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Open μPMU: A real world reference distribution micro-phasor measurement unit data set for research and application development

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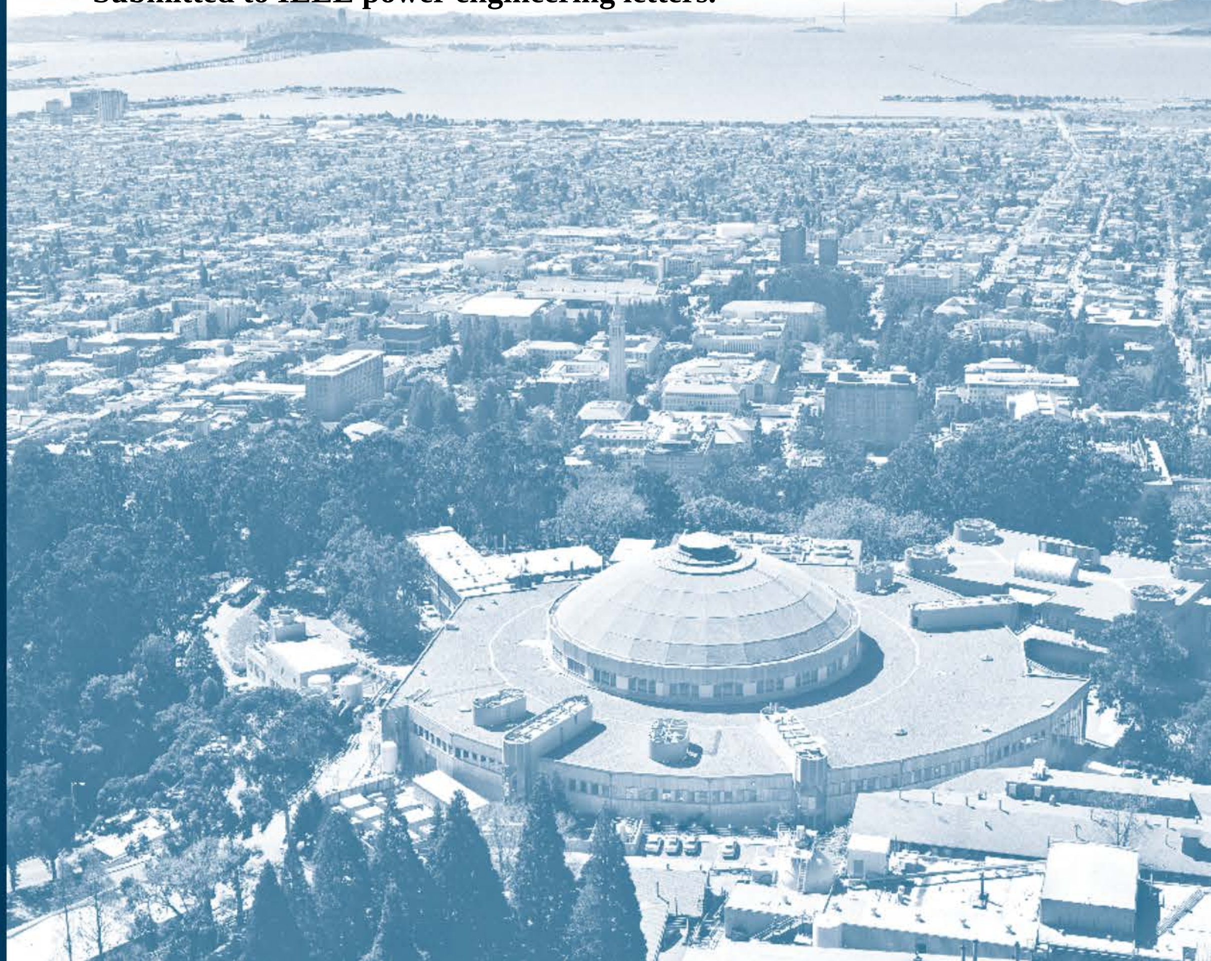

Open μPMU: A real world reference distribution micro-phasor measurement unit data set for research and application development

