ISSN: 1813-4890

Design of Energy Measurement and Monitoring System for Solar Water Heating Project

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Abstract

In the context of "carbon peaking and carbon neutrality", the research progress and characteristics of solar collector projects are described. Based on the Standard for Energy Metering and Monitoring of Solar Hot Water Systems and the Technical Guidelines for Data Monitoring Systems for Renewable Energy Building Application Demonstration Projects, the design and implementation of an energy metering and monitoring system for solar collector projects is proposed, Mathematical models for performance evaluation indicators and environmental benefit indicators are given .The design of the metering and testing device is described in detail，.NET platform based data centre application to receive, display, analyse and query data. The application results show that the system operates stably and the data is reliable, providing effective energy saving and emission reduction data for solar collector projects.

Keywords

Carbon neutrality, data collection, energy measurement, solar water heating project, remote monitoring.

1. Introduction

The report of the 20th Party Congress proposed that "actively and steadily promote carbon peaking and carbon neutrality", and solar thermal utilisation is an important means of achieving this goal. At present, China has become the world's largest equipment production base and application market for solar thermal utilization. Solar thermal facilities and equipment account for 80% of global installations [1]. Solar water heating systems are an important application direction for solar energy development and utilisation technology. With the national support and promotion of solar water heating systems, their application has developed from small domestic water heaters to commercial large-scale engineered water heating systems for building energy efficiency, industry and agriculture. However, the application of solar water heating projects can not simply be judged by whether hot water is produced, data collection and energy metering must be carried out to derive performance evaluation indicators and environmental benefit indicators for engineering application evaluation, providing data support for energy saving and emission reduction.

In this paper, an energy metering and monitoring system for solar collector projects with good real-time performance and sound energy consumption analysis is developed for system parameter acquisition, energy metering and comprehensive analysis according to the Standard for Energy Metering and Monitoring of Solar Water Heating Systems and the Technical Guidelines for Data Monitoring Systems for Renewable Energy Building Application Demonstration Projects.

2. Design of General System Architecture

2.1. Solar Water Heating Projects

The solar water heating project mainly consists of collectors, circulation pipes, storage tanks, auxiliary facilities (including auxiliary heating energy, sensor elements and control devices) and so on. The system starts the collector cycle when the temperature of the collector is higher than the temperature of the storage tank, and the water temperature of the storage tank is raised by collecting heat energy from the sun through the solar collector[2]. When the solar energy is not sufficient, the system turns on the auxiliary electric heating to ensure that the water temperature of the storage tank reaches the requirements of use. When the hot water from the storage tank is transported to the customer's end, or to ensure the temperature of the water pipeline, the customer pipeline cycle will lose some of the heat energy[3].

2.2. Structure of the energy metering and monitoring system

The energy metering and monitoring system consists of a heat meter, an energy meter, a sensor-transmitter, a data collector, and a server. The system measurement structure is shown in see Fig. 1.

