Realization of Control Subsystem in the Energy Management of Wind/Solar Hybrid Power System

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Abstract-In this paper, the realization of the energy management and control subsystem of a grid-connected wind/solar hybrid power system has been introduced. The hybrid power system is based on multi-agents theory, so the control subsystem is regarded as an agent. It is composed of programmable logic controller (PLC), human-machine interface (HMI), grid-connected control module, AC multi-function electric power meters, DC electric power meters, RS485/TCP converter etc., to control and manage the operation of multi-source, such as power grid, wind turbine generation, solar photovoltaic, storage batteries and loads, also to acquire data and communicate with others. In this paper we put the emphases on its hardware, communication and how to meet its requests and functions. Experiments show that this system is competent for both grid-connected mode and stand-alone mode.

Keywords: *Wind/Solar Hybrid Power System, Energy Management, Modbus RTU*

I. INTRODUCTION

Because of energy crisis and environment pollution, many attentions are put on alternative energy in recent years. Solar and wind energy sources are clean and renewable energy. Wind energy and solar radiation could complement each other during different months of the year, when the availability of wind energy is low (e.g. during summer months), solar energy availability may be high to complement it, or vice versa [1]. The complementarity is also existed in daytime and night. Wind/solar hybrid power generation system can maximize the use of the nature resource, plays high performance on reliability, efficiency and economy**.** As a result, more and more scholars are devoted to the research of wind/solar hybrid power generation.

Wind/solar hybrid power system usually contains several subsystems: wind turbine generation, solar photovoltaic (PV), storage batteries, grid-connected inverter and loads. The system generally runs in either stand-alone mode or grid-connection mode for providing reliable power to loads. Due to multi-source operation and decentralized distribution of subsystems, how to achieve better energy management and control is one of hot topics on hybrid power generation research.

M. Hashem Nehrir, Caisheng Wang and S.R.Guda [2] introduced wind, PV, microturbines (MTs) and fuel cells (FCs) etc., multi-source alternative energy distributed generation system (AEDGs). The need for multi-source operation of AEDGs was explored, and four different

configurations of such hybrid DGs were presented. Then the need for their modeling and control was discussed, and simulation was given. Based on the characteristics of decentralized power generation and distributed power supply, Liu Dan, Wu Jie, Zeng Jun etc., [3] studied a hybrid power generation mode for various reproducible energy sources, and developed a mathematical model for it. By applying the principle of distributed multi-agent system, the hybrid power generation was planned in a macroscopic point of view. The agent is endowed with the independence in operation as well as the cooperation ability to cope with the random variations in natural resources.

The above mentioned techniques and most existing literature mainly centralize the modeling, control arithmetic and theory about hybrid power system energy management and control. They provide concerned requirements, methods and guides for energy management and control, could make hybrid power system more reliable and efficient.

In this paper, the hardware realization of the energy management and control subsystem of a grid-connected wind/solar hybrid power system has been introduced. The hybrid power system is based on multi-agent theory, so the control subsystem is regarded as an agent. It is composed of programmable logic controller(PLC), human-machine interface (HMI), grid-connected control module, ac multi-function electric power meters, dc electric power meters, RS485/TCP converter etc., to control and manage the operation of multi-source, such as power grid, wind turbine generation, PV, storage batteries and loads, also to acquire data and communicate with others. The communication protocol in the subsystem and between subsystems is Modbus RTU, while the communication with computer is implemented by RS485/TCP converters. So then we will discuss the work about its communication.

Ⅱ. Multi-Agent System And Its Characteristics

The proposed wind/solar power system, shown in figure 1, containing several subsystems, is a decentralized, complex hybrid system. Further more, the nature of both wind and solar energy is unpredictable. Thus a distributed energy management should be applied to it. Multi-agent technology is a new technology of artificial intelligence farther development. In comparison with multi-agent system (MAS), there are many similarities between them.

