AN INTERVIEW WITH PROFESSOR ALEXANDRA VON MEIER ON AN EFFICIENT ELECTRIC GRID: IMPROVING VISIBILITY AND INTEGRATING RENEWABLE SOURCES

By: Manraj Gill, Saavan Patel, Harshika Chowdhary, Daniel Miller, Philippa McGuinness

Dr. Alexandra von Meier is an adjunct associate professor in the department of Electrical Engineering and Computer Science at the University of California at Berkeley and is co-director of the electric grid program of the California Institute for Energy and Environment (CIEE). Her interest in electric energy spans from making distribution systems more efficient to improving the integration of renewable energy sources into the electric grid. We got the opportunity to talk with Dr. von Meier about her passion for energy, the current and future power distribution grids, micro-synchrophasor technology and the challenges with optimizing the incorporation of renewable energy into the pre-existing system.

Figure 1. Professor Alexandra von Meier teaches courses in electric power systems at UC Berkeley.

Berkeley Scientific Journal: How do you find yourself here, in this research field?

Professor Alexandra von Meier: I was a physics major as an undergraduate at Berkeley. Then I taught high school physics and chemistry for two years. I came back here and as a master's and PhD student in energy and resources here at UC Berkeley. Then I did a postdoc in electrical engineering here with Felix Wu, during which time I started writing a textbook, which has done pretty well. The book is called "Electric Power Systems." It's a little atypical as an engineering text. The idea [with the book] was to teach people who are interested in energy and electricity but who don't have an electrical engineering background about essentially how the system works. Not dumbing it down, but not starting with a bunch of phasor diagrams that would be immediately unintelligible. So, the goal was to write something that would qualitatively explain what's happening and what are the constraints when you're operating the electric grid. That was a labor of love, and I started it during my postdoc.

Then I did another postdoc in nuclear engineering, also at Berkeley. I studied plutonium, in the context of nuclear materials management: what to do with spent fuel from nuclear reactors and what to do with plutonium that comes out of dismantled nuclear warheads. Long story, but then I got a job as a professor at Sonoma State University where I taught in the Environmental Studies and Planning Department. I taught energy management and design. This is a wonderful program, where I was for about twelve years, and taught a curriculum that's really pretty unique. It spans renewable energy, energy efficiency, green building. It's not really an engineering program, but it's quite technical and quantitative so it

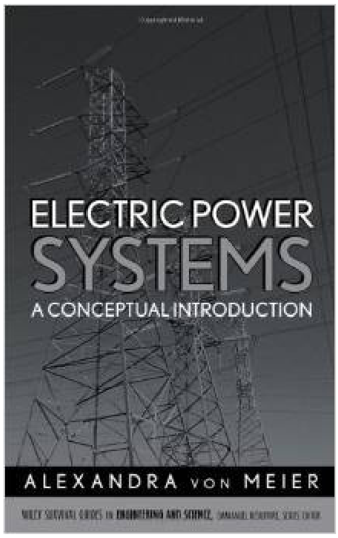

Figure 2. Professor von Meier's book, "Electric Power Systems: A Conceptual Introduction," is used in her 'Introduction to Electric Power Systems' at Berkeley.

enables students who graduate from it to have a really intelligent conversation with an engineer about such things as solar power, wind power, passive solar building.

Then I came back in 2010 to work part time here at CIEE. One reason for that was personal, that I wanted to move back into the Bay Area, and another reason was my interest in doing active research, which is hard to do within the California State University system where you have a big teaching load. And there wasn't really so much of a critical mass of electric power researchers. So I came here to refocus on the electric grid. So now I'm full time here, split between CIEE and the EECS department.

BSJ: When you first went after teaching two years in high school, why did you want to go into energy and power?

