LOW-COST DISTRIBUTED MEASUREMENT STATION FOR POWER QUALITY MONITORING

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Abstract: In the paper a low-cost measurement and control network for power quality monitoring is presented. The architecture is arranged on three hierarchical levels: the fieldbus, the intranet and the Internet. Particular attention has been paid to the lower level which represent the field level, based on the H8/3048F Hitachi microcomputer and linked to a VXIbus device by means of a suited, register based interface. The proposed network has been designed for industrial measurement applications. It can embody a number of analog signal conditioning circuits, processor and communication capabilities, to meet the industrial needs. In the paper, an application of proposed station to power quality monitoring is reported. Experimental results showing the system performance are also included in the paper.

Keywords: Power quality monitoring, control network

1   INTRODUCTION

Electronic devices that allow a more efficient use of the electric energy are also cause of a negative impact on the power network quality. Power supplies based on switch-based regulators or variable speed drives, could introduce high order harmonics on the power line. The quality of the electric feeding could be invalidated also because of fluctuations of the voltage, arising from brightness regulators that could cause ample variations on the effective value of the voltage. Additionally, the ampleness and the frequency of these variations of the voltage could cause flicker in the incandescence lamps that could be irritating for the consumers [1, 2].

The electromagnetic pollution covers an ample interval of frequencies. Additionally to the harmonics, those pollute the line in the low frequency up to some kHz, the pollution to high frequency, with slew-rate of microseconds or also less, are present in the waveforms of the switching feeding system [3].

The proliferation of the electronic apparatuses, has therefore wide the relative problem to the harmonics of current to the civic residences and to the commercial employment, don't sole those industrialists.

The monitoring of the quality of the electric feeding, is therefore become a matter of international interest in the last years. In this work is proposed and realized a low-cost distributed measurement system, that is usable for implement the control of the quality of the feeding, particularly in industrial field.

The actual tendency is orient to the realization of systems of measurement and distributed control that allow to decentralize the functions of process control and of centralize the functions of management and supervision of the plant; this reduces to the minimum the intervention of the operator on the single apparatuses of control. This has gotten through the construction of a net of communication that engages different in operation characteristics of the type of plant and of the environmental conditions in which the tools must operate [4].

Any characteristics of the communication nets for industrial applications, differ from those of the traditional communication nets, because of the difference of the applications (measure and control of industrial processes) and of the environment of installation, hostile and risky; they are generally build also for operate with elevated variations of temperature, tall degree of vibrations and elevated level of the electromagnetic of noise.

The industrial nets are not only a way for the interchange of data between two devices in a reliable environment, but a media that allows the implementation of distributes applications. For implement applications in real-time, the industrial net owes to support besides: functions of synchronization, messages to multiple priority, transmission of multicast messages; besides it owes guarantee a reliable communication.

The design of a measurement and control system requires, therefore, the analysis of two opposite appearances: a) the centralization of orders and of supervision functions; b) the decentralization of the process functions. The devices for the field bus allow for distributing the algorithms and the control procedures implement through the net, reducing the demand of computing resource to the central

processing unit. In this way, the total cost of the system could be reduced and becomes easier and fast future expansion [5,6].

In this paper, we are mostly concerned with the design and implementation of a microcomputer-based measurement system, which use as industrial data server a VXIbus device.

The proposed network has been designed for industrial measurement applications. It can embody a number of analog signal conditioning circuits, processor and communication capabilities, to meet the industrial needs. In the paper, an application of proposed station to power quality monitoring is reported.

Some hardware and software issues associated with the design and investigation of the system behaviour are presented, to highlight the achievable accuracy and speed of execution.

2   POWER QUALITY DEFINITION AND EVALUATION

The electronic apparatus and the devices, which causes current waveforms deformation, cause many annoying effects to the devices connected to the power distribution networks. In fact the following problems could be presented: i) reduction of the efficiency in the power generation, transmission and use of the energy, ii) aging of the isolation of the plant components and therefore shortening of their life, iii) overheating of the components of the system of distribution, iv) mechanical oscillations to the harmonic frequencies in the generators and in the motors, v) increases audio noise, vi) flicker of system voltage [1,2].

