Combining Web SCADA Software and Matlab-Simulink for Studying Wind-PV-Battery Power Systems

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Abstract

This paper presents a Web-based SCADA connected to the hybrid power system simulated using Matlab-Simulink. The proposed Web SCADA controls the hybrid power system by connecting/disconnecting the renewable energy resources and load to the bus. It monitors the environment conditions, such as solar irradiation, temperature of PV module, wind speed, and electrical parameters (current, voltage, and power) of hybrid power system. The communication between SCADA server and Simulink model is performed by serial communication using Modbus protocol. The experimental results show that the proposed system achieved the goal, i.e. allowing the Web SCADA system to access the simulated hybrid power system modeled by Simulink in real time.

Keywords: *Web SCADA, wind power, PV, hybrid power system, Simulink, Modbus.*

1. Introduction

Recently, the development and exploration of the renewable energy resources increase significantly. Among them, the wind and solar power systems are the most popular ones, due to their availibility. The prominent characteristic of those power systems is the location dependent, in the sense that the wind power plant should be installed in the place where there is enough wind speed, while the solar power plant requires large space to absorb the sun energy. Usually they are installed in rural area and located separately. Therefore it requires a SCADA (Supervisory Control and Data Acquisition) system to monitor and control them remotely [1-5].

In [1], they proposed a SCADA system to monitor the real-time electrical data of wind-PV-battery renewable energy system. In the system, a PLC (Programmable Logic Controller) and digital power meters are employed as remote controller and measurement devices. The data from remote devices are sent to the monitoring center using intranet. A SCADA system is used to monitor and detect the failure of wind turbine [2]. The wind turbine failure is detected by observing the anomaly data from several measurements. In [3], they presented the SCADA system used to monitor and control both individual wind turbine and whole wind farm. With SCADA, user might modify the parameters of wind energy converter and voltage control system which are important to optimize the power system operation. In [4], the SCADA is developed for sun-tracker system, which enables the operator to view the actual position of the tracker system and the actual solar power.

Due to the rapid development in IT fields, especially Internet, the web-based automation becomes a recent development in the industry [5]. Web SCADA is one of the web-based automation which utilizes Internet to supervise and monitor the remote devices. The advantages of Web SCADA are [6] : a) Easy to operate using the standard browser navigation tools; b) The implementation cost will generally lower than the traditional one.

This paper describes a novel method to combine a Web SCADA software (IntegraXor[7]) and the popular simulation software (Matlab-Simulink) for studying the wind-PV-battery power system. Instead of using the real power plants, the Simulink model of hybrid power system is modeled and connected to the SCADA software via serial connection. The Modbus protocol is employed for communicating the SCADA and Simulink. In the proposed system, the Web SCADA works in the normal operation, while the parameters of hybrid power system could be changed easily by Matlab-Simulink. The control operation of Web SCADA is also simulated in the Simulink model.

The rest of paper is organized as follows. Section 2 presents the proposed system consists of the model of hybrid power system and the design of Web SCADA. Section 3 discusses the experimental results. Finally, conclusion is covered in section 4.

2. Proposed System

2.1 Wind Power, PV, and Battery Modeling

Wind power system consists of a wind turbine, a permanent magnet synchronous generator (PMSG), and a three phase rectifier. The power absorbed by wind turbine depends on the wind velocity and expressed as [8]:

$$P = \frac{1}{2} C_p(\lambda, \beta) \rho A v^3 \quad (1)$$

While the torque of wind turbine is expressed as [8]:

$$T = \frac{1}{2} C_t(\lambda, \beta) \rho A R v^2 \quad (2)$$

where
ρ is the air density
A is the swept area of the rotor blade
v is wind velocity
$C_t(\lambda, \beta) = C_p(\lambda, \beta)/\lambda$ = the torque coefficient
β = pitch angle
λ = tip speed ratio

