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Exploiting Massive PMU Data Analysis for LV Distribution Network Model Validation

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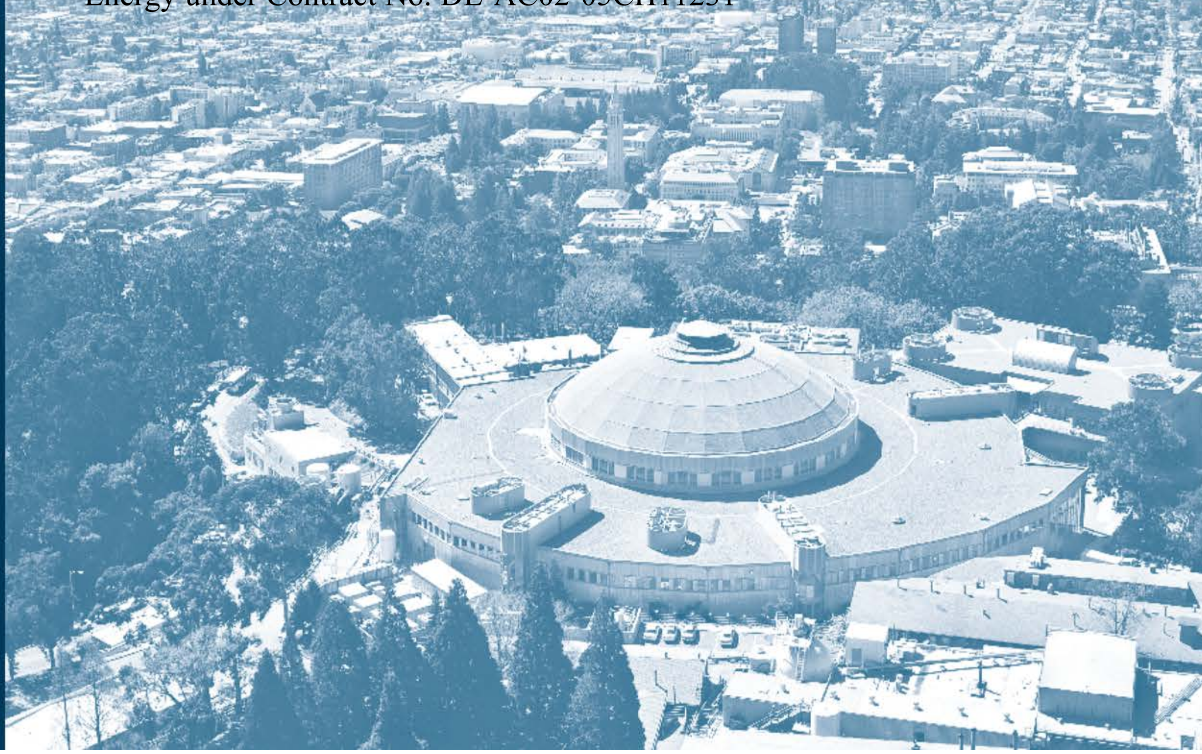

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Exploiting Massive PMU Data Analysis for LV Distribution Network Model Validation

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Abstract- **As utilities move towards more intelligent and autonomous networks, there is increased requirement for the analysis of how these changes will affect network operations and performance. Phasor Measurement Units (PMUs) can be integrated into a network for the analysis and identification of bad data. As PMUs contain a Global Positioning System (GPS) chip, it is possible for them to determine their own location when connected to a network. By creating a Common Information Model (CIM) network model in the cloud, with embedded geographical data, the PMU would be able to connect to this and determine what it is connected to and where in a network it is located. Network data could then be collected and analysed to help identify any points of bad data. Challenges to be overcome include the building of the network model from the available geographical data, the automatic integration of the PMU with the network, and the authentication of the data.**

***Index Terms*—Data Communication, Phasor Measurement Units, Data Exchange, Open Standards, Power System Analysis.**

I. Introduction

The move towards more advanced networks, with increased penetration of distributed generation [1], will require far larger amounts of data and results to be collected and transferred on a frequent basis between applications from a number of vendors, many of whom use their own proprietary data formats. This impacts online and offline analysis of the network, and there are huge challenges in collecting, integrating and aligning data among multiple disparate sources that are constantly changing.

In addition to the challenges of collecting and integrating data, utilising the data for network analysis is dependent on an accurate network model. Distribution network operators (DNOs) in particular suffer from large variations in data quality in their low voltage (LV) network models and often lack an electrical connectivity model below the medium voltage (MV) level. Identifying where the model is deficient is critical in allowing DNOs to construct accurate models suitable for detailed analysis and planning work.

