current of the diode, and I_{SC} is the short-circuit current under the solar radiation of 1000 W/m^2.

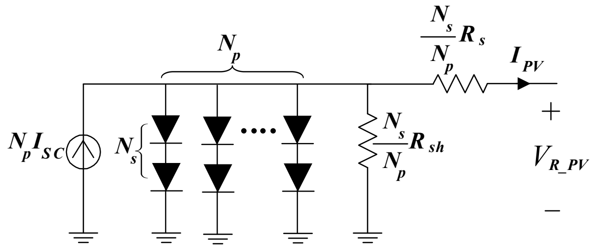

Figure 4. Equivalent circuit of the studied PV array

Figure 5 shows that the output voltage of the PV array is fed to an equivalent-T DC line and a DC-to-AC inverter. The capacitor C_{DC_PV}, which is located at the midpoint of the DC line, can be considered as a battery model for energy storage.

According to Figure 5, the p.u. differential equations of the DC line can be described by:

$$(L_{DC\_PV})p(I_{R\_PV}) = V_{R\_PV} - R_{DC\_PV}I_{R\_PV} - E_{DC} \tag{8}$$

$$(C_{DC\_PV})p(E_{DC}) = I_{R\_PV} - I_{I\_PV} \tag{9}$$

$$(L_{DC\_PV})p(I_{I\_PV}) = E_{DC} - V_{I\_PV} - R_{DC\_PV}I_{I\_PV} \tag{10}$$

where

$$V_{I\_PV} = \sqrt{\frac{V_{qINV\_PV}^2 + V_{dINV\_PV}^2}{2}} cos(g_{I\_PV}) - \frac{\pi}{6} X_{CI\_PV} I_{I\_PV} \tag{11}$$

Figure 6 shows the constant-current control scheme inside the DC-to-AC inverter. The corresponding p.u. differential equations for the DC-to-AC inverter can be expressed by:

$$(T_{I\_PV})p(\gamma_{I\_PV}) = K_{I\_PV}(I_{I\_PV\_ref} - I_{I\_PV}) - \gamma_{I\_PV} \tag{12}$$

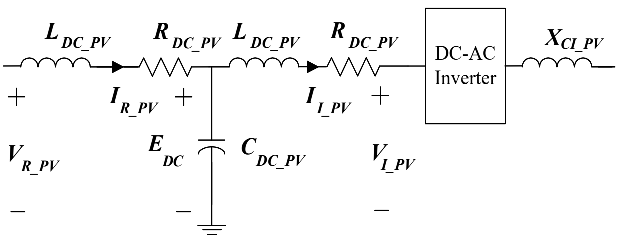

Figure 5. Equivalent circuit of DC line and DC-to-AC inverter of PV system

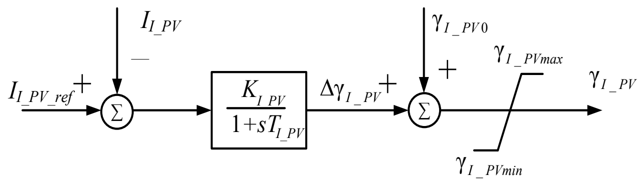

Figure 6. Control block diagram of DC-to-AC inverter of PV system

III. ZIGBEE NETWORK

Communication Protocol ZigBee / IEEE 802.15.4 is a protocol created for wireless networks. It includes hardware and software standard design for Wireless Sensor Network (WSN) that requires high reliability, low cost, low power, high scalability. ZigBee-style self-organizing digital radio networks were around in the 1990s, but the IEEE 802.15.4-2003/ZigBee specification was approved on December 14, 2004.

WSN includes wireless sensors which are capable of collecting, storing, processing information, and communicating with neighboring nodes.

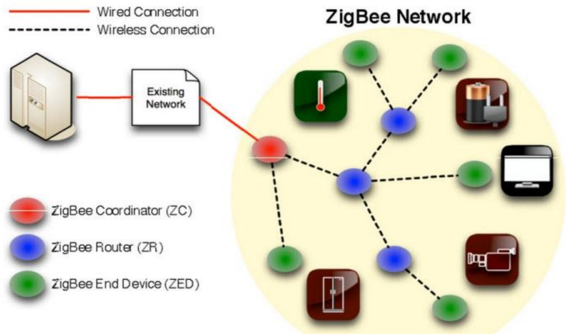

Figure 7. Structure of the Zigbee communication network.

