Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee:	Yilu Liu
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Transcriber:	Temi online

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Abstract:

Dr. Yilu Liu is UT-ORNL Governor's Chair Professor at the University of Tennessee Department of Electrical Engineering and Computer Science. Dr. Liu begins the interview by describing her educational background and professional path to UT. She describes her effort to develop an inexpensive way of collecting data to measure phase angles and frequency on the power grid, which she calls the "poor man's PMU." Her undergraduates at Virginia Tech devised a tool using off-the-shelf products. The data is available to researchers, regulators, and industry alike. She describes the way in which they triangulate and time stamp frequency deviations, which is useful for event alert and analysis. She notes that her team has worked with the automobile industry on coordinating GPS data with, for example, traffic lights, which are referenced to grid frequency. Her system, called FNET/GridEye, can be used to analyze grid oscillations. She explains that students working on her team learn how "dirty" the data are and how

important it is to verify simulations. Her students work with a hybrid digital and analog test bed, built on an old transient network analyzer. She describes the current grid as “sluggish” and able to “take the pounding” while the future grid will be much more fast acting, hence new algorithms for compressing and analyzing large quantities of data, produced by PMUs or other measuring devices, will be needed. She discusses the early cost of GPS and PMUs as instigation for finding other approaches. Prior to development of PMUs, engineers simply didn’t have the data they needed to determine phase angles with accuracy. She offers an explanation of how atomic clocks work. She explains that a network of family and friends were the first adopters of her measurement devices, which plug into a wall outlet anywhere. She describes her cross-disciplinary academic collaborators and her industry collaborators. She closes by encouraging students to join the study of power systems because the field is undergoing a revolution.

<u>Note regarding Transcript and Timestamps:</u>

Timestamps appear in the transcript but may not align with the recording. Pauses and interruptions may have been removed and the overall length of the recording may be reduced.

Transcript:

Sutanwi Chatterjee (00:50):

This is Sutanwi Chatterjee. I am conducting an interview with Yilu Liu on Wednesday 19, July 2023, at Hyatt Regency, Orlando in Florida. Daniel Molzahn will assist with the interview. Rachel Harris, Brian [*Johnson*] and Tari [*Jung*] are also participating in this interview and may ask questions. During today's interview, we are especially interested in your work on real time frequency measurements and data analytics for the power grid, and how they were adapted into power grid applications. We'll begin with some introductory questions and general background information about you. Please describe your educational background and your professional positions in the field of power systems.

Yilu Liu (02:26):

So, education background is—I got my bachelor's degree in China at Xi'an Jiaotong University. It's one of the major engineering schools, which originally moved from Shanghai to the city of Xi'an. Then I got my master's, PhD, from Ohio State, the Ohio State University. And then after that I went to Virginia Tech as a faculty for almost 20 years. And then when the State of Tennessee, the governor, come up with a method for the University of Tennessee, especially other universities, but Tennessee is close to Oak Ridge National Lab. So, in order to establish a close connection and a joint effort, the governor created a position, which is called the Governor's Chair. Faculty hired by this position will work both at UT and—our UT, not the other UT. University of Tennessee at Knoxville as well as at Oak Ridge National Lab. So that's how the process goes. So, I've been there for almost 14 years.

Sutanwi Chatterjee (04:05):

So now we'll turn to questions related to your significant contributions to data analytics and real-time power system sensing. So, what has been the most important technical problems you have tackled?

Yilu Liu (04:20):

I don't know. I would call it a significant contribution, but the most fun part of our work is being able to get real data, our data, instead of having to get pieces of data. So, what we did is—at Virginia Tech—which was the place where the phasor measurement was born. Arun Phadke, James Thorpe, others in their time created phasor technology, synchronized measurement technology. And I can see the suffering of not having data. Even if you are the inventor of the technology, but once it's measured from the utility, you are—very difficult to grab data, right? So, to create a platform for students to do research and to observe the true phenomena of the grid, we came up with a poor man's PMU, basically. A simple device. You just plug in the wall, 120, and then, you do have to have a GPS connection because that's where you can synchronize your sampling.

