Design of monitoring system for marine power station based on DSP

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Abstract. Based on the experimental platform of marine power station, the design of the collection circuit was presented and the electrical parameters such as voltage, current, frequency and phase were collected by taking digital signal processor (DSP) in type of TMS320F2812 as the core controller. As regards the site jamming signal existed in power system, the full-wave differential Fourier algorithm was applied to improve the sampling process. It could completely eliminate the DC component and suppress the aperiodic component, while obtaining the accurate fundamental component. Furthermore, the necessary conditions for establishing an effective monitoring system were provided. Combined with the touch screen in type of WEINVIEW MT8100i, the data monitoring and alarm display of the marine power station were realized. The designed data collection and monitoring system can be continuously and stably operated on the experimental platform, which verifies the feasibility of the design.

1. Introduction

The reliable operation of the marine power station depended on advanced monitoring system to control functionality is crucial to ensure safe and efficient navigation. Therefore, it is necessary to establish and improve the monitoring system. At present, the data are collected from marine power station by the transmitter or micro control unit (MCU). However, the measurement accuracy of transmitters is affected by harmonics and fewer sampling points are gathered by MCU for each cycle. To solve above stated problems, a new monitoring system of marine power station based on DSP has been proposed and described in main design guidelines.

Thanks to Harvard bus architecture, DSP can read a data value and write a data value in a single cycle, which supports real-time mode of operation. There are some of the benefits obtainable from the application of DSP in monitoring system, especially it is fully compatible with the requirements of accurate data collection and rapid data processing. Consequently, the study carried out is significant. On the other side, the monitoring system has been studied by many researchers. In [1], the overall frame of the monitoring system is described. In this frame, the characteristics of the data collection unit are discussed in detail. An application of fast Fourier transform (FFT) in monitoring system is presented in [2], and the effectiveness of the algorithm is verified by comparing the results of FPGA and MATLAB. In [3], the wireless sensor network and PLC are applied in real-time monitoring system. In order to better understand the performance of the ship, a method based on a physical model with the external forces is presented in [4-5]. In [6], a new data collection method based on sensors in remote monitoring is proposed, which improves the accuracy of data collection. In [7], using the real-
time data offered by the automatic monitoring system, the engine operating profile can be obtained, so as to formulate the energy saving method. In this proposed monitoring system, the voltage and current are sampled by the full-wave differential Fourier algorithm, as it can get precise results with low computational cost. Finally, the monitoring task has been successfully accomplished.

2. Architecture for monitoring system
Since the analog input range of the F2812 DSP is 0.0V~3.0V, the voltage and current of the shipboard grid or generators need to be transformed and adjusted before putting into the Analog-to-Digital Converter (ADC) module. Also, some power parameters collected in the field, as voltage, current, frequency, are calculated and analyzed by DSP [8]. Through the use of the MAX3232 with communication function, the acquired data are sent to the upper computer, then presented, recorded and stored to realize the integrated monitoring and management of the marine power station meaningful to the human operator. The monitoring system consists of data collection unit, DSP control unit, display and alarm unit, and the overall block diagram of the system is shown in Figure 1.

3. Data collection unit
The hardware architecture of this design takes DSP as the core, and peripheral circuits are mainly composed of current and voltage processing circuit, frequency and phase processing circuit. DSP grasps all kinds of working conditions by input data collected with peripheral circuits.

3.1. Current and voltage processing circuit
The voltage is converted into 0V~100V through the voltage transformer at first and further adjusted to a suitable sampling signal. Moreover, a similar approach is adopted in the current, and the current processing circuit is taken as an example as depicted in Figure 2, where it is converted to voltage by the current transducer LTSR 15-NP that nominal output voltage is 2.08V~2.92V. Specifically for the influence of site jamming signal, the output voltage is manipulated by the difference method to improve the accuracy. After adjusting the R9 resistance, it is converted into 0.9V~2.3V. Next, the ADC can start conversions on event triggers from the General-Purpose (GP) timer 2 in Event Managers (EVA). The F2812 DSP has a 12-bit ADC block with a built-in sample-and-hold (S/H) circuit for simultaneous sampling. However, in the practical process, due to the zero offset and gain error, the correction technology is needed. Reference voltages offered by the CJ431 chip, as 0.5V and 2.0V, are provided to the ADCINA0 and ADCINB0 input channels, and reference voltage circuit is plotted in Figure 3. So the gain and offset are calculated by using the correction technique, while obtaining the actual conversion curve.