The current harmonic distortion caused from not linear loads on the power line, could be classified in two general categories: static and fluctuating. In the first one the amplitude current harmonics appear time invariant on the feeding line; examples are non-linear load constant in the time. In the second one are classified the harmonics caused from electronic apparatuses that show time-varying non-linear load, in which the single harmonics varies both in amplitude and phase; examples are laser printer, photocopiers, arc furnace, microwaves ovens, etc..

Different are the measurement approach and then the instrumentation to analyze the above-mentioned quantity; in particular for stationary harmonics is required high resolution while for fluctuating harmonics require the monitoring of harmonics, in a continuous way, for a long time [7].

With reference to the above mentioned problems, for the test of the electric power quality, it is necessary to have available many information on different quantities measured on a specific site and information on the same quantities measured on different nodes of the network under test [8].

Performing the measurements with numerical instrumentation, it is possible to obtain the required information by processing the raw data of acquired voltage and current waveform [7, 9, 10]. In particular, the following information can be obtained:

· Spectrum of the sampled signal using the FFT

· Effective value of the voltage; $V_{rms} = \sqrt{\dfrac{1}{N} \cdot \sum_{i=0}^{N-1} (v_i)^2 \cdot w_i}$ where w is the function window

· Effective value of the current $I_{rms} = \sqrt{\dfrac{1}{N} \cdot \sum_{i=0}^{N-1} (i_i)^2 \cdot w_i}$

· Active power $W = \dfrac{1}{N} \cdot \sum_{i=0}^{N-1} i_i \cdot v_i \cdot w_i$

· Apparent power $VA = I_{rms} \cdot V_{rms}$

· Power factor $PF = \dfrac{W}{VA}$

· Total harmonic distortion: $THD = \dfrac{100 \sqrt{\sum_{i=2}^{N} (U_i)^2}}{U_1}$;   where U_1 is the fundamental component and U_i are the harmonic components

The monitoring of the network power quality requires distributed measurement system, which allows for finding out quality index at the same time in different node of the test plant [11].

In this way, the monitoring of the quality also allows: to determine what are the polluting elements and where they are located inside the plant.

3   DISTRIBUTED MEASUREMENT SYSTEMS ARCHITECTURE

The basic idea is to realize a measurement system on of a wide area, by distributing the processing power, creating sensors and actuators that has inherent processing ability, and that they could communicate between them with numerical, fast and reliable transmissions (smart sensors). This

measurement system allows for the monitoring of power quality and to verify the functioning of a single device on the plant from a remote site with high level interfaces.

It is structured in three hierarchical levels: i) the fieldbus network, ii) the Local Area Network (LAN) and iii) the Wide Area Network (WAN).

The field bus network, managed by means of a field bus server, is constituted of smart modules, which allow the acquisition of the needed information and to provide action on smart actators. The informations are collected by means of remote measurement units (RMU), connected on the fieldbus at the speed up to 2 Mbaud. When it is difficult to make a direct bus connection, Wireless Measurement Units (WMU), connected directly to the Communication Control Processor (CPP) with a radio link at 450 MHz, have been developed. The field bus is connected to a Communication Control Processor (CCP), which manage the information coming from the field and interface the field to the LAN. In this way, the field bus network acts as data server for the next level, the plant Ethernet intranet network (LAN). In the LAN, there are a Server and some Client machines; the first one allows organizing the information while the others allow to the operator to interact directly with the plant. In addition, the LAN is connected with a WAN, in particular the TCP/IP Internet, by means of a Gateway. The system architecture implemented is schematically represented in Fig. 1.
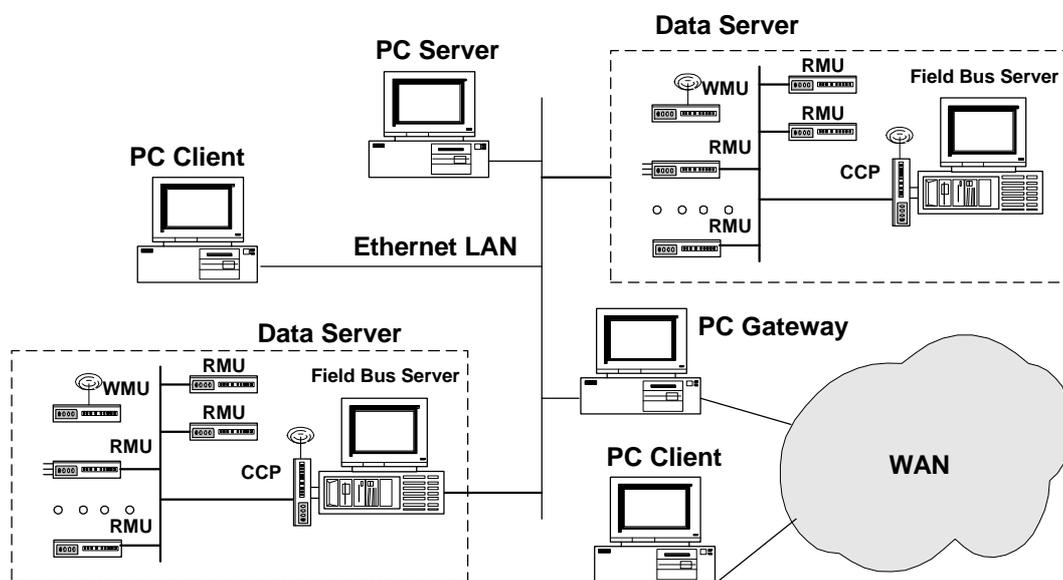