AvM: You know, I had actually decided at a really early age that I was interested in energy. In 1979, there was a big accident here in the United States at a nuclear reactor, Three Mile Island. And this made big headlines in Germany, where I was living. There was a big anti-nuclear movement. I was fourteen at the time, but I was really interested in this. People were starting to talk about solar energy as an alternative and I sort of had this idea of, "Oh I want to be an energy expert when I grow up." But there wasn't really an established career path for that, so I actually was going to be a chemistry major. But then I became a physics major…

I took two classes from John Holdren in energy and resources while I was an undergraduate here. John Holdren, who's one of the founders of the Energy and Resources Group here at Berkeley and is now President Obama's Science Advisor, taught ER100-200, Energy and Society, and he taught ER102, which is Quantitative Methods in Global Environmental Issues, and those classes blew my mind! I was like, "This is so cool! This is exactly what I want to study!" So I decided that I wanted to come back to grad school. I was really lucky to get a job teaching at a private high school without having a teaching credential [and it was] a great experience, so then I was ready [to come back for graduate school].

I always knew that I was fond of energy, that I had a passion for it. It was pretty clear that there's a need for finishing up with this whole era of fossil fuels as the mainstay of our energy supply. So, [there's need for] doing something different. And there are a lot of interesting puzzles about how do we do something different. How do we organize ourselves technically and socially around using different energy sources? Because energy touches every aspect of our life. It's really impossible to analyze in isolation.

BSJ: What would you say are some of the problems within the existing power grid today?

AvM: The most fundamental problem is that we're burning fossil fuels for energy. And we can't do that in the long run because we cannot keep taking carbon out of the ground and put it into circulation in the atmosphere, where it will change our climate in a way that will be catastrophic if we keep going. So, the big problem with the electricity grid is that while it's working ok right now, it is working ok with the help of fossil fuel resources. There are some challenges with maintaining very high reliability under all kinds of scenarios. We can improve the robustness and the resilience of the grid to be able to reliably provide high quality electricity to everyone.

The big driver in my mind is that we need to address those technical challenges while primarily addressing the question of how do we make the electricity and how do we get away from the fossil fuel sources. It turns out that some of the most obvious and economical replacements, the sustainable and affordable replacements, are really solar and wind power. Of which we have, for all practical purposes, unlimited resources. It's about where is it, how do we convert it efficiently, how do we transmit it efficiently, and then the big challenge is how do we coordinate the timing because you can't decide when the sun shines and when the wind blows.

Figure 3. Variability in the span of a day in the energy that is generated from wind farms

There are basically three approaches to addressing this variability or intermittency of solar and wind resources.

The first one, which has been our standard strategy ever since [we have had the electric grid, the last 100 years], is: Whenever there is a mismatch between generation and demand, you call on some reserve power plant and you say, "Turn up the knob, give us some more megawatts. Make it equal, make demand and supply equal." Those are called dispatchable power plants. Mostly they're dispatchable because they're burning fuel. So, they have in their backyard a big storage pile of coal, or a pipeline of gas. They have chemical fuel storage essentially. They can make electricity whenever we want. If we start to have less of that, then we have really a shortage of generation resources that can step in and compensate for the intermittence.

The second strategy is to use energy storage. There's a whole field of research on different storage technologies, and the question of the economics, and the control strategies and the coordination for storage – that is, for storing electric energy while the wind is blowing and then using it at another time. And right now, we're actually implementing a pretty aggressive program on building storage, electric storage, in the state of California. But it's not something that will happen right now just on the basis of economic incentives. There's a little bit of help because we think strategically this is a good idea. But if you're just comparing the price of electricity during high and low demand hours, the difference in itself, buying low and selling high, isn't quite enough to justify the expense of installing a huge battery plant.

Now, the third approach to mitigating this variability is to have intelligent, responsive demand. And that's what a lot of people on campus are working on. It encompasses a range of techniques for saying, "How can we use more or less electricity at particular times that doesn't really inconvenience people or make them terribly uncomfortable?" For example, have your air conditioner or water heater kick in at slightly different times or have some delay. This is the area of intelligent loads and demand responses.

So, you kind of have these three strategies for addressing the intermittence.

