A New phase sequence Detector for the Three-Phase Rotary Loads

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Abstract: **Automated load balancers can swap output phases of feeders in a distribution substation by the use of matrix converters. In addition, the rotational three phase loads operate clockwise if three phase system has positive sequence. In order to complete the proposed method for balancers, in this paper three different methods is proposed for recognizing phase sequence in power systems. The first evaluated method detects phase sequence by measuring of instantaneous symmetrical components. This method has drawbacks of complexity and low speed in detecting. The second method detects phase sequence by using a phase lock loop (PLL) for metering the power system frequency. The second technique is fast, but PLL that is used in this technique operates incorrectly under unbalanced condition. Finally, the third method is a new technique that is proposed for the first time in this paper which is very fast. This innovative method detects phase swapping by the zero crossing times. The whole methods are simulated by SIMULINK to verify and compare the suggested method with other techniques.**

Keywords: power system balancer, phase sequence, phase lock loop, zero crossing detection.

I. INTRODUCTION

The subject of minimizing distribution losses has gained a great deal of attention due to the high cost of electrical energy and therefore, much of current research on distribution automation has focused on the minimum-loss configuration problem [1–10]. Besides economic consideration, the effect of electric power loss is that heat energy is dissipated which increases the temperature of the associated electric components and can result in insulation failure. By minimizing the power losses, the system may acquire longer life span and have greater reliability [6].

Appropriate load allocation in a distribution system can not only balance the feeder loading but also reduce the real power loss. It is often accomplished by reconfiguring the feeders according to some optimal switching criteria by changing the status of sectionalizing switches and tie switches along the feeders. Up to now, many methodologies of feeder reconfiguration to minimize the real power loss of distribution systems have been developed and presented [11].

In recent years automated load-balancing maneuvering (ALBM) is proposed for distribution substation feeders [1], that this method in order to reduce losses in distribution systems. Paper [1] has suggested swapping output phases of a distribution transformer by the installed matrix converters in each distribution substation. More particularly, this invention introduces an intelligent device between the heavily loaded phases to the lightly loaded ones for all feeders. This process balances the three phase current flowing through Y-winding of the distribution transformer in the substation [1].

Many papers have studied the phase swapping in distribution substation based on intelligent algorithms [4, 5, and 7]. The phase swapping in distribution substation will be making phase sequence problems for rotating machines. So with the applying load-balancing maneuvering in distribution substations, three phase loads in distribution systems will need another device to correct phase sequence. To correct this problem should be used an analyzer to detect the phase sequence of rotary load's input. The phase sequence analyzer should detect phase sequence in the shortest time possible and produce output signal. An appropriate method that is used in the controller should be considering many factors such as speed of detection, reliability, simplicity and ease of implementation.

So this paper consists of two parts as follows: In the first part three different methods for detecting phase sequence are introduced and each of these techniques fully is explained. The first method detects phase sequence by using real time measuring of the positive and negative components. The second method detects phase sequence by using of a phase lock loop (PLL) for metering of power system frequency. Finally the third method is a new method that is proposed based on zero crossing time of three-phase voltage. In second part for comparison between methods all three methods are simulated by simulink software and their results are shown. Simulation results and comparison between the methods show that the third method is suitable for the aims such as simplicity, speed and cost.

II. PHASE SEQUENCE DETECTION METHODS

A. *Detection of phase swap by measuring the positive and negative components*

Table1 shows six different states for composition of network three phases. Three states have the positive sequence and other states have the negative sequence. That's enough to measure the positive and negative components then diagnosis phase sequence from measuring the positive component to negative component ratio.

TABLE I. DIFFERENT STATES FOR SYSTEMS CONFIGURATION

sequence	1	2	3	4	5	6
1	a	a	b	b	c	c
2	b	c	a	c	a	b
3	c	b	c	a	b	a
sequence	+	-	-	+	+	-

Measurement of the positive and negative components easily can be done by the symmetrical components' definition. Symmetrical components, first developed by C.L. Fortescue in 1918, is a powerful technique for analyzing unbalanced 3φ systems [13], but the symmetrical components theory is defined in the phasor domain, So measuring the symmetrical components need to one cycle time. Therefore, this method is not suitable to measure the symmetrical components. Thus PSD and NSD algorithms have been used for measuring the positive and negative components [14].