As PMUs contain a Global Positioning System (GPS) chip, it is possible for them to determine their own exact geographical location. By creating a Common Information Model (CIM) network model in the cloud that conforms to the Common Distribution Power System Model (IEC 61968-13 CDPSM) with embedded geographical data for the electrical components, the PMU would be able to connect to this server and automatically determine what it is connected to and where in a network it is located both geographically and electrically. This allows PMUs to be connected into a network for analysis of a specific area with automatic integration into the underlying network model. PMU data could then be collected and analysed to help identify any points of bad data; where readings do not match up to what they are expected to be; and where further investigation would be required.

There are a number of challenges to overcome before achieving this integration, including: building the network model from the available geographical data and creating a detailed low voltage electrical connectivity model; automatic connection and authentication of the PMU with the cloud server; the automatic integration of the PMU with the network model; and the validation of the electrical connectivity model data (including line parameters and topology). Industry standards must be conformed to for several aspects of the integration, such as connecting the PMU to the network, and also for the collection and transferring of data to different applications. These challenges will need to be investigated to improve upon the quality of the existing network operation and performance. This paper will focus on a particular aspect of this specific problem: locating the position of a PMU connected into the network and building the network model from the available geographical data. Section II will detail relevant background information on PMUs, smart meters, cloud computing and changes in the electricity grid. Section III will cover the proposed idea of a 'plug-and-play' PMU, and Section IV will discuss the methods of determining the location of a specific PMU and how it fits into the surrounding network. Finally, Section V will look at the main challenges involved in realising this solution.

II. Background

A. Changes in the Grid

Utilities are seeing more distributed energy resources (DER) being added at a low voltage level, impacting on the stability of the grid. This creates many situations where feeder loads can no longer be relied on to follow predictable daily, weekly or seasonal patterns, making it more difficult to balance supply and demand on the network.

The utilities need to do more analysis of how installed and planned generation will impact on their grid for short, medium and long term planning and daily operations. To do this they need to analyse the data with respect to the LV electrical network models, but the current quality of this data is often

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unreliable, if it exists at all. It is impractical and costly to resurvey the networks to obtain the necessary network models, resulting in an underutilisation of the collected data.

B. Phasor Measurement Units

Phasor Measurement Units (PMUs) are high frequency devices that sample analogue voltage and current data in synchronisation with a GPS clock [2]. Samples are taken every 13-15.6 µs and sent to a Phasor Data Concentrator (PDC), which validates and sorts them by their time-stamp, ensuring that all PMU samples taken at the same time across a network are processed together. Late samples can be identified using their time stamps and marked as problematic. An example of the voltage and current data collected from two PMUs on a single network over the course of an hour is shown in Fig. 1.

A phasor is a complex equivalent of a simple-frequency cosine wave quantity such that the complex modulus is the cosine wave amplitude and the complex angle (in polar form) is the cosine wave phase angle [2]. It is typically used to represent the power frequency signal in ac power, which is approximately 50 Hz or 60 Hz.

While transmission level PMUs must account for connecting to high voltage and are therefore higher cost than is considered reasonable for distribution expenditure [3], the price of a distribution level PMU is proposed to be significantly lower [4], in a range more practical for data collection in the distribution network. They are therefore becoming a more popular method of data collection.

C. Smart Meters

Smart meters collect and send data detailing the energy usage of consumers throughout the day. These devices are being installed on low voltage distribution grids, providing more insight into those areas of the network. This is only useful if the network operators have access to the data in close to real-time, which is not always the case on the GB or some parts of the North American system [5] where the liberalised electricity market separates the meter reading and network operations.

In other markets, where the DNO is also the retail provider, it is common to find an integration of smart meters with network and geographical data. This allows a direct correlation between an electrical grid supply point on the network model and the smart meter itself. In other cases, as exists in the GB system, the DNO may have no direct visibility of the smart meter and its data. It then becomes harder to correlate the meter with a point of consumption on the network.

D. Cloud Computing

Cloud computing allows relatively cheap access to huge amounts of processing power, without investing in dedicated computing facilities, which is ideal for the analysis of lots of data. If required, resources can be scaled up to deal with a large influx of data, and then reduced if the input returns to normal levels.

Trusted clouds are a development of private clouds. They allow only specified people or organisations to use the cloud and to verify that the image used to instantiate the virtual machines has not been modified since its creation. This provides an additional layer of trust and security for the data and applications deployed in the cloud, providing a more reliable and secure platform. As with all cloud platforms, different levels of access can also be created, so an administrator can access the underlying infrastructure of the cloud, while end users can only view the data or results stored [6].

III. PLUG-AND-PLAY PMUS

PMUs have a built in GPS chip for timing purposes; this will also provide the exact geographical location of the sensor. Plug-and-play PMUs are therefore possible, where a cloud-based analysis engine can automatically determine where on the electrical network a PMU is installed. This would be achieved by using the GPS location in combination with an electrical connectivity model with built-in geographical location data, such as that supported by the IEC CIM Common Distribution Power System Model (IEC 61986-13) [7].

