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An FPGA-based System for Real-time Monitoring of Voltage Harmonics

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Abstract- In this study, a real-time monitoring system has been prepared by using Field Programmable Gate Arrays (FPGA) in order to monitor three phase voltage harmonics instantly. In this monitoring system, a signal input card has been designed for the purpose of transferring three phase voltage signals of the network to the FPGA card. Harmonic values of the voltage signals belonging to each phase have been instantly calculated with the 128 floating point FFT algorithm embedded in the FPGA card. The obtained harmonic values are transferred onto computer with the RS232 communication protocol created in the FPGA device. A software featuring a graphical interface has been prepared on the computer for the purpose of visually displaying the voltage signals and the harmonic data belonging to the voltage signals. All the parameters regarding the monitoring system can be monitored easily on this software. The monitoring system that was designed for the present study was set up and tested in the laboratory at the Department of Electrics and Electronics Engineering, Tunceli University. The results show that the monitoring system can successfully obtain the voltage signals and the harmonic values of these signals.

Keywords: Harmonic, Monitoring, FPGA, Power Quality

I.Introduction

In electric energy systems, current and voltage wave forms are expected to have a basic sinusoidal change. For such a change, the system must be fed with a sinusoidal source and loaded with linear loads. Non-linear loads such as ever-increasing convertors connected to power systems, arc furnaces, power electronics elements, static Var compensators cause the current and voltage magnitudes in the system to be non-sinusoidal, that is harmonic distortion as a power quality problem [1]. Harmonics have many negative effects on power system elements and electrical devices connected to the system. These effects, in turn, generally cause devices malfunction or not function at all, engines and transformers to overheat, and lead to disturbances, wrong measurements, short lives of the loads connected to the system and power losses. In order to reduce these problems, the harmonics that occur in the power system have to be under the limit values specified in the harmonic standards. Therefore, harmonics in power systems must constantly be monitored and their harmonic elimination must be performed when necessary. There are three basic aims of harmonic measurement in industrial power systems. The first of these is to determine the source and characteristics of harmonics. The second is to design and set up the necessary filtering systems that are needed to reduce the harmonic effects that have an effect on the power system. The third is to ensure that the total harmonic distortion on the power system is in accordance with the standards.

For these reasons, harmonic monitoring systems are very important for electrical facilities and their beneficiaries[2, 3]. Generally, DSP-based methods[4, 5] and LabView applications are commonly used for harmonic monitoring systems[6,7]. In this study, an FPGA-based monitoring system has been developed for real-time monitoring of the voltage harmonics on a three phase network. In this system, three-phase instant voltage values obtained with 128 sampling rate are transferred to FPGA device. The harmonic components for each phase are obtained separately with the floating point based FFT algorithm embedded in FPGA. The obtained harmonic components are transferred onto computer with the RS-232 protocol. The voltage signals belonging to each phase and the harmonic components of these signals are presented visually to the users with a graphical interface program created on the computer.

II. Harmonics

Harmonics are the components of a distorted power frequency wave form, which are not in the main frequency. Harmonics in power systems can also be defined as steady-state distortions which occur in the wave form of currents or voltages. Harmonics have frequencies which are integer multiples of the fundamental frequency. The fact that there are non-linear elements or non-sinusoidal sources in the circuit are the key factors in the occurrence of harmonics. Sinusoidal wave form in the energy system is distorted as a result of such elements and occurrences. These distorted waves are called “non-sinusoidal waves”. Non-sinusoidal wave forms are made of the sum of sinusoidal waves although they are periodic and the other sinusoidal waves whose frequencies and amplitudes are different. The sinusoidal waves other than the main wave are called “harmonic components”. Harmonic distortion levels are defined by the phase angles, amplitudes and harmonic spectrums of each harmonic element. Harmonics affect all the elements in power systems. Therefore, power systems are affected negatively from harmonics.

III. Field Programmable Gate Arrays

FPGA is a logic device that is formed by connecting thousands and even millions of transistors in order to carry out logical processes. Complex digital filters perform simple functions like addition and subtraction for such operations as fault detection and improvement. Aircrafts, cars, radar systems, defense industry and computers are some of the fields where FPGAs are used. FPGAs can be structured as more complex circuit elements such as basic logic gates (AND, OR or SPECIAL OR) or decoder owing to the fact that they contain programmable logic elements called “logic cells” [8]. FPGA’s widely used in many areas such as power quality[9, 10], artificial neural networks [11], signal processing [12-14]. The structure of FPGAs that contain programmable switch elements and two-dimension logic cell series is given in Figure 1.