The PMSG is modeled by the differential functions and expressed as [8]:

$$\dot{i}_q = -\frac{R_s}{L} i_q - \omega_e i_d + \frac{\omega_e \phi_m}{L} - \frac{v_s i_q}{L\sqrt{i_q^2 + i_d^2}} \quad (3)$$

$$\dot{i}_d = -\frac{R_s}{L} i_d - \omega_e i_q - \frac{v_s i_d}{L\sqrt{i_q^2 + i_d^2}} \quad (4)$$

$$\dot{\omega}_e = \frac{P}{2J}\left(T_t - \frac{3}{2}\frac{P}{2}\phi_m i_q \right) \quad (5)$$

$$\omega_e = \frac{P\omega_m}{2} \quad (6)$$

where
i_q is the quadrature current
i_d is the direct current
L is the inductance of the stator windings
R_s is the resistance of the stator windings
ω_e is the electrical angular speed
ϕ_m is the flux linked by the stator windings
v_s is the line voltage in the PMSG terminals
P is the number of poles
J is the inertia of the rotating system
T_t is the turbine torque
ω_e is the angular rotor speed.

The PV is modeled by the following equations [9]:

$$I = I_L - I_0(e^{q(V+IR_S)/nkT} - 1) \quad (7)$$

$$I_{L(T_1)} = G * I_{SC(T_1,nom)}/G_{(nom)} \quad (8)$$

$$K_0 = (I_{SC(T_2)} - I_{SC(T_1)})/(T_2 - T_1) \quad (9)$$

$$I_L = I_{L(T_1)}(1 + K_0(T - T_1)) \quad (10)$$

$$I_0 = I_{0(T_1)} * (T/T_1)^{3/n} * e^{-qV_g/nk*(1/T-1/T_1)} \quad (11)$$

$$I_{0(T_1)} = I_{SC(T_1)}/(e^{qV_{OC(T_1)}/nkT_1} - 1) \quad (12)$$

$$R_S = -dV/dI_{V_{OC}} - 1/X_V \quad (13)$$

$$X_V = I_{0(T_1)} * q/nkT_1 * e^{qV_{OC(T_1)}/nkT_1} \quad (14)$$

where,
I_0 : saturation current for diode [A]
q : electronic charging [1.6e-19 C]
n : quality factor of diode
k : Boltzman's constant [1.38e-23 JK^{-1}]
T : temperature [^oC]
T_1 : reference temperature-1 [^oC]
T_2 : reference temperature-2 [^oC]
G : irradiance [W/m^2]
I_{sc} : short circuit current [A]
V_{oc} : open circuit voltage [V]
V_g : gap voltage band [V]

The battery model is shown in Fig. 1 and expressed in the following equations [10].

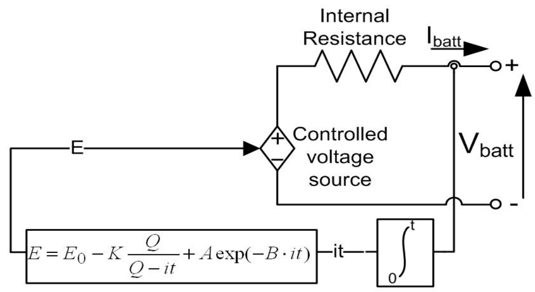

Fig. 1 Non-linear battery model [10].

$$E = E_0 - K \frac{Q}{Q - \int idt} + A\exp(-B\int idt) \quad (15)$$

$$V_{batt} = E - Ri$$

where
E = no load voltage
E_0 = battery constant voltage
K = polarization voltage
Q = battery capacity
$\int idt$ = actual battery charge
A = exponential zone amplitude
B = exponential zone time constant inverse
V_{batt} = battery voltage
R = internal resistance
i = battery current

