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Negative Phase Sequence Component Extraction Using A New Numerical Relay Algorithm From Three-Phase Alternating Current

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Abstract
The method of extracting negative phase sequence (NPS) components from three-phase alternating current voltages and currents has long been a problem for protection engineers. In order to recover the negative phase sequence components from sampled three-phase observations, a novel numerical three-phase filtering method is given in this study. The method has been developed to be suitable for usage in a numerical relay in order to determine either the absolute value of the negative phase quantity or the relative value of the negative phase sequence to the positive phase sequence measured at the operating point. This is a result of the method's development to make it appropriate for usage in the intended application. This research aims to demonstrate the method's capabilities by giving results showing that, with the use of a basic post-extraction smoothing filter, the quantity of negative phase sequence components may often be recovered within thirty milliseconds after a disruption. In order to maintain perfect synchronization between the power supply frequency and the sampling clock, an automatic frequency tracking technique was used in conjunction with a notional sampling rate of 1200 samples per second.

Key words: *Relay algorithm, Negative phase sequence, Three-phase alternating current.*

I. INTRODUCTION

It is possible that the existence of negative phase sequence components in the current or voltage signals of a three-phase system is an indication that the system is either malfunctioning or that it is being operated in an abnormal situation. Overheating is a consequence that is always brought about by the presence of negative phase sequence components in power transformers, motors, and generators. If all goes according to plan, this overheating will result in precautionary tripping, which will cut off the plant in issue from the rest of the power supply network. The usual techniques for collecting negative phase sequence components require the use of certain hardware filters that feature phase shifting components. This is one of the main components of the collection process. It is common for them to be coupled to electromechanical relays and early static designs the majority of the time.

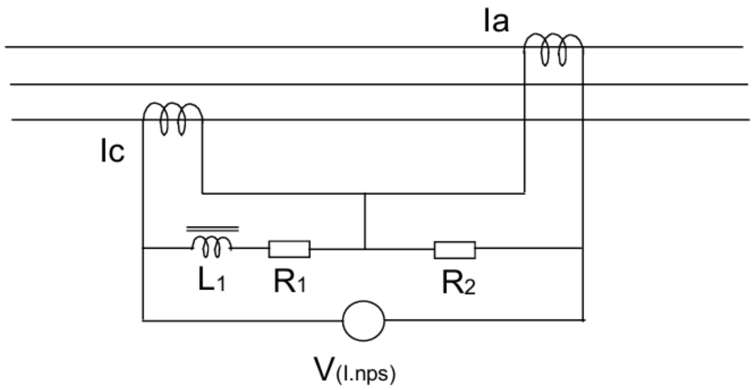

Figure 1. Basic Negative Phase Sequence Current Filter

An example of one of the most basic filter designs may be seen in figure 1, which can be found here. In this specific configuration, the output is derived by adding the values of Ia and Ic at an angle of sixty degrees. This approach has a downside in that it also generates an output for zero sequence components, which is a weakness in the solution. Figure 2 illustrates a design that is more sophisticated [1] and that has the capability to avoid this problem via its implementation. This utilizes the three phase electrical currents for the sole purpose of finding the value of the negative phase sequence current. This is the only reason with which this is accomplished. These two approaches are susceptible to changes in the frequency of the power system to which they are transmitted, which make them both vulnerable. With the use of this method, phase shifting and mixing circuits were able to be improved, which ultimately led to filters that were more efficient. The analogue static relays were designed with negative phase sequence filters that were quite similar to those before. On the other hand, this kind of technology proved to be more efficient than the alternatives.