The ZigBee network structure has 3 basic components:

- ZigBee Coordinator: responsible for creating, maintaining, and controlling the network. There is only one server per network.
- ZigBee Router: Connected to a coordinator or other routers. It may have multiple child nodes involved in the routing which are capable of transmitting data from the dispatcher to the terminals.
- ZigBee terminal: Not participating in routing and these are data communication devices.

One of the main advantages is that ZigBee is standardized in all layers, which ensures that products from different manufacturers are compatible with each other. Especially, the ZigBee network has low energy consumption but still operates stably.

In this project, 2 digital meters are installed to measure power parameters supplied by wind and solar power systems. This information is transmitted over the HMI by the ZigBee communication network as shown in Figure 8.

Figure 8. ZigBee connection of the system

IV. System Design

SCADA system of Haiwell software is downloaded from Haiwell home page at the following link: http://cloud.haiwell.com/app/qr and registered an account by using email or phone number.

For monitoring control function, local area network (LAN) or Internet connection can be selected in the software.

Figure 9 shows the designed screens for HMI, PC, and cellphone in this application.

HMI PC Cellphone

Figure 9. The main screen of the SCADA system

Supporting tools in the software, we can design interfaces that are suitable for each specific requirement based on information collected from the digital power meters. As shown in Figure 10 and Figure 11, the information of voltage can be seen in the voltage analog meter or the real-time trend, respectively.

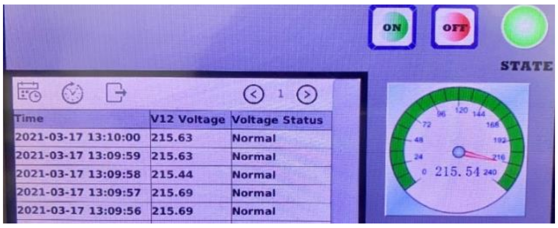

Figure 10. Display of a voltage

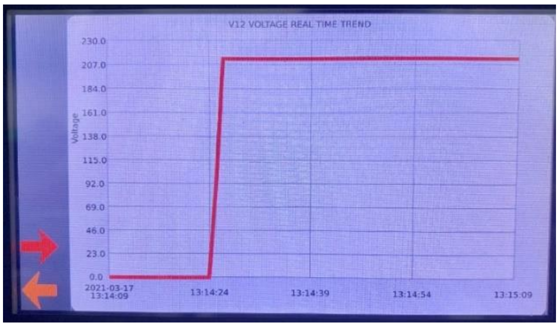

Figure 11. The real-time trend of a voltage

Another feature of the software is the ability to statistically calculate the voltage value and power-generating of the wind turbine or solar PV power system (Figure 12) daily for users to easily monitor.

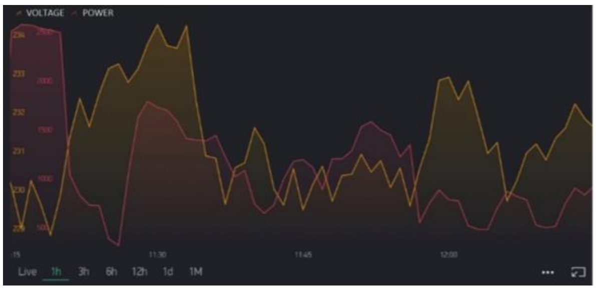

Figure 12. The voltage and the generated power of the PV system.

V. Conclusions And Discussions

This paper has geared towards developing a SCADA program to communicate data through IoT technology. Creating more convenience for remote devices to monitor the energy supply from the hybrid small-scale wind turbine generator and rooftop solar power systems. By using separated digital power meters that communicate wirelessly to the Programmable Logic Controller (PLC) through ZigBee communication network standard, this solution is not only suitable for integrated electrical systems but also applicable to existing electrical systems that do not have integrated remote monitoring solutions.

In addition, the more intuitive and easier-to-follow data types are graphs and charts. Users can compare data simply and quickly to make accurate and reliable diagnoses.

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