2.2 Hybrid Power System Architecture

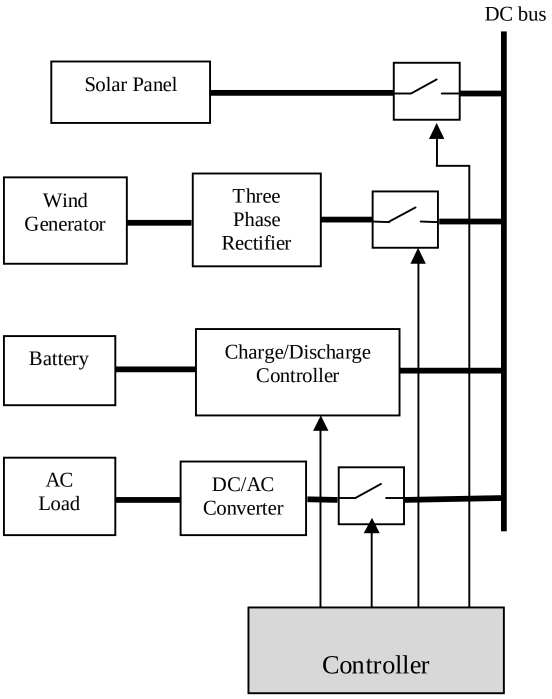

Fig. 2 Architecture of hybrid power system [11].

The architecture of hybrid power system is shown in Fig. 2. The hybrid power system consists of a solar panel and a wind power as energy resources, and a battery as the backup energy. They are connected to a DC bus which supplies energy to the load. Since the bus is DC, a DC to AC converter is required to convert the DC voltage to AC voltage required by the AC load.

2.3 Web SCADA System Design

In this work, the Web SCADA is implemented using IntegraXor software [7]. The SCADA configuration is shown in Fig. 3. The parameters of hybrid power system which are controlled and monitored by SCADA system are :

- Solar irradiation
- Temperature of PV
- Wind speed
- The current, voltage and power of PV
- The current, voltage and power of Wind energy system (WES)
- The current, voltage and power of load
- The current, voltage and power of DC bus
- The current, voltage and SOC of battery
- PV relay (connect/disconnet PV to DC bus)
- WES relay (connect/disconnet WES to DC bus)
- Load relay (connect/disconnet load to DC bus)
- Battery relay (connect/disconnet battery to DC bus)

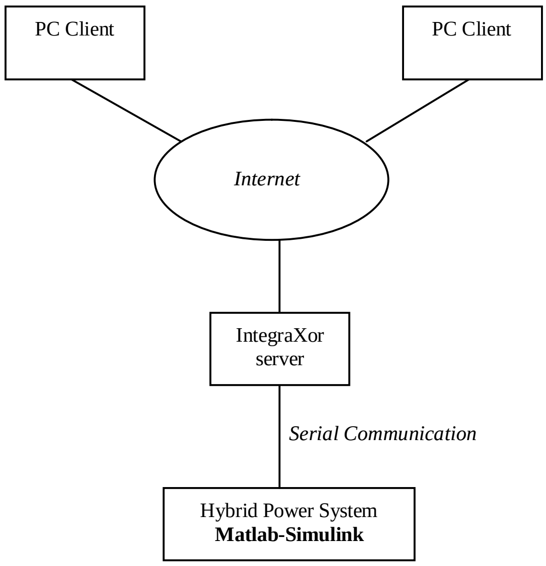

Fig. 3 SCADA architecture.

The communication between IntegraXor and Matlab-Simulink is established via serial communication using Modbus protocol. The main contribution of the work is in the development of the Modbus interface using Simulink to communicate with SCADA system. Once the Modbus interface is developed in the Simulink, the hybrid power system which is modeled using Simulink could be accessed by external application like SCADA system.

The device configuration for SCADA system is done using IntegraXor editor as shown in Fig. 4. As shown in the figure, every parameter to be monitored and controlled is assigned with tag name and the address.