MAS consists of many interactional agents that together realize a complicated task on the basis of communication and cooperation one another so as to optimize a system. It is a loose coupling agent network and these agents that have autonomous behavior are dispersive in physical unit and in logistic unit. The agents which associate one anther by some protocol can solve a problem beyond single agent's solving ability [4]. Therefore, the wind/solar power system adopts multi-agent theory, and its subsystems are all

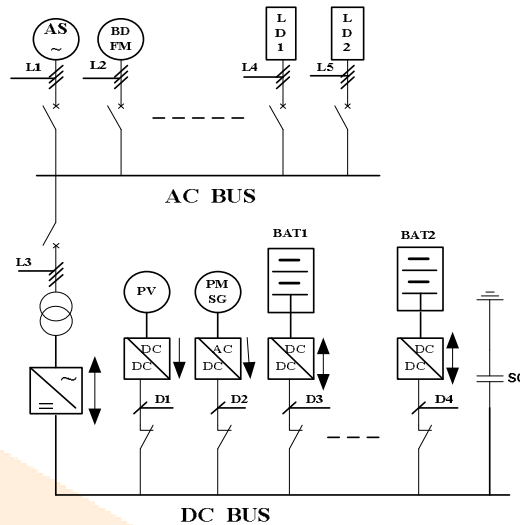taken as agents, which are not only independent with each other, but also work with tight cooperation.

Fig. 1: Block diagram of the hybrid power system.

PV: Solar Photovoltaic, SC: Super Capacitor, PMSG: Permanent Magnet Synchronous Generator, BDFM: Brushless Double-Fed Generator, BAT: Storage Batteries, AS: Assistant Source (Grid), LD1: Load 1, LD2: Load 2

An agent which displays flexible autonomy, i.e., an intelligent agent, has the following three characteristics [5].

- Reactivity: an intelligent agent is able to react to changes in its environment in a timely fashion, and takes some action based on these changes and the function in it is designed to achieve.
- Pro-activeness: intelligent agents exhibit goal-directed behavior. Goal-directed behavior connotes that an agent will dynamically change its behavior in order to achieve its goals.
- Social ability: intelligent agents are able to interact with other intelligent agents. Social ability connotes more than the simple passing of data between different software and hardware entities, something many traditional systems do.

As mentioned above, the subsystems in winy/solar power system are regarded as agents. They must have these characteristics, so does the energy management and control system. Now the following paragraphs mainly introduce its hardware and communication.

III. INTRODUCTION OF HARDWARE AND COMMUNICATION

The energy management and control system is designed to realize energy management and control with the cooperation of other subsystem. Thus it acquires the information about real time power of wind and solar energy, as well as residual capacity for batteries. In the light of loads, the system should realize the purpose of maximal use of nature resource.

A. Hardware introduction

The system is composed of several modules (shown in Fig. 2). Their function and materials are introduced below in detail.

PLC，the controller of the subsystem, is FBs-40MAT from FATEK. It is responsible for energy management and control of the whole system.

AC multi-function electric power meters detect and transmit the state parameter of the power sources, for example, the AC meter (1#) acquires the information including voltage, current, active and reactive power, power factor, frequency of the power grid. Then these data are displayed on the panel and transferred to PLC. DC electric power meters have the same work on DC side. All the meters are integrated communication module.

HMI in this subsystem is MT500 touch screen from WEINVIEW. It displays the information and operation status of each power source, also provides control command and instruction input.

Grid-connection control module mainly executes grid-connection command, connects AC sources together. As different AC power source will connect together, it should monitor the instantaneous voltage and find whether the voltage conditions are suitable for connection after the module receives the connection command. The controller is mainly composed of an AVR microcontroller, ATmega16, from ATMEL, and a high speed, 8-bit, 8-channel analog-to-digital converter with simultaneous track/holds, MAX155, from MAXIM. When the controller receives the grid-connection request of some channel, it will continuously sample the voltage of this channel and that of AC bus at high speed. The sample interval is about 312.5μs, namely it will sample the voltage 64 times in an AC cycle. And the sample will continue two cycles. Then calculate voltage virtual value,

frequency and voltage phase difference of the two channels. If the results are in the range of allowable error, this channel is regarded in phase with the bus, and the controller sends real grid-connection command to the contactor and solid state relay (SSR), also the MCU will transfer the information to PLC. Once the grid-connection completes, the controller will maintain this status until the PLC sends a break request.

