BEFORE THE
PENNSYLVANIA PUBLIC UTILITY COMMISSION

Petition of PPL Electric Utilities Corporation	:	
for Approval of Tariff Modifications and	:	
Waivers of Regulations Necessary to	:	Docket No. P-2019-3010128
Implement its Distributed Energy Resources	:	
Management Plan	:	

DIRECT TESTIMONY OF
KAREN MIU, PhD

PPL Electric Statement No. 3

December 11, 2019

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Dr. Karen Miu, and my business address is Drexel University, 3141 Chestnut Street, Philadelphia, Pennsylvania 19104.[1]

Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?

A. I am a Professor of Electrical and Computer Engineering at Drexel University. In my position, I conduct extensive research in the areas on the planning and operation of electric distribution systems, including the impact of distributed energy resources ("DERs") on those distribution systems.

Q. WHAT IS YOUR EDUCATIONAL BACKGROUND?

A. My educational background is in the field of electrical engineering. My MS thesis and Ph.D. dissertation focused on electric power distribution systems. Degrees received include: B.S. in Electrical Engineering from Cornell University, Ithaca NY, 1992; M.S. in Electrical Engineering from Cornell University, Ithaca NY, 1995; and Ph.D. in Electrical Engineering from Cornell University, Ithaca NY, 1998.

Q. PLEASE DESCRIBE YOUR PROFESSIONAL EXPERIENCE.

A. Since 1998, my professional experience has primarily been at Drexel University. I have also been a visiting professor at Northeastern University and the University of Hong Kong.

[1] I am testifying in my personal capacity, not in my capacity as a Professor of Drexel University. My views and opinions set forth in this testimony are my own and should not be taken as reflecting the position of Drexel University.

Q. HAVE YOU PREVIOUSLY TESTIFIED AS A WITNESS BEFORE THE PENNSYLVANIA PUBLIC UTILITY COMMISSION ("COMMISSION")?

A. No.

Q. HAVE YOU BEEN RETAINED BY PPL ELECTRIC UTILITIES CORPORATION ("PPL ELECTRIC" OR THE "COMPANY") TO TESTIFY ON BEHALF OF THE COMPANY IN SUPPORT OF THE ABOVE-CAPTIONED PETITION?

A. Yes.

Q. WOULD YOU PLEASE DESCRIBE THE SUBJECT MATTER OF YOUR TESTIMONY?

A. My testimony will address the need for the Company to implement its DER Management Plan now, including the issues PPL Electric is currently experiencing on its distribution system from the deployment of DERs due to the Company's inability to monitor and manage those systems. I also will explain why the Company's proposal is best addressed in a utility-specific proceeding, rather than a statewide proceeding.

Q. ARE YOU SPONSORING ANY EXHIBITS WITH YOUR TESTIMONY?

A. Yes, I am sponsoring the following exhibits:

- PPL Electric Exhibit KM-1 – a copy of my curriculum vitae.

- PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL) – a copy of a PowerPoint presentation prepared by Drexel University for PPL Electric, which summarizes research performed on the impacts of DERs on certain PPL Electric distribution circuits."[2]

A. NEED FOR PPL ELECTRIC TO TAKE ACTION NOW TO ADDRESS THE IMPACT OF DERS ON ITS DISTRIBUTION SYSTEM

Q. WOULD YOU PLEASE DESCRIBE THE RESEARCH YOU HAVE PERFORMED CONCERNING THE IMPACT OF DERS ON DISTRIBUTION SYSTEMS?

A. My research related to DER impacts on distribution systems has addressed aspects of the modeling, analysis, planning and control of the impacted distribution system. Please see my curriculum vitae attached as PPL Electric Exhibit KM-1. My approach is based on fundamental electric circuit theory[3] and subsequent power system foundations.[4] Research studies were conducted using advanced mathematics and engineering principles to create new, multi-phase models for capturing distributed energy generation flows and to integrate and implement them into large-scale distribution system models. [5] With multi-phase modeling, optimal planning and control problems were mathematically formulated

[2] PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL) is a PowerPoint presentation prepared by Drexel University for PPL Electric. This Presentation was not prepared by me in my personal capacity or in my capacity as an expert witness testifying on behalf of PPL Electric.
[3] *See* J. D. Irwin, "Basic Engineering Circuit Analysis," 7th edition, John Wiley & Sons, NY, NY, USA, 2002.
[4] *See* A. Bergen, V. Vittal, "Power System Analysis," 2nd edition, Prentice Hall, Upper Saddle River, NJ, USA, 2000.
[5] *See* S. Tong and K. N. Miu, "A Network-Based Distributed Slack Bus Model for DGs in Unbalanced Power Flow Studies," *IEEE Transactions on Power Systems*, Vol. 20, No. 2, May 2005, pp. 835-842; S. Tong; K. Miu, "Participation Factor Studies for Distributed Slack Bus Models in Three-Phase Distribution Power Flow Analysis," *Proceedings of the 2005/2006 IEEE Power Engineering Society Transmission & Distribution Conference,* May 21-24, 2006 Page(s):92 – 96; S. Tong and K. Miu, "A Participation Factor Model for Slack Buses in Distribution Systems with DGs," *Proc. of the 2003 IEEE Power Engineering Society Transmission & Distribution Conference*, Dallas, TX, Sept. 7-10, 2003.

for various problems with different types of DER; these range from looking at snapshots in time to online problems which account for variations in the system.[6] Subsequently, corresponding computational solution algorithms were devised and implemented in software and tested on various, large-scale, utility distribution systems and data. Typically, the research studies then applied and tested the models, algorithms and software implementations onto real, electric distribution utility data; specifically, multi-phase, unbalanced electric power systems. Integrated hardware/software systems have also been developed to elucidate distribution system impacts.[7]

In particular, the net power flows and power loss within a power system changes with the amount of power injected by generators and with the amount of electric power load demanded by consumers. These flows and losses are not known a priori. A particular challenge is accounting for losses (slack) experienced by a power system in order to deliver electricity across a distance. Given power system and component models, repeatable computations can be used to calculate the flows. Furthermore, the concept of generator domains and generator commons has been introduced and has been applied to attribute portions of the power system to specific generators based on the computed flows

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[6] *See* S. Tong, M. Kleinberg and K. Miu, "Distributed Slack Bus Model and Its Impacts on Distribution System Applications" *Proc. of the International Symposium on Circuits and Systems*, Kobe, Japan, May 23-26, 2005; M. Kleinberg, K. Miu, N. Segal, H. Lehmann, T. Figura, "A partitioning method for distributed capacitor control of electric power distribution systems," *IEEE Trans. on Power Systems*, Vol. 29, Iss. 2, March 2014, pp. 637-644; Y. Mao and K. N. Miu, "Switch Placement to Improve System Reliability for Radial Distribution Systems with Distributed Generation", *IEEE Trans. on Power Systems*, Vol. 18, No. 4 Nov. 2003, pp. 1346 – 1352; N. S. Coleman and K. N. Miu, "Distribution Load Capability with Nodal Power Factor Constraints," *IEEE Trans. on Power Systems*, vol. 32, no. 4, pp. 3120- 3126, July 2017.

[7] *See* N. S. Coleman, J. Hill, J. Berardino, K. L. Ogawa, R. Mallgrave, et. al., Hardware Setup of a Solar Microgrid Laboratory, *Proc. 2017 IEEE PES General Meeting*, Chicago, IL, USA, 16-20 July 2017; N. S. Coleman, K. L. Ogawa, J. Hill, and K. N. Miu, "Reconfigurable Distribution Automation and Control Laboratory: Solar Microgrid Experiments," *IEEE Trans. on Power Systems*, Vol. 33, Iss. 6, Nov. 2018, pp. 6379 – 6386.

for high voltage transmission systems.[8] The domains and commons can then be applied to distribute the slack across, for example, multiple distributed generators.[9] These concepts were adapted for unbalanced distribution systems.[10] Generator domains and commons are dependent upon the locations of DER within the power system itself and the individual amounts of generation.

Notably, in realistic, unbalanced distribution systems, multi-phase DERs have different domains per phase. In other words, it has been shown that even though a DER may be operated in a certain manner, ***e.g.***, balanced, at its own interconnection point, its impact on the system as a whole is driven by the nature of the interconnected system of loads and DER. Thus, both electrically and topologically, understanding DER impacts requires detailed system knowledge.

With respect to distribution system planning and distribution energy management techniques for systems with DERs, my research works have included demonstrating new DER model impacts on distribution application techniques[11] and cost analysis.[12] Switch placement and control problems for improved system reliability metrics via islanding distributed generators to form self-sustaining microgrids in the case of outages have been addressed.[13] Online control of distributed capacitors and distributed batteries to maintain

[8] D. Kirschen, R. Allan and G. Strbac, "Contribution of Individual Generators to Loads and Flows," *IEEE Trans. on Power Systems*, vol. 12, no.1, February 1997, pp 52-60.

[9] G. Strbac, D. Kirschen, S. Ahmed, "Allocating Transmission System Usage on the Basis of Traceable Contributions of Generators and Loads to Flows," *IEEE Trans. on Power Systems*, vol. 13, no. 2, May 1998, pp. 527-532.