(05:36):

And you're also—allow comparison between wide areas. So, we were able to—we started with asking some other company manufacturers to produce it. And then, because the market is not very huge, so there's not too much incentive. So, we did the—we created the device ourselves, we start to deploy them. And turned out it's actually quite nice because we started with measuring frequency, because the frequency at the low side, it's the same as the one near the substation, high water substation. So, you can see the dynamics of the grid just based on outlet measurement. But we also find that the angle deviation, the angle change, are very useful information. I don't know the true angle. I don't measure current. Now we do measure current because we have, since, created new monitors. Still principle is very accurate.

(06:46):

But low cost. We do measure current, but at that time we don't. And angle turned out to be also extremely useful. And that's something we use as a platform. We have several hundred in the US, deployed over the world, over the ground, east, west and Texas, Canada, of course, Mexico. But we also have covered the entire world, in almost all major grids worldwide. We have background information. And when UK has the, has their issues with the blackout, I think many entity actually reached to us to get free data for them to analyze information. So, one of the products this database produced for—not just for research, is an event alert system. So basically, the data come in and because they're measured at different locations of the grid you actually have a delay of time of arrival.

(08:08):

So, using the delay of the frequency disturbance measurement, we can track back, triangulate back, where the event happened. And that information is actually given back to many of our industry members. NERC is the main user of that. And the way the NERC use it, they use that information, maybe plus some other information, to know if there's a big enough event and which RC, which entity, they should ask for data preservation and for analysis. And that goes eventually to the year-end NERC analysis, NERC event analysis, analysis report. So, it becomes a quite handy tool for the industry, partly because, especially in Eastern interconnection, there is no federated data entity. Some groups have collected data in patches, like PJM may be getting data from their members. California may get member data from other entities, but there isn't anything that oversees the entire grid. However, the grid is a, I wouldn't say organic, but it's connected, right? They all really—it's one entity. So having an overview gives us a lot of advantages to do research and other things. I'll just stop here in case—

Tari Jung (09:57):

So is that information—like EIA for instance—it's like a public—

Yilu Liu (10:03):

We do have public. Not the whole database. The reason being that some of the data were from units that's owned by, like MISO, they bought like 30 units they deployed in their system. TVA bought some of them, but they all come to our site. So, there are some agreements where we don't release some of the data. But we do choose events, interesting events. We make it actually available for people who want to look at it individually. Also, nobody wants to have this massive amount of data. And partially for security reasons, partially for competitiveness. And there are practical reasons. Data—just way too massive.

Julie Cohn (11:03):

I have a question. Who are your primary users of the data? Do academic researchers use it as much as system operators? Is it transmission company owners? Who are—who's the audience?

Yilu Liu (11:19):

So, data use, the right use, are usually academic, right? But the metadata, which is like—we reproduce event analysis, event alert, we send out to the industry consortium members. So those are major utility operators or RCs, reliability coordinators, or balancing authorities. People have a responsibility, oversee the grid. That would be one area as well.

Julie Cohn (11:58):

And do international researchers use this data also?

Yilu Liu (12:03):

I would say yes. We have had people—UK, Australia, Germany, we have quite a number of international—but mostly domestic people are interested in the data. And majority of the time the data is anonymized when we give it away.

Julie Cohn (12:31):

So, have you seen academic researchers develop new approaches to power control as a result of having access to this?

Yilu Liu (12:43):

There's quite a few examples, but one I can give you is: when you triangulate events, the power grid is not homogeneous, right? It's meshed, but not homogeneous. So, we assume, typically assume, the disturbance travels at a fixed speed. But in different directions they're not same speed. So, we constantly try to improve the triangulation and the location method, like the earthquake. So, we have people who got interested in that, and then they got data and they even—a number of event data—and they actually tried to improve the algorithm. Let's see. In one university. We had another university, I don't remember which one. I think University of Florida. They took the data, and they help with—help us with the authentication approach, because those are signal processing faculty. What I mean by authentication, the data, frequency data, get embedded to other electrical systems, like audio, video, other things. So, you can use the frequency embedded—let's say this video somehow—let's assume it's run on some battery.

