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Phase Sequence Online Correction Based on PIC Technique

Bilal A. Mubdir, Dara H. Amin
Electrical Department, Sulaimani Polytechnic University, Iraq

Article Info	ABSTRACT
	Monitoring the delivered power quality (PQ) to a critical load, is a worry issue since it is matter as much as critical or quality sensitive equipment connected to the electrical network. Various PQ problems such as noise, voltage imbalance, waveform distortion, phase imbalance, phase sequence, over voltage or sag are the most popular quality problems that could be detected and fixed if needed. The present work presents a design and practical implementation of electronic embedded system to monitoring the sequence of a three phase electrical system and detects the occurrence of any change in the sequence and fixes it online, correct the phase sequence immediately during less than 70 milli-seconds. PIC Microchip microcontroller has been used as the core of the present system, where the correction of the phases has been achieved by using traditional electromechanical relays. The system has been tested successfully and it functions properly even with multiple sequence changes.

Corresponding Author:

Bilal A. Mubdir,
Electrical Department, Technic Institute of Sulaimani
Sulaimani Polytechnic University
Tawar St., Bakhtiary 46002 Sulaymaniyah, Iraq
Email: bilal.mubdir@spu.edu.iq

1. INTRODUCTION

Identification of correct sequence for the three phase AC power supply is quite necessary and very important routine and test during installation and operation of three phase AC motors, parallel operation of three phase transformers and the related scientific experiments. When three-phase motor needed to rotate in a specified direction, the phase sequence should be kept fixed and not changed for any reason. Also, synchronizing 3-phase AC generators together may take placed only when they have same phase sequences. Many literatures have been published, which used many techniques in detecting the sequences of the AC power system phases.

Asaad Yousif, eta al. [1], designed and implemented an observations system based Atmega32 microcontroller to monitor the failure and the conditions of the three phases AC system. The power quality of the three phases, unbalance, voltage level, and the phases sequences have been considered in their system to take the action for running a three phase induction motor and protecting it as soon as an abnormal condition occurs.

Bidgoli, M.A., eta al, [2] suggested a method to detect the swapping of the phases by using the zero crossing times technique. The proposed method is very fast compared to another methods have been described in their work. They described another two methods could be used to identify the sequence of the phases. The first described method was by using the phase lock loop for metering the frequency of the power system itself. On other hand, the second method to identify the sequence is by measuring the instantaneous symmetrical components.

Shinde A. A. [3], described different mythologies for identifying the phase sequence of multi-phases systems. He developed an 8085 microprocessor based multi-phase sequence detection system that chooses the reference phase randomly from the multi-phase and is assigned the first phase in sequence. Then,

according to the general equations and by using the microcontroller unit, the sequence of any other phase has been identified.

Li, F. and Moore, P.J. [4], have used a non-contact sensors to determine the phase sequence in addition to the voltage level of the overhead conductor. Experiments taken beneath 400 kV double-circuit transmission lines have been presented in details. The experimental results of the proposed method proved the success of determining the phase sequence using the proposed mythology.

Palash Kundu and Arabinda Das [5] developed a prototype detection system based on 8085 microprocessor / 8751 microcontroller for identification of phase sequence and detection. The proposed system worked on the principle of comparing two codes. The first code is generated code by the system's hardware circuit itself, and the second one is a predefined specific code related to the phase sequence for successful match in each measuring cycle.

2. PHASE SEQUENCE

Phase rotation or phase sequence, are the terms that represents the voltage waveforms sequences. If a poly-phase voltage source is being used, the connections of any two phases are reversed, this phase reversal will not affect heater or resistive loads but, a three phase motor will run backward. Sensitive equipment, e.g., centrifugal pumps, screw compressors and elevators, could be damaged in this condition of changing the rotation direction. As a result, phase reversal (incorrect phase sequence) has been classified as a type of phase failure [6],

The voltage and current magnitudes will all be the same whatever the sequence is. There are some applications of three-phase power, as mentioned above, that depend on having phase sequence in a specific order. Identifying the phase sequence required an advance equipment or instrument to do this action, where the traditional measurement instruments like multi-meter, are not capable of identifying the phase sequence [7]. Considering the running sequence of any 3-phase power system, as following:

1-2-3 rotation: 1-2-3-1-2-3-1-2-3-1-2-3-1-2-3 . . .
3-2-1 rotation: 3-2-1-3-2-1-3-2-1-3-2-1-3-2-1 . . .

