A Micro-Controller Based 3-Phase 600 V Universal Phase Sequence Tester

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Student Paper Abstract

This paper presents a 32 bit microcontroller based three-phase, high voltage phase sequence tester compatible with global utility grid frequencies. This digital phase sequence tester was developed as a course project for EGR 330 Power Systems Analysis, a junior level electrical engineering course at Grand Valley State University. For 3-phase systems phase sequence is crucial while connecting two systems together. Also, in case of ac motors, phase sequence determines the clockwise or counter clockwise direction of rotation. Unlike the phase sequence testers available in the market, this tester does not need any rotating parts (e.g. ac phase sequence motor) to indicate phase sequence by direction of motor rotation. High voltage of 600V to low voltage (digital level) conversion is implemented by a simple star-connected resistor circuit. Analog to digital conversion and processing of this digital signal are implemented using ATMEGA32 micro-controller from Atmel. Output of a test (a-b-c or a-c-b phase sequence) is displayed by one of the two phase indicator LEDs. A 600V, 50-60 Hz phase sequence tester is designed to explain design procedure. Designed tester is simulated using PSPICE to verify its operation. Simulation test results on a 600V system are presented. A laboratory prototype has been developed and tested. Test data acquired on a 150V system has already been collected and will be presented in the final paper. The developed prototype has also been used on a live 480V, 60 Hz, 3-phase system application successfully. Simulation and prototype experimental results verify the operation of this phase sequence tester for a voltage range of 6V to 600V. The tester takes 70 voltage samples at a sampling rate of approximately 2800 samples per second on each phase. As enough samples are acquired this battery powered tester will also work with 50 Hz utility system. The microcontroller program can also be easily configured to a frequency range from 1 to 1400 Hz by either increasing the sample size (but this has memory constraints) or by changing the program to sample and analyze at the same time (with no memory constraints because we are only storing one previous value, and resetting a counter if the voltage is not rising). Future work will investigate into implementing this feature. This tester is cheaper than the testers available in the market and suitable for universal frequency applications. This innovative course project work experience has natural and very relevant connection to undergraduate engineering research and education.

Key Words

Student Paper, School of Engineering, Electrical and Electronics Engineering, Computer Science

A Micro-Controller Based 3-Phase 600 V Universal Phase Sequence Tester

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1. Introduction

Electrical power system is the backbone of modern civilization. At this time, almost 100% of the total generated electrical power is in the form of three-phase ac systems. Moreover, transmission and distribution of this power are also performed using three-phase circuitry [1-2]. The underlying advantages of this form of electrical power systems are: i) 3-phase machines generates more power per kilogram of metal in the machine, ii) for loads more than few kilo-Watts 3-phase system is more efficient, and iii) instantaneous power of a balanced 3-phase system is constant while for single-phase system it is a time varying function. A three-phase system can be considered as 3 single-phase systems (phase *a*, phase *b* and phase *c*) connected together with 120^0 phase shift between any two phases. The phase sequence of a three-phase system is the order in which the voltage in individual phases peak as shown in Figure 1. Hence, there can be two possible phase sequence: *a-b-c* or *a-c-b*. While connecting 2 or more three-phase systems in parallel (usually required to make flexible systems with varying capacity) it is important to connect them with identical phases tied together. Moreover, improper connection of a 3-phase motor may lead to reverse rotation, and as a result it may damage equipment mechanically powered by the motor. Therefore, a phase sequence tester is required to determine phase sequences before integrating 2 or more systems. It is also an ideal tool for measuring proper rotation of motors, conveyers, pumps and other electrical devices interconnected on the power line before installation. The phase sequence testers available in the market have rotating parts and are costly. No phase sequence tester using micro-controller technology is available in the market at a cheaper cost [3]. Therefore, objective of this course project was to design and build a micro-controller based digital phase sequence tester that can determine the phase sequence of 3-phase power systems with up to 600 V and global utility grid frequencies.