Trusted Cloud-based systems will allow a PMU to automatically connect, authenticate, integrate and send its data to the back-end system. The data can be used either for offline analysis or made available for real-time control. Continuous analysis of the electrical network model based on the conditions and model parameters are then compared with the collected data.

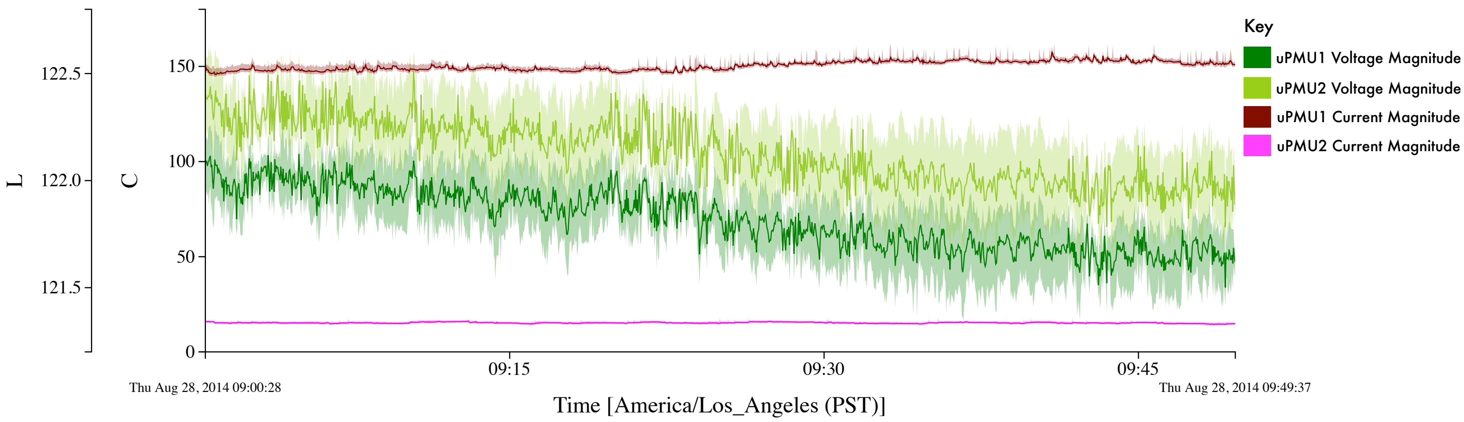

Fig. 1. PMU Voltage and Current Outputs over 1 Hour

This will allow utilities to identify where their predicted results, based on the network parameters, do not match up with what is actually happening. It will influence where the PMU should next be placed to better identify and analyse the areas that should be the focus for re-surveying. Alternatively, the network parameters could directly be updated based on back-computation of line parameters from the collected PMU data.

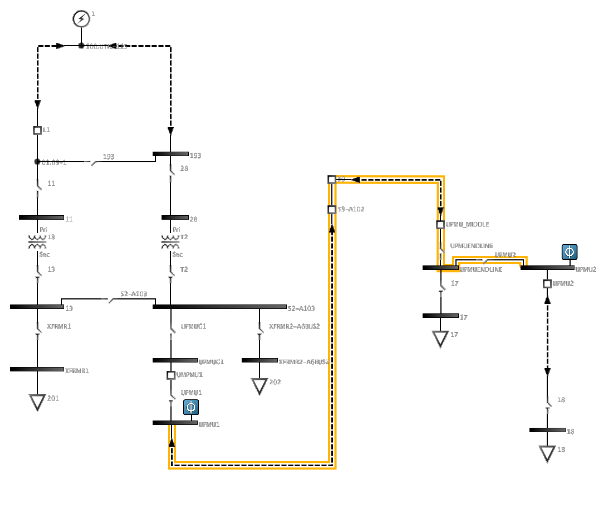

Fig. 2. Schematic Layout of Demonstration Network

A demonstration network schematic is shown in Fig. 2. This network contained two PMUs with known locations at buses UPMU1 and UPMU2. The path between the PMUs can be derived using topology analysis, thus allowing the measured changes in voltage and current to be compared with the simulated changes.

Using plug-and-play PMUs will enable a utility to gradually improve their network model with minimal human intervention. It will allow them to do more accurate analysis and provide better support for future grid changes such as DER and electric vehicles, while simultaneously collecting lots of data.

IV. Location Based Analysis

In the demonstration networks shown in Section III the location of the PMUs on the electrical network was already known, allowing the path between them to be derived using topology analysis.

For true plug-and-play PMUs this electrical location must be determined automatically. The GPS chip in a PMU allows it to determine where it is in the world, but it cannot know where it is located on an electrical network without additional information.