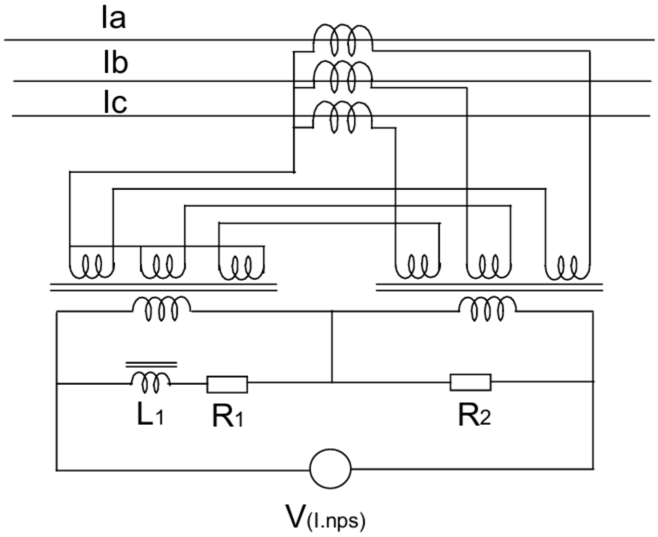

Figure 2. Practical Negative Phase Sequence Current Filter

As a consequence of the development of general-purpose microprocessor relay platforms, the use of processors that are ever more powerful has been brought about, as has the deployment of numerical relaying algorithms with an increasing frequency. One of the few numeric relay approaches that has been described for the purpose of extracting the negative phase sequence components was developed by Islam and Mostafa [2]. This technique is one of the few that has been documented. As shown in the following equation, the negative phase sequence current I_2 may be determined by using the following equation:

$$I_2 = \frac{1}{3}(I_a \angle 0 + a^2 I_b \angle \theta_b + a I_c \angle \theta_c) \quad (1).$$

Simple algebraic manipulation then yields;-

$$I_{r2} = \frac{1}{3}(I_{ra} - 0.5 I_{rb} - 0.5 I_{rc} + \frac{\sqrt{3}}{2} I_{xb} - \frac{\sqrt{3}}{2} I_{xc}) \quad (2).$$

$$I_{x2} = \frac{1}{3}(- \frac{\sqrt{3}}{2} I_{rb} + \frac{\sqrt{3}}{2} I_{rc} - 0.5 I_{xb} - 0.5 I_{xc}) \quad (3).$$

and,

$$|I_2| = \sqrt{I_{r2}^2 + I_{x2}^2} \quad (4).$$

where:-

I_2 is the negative phase sequence (NPS) current
I_{r2} and I_{x2} are the real and quadrature components of I_2 I_a,
I_b and I_c are the three phase currents I_{ra},
I_{rb} and I_{rc} and I_{xa}, I_{xb} and I_{xc} are the real and quadrature components of the three phase currents

A new sampling and time-multiplexed phase-sensitive rectification technique is used by Islam and Mostafa in order to discover the values of Ira, I_{rb}, I_{rc}, I_{xa}, I_{xb}, and I_{xc}, which ultimately makes it easier to determine I_2. This eliminates the need for complicated signal processing, which in turn reduces the amount of work that the relay's central processing unit (CPU) has to do. Through the use of a wide range of simulated unbalanced waveforms, the experimental data revealed that the measurement accuracy was within a range of ±5%. Usta et al. [3] devised a unique digital relaying approach with the intention of discovering asymmetrical defects by the monitoring of sinusoidal oscillations in the three-phase instantaneous power recorded at the terminals of a generator. Any unbalanced factors, on the other hand, introduce oscillatory components into the outcome, either at the frequency of the power system or at double that frequency. In the case of balanced conditions, the instantaneous power is a constant DC component. After that, their system examines the path that the negative sequence-reactive power flow takes at the machine terminal in order to discriminate between errors that are internal and those that are external. According to the findings of the power system test studies, the new relay is capable of providing speedy tripping for internal asymmetrical faults and additional protection for exterior asymmetrical fault situations.

II. THE NEGATIVE PHASE SEQUENCE ALGORITHM.

The recently established method for negative phase sequence makes use of a numerical filter that consists of three phases. The instantaneous power equation and the fourier series filter are both involved in the functioning of this. Both of these are important components. One of the most important components of its operation is the fourier series filter. By using a sampling rate that is moderate and sample points that are automatically locked to the frequency of the power system, it has been designed to be implemented in the digital signal processing environment of a current protection relay platform. This has been accomplished via the use of modern technology.