The outline of this paper is as follows: Section 2 explains a schematic block diagram of the phase sequence tester. PSPICE simulation results are given in Section 3. Data acquired from the designed and built tester is presented in Section 4. This paper is concluded in Section 5 with recommendations on future work.

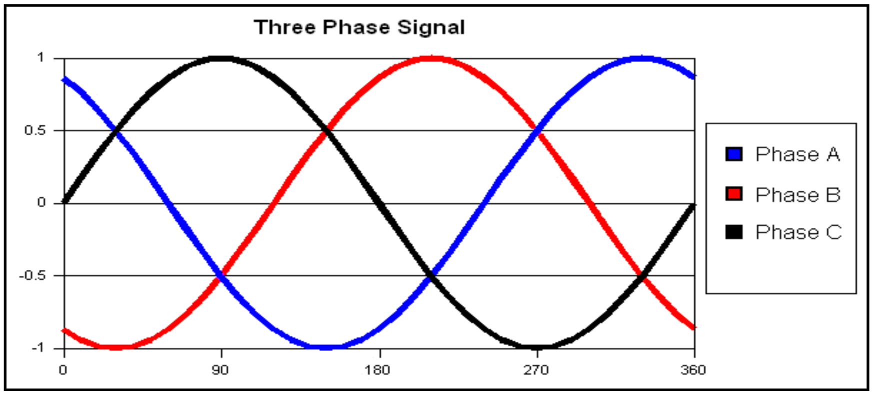

Figure 1 Three-Phase voltages as a function of phase angle

2. Block Diagram and Program Flow Chart

A micro-controller based phase sequence tester is designed with following specifications:

Input voltage: 0 to 600 V

Input frequency: 50 Hz to 60 Hz with flexibility to include universal frequencies.

Input power: 9 V dc battery

Output: 2 LEDs indication phase sequence

A schematic block diagram of the proposed phase sequence tester is shown in Figure 2. High voltage of 600V to low voltage (digital level) conversion is implemented by a simple low-power star-connected resistor circuit. Analog to digital conversion and processing of this digital signal are implemented using an embedded system built around ATMEGA32 micro-controller from Atmel. Output of a test (a-b-c or a-c-b phase sequence) is displayed by one of the two phase indicator LEDs.

