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New digital filter for unbalance distorted current and voltage estimation in power systems

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Abstract

This paper presents a novel algorithm for identifying and measuring the symmetrical components of distorted three phase voltage or current waveforms in electrical power systems. The proposed algorithm is capable of estimating the symmetrical components as well as the harmonic contents of a given unbalanced distorted signal. The proposed technique is based on stochastic estimation theorem. The problem is formulated as an estimation problem and presented in state space form. The proposed algorithm used to estimate the positive, negative and zero components of unsymmetrical waveforms as well as the harmonic content of a given distorted signal. Application of the proposed algorithm has been conducted on various test cases. Among which a practical simulated power system has been implemented using EMTP. Various scenarios are carried out to simulate realistic situations of unsymmetrical waveforms. Effects of bad data on the solution accuracy are also studied. The speed of convergence is examined by changing the estimator initial conditions. Results obtained show that the proposed technique can estimate and track the symmetrical components of non-stationary three phase unbalance voltage or current waveforms in noisy environments. Fast accurate solutions are guaranteed regardless of the initial conditions. It is also shown that bad measurements have no effects on the final accuracy of the estimation.

Keywords: Symmetrical components; Identification; Estimator; Harmonics; Protection; Unbalanced

1. Introduction

The method of symmetrical components is a very important tool for the analysis of three phase electrical systems. Protection of power system needs accurate identification of symmetrical components of the measured signals. During unbalanced disturbances, symmetrical components change their values significantly. It is thus very important to track symmetrical components on-line. Several methods have, so far, been proposed to calculate the symmetrical components of a voltage or current signals, many of these methods are based on static state estimation, others are based on dynamic state estimation techniques.

Reference [1] presents a review on some of static estimation techniques and proposed the use of recursive least error squares technique. Reference [2] proposed a digital filtering algorithm for the estimation of symmetrical components. The algorithm is based on using two digital filters working together for fast estimation. The input three phase unbalanced system is transformed, first, into α–β transformation. The least error square estimation technique is then used to identify the magnitude and phase angle of each sequence component. As known, the least error square estimation solution is affected by the presence of bad data. In reference [3] a fast efficient method based on fast Fourier transform (FFT) is presented. There are basic assumptions embedded in the application of the FFT. These assumptions are (a) the signal is stationary; (b) the sampling frequency is equal to the number of samples multiplied by the fundamental frequency assumed by the algorithm; (c) sampling theorem is satisfied. Misapplication of Fourier transform

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algorithm would lead to inaccurate results. Reference [4] presents a method based on non-recursive Newton type algorithm. The algorithm is not sensitive to power system frequency changes and to harmonic distortion of input signals.

Dynamic state estimation techniques such as Kalman filtering (KF) and weighted least absolute value dynamic filters are also presented in many Refs. [5–7]. The algorithm presented in reference [5] detects the positive and negative sequence components after filtering the zero sequence components. Although this method gives good results, it was not tested in the presence of bad data points. Reference [7] presents an application of a dynamic filter for on-line estimation of symmetrical components. The method detects the sequence components of pure sine waveforms. Sequence filters are also frequently used in power system protection for identifying voltage or current symmetrical components during abnormal operations. Sequence filters output can be affected by saturation that may happen to the filter coil elements [8]. In reference [8] another on-line method for estimating symmetrical components is presented. The method is based on the use of a set of enhanced phase-locked loop systems. Reference [9] introduced an adaptive linear combiner for symmetrical components estimation. The technique is capable of estimating both the symmetrical components as well as the harmonic contents of measured unsymmetrical distorted signals. The algorithm is based on Kalman filtering technique.

Approaches based on artificial intelligence techniques such as genetic algorithms, fuzzy logic and neural networks are also proposed to detect and identify voltage and current sequence components [10–12]. Many other techniques are suggested and implemented in the time domain [13,14].

This paper presents a novel technique based on recursive algorithm which can be used for digital identification of the symmetrical components of the harmonic contaminated voltage or current waveforms in electrical power systems. The algorithm is an optimal dynamic estimator based on stochastic estimation theory, which is applicable for estimating and tracking the non-stationary signals. Unlike Kalman filter, which minimizes the error square, the proposed estimator gain matrix is derived in such a way to minimize the absolute error in the estimation process, thus the estimator is named dynamic least absolute estimator (DLAVE). The method allows a very fast determination and isolation of the fundamental and harmonic components and consequently the desired parameters of symmetrical components when a change in the power system occurs. Results obtained show that the proposed technique efficiently estimates the symmetrical components of three phase unbalance voltage or current waveforms under different circumstances.

2. Mathematical modeling

The idea here is to present the relationship between the unsymmetrical waveforms and the symmetrical components in state space form which is suitable for the proposed algorithm. This is done via two steps. In the first step, the distorted signal is decomposed to its fundamental and harmonic contents. In the second step, the fundamental component is resolved to obtain its symmetrical components.

2.1. Distorted waveform modeling

Assume that we have a non-sinusoidal waveform given as

$$i(t) = I_{\mathrm{dc}} + \sum_{j=1}^{n} I_{\mathrm{mj}} \sin(w_j t + \theta_j) \tag{1}$$

where I_{dc} is the dc component of the current; j equals 1 for fundamental and equals 2, 3, ... for harmonics; n is the maximum order of harmonic considered; $I_{\mathrm{m}j}$ is the jth maximum value of the current component; θ_j is the phase angle of the jth current component

Eq. (1) can be expanded as

$$i(t) = I_{\mathrm{dc}} + I_{\mathrm{m1}} \cos(\theta_1) \sin(\omega_1 t) + I_{\mathrm{m1}} \sin(\theta_1) \cos(\omega_1 t) + I_{\mathrm{m2}} \cos(\theta_2) \sin(\omega_2 t) + I_{\mathrm{m2}} \sin(\theta_2) \cos(\omega_2 t) + \cdots \tag{2}$$

Without loosing generality, it can be assumed that the signals are contaminated with harmonics of orders 3rd, 5th and 7th in addition to the dc offset component, so we can write

$$\begin{aligned} i(t) = {} & X_0 + \sin(\omega_1 t) X_1 + \cos(\omega_1 t) X_2 + \sin(\omega_3 t) X_3 + \cos(\omega_3 t) X_4 + \sin(\omega_5 t) X_5 \\ & + \cos(\omega_5 t) X_6 + \sin(\omega_7 t) X_7 + \cos(\omega_7 t) X_8 \end{aligned} \tag{3}$$

where

$$\begin{aligned} & X_0 = I_{\mathrm{dc}}, \qquad X_k = I_k \cos(\theta_k), \quad k = 1, 3, 5, 7 \\ & X_k = I_k \sin(\theta_k), \quad k = 2, 4, 6, 8 \end{aligned} \tag{4}$$