BEGIN
Measure V_a, V_b, V_c

Compute phasors of V_a, V_b, V_c

a = exp(j*120°)

V_2 = (Va + a^2*Vb + a*Vc)/3

NPS_magnitude = |V2|

IF NPS_magnitude > Threshold THEN

Trigger alarm / protection

END IF
END

Algorithm Steps

Step 1: Measure three-phase signals

V_a, V_b, V_c or I_a, I_b, I_c

Step 2: Convert signals to phasor form (using FFT or DFT)

Step 3: Compute negative sequence component using symmetrical component equations

Step 4: Calculate NPS magnitude:

$|V_2|$ or $|I_2|$

Step 5: Compare with threshold:

$|V_2| > V_{2,\ threshold}$

Step 6: Generate alarm, protection trip, or control action

III. THE NEGATIVE PHASE SEQUENCE ALGORITHM IS BEING IMPLEMENTED.

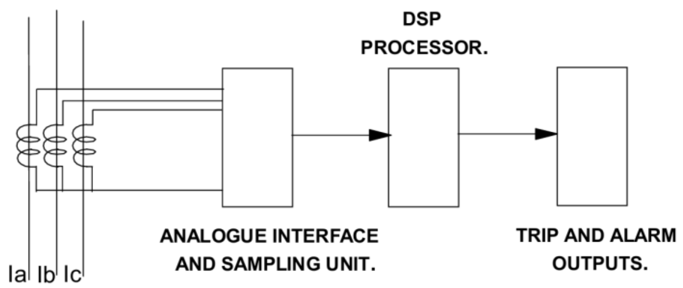

Figure 3. Block Diagram for the Numeric Relay

A relay platform using a general-purpose CPU has been equipped with the developed algorithms for implementation. A typical unit's current inputs would undergo 14-bit analog-to-digital conversion, using a digital signal processor (DSP). The experiments undertaken for the demonstration were based on a power supply operating at 50Hz, with a sampling rate of 24 samples per cycle across all channels. The sampling clock was synchronized with the frequency of the power supply system using a numerical phase-locked loop tracking approach. A block schematic of this system is shown in Figure 3, accessible online. The vast array of available functions made the selection of the right windowing function a formidable task [4,5]. After evaluating the performance of several functions, the two-cycle Kaiser window was chosen as the ideal option due to its suitable response speed and minimum overshoot. This resulted in a potential signal extraction time ranging from 10 to 40 milliseconds, along with an effective filtering function.

IV. SIMULATION STUDIES

For the purpose of simulations, MATLAB was used, and a model of a perfect three-phase synchronous generator that feeds a balanced load via a feeder network was developed. In order to demonstrate how the negative phase sequence algorithm works, a variety of different circumstances where there were a short circuit fault and damaged wire were examined.

A single phase to ground fault is applied to the connections of the generator after 0.1 seconds, as shown in Figure 4, which illustrates the results of this action. The new number is found by the software in a time span of less than 36 milliseconds after the error.