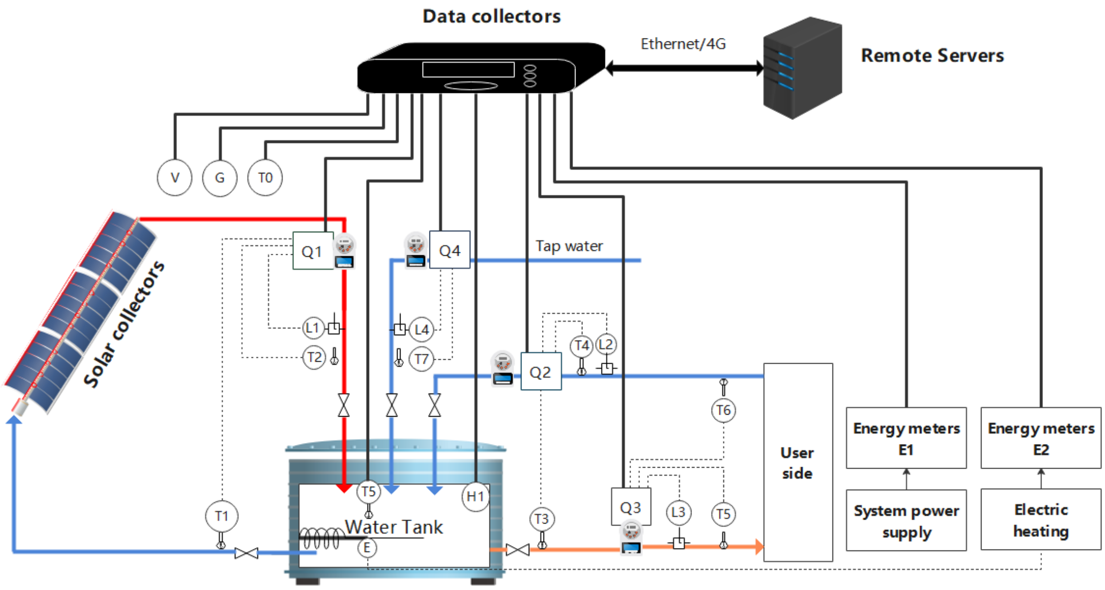

Fig. 1 System measurement structure diagram

Heat meter Q1 is installed at the outlet of the collector and is used to measure the collector circulation flow rate L1, inlet temperature T1 and outlet temperature T2, as well as to measure the amount of heat supplied by the solar energy. Heat meter Q2 is installed at the return water end on the customer side to measure the pipe circulation flow L2, water use temperature T3, return water temperature T4, and also to measure the heat lost from the pipes; heat meter Q3 is installed at the inlet on the customer side to measure the water use flow Q3, water use temperature T5, and return water temperature T6 on the customer side. heat meter Q4 is installed at the cold water inlet to measure the cold water inlet flow L4, cold water inlet temperature T7.

Energy meter E1 is installed at the main system power input to measure the current, power and total power consumption of the entire system. The energy meter E2 is installed at the electric heating supply input and is used to measure the electric heating power, current and power consumption.

Both the heat and energy meters have RS485 remote transmission capability and can reply with the corresponding data according to specific commands.

The data collector is the core of the entire measurement system and works in conjunction with the sensor-transmitter to collect data such as solar irradiance G, ambient wind speed V, ambient temperature T0, tank temperature T5 and tank level H1 from the solar water heating system. The data from the heat and energy meters are also read and integrated, summarised, encapsulated and sent to a remote server via Ethernet.

2.3. System functionality

The energy metering and monitoring system mainly accomplishes the following tasks.

1.Collecting real-time system operation data, including solar radiation, ambient wind speed, ambient temperature, water temperature of water storage tank, water level of water storage tank, cold water inlet temperature and inlet flow rate, solar collector inlet temperature and outlet temperature, collector circulation flow rate, user water temperature and water flow rate, pipeline circulation flow rate, pipeline inlet temperature and pipeline return temperature, etc.

2.Statistics of the accumulated data of solar water heating projects, including system power consumption, electric heating power consumption, solar heat supply, solar water heating system heat supply, auxiliary heat source heat supply, user pipeline circulation heat loss, etc.

3. realising the calculation of performance evaluation indicators and environmental benefit indicators of solar water heating projects.

4.To realize the functions of data storage, display, analysis, query and report export.

3. Hardware design of the system

3.1. Sensor selection

The ambient temperature and the water temperature of the storage tank are measured by a class A four-wire PT100 RTD. The accuracy of the class A PT100 is ±0.15°C and the four-wire PT100 can offset the measurement error caused by the lead resistance [4].

Wind speed and solar radiation measurements were selected to match the project's wind speed sensor and solar radiation sensor. Both of them output a standard current signal of 4-20mA through the transmitter.

The water level of the water storage tank is measured by a pressure sensor, which directly outputs a 4-20mA standard current signal, with a linear relationship between the current magnitude and the liquid level height.

3.2. Data Collector

The data collector is the connection centre of the whole system with multiple analogue input interfaces, RS-485 communication interfaces and Ethernet/4G interfaces. The data collector connection structure is shown in Fig. 2.