(14:20):

It may not get it, but if—let's see if something—well, it will get it. But it may be faint signal from the flicker of the lights. So, someone grabs the video, audio, we can actually—if we can extract the background power frequency signal, we can identify the time that the video was taken and also the location to a large part. Now, not between this room and that room, but reasonably far away. Definitely easy for between 50 hertz, 60 hertz, right? But also, between large cities. And we did find there's sufficient data, we can tell, between different buildings in one city. So that becomes a very interesting data authentication tool to—for industry to use. So, we have people doing that. We also have support of auto industry in terms of, there's a number of, I think Audi already have that application, a number of auto companies interested in providing information to the drivers.

(15:38):

Let's say you approach a red light, and they wanted to have this app telling you how much time you are waiting before the green light comes up. I don't know if you use any of the cars that does that, or apps. So, what they end up doing is they find out they can never synchronize with the traffic light, no matter how accurate they need to, because the traffic light is referenced to something else. It's not accurate to GPS time or absolute time. It's accurate to the power frequency accumulated delay. So, if the frequency goes up and the clock runs faster, frequency goes down—let's just make it simple. If you count zeros, right, count the sinus auto crossing. So that's the simplest way to make a clock for a traffic light as well. The reason they use that, because you don't have to worry about accumulative error, because the power industry will calibrate that error. Eventually, they move things back. Your time won't be delayed that much, but that may not be true anymore. So basically, our frequency information can actually help the app development so that they can go back and use the area frequency to calibrate to the light signal. As a broader application, not just the power system application.

Brian Johnson (17:27):

Sure. I was just going to ask whether—I assume here that you, you guys have recorded events and accumulated all the data, and I assume that there's—

Yilu Liu (17:39):

We started recording—of course not such full coverage—since 2004.

Brian Johnson (17:46):

Okay.

Yilu Liu (17:46):

And the data is kept indefinitely.

Brian Johnson (17:49):

Can you describe if there's been any efforts to study particular events and then create a simulation to see if you can match how the data compares to the ideal simulation? And did that enhance or degrade your confidence in these models that we have for simulations?

Yilu Liu (18:09):

Very good question, actually. So, one of the major applications for monitoring is that model validation, right? So, we did use the data to look at the Eastern Interconnection model. It turned out the model has sometimes a reasonably good match, but eventually the steady state part is a very wide gap between measurement and the model itself. So, once we—that's the MMWG model. So, if we adjust the governor, we adjust some other parameters, we can get it to match. So that's just one example. That would be a very good application as well. But in addition to—industry service is what you're interested in, right? So, in addition to the event part, we put a lot of effort on oscillation analysis. So we have a lot of—we grab sensors and analyze oscillations that tie to the event, or just simple oscillations like the one initiated in 20-, I forgot the year, I think it's 2019 in Florida that caused a major—some CT or sensor failure—caused the unit to continue to try to start back again.

(19:59):

And that caused a lot of oscillations in the southwest, northwest area, MISO. And Northeast. So, oscillations also are growing. We do historical tracking, how much more oscillation events we get per fixed period of time. And that has become one of our—leads to a lot of practical applications. Like, we constantly provide oscillation alerts, and we study oscillation change, mode change, frequency change, and also, gets to the point—we work with EPRI and others, NIPOC, DOE, to, and the Italian grid, to do oscillation damping. And those are all coming out of the observation and then leads to control. So, if you wanted the control example, right? The oscillation damper is one of those examples where we have actually a field test going on, actually the last two weeks, to probably continue. So, you use those measurements as feedback to control and to damp oscillations in the Italian system, as one example.

Daniel Molzahn (21:28):

So, one question kind of along these lines is we've been hearing a lot from folks over the last couple days about how there used to be a lot of modeling done with physical devices, build a replica of physical machines and—

Yilu Liu (21:42):

Digital twin.

Daniel Molzahn (21:44):

Well before this. I mean—

Yilu Liu (21:46):

I see.

Daniel Molzahn (21:46):

In the 1970s, 1980s, where you had physical replicas. I had a motor representing my generator. And then some of the concern being that: we're sort of moving, as we move to having digital simulations, you sort of lose a sense of—or students were sort of losing a sense of getting a feel for the system, how the system responded within a physical circuit. Do you think some of the work that you've done with the frequency measurements maybe brings us back to having more of a physical intuition for the system, given that you're, you're really measuring the physical system and watching the disturbances happen?