The structures of these two methods are very similar to each other and measuring of the symmetrical components is done in time domain. Figure 1 and 2 show block diagrams of NSD and PSD methods for measuring the positive and negative components of three-phase voltage. Output of these two methods will be positive and negative components for the basis frequency of three-phase voltages. Now set the proper ratio between these two components can be easily recognized the phase swap, but two low pass filters were used in the PSD and NSD algorithm and these low pass filter cause to be delayed in the detecting symmetrical components and phase sequence. Moreover most systems are unbalance and we can't find a specific ratio between two components to detect the phase sequence, Therefore this method is not suitable for our purpose.

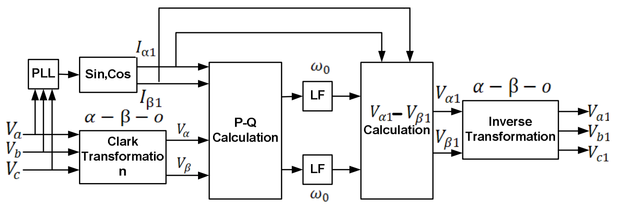

Figure 1: block diagram of positive sequence detection for the basis frequency

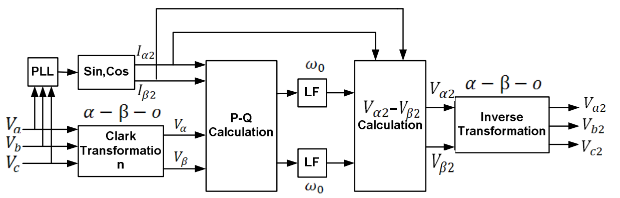

Figure 2: block diagram of negative sequence detection for the basis frequency

B. Detection of phase swap by Phase Lock Loop

In this section, a simple phase lock loop is used for locking on the frequency network to detect phase sequence.

Following equation show p(t) in the figure 3. If the phase sequence is positive, so P(t) will be zero while w in figure 3 same to angular frequency of three phase voltage (ω). Otherwise the phase sequence is negative, so p(t) will be zero while w in figure 3 same to minus of angular frequency of three phase voltage (−ω).

$$p(t) = -i_{b-pll}(t).v_{abs}(t) + i_{c-pll}(t).v_{cas}(t) \quad (1)$$

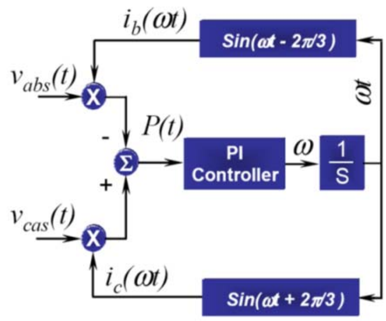

Figure 3: Phase-locked loop block diagram

The PLL circuit generates an angular frequency ω and an instantaneous phase angle ωt, locked at the fundamental positive-sequence component of the phase supply voltages. Two major problems exist in detecting of phase swap by this method. At first PI tuning in PLL is difficult and depending on balancing of three phase voltage otherwise PLL can't locked on the frequency. Implementation of this method for detecting of phase swap is not easy and must be applied a DSP board for controlling of it.

C. Detection of phase swap by zero crossing detection

This method is based on zero crossing times of three phase voltage and diagnosis phase sequence by measuring the absolute of two voltages in zero crossing time of third voltage.

In a three phase voltage, two times exist for zero crossing of each wave. Each phase is connected to a comparator. These comparators transform three sinusoidal waves to three normalized square waves. Amplitude of these waves is 1 in half period and 0 in other half period. So these square waves will have rising and falling edges. According of table 1 3 state of arrangement of three phase have positive sequence and other states have negative sequence. Rising and falling edges for 3 states of positive sequence are shown as highlighted in figure 4 and this case are shown in figure 5 for negative sequence. In the rising and falling edges of each phase in figure 4, 5 two other phase have same amplitude in three states. For example, in the rising edge of the first phase, the second phases in each states of positive sequence have zero amplitude. With this trait in the sequence states can detect type of sequence and swapping of phases.