3.2. Frequency processing circuit
The line frequency on the power bus should be fixed to 50Hz, and one of the power quality issues is frequency control [9-10]. The rated speed of the generator on the platform is 1500 rpm and the frequency is measured by installing the incremental encoder with a resolution of 2000P/N in generator rotor. In other words, the output frequency is 50 kHz. The capture input (CAP4_QEP3 and CAP5_QEP4 for EVB in DSP) can be used to interface the on-chip Quadrature-Encoder Pulse (QEP) circuit. GP timer 4 worked in the up/down-counting operation as the time base is incremented by the rising and falling edges (four times the frequency of either input pulse), and GP timer 3 is used to read the value of T4CNT at time t1. The frequency is derived by

$$f = \frac{T4CNT[(k+1)t_1] - T4CNT(kt_1)}{4000 \times t_1}$$

(1)
3.3. **Phase Processing Circuit**

The collection of the phase signal includes the phase difference between the busbar voltage and the generator voltage or the phase difference between the voltage and current of generators. The former is a key factor for generators to be automatically paralleled to the grid, and the latter is beneficial to calculate power factor, active power, reactive power, while both measuring principles are similar.

Now, the measurement method of the phase difference between the busbar voltage and the generator voltage is presented. The EVA includes capture inputs (CAP), and the capture unit consists
of three capture circuits. The busbar voltage is converted into a pulse signal by the converter circuit and sent to the CAP1 pin. At the same time, the converted pulse signal of the generator voltage is also sent to the CAP2 pin, and the converter circuit is shown in Figure 4. When the CAP1 captures the rising edge of the busbar voltage, the value of the selected GP timer 1 counter is captured and stored. When the CAP2 captures the rising edge of the generator voltage, the value of the GP timer 1 counter will be read. Figure 5 shows the actual time between pulses can be measured by the interrupt so that the phase difference can be obtained. As the generator-set will be automatically thrown into the parallel operation with zero phase difference, the impulse current is minimized. However, considering about the stroking time of the circuit breaker, it is necessary to issue a command to parallel to the grid in advance. So the \( t_2 \) will satisfy

\[
\frac{t_2}{t} = \frac{f_g - f_w}{f_w}
\]

Where \( f_g \) and \( f_w \) are the generator frequency and busbar frequency; \( t \) is the stroking time of the circuit breaker.

\[
\text{Figure 4. Converter circuit.}
\]

\[
\text{Figure 5. Waveform of voltage and phase.}
\]

4. Data collection algorithm

Data collection of marine power station using the filtering algorithm and the discrete Fourier transform (DFT) is of great significance for real-time monitoring, relay protection, fault judgment. Since the voltage and current are periodic functions, the voltage can be described with Fourier series.
\[ x(t) = \sum_{n=0}^{\infty} \left[ b_n \cos nw_0 t + a_n \sin nw_0 t \right] \]  
\[ a_i = \frac{2}{T} \int_0^T y(t) \sin w_0 t \, dt \]  
\[ b_i = \frac{2}{T} \int_0^T y(t) \cos w_0 t \, dt \]  

Where \( n = 0,1,2,3 \ldots \); \( a_n \) is the sinusoidal amplitude; \( b_n \) is the cosine amplitude. When \( n = 0 \), \( x(t) = b_0 \), and \( b_0 \) is the DC component.

The generator voltage is assumed to satisfy \( x(t) = \sqrt{2} X \sin(w_0 t + \phi) \), where \( X \) is the voltage effective value. After first order difference, we have

\[ y(t) = \sqrt{2} X \sin[w_1 (t + \Delta t) + \phi] - \sqrt{2} X \sin(w_1 t + \phi) \]  

When it is simplified, we have

\[ y(t) = \sqrt{2} [\cos w_1 \Delta t - 1]^2 + \sin^2 w_1 \Delta t] X \sin(w_1 t + \phi) \]  

Where \( \phi_1 = \phi + \phi' \), \( \phi' = \arctan \frac{\sin w_1 \Delta t}{\cos w_1 \Delta t - 1} \). Substituting (7) into (4) and (5), it follows that \( a_1 \) and \( b_1 \) become

\[ a_i = \sqrt{2} [\cos w_1 \Delta t - 1]^2 + \sin^2 w_1 \Delta t] X \cos \phi_1 \]  
\[ b_i = \sqrt{2} [\cos w_1 \Delta t - 1]^2 + \sin^2 w_1 \Delta t] X \sin \phi_1 \]  

From (8) and (9), \( X \) can be expressed as

\[ X = \frac{a_i^2 + b_i^2}{\sqrt{2} [\cos w_1 \Delta t - 1]^2 + \sin^2 w_1 \Delta t} \]  

