Power System Stability Monitoring and Control using Dynamic Phasors

Proposal of Ph. D Research Plan

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PROPOSAL OF RESEARCH PLAN

1.0. Proposed Topic of Research

*Power System Stability Monitoring and Control using Dynamic Phasors*

2.0. Objective of the Proposed Research

1. To develop a novel approach for estimating the phasor parameters by PMU, namely magnitude, angle and frequency of a signal in real time.
2. The new algorithm to be free from modeling the parameters during phasor estimation.
3. To develop phasor estimation technique improves the dynamic performance of PMU when exposed to sinusoidal waveform distortions, such as modulation, frequency drift, abrupt change in magnitude, etc.
4. To propose algorithm to monitor the wide area power system model.
5. To increase the reliability and the transient stability of the power system by fast detection of faults, isolation of healthy system with proper coordination of relays and the prevention of power outages.
6. A case study to be performed on Indian power grid by the implementation of proposed approaches

3.0. Background of Proposed Research

3.1. Introduction

The work has been divided into two sections to achieve the proposed research objectives: literature review and key research questions. The literature survey has been carried out in two parts: dynamic phasor estimation of voltage and current signals under power dynamics and synchrophasor applications like monitoring of wide area power system, protection of long transmission lines and angle stability analysis of power system.

3.2. Literature Review

3.2.1. Dynamic Phasor Estimation

In [1], the microcomputer based Symmetrical Component Distance Relay (SCDR) facilitates real-time monitoring of positive sequence voltage phasor at the local power system bus. A new approach to the design of digital algorithm for voltage phasor and local system frequency estimation was presented based on Newton’s iterative method. The algorithm showed a very high level of robustness as well as high measurement accuracy for stationary signals [2]. A series of precise
digital algorithms based on Discrete Fourier Transforms (DFT) to calculate the frequency and phasor in real-time were proposed. These algorithms smartly take frequency deviation and harmonics into consideration but not modulated signals [3].

The paper [4] discussed about the DFT phase detection error caused by the off nominal ac frequency, proposed the error correction scheme using the estimated ac frequency and evaluates the accuracy of corrected phase. The error correction scheme for the positive sequence phase detection of the three-phase system with compensating the harmful influence of the negative sequence component to the highly unbalanced condition is also discussed. In [5], the raised cosine filter, widely used in digital transmission, is described to accurately estimate phasor under power system oscillations. An improvement in the performance (accuracy and speed) of these phasor estimates as compared with those obtained with the Fourier-boxcar filter, commonly used in present commercial applications is shown.

Comprehensive analysis of discrete Fourier transform (DFT) error is given in [6]. Simple but precise expressions of phase angle error and amplitude error are provided. These expressions estimate phasor with large error during transients’ period. Paper [7] presented a new technique, which effectively remove the effect of harmonics and the decaying dc component present in the input signals, within half a cycle of the power system frequency. The relaying algorithm has a faster convergence and better accuracy during sinusoidal conditions.

The paper [8] breaks that old paradigm by relaxing the static phasor concept to a dynamic phasor. This paper presented the algorithm to approximate the dynamic phasor by a second-order Taylor polynomial and compares its phasor estimate to the traditional method of estimation. But the algorithm faces a problem of modeling the parameters to accurately estimate the dynamics phasor which usually didn’t suit the existing protective devices. In [9], a novel algorithm for estimating synchrophasors under dynamic conditions is presented. In contrast to the classical Fourier algorithm, proposed complex Taylor expansion model, resulting several parameters in the model to be estimated. Four- and six-parameter models are presented corresponding to first and second order Taylor expansions. Implementation of synchrophasor measurements on protection and control intelligent electronic devices (IEDs) is discussed but still challenges to model parameters under dynamic conditions.

A new technique for estimation of the instantaneous frequency based on simultaneous sampling of three-phase voltage signals is presented in [10]. The structure consists of two decoupled modules: the first is for adaptive filtering of input signals, and the second is for frequency estimation. This technique provides better performance, compared with the technique based on a
single-phase signal in relation to waveforms with noise. The technique is strong when asymmetric sags generate zero voltage in one of the three phases and ignores the concept of modulation signals effect.

The Kalman filter algorithm is applied to their state vectors in order to find observers able to estimate the dynamic phasor and its first derivatives. The estimates obtained through this technique are not only instantaneous (no delay) but also synchronous, an important attribute for control applications. They are promising and open the way to a new family of phasor estimators [11].

A novel digital signal processing algorithm for online estimation of the fundamental frequency of the distorted power system signals is presented in [12]. The algorithm has higher degree of immunity and insensitivity to harmonics and noise, faster response during step frequency change as compared with the enhanced-phase-locked-loop (EPLL) system. The only limitation as compared with the EPLL system is its slower transient response during step change in signal magnitude. A dynamic phasor estimator for fault current (DPEFC) is proposed to remove the phasor-estimation errors caused by dynamic characteristics and decaying dc components [13]. DPEFC can achieve accurate phasor estimation of fault current in the presence of dynamic characteristics and decaying dc components with a minimal increase of computational cost which meets the requirements of the application in phasor measurement units. The algorithm fails during power swings to estimate the phasor of an operating signal.

