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On-line estimation of transmission line parameters, temperature and sag using PMU measurements

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ABSTRACT

This paper presents a framework for estimating transmission line positive sequence parameters, temperature, and sag utilizing on-line voltage and current phasors measured by Phasor Measurement Units. Transmission line parameters, temperature, and sag are vital inputs to various power system analyses and applications, such as the power flow analysis, the protective relaying application, and the dynamic thermal rating application. In this study, different types of transmission line topology are classified and modeled to facilitate the development of corresponding algorithms. All models are based on distributed parameters, so it automatically considers the shunt capacitance effect of long lines. It is assumed that the line is transposed. The proposed least squares based algorithms harness the non-linear optimal estimation theory and are capable of detecting and identifying bad data, minimizing the impact of measurement errors and thus significantly improving the estimation accuracy. The line temperature and sag are calculated according to the obtained parameter estimates. Numerical case studies based on simulated data are presented.

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1. Introduction

The research on power transmission lines requires transmission line parameters, including series resistance, series reactance and shunt susceptance as vital inputs to various power system analyses and applications, such as the power flow analysis and the protective relaying application [1]. Accurate estimate of line parameters may also be employed for transmission line thermal condition monitoring [2]. So it will be desirable if line parameters can be accurately estimated using on-line voltage and current measurements.

Numerous algorithms for estimating transmission line parameters have been proposed in the past. Ref. [3] introduces classical approaches for estimating line parameters. Deviations from actual values of employed factors such as conductor type and geometric parameters may cause errors in estimation. Another procedure presented in [4] harnesses voltage and current phasors from one end of a line while assuming the other end is open or short-circuited. Difficulties in obtaining the required measurements hinder the applicability.

The on-line parameter estimation approaches which employ voltage and current phasors should be beneficial to various applications. In [5], the ABCD parameters are obtained by using two sets of synchronous phasors from two terminals, yet without showing how distributed parameters are obtained. The Global Positioning System provides a way to improve synchronization while the estimation accuracy relies essentially on the precision of the synchronization angle [6]. As introduced in [7], the characteristic impedance and propagation constant of a line can be derived by making use of on-line phasors captured at both ends. According to [8], by utilizing three sets of synchronous phasors based on Laplace transform, the proposed algorithm can solve for line parameters. It is assumed by all these approaches that high precision in synchronization is available; otherwise, it may yield significant estimation errors.

To sum up, existing line parameter estimation algorithms work well with accurate phasors and synchronization. Sometimes in practice, bad measurements may occur due to various reasons, such as current transformer saturation [9], data conversion errors or communications abnormalities [10]. The occurrence of such bad data could result in substantial estimation inaccuracy, which brings the challenge for the performance of developed algorithms.

With the recent development of Smart Grid technology, especially in the key technology area of sensing and measurement, Phasor Measurement Unit (PMU) is considered as a promising tool for advanced wide-area monitoring systems [11]. It is capable of capturing time synchronized phasors from a large transmission network, which are employed for monitoring, control and protection.

A method for monitoring transmission line sag is proposed in [12], using a tension based model and state estimation method.

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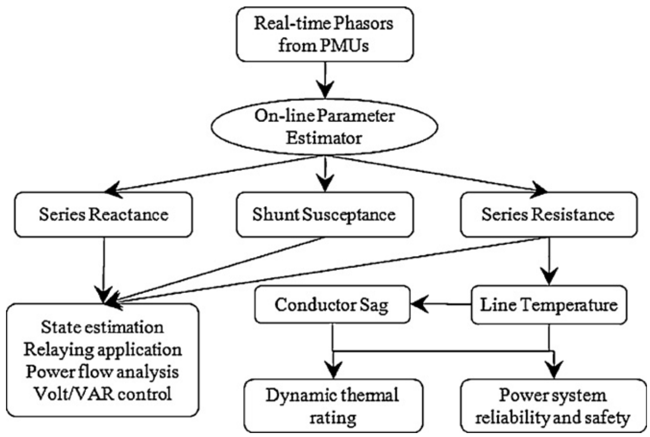

Fig. 1. The overall framework.

The required parameters such as wind, ambient temperature, air and solar data, etc., are obtained through local weather stations or additional sensors are needed. Hence an alternative way to calculate the conductor temperature and sag using fewer parameters is desired.