Where \( \Delta t \) is the time between the two sampling values. As \( a_1 \) and \( b_1 \) are discretized, they are rewritten as

\[ a_i = \frac{2}{N} \sum_{k=0}^{N-1} \sin \frac{2\pi k}{N} (x_{k+1} - x_k) \]  
\[ b_i = \frac{2}{N} \sum_{k=0}^{N-1} \cos \frac{2\pi k}{N} (x_{k+1} - x_k) \]  

Where \( x_k \) is the sampling value and \( N \) is the number of samples per cycle. In order to reduce the complexity of the DFT, it is replaced by fast Fourier transform (FFT) to reduce the computational time, but the number of samples must be an integer power of 2. After analysis, it is decided that 64 points will be sampled per cycle. Finally, \( a_1 \) and \( b_1 \) can be expressed as

\[ a_i = \frac{1}{32} \sum_{k=0}^{63} (x_{k+1} - x_k) \sin \frac{\pi k}{32} \]  
\[ b_i = \frac{1}{32} \sum_{k=0}^{63} (x_{k+1} - x_k) \cos \frac{\pi k}{32} \]
The full-wave differential Fourier algorithm has a better compensation effect on the measured amplitude. Since the sampling signals are instantaneous values, it is necessary to find the relevant values by discrete algorithm.

5. Marine power station monitoring system

The main purpose of the monitoring system is to monitor the power parameters, so as to reduce the daily management and ensure the efficiency and safety of its operation [11-12]. The digital communication is based on MODBUS protocol, providing master/slave communication between DSP and touch screen. The serial communications interface (SCIA) module is designed as serial port RS232 by using MAX3232 chip. Besides, the touch screen interface type is also selected as RS232. The touch screen acts as the master to initiate requests and DSP acts as the slave to initiate responses by a 16-level FIFO for reducing servicing overhead.

5.1. Functional design of monitoring system

The configuration software implements the following functions based on the data sent by the DSP: 1) The above information including voltage, current, frequency, power and performance of the generator-units is displayed centrally in real time. 2) If the deviation between the measured value and the set value is found to be beyond the allowable range, alarm devices of control panels will be activated [13]. 3) Important information is stored. In daily maintenance, it is necessary to analyze current and historical data frequently, so as to discover abnormal phenomena and potential threats in time.

According to the acquired data, the precise protection of the power station is realized particularly in reverse power protection. The set value of the reverse power protection in parallel operation of the generator-set should be set to 8%~15% of the rated power with a delay of 3~10s in the requirements of ship construction standards and China Classification Society (CCS). In order to improve the measurement accuracy of the reverse power, the DSP detects that the generator-set is in operation and then performs reverse power protection. If generators have been run over 10% of the reverse power for more than 5s, DSP issues a trip instruction, and the generator-set will be split up from the grid. Moreover, the touch screen indicates the main switch trip because of reverse power. When the reverse power phenomenon is eliminated or less than 8% of the rated power during the 5s delay period, the value of the timer counter is cleared and the detection is carried out again.

5.2. User interface of monitoring system

The new version of the WEINVIEW MT8100i comes with a much better user interface, as real-time curve, historical curve, data report, error alarm, than the original. For all of those functions noted in the foregoing, the following user interfaces are mainly designed: 1) The control interface of generators is given by Figure 6, in which generators on the experimental platform are equipped with the separate user interface and the operator can fully understand status of the system from changes in the display. All generators can be controlled by buttons on the interface in manual regulation according to the working conditions. 2) The main switchboard can be able to start and stop generators, connect or cut off bridging connection of bus-bars through buttons, have the measurement and display unit about the performance of generators. 3) Once the running unit is at fault, the alarm interface will pop up at once and show the date and type of failure. For example, if the capacity of generators in operation cannot meet the power demand of the load, or several generators in parallel operation stop automatically due to faults and the load of generators cannot be evenly distributed, which may cause overload. Then, the touch screen displays the overload alarm and points out the time of failure. Alarms will be recorded. At the same time, the monitoring system will unload nonessential load after 30s delay (time adjustable) or start a stand by diesel generator to provide power for the power net quickly in the automatic control. Finally, the power station capacity is available. In a word, the marine power station can be well controlled by the user interface.
6. Conclusions
After analyzing some solutions for monitoring system, the proposed monitoring system is designed to combine rapid data processing of DSP with the functions about display, storage and alarm of the configuration software, so as to calculate data, display power parameters, monitor status, set up the protection. To conclude, the integrated monitoring system possessed of accurate data collection and stable operation makes it possible to monitor the operational performance of marine power station by DSP and configuration software.

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