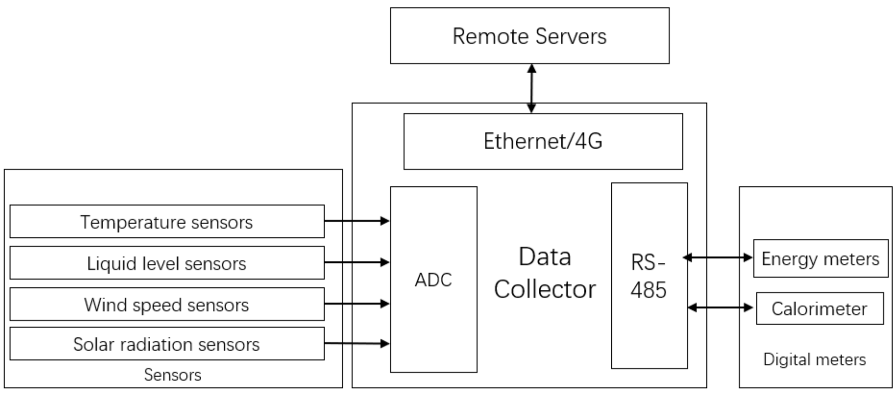

Fig. 2 Connection structure diagram of Data collector

The data collector achieves the following functions.

a. Measurement of PT100 resistance signal and 4-20mA current signal simultaneously converted into actual data, with measurement accuracy better than 0.1%FS.

b. RS485 communication with heat and energy meters, parsing the corresponding data according to the meter protocol.

c. Calculation, saving and encapsulation of the data into a specific XML format for uploading to a remote server via Ethernet.

Hardware design of the collector

3.2.1. Hardware design of the collector

The data collector mainly consists of a signal conditioning module, an A/D converter module, a main control CPU, an SD card memory module, an RS485 communication interface and an Ethernet communication interface.

The signal conditioning module converts the sensor input resistance and current signals into voltage signals from 0 to 2.5V and inputs them to the A/D converter module, which converts the analogue signals into digital signals. The main control CPU adopts ARM Cortex-M3 core, which is the control and computing unit of the data collector, and its main functions are: 1. to process the digital signal after A/D conversion; 2. to communicate with the heat and energy meter through the RS485 communication interface to obtain the corresponding data and carry out format conversion; 3. to package all data in a fixed format, store it on the SD card and send the data to the server through the Ethernet The data is sent to the server via the Ethernet communication interface. The hardware block diagram of the data collector is shown in Fig. 3

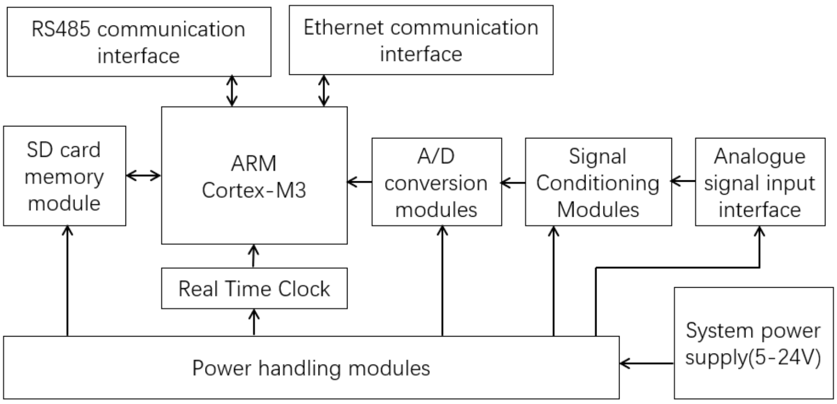

Fig. 3 Block diagram of the data collector hardware architecture

3.2.2. Software design of the collector

The collector software mainly completes the functions of data acquisition, data conversion, data storage, data encapsulation and data communication. The collector software is designed to take into account the principles of flexibility and advice, and is developed using C as the main language and assembly language as a supplement. The flow chart of the data collector software program is shown in Fig. 4.

