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A New Solar Tracking System of HCPV Based on Zigbee

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Abstract—In this work, we propose a solar tracking system for HCPV (high concentration photovoltaic) system in a wireless environment. The hardware structure and the control strategy are introduced in detail.

Keywords-Solar Tracking System; HCPV; wireless; Zigbee

1. Introduction

High concentration photovoltaic (HCPV) systems employ concentrating optics consisting of dish reflectors or Fresnel lenses that concentrate sunlight to intensities of 500 suns or more. Today, HCPV is already at 40% efficiency nearly 3 times the economic revenues of any 12-15% efficient PV panel. And in the near future it will be more.

What the HCPV need to keep the higher efficiency is to keep the plant getting the most radiation. So, Tracking systems are found in all concentrator applications because systems do not produce energy unless oriented toward the sun. A high-precision solar tracking system to increase their photovoltaic efficiency is required. [1-2] It orients photovoltaic panels toward the sun all the day time.

Fig. 1 is a 5kW HCPV system from *ENVOLTEK* corp. Like most HCPV systems, each system combines a solar tracking system based on DSP unit controlling a dual-axis tracker. Then, a 100kW HCPV power station will contain 20 solar tracking systems. That lifts the cost of installation or maintaining the power station. Very few alternative solutions have been proposed.

This article provides a new type solar tracking system base on the use of ZigBee technique which has not been explored previously. In this system, a MCU system works as a server of the solar tracking system, terminals is another simple MCU system with two servo motors. Data or commands between server and all the terminals are through the Zigbee system to translate on wireless.

Fig.1. A 5kW HCPV with solar tracking system

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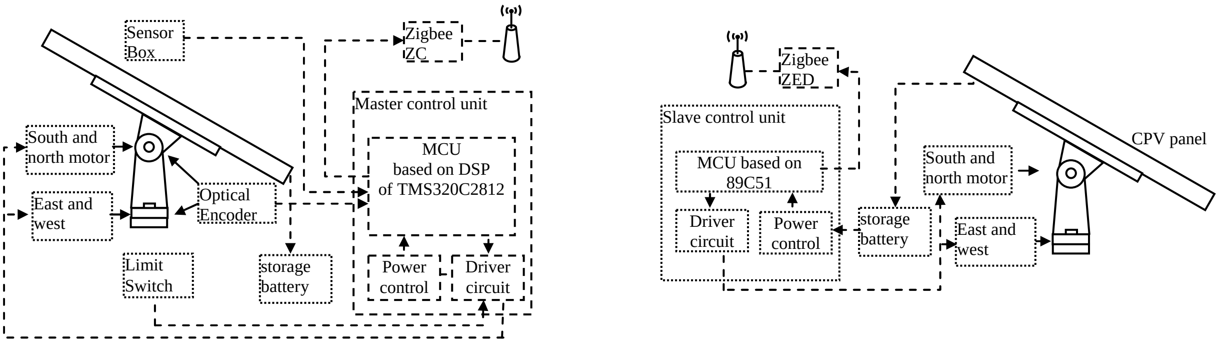

Fig.2. The structure of the solar tracking system based on Zigbee technique

2. Structure

The basic functional blocks of this system are shown on Fig. 2. This system contains two kinds of control unit: master control unit and slave control units. The master control unit does the main tasks of getting the signals or values from all kinds of the sensors, calculating the sun's angle, sending out the commands to let the solar tracking systems working and receiving the answer from the slave control units. The slave control unit is a executive part of the system. There are one master control unit and many slave control units in a photovoltaic power station. Zigbee technique is invited to the system to take the charge of communicating the master and the slave control unit. Commands and data will be delivered by the Zigbee devices in a wireless communicate method.

Also, some other devices are needed in the whole system. The sensor box contains many types of sensors, such as temperature sensor, light sensor, humidity sensor, wind direction and speed sensor, optical encoder dish and so on. A two-axis rolling mechanism can rotate the HCPV panels to face the sun all the daytime.

2.1. master control unit

1) microcontroller

The TMS320C2812 is selected to be the core of the master control unit. It belongs to the TI C2000 series. It consists of a Delfino high-performance floating point line and a low-cost Piccolo line. The C2000 series is notable for its high performance set of on-chip control peripherals including PWM, ADC, quadrature encoder modules, and capture modules. The series also contains support for I2C, SPI, serial (SCI), CAN, watchdog, external memory interface and GPIO. Due to features like PWM waveform synchronization with the ADC unit, the C2000 line is well suited to many real-time control applications. The C2000 family is commonly used for digital motor control and power conversion. A line of low cost kits for digital power, renewable energy and digital motor control allow experimentation with the MCU.

2) Sensors

All sensors with different function send their output to the ADC port of the microcontroller TMS320C2812. Then the microcontroller executes predefined task in its software. These sensors are being used with following names and functionality:

- Max wind detector and the wind direction detector, when the wind speed sensor find the wind is bigger than the alarm value, the
- Cloud detector, a photovoltaic cell, is taken as the cloud detecting. When the voltage of the cell is lower than a certain value we think it is cloudy.
- Snow detector, when the snow detecting sensor get a heavy snow signal, the system will set the HCPV panels to vertical direction in order to letting the snow slip down more easily.
- Temperature detector and Humidity detector, these two sensors are located in the panel box to call a fan- system to work to cool the photovoltaic system or to get rid of the water vapor. (The fan-system hasn't been installed on the system yet.)