Emma M. Stewart, *Senior Member, IEEE,* Anna Liao, *Member, IEEE,* and Ciaran Roberts, *Member, IEEE*

***Abstract*—LBNL Open μPMU is a new dataset, measured on the Lawrence Berkeley National Laboratory electrical network. The micro Phasor Measurement Unit (μPMU) is a distribution PMU technology, was developed by Power Standards Lab in partnership with LBNL, CIEE, UCB, ARPA-E and the U.S. Department of Energy. This paper describes what basic data are available, how to view and download the data, any associated metadata for the location collection, and specifications of the sensor which was used for data collection.**

***Keywords*—distribution, phasor measurement unit, open data, reference data.**

I. Introduction

The purpose of this document is to enable researchers and development teams to access a new Open μPMU dataset collected on the LBNL network. This data set is a subset of μPMU data from LBNL and is being released for research use in the community, with related electrical circuit information which will be described in this paper. The sensor used to collect the data at LBNL is the μPMU.

Innovative aspects of the data release include: access to a demonstration of the open source data streaming visualization, real connected data for input to analysis, and high fidelity information for research purposes.

II. The μPMU itself

Micro-synchrophasors, or micro-phasor measurement units (μPMUs) are designed for direct measurement of voltage phase angle at power distribution level to support a range of diagnostic and control applications [1].

Power Standards Lab (PSL) has developed high-precision μPMUs, funded via the ARPA-E project Micro-synchrophasors for Distribution that are being deployed across the U.S. and initially studied at Lawrence Berkeley National Laboratory (LBNL). Specifically, LBNL is studying the benefits of synchrophasor data for diagnostic and control purposes in distribution systems [2], [3]. A network of these μPMU devices provide high-resolution GPS-enabled time synchronized power measurements that can be used to compare voltage and phase changes at multiple locations on the grid [4]. This capability can greatly benefit event detection, diagnosis, and post-event analysis. This data set is significant and unique in that it was collected on a true distribution network, with no attempt being made to clean the data from its raw format before release. This enables researchers to develop true to life applications and understand implications of real sensor data.

Through an Advanced Research Projects Agency-Energy (ARPA-E) award, these μPMUs are being deployed at multiple utility and campus locations, including a network of several units installed on LBNLs 12 kV distribution grid, at varied locations including low side of building transformers, and substation head. This was the first μPMU network to be installed on a real electrical grid, and this data release is intended to enable further research and development in the community. Three key objectives of this deployment are: (i) supporting distribution system planning and operation functions related to utility-owned infrastructure; (ii) diagnosing wide geographical system conditions with increased density of measurement nodes; and (iii) facilitating control of distributed energy resources (DER), including generation, storage, and demand response (DR).

The monitoring applications that can be supported by data obtained from our μPMU network include island detection, oscillation detection, fault location, distribution system state estimation, characterization of inertia contributed by individual generators, and supporting transmission system diagnostics [2].

The μPMU device is based on the PQube, PSLs commercially available power quality recorder. PQubes continuously sample ac voltage and current waveforms at 512 samples per cycle, simultaneously with a wide range of power quality measurements and environmental conditions. The μPMU device can be connected to single- or three-phase secondary distribution circuits up to 690V (line-to-line) or 400V (line-to-neutral), either in standard outlets or through potential transformers (PTs) as are already found at distribution substations, or other more advanced methods for connection including optical current transformers (CTs) and Voltage Dividers.

Enabled with a remotely-mounted GPS receiver, the key advantage of the phasor measurement units is voltage measurements with precise time stamps to compare the phase angle between different locations, down to the very small variations (fractions of a degree) that exists on distribution circuits. μPMUs measure voltage phase angle to a 0.01 degree accuracy, giving measurements of the precise difference in timing on the AC grid. All measurement values are aligned in time to better than 1 microsecond between any pair of μPMU devices.

Each μPMU device produces 12 streams of 120 Hz high-

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precision values with timestamps accurate to 100 ns (the limit of GPS). The devices at LBNL are connected via a 4G LTE modem.

