DEVELOPMENT OF DSP BASED INSTRUMENT FOR MONITORING PLC AND OTHER HIGH FREQUENCY SIGNALS IN DISTRIBUTION NETWORKS

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ABSTRACT

Concerns in indentifying and diagnosing power quality related disturbances in power line communication (PLC) network has enforced special requirement for power quality monitoring equipment and creates a need for sophisticated software to analyze the monitored data. Most of the existing monitoring equipment are too expensive, they are neither handy nor capable of detecting the disturbances in real-time. Therefore, there is a need for remotely readable low-cost monitoring equipment that can be used to perform accurate and real-time detection of power disturbances. Digital signal processor (DSP) is the optimal choice to fulfill real-time analysis. Advanced DSP provides fast data capture, fast data processing and flexibility in processing signals, increased system performance and reduced system cost. Successful completion of this research work would be of immense benefit to electrical power industry in general and smart grid applications in particular.

Keywords- Digital Signal Processors, Information Technology (IT), Power Line Communication, Power Quality Measurement, Smart Grid.

INTRODUCTION

Power line communication is a technique that employs the infrastructure of electrical power distributed system as a communication medium. The system is attractive because it uses the existing low voltage (LV) distribution network, since no new wiring is required. In Europe, the available frequency intervals for communication systems in low voltage and medium voltage (MV) power networks are established by CENELEC EN 50065-1 [1]. This standard applies to electrical equipment using signals in the frequency range 3 kHz to 148.5 kHz to transmit information on low voltage electrical systems. It also specifies the allowed maximum signaling voltages used by the PLC system. The use of frequency band 3 kHz up to 95 kHz is restricted to electricity suppliers and their licensees. The object of the standard is to limit interference caused by signal transmission equipment to sensitive electronic equipment. However, the signal-to-noise ratio (SNR) depends on the network and devices connected to it. Recently, the low voltage PLC system has gotten much attraction and became a hot research topic for electrical advancement using IT & DSP techniques. However, effective implementation of high quality signal over power line is difficult enough, because of the unpredictable load, noise, attenuation and resonance effects. Power quality and high frequency interference problems have increased in power networks during the past few years with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. The proliferation of power electronic devices and nonlinear loads and the occurrence of electrical faults causes significant amount of power quality problems in distribution network [2]. The most common high frequency noise sources are fluorescent lamps, when it is set to medium brightness, the maximum inrush current may cause impulse of several tens volts. Other potential sources of high frequency interference are AC motors (which can be found in vacuum cleaners, electric shavers and many common kitchen appliances), switched power supplies and frequency converters that can cause significant amount of attenuation in PLC network [3].

The concept of smart grid is developing rapidly and spreading globally as an enabling technology for efficient and flexible power delivery [4]. In the ongoing discussions about smart grids, power quality has to become an important aspect and should not be neglected. The adequate power quality guarantees the necessary compatibility between all equipment connected to the grid. Therefore, it is a considerable issue for the successful and efficient operation of existing as well as future grids. In addition to monitor PLC signals, this paper also discusses adding advanced features to monitoring instrument useful in smart grid applications, such as measurement of high frequency interference, disturbance recording, transient recording and partial discharge (PD) measurement.

Monitoring and management of power quality in distribution networks are becoming more important because customers are demanding better services and higher power quality. Utilities understand that measurements are important in detecting, analyzing and solving these problems. Therefore, to have detailed knowledge about the power line channel at any time, numerous measurements are necessary at different locations and times. Some mobile solutions for monitoring distribution networks like oscilloscope, network analyzers and spectrum analyzers as shown in Figure 1 are available but they are too expensive for extensive permanent installation and are not compact to handle. The measurement could be very troublesome and takes a lot of time. Moreover, additional post-processing on measurement results might be necessary.

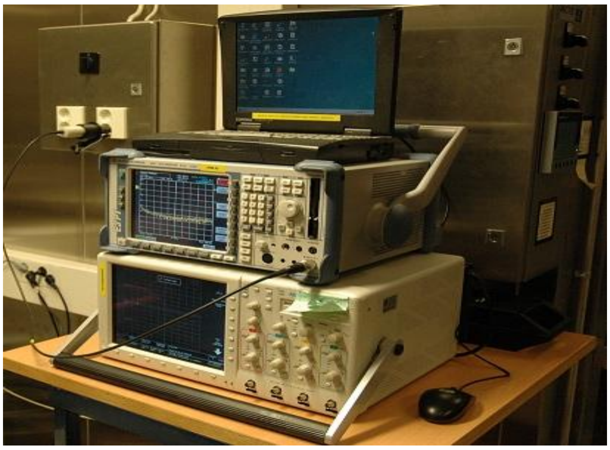

Figure 1. Field Measurement Setup.

