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Line outage identification-based state estimation in a power system with multiple line outages

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ABSTRACT

Line outages in power systems cause data centers to miss some measurements thus making parts of networks unobservable. They also change the network topology and, consequently, classical state estimators do not converge. This paper proposes a new state estimation methodology based on the concepts of sparse vector recovery and line outage modeling. The proposed method first uses the pre- and post-outage voltage angle measurements to find the changes in network topology. Then it uses either the post-contingency data from PMUs and updated line flows or post-contingency measurements from PMUs and conventional PQ meters, as well as the updated topology, to provide an estimate of the power system state. The performance and accuracy of the proposed method are evaluated for the IEEE 24-, 57- and 118-bus systems. The simulation results show that the method provides good results for the three networks.

1. Introduction

With the increasing rate of transmission system loading, there is a vital need to monitor the status of transmission networks. This is more important for restructured power systems where the inherent inertia of the decisions made by market participants delays corrective actions. The lack of situation awareness is a major reason for blackouts in North America [1]. According to the report prepared by NERC for the August 2003 power black-out, a 345-kV transmission line was lost due to tree falling and appropriate actions were not performed by the responsible utility to inform other utilities and coordinators about the emergency situation [2]. This report concludes that the deficiency in the tools assisting operators to better visualize power system situations is one of the main reasons for that black-out. Unexpected events such as faults, breaker failures, tree falling, and lightning are major reasons for transmission line outages. In each situation, power system operators need to be aware of the event promptly to take corrective actions [3]. After the August 2003 power black-out, the system data are updated every one hour to increase the knowledge of the system topology [1]. Because many events may occur during a one-hour interval, developing an appropriate algorithm for real-time monitoring and identifying transmission network outages is crucial.

Phasor Measurement Units (PMUs) monitor power systems by providing near real-time measurements of voltage magnitudes and angles [4]. These synchronized measurements capture a snapshot of power systems that state estimators can use to estimate the state of a power system [5]. A PMU installed at a bus provides the voltage phasor at the bus and current phasors through the lines connected to it. This makes the bus and all other buses connected to it observable [6].

Line outage detection is the topic of several studies [7–13]. References [7,8] propose methods that detect line outages by comparing the changes in voltage angles with those obtained from PMUs for every single or double contingency. This is a time-consuming process as each contingency must be simulated repeatedly and is not practical for a large number of contingencies and large networks. Reference [9] proposes an optimization method to find line outages but only formulates it for single line outages. References [10,11] propose two methods based on compressive sensing for health monitoring and line outage detection, but the performance of their model degrades due to an internal noise term and measurement noise. Also, the major issue with [11] is that it does not consider the impact of missing some post-outage measurements which makes it impractical. Reference [12] proposes a method for faulted line detection but assumes independent Gaussian voltage angles, which is not a realistic assumption. In [13], a method based on [8] is developed to locate only

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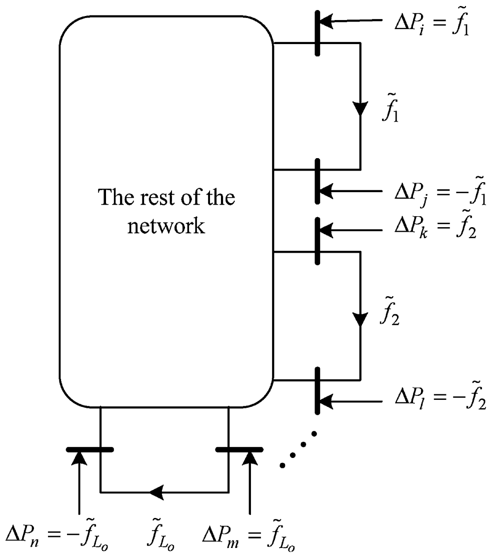

Fig. 1. Line outage model.