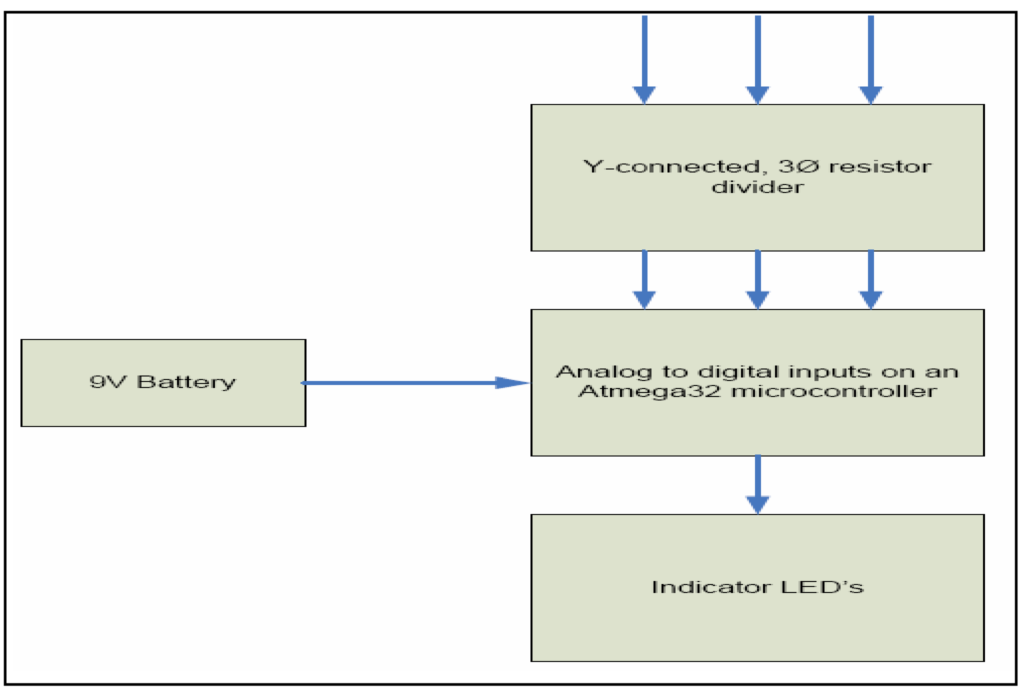

Figure 2 Block diagram of the proposed Phase Sequence Tester

A program flow chart of the proposed design is shown in Figure 3. As shown in this flow chart the micro-controller takes 70 samples per phase. The sampling rate of 2800 samples per second facilitates the tester to work with both 50 and 60 Hz. Since this is a micro-controller based embedded system the program code can be reconfigured to make the working frequency flexible for a range from 1 to 1400 Hz by either increasing the sample size or by changing the program to sample and analyze at the same time. However, increasing the sample size will require more memory space while sample and analyze will function with no memory constraints because we are only storing one previous value, and resetting a counter if the voltage is not rising.

3. PSPICE Simulation Results

The proposed design was simulated using PSPICE simulation program to verify its operation. A PSPICE schematic is shown in Figure 4. Output waveform of the simulation verified the design as shown by the acquired data in Figure 5.

