

Lawrence Berkeley National Laboratory

Recent Work

Title

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

Permalink

<https://escholarship.org/uc/item/8d78w2b7>

Authors

Stewart, Emma

Liao, Anna

Roberts, Ciaran

Publication Date

2016-10-14



Lawrence Berkeley National Laboratory

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

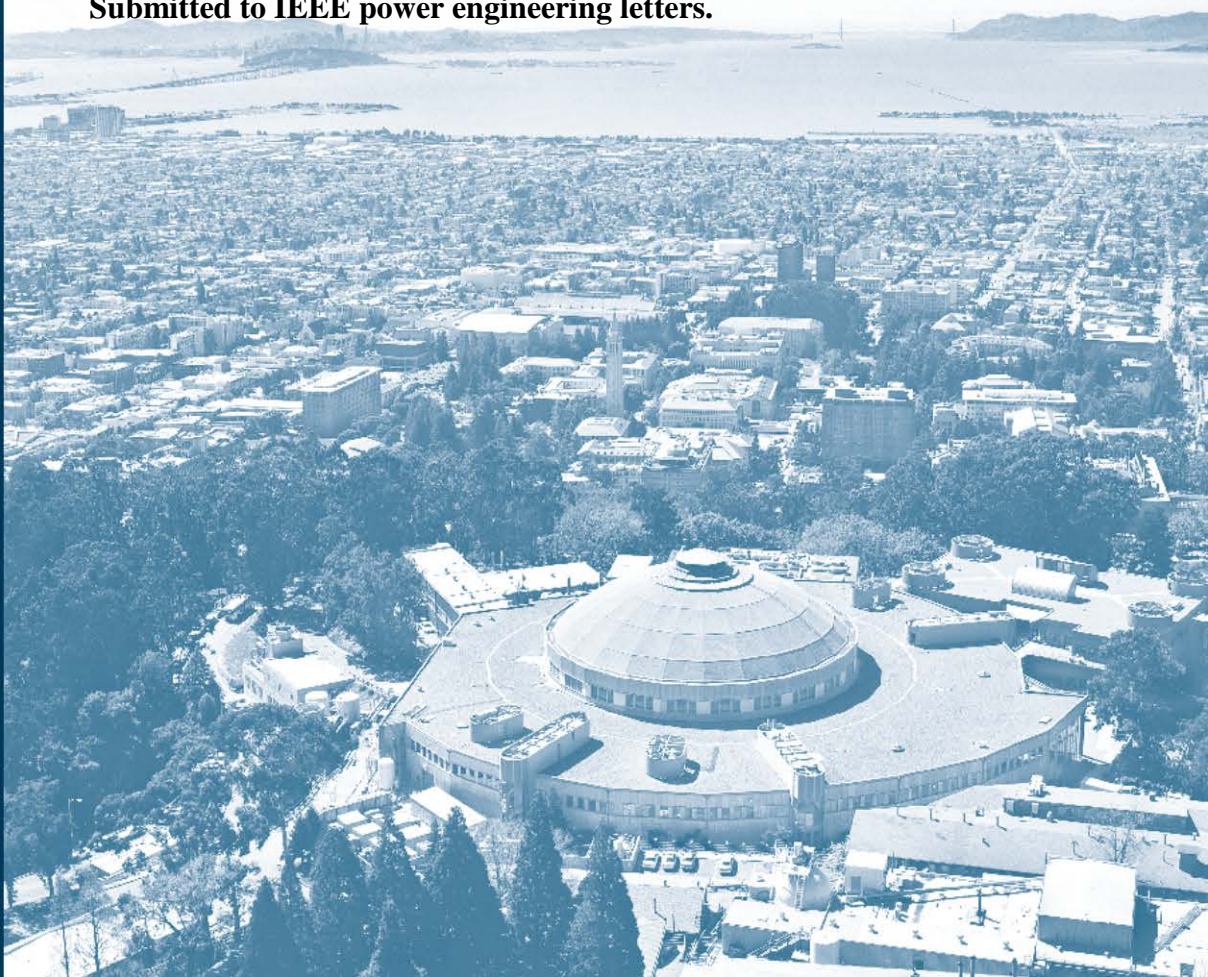
Emma M. Stewart, Senior Member, IEEE, Anna Liao, Member IEEE, and Ciaran Roberts, Member, IEEE

Lawrence Berkeley National Laboratory, Berkeley, CA., U.S.A.

October 2016

This research is sponsored in part by the U.S. Department of Energy ARPAE program (DE-AR0000340).

Submitted to IEEE power engineering letters.



This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

Open μ PMU: 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 μ PMU is a new dataset, measured on the Lawrence Berkeley National Laboratory electrical network. The micro Phasor Measurement Unit (μ PMU) 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 μ PMU dataset collected on the LBNL network. This data set is a subset of μ PMU 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 μ PMU.

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 μ PMU ITSELF

Micro-synchrophasors, or micro-phasor measurement units (μ PMUs) 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 μ PMUs, 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 μ PMU 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 μ PMUs 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 μ PMU 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 μ PMU 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 μ PMU 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 μ PMU 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. μ PMUs 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 μ PMU devices.

Each μ PMU device produces 12 streams of 120 Hz high-

E. Stewart, A. Liao, and C. Roberts are with the Energy Technologies Area, Lawrence Berkeley National Laboratory, Berkeley, CA, 94720 USA e-mail: (see <http://eetd.lbl.gov/people/emma-stewart>).

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: lbln-team, password: chocolateclair
- 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 μ PMU 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 μ PMU 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 μ PMU 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 openPMU 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.

ACKNOWLEDGMENT

The authors would like to thank Alexandra von Meier, Michael Anderson from UC Berkeley, Sean Peisert of LBNL and the ARPA-E program managers Tim Heidel. This research is sponsored in part by the U.S. Department of Energy ARPA-E program (DE-AR0000340).

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.

Emma M. Stewart (SM'14 M'08) completed her undergraduate degree in Electrical and Mechanical Engineering from the University of Strathclyde in 2004 and a PhD in Electrical Engineering in 2009. She joined BEW Engineering (now DNV GL) as a Power Systems Engineer in March 2009 and held the position of Senior Engineer in the Transmission and Distribution team. Dr. Stewart joined Lawrence Berkeley National Laboratories in 2013, and is deputy group leader for the Grid Integration Group.

Anna Liao (M'15) received the M.S. degree in Robotics from Carnegie Mellon University and B.S. degree in Electrical Engineering and Computer Sciences from UC Berkeley. She is a Senior Scientific Engineering Associate at Lawrence Berkeley National Laboratory in Berkeley, CA. Her current research interests are focused on software algorithms and data analysis of networked micro-synchrophasors.

Ciaran Roberts (M'15) received his BSc degree from University College Dublin in 2013 and an MSc in Energy Systems Engineering in 2015. He joined the Grid Integration Group at Lawrence Berkeley National Laboratory in 2015. His primary area of research is the use of high frequency data to understand the challenges and opportunities for distributed energy resources on the distribution grid.