Specific DSP based monitoring system for hydro-generator sets

Jesús Ibáñez, Carlos J. Pantaleón, Ignacio Santamaría, David Luengo,
Marcelino Lázaro

DEPARTAMENTO DE INGENIERIA DE COMUNICACIONES
ETSII y Telecomunicación, UNIVERSIDAD DE CANTABRIA
Avda. de los Castros s/n, 39005 SANTANDER SPAIN
Phone: +34 942 201553 Fax: +34 942 201488 Email: jesus@gtas.dicom.unican.es

Abstract – This paper presents a specific DSP based acquisition system developed for monitoring the behavior of low speed hydro-generator sets. The designed unit can acquire up to 16 channels and is based on the TMS320C30 DSP. It implements several digital signal processing algorithms: decimation, time delay correction to get simultaneous sampling, spectral estimation, etc. The acquired time signals, their spectra, and some relevant parameters useful for monitoring purposes, are transmitted to a remote host computer by means of a communications network that follows the RS-422 standard. A host computer program is used to store and display the received data and also to perform data trend.

1. Introduction

The reliability of rotating machines such as an electrical hydro-generator is critical to the overall reliability and operation of an electrical power plant. It is becoming more and more important to receive early warning of any problem before failure and long outage occurs. The analysis of vibra-tion signals is the most popular monitoring tool for its capability to detect most of the mechanical related and hydraulic malfunc-tions [1].

The objective of a monitoring system is to solve problems such as: instantaneous protection of the machines, prediction of catastrophic risks, real time detection of mechanical failures generating electrical faults and early detection of possible failures.

This work has been partially financed by BRITE EURAM BRE-7289 and by CICYT grant TIC96-0500-C10-07.

Monitoring electrical machines is a complex task: many different sensors are necessary, each one having different charac-teristics. Moreover, electrical machines are quite big, therefore, sensors could be placed far away from each other, and even probably in different floors of the building. Finally, electrical and magnetic fields can be strong; thus impairing the transmission of data to a remote control room.

To avoid some of these drawbacks, in this paper we propose a hierarchical, distri-buted system as the one shown in Fig. 1.

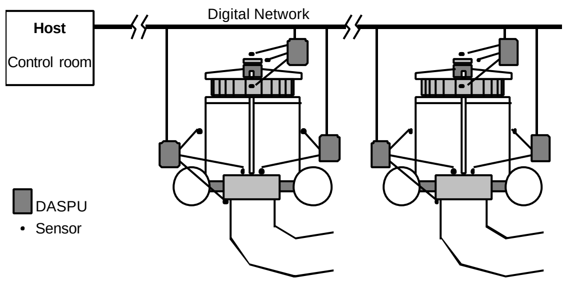

Figure 1. DASPU’s network.

Actually, two different kind of signals must be acquired: static signals (very low frequency signals, e.g., active and reactive power, temperatures, flow rate, levels, etc.); and dynamic signals (shaft´s displacement at the guide bearings level, acceleration of the bearings support, etc.). Usually, static and dynamic signals are acquired using two different units. In this paper, we mainly consider the characteristics of the Data Acquisition and Signal Processing Unit (DASPU), which only deals with dynamic signals.

In particular, the proposed DASPU is a stand-alone unit that acquires and processes 16 channels with a bandwidth of up to 450 Hz. It deals with signal conditioning, analog to digital conversion and implements several digital signal processing algorithms. For instance, it is able to simultaneously sample the 16 channels. Moreover, it performs spectral analysis via FFT, detection of frequencies, amplitudes and phases of harmonics of the fundamental frequency, asynchronous to synchronous conversion, etc. Several DASPUs can be connected to a host computer by means of a digital interface.

In the rest of the paper we describe with more detail the main hardware and software characteristics of the DASPU.

2. Hardware description of the DASPU

Each DASPU is composed of two boards: the Data Acquisition Unit (DAU), which implements the continuous-time processing; and the Signal Processing Unit (SPU), which carries out the digital signal processing algorithms. They are connected with a high-speed serial line (Figure 2).

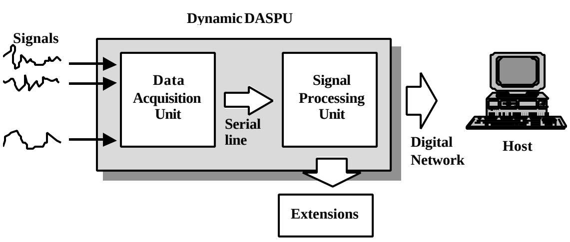

Figure 2. Dynamic DASPU: block diagram.

2.1 The Data Acquisition Unit

The Data Acquisition Unit (DAU), depends on the bandwidth of the signals that have to be acquired (up to a maximum of 450 Hz). It implements the signal condi-tioning, antialiasing filtering and analog to digital conversion. Specifically, it is compo-sed (see Fig. 3) of two A/D converters (MAX186), each one including one Sample and Hold and one 8-1 multiplexer; and 16 antialiasing filters.