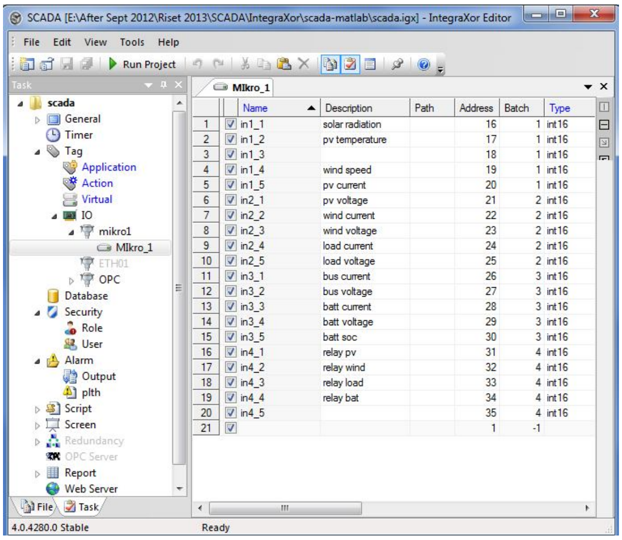

Fig. 4 Device configuration.

The other tasks should be configured in the IntegraXor editor are alarm, trending and report. The alarm management is used to give information to the operator when some of parameters exceed the desired limit. The trending displays a change of value of the parameters over the time. The reporting module provides the reports of the log data both for screen viewing and printout.

The graphical animation is created using Inkscape SAGE as shown in Fig. 5. This animation is used to control and monitor all parameters of hybrid power system.

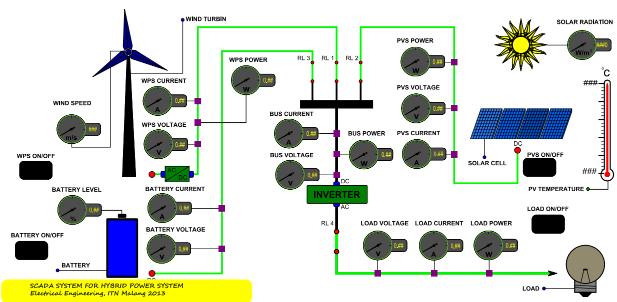

Fig. 5 Graphical animation

3. Experimental Results

The proposed wind-PV-battery hybrid power system is implemented using Matlab-Simulink as shown in Fig. 6. The Simulink model consists of PV module, Wind energy system module, Battery module, Serial communication module, and Embedded Matlab function. The embedded Matlab function handles the Modbus communication between Simulink and SCADA software.

In the experiment, the hybrid power system is simulated during 600 seconds. To provide the real-time simulation, the Simulink Real Time Execution [12] is employed. Figure 7 shows the simulation results, where the first, second, third, and fourth figures represent the PV power, WES power, load power, and battery voltage respectively. During 0 to 100 second, the total power generated by WES and PV is greater that the load power. Therefore, the surplus energy is used to charge the battery. In this case, the battery voltage will be negative as shown in the figure. In the rest of the simulation time, the total power generated by WES and PV is lower than the load power. Therefore the battery will discharge to supply the load. In such situation, the battery voltage will be positive as shown in the figure.

The Web SCADA animation display is shown in Fig. 8. In the figure, the parameters of hybrid power system which is simulated using Simulink is displayed in the web browser. The control action to connect/disconnect WES, PV, load, and buttery is indicated with On/OFF buttons. As shown in the figure, all the buttons are green to indicate that all components are connected to the bus. User could change the connection by pressing the respective button. Figure 9 shows the trending of WES. It is shown that the profile of power generated by wind energy system conforms with the one shown in Fig. 7.

4. Conclusions

The method to combine the real Web SCADA software and simulation model using Simulink is described. The proposed Web SCADA system is designed to control and monitor the parameters of wind-PV-battery power system. Both the Web SCADA software and Simulink coud communicated in real time. The control action and monitoring operation of the SCADA system could work properly.

In future, the developed system will be expanded to include the sophisticated supervisory control system of hybrid power system. Further, the more SCADA features will be implemented.