Based on the relationship between conductor temperature and resistance [13–15], a possible online method for transmission line thermal condition monitoring based on synchronized phasors installed at terminals of transmission lines is put forth in [2]. The average line temperature can be estimated based on the conductor characteristics and the average line resistance, from which the conductor sag can be derived. This type of method will only require PMUs to be installed to collect phasors, and appropriate algorithms for estimating the line resistance, eliminating the need for extra tension or weather sensors.

Building upon [2], this paper further develops and describes the method for estimating positive sequence line parameters, temperature, and sag using on-line voltage and current synchrophasors. A bad data detection and identification method capable of minimizing the impact of measurement and synchronization errors is also presented. The equivalent π circuit based on distributed parameter line models is employed for the development of algorithms. Hence, the proposed solution automatically considers the shunt capacitance effect of long lines [3]. In this paper, the transmission line is assumed to be transposed.

In the rest of the paper, Section 2 presents the overall framework for estimating the line parameters, temperature and sag. Section 3 classifies typical network topologies of transmission lines. The proposed algorithms to estimate line parameters for each type of sub-network are delineated in Section 4. Section 5 introduces the method to estimate the line temperature and conductor sag. Numerical case studies and estimation results are presented in Section 6, followed by the conclusion.

2. The overall framework

The overall framework for estimating transmission line parameters, temperature, and conductor sag using on-line voltage and current phasors measured by PMUs is described in Fig. 1. Real-time phasors from PMUs are firstly transferred through communication links to on-line parameter estimator, where line parameters including series resistance, reactance and shunt susceptance are derived. The average line temperature is then computed based on the estimated series resistance. Next, the conductor sag of selected span can be calculated accordingly. The estimated line parameters can also be exploited for the state estimation, relaying application, and other such power system applications, e.g. power flow studies and the real and reactive power control for improved grid operations. The obtained line temperature and conductor sag data can be employed for the dynamic thermal rating application and other power system reliability and safety utilization. It is observed that the line temperature and sag are calculated indirectly from real-time phasors from PMUs, which means this method does not require additional tension sensors or weather data, and thus greatly simplifies the process and reduces both equipment and maintenance costs.

3. Typical transmission network

Large power transmission networks can be decomposed based on the topology of connections to small basic networks. In this study, totally four types of sub-networks are classified to facilitate the development of line parameter estimation algorithms, as shown in Fig. 2. The circle labeled “Sub-system” in Fig. 2 could connect to a generation source or to the remaining part of a large system. A bar labeled in numerical order represents a substation or a bus, where measurement devices such as PMU can be installed. The Sub-network Type 1 is a basic two-bus single-circuit transmission network with one Sub-system connected at each terminal. The Sub-network Type 2 is a two-bus single-circuit transmission network equipped with a series capacitive compensation device, which can be a capacitor bank or thyristor-based power flow controller. The Sub-network Type 3 is a three-bus transmission network that shares a common bus at one substation. The Sub-network Type 4 is a two-bus double-circuit network that shares a common bus at both terminals.

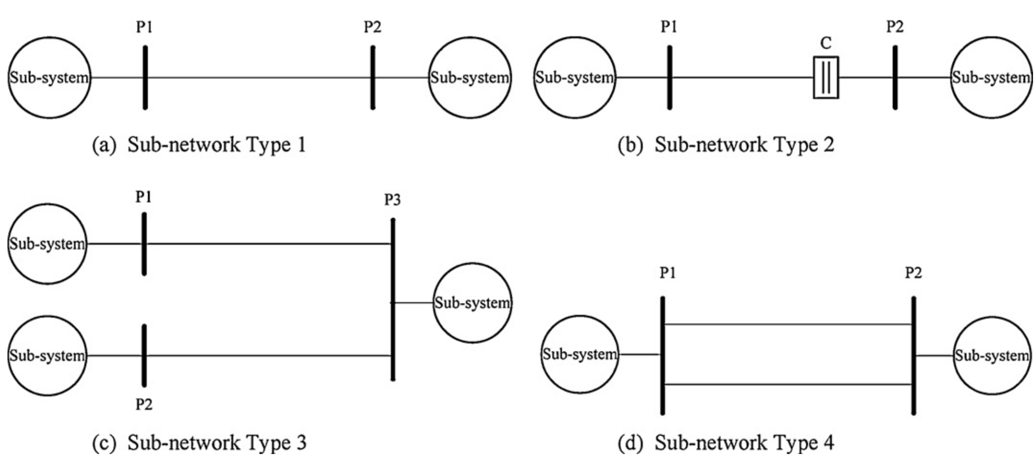

Fig. 2. Typical transmission network.

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