[10] *See* note 5, *supra*, S. Tong and K. N. Miu, "A Network-Based Distributed Slack Bus Model for DGs in Unbalanced Power Flow Studies."

[11] *See* note 6, *supra*, S. Tong, M. Kleinberg and K. Miu, "Distributed Slack Bus Model and Its Impacts on Distribution System Applications."

[12] S. Tong and K. N. Miu, "Slack Bus Modeling and Cost Analysis of Distributed Generator Installations," *ASCE Journal of Energy Engineering*, Vol. 133, Iss. 3, Sept. 2007, pp. 111-120.

[13] *See* note 6, *supra*, Y. Mao and K. N. Miu, "Switch Placement to Improve System Reliability for Radial

feasibility of distribution systems under injection (net load and generation) variation forecasts have also been formulated and studied.[14]

Q. WHAT RESEARCH HAVE YOU PERFORMED SPECIFIC TO PPL ELECTRIC'S DISTRIBUTION SYSTEM, AND WHAT WERE YOUR FINDINGS?

A. As principal investigator of the Drexel University team for two Department of Energy projects led by PPL Electric, I have performed detailed simulations of several actual PPL Electric distribution circuits. Resulting research on PPL Electric circuits have included the studies with distributed energy storage mentioned above[15] as well as for the U.S. Department of Energy, ENERGISE: Keystone Solar Future Project, photovoltaic DER installations appearing in PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL).[16] Specifically, in PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL), research studies focused on power flow and voltage impacts on PPL Electric circuits with and without existing photovoltaic DER installations. In addition, projected increases in photovoltaic installations were considered in both systematic and random fashions, to mimic independent, consumer driven adoption of solar energy systems.

Nine power distribution systems' circuit data was provided. Circuit data included electrical bus and node connections, representing possible electrical interconnection

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Distribution Systems with Distributed Generation."

[14] *See* note 6, *supra*, N. S. Coleman and K. N. Miu, "Distribution Load Capability with Nodal Power Factor Constraints."

[15] *See* note 6, *supra*, M. Kleinberg, K. Miu, N. Segal, H. Lehmann, T. Figura, "A partitioning method for distributed capacitor control of electric power distribution systems"; N. S. Coleman and K. N. Miu, "Distribution Load Capability with Nodal Power Factor Constraints."

[16] My understanding is that the Company is treating this exhibit as HIGHLY CONFIDENTIAL because it specifically provides the names and identification numbers of the circuits that were studied. Although I provide data about these circuits in my testimony, I do not specifically reference or provide their names or locations.

points to the distribution system. Circuit data also included electrical and topological information on the branches interconnecting the buses and nodes, such as series impedance and the bus and node information at each side of the branch. In such a manner, a graphical representation of the power distribution circuit can be constructed. Please note Figure 1 from PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL).

Finally, corresponding to each bus and node, circuit data included both electric power demand, *e.g.*, load and time-of-load data, and corresponding photovoltaic installation data, *e.g.*, maximum capacity and net (DER and load) power injected. Then, power injections attributed to the photovoltaic installations at a node were estimated based on the National Oceanic and Atmospheric Association (“NOAA”) temperature and solar irradiance data. These power values change over time and, for example, with the seasons. Table 1 from PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL) shows five loading levels under consideration where the base loading level was stated as the average loading level experienced by the circuit.

Six of the nine distribution circuits were studied with and without the existing photovoltaic DER installations. Simulation studies were performed at different, seasonal power loads/demand and, for simulations with photovoltaic DERs, power injections for corresponding dates and times. PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL) provides focused results on one of those six distribution circuits. Results on the other five circuits were qualitatively similar, but quantitatively different as each circuit consists of its own topology, different loads/consumers and, thus, different DER installations.

Overall, for the distribution systems studied with existing photovoltaics, the DERs number in the single digits on each circuit. The photovoltaic installations themselves had power capacities varying in size and were distributed within the power distribution circuit across different, unequal phases. For example, as seen in Table 3 of PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL), the five existing photovoltaic installations and their corresponding active power generation represent approximately 6.4% of the base load.[17]

In another circuit, the solar power capacity of the installations varied from 5.2 megawatts across three-phases to 3.6 kilowatt on a single phase (a 1,444 times variation between total power capacity, and assuming a balanced three-phase injection, a 481 times variation on a single phase) with similar magnitude variations seen in corresponding active generation. Since DER installations are dependent upon customer adoption, the size and location of installations can vary; thus, quantitatively, each distribution system is impacted differently by DERs, and detailed knowledge of that system is needed.

The impacts of DER on the distribution system with and without photovoltaic installations were studied across a range of consumer demands (the five load profiles referenced above) for electric power in order to capture the natural, behavioral variations in power demand the distribution system experience. With a focus on the one particular distribution circuit referenced above, system level impact metrics included minimum and maximum voltages experienced at any node in the system and real power loss (a measure of energy efficiency) for the base (average) loading case, which are shown without photovoltaics in Table 4 and with the existing photovoltaics in Table 5 of PPL Electric

[17] Please note that the five installations exist on different phases. Also, the solar power capacity of the installations, in this case, varied greatly such that the resulting active (experienced) injection varied by more than an order of magnitude (>10 times) (here, approximately 15 times).

Exhibit KM-2 (HIGHLY CONFIDENTIAL). It is noted that total system losses have been reduced by 8% and that the minimum voltage level has been improved with the corresponding photovoltaic injections. From Table 8, it is also seen that the electric distribution system experiences measurable imbalance across phases, with and without PV installations. When adding DERs purposefully to certain phases on this distribution circuit, the voltage imbalance improved slightly. This result demonstrates that DERs can help improve voltage imbalances if they are managed intelligently on the distribution system, such as through PPL Electric's DER Management Plan.

In addition to studying the impacts of PPL Electric circuits with and without existing photovoltaics, research simulations have been performed to accommodate increases in the number and the power capacity of projected, new photovoltaic installations. Since individual consumer adoption behavior is not truly predictable, various locations and sizes of projected photovoltaic installations were systematically studied and allowed for randomness in location and/or sizing. An example increase in photovoltaic DER installations from five to 12 and the corresponding values are shown in Table 6 of PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL). It is noted, the methodology adopted to add seven installations purposely tried to improve the system voltage balance across the three phases; it is outlined in to the left of Table 6. Within this construct, the locations on each individual phase of the system were randomly selected, and the capacity was also randomly selected within a range. The subsequent results show quantitatively expected reduction in real power loss, continued improvement in voltage profile, and improvement in imbalance metrics, as seen in Tables 7 and 8 of PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL).

However, I would like to note that different placements and sizing of additional DERs can and did increase the levels of voltage imbalance from the existing system, *e.g.*, non-guided placements of DERs may place new photovoltaics all on one phase and worsen voltage imbalance. Therefore, although the one particular circuit profiled in Tables 7 and 8 did show improvement in voltage imbalance from existing DERs, such a result certainly is not the case for all distribution circuits.

Through all of this research, I have found that even current, existing DER levels measurably impact voltage power quality at various individual nodes throughout the distribution system itself. In particular, DER injections are non-uniform across electrical phases. Therefore, core assumptions on balanced behavior of injections made in bulk power transmission systems and their energy management systems cannot capture the physical reality of DER installations at the distribution level. Yet, especially as DER adoption is expected to increase, capturing this physical reality is fundamental to determining safe control actions, especially in the case of electric service restoration in emergency circumstances to the public and to distribution personnel. In addition, under normal operating conditions, voltage power quality with respect to voltage levels and voltage balance are critical to energy efficiency of the power distribution system and to equipment safety controls of both utility-owned and customer owned devices.

Q. DO YOU BELIEVE THAT PPL ELECTRIC'S DER MANAGEMENT PETITION IS PREMATURE?

A. PPL Electric's DER Management Petition is not premature—it is late. Based on my experience, education, and research, I have determined that it is critically important for

PPL Electric to take steps now to monitor and manage the deployment of DERs on its electric distribution system.

Modern DERs interconnect to distribution systems via power electronic inverters, which locally sense and control DER characteristics such as voltage levels and power characteristics. PPL Electric's distribution systems already include DER deployments. State of the art planning, operation, and maintenance efforts in distribution systems include active voltage management for energy efficiency and power quality preservation,[18] and coordination and management of distribution protection and switchgear to support electric service restoration efforts in times of faults. The lack of monitoring and management of DER deployments introduces uncertainty into these efforts and challenges the efficacy of existing control schemes that support an electric utility's duty to provide safe and reliable electric service. Furthermore, this uncertainty increases with the amount of DER installments.

The steady adoption of DERs has physically changed net electric power flows and, in particular, power flow directions. Historically, under normal operating conditions, individual customers (residential, commercial, industrial) interconnected directly to power distribution system nodes and solely consumed net energy. Power was drawn from bulk high voltage transmission system (three phase) substations, disaggregated by the distribution system, and delivered to individual customers (single and multi-phase) – in a one-way flow of power. Moreover, for several reasons primarily related to safety, the majority of distribution systems are operated in a physically, radial manner – *i.e.*, no electrical loops exist, and there is only one electrically active path for electricity to travel

[18] N. Segal, M. Kleinberg, H. Lehman, T. Figura, K. Miu, "Analytically driven capacitor control for voltage spread reduction," *Proc. of the IEEE Transmission &Distribution Conference,* Orlando, FL, May 7-10, 2012.

from the substation, through the distribution system, to the customer. This is especially the case in above-ground, power distribution systems that are open-air and accessible to the public.

