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An adaptive method of symmetrical component estimation

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ABSTRACT

This paper proposes a novel approach of estimating the symmetrical component into a network. The power grid development and deployment offer several advantages regarding the overall system performance of the electrical system. Currently, through the smart metering system, the symmetrical components problems can be resolved in real-time by extracting, tracking and detecting any issue related to power disturbance on the grid. An adaptive method to estimate symmetrical components in the framework of the power systems is presented. The proposed method is based on a nonlinear adaptive tracking of amplitude, phase and frequency of a non-stationary sinusoidal waveform in real-time. The method offers structural simplicity while maintaining performance robustness and controllable speed and accuracy. Experimental results are presented to verify the performance of the proposed method. The results show that the method can provide an accurate estimation of the symmetrical components in the presence of amplitude and angle variations, as well as in the presence of harmonics. The simplicity of the structure and ease of the parameter settings render the proposed method suitable for both software and hardware implementation. Two scenarios are analysed to validate the proposed algorithm.

1. Introduction

The topic of symmetrical components is standard in most textbooks on electrical power systems. A system that is considered balanced has three voltage and current signals that have equal magnitudes and 120° phase-displacements. When these conditions are not met, the system is unbalanced. The theory of symmetrical components indicates that an unbalanced set of signals can be decomposed into three balanced sets of signals. Symmetrical components find applications in a variety of power system problems such as protection, fault analysis, reactive power compensation, unbalance mitigation, and distributed generation. Many papers describe the application of symmetrical components [1–5]. Fortescue [6] introduced the theory of symmetrical components for complex phasors that can be applied to the solution of polyphase networks. Several methods of estimating symmetrical components have been proposed [7–19].

In Ref. [7], the smart power grid synchronization uses the effectiveness of real-time estimation into a novel nonlinear strategy to track the system frequency, voltage magnitudes and phase angles. This method employs the symmetrical component transformation separately, i.e. the positive, negative and zero sequences are analysed independently to be transformed into the stationary coordinate frame. This approach describes the system modelling, which contains a fault tolerant extended Kalman filter. In Ref. [8], the synchronization of unbalanced three-phase voltages with nonlinear estimation is performed through an extended Kalman filter and the unscented Kalman filter in the framework of the smart grid. This strategy uses the methodology of the symmetrical component transformation to apply Clarke's transformation that can describe the state space equation. The procedure aims to estimate the voltage magnitude and phase angle. In Ref. [9], an adaptive notch filtering method based synchronization technique is introduced. This is a modified structure where the three-phase quantities are decomposed into symmetrical components, harmonics are extracted, the frequency variation is tracked, and the voltage regulation and reactive power control are provided. The main advantage of this proposed strategy is it does not require a phase-locked loop to be synchronised. In Ref. [10], a pre-filter based phase locked loop for three-phase grid-connected applications is proposed. This approach is fast and precise regarding phase estimation for both unbalanced and high distorted three-phase electric

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variables, and it can control the system equipment and dynamic voltage restorer.

Luna et al. in Ref. [11] propose an algorithm for phase angle estimation based on symmetrical sequence components. This strategy applies the recursive weighted least-squares structure that can estimate the negative and positive sequences. It is observed that the proposed approach is capable of eliminating the low order harmonics and direct current offset in the sampled variables. In Ref. [12], a new state-space model in the framework of the extended Kalman filter that can estimate the symmetrical components of distorted and time changing power systems is introduced. This model can detect and quantify the overall three-phase power system unbalance problem, and the algorithm has the capability of deducing in each interaction the amplitudes and phase angle values of the symmetrical components. In Ref. [13], a novel fast detection algorithm for grid symmetrical components extraction is proposed. This new generation algorithm utilises the complex least squares strategy. This method applies a quick and accurate detection of the amplitude and phase of grid voltage for both the positive and negative sequence when the system voltage has high order harmonics and random noise. In 1992 Pinto de Sá [14] has introduced a new Kalman filter approach that supports symmetrical components based distance estimator with moderate sampling rate for digital relaying. The paper describes how to include the Kalman filter state space analogic pre-filters' transients simply. It also presents how to handle the colouring effect of the pre-filters and the network into the model.

