Sensor Network Based Automatic Control System for Oil Pumping Unit Management

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Abstract— Most oil pumping units (OPUs) have been using manual control in the oilfield. This existing oil-pumping system has a high power-consuming process and needs more manual power. In this paper, a sensor network based intelligent control is proposed for power economy and efficient oil well health monitoring. This paper consists of several basic sensors such as voltage sensor, current sensor, oil pressure sensor, temperature sensor and gas sensor. These sensors are used for oil well data sensing, i.e. it senses and collects the data from the oil well. The sensed data is given to the controller which processes the oil wells data and it is given to the oil pump control unit which controls the process accordingly. If any abnormality is detected then the fault is informed to the maintenance manager. The malfunction is sent as an SMS to the manager's mobile via GSM. Thus oil wells can be monitored and controlled from remote places.

Index Terms- Health monitoring, intelligent control, power economy, sensor network, GSM

I. Introduction

In the last few years, sensor networks have drawn much attention for their broad practical application. In this paper, a sensor network based intelligent system is proposed and applied for remote oil well health monitoring and automatic oil-pumping control. The motivation of developing this system is that 1) due to the special nature of oil exploration and oil drilling, the majority of oil pumping units (OPU) are spread over barren hills, mountains and deserts, and 2) the existing oil-pumping systems still adopt manual control. Existing manual control systems have three evident drawbacks: 1) The OPU administrators have to frequently go to the oilfield to check the OPU status and collect its health analysis data. 2) Power consumption for OPU is huge during the oil pumping process.3) Since an administrator has to take charge of a number of oil wells, an OPU malfunction is difficult to locate and repair in a reasonable time, which causes an oil production drop.

To overcome these three disadvantages of the existing manual control system, a sensor network based automatic control system is proposed for OPU management and oil well health monitoring. This proposed system consists of three-level sensors: the fist level sensors (FLS), the intelligent sensors (IS) and the third level sensors (TLS). A set of FLS, i.e., five sensors, are commonly used for an oil well's data sensing, which includes a temperature sensor, an gas sensor, a voltage sensor, a current sensor and an oil pressure sensor. The IS is developed mainly for an oil well's data elementary processing, typical data storage/indication, data/status transmission up to the TLS and command transmission down to the OPU motor. The software-defined (SD) TLS is designed for hundreds of oilwells's data storage/management, data processing, malfunction diagnosis; oil pumping stroke-adjustment command transmission down to a specific IS for power economy and the malfunction report to the maintenance staff via global system for mobile communications (GSM) short message service.

II. System Description

The proposed system is comprised of developed TLS, each of which wirelessly communicates with hundreds of IS. Each IS is designed with the capability of data transferability with a set of FLS, its adjacent IS and its corresponding TLS as well as the capability of command transmission down to its OPU motor. Each group of FLS, including a temperature sensor, an gas sensor, a voltage sensor, a current sensor and an oil pressure sensor, are used for data sensing from an OPU, which convert all measurements into electrical signals and then transport them into its corresponding IS.

The developed IS have the following features:

• Setting of oil well static parameters: manual input, edition and interface indication;

• Reception, storage and indication of sensing data from FLS;

• Elementary processing of sensing data, such as calculating the maximum value, the minimum value and the average value, etc., or such as calculating the active power, the reactive power and system efficiency of the current OPU, etc.;

• Significant malfunction detection and indication/alarm based on the elementary processing of data, such as short circuit, missing phase and over current;

• Relay protection: the power will be cut off when the phase is missing or over current occurs;

On the other hand, the capability of the developed SD TLS can be summarized as follows:

• Storage (using database) and indication of data from all IS, where data commonly consists of OPU static parameters, significant malfunction reports, sensing data and elementary processing data;

•Further data processing for oil well malfunction diagnosis by measuring OPU's load-position diagram (LPD) using a back propagation (BP) neural network;

•Data processing for recommending/transmitting the optimal pumping stroke to the IS for more oil production;

• Sending the detected oil well malfunction out to the maintenance staff using GSM SMS.

III. DEVELOPMENT OF IS

A. System Description of IS

The IS mainly contains two components: the designed control board and the frequency converter. Five kinds of sensing data from FLS are imported to its IS. The IS usually transmits oil well static parameters, significant malfunction reports, dynamic sensing data and elementary processing data directly to the TLS.