With DERs installed, the one-way flow of power has physically and dynamically changed to a two-way power flow depending on power system conditions. In addition, the frequency and the magnitude of these changes will increase with increased DER adoption. Several examples of such changes in power flows can be seen in distribution systems and have been documented in California[19] and Hawaii[20] and, more locally, have been recognized by PJM Interconnection LLC, which is Pennsylvania's regional transmission operator.[21] With respect to PPL Electric, based upon my research findings on actual PPL Electric circuits, it has been shown that even with existing levels of photovoltaic DER penetration, bi-directional power flows are experienced. In addition, existing levels of DER penetration consistently result in quantifiable changes in operating characteristics, such as nodal voltage levels and phase imbalance levels within the system. (*See* PPL Electric Exhibit KM-2 (HIGHLY CONFIDENTIAL).)

Thus, there is an urgent need for PPL Electric to have the ability to monitor and manage DER deployments in order to preserve power quality, reliability, and safety. All power delivery systems (transmission and distribution) are operated with some reserve generation and varying levels of spare power flow capacity in order to factor in historical power injection fluctuations. However, as more DERs are deployed, it is the distribution

[19] P. Denholm, M. O'Connell, G. Brinkman, and J. Jorgenson, "Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart," National Renewable Energy Laboratory. Nov. 2015.
[20] A. Hoke, J. Giraldez, et.al., "Setting the Smart Solar Standard," IEEE Power & Energy Magazine, vol. 16, no. 6, pp. 18-29. Nov. 2018.
[21] "Distributed Energy Resources: Technical Considerations for the Bulk Power System." Staff Report, Federal Energy Regulatory Commission, Feb. 2018.

system and its distribution energy management system that bear the brunt of non-aggregated, physically differentiated (single and multi-phase) DER power injections.

In the case of faults, distribution operators must be able to remotely sense the power injection level of individual DERs. Institute of Electrical and Electronics Engineers ("IEEE") interconnection standards for distributed sources currently require disconnection in the presence of an electrical fault in the system.[22] Lack of communication between DER inverters and system operators create uncertainty in whether a DER is actually disconnected from the grid in faulted, emergency conditions. Thus, while historical fault isolation in one-way flow direction systems should have de-energized a faulted, affected area, with no knowledge of DER inverter status, it is possible the affected areas are still energized. This poses safety risks to PPL Electric's personnel and the public. Furthermore, distribution operators who are unable to monitor and manage the deployment of DERs on their systems cannot dispatch distribution personnel as rapidly to repair the faults.

Moving forward, it is imperative that PPL Electric monitor and manage the incoming DERs before even more significant levels of DER inverters lacking communications with distribution system operators are deployed. For example, deployment of large numbers of photovoltaic DERs without strong coordination to the underlying electric distribution systems has strained California power systems, resulted in two-way power flows, and cases of too much power generation.[23] Subsequently, for

[22] IEEE 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, historical base standard 1547-2003.

[23] *See* California Independent System Operator, "What the Duck Curve Tells Us about Managing a Green Grid," CA ISO Fast Facts, 2016; U.S. Department of Energy, "Confronting the Duck Curve: How to Address Over-Generation of Solar Energy," Office of Energy Efficient & Renewable Energy, Oct. 12, 2017.

example in southern California, significant grid modernization efforts have been identified in order to accommodate DERs. PPL Electric's DER Management Petition is proactively trying to address the inevitable increase of DERs within the Company's distribution systems in order to maintain power quality and system reliability levels. The issues are technically and economically important because the sooner they can be addressed, the clearer the requirements for electric utility investments and customer investments in DER deployments.

B. UTILITY-SPECIFIC VERSUS STATEWIDE PROCEEDINGS

Q. FROM YOUR PERSPECTIVE, SHOULD THE ISSUES RAISED BY PPL ELECTRIC'S DER MANAGEMENT PETITION BE RAISED IN A UTILITY-SPECIFIC PROCEEDING OR A STATEWIDE PROCEEDING?

A. PPL Electric's DER Management Petition is best addressed in a utility-specific proceeding such as the current one. Each utility owns, operates, maintains, and plans its multiple distribution systems and safeguards electrical system and customer usage data to fulfil its duty to provide safe and reliable electric service. Each utility serves different types of consumers and different physical environments. Consequently, each utility adopts and adopted different components, control capabilities, and configurations depending on locally forecasted electrical characteristics and physical terrain. These performance characteristics change over time with power demand changes and with the integration of new technologies such as DER into the distribution systems. As such, the technical issues related to the monitoring and management of the deployment of and the operation of DERS are dependent upon the underlying utility-specific distribution system itself. Each utility needs to monitor and manage DER inverters in a manner congruent to its corresponding distribution systems.

In addition, electrical location and phasing of DERs within distribution systems vary. As explained previously, my simulations on existing PPL Electric circuits demonstrate that even modest numbers (*e.g.*, single digits) of existing DER installations measurably impact power quality at locations where no DER is installed. Management of DERs without visibility to the underlying distribution system interconnecting them could negatively impact power quality and increase risks, especially during emergencies, in a manner that knowingly ignores available system data and state-of-the-art distribution planning and operating tools. PPL Electric has been an industry leader in the adoption state-of-the-art distribution energy management systems and, as DER installations are increasing, it is more than an appropriate time for PPL Electric to develop and implement utility-specific solutions.

Moreover, I fear that if these issues were deferred to a statewide proceeding, then we would simply be delaying the resolution of these problems for several years as we have seen in other states such as New York and California. During that time, the problems I have outlined above would compound with each new DER that is deployed on PPL Electric's distribution system. Rather than stifling PPL Electric's proactive efforts to address these issues, I believe that the Company's DER Management Petition should be addressed in this utility-specific proceeding and should be approved by the Commission.

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY AT THIS TIME?

A. Yes, although I reserve the right to supplement my direct testimony.

PPL Electric Exhibit KM-1

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EDUCATION

8/1998	Ph.D.	Cornell University, Ithaca NY *Dissertation Title*: "Some Contributions to the Analysis and Automation of Practical Distribution Networks" Advisor: H.-D. Chiang
1/1995	M.S.EE	Cornell University, Ithaca NY *Thesis Title*: "Capacitor Placement and Control in Unbalanced Distribution Systems By a GA-Based Two-Stage Algorithm" Advisor: H.-D. Chiang
1/1992	B.S.EE	Cornell University, Ithaca NY

EXPERIENCE

9/2011 – PRESENT	PROFESSOR	Drexel University, Philadelphia PA
3/2007 – 4/2007	VISITING RESEARCH PROFESSOR	The University of Hong Kong
1/2007 – 6/2007	VISITING RESEARCH PROFESSOR	Northeastern University, Boston MA
9/2004 – 8/2011	ASSOCIATE PROFESSOR	Drexel University, Philadelphia PA
9/1998 – 8/2004	ASSISTANT PROFESSOR	Drexel University, Philadelphia PA
6/1991 – 7/1998	RESEARCH ASSISTANT	Cornell University, Ithaca NY
5/1994 – 5/1997	TEACHING ASSISTANT	Cornell University, Ithaca NY

PUBLICATIONS

(Journal)

[RJ32] M Rahman, V Cecchi, K Miu, "Power handling capabilities of transmission systems using a temperature-dependent power flow," *Electric Power Systems Research,* 169, April 2019, 241-249.

[RJ31] C Elmi, N Coleman, K Miu, E Schruba, "Experimental Simulation of Lightning Current Discharge on Rocks," *Applied Sciences* 8 (12), Nov. 26 2018, 2394-2408.

[RJ30] N. S. Coleman, K. L. Ogawa, J. Hill, and K. N. Miu, "Reconfigurable Distribution Automation and Control Laboratory: Solar Microgrid Experiments," *IEEE Transactions on Power Systems,* Vol. 33, Iss. 6, Nov. 2018, pp. 6379 - 6386.

[RJ29] X. Rivas Rey, T. J. Halpin, S. Hadgekar, K. Miu, K. R. Dandekar, "Cybersecurity Analysis of an IEEE 802.15.4 based Wireless Sensor Network for Smart Grid Power Monitoring on a Naval Vessel," *Naval Engineers Journal,* Sept. 2018.

[RJ28] N. S. Coleman and K. N. Miu, "Identification of Critical Times for Distribution System Time Series Analysis," *IEEE Transactions on Power Systems*, vol. 33, no. 2, pp. 1746-1754, Mar. 2018.

[RJ27] N. S. Coleman and K. N. Miu, "Distribution Load Capability with Nodal Power Factor Constraints," *IEEE Transactions on Power Systems*, vol. 32, no. 4, pp. 3120-3126, July 2017.

[RJ26] A. St. Leger, V. Cecchi, M. Basu, K. Miu, C. Nwankpa, "Automated system for determining frequency dependent parameter model of transmission line in a laboratory environment," *Measurement*, Oct. 2016, pp. 1-10.