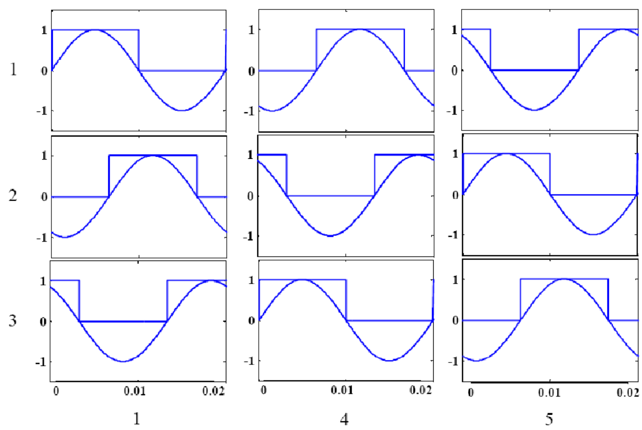

Figure 4: positive sequence states of comparator output

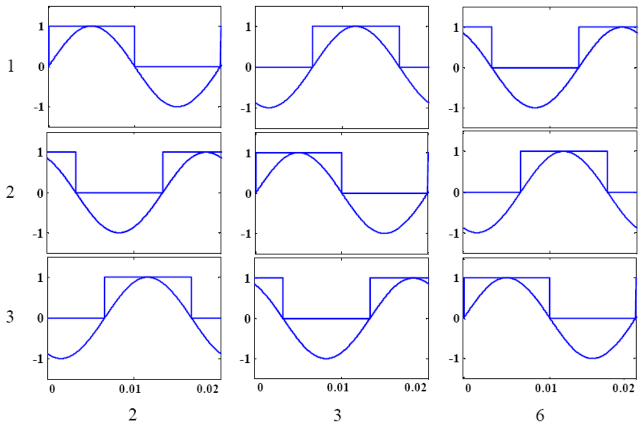

Figure 5: negative sequence states of comparator output

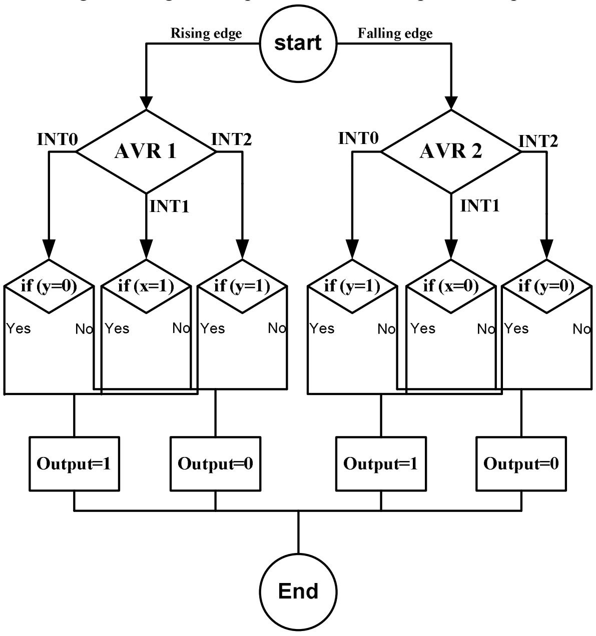

Figure 6: block diagram of phase swap detecting by zero crossing detection.

Block diagram of this method are shown in figure 6. In times of rising edge of output of comparator microcontroller 1(AVR1) interrupted. Each AVR has three interruptions that everyone is activated by one of the phases. Finally AVR detects phase sequence by checking the amplitude of other phase in the interruption times.

III. Simulation Results

This section is simulated previous section and compression it. All of the under review methods must detect phase swap in a three phase system. So simulation of it needs to phase swapping in input phases. Figure 7 shows testing stages of methods.

As noted in the introduction section, phases swap are made by installed matrix converter in distribution substation. In simulation a matrix converter 2×2 swap R and S phases. This matrix converter controlled by a manual push button. This matrix converter is shown in figure 8 [10, 12]. After the matrix converter control system is installed to detect the phase sequence.

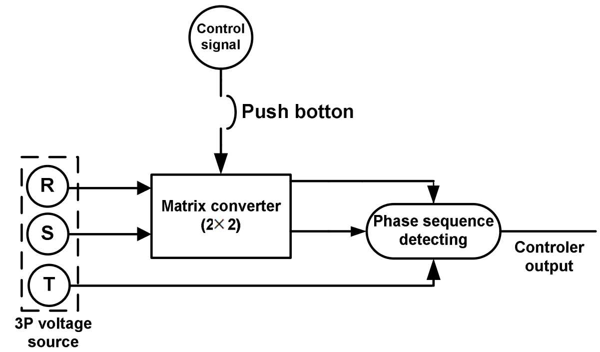

Figure 7: testing block diagram of phase sequence detecting methods.