Estimation of dynamic phasors, under power-system oscillations, is proposed using subspace based techniques. A high sampling rate and few modifications in the subspace-based techniques are suggested to estimate the voltage phasor with a fundamental frequency component without using anti-aliasing filter to the input signal. The proposed algorithm challenges to model parameters under dynamic conditions. Prony’s method is used as a dynamic phasor estimator and the adaptive approximation of its complex exponential signal model to the dynamic phasor of an oscillation over a finite time interval [14]. With its static signal model, it is unable to accurately follow oscillations when the frequency fluctuates.

In paper [15], the performances of three state-of-the-art techniques based on phasor Taylor’s series expansion specifically conceived to track phasors in dynamic conditions are analyzed and compared with the one-cycle discrete Fourier transform estimator under the effect of amplitude step changes, phase step changes, and linear frequency variations. However, the peak TVE increments for a given step size are quite similar for all the considered techniques and are dominated by amplitude or phase errors.
3.2.2. Synchrophasor Applications

Till now, many WAMS applications have been developed which use synchrophasor data. However, this is a comparatively new area. Initially, post-event analysis was the main application of synchrophasors. PMUs at this stage mainly acted as system disturbance recorders [16].

Situational awareness is one of the basic applications of synchrophasors. Power system operators use display and visualizations tools [17] to make themselves aware of the evolving situations. Synchrophasors make direct monitoring and visualization of voltage and current phase angles possible. Now, system operators can easily sense the stability conditions of power grids by monitoring the accurate synchrophasor angles.

Synchrophasors are increasingly being used in state estimations. Currently, several synchrophasor based state estimation algorithms are being reported in the literature [18] [19].

Large power exchanges over long transmission lines often cause oscillatory instability in the grid. Negatively damped inter-area modes can cause widespread blackouts. Blackouts may be avoided if these poorly damped oscillations are detected in the early stages. With SCADA measurements, it was difficult to measure the oscillations directly and accurately. Synchrophasors allow direct measurement of the small signal oscillations. Many algorithms [20]-[22] have been proposed in the literature to estimate the small signal oscillation modes using synchrophasors data.

The possibility of voltage instability is increasing with increasing load, renewable energy penetration and interconnected networks. Traditional voltage stability estimation techniques are offline and time-consuming. Recently, several synchrophasor based voltage stability prediction algorithms [23] [24] have been proposed in the literature. Synchrophasor based voltage stability prediction algorithms need lesser computations.

Synchrophasors are increasingly used in many power system protection applications. Out of step relaying and wide-area angle instability detection [25] are examples of this. Traditional out-of-step relays [26] use distance relays and timers for the detection. Recently, synchrophasor based techniques [27] have been proposed for out of step relaying as synchrophasors allow direct measurement of phase angles. Phase angles are often used as inputs in these relaying algorithms.

Accurate fault location helps to speed up restoration and reduce outage time for transmission lines. Fault location algorithms can be divided into three categories: phasor based, knowledge based and travelling wave based algorithms [28]. Travelling wave based algorithms are time domain algorithms. Traditional phasor based algorithms use unsynchronized phasors [29]. These algorithms can be further divided into three categories: single end [30], double ends [31] and multi-terminals [32]. Recently, synchrophasor based algorithms are being proposed for fault location applications.
Accurate fault location estimation depends on the measurement accuracy. Inherent accuracies of synchrophasors help to reduce the fault location estimation errors.

### 3.3. Key Research Questions

1. How to address simultaneous modulations in both amplitude and phase angle, and frequency ramps through non-parameter model to estimate the dynamic phasor of PMU.
2. The power grid monitoring requires phasor measurements with high accuracy while the protection applications require such measurements with fast response. An appropriate dynamic phasor estimation algorithm to be developed such that it can able to fit for two requirements.
3. How to achieve a robust coordination scheme among distance relays under fast and accurate synchrophasor measurements so as to isolate only fault element from the healthy systems.
4. Estimation of rotor stability margin under various fault conditions on transmission lines with synchrophasor measurements by the proposed algorithm and determination of its practical impact on Indian power system.

### 4.0. Methodology

**Task 1:** Extensive Literature Survey and development of robust dynamic phasor estimation algorithm

a. Study the characteristics of voltage and current waveforms during power system transients.

b. Based on better understanding the fundamental properties of the signals that need to be monitored, and corresponding signal processing techniques, define the specific requirements for a reference phasor estimator under power system transient.

c. Develop an adaptive algorithm to improve the accuracy of synchrophasor measurements for better tracking dynamic transients during power system disturbances.

d. Propose a new phasor estimation algorithm for real-time applications featuring better dynamic performance, capable of eliminating decaying DC components, flexible window size and low computation burden.

**Task 2:** Monitoring of power system variables

**Task 3:** Development of adaptive distance relay for transmission line protection

a. The accurate and fast measurements made available to distance relaying systems.

b. The robustness of dynamic phasor estimation algorithm to be tested under various power system faults.
**Task 4:** Analysis of rotor angle stability for various faults on transmission line
   a. Traditional rotor angle stability analysis method development.
   b. Synchrophasor based rotor angle stability models development.
   c. A case study on Indian power system.

**Task 5:** Documentation of Results

**5.0. Timeline/Research Planning**

![Timeline Diagram]

- **Research Tasks:**
  - Task 1
  - Task 2
  - Task 3
  - Task 4
  - Task 5

- **Timeline:**
  - 00:00
  - 06:00
  - 12:00
  - 18:00
  - 24:00
  - 30:00
  - 36:00

- **Legend:**
  - : Pre-Start
  - : Active

- **Work Months:**
  - Pre-start
  - Active
References