[RJ25] M. Kleinberg, K. Miu, N. Segal, H. Lehmann, T. Figura, "A partitioning method for distributed capacitor control of electric power distribution systems," *IEEE Transactions on Power Systems*, Vol. 29, Iss. 2, March 2014, pp. 637-644.

[RJ24] V. Cecchi, M. Knudson, K. Miu, "System Impacts of Temperature-Dependent Transmission Line Models," *IEEE Transactions on Power Delivery*, Vol. 28, Iss. 4, Sept. 2013, pp. 2300-2308.

[RJ23] V. Cecchi, A. St. Leger, K. Miu, C. Nwankpa , "Incorporating Temperature Variations Into Transmission-Line Models, *IEEE Transactions on Power Delivery*, Vol. 26, Iss. 4, Oct. 2011.

[RJ22] M. Kleinberg, K. Miu, H.-D. Chiang, "Improving Service Restoration of Power Distribution Systems Through Load Curtailment of In-Service Customers, *IEEE Transactions on Power Systems,* Vol. 26, Iss. 3, August 2011.

[RJ21] K. Miu, V. Cecchi, M. Kleinberg, A. Deese, M. Tong, B. Kleinberg, "A Distribution Power Flow Experiment for Outreach Education," *IEEE Transactions on Power Systems,* Vol. 25, Iss. 1, Feb. 2010, pp. 3-9.

[RJ20] V. Cecchi, A. St. Leger, K. Miu, C. Nwankpa, "“Modeling Approach for Transmission Lines in the Presence of Non-Fundamental Frequencies" *IEEE Transactions on Power Delivery,* Vol. 24, Iss. 4, Oct. 2009.

[RJ19] M. Kleinberg, K. Miu, C. Nwankpa, "Distributed Multi-Phase Distribution Power Flow: Modeling, Solution Algorithm, and Simulation Results," *SIMULATION - Transactions of the Society for Modeling and Simulation,* Vol. 84, No. 8-9, Aug/Sept 2008.

[RJ18] V. Cecchi, X. Yang, K. Miu, C. Nwankpa, "Instrumentation and Measurement of a Power Distribution System Laboratory for Meter Placement and Network Reconfiguration Studies", *IEEE Transactions on Instrumentation and Measurement,* Vol. 56, Iss. 4, Aug. 2007, pp.1224 – 1230.

[RJ17] S. Tong and K. N. Miu, "Slack Bus Modeling and Cost Analysis of Distributed Generator Installations," *ASCE Journal of Energy Engineering*, Vol. 133, Iss. 3, Sept. 2007, pp. 111-120.

[RJ16] X. Yang, S. Carullo, K. N. Miu, C. Nwankpa, "Reconfigurable Distribution Automation and Control Laboratory: Multi-phase, Radial Power Flow Experiment," *IEEE Transactions on Power Systems*, Vol. 20, No. 3, Aug. 2005, pp. 1207-1214.

[RJ15] S. Tong and K. N. Miu, "A Network-Based Distributed Slack Bus Model for DGs in Unbalanced Power Flow Studies", *IEEE Transactions on Power Systems*, Vol. 20, No. 2, May 2005, pp. 835-842

[RJ14] J. Wan and K. N. Miu, "Weighted Least Squares Methods for Load Estimation in Distribution Networks", *IEEE Transactions on Power Systems,* Vol. 18, No. 4, Nov. 2003, pp. 1338 – 1345.

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(Other Archival)

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(Conference Refereed)

CR-2019.1 Z. Minter, J. Hill, J. de Oliveira, S. Hughes, K. Miu, "A Study of Imbalance Levels Attributed to Photovoltaic Penetration in Distribution Systems," to appear *2020 IEEE T&D Conference*, (*accepted, to appear*)

CR-2018.1 N. S. Coleman and K. N. Miu, "Time Window Selection via Online Risk Assessment for Power Distribution System Analysis," *Proc. 2018 International Symposium on Circuits and Systems (ISCAS)*, Florence, Italy, 27-30, May 2018.

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CR 2018.3 X. Rivas Rey, T. J. Halpin, S. Hadgekar, K. Miu, K. R. Dandekar, "Cybersecurity Analysis of an IEEE 802.15.4 based Wireless Sensor Network for Smart Grid Power Monitoring on a Naval Vessel," ASNE's Technology, Systems & Ships 2018, Washington, DC, June 18-20, 2018.

CR 2018.4 M. Maris, T. Halpin , D. Ezeh, K. Miu and J. de Oliveira ,"Adaptive packet transmission in response to anomaly detection in software defined smart meter networks," *in the The 14th International Conference on emerging Networking EXperiments and Technologies (CoNEXT) 2018 Student Workshop*, Heraklion/Crete, Greece, December 2018.

CR-2017.1 N. S. Coleman, J. Hill, J. Berardino, K. L. Ogawa, R. Mallgrave, et. al., Hardware Setup of a Solar Microgrid Laboratory, *Proc. 2017 IEEE PES*

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CR-2015.2 N. S. Coleman, C. Schegan, and K. N. Miu, "A study of power distribution system fault classification with machine learning techniques," *Proc. 2015 North American Power Symposium (NAPS)*, Charlotte, NC, USA, 4-6 Oct. 2015.

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CR-2014.1 Harry G. Kwatny, Gaurav Bajpai, Karen Miu, Murat Yasar, "Fuel Optimal Control With Service Reliability Constraints for Ship Power Systems," *IFAC Proceedings*, Vol. 47, Aug. 24-29, 2014.

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CR-2011.2 S. Lahiri, H. Kwatny, K. Miu, Gaurav Bajpai, Adam Beytin, Jaymit Patel, "Fuel optimization under quality of service constraints for shipboard hybrid electric drive," *Proceedings of the International Symposium on Resilient Control Systems*, Aug. 2011

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CR-2010.1 Thomas Dunmore ; Eric Jaffe ; Sean Kennedy ; Dhruv M. Patel ; Preet Soni ; Michael Kleinberg ; Karen Miu, "Experimental studies of a phase identification system for distribution systems," Proceedings of the IEEE Transmission and Distribution Conference, April 2010.

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CR-09.1 M. Kleinberg, K. Miu, H.-D. Chiang, "Service Restoration of Power Distribution Systems Incorporating Load Curtailment," Proc. of the 2009 IEEE International Symposium on Circuits and Systems, Taipei, Taiwan, May 23-26, 2009.

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CR-08.1 M. Kleinberg, K. Miu, C. Nwankpa, "Distributed Simulation of a Large Scale Power Distribution Network," Proc. of the 2008 Society for Modeling and Simulation

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CR-07.3 V. Cecchi, M. Kleinberg, M. Tong, B. Kleinberg, K. Miu, "Design of a Power Engineering Outreach Experiment Using Feedback from Non-Engineers and Grades 9-12 Students," Proceedings of the 2007 American Society of Engineering Education (ASEE) Annual Meeting, AC 2007-2880, Honolulu, HI, June 2007.

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CR-05.2 X. Yang, V. Cecchi, K. Miu and C. Nwankpa " Reconfigurable Distribution Automation and Control Laboratory: A Network Reconfiguration Experiment for Load Balancing and Loss Reduction in Power Distribution Systems," *Proceedings of the 2005 ASEE Annual Meeting*, Portland, OR, June 12-16, 2005.

CR-05.3 S. Tong, M. Kleinberg and K. Miu, "Distributed Slack Bus Model and Its Impacts on Distribution System Applications" *Proceedings of the International Symposium on Circuits and Systems,* Kobe, Japan, May 23-26, 2005.

CR-05.4 S. Tong and K. Miu, "Distribution System Expansion Planning Using a GA-Based Algorithm" *Clemson University Power System Conference*, Clemson, SC, March 9-12, 2005.

CR-05.5 A. Golder, K. Miu, C. Nwankpa, S. Carullo, "Remote Power System Loading Experiments over the World Wide Web," *Proceedings of the 2006 North American Power Symposium*, Ames, IA, Oct. 23-25, 2005.

CR-04.1 Y. Mao and K. Miu, "Sizing and Switch Placement for Distribution Systems with DGs," *Clemson University Power System Conference*, Clemson, SC, March 2004.

CR-04.2 J. Wan and K. Miu, "Meter Placement for Load Estimation in Distribution Systems," *Proceedings of the International Symposium on Circuits and Systems*, Vancouver, CAN, May 23-25, 2004.

CR-04.3 X. Yang and K. Miu, "Thyristor Rectifier – PWM Inverter Model for Unbalanced Radial Power Flow Studies" *Proceedings of the IEEE Proceedings of the 2004 Power Engineering Society General Meeting*, Denver, CO, June 5-10, 2004.

CR-04.4 P. Wiesner, N. Schulz, M. J. Miller, K. Miu, " The Power and Energy Reference Guide: A Living Document for Selecting and Filtering Web-based Resources ," *Proceedings of the 2004 ASEE Annual Meeting*, Salt Lake City, UT, June 20-24, 2004.