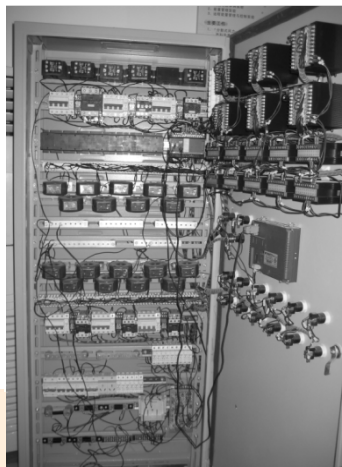Other apparatus, such as relays and contactors, compose the whole subsystem with above parts.

Fig. 2 Photograph of the control box

B.   Communication introduction

Communication plays an important role in the system safe, reliable and precise operation. As shown in Fig. 3, it is the sketch map of communication in the system. According to different position of the communication objects, we classify two communication ways. Inner communication just refers to the devices of the control system, while extend communication is done between the subsystem of the wind/solar power system.
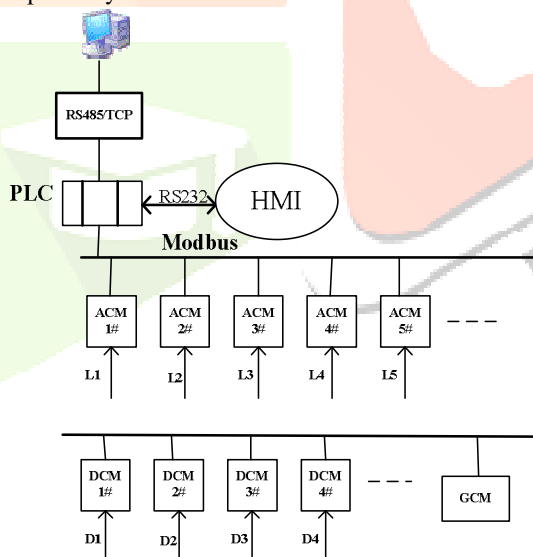

Fig. 3: Sketch map of communication in the control system

ACM: AC multi-function electric power meter, DCM: DC electric power meter, GCM: Grid-connection control module

• Inner communication:

In the subsystem, there are two lines of communications: one is the line between PLC and HMI. As the protocol between them is fixed, sending/receiving data and commands must be in accord with FATEK communication protocol which the company has instituted. HMI is connected with the port0 of the PLC via RS232 interface. Because the HMI will display the information and operational status of each power source, when programming with HMI, PLC memory address of the parameters which will show on the HMI should be written to corresponding position. During running if the screen will show several data, touch screen immediately sends command to PLC according to FATEK communication protocol. Then PLC responds the command, transmits

the right data to HMI.

The other line of communication is between PLC, multi-function electric power meters and grid-connection control module. It employs Modbus RTU. This protocol defines a message structure that controllers will recognize and use, regardless of the type of networks over which they communicate. It describes the process a controller uses to request access to another device, how it will respond to requests from the other devices, and how errors will be detected and reported. It establishes a common format for the layout and contents of message fields. During communications on a Modbus network, the protocol determines how each controller will know its device address, recognize a message addressed to it, determine the kind of action to be taken, and extract any data or other information contained in the message. If a reply is required, the controller will construct the reply message and send it using Modbus [6].

Each parts has integrated communication module, therefore it is necessary to set suited communication parameters. In PLC communication setting, WinProladder, the PLC programming software, provides Modbus Master table. In the table, PLC assigned device address number 1 is set as master node; electric power meters and grid-connection control module are set as slave node, respectively assigned device address number 2, 3, 4, etc.. Usually, PLC reads data from other slave node. As each operation contains address field, function field, data field and contents of the error checking field, the later work in communication setting is setting initial store address of data in PLC, data length and function code. As for electric power meters, only the transfer rate and slave address need be set, transfer rate is 9600bps. The meters connect to port 1 of PLC by RS485 interface.