To do all this well, one big challenge is having visibility and situational awareness of how exactly power is flowing in the electric grid. My research is centered on techniques for measuring and observing what is going on electrically on the grid, so that we can operate intelligently and reliably, and so that we can make use of the resources that are called distributed resources, whether it's rooftop solar or smart water heaters or community scale batteries. These distributed resources can be coordinated and integrated in an intelligent way.

To do that, I believe it's necessary to have a good visibility of the electrical conditions on the wires. There are constraints right now that aren't exactly noticeable. For example, your utility company doesn't really know the voltage! They know it's supposed to be within some range, some nominal value plus or minus 5%, but they don't have a good way of knowing in real time about who is close to violating that. So, if you're integrating more solar and you might have reverse power flow and might be violating some of those constraints, you can feel a lot better about integrating these distributed resources if you have better visibility! That goes for real and reactive power flow and voltages. And the project that I've been working with, the micro-synchrophasors (μPMUs), that's a really advanced way to look at the power distribution system and be able to have visibility of what's going on.

BSJ: Regarding this data collection through micro-synchrophasors, how exactly do you use the data? What can you then tell the power supplier?

AvM: For example, one of the things is that you want to manage is the voltage on a distribution circuit. You would want to include the rooftop solar into this. Really, it's the inverter which is the gadget that sits between the DC (direct current) solar panel and AC (alternating current) grid that has the brains to respond. Now the inverter can do two things. It can inject real power to the grid or it can inject what we know in electrical engineering as "reactive power" into the grid. Reactive power is a phenomenon that has to do with the relative timing between AC voltage and current. It's not a real energy transfer on average, but reflects a kind of circulating energy. So a smart inverter can adjust the power factor and inject different amounts of reactive power. We would like to know what the right amount of real and reactive power that the inverter should be injecting at a particular time is. So as to [not only] optimize the resource use but also the voltage profile.

Our hypothesis it that by having a very precise measurement of the voltage phasor along the distribution system, which includes information not only about the magnitude of the voltage but also the timing, will allow the inverter to make better informed decisions. For instance, you can avoid situations that would be very inefficient or maybe you're maintaining the voltage within bounds but by having relatively high real and reactive power flow in opposite directions which leads to large losses. Our work focuses on specifically identifying the operating states to make the best decision with regard to what you're demanding from your resources.

BSJ: Do you see there is a lack of efficiency currently due to a lack of data? And where is this problem most profound?

AvM: Well, I think many observers of the electric power industry would say that the most pressing issue is reliability and not having data about the operating state. Not having observability of the grid makes you more vulnerable and exposes you to more risks of power outages and makes it longer to restore services to customers. Some of the work in recent years has focused on just getting the data from smart meters to help utilities bring back service quickly.

For the electric utility companies, they feel this pressure where their performance is being evaluated: "How many minutes or hours are the customers out of power?" In my mind, the question that is just as important is: "What exactly is the hosting capacity for renewable resources?"

This capacity is measuring how much solar we can get away with in a neighborhood on a particular circuit serving some thousands of houses. Think of this area being served by a network of transformers and infrastructure and there is a limit to how much solar can be installed without creating a threat of violating constraints of the infrastructure. Reverse power flow can confuse the protection systems (fusers and circuit breakers). There's a very delicate coordination among the protection devices. The topology of the network is a very subtle system. The protection system can be confused through power flowing in the reverse direction. This is because everything was designed decades ago with [one-way flow], from the power plant to the customer. The reverse power flow is one concern and then the voltage limits are another. In order to be on the safe side and not have violations, that would then maybe cause problems, there are rules how much solar could be hosted on a particular distribution circuit. One number that's been worked with is 15% as the maximum. There are revisions but it gives you the sense that you want to be a little cautious.