It is clear from above; the sequence "1-2-3" is the same as "3-1-2" or "2-3-1", starting from the left to the right. Also, the same criteria applicable on the reverse sequence as "3-2-1", "1-3-2", or "2-1-3". If the sequence pattern "1-2-3" had taken into consideration to find all the swapping (swapping two wires) options available on this sequence, the resultant sequence possibilities are illustrated in Figure (1).
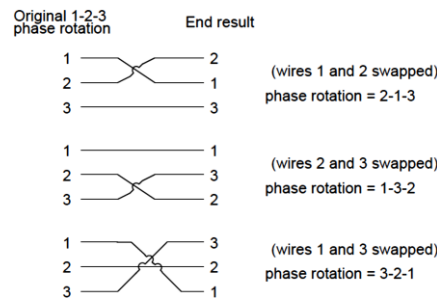

Figure 1. All Possibilities of Swapping Any Two Wires

At the end, the phase sequence will be reversed for all cases and it doesn't matter which phases' wires are swept. The resultant sequence after swapping could be either "3-2-1", "2-1-3", or "1-3-2", where all are the same.

3. MATHEMATICAL ANALYSIS

In the following analysis, we consider that we are dealing with an n-phase balanced AC system. A random phase could be chosen as the reference phase and assigned to phase number "1". Then we derive the necessary equations to identify the sequential position of any other phase p, (p ∈ {2, 3,..., n}). The sequence of any phase p is identified depending on the zero-crossing of the AC waveforms by measuring the time shift

between **p** zero crossing with respect to the reference phase. To find out a definite pattern of this time shift for n-phase system, we consider the AC waveforms of n = 3 and these are shown in Figure (2).

When taking phase-1 as the reference phase and looking closely at Figure (2), it is clear that after time intervals **t₂** and **t₃,** phase-2 and phase-3 have their zero crossing respectively with respect to the point "0". The reference point has been chosen in such fashion that the reference phase waveforms crosses zero in the positive direction (i.e., from low to high) at that instant. Phase-2 waveforms crosses zero at time **t₂** in a positive direction and phase-3 waveform crosses zero in a negative direction at time **t₃**. The magnitude of phase-2 waveform during the time interval **t₂** is negative (low), while the magnitude of phase-3 waveform during interval **t₃** is positive (high). The pattern described above is repeated in each cycle.

From the above observations, t_p is the time instant of zero crossing of phase **p** (to be identified) waveform measured from the reference point, **T** is the time period of the waveforms. Now one can identify the phase sequence, by measuring t_p the time instance of the first zero crossing of the pth waveform negative to positive or positive to negative from the reference point.

As suggested by the method stated in [8], consider the phasor diagram of a balanced **n** phase sinusoidal supply shown in Figure (3), one of the phasors marked 0, is chosen as the reference, and the others are marked as 1, 2, p ,.., n -1. The angle between any two consecutive phases is 360/n degrees and the angle of lag of the **p**th phase will be,

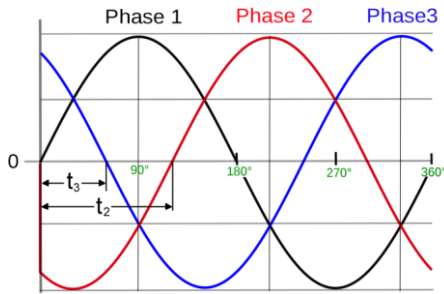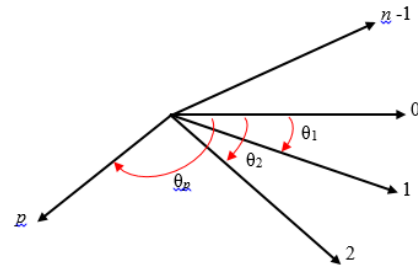Figure 2. The Waveforms for the 3-Phase AC System

Figure 3. Phasor Diagram of Balanced and Phase System

$$\theta_p = p\left(\frac{360}{n}\right) \tag{1}$$

The waveforms for the reference and the **p**th phases are shown in Figure (4), where t_p is the time instance of the first zero crossing from the negative to positive value of the **p**th phase measured from the reference point thus,

$$\theta_p = 360\left(\frac{t_p}{T}\right) \tag{2}$$

From equation (1) and (2) we got,

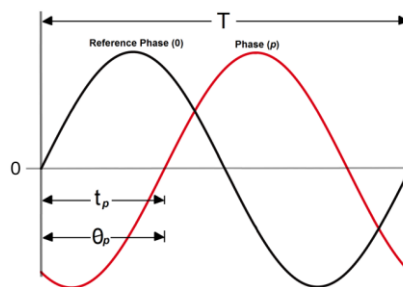$$p = n\left(\frac{t_p}{T}\right) \tag{3}$$