CR-03.1 S. Tong and K. Miu, "A Participation Factor Model for Slack Buses in Distribution Systems with DGs," *Proceedings of the 2003 IEEE Power Engineering Society Transmission &Distribution Conference*, Dallas, TX, Sept. 7-10, 2003.

CR-03.2 K. Miu, C. Nwankpa, X. Yang, A. Madonna, "The Development of a Comprehensive Power Distribution System Curriculum," *Proceedings of the 2003 ASEE Annual Meeting*, Nashville, TN, June 21-25, 2003.

CR-03.3 S. Ayasun, R. Fischl, T. Chmielewski, S. Vallieu, K. Miu, C. Nwankpa, "Evaluation of the Static Performance of a Simulation-Stimulation Interface for Power Hardware in the Loop," *Proceedings of the 2003 PowerTech Conference*, Bologna, Italy, June, 2003.

CR-02.1 K. Miu, C. Nwankpa, X. Yang, A. Madonna, "Hardware Layout of a Reconfigurable Distribution Automation and Control Laboratory," *Proceedings of the 2002 ASEE Annual Meeting*, Montreal, CAN, June 18, 2002.

CR-02.2 J. Wan and K. N. Miu, "Zonal Load Estimation Studies in Radial Power Distribution Networks," *Proceedings of the 2002 IEEE International Symposium on Circuits and Systems*, Scottsdale, AZ, May 2002.

CR-02.3 J. Wan and K. N. Miu, "A WLS Load Estimation Method for Distribution Systems," *Proceedings of the 2002 IEEE Power Engineering Society Winter Meeting*, New York, NY, Feb. 2002.

CR-01.1 X. Yang, C. Bruni, D. Cheung, Y. Mao, G. Sokol, K. Miu, C. Nwankpa, "Setup of RDAC - A Reconfigurable Distribution Automation and Control Laboratory", *Proceedings of the IEEE Power Engineering Society Summer Meeting*, Vol. 3, Vancouver, CAN, July 2001, pp. 1524-1529.

CR-00.1 K. N. Miu and J. Wan "A Post-Processing Method for Determining the Control Sequence of Distribution Application Functions Formulated Using Discrete Load Levels," *Proceedings of the 2000 IEEE Power Engineering Society Summer Meeting*, Seattle, WA, July 2000.

CR-00.2 Y. Mao and K. N. Miu, "Radial Distribution System Short Circuit Analysis with Lateral and Load Equivalencing: Solution Algorithms and Numerical Results," *Proceedings of the 2000 IEEE Power Engineering Society Summer Meeting*, July 2000.

CR-00.3 J. Wan and K. Miu, "Load Estimation in Radial Distribution Systems Using Limited Measurements," *Proceedings of the 2000 International Symposium on Circuits and Systems*, Geneva, Switzerland, May 2000.

CR-99.1 R. Delp Jr., W. D. Bradley, S. J. Waller, J. Sauer, C. Kwoka, C. J. Dafis, T. Hover, W. Ruggeri, A. DiBartolo, C. Mason, K. Miu and R. Fischl, "An Educational Hardware and Software Platform for Sub-Transmission and Distribution Systems," *Proceedings of the 31st North American Power Symposium*, San Luis Obispo, CA, Oct. 10-12, 1999.

CR-99.2 K. N. Miu, and H.-D. Chiang, "Service Restoration for Unbalanced Radial Distribution Systems with Varying Loads: Solution Algorithm," *Proceedings of the 1999 IEEE Power Engineering Society Summer Meeting*, Edmonton, Canada, July 18-22, 1999, pp. 254-259.

CR-99.3 K. N. Miu, H-D. Chiang, R. J. McNulty, "Multi-tier Service Restoration Through Network Reconfiguration and Capacitor Control For Large-Scale Radial Distribution

Networks," *Proceedings of the 1999 IEEE Power Industry Computer Application Conference*, San Jose, CA May 16-21, 1999.

CR-97.2 K. N. Miu and H. D. Chiang, "A Study of Electric Distribution Network Load Capability," IEEE International *Symposium on Circuits and Systems*, Hong Kong, June 9-12, 1997, Paper ID: 22071.

CR-96.1 K. N. Miu, H.-D. Chiang, B. Yuan and G. Darling, "Fast Constrained Service Restoration for Large-Scale Distribution Systems with Priority Customers," *Proceedings of the 28th North American Power Symposium*, Cambridge MA, Nov. 10-12, 1996, pp. 25-31.

(Conference – invited panel summary)

CPS-16.1 N. S. Coleman and K. N. Miu, "A Study of Fault Detection Thresholds under Stochastic Conditions Intrinsic to Power Distribution Systems," invited panel, *2016 IEEE PES General Meeting*: Stochastic Modeling and Analysis of Distribution Systems/Microgrids, Boston, MA, USA, 17-21 July 2016.

CPS-15.1 K. Miu, C. Nwankpa, D. Niebur, Power Distribution Systems: Educational Activities at Drexel, *2015 ASEE Annual Conference*, June 16, 2015

CPS-09.1 K. Miu, A. Deese, X. Yang, V. Cecchi, M. Kleinberg, C. Schegan, "Integrating Distribution Automation and Control Techniques Into Power System Curriculum," Proc. of the 2009 IEEE Power & Energy Society General Meeting, Calgary, Canada, July 26-30, 2009.

CPS-07.1 K. Miu, S. Carneiro, "Assessing Impacts of Distributed Generation on Distribution Systems Analysis Tools, 2007 IEEE PES General Meeting, July 2007.

CPS-06.1 M. Kleinberg and K. Miu, "A Study of Distribution Power Flow Analysis Using Physically Distributed Processors," 2006 IEEE PES Power Systems Conference and Exposition, Atlanta, GA,Oct. 28-Nov.1, 2006.

CPS-06.2 Representation of Multi-Frequency Power Systems, Karen Miu, Venkat Ajjarapu, Karen Butler-Purry, Dagmar Niebur, Chika Nwankpa, Noel Schulz, Alex Stanković, 2006 Electric Ship R&D Consortium Workshop

CPS-05.1 C. Nwankpa, K. Miu and D. Niebur, "Power Hardware Laboratories at Drexel," *Proceedings of the 2005 IEEE Power Engineering Society General Meeting*, June, 12-16, 2005.

CPS-04.1 K. Miu, C. Nwankpa, D. Niebur, R. Stoicescu and X. Yang, "A General Approach to 3-Phase Converter Modeling for Unbalanced Power Systems," *Proceedings of the IEEE Proceedings of the 2004 Power Engineering Society General Meeting*, Denver, CO, June 5-10, 2004.

CPS-03.1 R. Zimmerman, H.-D. Chiang and K. N. Miu, “Transformer Modeling Using Line-to-Line Voltages,” *Proceedings of the IEEE PES Transmission & Distribution Conference*, Dallas, TX, Sept 6-10, 2003.

CPS-03.2 K. Miu, K. Scoles and M. Bystrom, “Senior Design Projects at Drexel University – Focus on Power Engineering”, *Proceedings of the IEEE Proceedings of the 2003 General Meeting*, Toronto, Canada, July13-17, 2003.

CPS-03.3 D. Niebur, H. Kwatny, C. Nwankpa and K. Miu, “ONR Funding at Drexel University”, *Proceedings of the IEEE Proceedings of the 2003 General Meeting*, Toronto, Canada, July13-17, 2003.

CPS-02.1 K. Miu, C. Nwankpa, D. Niebur, R. Stoicescu, X. Yang, “3-Phase Converter Modeling for Unbalanced Radial Systems,” *Proceedings of the IEEE Power Engineering Society Transmission & Distribution Conference Asia-Pacific*, Yokohama, Japan, Oct. 2002.

CPS-02.2 K. Miu and J. Wan, “Zonal Load Estimation Techniques,” *Proceedings of the 2002 IEEE Power Engineering Society Winter Meeting*, Feb. 2002.

CPS-02.3 K. Miu and Y. Mao, “Network Equivalent Models for Short Circuit Analysis,” *Proceedings of the 2002 IEEE Power Engineering Society Winter Meeting*, Feb. 2002.

CPS-01.1 C. Nwankpa, D. Niebur and K. Miu, “Power Engineering Education at Drexel,” *Proceedings of the 2001 IEEE Power Engineering Society Winter Meeting*, Jan. 2001.

PATENT

United States Letters Patent No. 9,857,808 – C. Nwankpa, K. Miu Miller, J. Berardino, A. Steven, “Dynamic Load Modeling Of A Building’s Energy Consumption For Demand Response Applicants.” Jan. 2, 2018.

INVITED TALKS

6/6/2011 2011 Japan-America Frontiers of Engineering Symposium, Smart Grid Session, Integration of Smart Grid Enabling Technologies within Power Distribution Systems, Tsukuba, Japan.

7/21/2009 Emerging Power Distribution Systems, Electric Power Grid Technical Interchange Meeting, Lockheed Martin Corporation, Dallas, TX.

7/1/2009 Electric Power Distribution Systems: The First and Last Mile, Lockheed Martin Corporation – Corporate, Philadelphia, PA.

4/12/2007 Emerging Power Distribution Systems: Modeling, Analysis and Application Tools, University of Hong Kong, Hong Kong.