With this inexpensive configuration, each pair of input channels can be simulta-neously sampled using a different A/D converter: each channel is sampled at 15625 samples/sec. Further on, the SPU will use digital signal processing algorithms [2] in order to compensate the time delay among all the channels.

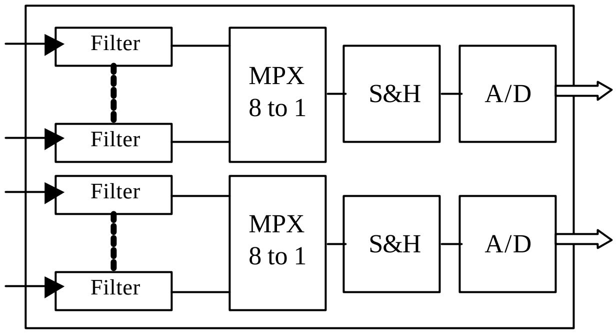

Figure 3. Data Acquisition Unit

The antialiasing filters are 4^{th}-order Butterworth continuous-time active ones (MAX274) and are plugged in the DAU board. The characteristics of these filters (cut-off frequency, gain, etc.) can be mat-ched to the sensor requirements, improving the overall system flexibility.

In our design two types of dynamic signals were considered: low frequency signals (displacement sensors with a bandwidth of 140 Hz), and high frequency signals (accelerometers with a bandwidth of 450 Hz). The high oversampling ratio of the signals simplifies the design and reduces the cost of the antialiasing filters.

2.1 The Signal Processing Unit

The second board of the DASPU, the Signal Processing Unit (SPU), is based on the Texas Instruments TMS320C30 with a 40 MHz clock. It carries out the digital signal processing algorithms.

A block diagram of the SPU is shown in Figure 4. Now, the main components of the design are described.

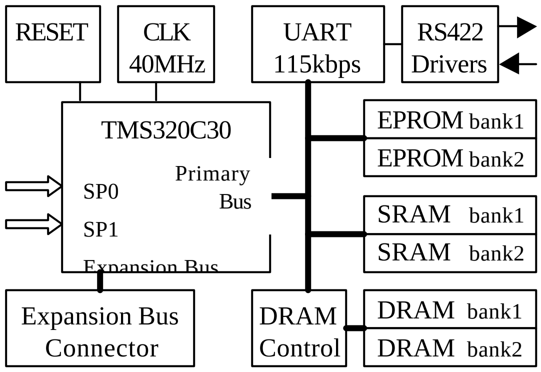

Figure 4. Signal Processing Unit

The 40MFLOPS TMS320C30 internally presents 4Kx32 bit of ROM memory and two blocks of 1Kx32 bits of RAM memory. This is not enough for our application, so external memory has to be provided. The SPU includes two banks of 256Kx32 EPROM memory, reaching 512Kx32 bits of program memory. A full compatible and cheaper 64Kx32 IC exists that can be used when the application program is not too complex.

Two banks (SIMM sockets) of fast access static RAM (20 ns) reach the full 40 MHz clock frequency of the DSP. Because of the high cost of these ICs, only the minimum amount of memory, depending on the application, should be installed. The admissible range is between 8 Kbytes and 2 Mbytes.

Inexpensive DRAM memories (70 ns) allows a maximum of 16 Mbytes (two SIMM's) of data storage. A DRAM con-troller is needed to connect the DRAM modules and the C30 processor.

A RESET circuit its provided to initialize properly the unit. The selection circuits (PAL's), buffers and transceivers allow that several devices share the same bus. The C30 Expansion Bus its available trough a 96-pin connector for future developments.

As it can be seen in Fig. 2, the SPU communicates with both the DAU and the host computer. The connection with the DAU is done using a high speed synchronous serial port (working at 2MHz) for each of the two A/D converters. On the other hand, the connection of the SPU to the commu-nication network is implemented following the RS-422 standard. A Universal Asyn-chronous Receiver Transmitter (UART) mapped in the primary bus of the C30 and a RS-422 transceiver IC are necessary. A data rate of 115 kbps insures fast data transfer between the DASPUs and the host computer. Up to 32 DASPUs could be installed over more than 1200 meters without repeaters and a specific and simple Master-Slave Protocol has been developed.

3. DSP software and algorithms

In this section we describe the characteristics and specifications of the software implemented within the DASPU. Some of its general characteristics are: firstly, it is able to monitoring machines running from 1 to 14 Hz. Secondly, a different processing is performed for low and high frequency channels. Finally, depending on the running frequency three possible bandwidths of analysis can be selected for the low frequency channels (40, 80 and 140 Hz). Besides, the DASPU can operate in two modes: manual or automatic.

3.1. Automatic Mode

In automatic mode, the DASPU is continuously sampling new data and processing them. Figure 5 indicates the tasks performed by the DASPU: the white boxes represent the on-line processing (operations performed while sampling, in real-time) and the dark ones the off-line algorithms. The DASPU stores the temporal signals acquired during the last 24 hours. They may be retrieved from the host at any time.