Figure 4. Waveform of the Reference and the Pth Phase

Since p is an integer, the right hand side of eq. (3) must result into an integer. However, it is possible that the calculation by the micro-controller may not result into an integer value. Hence, choose the closest integer value. Phase measurement can be carried out based on eq. (2). Employing a Microcontroller, both t and $\mathbf{T}$ can be measured digitally and then the calculation of eq. (2) can be carried out with the help of the micro-controller. Since t and $\mathbf{T}$ appear in the form of a ratio in the expression, any change in the microcontroller's clock frequency will not affect the accuracy of the measurement.

4. HARDWARE DESIGN

The implementation of the system is based on PIC microcontroller unit PIC18F4620 [9]. The proposed system consists of two units in addition to the PIC microcontroller as shown in Figure (5). "Sampling unit", Figure (6), designed to step down the phase's voltage and converted into unidirectional signal and then compared to zero reference voltage to generate rectangular signal corresponding to the positive half of the input signal by using three LMV7291M5 comparator, each one is has been connected as shown in Figure (7).

The output of each sampling unit is connected to a specific port in the microcontroller as shown in Figure (5). The load during the system startup is normally disconnected to the main sours. When the system evaluates the state of the phase's sequence according to the mathematical equations (1-3), it will act immediately to correct the sequences if it needed, and then connecting the load to the main source through the (*control*) pin in the PIC microcontroller.

The sequence correction could be made by using electromagnetic relay. When phase's sequence correction is needed, the relay will swap the last two phases to achieve the correct sequence through the (*Correction EN*) pin on the PIC. The processing of controlling the load and swapping the phases is carried out in the "Actuators Unit", as shown in Figure (8).
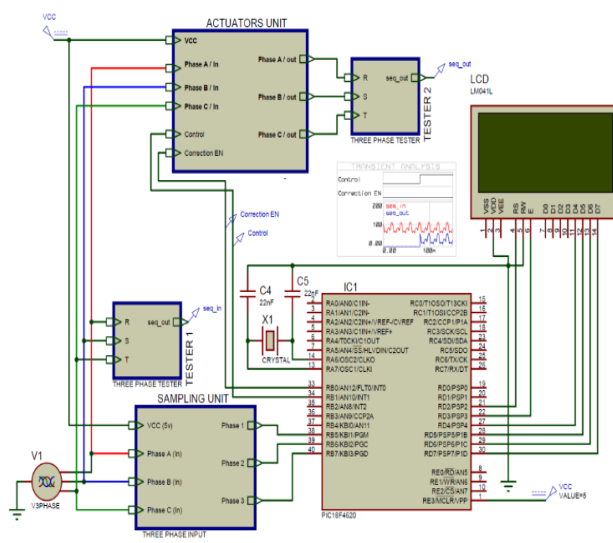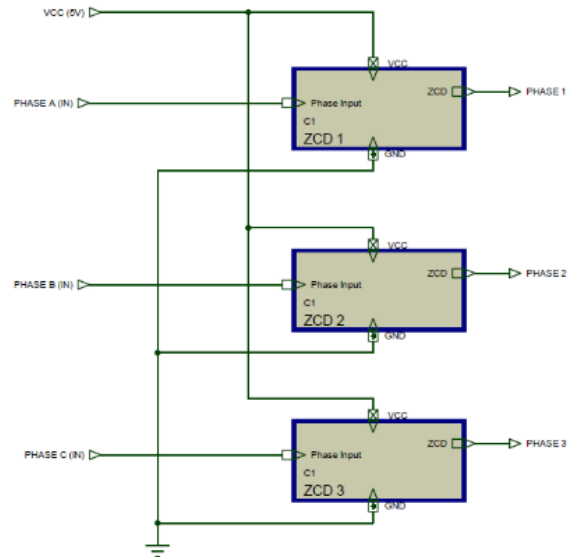

Figure 5. System Circuit Diagram

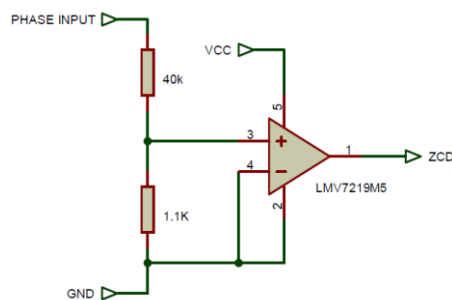Figure 6. Block Diagram of the Sampling Unit
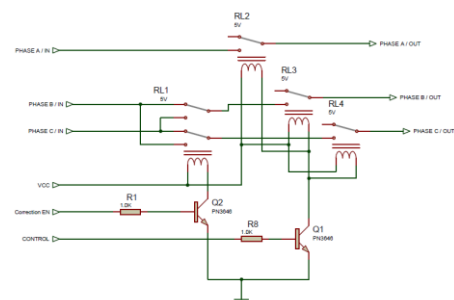