2/20/2007 Emerging Power Distribution Systems: Modeling, Analysis and Application Tools, Cornell University, Ithaca, NY.

2/2/2007 Modeling and Analysis of "Modern" Power Distribution Systems, Arizona State University, Tempe, AZ.

8/22/2006 2006 International Workshop on Sustainable Energy and Materials, Tokyo, Japan.

11/20/2003 – 11/22/2003 National Academy of Engineering, Japan-America Frontiers of Engineering Symposium, Irvine, CA.

11/6/2002 Office of Naval Research, AEPS Workshop, "3-Phase Converter Modeling for Unbalanced Radial Power Systems," Arlie, VA.

9/30/2002 Fuji Electric Corporate, "Modeling and Analysis of Emerging Distribution Systems," Tokyo, Japan.

4/16/2002 Villanova University, SWE Seminar – "Electrical Engineering - Graduate School and Academia," Villanova, PA.

3/1/2002 Iowa State University, Seminar – "Load Estimation for Unbalanced Distribution Systems," Ames, IA.

10/19/2000 IEEE Frontiers In Education 2000 – NSF CCLI Showcase "Hardware Design of a Reconfigurable Power Distribution Automation and Control Laboratory," Kansas City, MO.

5/1/2000 US Army War College, Center for Strategic Leadership – Information Warfare Issues, Carlisle, PA.

5/10/1999 US Army War College, Center for Strategic Leadership – Information Warfare Issues, Carlisle, PA.

3/4/1999 Drexel University, HKN Seminar - "Power Engineering – It's not just your local utility," Philadelphia, PA.

2/17/1999 US Army War College, Center for Strategic Leadership – Information Warfare Issues, Carlisle, PA.

2/24/1999 Department of Justice, FBI - NIPC Key Asset Program and Energy Sector Training, "Key Asset Protection – Electric Power Systems," Washington D.C.

2/25/1999 Department of Justice, FBI - NIPC Key Asset Program and Energy Sector Training, "SCADA Systems & Question/Answer," Washington D.C.

10/9/1998 Massachusetts Institute of Technology, LEES Seminar, Cambridge MA - "Some Analytical Results for Unbalanced Power Distribution Application Functions: Implications, Justification and Recommendations," Cambridge MA.

3/1998 Drexel University, ECE Seminar, "Recent Developments in Power Distribution System Analysis and Their Implication, Philadelphia, PA.

6/16/1997 Taipower Co, Seminar, "Service Restoration in Large-Scale, Radial Power Distribution Systems," Taipei, Taiwan.

5/30/1997 Zhe Jiang University, Electrical Engineering Department Seminar, "Service Restoration in Large-Scale, Radial Power Distribution Systems," Hangzhou, China.

GRANTS

Office of Naval Research (2017-2020)
PI – K. Miu
Networked Multi-Converter Power System: Uncertainty Analysis: Formulation and Related Issues (~$700K)

NAVSEA NEEC (2017 – 2020)
PI – K. Miu, co-PI – J. de Oliveira
Networked Multi-Converter Power System: Instrumentation and Measurement (~$709K)

DOE/PPL ENERGISE (2017-2020)
PI – K. Miu, Co-PI – J. de Oliveira
Keystone Solar Future Project (~$403K)
Additional $50K, 2019

Office of Naval Research via Florida State University (2016-2018)
PI – K. Miu
Controls Framework for Shipboard Power Systems
SubAward ($70K)

National Science Foundation (2013-2018)
PI – K. Miu, co-PI – C. Nwankpa, J. de Oliveira, D. Niebur
TUES: Smart Power Distribution System Curriculum
Collaborative Proposal – Drexel (Lead), Cornell, TCNJ, UNCC, WSU
Total Sponsor Funding to Drexel: 259,114

Techno-Sciences Incorporated with US Navy (2012 – 2015)
PI – K. Miu, Co-PI – H. Kwatny
SBIR Stage 2 and Stage 2 Option: Load Leveling

Lockheed Martin (2010-2014)
PI – K. Miu, Co-PI – H. Kwatny, C. Nwankpa, J. DeOliviera
Understanding and Controlling Smart Power Delivery Systems
Total Sponsor Funding: $700,000, Total Project Funding: $700,000.

Techno-Sciences Incorporated with US Navy (2010 – 2010)
PI – K. Miu, Co-PI – H. Kwatny
Mixed Logic-Dynamics Controllers for Generation and Load Management in Smart Distribution Systems
Total Sponsor Funding: $15,001, Total Project Funding: $15,001.

PPL Electric Utilities with US Department of Energy (2010 – 2012)
PI – K. Miu
Smart Grid Investment Grant: Keystone Smart Distribution – (Enabling Technology Placement)
Total Sponsor Funding: $320,626, Total Project Funding: $369,730.

PECO Energy with US Department of Energy (2010 – 2012)
PI – C. Nwankpa, Co-PI – K. Miu (40%)
Smart Grid Investment Grant: Smart Future Greater Philadelphia
Total Sponsor Funding: $1,179,500, Total Project Funding: $1,773,972.

Office of Naval Research (2010-2013)
PI – C. Nwankpa, Co-PI – H. Kwatny, K. Miu (25%)
Control Limit Identification for Power Electronic Driven Power Systems
Total Sponsor Funding: $344,346, Total Project Funding: $442,604.

Office of Naval Research with University of South Carolina (2010-2013)
PI – C. Nwankpa, Co-PI – K. Miu (15%), N. Kandasamy, H. Sethu
Simulation Methods for Design of Networked Power Electronic and Information Systems
Total Sponsor Funding: $379,412, Total Project Funding: $490,878.

Viridity Energy (2009-2011)
PI – C. Nwankpa, Co-PI – K. Miu (30%)
Controllable Load Feasibility Study at Drexel University
Total Sponsor Funding: $95,084, Total Project Funding: $122,640.

National Science Foundation (2006-2009)
PI – C. Nwankpa, Co-PI – J. Johnson, P. Nagvajara, K. Miu
"Computation of Power System Dynamics Through Mixed-Signal VLSI Emulation"
Total Sponsor Funding: $220,000

Office of Naval Research (2004-2008)
PI – K. Miu, Co-PI – V. Ajjarapu, K. Butler-Purry, D. Niebur, C. Nwankpa, N. Schulz, A. Stankovic

MURI: Device Development for Remote, Non-Destructive Testing of Power Systems
Total Sponsor Funding: $2,854,157, Total Project Funding: $3,006,599.

Hydro One(2004-2005)
PI – K. Miu
Transmission Asset Planning Under Uncertainty
Total Sponsor Funding: $30,000, Total Project Funding: $30,000.

PJM (2004-2004)
PI – C. Nwankpa, Co-PI –P. Nagvajara, J. Johnson, K. Miu, D. Niebur
Parallel Computation Algorithms for State Estimation and Power Flow Calculations
Total Sponsor Funding: $40,000, Total Project Funding: $40,000.

Mary and Christian Lindback Foundation (2003-2004)
PI – K. Miu
Electric Service Restoration of Power Distribution Systems with Critical Loads
Total Sponsor Funding: $12,700, Total Project Funding: $25,400.

US Department of Energy (2003-2004)
PI – C. Nwankpa, Co-PI –P. Nagvajara, J. Johnson, K. Miu (10%), D. Niebur
Powergrid: A Computation Engine for Large-Scale Electric Networks
Total Sponsor Funding: $1,856,736, Drexel: $162,474, Total Project Funding: $2,019,210.

US Department of Energy (2002-2003)
PI – C. Nwankpa, Co-PI – K. Miu (10%), D. Niebur, P. Nagvajara, J. Johnson
Powergrid: A Computation Engine for Large-Scale Electric Networks
Total Sponsor Funding: $969,000, Total Project Funding: $1,064,024

Office of Naval Research (2001-2004)
ONR N00014-01-1-0760
PI – K. Miu
Young Investigator Program - Multi-Frequency Analysis of Large-Scale Systems
Total Sponsor Funding: $330,000, Total Project Funding: $441,000.

National Science Foundation (2000-2004)
NSF #9984692
PI – K. Miu
CAREER Electric Power Distribution Systems: Theory, Applications and Performance
Total Sponsor Funding: $200,000, Total Project Funding: $349,879.
REU Supplement (2002-2003)
Total Sponsor Funding: $12,000, Total Project Funding: $14,000.
REU Supplement (2003-2004)
Total Sponsor Funding: $12,000, Total Project Funding: $14,000.
Equipment Supplement (2003-2004)
Total Sponsor Funding: $10,000, Total Project Funding: $30,000.

F&H Applied Sciences, Inc. (2000-2002)
PI – K. Miu, Co-PI – C. Nwankpa
Application of IPSL Towards the Definition of a Simulation-Stimulation Interface
Total Sponsor Funding: $227,648, Total Project Funding: $227,648.

Office of Naval Research (2000-2001)
PI – K. Miu, Co-PI – C. Nwankpa
Definition of Hardware/Software Interface for Small-Scale Machinery R&D - Task 2
Total Sponsor Funding: $70,424, Total Project Funding: $70,424.