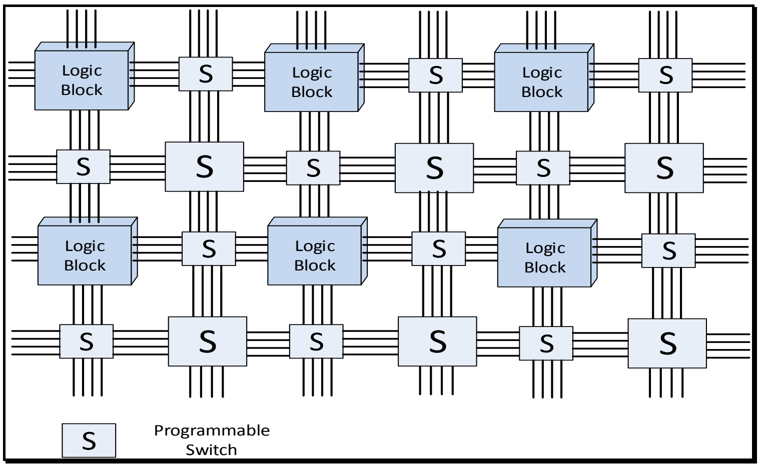

Figure 1. Basic FPGA structure that contain two-dimension logic cell series

A logic cell unit can be programmed to perform a simple function. Programmable key elements can be adjusted to ensure the link between logic cells. By adjusting the programmable key element that will serve as the link between each logic cell function and the cells, the desired designs are done. After the design synthesization is done, the desired logic cell and key element adjustments are embedded in the device by using programming properties of the device. These are realized in the field rather than manufacturing in a factory and hence, these devices are called “Field Programmable” devices [15].

IV. The designed real-time voltage harmonic monitoring system

In this study, an FPGA-based monitoring system for real-time monitoring of the harmonic data belonging to voltage signals has been developed. In this system, harmonic values of voltage signals are measured instantly with the 128 floating point Fast Fourier Transform (FFT) algorithm embedded in the FPGA device and

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transferred onto computer with the RS232 communication protocol. Cooley-Tukey algorithm was used in the FFT module within the FPGA device in order to reduce the load of multiplication. Signal data belonging to 3-phase voltages and the harmonic values of voltage in each phase separately are given presented graphically and numerically with the visual software created on the computer. Figure 2 illustrates how the harmonic monitoring system works.