The Discrete Fourier Transform (DFT) is proposed as one of the algorithm methods that can be easily embedded in hardware for power system real-time phasor estimations [15]. Carugati et al. [16] have presented a new method of measuring the three-phase harmonic and sequence components by using a sliding DFT and variable sampling period technique. This strategy also permits the computation of the corresponding imbalance by guessing the instantaneous symmetrical components. In Ref. [17], a modified artificial bee colony algorithm method is proposed to estimate the solution of the power system harmonic. This approach can provide excellent basic designing active filters that can be exploited in power system. The Kalman Filter, as a recursive estimator, is introduced as a powerful tool for the estimation of time-varying parameters of symmetrical components. The filter has the capability of processing noisy measurements, and it gives a least a square optimal estimate. The main drawback of the Kalman Filter is the number of calculations that it must perform. Kusljevic [18] proposed the use of the enhanced phase-locked loop for symmetrical component estimation. This method takes longer than a cycle to provide its response but can provide an accurate estimate when power frequency excursions occur. A non-recursive Newton-type numerical algorithm is presented in Ref. [19]. This approach is used with the second stage algorithm for symmetrical components calculation that derives from the estimated fundamental phasors of the arbitrary voltages or currents in three-phase system signals.

The algorithm has linearity, is very simple, and involves moderate computation. The Newton-type algorithm provides accuracy and is not sensitive to power-system frequency deviations and harmonic distortions in three-phase signals. The different approaches include stochastic estimation theory, Kalman filters, weighted least-squares estimations, and time-domain methods. In most papers presented, there has been much argument presented with little focus on the practical application [5,7–20]. However, some practical applications in the framework of a smart grid have been developed in conjunction with network synchronisation of fault-tolerant estimation and renewable energy integration [21]. Thus, the influence of frequency deviations, harmonics and noise can affect the performance of the different methods. This has also received little attention in real-time estimation strategy. The proposed method is based on converting the input signal into phasors. This is done by an estimation of the magnitude, phase angle, and frequency of an input signal. From this, the sequence components are computed in the time-domain. An overview of the approach is shown in Fig. 1.

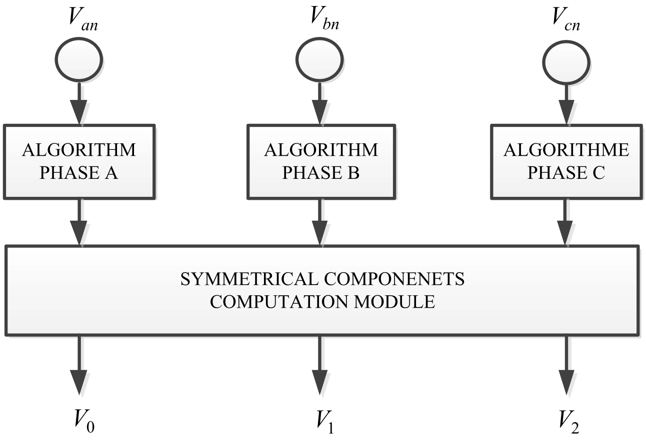

Fig. 1. Overview of the proposed approach.

The main contribution of this proposed approach is to develop a DFT and an online algorithm that can analyse the system performance through an adaptive method of symmetrical component estimation. This study is simulated in Matlab Simulink, and an experimental study is investigated by using an Omicron 56 and a TMS320F240 processor. Main contribution of this work are as follows:

1. Develop a method that can handle the amplitude changes on the electrical system in real time for better control of the network.
2. Propose a new strategy of symmetrical component estimation in real-time that can tract any change into the phase angle by using a DFT and algorithm.
3. Develop a dynamic approach to extract the harmonic and noise levels on the system signal.

The paper is organized as follows: Section 2 presents a description of the adaptive algorithm. An adaptive model of the symmetrical component estimation is described in Section 3. The simulation performance under the influence of step changes in amplitude and phase, as well as, the influence of harmonics and noise is presented in Section 4. The experimental testing of the formulated model is shown in Section 5. In Section 6, the proposed method is evaluated by using actual faulted data and Section 7 presents the conclusion of the results.

2. Formulation of the non-linear filter

The adaptive symmetrical component estimation model is formulated based on the nonlinear adaptive filter of Ziarani and Konrad [22]. Let $v(t)$ represents a voltage signal in which $n(t)$ denotes the superimposed disturbance or noise. In atypical operation i.e. a power system, $v(t)$ has a general form of:

$$v(t) = \sum_{i=0}^{\infty} V_i \sin(\omega t + \phi) + n(t) \tag{1}$$

where V is the system voltage, ω is the angular frequency and ϕ is the phase angle. All these parameters, V, ω and ϕ, are functions of time. In a power system, this function is usually continuous and almost periodic. A sinusoidal component of this function is:

$$S(t) = V_s \sin(\omega t + \delta_s) \tag{2}$$