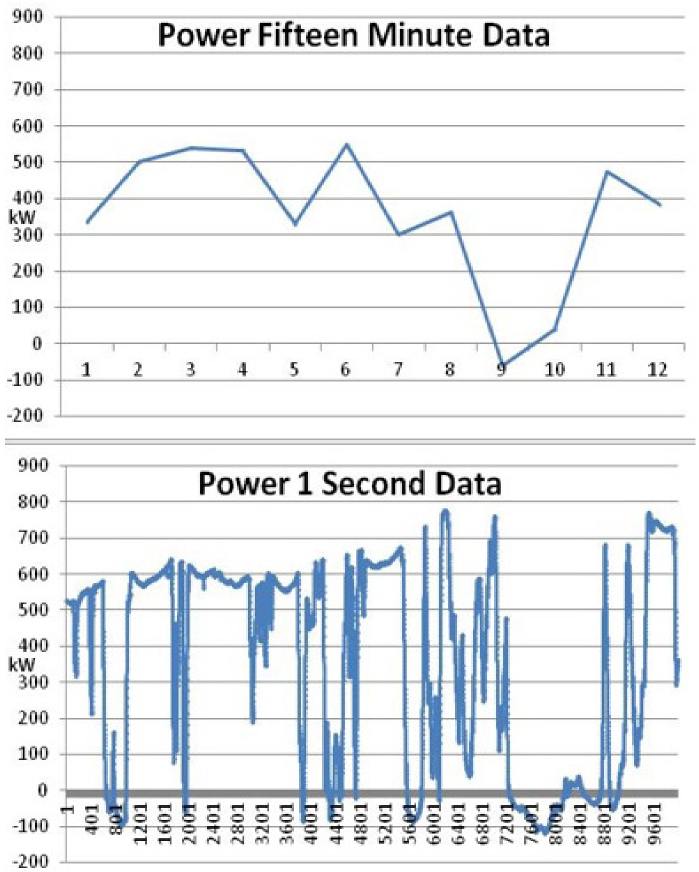

Figure 4. Portraying the variability in a distribution system that is lost in the absence of real time data.

So, there are conservative rules about these hosting capacities. I want these hosting capacities to be dramatically increased! Because if people are willing to pay money to put solar on their roof tops, we should be encouraging that! That's great and all this helps us avoid burning fossil fuels. But the visibility is really a crucial piece of the infrastructure. It would help us get rid of the constraints that are currently in place regarding what is allowed. If people are eager to put them on their houses, then it's too bad if we have to restrict it!

BSJ: How [does the information from the micro-synchrophasors help] protect the grid from the reverse flow? [How would it ensure] that integration of renewable energy is smooth?

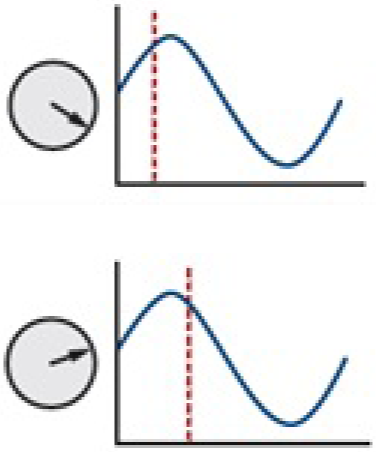

Figure 5. Phase angle (ϕ) differences.

AvM: Let's go into the actual math a little bit. In an AC system, it's really an alternating voltage. To a first approximation, we imagine this sine wave and if you just look at the voltage from your outlet, then it goes from positive to negative sixty times a second. 120V might be the root-mean-square value. But we imagine that, to a first approximation, as being exactly synchronous everywhere across the western United States which is connected as a "synchronous" AC network. When you learn about AC power flow through transmission lines, you realize that they're not exactly synchronous. For the power to be transmitted, there's actually a shift in the timing of the sine wave. It's not just $\sin(\omega \cdot t)$ but it is $\sin(\omega \cdot t + \phi)$. And that phase angle ($\phi$) of the voltage is actually a state variable. There are two state variables: voltage magnitude and phase angle. So, if you know the angle at every node in the network, you have complete information about the state of power flow.