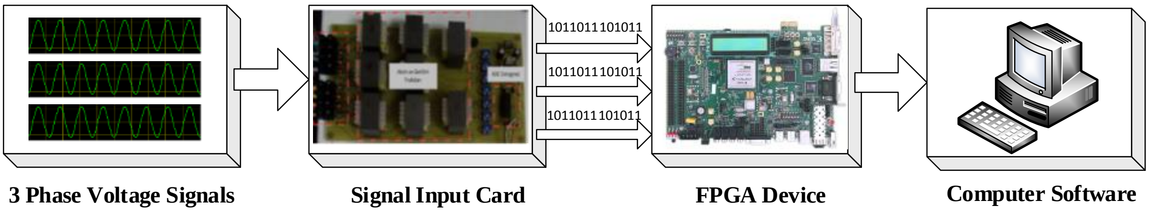

Figure 2. The structure of FPGA-based real-time harmonic monitoring system

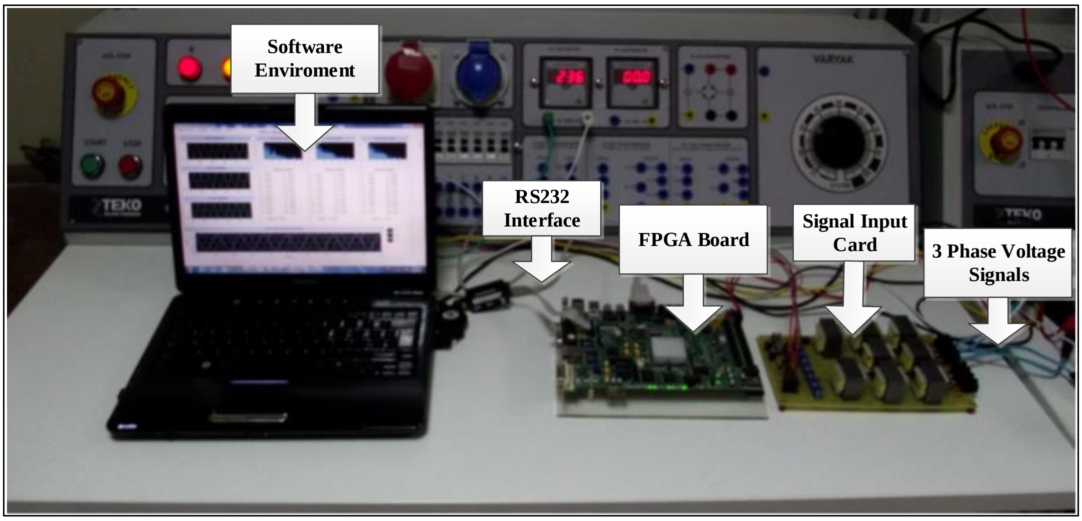

Figure 3. Monitoring set-up of the harmonic monitoring system

The voltage signals obtained from the network are applied to the inlet card and transformed into the level that the analog digital convertor(ADC) can process. These voltage signals which are sampled by the ADC integrated are transferred to the FPGA device after necessary links are established. After the FFT algorithm and other transform processes, the voltage signal data coming to the FPGA device are transferred onto a computer with the help of a high-speed communication interface. The data coming onto the computer are obtained with the graphical interface software that has been created for the monitoring system and these signals are presented visually with graphical tools that users can use easily. The real-time harmonic monitoring system designed for the present study is comprised of three different parts. These are signal inlet, FPGA medium and graphical software medium. The general structure of the monitoring set-up for the real-time harmonic monitoring system is given in Figure 3. The 3-phase voltage data and the harmonic values belonging to these signals were aimed to be monitored in the monitoring system set up in the laboratory of the Department of Electrics and Electronics Engineering, Tunceli University. Monitoring system consists of the signal inlet card, FPGA device and the computer to run the graphical interface program.

A. FPGA design of Harmonic monitoring system

Transforming the voltage signals obtained on the signal inlet card into digital data and determining harmonic values by applying Fourier transform to these data are maintained with the algorithms embedded in the FPGA device. For this study, a Virtex-5 LX110T model FPGA card produced by the company Xilinx has been used. The algorithms realized within the FPGA card have been prepared on the ISE(Integrated Software Environment) platform with VHDL(Very Fast Hardware Description Language) and embedded in the device. The flow chart representing the working structure of the softwares prepared on the FPGA is given in Figure 4.

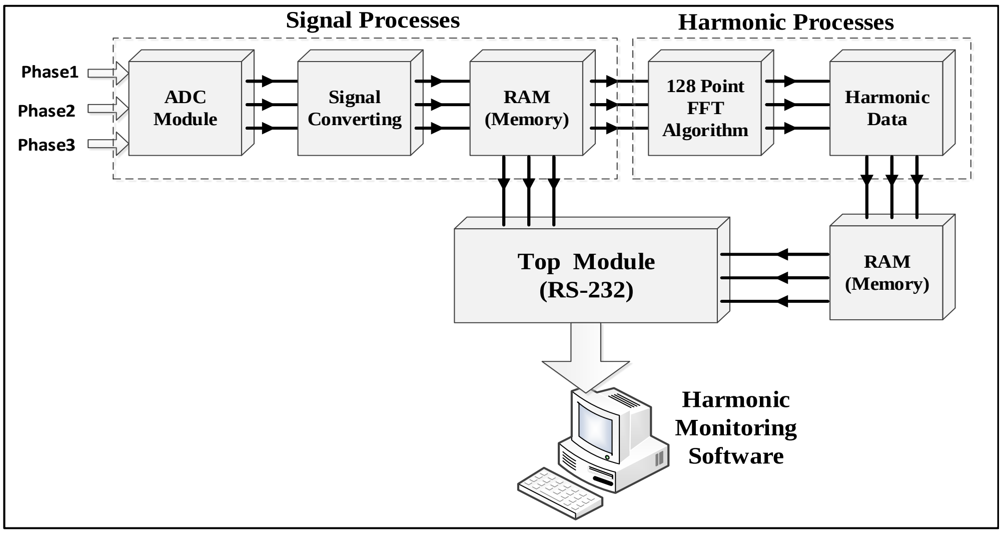

Figure 4. The block representation of the working structure of the softwares in FPGA