Data is available in the time period of October 1 to December 31, 2015. There are two ways to access the data:

- archive.upmu.org, an online web plotter
  - Username: lbnl-team, password: chocolateeclair
- powerdata.lbl.gov for raw csv file
  - Bulk download of approximately 130GB of data
  - Instructions for utilizing the archive plotter

The backend for archive.upmu.org is a custom time series database, Berkeley Tree Database (BTrDB), developed at UC Berkeley. This system has been demonstrated to handle 2.1 trillion μPMU data points in one year and support 119M queries per second (53M inserts per second) [5]. This database infrastructure is open source and available through http://www.github.com/SoftwareDefinedBuildings.

The μPMU devices communicate live via Ethernet or 4G LTE Cellular service to the BTrDB server, which handles storing data and data retrieval queries both in near real-time and historically. In addition, this library includes a front-end plotter to display data at various time resolutions from raw data at 120 Hz to a high-level preview of multiple months. BTrDB enables real-time monitoring of distribution events and downloading data for post-fault analysis. There are also modules for efficient statistical queries (i.e. min/mean/max) over specified time windows and identifying time windows when the data is over or under a given threshold value.

III. Related Metadata

Data from 3 electrically connected μPMU devices at LBNL on separate buses downstream from the distribution substation feeder head is available. The data was collected from October 1 to December 31 2015. Voltage and Current on 3 phases, Magnitude and Phase Angle is available.

The devices are connected via 0.3 Class PTs and 1.2 Class CTs at both LBNL 1 and 2. At LBNL 3 the devices are connected on the low side of a 1500KVA Delta/Wye Transformer, through a 1.2 Class CT. Metadata is described in detail below.

In Summary the metadata is as follows for these locations:

- All locations for the data these measurements have been scaled to the primary voltage with the applied PT and CT ratios.
- LBNL 1 (Grizzly bus1 2):
  - 7.2kV-120V x 3 0.3 Class PTs
  - 1.2 Class CT 1200:5A, PSL precision CT 5A: 0.333mV
- There are two copper busbars of negligible impedance between LBNL 1 and 2 and the following underground cable.
- 6-750 KCMIL, underground cable, 2459 ft.
- LBNL 2 (a6 bus1):
  - 7.2kV-120V x 3 0.3 Class PTs
  - 1.2 Class CT 1200:5A, PSL precision CT 5A:0.333mV
- LBNL 3 (bank 514):
  - 480V/208VL-L
  - 1.2 Class CT 9600:1A, PSL precision CT 5A:0.333mV
- LBNL 3 is connected on the low side of a distribution transformer with the following specification
  - Delta Y-G
  - 1500/2000 KVA, AA/FA, 12.47kV/480Y-277V, Z=5.75%

IV. Conclusion

This paper describes the basic data which is available through the LBNL openuPMU dataset, methods to access, metadata for the location collection, and data on the sensor which was utilized in the data collection activities. Work which is completed utilizing this dataset should cite this paper.

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References

[1] E.M. Stewart, S. Kiliccote, and C. McParland. *Software-Based Challenges of Developing the Future Distribution Grid*. Tech. Rep., Lawrence Berkeley National Laboratory, 2014.

[2] A. von Meier, D. Culler, A. McEachern, and R. Arghandeh. "Micro-synchrophasors for distribution systems". In: *IEEE 5th Innovative Smart Grid Technologies Conference, Washington, DC*. 2014.

[3] *Power Standards Lab*. URL: http://pqubepmu.com/about.php.

[4] E.M. Stewart, D. Arnold, A. von Meier, R. Arghandeh, and S. Kiliccote. "Accuracy and Validation of Measured and Modeled Data for Distributed PV Interconnection and Control". In: *IEEE PES General Meeting*. Denver, CO, July 2015.

[5] M.P. Andersen and D.E. Culler. "BTrDB: Optimizing Storage System Design for Timeseries". In: *Proc. 14th USENIX Conference on File and Storage Technologies (FAST 16), Santa Clara, CA*. 2016.

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