BSJ: And how small are these phase angle differences?

AvM: Very good question! If you are comparing phase angle differences across the transmission grid, between San Francisco and Seattle or San Francisco and LA, you might see tens of degrees. If you are looking at the angle differences in the distribution system, such as nearby locations, it'll be 1 degree, or 1/10th of a degree, or even less than that. Now, what do we mean by a degree? Well, 360 degrees = 1 cycle or 1/60th of a second. You can do the math, and very quickly when you're talking about fractions of a degree you're talking about microseconds rather than milliseconds.

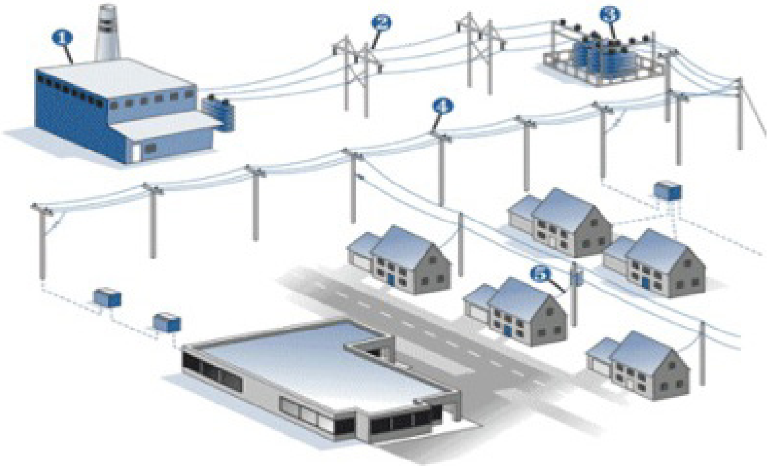

Figure 6. Micro-synchrophasors (μPMU's) at every node in a distribution grid

So the micro-synchrophasors [are designed specifically] for the purpose of discerning these very small phase angle differences down to 1/100th of a degree. We've tested them in the lab to make sure they are precise and accurate. We've installed them on some of the distribution circuits on campus and the Lawrence Berkeley National Lab to observe actual phasor differences between locations. The differences are about what we'd expect, on the order of 10ths of degrees, with some small variations. Synchrophasors for transmission have been around for a few years and really in the last 10 years there has been an enormous increase in deployment and applications for making sense of the measurements. They've never had to be incredibly accurate; down to plus or minus a degree is perfectly fine if what you're looking at is big power oscillations across the western grid. These differences actually exist and are actually a threat to the reliability of the grid, making this a very important use case for synchrophasors: to detect these oscillations and to observe the stability of the network.

In this research project, we asked the question "Could there be a use case for looking at these phasor measurements at the distribution level?" Really, we didn't start with our minds made up, we didn't know if there would be practical value to it. There's a null hypothesis that says, "Maybe we could measure it, but so what? There's nothing useful in it." But we are beginning to see useful things that it tells you, and we have plans for a whole lot more research to really articulate which applications make the most sense.

One of the things we were able to do [was distinguish between] whether [a disturbance came from] the local distribution system or from the transmission system. There's also something really fundamental about measuring the voltage phasor, which is that you can get information about power flow on the network by measuring only voltage and not current. You can get information about power injection elsewhere, not just at your location. Between measuring the frequency and measuring the voltage phase angle difference and the voltage magnitude difference, you can get a picture of what the power flow looks like with relatively few measurements compared to all the other measurements you'd have to install conventionally. The hypothesis is that this gives you a more precise insight and that will be more economical.

BSJ: What are the current costs of implementing these micro synchrophasors, and how could these costs be reduced? Is cost as an issue?