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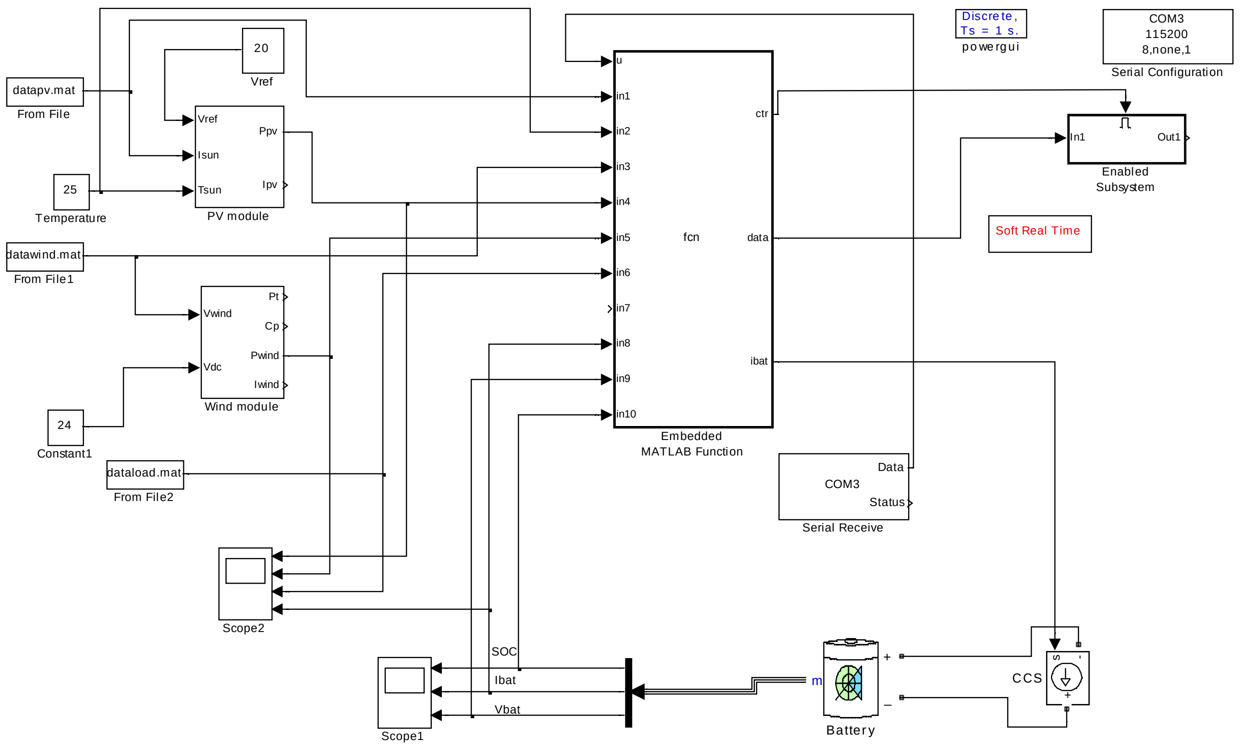

Fig. 6 Simulink model of the hybrid power system.