Selection of channels between the signal inlet card and FPGA device and sampling of voltage signals are performed in the ADC Module. The voltage signals obtained from ADC are transformed into a suitable number format in the voltage transform part. In this study, 32-point floating number system has been used for the operations in FPGA. Signal data are recorded on RAM memories after the necessary transforms. The signal data on RAMs are sent to the RS-232 module for instant monitoring of voltage values and to the FFT algorithm for simultaneous obtaining of harmonic values. The algorithms written within the device have been formed as separate modules that work in parallel with each other and associated under a single entity. Such code writing is vital in terms of both order and parallel functioning. One of the most important points to pay attention to about the programs written within the FPGA device is that the sources the device has must be able to sustain the designed algorithm. Table 1 shows the source amounts the real-time harmonic monitoring system consumes in the FPGA device.

Table 1. Source amounts the softwares use in FPGA

Unit	Used	Available	Usage
Slices	8.150	69.120	%11
Logic Elements	7.508	69.120	%13
Memory Bits	1.408	17.920	%7
Block RAM/FIFO	24	148	%16
Total Memory (KB)	720	5.328	%13
DSP48Es Number	24	64	%37

B. Computer software prepared for the system

The graphical interface program that is an important part of the real-time harmonic monitoring system offers a platform in which users can monitor the signal data and harmonic data visually and record these data. The program created with Microsoft Visual Studio 2010 C# programming language and in which 3. party components are used for graphical drawings presents users with great ease. The view of the graphical interface program prepared for the harmonic monitoring system is given in Figure 5.

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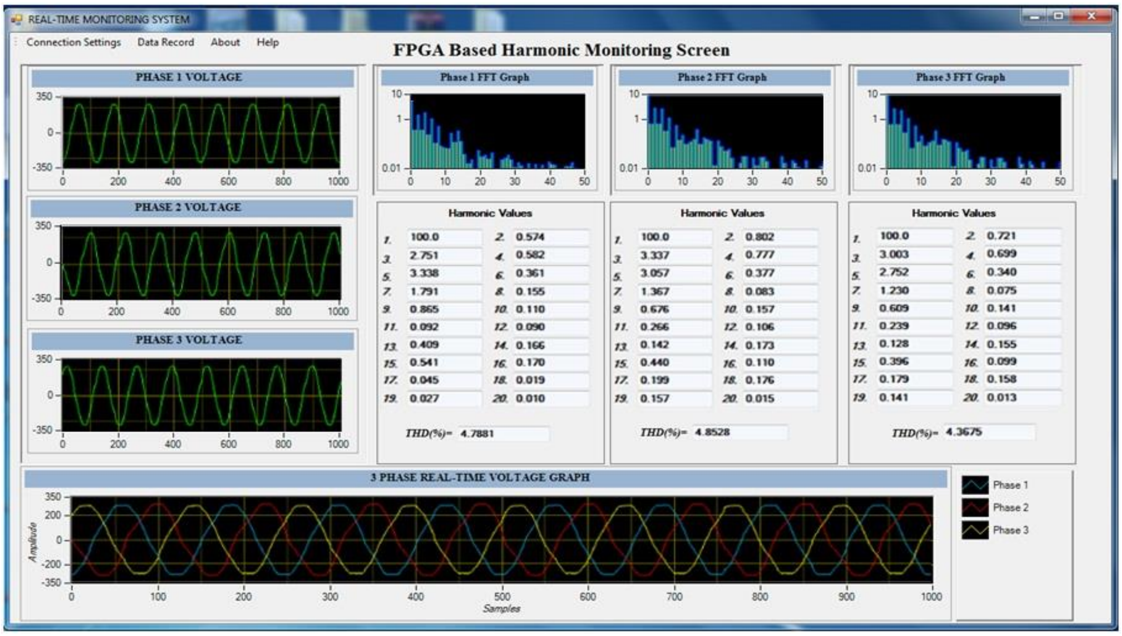