Yilu Liu (22:26):

I think that's a very good point. That's true. We don't necessarily make our student able to picture one component, per se, but we definitely give students a very solid understanding in terms of how dirty the data are and how much you should not trust the simulation until you verify. And also, and they get a good dimension of—well, the first thing they learn is geography—where is where—very quickly. Some students are international, and they don't know where is where until—. But this gives them a very interesting opportunity to see, okay, which unit is where and which generator. So, I think the measurement data definitely keeps all of our research and the students grounded and also interested.

(23:37):

So—but on the other hand since you brought up the physical model. The analog model or physical model has its own merit because everything now is digital. It's really too virtual for students to learn, right? So, as part of our engineering center, we have built a system. I don't know if any of you remember the TNA, transient network analyzer, that's all made of motors, relays. It's a big wall, but nobody uses it anymore because it's replaced by the digital, right? But we actually come back from it. But at a new level. I'm not the person that built it, but the—our group, our team at UT as well as the engineering, ERC, center, we build this hybrid digital and analog test bed, which is made of, all made of converters.

(24:50):

You can use converters or inverters where we see it, to mimic an electric machine, a generator, a line, which is very important because you couldn't control the line RX ratio otherwise. And the storage, load, everything. Of course, within each inverter you have the digital control, everything, right? But they are all connected to a real grid or bus. And you have power flowing through this. So that's one way to create a simulated reality, which is closer, slightly closer, to reality than a pure RTDS property. Which is great, because the convenience you provide. But this thing is bulky. You have to have it in the room. We are in the process to make it a transportable hybrid analyzer for the grid. That's the direction we believe will be helpful for students to learn.

Brian Johnson (26:00):

Yilu, what is the most surprising thing that you've learned about the nature of the grid? Having seen all of this data over time? Because it is such a complex thing. It's almost like this giant organism of people participating in it, all this technology. And I feel like you've probably spent so much time actually seeing how it behaves. So, what has surprised you the most about it?

Yilu Liu (26:23):

The most surprising thing—I learned a lot because I'm a high-voltage engineer by training. I spend my PhD time: model transformers, right? So, I'm a device person, power quality person. But joining Virginia Tech, we have this environment—got me into a little bit of the grid type. But still starting from a device, we start by making those devices. So, what surprised me—if I need to pick, I would say—how easy we have designed a grid to operate. Because you have so many—inertia. You kind of have to be sluggish to control it. You don't really have to respond like this [gestures] to control a grid. You can just let it take—what's the—you can take—have this grid take the pounding, and without worrying because it has a huge inertia.

(27:33):

Everything can be done slowly. Not relays. If something's burning, the relays act quickly. But those are individual. But as a grid, as one animal, right? Especially Eastern grid, because of the tremendous inertia and the way the design is so elegant, it's droop. Your governor droop, everything, it automatically adjusts itself. We designed such a clever thing that we really don't have to put so much effort to make it run. So, we are all in research. We push this technology, that technology, phasor measurement, actually, we don't necessarily need them for the grid of, almost, yesterday, right? But we do need to worry about later, because everything becomes fast acting. Inertia starts to diminish. And grid strengths, I like to emphasize, are diminishing because they are only the product of rotating machines. So, we now got job security because this grid is going to be much harder to deal with. That would be how my reaction is.

Rachel Harris (29:01):

Can I ask, so you were talking about phasor measurements being born at Virginia Tech.

Yilu Liu (29:06):

Yeah.

Rachel Harris (29:07):

Could you just describe a little bit about the history of phasor measurements and what they've been used for in the past, although you say maybe we haven't even needed them, and then it sounds like you see them becoming more important in the future—sort of the history of the future.

Yilu Liu (29:19):

Well, we needed them as a niche, right? We haven't got to the desperate point where we have to have the management say, “You have to install this many, you have to operate.” So, we needed them in many things, but we don't really rely on them only to operate. We can operate our grid okay without it. But still the PMU technology, from my understanding, with Arun and others, they are thinking about the way to measure the angle between two points, far away points. And the easy thing to do may be using, I don't know what we call that thing, the line carrier, something—you can use optical cables to be able to give the precise timing. And then, when they thought about—there's need to measure angle, and to know what the angle is, because there's no way you know it—you only get it from state estimation.