Real-time monitoring and identification of power quality disturbances in distribution network is an important concern to electrical utilities so that diagnosis and mitigation of such disturbances can be handled quickly. Conventional monitoring equipment focuses on measuring voltages and currents at the metering locations but are not capable of detecting the high frequency disturbances in real-time. Thus there is a need for a cheaper, remotely readable real-time high frequency power network monitoring instrument that can measure and record high frequency phenomena in distribution network.

PROPOSED HARDWARE ARCHITECTURE

Digital signal processors have become a very key component in many applications, such as communications & telecom, computers and peripherals, consumer electronics, medical, industrial, energy and so on. DSP based devices are more popular solution for several reasons: They are distinct from the general-purpose microprocessor in terms of having a far higher computing power, they can potentially be reprogrammed in the field, and allowing product upgrades or fixes [5]. They are often more cost-effective than custom hardware, particularly for low-volume applications, where the development cost must be kept lower. Real-time system measuring and recording high frequency phenomena requires higher sampling frequency and much more data processing capacity, thus, digital signal processor is a promising choice due to low-cost, high speed and great performance.

Figure 2 depicts the development idea of monitoring instrument. The digital board includes signal conditioning section, an anti-aliasing filter, an analog amplifier (with adjustable/programmable gain), a high resolution analog- to-digital converter (ADC) and a high-performance digital signal processor.

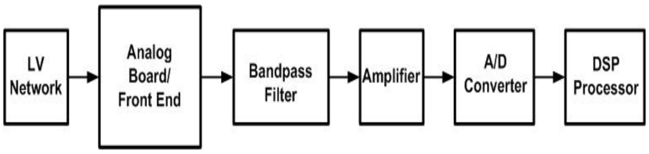

Figure 2. Block Diagram of the Monitoring Instrument.

In the block diagram, a voltage divider circuit will be used as a front end module to attenuate the voltage signal to the bandpass filter input. Bandpass filter will be used to pass frequencies within a certain range and attenuate frequencies outside that range, which will help to screen out frequencies that are too low or too high, giving easy passage only to frequencies of interest to amplifier input and to avoid aliasing of the sampled signal. The effects of system noise can be extreme if care will not be taken. An amplifier which applies gain to the small signal before ADC conversion can increase measurement resolution and effectively reduce the effects of noise. A 12-bit resolution analog-to-digital converter (ADS7881) will be used to convert a continuous quantity to a discrete digital number and then DSP (TMS320C6713) will be used to mathematically manipulate them. Here the manipulation can and often does involve complicated higher order mathematics, such as Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT) and the Z-transform. All of these mathematical tools are used to manipulate the digital signal to produce the result.

TMS320C6713 DSP Starter Kit (DSK)

The TMS320C6713 DSK shown in Figure 3 is a low cost development platform designed to speed the development of high precision applications based on Texas Instrument's (TI) TMS320C6713 floating point DSP generation. The

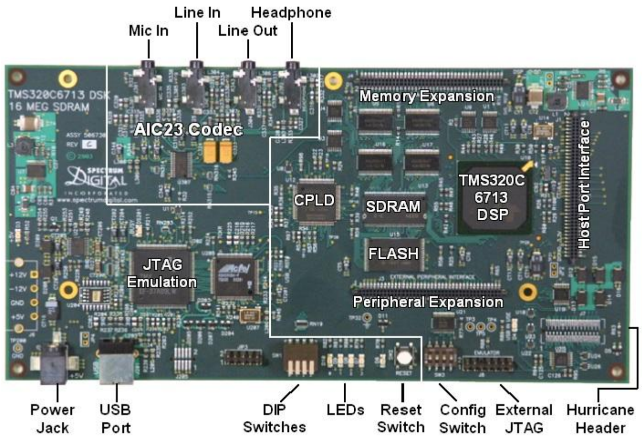

Figure 3. TMS320C6713 based DSK board.

DSK features the TMS320C6713 DSP, a 225 MHz device delivers up to 1350 million floating-point operations per second (MFLOPS), 1800 million instructions per second (MIPS) and with dual fixed-/floating-point multipliers up to 450 million multiply-accumulate operations per second (MMACS). The C6713 device is based on the high-performance advanced very-long-instruction-word (VLIW) architecture making C6713 DSP an excellent choice for numerically intensive algorithms and real-time signal processing [6].