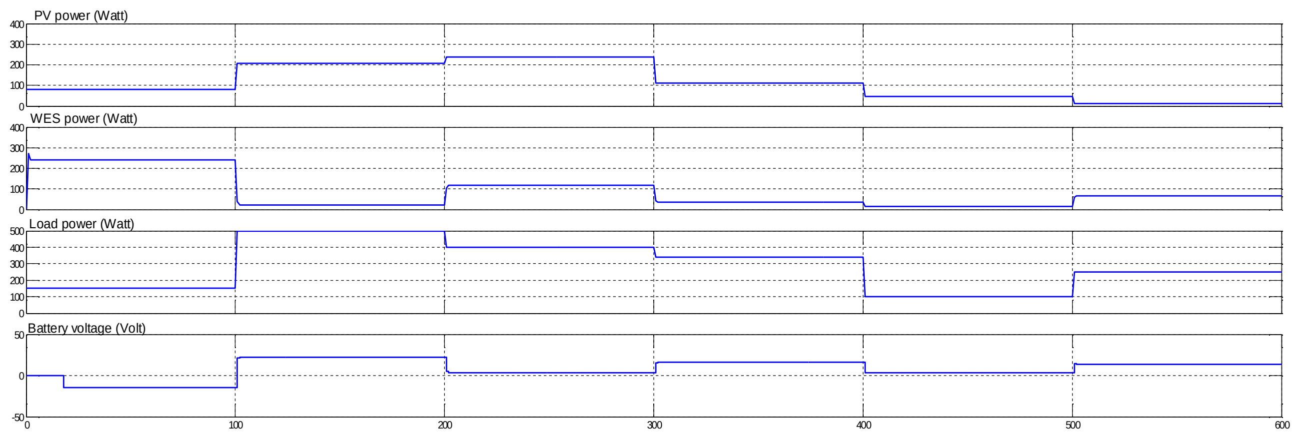

Fig. 7 Simulation result

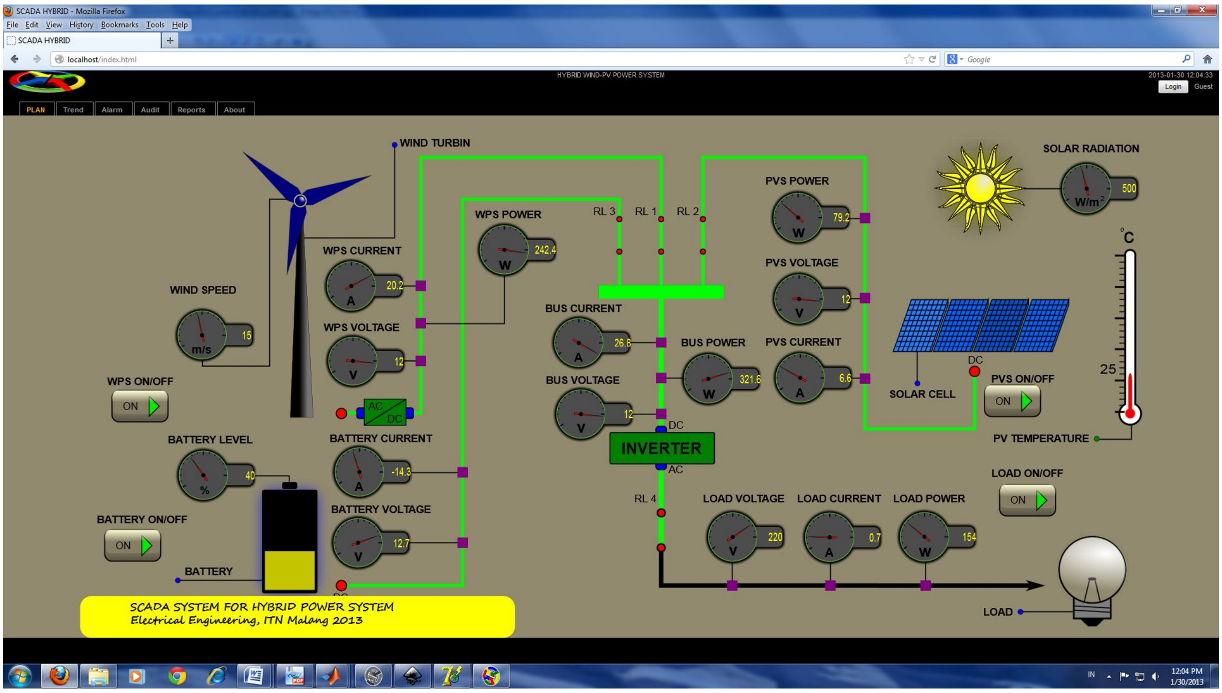

Fig. 8 Web SCADA animation display

Fig. 9 Trending of WES.