(30:30):

You don't know the true, true angle, right? So, they like to know that, and they figure out, “Ok, we can use GPS as a synchronization.” At that time, the GPS cost, probably cost this big [gestures], and cost $20K. My GPS cost $20, and that's expensive because I'm not doing mass production. So that's how—that's in the early, I would say, in the mid '80s, people start thinking about it and they did the test one—they're huge. Just the clock is so expensive. People said, “Okay, how practical could this be?” But look, the price dropped tremendously, right? And so, it has been a quite a development process. And there are many, many successful examples of using PMU: out-of-step relay, remedial action, or damping control definitely need it.

(31:38):

But those are not essential elements in operation yet. We can get by without it, right? But slowly, slowly measurement, not necessarily PMU, which is phasor, but slowly, slowly, I mean, gradually, synchronize the measurement. It can be pulling away, which is very important for knowing what IBR does, right? Just like running your fault recorder continuously. Synchronized measurements are more and more useful and become more widely spread. The breakers have it, the relays have it—it's just calculation algorithm. And many things automatically have it, and all time-synchronized. So that's how I see the technology—not necessarily have to be a PMU application, but the synchronization, and the higher data-rate sampling becomes, it will be very essential part of the future grid.

Daniel Molzahn (32:55):

Do you know when this was developing in the '80s, and it was a bit before your time, but was it just—everyone knew, or was it sort of everyone knew GPS was the thing to do, and if only we had cheaper GPS units, we could make this work? Or was it really kind of a flash of insight that people had where they said, Oh, there—we could use GPS, and that was kind of a—

Yilu Liu (33:17):

I think it's the later part. I wasn't even graduated at that time. I joined Virginia Tech in 19-, 1990. Right. And at that time that group has already had some prototypes developed, but based on their discussion, and that's—

Daniel Molzahn (33:41):

So, it was really an insight of folks.

Yilu Liu (33:42):

I think so. I think so. I think they feel, "Okay, maybe we can try that," because at that time, very expensive. But it gets very widely used because cars use them. No, we actually borrowed a lot of—we—the GPS gets cheaper—it's not because our power industry, it's some other industry. We just get a free ride.

Julie Cohn (34:06):

So just as a follow-on to that question, were people prior to the 1980s, this is, you're going to have to make a guess on this yourself, but were they wishing they could collect this kind of information, but they simply didn't have tools that made sense?

Yilu Liu (34:24):

I think they had a, definitely a desire to know if the state—because the angle, you just couldn't compare it, without accuracy. See one microsecond is where the IEEE standard asks for—correspond to 0.02 degrees, right? So, you need microsecond accuracy to get angle correctly. I think people probably do like to know what's the true angle between any arbitrary point, but that can only come out of the state estimator. So, there's definitely need, but there's not a—it doesn't get to the very painful point where we have to have it.

Brian Johnson (35:18):

Yilu, can you educate us a little bit on how these GPS systems work? I mean, I assume here there's, these, these clocks that are, are these atomic clocks and how do they keep a master synchronization? Or is my guess totally wrong? How does this actually work?

Yilu Liu (35:36):

I don't think that's wrong at all. I have limited knowledge because I didn't have to worry about it too much. GPS carry atomic clock, they all have atomic clocks in there. So that's one major source. And if we have an atomic clock in our room, in our house, that's actually not a true one. It's the radio frequency correction, constantly, from, let's say Denver, Colorado, where that master correction is. So, they do carry that atomic clock. And when we get it, we get the, we get the loc-, we have a loc-—the receiver gets that clock. It comes as a one-pulse-per-second accurate time. It's actually close to 50 nanoseconds. It's far more accurate than one microsecond, 50 nanosecond. And then once it's just one pulse per second, and following that, there is a timestamp.