ADS7881 Evaluation Module (EVM)

The ADS7881EVM shown in Figure 4 serves as a reference designed for the prototyping and evaluation of the ADS7881 analog-to-digital-converter. The ADS7881 is a 12-bit 4-MSPS ADC converter with 2.5-V internal reference and conversion time of 200ns. The device includes a capacitor based successive approximation register (SAR) ADC converter with inherent sampling and hold. The EVM uses a low noise THS4031 inverting gain of one and a buffer amplifier. It has high speed parallel interface, onboard signal conditioning and internal reference buffer. To meet the real-time requirement of monitoring instrument, ADS7881 is an optimal choice for its high performance in data acquisition systems [7].

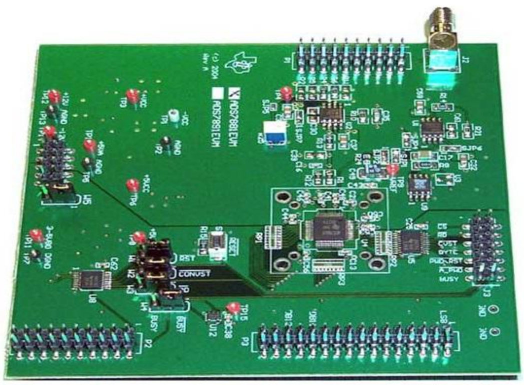

Figure 4. ADS7881 Evaluation Module.

Code Composer Studio

Code composer studio (CCS) is an integrated development environment (IDE) for developing and debugging DSP codes for TMS320 DSP processor family. It includes compiler, source code editor, debugger, project built environment, simulator and many other features. The real-time operating system for DSP, DSP/BIOS is inbuilt with CCS software and provides various advantages i.e. easy development of code, multitasking environment and real-time data exchange [8]. A number of debugging features such as setting breakpoints and watching variables, viewing memory, registers and graphing results can be used to analyze the signal processing algorithm in a proper manner.

MEASUREMENT METHODOLOGY

Figure 1 earlier demonstrated the idea of PLC measurement setup adopted by our research group during the field measurement. Oscilloscope and frequency analyser are used to monitor the quality of PLC signal. It is very evident from the figure that the measurement setup is indeed very complex and not too handy from mobility point of view. Figure 5 shows the time and frequency domain representation of PLC signal acquired by a 12-bit oscilloscope and a HF voltage probe during a field measurement performed in Tampere, Finland.

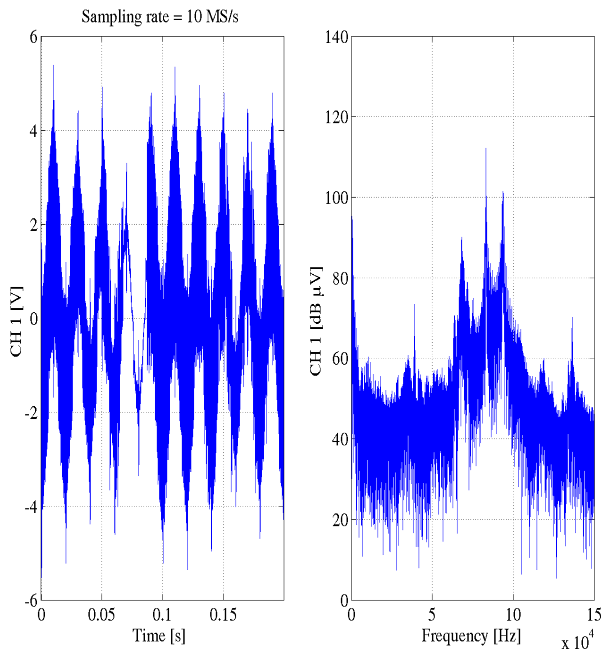

Figure 5. Time and Frequency domain representation.