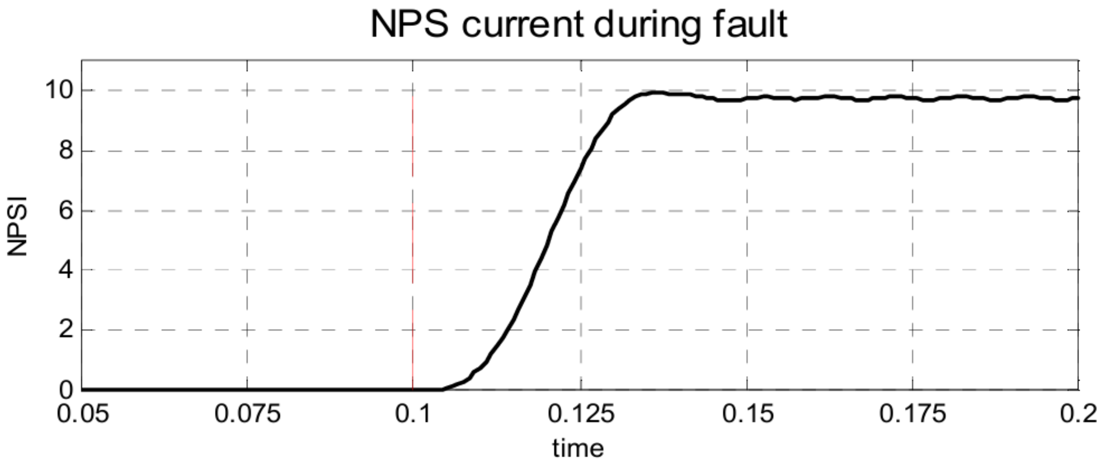

Figure 4. Single Phase to Ground Fault at the Generator Terminals

If there was a phase-to-phase fault on the generator's inputs, the reaction was the same, as shown in Figure 5.

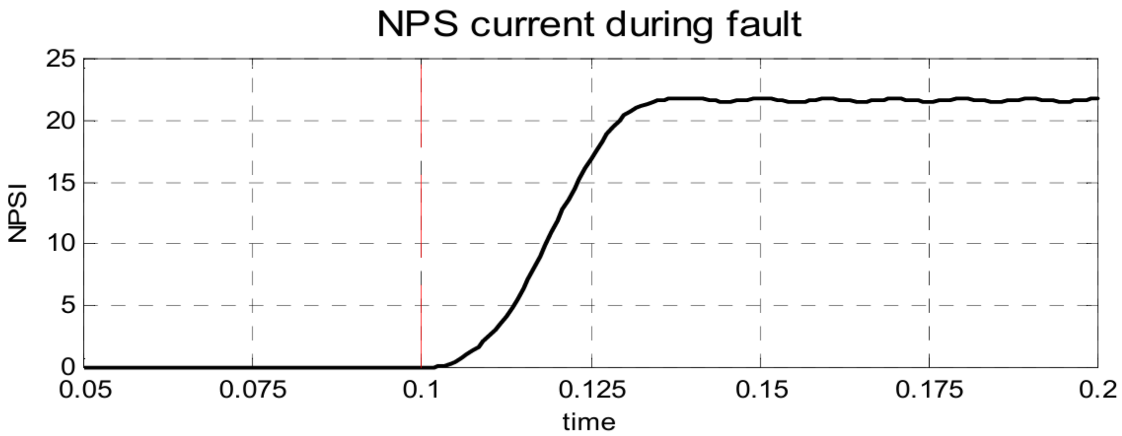

Figure 5. Phase to Phase Fault at the Generator Terminals

In the event that there was a three-phase defect at the generator terminals, the answer indicated that a negative phase sequence component was discovered throughout the data collection time of the algorithm, which is equivalent to the duration of the window. In the event that the filter output was used without any further processing, this can be a source of confusion. The solution to this issue is to add a check to the output that lasts between 30 and 40 milliseconds to ensure that a transient such as this does not result in a tripping that is obnoxious. The job of the transfer would, of course, take longer, and the decision to go would take longer as a result of this. When you look at figure 6, you will see how to correct this error.