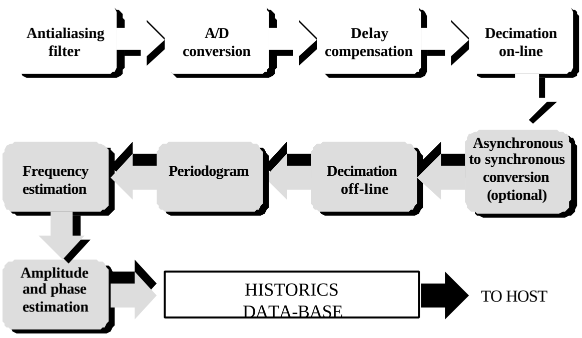

Figure 5. DASPU processing chain.

The on-line processing is the same for low and high frequency channels. Also, it is identical for the three possible bandwidths analysis that can be selected, thus simpli-fying the design of the DASPU. In particular, it consists of the following steps:

- Sampling the 16 channels at a sampling rate of 15625 Hz.
- Linear interpolation [2] to ensure simultaneous sampling up to a bandwidth of 140 Hz.
- Decimation by a factor of 11, giving a final sampling rate of 1420 samples per second and increasing the signal-to-noise ratio over the A/D converter performance.
- Storage of the sampled data in memory for off-line processing.

The off-line processing depends on the DASPU configuration, mainly on the bandwidth of analysis. The most important parameter is the second decimation factor, that is chosen from the bandwidth of analysis. Besides, the off-line processing is different for low frequency and high frequency channels.

For low frequency channels, the off-line processing consists of:

- Decimation by a factor of 4, 7 or 14 as a function of the running frequency of the machine.
- 4096 FFT of each channel and evaluation of the amplitudes and phases of the 10 largest spectral components [3].
- Evaluation of the signal power in some frequency bands.
- As an option, the asynchronous sampled signals are converted into synchronous sampled data in order to obtain the amplitudes and phases of the running frequency harmonics [3].

For high frequency channels, the off-line processing consists of:

- 4096 FFT of each channel and evaluation of the amplitudes and phases of the 10 largest spectral components.
- Averaged spectrum and evaluation of the signal power in some frequency bands.

3.2. Manual Mode

In manual mode, the operator can start the data acquisition from the host. The acquisition is carried out until the host issues a command to stop it, or until the memory is full. Typically, the manual mode is used to analyze the machine's start up or shutdown.

A maximum sampling time of around three minutes is allowed. Simultaneous sampling is assured, as in automatic mode, up to a bandwidth of 140 Hz, and decimation by a factor of 11 is performed on-line.

All the dynamic memory may be used by the manual mode. This means that the historic data stored by the DASPU up to that moment will be lost, and therefore the host must allow the operator to optionally retrieve them before starting the operation.

4. Host computer software

The host computer is a PC running under Microsoft Windows NT Operating System. The monitoring software processes the information from all the DASPUs and does the following main tasks: configuration of the system, data transfer from the DASPUs, data storage in a signal data base, statistical data analysis, and display of signals, alerts, alarms and other parameters.

The software continuously monitors the status of the DASPUs, by means of a master-slave communication protocol. A set of very short messages allows to know if there is some variable out of alert/alarm ranges in each DASPU. When an alert/alarm condition occurs, a flashing and acoustic warning will appear on the operator terminal.

The host computer software can process further the data in order to obtain diagrams, to plot orbits and to perform data trend (short, medium and long term).

4. Conclusions

This paper has described a high-performance acquisition and processing DSP board (DASPU) for low frequency dynamic signals, based on the Texas Instruments TMS320C30 processor. It is specially suited for monitoring low speed rotating machinery: hydraulic generating sets, turbines, thermal power plants, etc. Up to 16 transducers can be connected to each DASPU and up to 32 DASPUs can be connected, via a communications network, to a remote host. Therefore, the proposed unit provides the flexibility and high performance characteristics required in monitoring and predictive maintenance systems.

The presented DSP based monitoring system is currently working in one hydroelectric power plant in Spain.

References

[1] F. Arregui, *et al*. "Protection and Monitoring system for hydroelectric generating sets", *EUROMAINTENANCE,* pp. 741-750, Copenhagen, 1996.

[2] D. Luengo, C. Pantaleón, I. Santamaría, J. Ibáñez, E. Gómez. "Simultaneous Sampling by Digital Phase Correction", *IEEE Instrumentation and Measurements: Technology Conference,* Vol. 2, pp. 980-984, Ottawa, Canada, 1997.

[3] R. González, I. Santamaría, C. Pantaleón, , J. Ibáñez, E. Gómez. "Improved Procedures for Estimating Amplitudes and Phases of Harmonics with Application to Vibration Analysis", *IEEE Instrumentation and Measurements: Technology Conference,* Vol. 1, pp. 398-403, Ottawa, Canada, 1997.