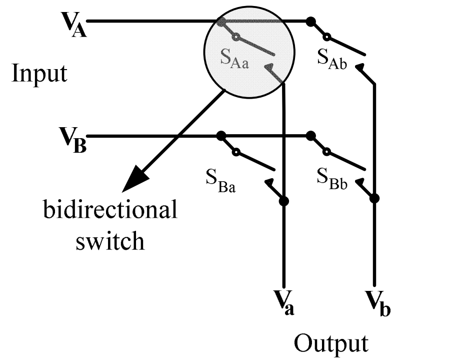

Figure 8: simulated matrix converter 2×2 in Matlab/simulink

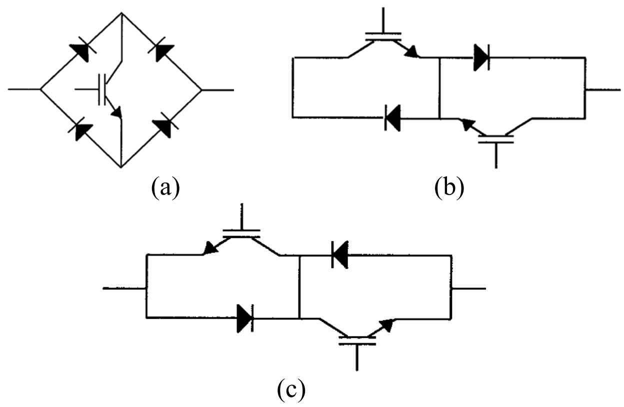

Figure 9: three different bidirectional switch implementations for matrix converter

a) Diode embedded switch

b) Antiparallel switch common emitter mode

c) Antiparallel switch common collector mode

Figure 9 shows output voltage waveform of matrix converter 2×2 in figure 7 for R and S phases. R and S phases have been swap in t=0.943s.

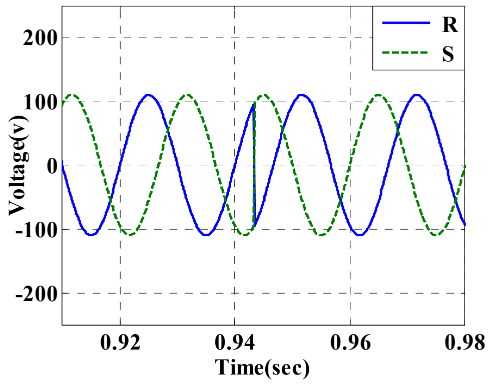

Figure 9: swap of R and S phases in t=0.943s

A. *The first method*

As described in the previous section, the first method with measuring of positive and negative components diagnosis phase sequence. Figure 10 shows changing of positive and negative component in during of phase swap.

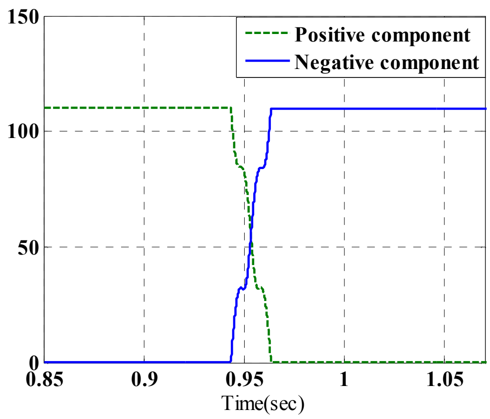

Figure 10: measured positive and negative components in during of phase swap by PSD and NSD method

Figure 11 shows phase swap time and detecting time of it by first method. According to this figure the first method approximately 4.5 msec takes to detect phase swap.

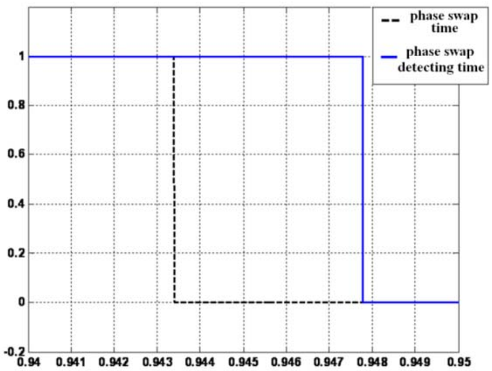

Figure 11: phase swap time and detecting time of it by the first method.

