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A backend framework for the efficient management of power system measurements

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ABSTRACT

Increased adoption and deployment of phasor measurement units (PMU) has provided valuable fine-grained data over the grid. Analysis over these data can provide insight into the health of the grid, thereby improving control over operations. Realizing this data-driven control, however, requires validating, processing and storing massive amounts of PMU data. This paper describes a PMU data management system that supports input from multiple PMU data streams, features an event-detection algorithm, and provides an efficient method for retrieving archival data. The event-detection algorithm rapidly correlates multiple PMU data streams, providing details on events occurring within the power system. The event-detection algorithm feeds into a visualization component, allowing operators to recognize events as they occur. The indexing and data retrieval mechanism facilitates fast access to archived PMU data. Using this method, we achieved over 30× speedup for queries with high selectivity. With the development of these two components, we have developed a system that allows efficient analysis of multiple time-aligned PMU data streams.

1. Introduction

Recently, power grid operations have been complicated by increased penetration of variable generation, load congestion, demand for quality electric power, environmental concerns, and threats to cyber-security and physical infrastructure. Pressure from these issues compel engineers to create tools that leverage modern communications, signal processing, and analytics to provide operators with insight into the operational state of power systems. As Horowitz, et al. explained, there are multiple aspects to achieving the level of knowledge and control necessary to keep one of the world's greatest engineering feats stable and operational [1]. To this end, utilities have been deploying phasor measurement units (PMU)[1] across the grid. At a high-level, PMUs are sensors that measure electrical waveforms at short fixed intervals [2]. A unique feature of PMUs is that they are equipped with global positioning systems (GPS), allowing multiple PMUs distributed in space to be synchronized across time. With a proper set of analytics put in place, the mass deployment of PMUs can offer utility operators a holistic and real-time sense of grid status.

With the recent deployment of PMUs on a large scale, their applications are growing. PMUs provide visibility over the grid at increasing speeds allowing for real-time monitoring of grid conditions [3–5]. PMU placement is also being optimized to provide accurate information about the grid while minimizing the number of units required to achieve observability [6]. Furthermore, this space has seen a significant increase in algorithms that aid in control and mitigation of grid operational issues. For example, efforts have emphasized using PMU data to monitor critical power paths [7], identify transmission line fault locations [3], isolate and mitigate low-frequency zonal oscillations [8], and predict critical slowing down of the network [9].

Despite increase in PMU use, there is still a lack of verification of the data generated by PMUs. Many algorithms assume input data streams to be robust, reliable, and available at all times. However, this is not the case in a real PMU network. Not only do corrupt data streams cause false positives during normal operation, but they reduce confidence in data generated during transient events. The standard for PMU measurements (IEEE C37.118.1-2011) provides some testing and error measurement specifications for these types of situations, but clarification of how a PMU should act is not stated

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[1] Also known as *synchrophasors*, we refer to them as PMUs throughout this paper.

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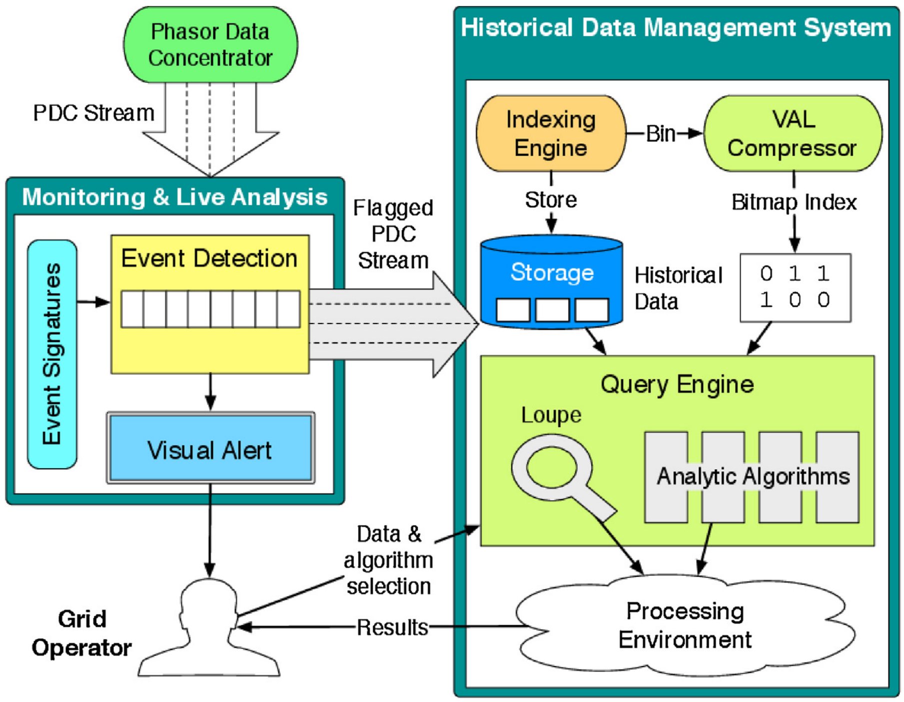