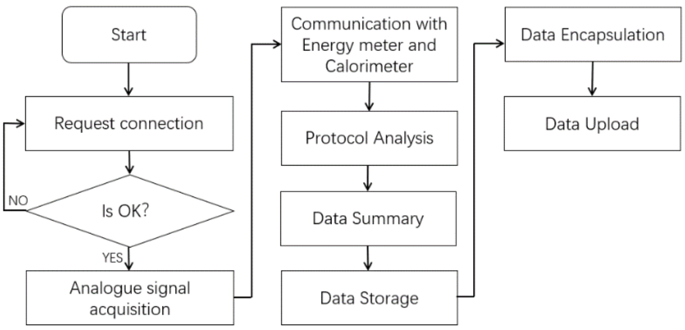

Fig. 4 Software flowchart of Data collector

After the collector is powered on, it automatically makes a TCP/IP connection with the data centre and judges whether the connection is normal through heartbeat packets; after successful connection, it takes turns to collect multiple analogue signals and converts them into actual values, then communicates with heat meters and energy meters to obtain data such as temperature, flow, accumulated heat, current, power and power consumption through different commands; it converts the obtained data into data format and calculates the The data obtained is converted into a data format and the real data is calculated; the converted data is summarised and stored on an SD card for backup; the stored data is encapsulated and integrated into an XML formatted data package and sent to a remote server via Ethernet.

The collector can either upload data manually by command or at regular intervals, the upload period can be configured by the server and the default time is 5 minutes.

4. Software design of Data centre application software design

NET platform based data centre application software has been developed in accordance with the requirements of the monitoring system， incorporating UML, Socket and other programming technologies, Microsoft SQL2012 as the database and the introduction of NI, MSChart and Flash as drawing controls.

The functional structure of the application software is shown in Fig. 5. The software has five modules: human-machine interface module, which realises system parameter setting, real-time operation data and curve display; network communication module, which realises network listening, establishing network connection and accepting network data; data processing module, which realises parsing, calculating, storing and querying the data sent by the data collector; report export module, which realises generating statistical reports including daily, weekly, monthly, quarterly and annual reports from the system operation data, performance evaluation index and environmental benefit index. Generate statistical reports including: daily, weekly, monthly, quarterly and annual reports; alarm module, realising system alarm threshold setting and SMS alarm prompt.

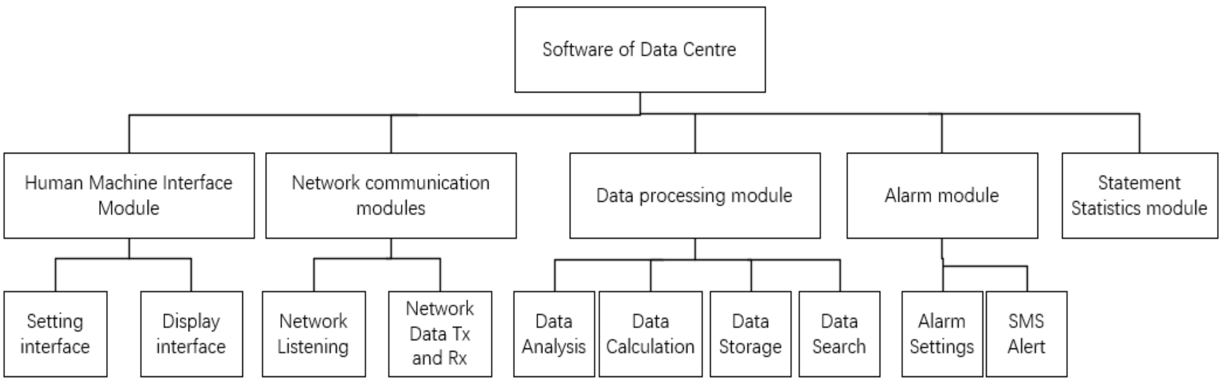

Fig. 5 Functional structure of the centre software

5. Mathematical model of evaluation indicators and benefit indicators

Performance evaluation indicators and environmental efficiency indicators are the main indicators for the long-term comprehensive evaluation of solar water heating projects [5]. Performance evaluation indicators include total solar irradiation H, solar heat supply QS, total system power consumption Q_p, solar water heating system heat supply Q_{sh}, and heat loss from customer pipeline circulation Q_{tc}; environmental efficiency indicators include conventional energy substitution and emission reduction, including carbon dioxide emission reduction Q_{co2}, sulphur dioxide emission reduction Q_{so2} and dust emission reduction Q_{mfc}.