Figure 1. Architecture of developed power quality monitoring system.

To the lowest level of the system of realized measurement is present the elements that allow to effect the real measures, but that they could be besides used also for different purposes such as the signal processing, the control of process and the implementation of smart sensors and actuators [4]. The first problem to face in a plan of this type is tied up to the standards on the fieldbus that unfortunately are not well definite and currently are in number really elevated (more than 50). Have a system that respects a common standard is extremely advantageous, because it makes the system open, modular and integrable also with commercial devices. With these goals, the Fieldbus Fundation has been adopted.

The system of developed measurement foresees the use a LAN of Ethernet type, and eventually a geographic network said WAN (Wide Network Area) that in the specific case is Internet. The choice of this type of net has born from the consider that currently Ethernet is the more used in the world and then characterized from the constant decreasing of the costs and from the increasing development of software tools, that are essential in any industrial and civic reality.

The natural evolution from a local area network (LAN) to a geographical wide Area Network is today possible through public network, such as Internet, with TCP/ IP (Transmission Control Protocol/ Internet Protocol) communication protocol.

This protocol of communication allows for to establish a connection with a remote calculator, specifying the IP address, or the name and the domain that they will be then resolved from the DNS (Domain Name Server).

The system chosen for manage the communication between the LAN and the field bus, is of type client-server, and it allows to the consumer of establish a TCP/IP connection in a transparent way, by means of a browser. As the hardware is concerned, it is constituted by standard Personal Computers and Workstations except for the field bus level, which acts as Data Server, described in the following.

4   DATA SERVER DESCRIPTION

Our choice of the VXIbus as fieldbus server is because its specification adds the standards necessary to combine modular form factor and high-bandwidth, to create a modular instrumentation platform that can meet the needs of high-performance measurement applications [3, 11, 12].

Although many VXI boards with different instruments are available, sometimes it is not possible to find the specific features in off-the-shelf modules, especially in the industrial application field. In fact, some features of an industrial measurement system are quite different from those of a traditional one, because of the different application (industrial process measurement and control) and the different (harsh and hazardous) environment of installation. They are generally designed to operate with a wide operating temperature range, high degree of vibration, and high level of signal noise.