National Science Foundation (1999-2003)
NSF #995075
PI – K. Miu, Co-PI – C. Nwankpa, D. Niebur
Course, Curriculum, and Laboratory Improvement: Power Distribution Systems Curriculum
Total Sponsor Funding: $125,000, Total Project Funding: $323,712.

REU Supplement (2000-2001)
Total Sponsor Funding: $12,000, Total Project Funding: $14,000

TEACHING ACTIVITIES

Courses Development
Developed a new graduate/senior level three-course sequence

— Power Distribution Systems I: Modeling and System Analysis
— Power Distribution Systems II: Distribution Automation and Control
— Power Distribution Systems III: Power and Service Quality

Co-developed a new senior level three-course sequence

— Energy & Control Systems I: Fundamentals of Power System Analysis
— Energy & Control Systems II: Fundamentals of Energy Control Systems
— Energy & Control Systems III: Advanced Control Systems

Laboratories Developed and In Progress
Reconfigurable Distribution Automation and Control Laboratory: Led Development of

— 36-bus, multi-phase 7.5KW multi-feeder power distribution system
— Embedded sensing and data acquisition instrumentation

— Embedded components required for automation and control functions

— Currently developing hardware/software educational laboratory modules.

Orthlip Systems and Control Laboratory: Co-developed the new Electrical and Computer Engineering Department's system and control laboratory (with Dr. P. Kalata)

Center for Electric Power Engineering (CEPE) research facilities: Co-designed the renovations (with Drs. C. Nwankpa and D. Niebur)

Matpower Software Laboratory and Course Project: Developed a software-based class project to supplement ECE-P412/502 Power Systems Analysis II

Senior Design Advisor (Select Examples)

2017-2018	ECE-20: Power Restoration for Systems with Distributed Resources
2015-2016	ECE-18: The Effects of Distributed Energy Storage on a Power Distribution Grid
2013-2014	ECE-22: Integration and Analysis of Distributed Generation Resources in Micro-Grid Environments
2012-2013	ECE-20: Characterizing Disturbances in Smart Power Distribution Systems
2012-2013	ECE-28: Designing and Testing of an Energy Storage System
2012-2013	ECE-22: Analysis of Distributed Resources for Microgrids
2010-2011	ECE-11: Secure Distribution Energy Management System to Support Smart Grids
2010-2011	ECE-37: Small-Scale Wind Generation Systems for Residential Use
2005-2006	Project: Wavelet-based Fault Detection Algorithms
2005-2006	Project: Energy Management System for RDAC
2005-2006	Project: Adjustable Signal Conditioning. Boards for Power Measurements
2004-2005	Project: A Multi-purpose Inductive Device for Load and Fault Experiments – Awarded Top 6 Electrical and Computer Engineering Senior Design Project
2003-2004	Project: Optimal Placement of Distributed Generators – Awarded Top 5 Electrical and Computer Engineering Senior Design Project
2003-2004	Project: Optimal Polling of AMR for Load Estimation
2001-2002	Project: A Three-Phase Variable Frequency Inverter — Awarded Top 5 Electrical and Computer Engineering Senior Design Projects
1999-2000	Project: An Energy Management System for Electric Vehicles — Awarded Top 5 Electrical and Computer Engineering Senior Design Projects

1998-1999 Project: ARMED: Analysis and Restoration Model for Electric Distribution — Third Place in the Electrical and Computer Engineering Senior Design Competition and Honors at the College of Engineering Senior Design Competition, Drexel University (resulted in 1st place NAPS student paper prize)

Freshman Design Advisor

2005-2006 Project: Sizing Photovoltaic Systems

2004-2005 Project: Wireless Power Transfer (for handheld electronic devices)

2000-2001 Project: An Innovative Power Source Harnessing Wind and Wave Energy

1999-2000 Project: EnLIGHTenment of Drexel University - Redesigning Drexel's Outdoor Lighting System

1998-1999 Project: A Warm Night Sleeping When Camping - a Self-Heated Sleeping Bag

COURSES TAUGHT

Graduate

ECE-P601 Power Distribution Systems I: Modeling and System

ECE-P602 Power Distribution Systems II: Distribution Automation and Control

ECE-P603 Power Distribution Systems III: Power and Service Quality

ECE-P501 Power System Analysis I (Fall 2001)

ECE-P502 Power System Analysis II (Winter 2002)

ECE-P503 Power System Analysis III (Spring 2002)

ECEP803 Advanced Topics in Power Systems III – Numerical Analysis in Power Systems

Undergraduate

ECE-P421 Power Distribution Systems I: Modeling and System Analysis

ECE-P422 Power Distribution Systems II: Distribution Automation and Control]

ECE-P423 Power Distribution Systems III: Power and Service Quality (Spring 1999,

ECE-S490 Energy and Control Systems I

ECE-S490 Energy and Control Systems II

ECE-P354 Energy Management Systems

ECE-P352	Motor Control Principles
ECE-P411	Power System Analysis I
ECE-P412	Power System Analysis II
ECE-P413	Power System Analysis III
ECE-201	Circuits
TDEC221	Systems I
TDEC222	Systems II

Faculty and Course Evaluations

In general, a high percentage of students participated in evaluations for each class. Feedback has consistently ranged from good to excellent. With permission (or from Drexel networks), numerical results can be viewed online at http://eval.coe.drexel.edu.

STUDENTS AND POST-DOCTORATES SUPERVISED

Ph.D. Advised and In Progress

Jie Wan	Nodal Load Estimation in Electric Power Distribution Systems (Sept. 2003)
Yiming Mao	Protection System Design in Power Distribution Systems with Distributed Resources (June 2005)
Xiaoguang Yang	Unbalanced Power Converter Modeling for AC/DC Power Distribution Systems (Dec. 2006)
Shiqiong Tong	Slack Bus Modeling for Distributed Generation and Its Impacts on Distribution System Analysis, Operation and Planning (Dec. 2006)
Valentina Cecchi	Temperature-Dependent Transmission Line Models for Electric Power Systems and Their Impacts on System Studies (Sept. 2010)
Michael Kleinberg	Online Optimization of Capacitor Switching in Electric Power Distribution Systems (June 2015)
Christian Schegan	Non-Destructive, Remote Testing of Physically Distributed Power Systems: Modeling, Analysis and Experimental Prototyping (Sept 2015)

Nicole Segal	Realizable Constraint Driven Capacitor Placement and Control Sequences for Voltage Spread Reduction in Distribution Systems (Sept 2015)
Sachi Jayasuriya	Modeling and Analysis of Information-Embedded Power Electronic Converter Systems (June 2017)
Nicholas Coleman	Online Analysis and Control of Electric Power Distribution Systems," (June 2018) (recognized as the 2018 Drexel University Outstanding Dissertation Award)
Mohammed Muthalib	An Electrical-Thermal Circuit Framework for Utilizing Buildings as Controllable Power System Loads (June 2018)
Jesse Hill	(expected 2021)
Tiffany Lakins	(expected 2021)
Shaun Cruz	(expected 2022)
Zachary Minter	(expected 2022)
Keith Zuckerman	(expected 2023)

M.S. Advised and In Progress

Razvan Stoicescu	Three-Phase Converter Model for Power Distribution Systems (June 2000)
Andrew Golder	Photovoltaic generator modeling for large scale distribution system studies (Dec. 2006)
Michael Kleinberg	(March 2007)
Valentina Cecchi	(March 2008)
Christian Schegan	(Aug. 2007)
Nicole Segal	(Aug. 2007)
Nicholas Coleman	(June 2013)
Uthara Reji	Load Frequency Control in Shipboard Power Systems: Design and Simulation (co-adv: H. Kwatny) (June 2015)
Edwin John	Experimental Testbed for Load Control on an AC/DC Microgrid (Sept. 2017)
Zachary Minter	Jan. 2019
Thomas Halpin	Nov. 2019

Undergraduate Research Assistants

Over 25 UG RA (typically employing 1-2 per academic year of service)

Graduate Student Committee Membership

Over 20	Ph.D. Committees
Over 20	M.S. Committees

Postdoctorate –Status

1. A. Deese (2009 – 2010) *Present Status:* Associate Professor, Department Head, The College of NJ – Trenton
2. J. Wan (2003) *Present Status:* GE-Alstom, Redmond, WA.