AvM: Cost will definitely be an issue. But what's interesting is that in the world of electric utilities, the cost of the individual gadget might not be the decisive factor. So let's say each μPMU costs several thousand dollars, but what is the really decisive factor is how many person hours did you spend installing it and running all the wires safely where they have to go, and what else did you need to do get the data back to your computer where you can look at it. So the whole engineering of the monitoring system is a lot more than just the sensor device. For example, one thing that we're seeing in our measurements is that the accuracy of the voltage measurement depends on the transducer, that is, the potential or current transformer. That is the piece of equipment that sits between 12,000-volt piece of aluminum or copper and the 120-volt piece that you're actually touching with the sensor, that makes it safe to touch it. In the end, the transformer has some accuracy that is stamped on it like ± 0.3%. If you're trying to make an exquisitely accurate phasor measurement, that is affected by the accuracy of the instrument transformer. One of our research questions is [finding out to what extent you can] use the existing instrument transformers, and to what extent can you use the service transformer, which are also serving load, in between your μPMU and the primary distribution system you are actually trying to measure, and perhaps correct for the error with the right mathematical algorithm.

If you can just take the μPMU and plug it into the wall, then the deal is done! This is cheap, this is easy, and nothing competes with it! The challenge is how to measure the primary voltage, and you don't just go touching 12,000V, there's an expensive transformer in between. So, it comes down to how much can you take advantage of the instrument transformers that already exist and deal with the errors on the analytic side. That’s a critical piece of the distribution monitoring problem.

BSJ: So would you say public policy and bureaucracy provide a hurdle to adoption of these new technologies?

Figure 7. µPMU concept (along with size reference) and implementation in the grid around Berkeley.

AvM: With these technologies, not really. The main reason these technologies have not been adopted yet, or haven’t really been developed is that there hasn’t been a need for it historically. There are sensing technologies that you can buy off the shelf, like really good voltmeters, but the reason they are not all over the place is that there’s never been a need to track how this system is behaving. That’s what is really changing. What’s different today is that we’re interested in the time series behavior of distribution systems, and we’re interested in two-directional flow, and we’re interested in controlling things actively. If we want to make intelligent decisions, we need better information. This is a completely new set of circumstances that have never existed.

BSJ: In future, 20-30 years from now, what do you want the smart grid to look like?

AvM: We will want to use our distributed resources during times of disturbance or crisis, like a big storm. In a situation like Hurricane Sandy, if some major interruption happened in a place where you have a lot of rooftop solar panels installed and the power is out for some number of days, people are going to start asking the question, “How come I cannot use the power I have on my roof right now?”

By code, solar panels are required to be shut off safely when there is a power outage in the neighborhood. What people are going to want to do is to use those local resources in a standalone mode, which is known as “intentional islanding.” Operating power islands safely requires some technical changes in what is in the infrastructure now because you have to balance generation and demand on your island. You need knobs that you can turn up or down so that the load and generation match each other. This may require storage, but in any case a coordination task needs to happen. The process of opening and closing the switch at the point of common coupling, or the connection between the power island and the mainland, is also a challenge. For AC, you need to match the frequency and the phase angle of the voltage before you close the switch, otherwise you damage things. This is an area where I think the µPMUs are going to be very helpful.

I envision we will have pieces of the electric grid that are capable of operating as power islands by themselves, but also seamlessly connect with each other or the backbone of the transmission grid for the purpose of sharing and getting good deals on bulk energy. The transmission system is good for importing less expensive energy from far away. We do not want to do away with the transmission system, but I think we want to become less dependent on it. Power quality and reliability will be provided more locally and allow us to have a grid that is more flexible. The topology can change and you can have small connected pockets that can mix and match as conditions demand in the future.

Image Sources

http://sgc2013.ieee-smartgridcomm.org/content/keynotes

http://www.amazon.com/Electric-Power-Systems-Conceptual-Introduction/dp/0471178594

http://uc-ciee.org/downloads/Renewable_Energy_2010.pdf

http://uc-ciee.org/all-documents/a/700/113/nested

http://www.aln.fiu.edu/?p=89

http://uc-ciee.org/all-documents/a/694/113/nested

http://citris-uc.org/energy/project/micro-synchrophasors-distribution-systems/

Layout by Jingting Wu