To this aim, a low-cost general purpose, modular, remote measurement device, reported in Fig.2, based on a microcomputer (µC) has been designed and implemented. It can be easily specialized with special purpose piggy-back modules (the shadowed blocks in Fig. 2); in particular with: i) the VXI interface for the communication control processor (CCP), ii) the analog I/O interface for the RMU and iii) the wireless interfaces for the wireless measurement unit (WMU).
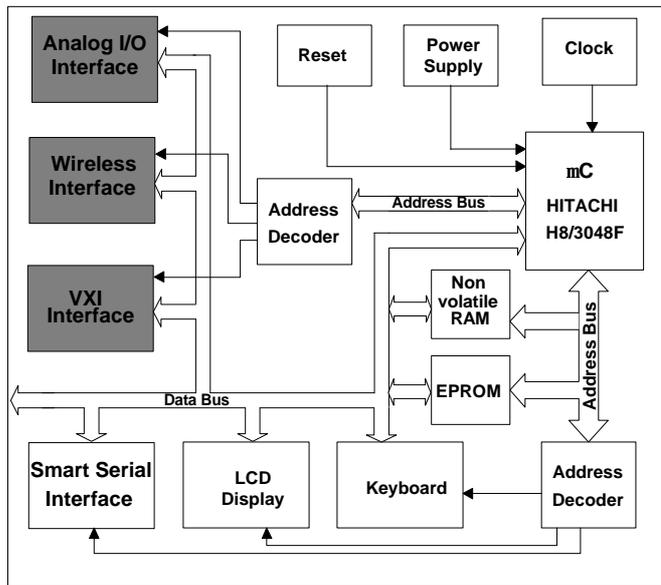
The implemented measurement device has been built using an inexpensive high-performance processor, the H8/3048F Hitachi [13]. This is a microcomputer with a 32-bit internal architecture. It embodies on-chip RAM (4 kbytes), on-board programmable Flash memory (128 kbytes), a 16-bit integrated timer unit which can provide PWM outputs with arbitrary duty-cycle, a programmable timing pattern controller, a watchdog timer, a two channel serial communication interface, a 10 bits SAR A/D converter (8 channels with S/H circuit), an 8 bits D/A converter (2 channels), I/O ports, a direct memory access controller, a refresh controller and other facilities. Operating frequency is 16 MHz.

Figure 2. Functional block diagram of realized measurement device

The µC on-chip circuits provide many functions suitable to facilitate the implementation of an expanded memory system, such as the address area decoding (memory chip select generation). The board has been designed to include external memory (up to 128 kbytes of EPROM and up to 256 kbytes of static RAM, addressed in 16 bit words). During the software development phase, the EPROM has been used to store a firmware monitor program.

The Dallas DS 1230Y/AB, a 32Kx8 non-volatile static RAM, has been used. This is a single package static RAM with a supply memory controller and a lithium battery, which is forced to supply the memory when the external voltage falls below a fixed value. This component has been adopted to store the program variables in order to guarantee the right program execution, also after a supply interruption.

The in situ Flash self-programming capability of this processor (the Flash can be programmed under the control of the user application program) provides code upgrades and measurement parameters modifications.

Particularly important is the VXIbus interface module. It can implement a register-based or a message-based slave VXI interface towards the application hardware circuitry. The main difference between register-based and message-based cards is that the former can contain logic circuits only, while the latter must contain an interpreter to process and execute text-based commands from the VXI controller (slot 0). Register-based devices present high transmission speed, while message-based devices present better flexibility [14].

This section embodies the four standard Configuration Registers. Three are read registers: the ID, Device Type and Status Registers, used by the slot 0 to identify the VXI device, its type and the working status. Specifically, we used four bits to read diagnostic signals from the µC module. One, the Control Register, is a write register used to control the device. An optional read/write register is the Offset Register. In addition, the board can include six Communication Registers, to implement Message-based

devices. As shown in Fig. 3, the VXIbus I/F can be functionally divided in two blocks: the timing and control section and the data interface section.
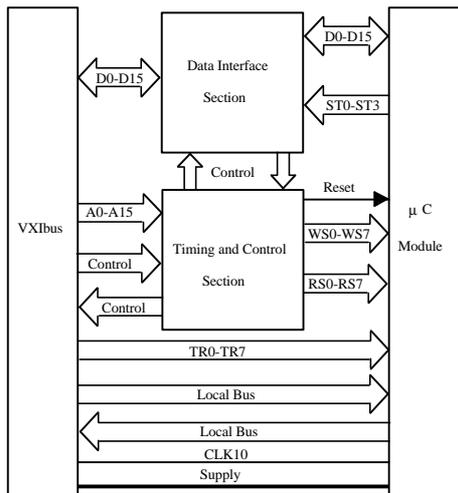

Figure 3. Functional diagram of VXI interface

The timing and control section receives the address bus (A0-A15) and the control signals from the VXIbus. It supplies/receives some control signals to/from the data interface block. It also supplies eight Write (WS0-WS7) and eight Read (RS0-RS7) 250 ns strobe signals, corresponding to different memory addresses, to the µC block.

The data interface block makes available the 16-bit data bus (D0-D15) to the µC and receives the status signals (ST0-ST3). It implements a double FIFO buffer structure for the communication from the µC to the VXIbus, and vice versa, for a fast data transfer rate.

The VXI I/F output versus the µC section also includes the 12-bit P2 local bus, the TTL triggers (TR0-TR7), and other signals (clock, supply,).