(36:56):

And in that timestamp, it will give you the explanation for that one-time clock. And it gives you a count from maybe 1972 as a clock, second one, it gives you a clock, a second number as a total number from that time. And then the location information. I need to think about it. The location information is a combination of several GPS. And then you generate that location information from, based on the mechanism, from the receiver. The receiver has a brain—antenna, come in, get the data, and goes through the GPS receiver. The GPS receiver collects information from several, you needed the four GPS. We always have to have a lock-in time. Four GPS, because you have three coordinates, one time access to get you pointed to the location. So, you get the location, you get the time information. And in our case, in the driver case, you get the location where you are. Right. But in our case, we mostly use the one point, one post per second, because that's nanosecond accurate. To absolute time.

Tari Jung (38:29):

What were the initiatives you had to take to kind of make sure that these are spread out? So, you need those devices—?

Yilu Liu (38:37):

Oh, It's a family-friends network. We do have a lot of volunteers from radio, amateur radio clubs. They like to have one more gadget on their shelf. And they contact us. And there's also—remember I mentioned that utilities own some of them, because there are places they couldn't get in easily. And they like to see that. Some high schools. A lot of power faculty, a lot of our ex-students and our relatives, because it's—we have an international community in any university, so the international units were hosted by a lot of our former students, roommates, nephews, or whatever. So, it's getting spread out for all kinds of reasons. And DOE at some point wanted to see if they can put one in every post office or McDonald's. We've always talked about all those different initiatives. Possibilities.

Tari Jung (39:58):

Sorry, there is actually one at MISO. We don't get to actually access the data itself directly, obviously.

Yilu Liu (40:05):

Oh, actually, MISO's case—the data goes back to MISO. All the data goes back to MISO, but I don't know if they are still using it or not. So, the way we deploy for MISO is they come in and then we forward. A lot of forwarding of options. What time do we have? Oh, we're good. Still good.

Daniel Molzahn (40:33):

Sorry to follow up on this. So, I'm wondering if you could take us back to when you were first kind of conceptualizing this idea of having this network of these frequency measurements.

Yilu Liu (40:45):

Oh. OK.

Daniel Molzahn (40:45):

So, I could imagine there was existing phasor measurement units out there. It would've presumably been easier to, at least at a conceptual level to get access to that data versus building your own devices, deploying them, putting a system in place to collect all the data. And it seems like an enormous undertaking.

Yilu Liu (41:05):

Yeah.

Daniel Molzahn (41:06):

So, what was it that convinced you that this was the way to go versus spending more effort trying to get access to the data? Was it just: you ran into brick wall after brick wall for the data availability?

Yilu Liu (41:21):

So that's a very interesting question. And we, remember I got hired by Virginia Tech? I wasn't doing any of the phasor stuff at all, but I saw them struggling with getting data. And then also I thought, if we only care about frequency, then the one we measure from the wall should be fairly close to the substation, or at least we get something. So, it's really the struggle of getting data provided this incentive to do it. I—we have some undergraduate students who are brilliant. And we were thinking about some undergraduate project. They said, "Okay, let's try this." So, the first units were actually built by undergraduates.

Daniel Molzahn (42:27)

Wow.

Yilu Liu (42:28)

And stuck into a Cisco box. People got it. They said, "Oh, this is UL certified." No. It was the original label. Everything. It was just different ideas, try and then—we got really excited when the data really come in from a remote location, because I didn't really know how this could work.

Daniel Molzahn (42:54):

Is it—so how—at what point did you realize that this could be—so if it started as an undergraduate project—you're kind of messing around with students?

Yilu Liu (43:03):

And immediately we applied for NSF MRI Project—measuring instrument—in that way we say, "We are going to build a bunch of units and we're going to send out and see what's going on." So, it's gradual.

Daniel Molzahn (43:17):

I see. But you knew pretty early on that this was—

Yilu Liu (43:19):

Oh yeah. We started in 2000 to deal with the device, a design. And we have an algorithm because that's what the school is doing. We hired a company to make it. But the—because there's not a—nobody sees a large order, right? It's still not a large market, and there's less incentive for the company to do it. So after maybe half-a-year, a year, our undergrad students already got something running. And we got the prototype from the company. But we find out our design and our thing seemed to be much better because they're just converting one thing for another. So, I say, "Okay, we can do it." So, one of my office—not office-mate—but my neighbor is an embedded system designer. He said, "Oh, this sounds interesting. I want to do it." So, we work together with this faculty in embedded signal processing—a true expert in this. And we just got a bunch of good students. And then they take off. And then, also ABB, TVA are the two companies who think, "oh, that could be an interesting tool." And they sponsor the work as well.