3) Dual axis tracker and Servo motor

Dual axis tracker is the common device to keep the photovoltaic panel facing the sun all the daytime. It has two degrees of freedom that act as axes of rotation.

There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are Tip-Tilt tracker and Azimuth-Altitude tracker. The tracker can be drived by a step motor or a servo motor. Some disadvantages of the stepper motor are considered to give it up for the solar tracking system on HCPV. The stepper motor has low torque capacity (typically less than 2,000 oz-in). They have high vibration levels due to stepwise motion. Large errors and oscillations can result when a pulse is missed under open-loop control.[4] So, the servo motor is selected.

A Servo motor is an automatic device that uses error-sensing feedback to correct the performance of a mechanism. Usually, it has an output shaft. This shaft can be positioned to specific angular positions by sending the servo a coded signal. As long as the coded signal exists on the input line, the servo will maintain the angular position of the shaft. As the coded signal changes, the angular position of the shaft changes.

TMS320C2812 has 12 Pulse-Width Modulation (PWM) Channels in it. The two servo motors on the solar tracking system are connected to the TMS320C2812 with the PWM channels.

2.2.Slave control unit

The slave control units are in the charge of controlling all the solar trackers' movement except the one with the master control unit. An 8051 type of MCU, STC12C5A60S2, is selected to be the main core of the slave control units. It contains two serial ports which can be connected to the GPRS DTU and the ZigBee coordinator, 2 PWM channels and 10 eight –bits ADC channels. The main tasks of the slave control unit are to control the two motors to turn certain angles and to give an answer back when the turning is finished. The commands of turning angles information and the answer signal between the master control unit and the slave control units are delivered by the Zigbee devices.

2.3.Wireless system

We designed the system a master-slave mode instead of the independent mode. One master control units and many slave control units compose a wireless network through Zigbee devices. Since ZigBee is a global wireless standard based on IEEE 802.15.4, it makes it easy and inexpensive to wirelessly connect dramatically different devices no matter where they are used. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption and the solar tracking system in this article is just a one like this.[8]

ZigBee operates in the industrial, scientific and medical (ISM) radio bands; 868 MHz in Europe, 915 MHz in the USA and Australia, and 2.4 GHz in most jurisdictions worldwide. ZigBee chip vendors typically integrated radios and microcontrollers with between 60K and 256K flash memory, such as the Jennic JN5148, the Freescale MC13213, the Ember EM250, the Texas Instruments CC2530 and CC2520, the Samsung Electro-Mechanics ZBS240 and the Atmel ATmega128RFA1. Radios are also available as stand-alone components to be used with any processor or microcontroller.

There are three different types of ZigBee devices:

ZigBee coordinator (ZC): The most capable device, the coordinator forms the root of the network tree and might bridge to other networks. There is exactly one ZigBee coordinator in each network since it is the device that started the network originally. The device connected with the master control unit is a ZC.

ZigBee Router (ZR): As well as running an application function, a router can act as an intermediate router, passing on data from other devices.

ZigBee End Device (ZED): Contains just enough functionality to talk to the parent node (either the coordinator or a router), it cannot relay data from other devices. This relationship allows the node to be asleep a significant amount of the time thereby giving long battery life. A ZED requires the least amount of memory, and therefore can be less expensive to manufacture than a ZR or ZC.

Fig. 3 is the star topology of the Zigbee network that we selected for our solar tracking system. The part with dotted line represents the ones that to be added to the original system in the future. There will need a ZR to expand terminal nodes, only when the solar trackers are separated by so far distance. The work of the Zigbee network makes it available to add CPV system with solar tracking system to the original one.

3. Control Strategy

The whole system is running automatically and need no personal interference. The master control unit does the main task of processing all the incoming signals, calculating, sending out the commands and dealing with the emergency on time. The slave control unit is just an executive terminal which can give answers back to the master control unit when the commands are executed perfect. [5-6]

3.1.Solar angles

A chronological tracker counteracts the Earth's rotation by turning at an equal rate as the earth, but in the opposite direction. Actually the rates aren't quite equal, because as the earth goes around the sun, the position of the sun changes with respect to the earth by 360° every year or 365.24 days.

The following procedure allows conversion of equatorial coordinates to horizontal coordinates. The hour angle and declination may be determined from [7-9]

$$\sin a = \sin\delta \sin\varphi + \cos\delta\cos\varphi\cos\tau$$
$$\sin A\cos a = -\cos\delta\sin\tau$$
$$\cos A\cos a = \cos\varphi\sin\delta - \sin\varphi\cos\delta\cos\tau$$

for a given azimuth and altitude. Here A is the azimuth, a is the alititude, φ is the geographical latitude, τ is the local hour angle, δ is the solar declination angle. Fig. 4 shows all the angles.