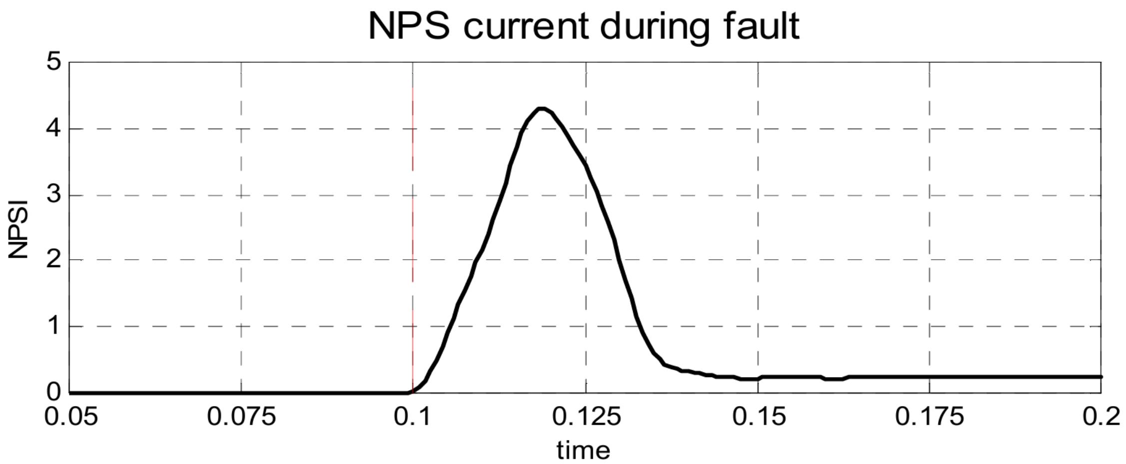

Figure 6. Three-Phase Fault at the Generator Terminals

The successful removal of a phase-to-phase fault is shown in Figure 7. The fault is put in place after 0.1 seconds and taken away after 0.15 seconds.

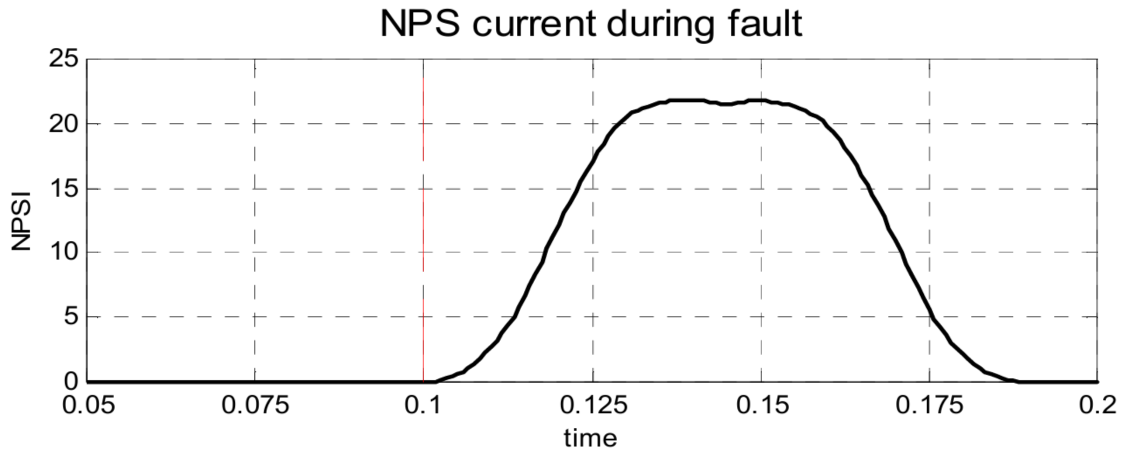

Figure 7. Phase to Phase Fault at the Generator Terminals cleared after 50 ms

A load that isn't balanced is shown in Figure 8, which looks at what happens when one part of the load is lost.