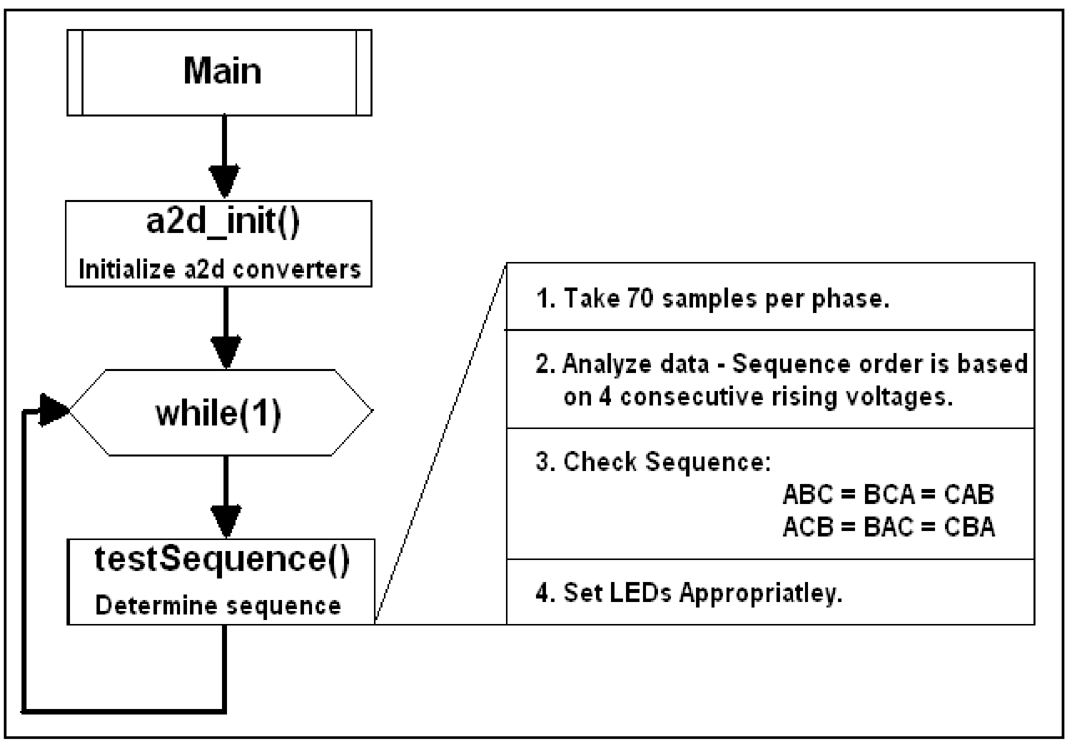

Figure 3 Micro-controller Program Flow Chart

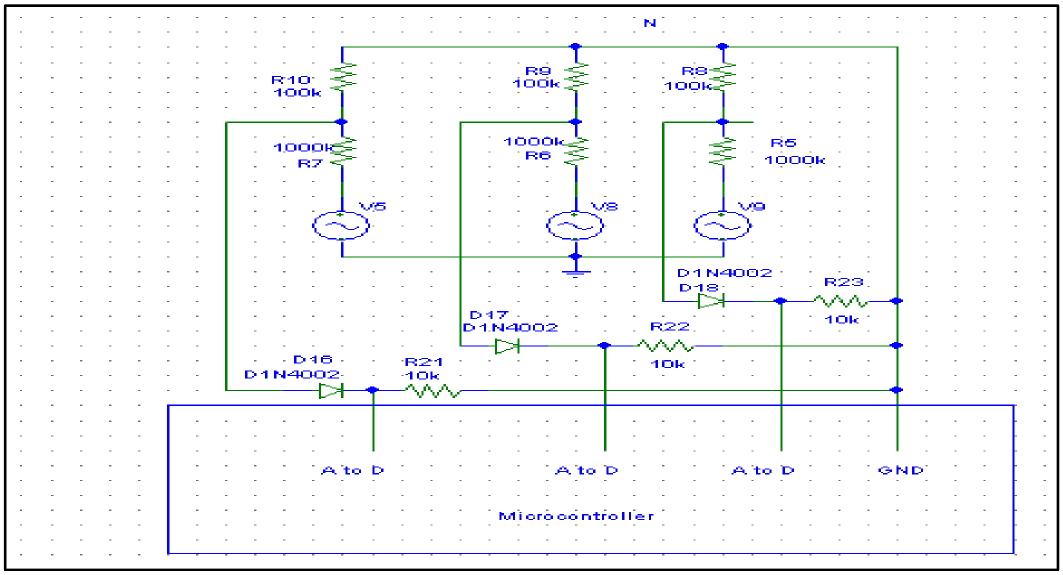

Figure 4 PSPICE Schematic Diagram

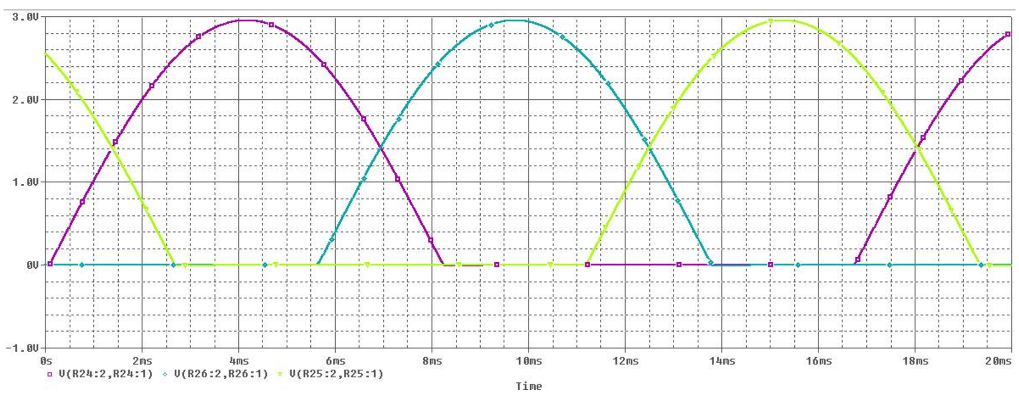

Figure 5 Simulation results (Phase a: purple, phase b: blue and phase c: yellow)

4. Prototype Test Results

The phase sequence tester designed was implemented in Energy and Power System laboratory using ATMEGA32 micro-controller from Atmel. A laboratory prototype was developed and tested. Some of the test data acquired on a 150V, 60 Hz system is shown in Figure 6. It was found that the prototype model functions smoothly from 6 to 240 V, 60 Hz 3-phase system. Although design was for a voltage range up to 600 V it could not be verified due to unavailability of variable 600 V supply in the lab. However, the developed prototype has also been used on a live 480 V, 60 Hz, 3-phase fixed voltage system application successfully. This application is evidenced by a picture shown in Figure 7.