Daniel Molzahn (44:48):

What were their initial comments when you brought this idea to them? Did they realize that this could be—I mean, ABB and, you said ABB and TVA—.

Yilu Liu (44:55):

They liked the portability, that it doesn't have to—I remember at that time, or maybe even later, it cost $80,000 to deploy one PMU. Now it's much cheaper. They liked the flexibility of being able to plug in, get some information—and we don't necessarily, and so that's part—

Daniel Molzahn (45:19):

So, it seems like a reasonably easy sell. I mean, good idea, right place, right time and industry connections.

Yilu Liu (45:25):

We have already had the working relationship with ABB, TVA. It's not a code—I approach a company, wanting to sell the idea. We just—we just talk about things. They say, “Why don't we make this happen?” Things like—So, it's very—it's interesting. Yeah, it's interesting.

Sutanwi Chatterjee (45:59):

If a general audience could walk away with one important thing to know, what would that be?

Yilu Liu (46:06):

In what sense?

Sutanwi Chatterjee (46:08):

Well, you speak—

Julie Cohn (46:11):

Oh, about this initiative.

Yilu Liu (46:14):

Oh, about this work?

Julie Cohn (46:16):

Yeah.

Yilu Liu (46:17):

Oh, okay. Well, I think it's a very—it's research—and—but it's a very multi-disciplinary. And it's very fun in a sense that it involves—it's a mixture of many technologies. It's like, in our team, we have IT people who study computer science. We have people who study embedded systems. We have people who are data scientists, know nothing about power. And we have—of course, eventually they have to know, right? And we have people running simulations. So, I would say this is a really fun thing to get involved in. And that's a good representation of what power engineer doing. I think this could be a real recruiting tool to get our newer generation interested. See how things can be interesting, how a power field can be applied to forensics and self-driving or—so it's hard to do a single thing, but I probably didn't distill enough. But that would be what I say.

Sutanwi Chatterjee (47:46):

So, it's basically a collaboration?

Brian Johnson (47:48):

Actually. Sorry. I do want to make sure I can get to my next thing here, because I'm finding a pause here. So, thank you, Yilu.

Yilu Liu (47:57):

Oh, you're welcome. Let's keep it touch.

Brian Johnson (47:58):

I feel like I'm missing out on the part, because you're going to get to the future and—

Yilu Liu (48:03):

Oh, I don't know what the future is. Spoiler alert.

Brian Johnson:

Okay, thanks.

<Sound of door opening and closing>

Sutanwi Chatterjee (48:13):

So, it's basically, it's the collaboration of different engineers from different streams altogether, as you said: power engineers, IT engineers, data scientists. So, all the branches are collaborating all together.

Yilu Liu (48:33):

Yes. That's right.

Sutanwi Chatterjee ():

Interesting.

Yilu Liu (48:39):

Oh, we have a department that's unique. We're electrical engineering and computer science. So that made it happen easily. So, our graduate student graduates as a computer science degree, but work in our lab.

Yilu Liu (48:57):

It made it very convenient. Oh, course we have the computer engineer, electrical engineer, and computer science.

Daniel Molzahn (49:03):

Can I ask one other follow up on this is—so you moved to Tennessee, you already have this affiliation with Oak Ridge, with the folks in the National Lab system, how did that relationship—?

Yilu Liu (49:15):

Oh, that's a—that's a good thing. So, we—people usually know our network as FNET. Right. But after I moved to Tennessee, we decided to—the lab and DOE decided to make it bigger. Of course, it was definitely helpful to make it bigger. And then we give it a name, called Grid Eye. But then people keep saying, “Is that still—how do the two different?” So, I put a slash: Grid/Eye. So, working in the lab allows us to open up much more applications and do some future studies as well.

Sutanwi Chatterjee (50:04):

So, looking ahead, to what extent do you see the solutions we have today as appropriate for future power systems?

Yilu Liu (50:12):

The solutions meaning?

Daniel Molzahn (50:16):

Say, these measurements you control, methodologies?