The total solar irradiance H is calculated by integrating the irradiance meter information from the metering and monitoring instrument; the solar heat supply Q_S is obtained by uploading the data from the remote heat meter Q1; the total system electricity consumption Q_p is obtained by uploading the data from the remote energy meter E1; the heat loss from the customer's pipeline cycle Q_{tc} is obtained by uploading the data from the remote heat meter Q2; and solar water heating system heat supply Q_{sh} is calculated by adding up the points from the metering and monitoring meters. The rest of the data is calculated according to the following formula[6].

5.1. Heat supply from auxiliary heat sources Q_{aux}

$$Q_{aux} = 95\% \times 3.6 \times 10^{-3} \times Q_e$$

Where Q_e is the electrical heating power consumption, derived from the telemeter E2 in kW-h, 95% is the electrical heating conversion efficiency, Q_{aux} in GJ.

5.2. Heat supply from auxiliary heat sources f

$$f = Q_s / (Q_s + Q_{aux} + 3.6 \times 10^{-3} \times Q_P)$$

Where Q_S is the solar heat supply accumulated from the heat meter Q1 in GJ; Qaux is the auxiliary energy heat supply in GJ; Q_p is the total system power consumption accumulated from the electricity meter in kW-h.

5.3. Conventional energy substitution Q_{ss}

$$Q_{ss} = (Q_{sh} - Q_{aux} - 3.6 \times 10^{-3} \times Q_P)/W$$

Where W is the standard coal conversion factor of 29.308 GJ/tce, in tonnes of standard coal (tce).

5.4. Emission reductions include carbon dioxide emission reductions Qco2, sulphur dioxide emission reductions Qso2, dust emission reductions Qmfc

$$Q_{co2} = 2.47 \times Q_{ss}$$

$$Q_{so2} = 0.02 \times Q_{ss}$$

$$Q_{mfc} = 0.01 \times Q_{ss}$$

where 2.47 is the CO2 emission factor for standard coal, 0.02 is the SO2 emission factor for standard coal, and 0.01 is the dust emission factor for standard coal[7].

6. Analysis of system results

The system has been verified in a solar water heating project of a company in Wuxi, Jiangsu Province, with good operation, easy operation, normal operation of the data collector, measurement accuracy meeting the requirements, reliable RS485 communication with heat meters and energy meters, and stable remote network communication transmission function with the server, realising the functions of data collection, remote monitoring, alarm output and energy metering. The performance evaluation data and environmental benefit data of the system operating for six months are shown in Table 1 and Table 2 below respectively.

Table 1 Solar Water Heating Project Performance Evaluation Data for the first half of 2022

Month	$H/MJ\cdot m^{-2}$	Q_s/GJ	Q_p/(kW·h)	Q_{tc}/GJ	Q_{sh}/GJ	Q_{aux}/GJ	f
1	323.27	25.11	4494.22	11.31	44.43	13.83	0.455
2	319.64	24.73	4612.31	10.34	43.68	14.20	0.445

3	325.33	25.34	4343.63	9.25	42.19	13.37	0.466
4	399.31	31.33	3432.74	8.48	43.31	10.57	0.574
5	427.92	33.24	3112.95	6.66	44.18	9.58	0.614
6	433.93	32.92	3068.37	5.78	42.27	9.44	0.613

Table 2 Solar water heating project environmental benefits data for the first half of 2022

Month	Q_{bm}/tce	Q_{co2}/t	Q_{so2}/t	Q_{mfc}/t
1	0.49	1.211	0.01	0.005
2	0.44	1.084	0.009	0.004
3	0.45	1.112	0.009	0.005
4	0.69	1.71	0.014	0.007
5	0.80	1.967	0.016	0.008
6	0.73	1.809	0.015	0.007

7. Conclusion

An energy metering and monitoring system was developed to address the lack of data on existing solar water heating project operating parameters, performance evaluation indicators and environmental benefit indicators. A data collector with an Ethernet interface was developed and a data centre software based on the .NET platform was designed. NET platform. The system has achieved the functions of data collection, energy measurement, data display, storage and report export for solar water heating projects. After nearly half a year of operation, the system is in good condition, with accurate data collection and correct calculation of performance evaluation indicators and environmental benefit indicators. The development of the system provides a reliable data basis for the comprehensive evaluation system of solar water heating projects, and promotes the carbon peak carbon neutrality to provide important data support.

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