Grid-connected control module is based on MCU Atmega16. So it is necessary to think over communication process. As the message frame in Modbus RTU doesn't include any code or character to show transfer end, parameters receiving time-out sets to 12ms. If a silent interval of more than 12ms occurs after the later character, it means this communication ending. Similarly, abnormity checking time-out sets to 0.5s. PLC uses time-out to find whether the inquired device runs in normal situation. When master node queries one slave node, if slave node has no response beyond the time, it means communication time-out abnormity. Therefore even one slave device is off or runs abnormity during multi-devices running, it doesn't impact other device's running and communication. In order to respond in time, Modbus communication in grid-connected control module works on interrupt mode. So timer is to turn on, after the MCU receives a character. Until the timer counts 12ms, if MCU doesn't receive a new character, then the program turns to interrupt mode, and ends this communication, if does, MCU continues the communication. After communication end, MCU checks the received node address to find whether PLC query to it. If true, MCU continues error check, i.e. cyclical redundancy check (CRC). Till all is true, MCU executes the commands that PLC has queried, or gives up the operation.

- Extend communication:

The control system is taken as an agent in a multi-agent system. It has not only the characteristic of self-determination, but also has social ability, therefore it must associate with other agents. There are two ways to communicate with others. One is connecting to local Internet by RS485/TCP converter, the system transmits the data to computers. In that way, the system can work on remote control mode by computer, and we can do farther work about complex energy management and control. The other way adopts Modbus protocol. In the proposed wind/solar power system, other subsystems, for example, wind turbine generation system and storage batteries management system, should have good cooperation with the energy management and control system. All subsystems are considered as agents, and have their own controller. The communication between them also employs Modbus RTU. By communication with them, the control system gets information about real time power of wind and solar energy, as well as charge residual capacity for batteries. Meanwhile, the system can calculate the current loads by measuring the current and voltage of loads. Eventually, the system can realize energy management and control to better and maximally use nature resource.

The communication between the subsystems is more difficult then the one between PLCs. For example, how to tell storage batteries management system to charge or to discharge with character should be predefined. In Modbus, the code in the function field of the message frame has been defined (as listed in table 1), but these definitions mainly refer PLC. In storage batteries management system, the controller is MCU or DSP, so we need predefine the operation with each other. Now we take the communication between the control system and storage batteries management system as an example to introduce the process.

Table 1: The part function codes

Code	Name and mean
01	Read Coil Status
02	Read Input Status
03	Read Holding Registers
04	Read Input Registers
05	Force Single Coil
06	Preset Single Register

The control system needs to get the information about the charge residual capacity of batteries, and tells storage batteries management system to charge or to discharge. So the control system should have communication with the later system two times. First, the control system reads charge residual capacity of batteries, which is saved in the controller of storage batteries

management system. According to the function codes listed in table 1, it can use code 03 to read concerned registers in Modbus communication. The second communication is to tell storage batteries management system to charge or to discharge. In the controller of this system, a variable is defined to indicate the status of batteries, for instance, binary number 00 means discharge, 01 charge, and other number means the batteries is off the DC bus. Actually, the PLC of the control system transfers different commands to the controller according to actual situation. Code 06 is used to write a binary number to the register. If the controller of storage batteries management system is assigned the device address 18, and the address of the register about charge residual capacity in controller is 00FA (in Hex format), Table 2 gives an example of a request the PLC in control system has queried to read current capacity about batteries:

Table 2: Query Example

Field Name	Hex
Slave Address	12
Function	03
Starting Address Hi	00
Starting Address Lo	FA
No. of Points Hi	00
No. of Points Lo	01
CRC	--

IV. CONCLUSION

In this paper we have introduced the hardware and its functions of the control system in the energy management of a wind/solar hybrid power system. It is composed of PLC, HMI, grid-connected control module, ac multi-function electric power meters, dc electric power meters, RS485/TCP converter etc. Then we introduce the communication of the system. The control system is regarded as an agent, and under cooperation with other subsystem, it can be competent for medium-to-large-size of hybrid power systems or other similar applications. Experiments show that this system can run under both grid-connected mode and stand-alone mode. Further investigation and experiments will be done to optimize the operation of the system.

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