Time domain waveform doesn't provide sufficient information about the PLC signal and it needs additional post processing (FFT) to draw the meaningful result to analyze the signal, whereas the frequency spectrum clearly shows the presence of PLC signal with carrier frequencies 83 kHz and 94 kHz, respectively along with some noise signals. Y-axis in both time and frequency domain graphs indicates the voltage level of the signal. It is very common in communication receivers to express voltage in terms of dBµV. 120 dBµV in frequency spectrum corresponds to 1 volt according to the mathematical expression given below. These figures present the idea that CCS software and signal processing algorithm will be used to capture the input waveforms and analyze the power disturbances in real-time by producing similar kind of result as shown in Figure 5 in more meaningful ways.

$$dB\mu V = 20\log(\frac{V}{1\mu V})$$

Measuring Quantities

The key focus of this DSP based instrument can be summarized as follows:

Monitoring of PLC Signals and Disturbance

- PLC signal voltage [dBµV or mV]
- Noise level [dBµV or mV]
- Signal to noise ratio

The frequency band used for this purpose extends from 3 to 150 kHz. A key parameter when estimating the performance of a communication system is the signal-to-noise ratio. The noise generated on power line can results from different load connected to the grid, such as TV, computers, vacuum cleaners and so on. If the noise level is very high, the PLC signal-to-noise ratio gets very low and the signal might not be detected. An advanced signal processing algorithm will be developed to enable the detection of PLC signal voltage and noise level to calculate the signal to noise ratio.

Potential Future Applications

The initial development phase of the monitoring instrument and main focus of this paper is to deal with PLC signals and disturbance. However, other advanced features that will be added to the monitoring instrument are as follows:

Disturbance and Transient Recording

Disturbance recording will be used to monitor the operation of circuit breakers and protective devices in the event of a power system fault, or of a malfunction of control or protection equipment. The resulting recorded data can also be used for estimating the fault locations. The DSP based instrument may be used also for transient recording. Transient over voltages are caused by switching operations in the network and they may cause malfunction or breakdown of sensitive electronic loads in the network.

Monitoring of Partial Discharge Signals

PDs have a distinct effect in the ageing processes and lifetimes of high voltage (HV) insulation. Preventing incipient faults leading to permanent failures can greatly reduce losses and save the power industry millions of dollars in lost revenue. Compared to periodical PD testing, continuous on-line monitoring is more effective way to detect rapidly developing faults. On-line PD measurements for condition monitoring has not been economically possible in medium voltage networks because of the high costs of the equipment and resources needed [9]. In future, the DSP based instrument can be developed further for detection and location of partial discharges in the power network.

CONCLUSION

This research paper focuses on the development of a DSP based low-cost instrument for monitoring quality of PLC and other high frequency signals. The initial stages of development of the monitoring instrument are described in this paper. A novel method for detection and classification of power quality disturbances will be developed using digital signal processing algorithm. DSP algorithms are fundamental as they can produce very accurate results and are a flexible component of instruments which can be upgraded and improved without the need for expensive and time consuming hardware re-designing. This low cost instrument with these monitoring functions would enable cost-effective implementation of many smart grid applications. One of the promises of smart grid is improved power quality. Thus, DSP based monitoring instrument has a big role in future distribution network and smart grid infrastructure as well. This instrument can be installed to different locations permanently to monitor electricity as efficiently as possible. The disturbances and poor quality can be detected before it causes harm to equipment owned by the customers or the power distribution companies.

REFERENCES

[1] EN 50065-1, "*Signaling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz-Part 1: General requirements, frequency bands and electromagnetic disturbances*".

[2] Tao L, Alexander D, 2006, "Real time Measurement of Power Disturbances: Part 1. Survey and a Novel Complex Filter Approach". *Electric Power Systems Research*. Vol. 76.

[3] Vellano N, Soletto K, 2007, "PLC Systems Performance Analysis Regarding Power Quality Disturbances". *IEEE International Symposium*. Vol. 10.

[4] E. Lightner and R. Scheer, Nov/Dec 2008, "Transforming the Grid". *Electric Perspectives*. <http://www.energetics.com/features.asp?Features=91>

[5] S. A. Boggs, 1990, "Partial Discharge - Part I: Overview and Signal Generation". *IEEE, Electrical Insulation Magazine*. Vol. 6, 33-39.

[6] User Guide, 2005, "TM320C6713- Floating-Point Digital Signal Processor", *SPRS186L*. Texas Instrument, Dallas, USA.

[7] User Guide, 2004, "ADS7881 Evaluation Module", *SLAU150*. Texas Instrument, Dallas, USA.

[8] Getting Started Guide, 2006, "Code Composer Studio Development Tools V3.2", *SPRU509G*. Texas Instrument, Dallas, USA.

[9] Pertti Pakonen, 2007, "Detection of Incipient Tree Faults on High Voltage Covered Conductor Lines", *Dissertation*, Tampere University of Technology, Finland.