The Sun declination of the corresponding day of the year, which is given by the following formula:

$$\delta = -23.45\cos\left(\frac{360°}{365}(N+10)\right)$$

here N is the number of days spent since January 1.

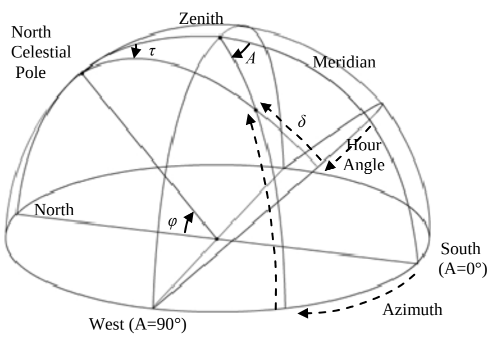

Fig.4. Star Topology of the Zigbee network

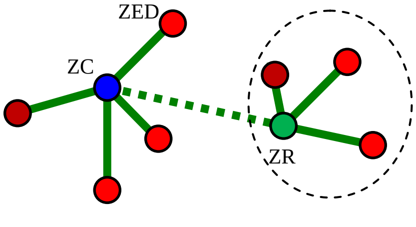

Fig.3. Star Topology of the Zigbee network

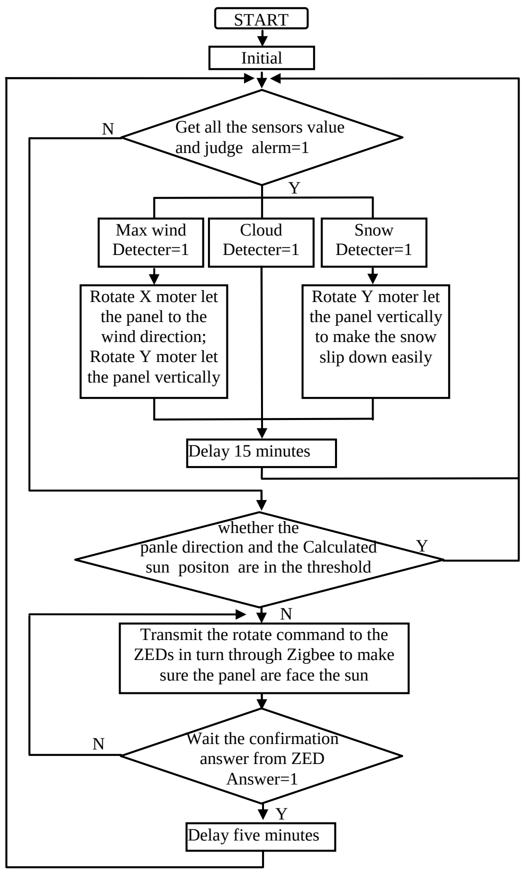

Fig.5. Flow chart of the master control system

We can also get the rising and the setting time from the equations above.

3.2.The main process of the master control unit

Fig. 5 shows the Flow chart of the master control system in brief. Once the system start running, DSP will initial all the variables and the parameters at first. The devices include the sensors, the motor driver circuit and the Zigbee coordinator device get initial signals to make sure those devices are ready to work. The main program has three parts:

- Alarm judging will compare the values getting from the wind speed sensor, light sensor and the snow sensor and so on to the setting thresholds. The alarm flag will be set to 1 if the values are larger than the setting thresholds. The light sensor, a photovoltaic cell, is taken as the cloud detecting. When it is cloud, the system does nothing to wait the delay. When the snow detecting sensor gets a heavy snow signal, the system will set the CPV panels to vertical direction in order to letting the snow slip down more easily. Then, the system will wait for a 15 minutes delay to turn back to the alarm judging.
- Calculating the sun's angles and comparing the results to the values from the servo motor's optical encoder. If the difference between them is more then 1.8°, it means there is a need for turning the HCPV panels to the calculated angles to get more solar radiation. If not, go back to the alarm judging.[10]
- Sending the rotating commands to the ZigBee coordinator first, the ZigBee coordinator will call the connecting requires to the ZigBee end devices on the wireless net. When the connections are established the rotating commands will be delivered to the slave control units of the HCPV system.

3.3.The main process of the slave control unit

The process of the slave control unit only has two tasks. The first is to get the commands from the master control unit then to drive the servo motors letting the HCPV panels face to the sun. The second is to give back an answer when the turning is finished.

Both the master control unit and the slave control unit need a watchdog timer to trigger the system reset or other corrective action if the main program, due to some fault condition, such as a hang, neglects to regularly service the watchdog. The intention is to bring the system back from the unresponsive state into normal operation.

4. Conclusion

In this work, we designed a solar tracking system for HCPV in a wireless environment. In general, there is a solar tracker for each HCPV modular. Thus, when a HCPV array is installed there should be more solar tracking systems based on DSP demanded. The cost of the station's installation and the regular maintaining will be an important part which could not be ignored. The one based on ZigBee we designed need only one DSP system to control all of the HCPV modular.

In the future, we can also lead the GPRS technique to our system to get the long distance transparent into reality. And then, all the data and the commands can get or deliver in the monitoring center of the power station.

5. Acknowledgment

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