Figure 5. Harmonic Monitoring System Graphical Interface Program

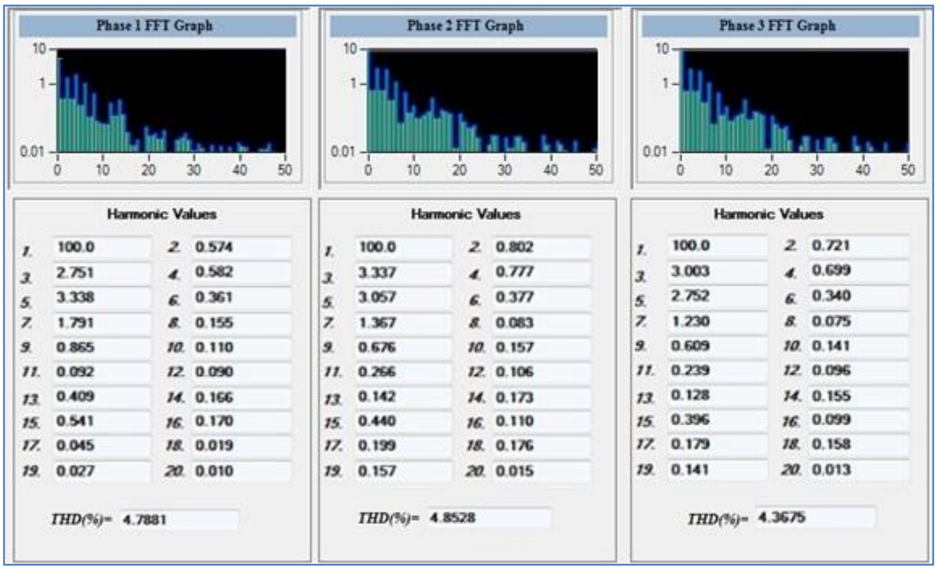

Figure 6. Harmonic values obtained from harmonic monitoring system for 3 phase voltages

Separate graphs of each phase voltage signal and a shared graph for 3 phases take place on the program. The harmonic graphs belonging to each phase and the values up to the 20th harmonic can be viewed on the software. The menus that enable connection with the FPGA device and the recording menu for the data obtained in the program generally are found in the menus situated in the upper part of the program. Owing to the flexible and fast nature of the C# programming language, receiving and sending data in the communication parts of the FPGA device and the program have been successfully performed over the high speed port. The data received over the high speed port are read on the buffer memory and used on the graph screen and other operations. Figure 6 shows the results determined for each phase by the 128 point floating FFT algorithm that runs embedded in FPGA. These results are presented both graphically and digitally on the screen so that users can evaluate them with ease. Voltage signal values have been transferred to the FFT algorithm in the MATLAB medium and results have been obtained in order to compare the voltage harmonic values obtained real-time from the FPGA medium. It has been observed that, when compared, the results obtained with FPGA-based harmonic monitoring system and in the MATLAB medium are consistent

V. Results

In this study, a FPGA-based monitoring system has been prepared in order to measure 3 phase voltage harmonics real-time and monitor the measurement results. . In this monitoring system, FFT of 3 phase network voltage signals has been measured based on floating point digits on the FPGA card and transferred to the software on the computer with the communication protocol RS232. The signal data belonging to the 3 phase voltages and the harmonic values of each phase separately have been obtained both graphically and digitally. The designed monitoring system was set up in the laboratory of the Department of Electrics and Electronics Engineering, Tunceli University and the harmonic values were obtained.

Voltage signal values have been transferred to the FFT algorithm in the MATLAB medium and results have been obtained in order to compare the voltage harmonic values obtained real-time from the FPGA medium. It has been observed that, when compared, the results obtained with FPGA-based harmonic monitoring system and in the MATLAB medium are consistent

According to the results, the superiorities of FPGA-based voltage harmonic monitoring system over traditional monitoring systems can be summarized as follows;

- It has a flexible structure,
- It can run fast and parallel operations,
- It has an economic design,
- It can be monitored and interfered with on computer screen and
- It is field programmable.

The present study shows that FPGA perform quite well in signal processing designs.

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