The interface circuits have been implemented using four PLD circuits to reduce physical dimensions and coupled noise.

The Analog I/O interface which uses the µC internal ADC, embodies hall-based current and voltage transducers, a low pass filter and external S/H circuits for the simultaneous acquisition of the channels.

The eight analog input channels with a conversion time less than 10 µs per channel [8], the selectable reference voltage, the S/H and the external trigger allow a powerful data acquisition system to be implemented. The two analog output channels with a conversion time of 10 µs per channel allow control signals to be generated, also for applications that require a fast response from the controller.

As the wireless interface is concerned, it is realized around a 450 MHz, MSK modulated devices, with a maximum output power of 1 W. It allows a transfer rate up to 1 Mbit/s and an operating range of 2 km.

In order to reduce the processing load, the field bus interface has been realized with a smart UART. It is realized by using a Finite State Machine which allows the decoding of fieldbus address without the intervention of µC CPU.

Because industrial applications may suffer from electrical noise, some noise reduction techniques have been applied during the hardware implementation, especially during the PCB (printed circuit board) design, adopting special guidelines to reduce EMI interferences i.e. control of the component layout and power supply bussing [15]. In the actual configuration the cost of basic module is about one hundred of USD.

As the software is concerned, the C language has been used both for the µC and for the VXI device. In this way, the portability for the measurement algorithms is assured.

5   EXPERIMENTAL RESULTS

In order to verify the behaviour of the implemented measuring system, at first we acquired a test wave produced by a high accuracy sinusoidal generator. A coherent and prime sampling was adopted to maximize the number of different codes at the A/D output, in order to analyze all the operating working conditions. At the analog input channels of the µC, a non-linearity error lower than ±1.5 LSB, an offset error lower than ±1.0 LSB, a full scale error lower than ±1.0 LSB have been measured. By considering the overall circuits of each channel, including the protection circuit, accuracy better than 0.2% has been obtained in rms measurement.

The behaviour of the analog output channels with 2 MΩ resistive loads has also been measured, obtaining accuracy better than 0.6%.

The on-field application of the proposed system has been made in a small size industrial plant, by testing the communication channel and its power quality measurement capability. In particular, a bit error rate (BER) less then 10^{-8} and a character error rate (CER) of 10^{-10} were obtained. Successively some data comparison between standard and proposed instrumentation have been made in order to evaluate the accuracy in the evaluation of power quality indexes. The obtained results are summarized in Tab. 1 together with the time afterward the measurement is updated. With the aim of highlight the processing capability of the measurement network, in Fig. 4 is reported, as an example, the current spectrum obtained by processing power net data.

Table 1. Performance evaluation results

Quantity	e%	Processing time
True rms	0.3%	40 ms
THD	0.5%	0.5 s
Flicker index	0.8%	0.4 s
Crest Factor	0.5 %	40 ms
Active Power	0.4%	60 ms
Power Factor	1.1 %	60 ms
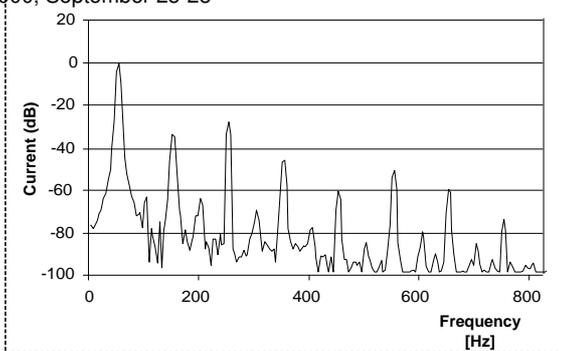
Figure 4. Example of data processing capability

6   CONCLUSIONS

In this paper a low-cost measurement and control network for power quality monitoring is presented. The architecture of the network is arranged on three hierarchical levels: the fieldbus network, the local area network and the Internet network. Particular attention has been dedicated to the lower level, which represent the field level, realizing a flexible, modular measurement module, based on the H8/3048F Hitachi microcontroller. As field bus server a VXIbus device is employed with a suited, register based interface. The proposed network, designed for industrial measurement applications, has been applied to power quality monitoring of an industrial plant.

The performance of the instrument has been investigated in terms of both acquisition error and acquisition and data transmission times, obtaining satisfactory results.

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