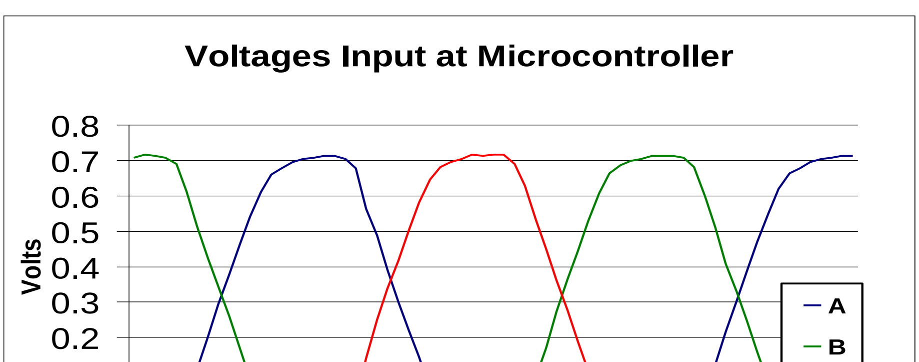

Figure 6 Test data collected using laboratory prototype

5. Conclusions

A micro-controller based 3-phase 600 V digital phase sequence tester as a student design project has been presented. Motivations, design steps and operating principle of the phase sequence tester are explained using block diagram schematics and program flow chart. PSPICE simulation results of the proposed design steps are obtained. A prototype laboratory model of the designed phase sequence tester was built around an ATMEGA32 micro-controller and was tested in lab.

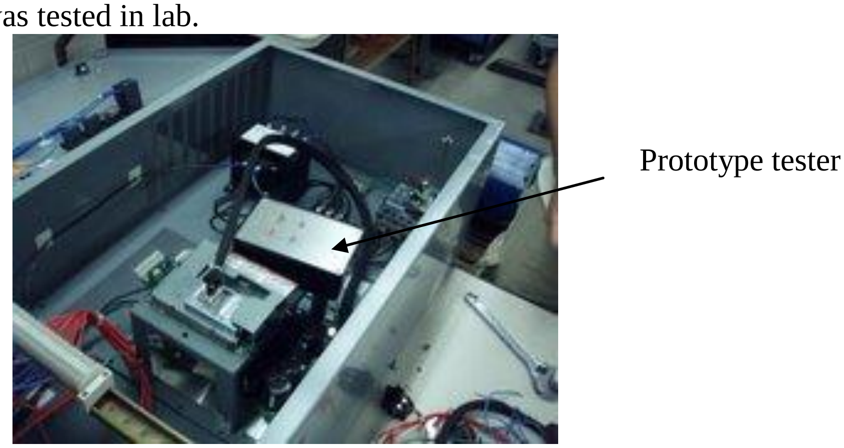

Figure 7 Phase sequence tester being used on a 480 V 3-phase line

Some of the experimental results with 3-phase 60 Hz power utility are presented in Section 4. Results show that the built prototype reliably detects phase sequence of a 60 Hz 3-phase system with a voltage range of 6 to 480 V. A sampling rate of 2800 samples per second facilitates the tester to work with both 50 and 60 Hz. Since this is a micro-controller based embedded system the program code can be reconfigured to make the working frequency flexible for a range from 1 to 1400 Hz by either increasing the sample size or by changing the program to sample and analyze at the same time. Future work will investigate into this feature.

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BIOGRAPHY

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Dr. Rahman is an assistant professor of engineering at Grand Valley State University, Allendale, MI. He earned his Ph.D. in electrical and computer engineering from University of Victoria, Canada. He has been teaching and doing research since 1994. His research interests include power electronics, electronic circuit design and electrical drive systems. He is a Commonwealth Scholar and member of ASEE and IEEE.

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