Yilu Liu (50:19):

Oh, okay. Okay. In the future, this is a good story. We work with Hawaii grid, it's an island grid. It's small, it jumps real quick. And we find that we are hitting the limit in terms of our capability to capture data and our synchronization limit, because they move very fast.

Tari Jung (50:43):

It's moving faster than one microsecond.

Yilu Liu (50:49):

I don't know if I can qualify by saying moving faster than one microsecond. One microsecond is the—one microsecond is the absolute accuracy of data sampling. But it's pushed to the limit in the sense that when we calculate the drop of frequency, right? We need many, many points in order to filter out noise. And we don't have enough points—to—so we have to increase that data density, like 50 hertz, 60 hertz phasor is what the industry use. And that's useless for the—for those change. So that's why the industry moving to synchronized measurement per se, instead of phasor, but pulling away, which can be sampling at much higher frequency. So, in that sense. But overall, if we need to manipulate a much faster system than we do now, we're going to need much more ears and eyes and faster and much broader sensors. Whenever you have automation, you have to have something to feedback for the automation to happen. Those are the sensors. So, this FNET or Grid/Eye, it just one small example, right? We're going to have many, many different measurements, for sure. Increase, and increase the density, maybe accuracy and data rate from today's technology.

Tari Jung (52:39):

Just a quick follow up question on that. So, for the PMU data, for instance, when you first started, you said like the cost of installation, for instance was a really big challenge. Do you think we're improving like synchronized measurement, better PMU, or whatever that might be? What do you think are the big roadblocks that we're hitting?

Yilu Liu (52:58):

I think the big roadblocks is—actually you need—you want to collect the data at a very high data rate, but only some of the time. So, be able to do some kind of intelligent compression and be able to know: what is the time I don't have to record that much, because you don't want to waste your communication pipes to—by getting a lot of useless ambient data. But then to tell it's useless for one person, but it's useful for another. So, to intelligently manipulate, and flawlessly, I think it's very useful. And data compression, the image compression technology is very helpful for pictures, but it's not good for phasor data. It's extremely difficult for this event-filled sinusoidal data. And we're looking at a compression rate of 3, 4, 5 only. For lossless compression. So, we have to look at the lossy, but then the lossy, you have to make a judgment call what to lose, right? I think that's—

Daniel Molzahn (54:19):

So, it sounds like it—you think there's—on the kind of computational side or algorithmic side—there's work to be done?

Yilu Liu (54:26):

Oh, yes. There's work to be done. Also, I'm talking about—because we do large-area measurement, we also do large-area calculations. We use the MMWG for computations. And right now, we couldn't even run a single contingency in real time. We're far from there. We have the supercomputer, but they can only do what they call the, embarrassingly, parallelism. They can solve many contingencies together, but each one is slower than real time. Right. That's—I think, we as an industry, couldn't do this alone because the parallelism sometimes is towards the gaming industry, right. But we have to think about how do we run one case very fast? One option would be dynamic system reduction, but that depends on measurement.

Sutanwi Chatterjee (55:28):

Okay. So, are there any other questions anyone wants to ask?

Daniel Molzahn (55:35):

Just, one thing you've touched on a little bit, Yilu, is the importance of how you've used this with students. The project came out of a—the eventual project came out of the student project. You've used the data with student-related work or related projects. So, what advice do you have for kind of the next generation of students as they're getting into the power industry? I know this is something you care a lot about is educating the next generation.

Yilu Liu (56:00):

I think the first message we tell them is that there's a, there's a tremendous need. Actually, every other week, we would get some industry requesting students. We couldn't make enough of them. Because of this change the industry suddenly needs a lot of new blood and there's a lot of new sectors become—another employment. So, I think the message to tell a new generation is: “This is a revolution going on. This is where you can apply your computer skills, you can apply your, even, any skills.” So, we have the people who are studying history and journalism get involved. So, we are going need people in all sectors—and then they will find way a role in our industry because we are during this major revolution.

Sutanwi Chatterjee (57:05):

That's a very good point. Okay. Any more questions? Okay. So, thank you. Your information was really enriching and useful and it’ll really benefit the coming future generations.

Yilu Liu (57:23):

Good, good. So, did I convince anyone to join our program?

[End of interview]