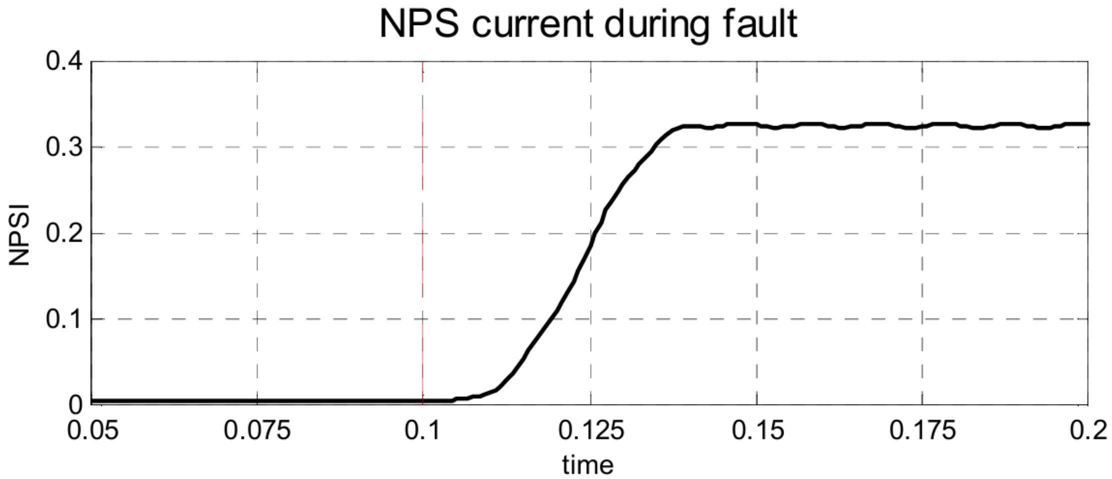

Figure 8. Loss of One Phase of the Load on the Generator

Figure 9 illustrates the reaction that transpired as a result of the loss of two phases of the load.

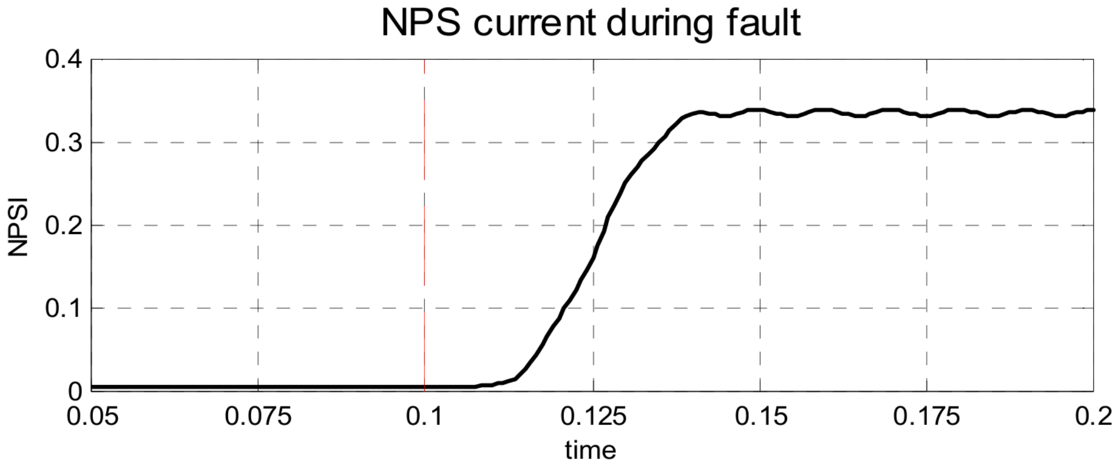

Figure 9. Loss of Two Phases of the Load

Following the loss of two phases of the load, an investigation was conducted to determine the reason for the observed increase and decrease in the negative phase sequence component, as seen in Figure 9. It was discovered that the approach of power system frequency tracking, which was used in order to lock the sample to the power system signal pattern, had problems with this. In the event that the tracking technique requires a significant amount of filtering and pauses, this may be a problematic area in the event that the application involves creation of a small or medium size that has the potential to create significant variations in frequency after a disruption.

V. CONCLUSIONS

An attractive protection and monitoring approach could be built by using a three-phase rotating set of reference phasors as the basis for a filter that is intended to extract the negative phase sequence from three-phase data. This would be done in order to achieve the desired effect. The use of a two-cycle Kaiser window yields an effective filter characteristic and a potential signal extraction time that falls within the range of ten to forty milliseconds, respectively. To reduce the possibility of a nuisance tripping happening as a consequence of filter transient activities, it is advised that a wait of thirty to forty milliseconds be included into a relaying application. This delay should be provided in order to avoid the trip from occurring. Because of this, the tripping time would be reliable and would lie somewhere in the range of forty to eighty milliseconds.

This negative phase sequence extraction approach, together with the accompanying algorithm for positive and zero phase sequences, is capable of being implemented in a protection platform that is based on a DSP processor and makes use of a sufficient sampling rate at the same time. Due to the fact that the platform is underpinned by a numeric microprocessor, this is feasible. In the course of additional research, these ideas will be expanded in order to provide specific relaying capabilities and to include these algorithms into software that is able to fulfil a variety of relay tasks.

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