On the other hand, when acquiring a pumping stroke adjustment command from the TLS, the control board executes this command by transporting the corresponding control logic down to the frequency converter, which has the capability of changing power frequency as well as the OPU's pumping stroke.

B. Design Diagram of IS

Fig. 1 shows the block diagram of the proposed IS. The IS consists of the following six modules: a central processing unit(CPU) module, a sensing module, a relay protection module, a frequency converter module, a wireless communication module and a user interface module.

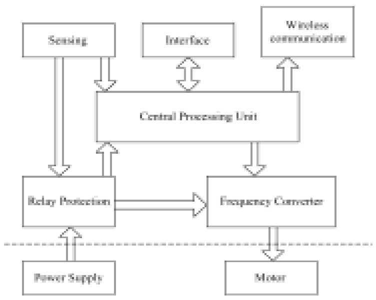

Fig. 1: Block diagram of the designed IS

1) CPU Module: The CPU in our system is the ARM LPC2148 microcontroller based on a 16-bit/32-bit ARM7TDMI-SCPU with real-time emulation and embedded trace support, that combine microcontroller with embedded high speed flash memory ranging from 32 kB to 512 kB. Serial communications interfaces ranging from a USB2.0 full-speed device, multiple UARTs, SPI, SSP to I^2C-bus and on-chip SRAM of 8 kB up to 40 kB.32-bit timers, single or dual 10-bit ADC, 10-bit DAC, and PWM channels. Evidently, this module, i.e., CPU, is in charge of all data analysis and processing for all I/O ports. All other five modules are connected to the CPU. All data from other four modules except for the frequency converter module is imported to CPU before making a decision. The stroke-adjustment command coming from TLS is also translated by the CPU and then sent out to the frequency converter module.

2) Sensing Module: Sensing module contains a temperature sensor, a gas sensor, a voltage sensor, a current sensor, an oil pressure sensor and a conditioning circuit. This temperature sensor is employed to measure temperature of the oil well. The gas sensor is used to detect the pipeline leaks in the oil well. The voltage sensor and the current sensor are to measure the instantaneous voltage and the current of power supply, respectively. The oil pressure sensor is to measure the oil pressure of the oil pipe.

3) Relay Protection Module: Relay protection module consists of a circuit breaker, a contactor and a connection circuit. This module is used for detecting the motor operation by analyzing sensing data from the voltage sensor and the current sensor. Once a malfunction, such as a short circuit, a phase missing or an overcurrent, occurs on the motor power, relay protection module will immediately cut off the power supply.

4) Interface Module: Interface module includes 4*4 keyboard, 128 64 LCD, indicator lights, a buzzer, power switch, start button and stop button. This module is the interface between staff and IS, by which OPU can be started or stopped, the stroke of OPU can be changed, OPU parameters can be preset, sensing data can be inquired and the malfunction information can be acquired.

5) Frequency Converter Module: Frequency converter module contains frequency converter and a braking resistor. This module can adjust the motor speed according to the received command from CPU so that the stroke of OPU is adjusted and the power is saved.

6) Wireless Communication Module: Zigbee module is used for wireless transmission between third level sensor and intelligent sensor. Sensing data and OPU parameters are sent to network center by using this Zigbee module.

C. Embedded Software Development of IS

The operating system (OS), a preemptive real-time multi-tasking OS, is utilized as a platform for the IS embedded development. Once the CPU chip powers up, both the hardware initialization and the software initialization are executed. After OS system initialization, the kernal dispatches tasks to be implemented. In proposed IS, embedded software development for the CPU contains 4. The 4 tasks consist of sensing data collection from FLS, data elementary processing, significant malfunction scan and user interface response. Sensing data collection indicates collecting dynamic sensing data and automatically storing these data in the IS. Data elementary processing means to process the raw sensing data to acquire the required typical data, such as the maximal/minimal/average value, the active/reactive power and the system efficiency, etc.. Significant malfunction scan is to detect the severe malfunctions, such as short circuit, missing phase and overcurrent, and report them. Also, the user interface is in charge of the external input, the oil well static parameter storage and the static parameter update.