IEC 61968-13[7] includes a geographical profile that adds physical geographical location data to functional electrical components. This provides a direct link between the electrical element such as a busbar, switch, transformer, load point or substation and its physical location.

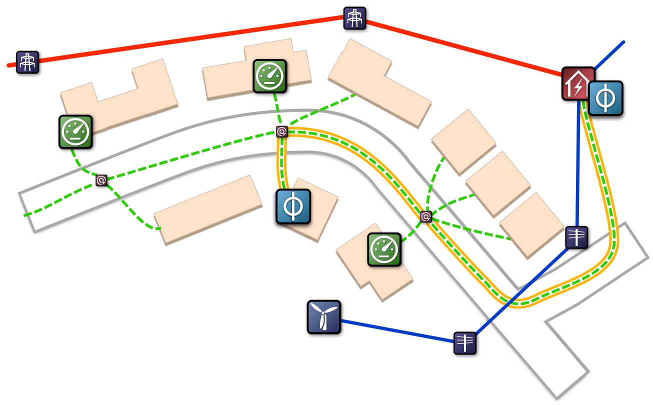

Fig. 3. Example Geographical Display of a Network

Fig. 3 shows an example geographical display for a network with two PMUs installed on a low voltage network. When there is detailed geographical location data for all equipment including cables, overhead lines and load points (e.g. meters) it is possible to correlate the reported PMU location with a corresponding component on the electrical network.

The path can once again be determined using topology analysis of the electrical network model. As shown in Fig. 3, the resulting path can then be highlighted on the display using the embedded geographical routing data for the branch segments (in this case, underground cables).

V. Challenges

A. Standards

One of the main challenges involved with the development of plug-and-play PMUs is ensuring that they conform to industry standards for several aspects of the integration, such as connecting the PMU to the network, and also for the collection and transferring of data to different applications. These standards are necessary for keeping data secure and guaranteeing that the outputs and communicated information is in an acceptable format that can be understood by other areas of the industry [8].

There is also the challenge of integrating data defined by different, potentially incompatible standards. Electrical network model standards such as IEC 61968-13 and PMU standards such as IEEE C37.118.1 [9] are defined by different standards organisations for different purposes.

Translating between standards, even when defined within the same organization such as CIM and IEC 61850 within IEC Technical Committee 57, has required novel solutions [10] [11]; translating between IEEE C37.118.1 and IEC 61968-13 will also require extensions to the CIM and the development of translation modules.

B. Trusted Cloud

Another challenge is the additional software that will be required to enable the connecting PMUs to automatically authenticate, integrate and communicate with a trusted cloud platform. The cloud-based platform must meet the specific utility's requirements for security, and verify that the connecting PMU is trustworthy when it is connected to the network. The PMU must also verify that it is communicating with a known, trusted platform.

C. Electrical Network Model

Once the connecting PMU has been verified, it must then be integrated into the network model, which also requires validation. This will check the electrical connectivity model data, including line parameters and topology. Building a low voltage electrical model requires the conversion and integration of many sources, including geographical information systems (GIS), operational, planning and asset management models.

It can be difficult to source all the necessary data, which is often spread across multiple systems with different naming conventions, identifiers and varying levels of completeness. These systems are often maintained separately making it time consuming to integrate the data and create a single, common model.

D. Simulation and Analysis

The cloud-based simulation and processing engines need to analyse the model and data and determine any problem areas. Power-flow analysis can be run large LV networks using open-source engines such GridLab-D [12] or OpenDSS [13] or commercial analysis applications. The challenges will be ensuring that they will run securely on the trusted cloud platform, and whether they can scale to accommodate the huge amounts of data being collected.

VI. Conclusion

The power industry is moving towards more advanced networks, which are more automated and intelligent, and therefore more unknown. To analyse how this will affect the operation and functionality of the grid more analysis is required. Utilities are also having to adapt to an increased amount of DER being added at a low voltage level, necessitating an increase in the amount of data being collected and exchanged between users and systems for processing. To fully utilise this data and understand the impact changes to the network will have requires accurate network models, which are often unavailable. The impact of insufficient analysis could potentially be damaging to the future of the electricity grid.

A proposed solution to this is to create plug-and-play PMUs, which would use their inbuilt GPS chip and a trusted cloud platform to perform analysis of networks where it is most needed. This paper has proposed a method for determining the location of a specific PMU and how if fits into the surrounding network.

A number of challenges were also discussed, both with regards to determining the position of a PMU on a network and other concepts within the larger scale plug-and-play PMU concept. These include the difficulties in building a LV electrical network model from the available data and maintaining security of the trusted cloud platform while allowing it to verify and connect to newly installed PMUs.

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