Fig. 1. System architecture.

[10]. Some recent works, namely [11–13], have made some initial steps in verifying the output of PMU devices before informing the operation of higher-level power system control algorithms. They have specifically stressed the importance of data integrity during transient situations. These efforts, however, have not sufficiently solved the event-detection problem.

A second issue not addressed in many of the above works is a result of the sophisticated nature of sensing and data gathering in today's PMUs. In the field, each PMU data stream is collected and coalesced by a device known as a phasor data concentrator (PDC) before being written to large, but slow, non-volatile storage, e.g., hard disks or tape. When data streams from many PMUs are combined, it can amount to massive volumes of data each year (on the order of 100 s of TBs). Unfortunately, common data processing tasks, such as real-time event detection, *ad hoc* querying, data retrieval for analysis, and visualization require scanning or randomly accessing large amounts of PMU data on disk. These tasks can require prohibitive amounts of time. Therefore, in addition to the identification problem stated above, there is also a significant data management problem that has thus far gone unaddressed.

In this paper, we describe a framework for addressing both the inconsistent data (data-flagging) problem, as well as the back-end mechanisms that manage the massive PMU data streams. Our goal is to improve near-real-time event/error detection, data management, and archived data access in a manner that can inform higher level control operations and visualization for operator decision-making. To this end we have developed a system architecture capable of interchanging components. This paper presents our execution of these system components, providing the outcomes expected of this system.

The remainder of this paper is organized as follows. The following work will first depict the system architecture as a whole and how each component works in Section 2. Next, Section 3 will describe the details of implementation of these components. The results from our experiments will be discussed in Section 4. Possible future expansion routes are highlighted in Section 5. Finally, we conclude this work in Section 6.

2. System design

We have created a system that is composed of two primary components, *Monitoring and Live Analysis* and *Historical Data Management*. Within these components we developed two methods to fulfil these functions, a correlation matrix with a graphical display and a data management algorithm known as a *bitmap index*. This system allows for sufficient validation of the PMU data while providing fast operator query support on the large database.

Fig. 1 illustrates the system architecture. Data arriving from a phasor data concentrator (PDC) is first given to the *Monitoring and Live Analysis Subsystem*. This subsystem comprises three main components. The Event Detection engine inputs a set of known power-systems event signatures and analyzes the PDC stream in a single pass. To perform this one-pass analysis, we use a correlation matrix, which also provides visual alerts to the operator by depicting various event signatures. Using this correlation matrix we are able to detect and identify events occurring within the power grid monitored by the PMUs.

The PDC data is sent to the Historical Data Management System for archiving. First, data is discretized (binned) to generate a bitmap index (described in detail in the next subsection). The bitmap, once compressed, allows for efficient response to queries from the operator. This system architecture allows for the operator to monitor the grid in real time, including the ability to detect various power system events and data errors. While monitoring the grid the operator can query the large database of past PMU values using the Data Management subsystem, allowing for replay of historical events through the Monitoring and Live Analysis system or simply for further examination.

We believe that the Monitoring and Live Analysis subsystem, coupled with the Historical Data Management subsystem, may improve operator decision making. Being able to monitor the grid and detect events while having the capability to query past synchrophasor measurements grants the operator this capability.

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