IV. DEVELOPMENT OF TLS

A. System Description of TLS

The TLS includes three components: 1) a user interface for interaction; 2) some embedded algorithms for wireless communication between the TLS and the IS, a regular data request on all managed IS, a malfunction diagnosis, a pumping stroke adjustment and GSM SMS; and 3) a database for data storage. The wireless data, usually including dynamic sensing data and significant malfunction reports for OPU is acquired via the communication protocol and is then stored in its database. After thorough malfunction detection in the TLS, once a malfunction is identified, it is immediately sent to the maintenance staff via a GSM AT command, which generates a corresponding short message transmission. Furthermore, after a thorough data processing, if one OPU needs a different pumping stroke to improve power efficiency or increase oil production, a pumping stroke adjustment command will be sent down to its IS, by which the corresponding OPU's pumping stroke can be changed. This command is executed via the frequency converter.

B. Malfunction Diagnosis

This paper considers the 4 most important oil well malfunctions, including (1) underground oil shortage, (2) gas effect, (3) wax deposition, and (4) oil pump serious leakage. Different malfunctions have quite different LPD. The typical LPD of these 4 malfunctions are illustrated where no malfunction corresponds to a quasi-parallelogram LPD; underground oil shortage corresponds to a 'gun'-shape LPD; some irregular dog teeth occur for wax deposition; and the top-right corner is gone under the condition of oil pump serious leakage. The oil well malfunction diagnosis can be executed based on LPD classification.

BP neural network is used for malfunction classification since it is a global approximation method and thus has a good generalization capability although its convergence is slow. Three-layer neural network is sufficient for oil-well malfunction diagnosis. In our design, the input layer has 70 neurons, where 70 uniformly spaced LPD points are considered and the distances between them and their average point are regarded as the input data for classification: 1) drawing the LPD based on the sensing data from the load sensor and angular sensor; 2) selecting 70 points from LPD with an equal sample space; 3) calculating the arithmetic average of all these points and regarding it as the average point; 4) calculating the distance between all 70 LPD points and this average point. All these distance values are the input of BP neural network. The number of neurons in the hidden layer is not fixed which is determined by optimizing the classification performance; the output layer has 4 neurons, which correspond to 4 considered malfunctions, respectively. Once a malfunction occurs, its corresponding neuron output should be equal to 1 while other neurons all output a 0.

C. Pumping Stroke Adjustment

Pumping stroke adjustment is another significant feature the proposed sensor network based automatic control system can offer. The OPU is a huge power-consuming device and automatic pumping stroke adjustment may save a considerable power. Due to the constraint of the motor belt, the OPU's pumping stroke availably ranges from 2 to 10. The recommended pumping stroke always leads to an optimal performance for maximal oil production with optimal power efficiency.

G. GSM SMS

1) Short Message Transmission Using AT Commands: There are two modes for short message transmission of the Siemens GSM module TC35i: TEXT mode and PDU mode. Both modes utilize the AT commands for short message communication. The entire short message transmission consists of four steps: 1) setting the telephone/cell phone number of the short message center using the command: AT+CSCA, 2) changing to the PDU mode using the command: AT+CMGF, 3) encoding the short message to PDU code; and 4) sending the whole PDU code using the command: AT+CMGS.

2) Malfunction Transmission via GSM SMS: The malfunction transmission to the related maintenance staff is accomplished using GSM SMS. Once the OPU malfunction is identified, the COM1 port is then continuously checked4 until it is idle. Furthermore, calling the sub function of GSM short message transmission sends the OPU malfunction name to all maintenance staffs one by one.

V. CONCLUSIONS

In this paper, a sensor network based oil well remote health monitoring and intelligent control system was proposed for OPU management in the oilfield. This proposed system consists of three-level sensors: the FLS, the IS and the TLS. The FLS have been used for an oil well's data sensing, including a temperature sensor, a gas sensor, a voltage sensor, a current sensor and an oil pressure sensor for each oil well. The IS was designed mainly for an oil well's data elementary processing, main fault alarm/indication, typical data storage/indication, data/status transmission up to the TLS, data/status transmission between IS, command transmission down to the OPU motor. And the SD TLS was designed for hundreds of oil well's data storage/management, data processing malfunction detection, malfunction alarm/indication; stroke-adjustment command transmission down to a specific IS for power economy and malfunction reporting to maintenance staff via GSM SMS. Two significant goals: remote pumping stroke adjustment and automatic oil well malfunction diagnosis have also been justified. Furthermore, the remote OPU management in the proposed system was convenient than the existing manual control system.

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