B. *The second method*

In the previous section is explained that PLL method detected phase swap with measuring of network's angular frequency. Figure 12 shows measured angular frequency by PLL. The changing slope of frequency from positive to negative depends to proportional and integral gain. In accordance with figure 13 this method approximately 1.5 seconds need to detect phase swapping.

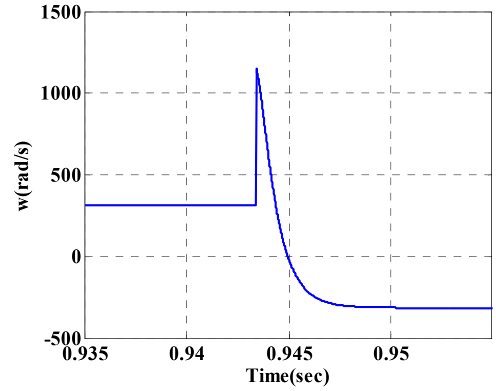

Figure 12: measured angular frequency by PLL in during of phase swap.

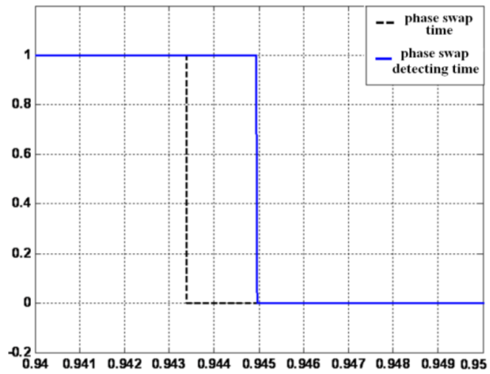

Figure 13: phase swap time and detecting time of it by the second method.

C. *The third method*

This method is explained in previous section. So it is obvious that the length of time that this method needs to detect phase swap is dependent on the exact moment of phase swap. While the phase swap occurs immediately after zero crossing time of one of the phases, it takes the maximum time of detection. Because phase sequences is determined in zero crossing time. According to figure 9, one of the worst moment of swapping phase is t=0.934 sec. It is shown in figure 14 that the maximum needed time to detect the phase sequence by third method is almost 3 msec which is equal to the theoretical calculation.

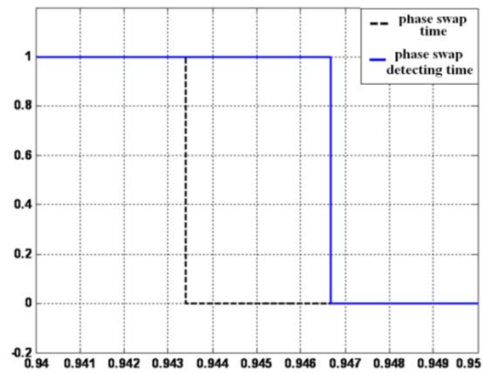

Figure 14: phase swap time and detecting time of it by the third method.

D. compression of three method.

Comparison of the phase sequence detection methods in respect to different factor is express in this part. Speed detection, implementation, reliability and the impassibility to condition of the methods is compared in table 2. All of the methods operate in proper speed detection. The first two methods do not operate properly in a point of view of impassibility and reliability in opposite of the third method which has a good reliability. The third method can be implemented by a simple micro controller such as AVR.

Table2: comparison of different method of phase swap detecting

Method	Insensitivity	Can be Implemented by	Reliability	Time detection
1	×	DSP	×	4.5 ms
2	×	DSP	×	1.5 ms
3	✓	AVR	✓	under 3 ms

IV. CONCLUSION

In this paper, two old methods are reviewed for phase swap detection and a new effective method is proposed. These old method detect phase sequence by measuring of instantaneous symmetrical components and using a PLL, respectively. The new method is a novel technique that detects phase swap using zero crossing times of the three-phase voltage. The whole methods are simulated by SIMULINK. Simulations show that none of the two reviewed methods are not suitable. The third method, however, is better than those two methods in term of reliability, sensitivity, and the detection speed. Also, this suggested method can be easily implemented on microcontrollers like DSP and AVR.

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