Figure 7. Step Down and Zero-Cross Detecting Circuit

Figure 8. Circuit Diagram of the Actuators Unit

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5. SOFTWARE DEVELOPMENT

The program (PIC firmware) of the system has been developed by using the Proton IDE software, where the instructions are written in Basic programming language. There are three inputs to the microcontroller represents the signal of each phase from the Sampling Unit. On the other hand, two outputs only have been used to manage the Actuators Unit.

The program has been designed to act continuously even if the phases sequence is correct. Whenever the order of the phases is changed, the system will act immediately. The whole program is illustrated in the flow chart of Figure (9).
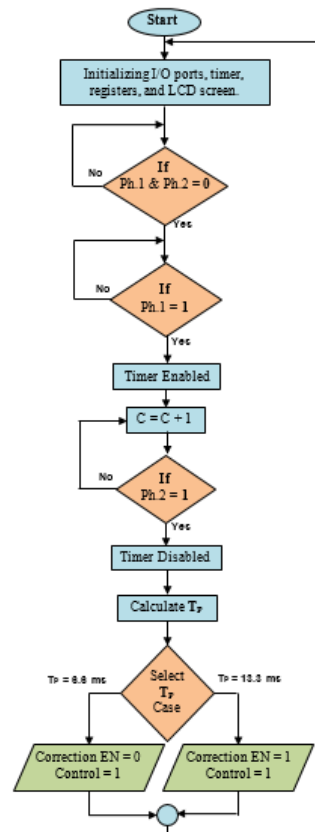

Figure 9. The Flow Chart of the System's Main Program

6. RESULTS

After the implementation, the system has been simulated and tested by using the "Proteus 8 Professional" application program. The two cases of involving a correct and incorrect sequence have been tested, where the system has been worked and acted successfully.

For testing the sequence, a simple three phases rectifier has been using with different input scales, to generate an output waveform reflecting the phase sequence as shown in the input waveforms for each case. This method has been used for test purposes only. The results of the two cases are shown in Figure (10) and Figure (11) including the timing diagram of the (control) and (correction EN) output signals in the both cases. Noting that the archived response time when the phases sequence is not correct is 72 milli-seconds as shown in Figure (11).

7. CONCLUSIONS

Detecting the sequence pattern of the three phases electrical power system could be achieved by using many approaches. The proposed method for identifying the sequence of the phases has been proved as a fast method to detect the sequence of the phases, approximately 72 milli-seconds. The presented technique

is reliable for any multi-phase system and it is independent on the frequency of the system. As a result, the recognition of phases sequence is accurate even if the there is any variation in the system's frequency. The implemented system is very efficient and fully automatic; it acts automatically whenever the sequence of the phases changed.
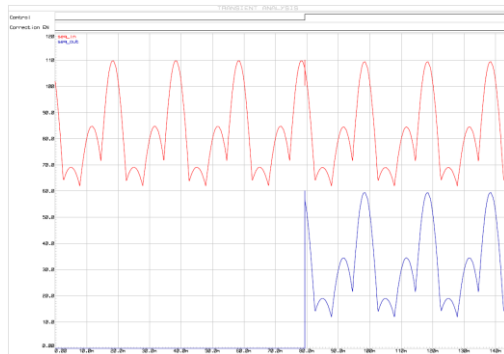

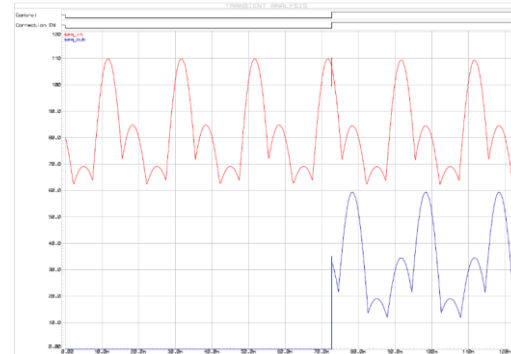Figure 10. The Results of the "Correct Sequence" Case

Figure 11. The Results of the "Incorrect Sequence" Case

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