HONORS AND AWARDS

2007 IEEE Power Engineering Society, Power Engineering Education Committee – Best Paper Award [RJ16]

2007 IEEE Power Engineering Society Walter Fee Outstanding Young Electrical Engineer Award

2005 Eta Kappa Nu Outstanding Young Electrical and Computer Engineer Award

2005/2006 IEEE Drexel Best Electrical Engineering Teacher Award

2003 Drexel University, Department of Electrical and Computer Engineering – Research Award

2003 Eta Kappa Nu Outstanding Young Electrical Engineer – Honorable Mention

2001 Eta Kappa Nu Outstanding Young Electrical Engineer - Finalist

2001 Office of Naval Research Young Investigator Award

2001 IEEE Power Engineering Education Committee – Technical Committee Working Group Award

2001 IEEE Power Engineering Society – Outstanding Technical Report Award

2000 National Science Foundation CAREER Award

1999 North American Power Symposium Best Student Paper Contest - First Place (advisor/co-author)

1996 Liu Memorial Award - Cornell University

1996 North American Power Symposium Best Student Paper Contest - Third Place

SERVICE TO DREXEL UNIVERSITY

Member (academic committees, typically rotating every 3 years, unless noted)

ECE Promotion Committee – Member	(2019-2020)
ECE Tenure and Promotion Committee – Chair	(2017-2018)
ECE Promotion and Recognition Committee – Chair	(2014-2017)

ECE Tenure and Promotion Committee – member	(2009-2010)
ECE Senior Design Committee	(2002-present)
ECE Graduate Affairs Committee	(2008-2011)
ECE Undergraduate Committee	(1999-rotated to present)
ECE ABET, Accrediation Committee	(2000-2002, 2005-2007, 2016-present)
External Member of Tenure and Promotion Committees	(multiple)
College of Engineering (CoE) – Tenure and Promotion Policy	(2015-2016)
College of Engineering (CoE) – Department Head Search Committees	(twice)
College of Engineering (CoE) – Dean's Advisory Committee	(2009-2010)
Drexel University – Director Review Committee	(once)
Drexel University – Awards Committee	(twice)
Drexel University – Multicultural Diversity Committee	(2002-2005)

Advisor

2004 – 2006	SWE – Drexel Student Chapter Technical Advisor
2002-2003	HKN – Drexel Chapter co-advisor
2000-2002	HKN - Drexel Chapter advisor

Participant

Drexel University Open Houses (recruitment events, lab tours, etc.)	2-4 times/year
College of Engineering - Summer Engineering Camps (9-12th graders)	multiple years
IEEE Info. Sessions: Academic Track Forums (Drexel community)	2 times/year
College of Engineering – Outreach Programs (7-11th graders)	3-4 times/year
Women in Engineering Outreach Events	once/year
Scholar's Day (prospective student interviews)	3 times

PROFESSIONAL ACTIVITIES

Editorial

Editor – IEEE Transactions on Power Systems 2007 - 2010

Associate Editor – IEEE Transactions on Circuits and Systems I: Regular Papers
Formerly: Fundamental Theory and Applications 1/2007 – 12/2009

Reviewer – IEEE Transactions on Power Systems, IEEE Transactions on Power Delivery, IEEE Power & Energy Society Letters, IEEE Proceedings, IEEE Transactions on Education, IEEE Transactions on Signal Processing, IEEE Circuits and Systems Society International Symposium on Circuits and Systems, ASEE Proceedings, PSCC Power System Computational Conference, North American Power Symposium

Proposal Reviewer – National Science Foundation

Member

Institute of Electrical and Electronic Engineers (IEEE), 1994-present

American Society of Engineering Education (ASEE), 1998-2015

Society of Women Engineers (SWE), 1996-2010

IEEE Power Engineering Society

— WiE Liason (PES) (2006 – 2008)

— AMPS – Formerly Power System Analysis, Computing and Economics (PSACE)

Distribution System Analysis Subcommittee (chair: 2006 – 2007, vice-chair 2001-2006)

— Power Engineering Education Committee

Power Engineering Career Promotion Subcommittee (chair 2001 - 2003, vice-chair 1999-2001)

— Transmission and Distribution Committee

Data Requirements for Distribution Systems Subcommittee

IEEE Circuit and Systems Society Committee:

— Power System and Power Electronics Technical Committee (past-chair, chair – 2005-2006, chair-elect - 2004-2005, secretary 2001- 2004)

Proposal Reviewer

National Science Foundation 8/1999, 7/2000, 12/2001, 3/2002, 2003, 2004, 1/2005, 5/2005, 8/2006, 7/2019

Manuscript Reviewer

Participated in manuscript review for several international journals and conferences, these include:

IEEE Transactions on Power Systems

IEEE Transactions on Power Delivery

IEEE Transactions on Signal Processing

IEEE International Symposium on Circuits and Systems

Journal of Electric Power and Energy Systems

ASEE Proceedings

PSCC Power System Computational Conference

North American Power Symposium

Conference Organization

2017 ONR Control Group Workshop, Philadelphia PA 19104, August 2017.

2007 IEEE Power Engineering Society General Meeting, Tampa FL, PSACE Technical Chair Program Committee – Distribution System Analysis Sub-chair

2007 IEEE Circuits and Systems Society, International Symposium on Circuits and Systems, New Orleans, LA Technical Program Co-Chair for Power Systems & Power Electronics

2006 IEEE Circuits and Systems Society, International Symposium on Circuits and Systems, Kos, Greece, Technical Program Co-Chair for Power Systems & Power Electronics

2006 SWE Region E Conference, Philadelphia, PA, Drexel Faculty Host & Conference Organizer

2005 IEEE Power Engineering Society, Transmission and Distribution Conference, New Orleans LA/Dallas TX, PSACE Technical Chair Program Committee – Chair

Session Chairperson

7/2008	IEEE PES General Meeting, PES/WIE Reception, Chair
6/2007	IEEE Power Engineering Society, Panel Session, 2007 IEEE PES General Meeting, "Modeling and Analysis of AC/DC Distribution Systems" to occur.
11/1/2006	IEEE Power Engineering Society, Panel Session, 2006 IEEE Power Systems Conference and Exposition, "Current Topics in Distribution System Analysis II," Nov.1, 2006.
5/2006	IEEE Circuits and Systems Society, Poster Session, "Power Systems I," Kos, Greece.
6/2005	IEEE Power Engineering Society, Panel Session, 2005 IEEE General Meeting, "Advanced Models for Distribution System Analysis."
7/16/2003	IEEE Power Engineering Society, Panel Session: Future Power Engineering Professor, 2003 IEEE PES General Meeting, Toronto, CAN

10/15/2002 NAPS North American Power Symposium, Paper Session, Tempe, AZ

10/10/2002 IEEE Transmission and Distribution: Panel Session: Distribution Automation, Asia Pacific, Yokohama, Japan

10/2001 NAPS North American Power Symposium, Paper Session, College Station, TX

7/15/2001 IEEE Power Engineering Society, Panel Session: Challenges in Distribution System Analysis, 2001 IEEE PES Summer Meeting, Vancouver, CAN

6/25/2001 ASEE Annual Meeting, Energy Conversion and Conservation Division, Paper Session: Energy Programs and Software Tools, Albequerque NM

7/20/2000 IEEE Power Engineering Society Summer Meeting, Panel Session: Intelligent Systems Application in Distribution Systems, IEEE PES Summer Power Meeting, Seattle WA

1/2001 Organized a two-day ONR/F&H/NSWC/Drexel Training Workshop for VTB – Virtual Test Bed (20 people in attendance)

1/2001 Organized a two-day ONR/F&H/NSWC/Drexel Seminar on dynamic modeling of ship electrical systems (18 people in attendance)

Invited Panelist

Participated as an invited panelist in several symposiums, conferences and meetings, these include (see also CPS above):

7/2016 2016 *IEEE PES General Meeting*: Stochastic Modeling and Analysis of Distribution Systems/Microgrids, Boston, MA, USA.

6/2015 2015 ASEE Annual Conference, ECCD Electric Energy and Power Education & Research Issues, Seattle, WA.

3/2014 2014 EAPA - Transmission and Distribution Meeting, “On Measurements’ Role in Supporting Capacitor Control,” Grantville, PA.

9/2012 2012 Energy Association of PA Meeting, “Practically Driven, Analytically Based Capacitor Control Methods," - Lancaster, PA,

5/2012 2012 IEEE T&D Panel Presentation, Orlando, FL

7/2011 2011 IEEE PES General Meeting Smart Grid Supersession: Analytics and Integration

PROFESSIONAL DEVELOPMENT ACTIVITIES

2/2010	Attendee – NSF Dissemination of Educational Innovations Workshop, Arlington, VA, Feb 18-19
6/2004	Attendee – NSF PAESMEM/Stanford Workshop, Mentoring for Academic Careers in Engineering, Palo Alto CA
7/2003	NSF Workshop – Power Electronics, Minneapolis, MN, July 10-12
11/2002	ONR AEPS Workshop, Arlie, VA, Nov. 5-7
6/17/2002	EC2000 ABET Evaluator Training Workshop, St. Louis MO
6/2000	Teaching Portfolio Workshop, Philadelphia PA, June 12-15
3/2000	Gateway-Succeed Coalition, Greensboro, NC, March 27-28
11/2000	NSF/DOE/EPRI Workshop on Critical Infrastructure
1/2001	ONR/F&H/NSWC/Drexel Workshop: VTB – Virtual Test Bed
1/2001	ONR/F&H/NSWC/Drexel Workshop: Dynamic Machine Modeling through Object Oriented Modules

PPL Electric Exhibit KM-2
(HIGHLY CONFIDENTIAL)

VERIFICATION

I, DR. KAREN MIU, hereby state that the facts above set forth are true and correct to the best of my knowledge, information and belief and that I expect PPL Electric Utilities Corporation to be able to prove the same at a hearing held in this matter. I understand that the statements herein are made subject to the penalties of 18 Pa.C.S. § 4904 relating to unsworn falsification to authorities.

Date: 12-10-2019

Karen Miu, PhD

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