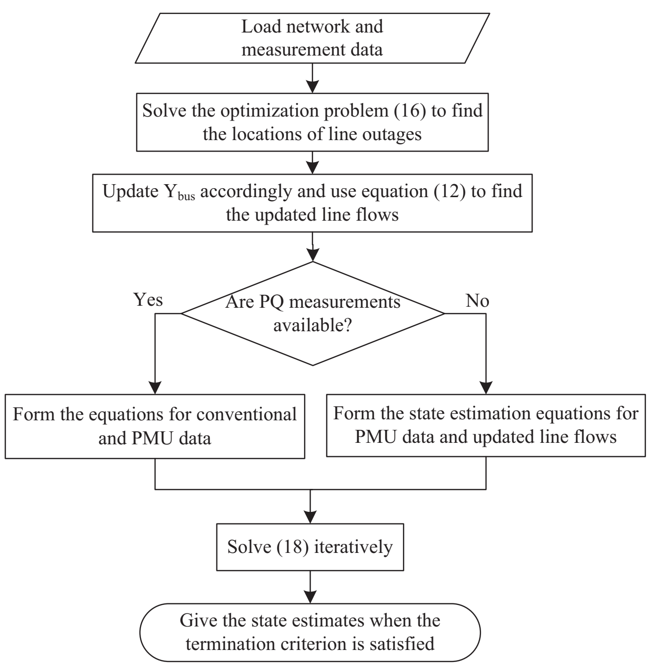

Fig. 2. The flowchart of the proposed method.

single line outages for a particular area. In [14], the impact of PMU uncertainty on the power line outage detection and identification is quantified using a multi-hypothesis test and a general Bayesian criterion, but the performance of the method is just validated for single line outages and in a very small network (IEEE 9-bus test system). Reference [15] studies the problem of line outage detection in an external area by solving an integer programming problem, but the proposed integer programming algorithm is unable to find a solution if the operating conditions between the pre-outage and post-outage scans change. In [16], a global stochastic optimization technique based on cross-entropy optimization is proposed to identify multiple line outages, but it assumes that all buses are equipped with PMUs in one of the main scenarios which is not practical. In [17], an efficient algorithm inspired by the ambiguity group theory is introduced to identify the locations of multiple line outages with limited PMUs. However, the impacts of

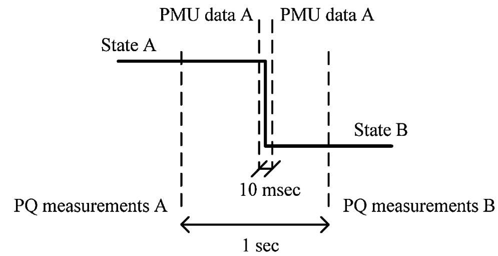

Fig. 3. PMU and PQ measurements.

measurement losses due to line outages are not considered in these studies.

The major contributions of the proposed method in this paper are described as follows.

- Unlike [7,8], this paper identifies the single, double, and triple line outages in one step. Therefore, its computational burden is not dependent on the system size.
- The performance of the proposed method in this paper is verified for up to three contingencies. However, single line outages are just investigated in [8,9,13].
- Unlike [10,11], this paper derives the line outage identification formulations without any internal noise reducing the line outage detection accuracy.
- Unlike [11], this paper not only addresses the impact of missing some post-outage measurements in the line outage identification step, but also proposes a solution to overcome this technical difficulty in the state estimation step. To the authors' knowledge, this issue has not been addressed in the literatures.
- Unlike [12], this paper does not assume independent Gaussian voltage angles in the proposed methodology.

Several studies have examined state estimation of power systems with PMUs and/or conventional meters [18–23]. However, few studies evaluate the state estimators under contingencies with measurement loss and network topology changes [18,23]. Aminifar et al. [18] formulates a linear program for the optimal placement of a network such that the post-contingency network is observable. The method requires a large number of PMUs to make the network observable for more than one outage and does not give an upper bound on the required number of PMUs. However, in this paper, the states of the system are estimated by a limited number of PMUs and active/reactive power measurements for all loads even with three contingencies. Kashyap et al. [23] estimate the state of an unobservable network using a two-state method but do not evaluate the effects of changes in topology on the estimation. Some references tried to formulate a generalized estimation to estimate the status of the breakers to find the change in the topology of power systems [24,25]. However, the optimization problem developed to identify the statuses of breakers is mixed integer and non-convex which does not guarantee reaching the global optima.

- The contributions of the paper in the state estimation area are described as follows:
- Unlike [24,25], the line outage problem is formulated as a convex optimization problem with continuous variables which guarantees the global optima.
- Unlike [23], the paper addresses the impacts of outages and network changes in the state estimation.
- Unlike [24] which only claims the breaker outage identification can be used in state estimators, this paper combine the proposed line outage detection scheme with the state