Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee: Nicholas (Nick) Miller

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***Abstract*:**

Nicholas Miller, MS, briefly discusses his education and shares the trajectory of his professional experiences in power systems engineering. He describes the somewhat unique electric power engineering degree program at Rensselaer Polytechnic Institute (RPI), developed by Eric Gross with funding from American Electric Power. He explains that his work focused on research on bulk power system dynamics. He discusses the technical challenges that arose as the power industry transitioned from regulated monopolies to competitive markets between 1980 and 2000. He describes working on modeling and dynamics of longer-distance power transmission during that time. He mentions early integration of power electronics, the destabilizing effects on systems, and the development of power system stabilizers. He discusses working for Tokyo Electric Power (TEPCO) and lessons to be learned from Japan's need to transmit very high voltage through very narrow corridors. He describes the 1987 Tokyo/Yokohama voltage collapse and resulting blackout. He explains the "nose curve" and the

limitations of the analytical tools available to investigate the blackout. Mr. Miller discusses developing algorithms that operate on very large models – too large for the computer systems of the 1980s and 1990s – and later discerning simpler and more effective models. He reviews the history of his academic department at RPI and the lack of interdisciplinary opportunities. He further describes the functioning of his research unit at GE, its opportunities and limitations, and the nature of its internal and external collaborations. He discusses GE's second entry into wind-power in the early 2000's, when GE acquired Enron Wind. He underscores the importance of being able to model wind integration in order to persuade utilities to add wind to their generating fleets. He reflects on economic and technical characteristics of power systems in the early 2000s. He notes that introduction of new technologies leads to unexpected outcomes at both the business and the system dynamics levels. He considers the pros and cons of a corporate research program vs. an academic research program. He closes by advising students entering power systems engineering to remember that the mission is to make the system clean, safe, economic, and reliable, and to "make your own luck."

<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:

Julie Cohn (00:00:01):

This is Julie Cohn. I'm conducting an interview with Nicholas Miller on July 23rd, 2024, at the Seattle Convention Center in Seattle, Washington. Sairaj Dhople will assist with the interview, and Brian Johnson and Jessica Slater are both in the room and may also participate and ask questions. Daniel Molzahn is joining us via Zoom. Dr. Miller, during today's interview, we're especially interested in your early work on power system control and how it later was carried forward into standardized approaches. But we're also interested in your work on integration of renewables into power grids. We'll begin with some introductory questions and general background information about you. So, if you would, please describe your educational background and your professional positions in the field of power systems.

Nick Miller (00:00:50):

Well, my CV reads that I spent three-eighths of a century at General Electric. So that's kind of the headline. So, I have a Bachelor's and Master of Engineering degrees in Electric Power Engineering—that's a point of some pride. I have a Power Engineering degree, I'm not a double E—that's a pretty rare, pretty rare thing—from Rensselaer Polytechnic Institute, graduated with a master’s degree in 1980, so I'm not actually a PhD. And I think this scenario, this is maybe an important part of the era. I started to look—and I was going to go work for utilities, whatever—and I was introduced to the group at General Electric in Schenectady that has existed for about 120 years. But the company's changed its name regularly, so at the time it was called Electric Utility Systems Engineering. And you gotta go talk to these people.

(00:01:55):

And that group is amazing, was amazing, still is amazing. But at the time, it was the place where the people that wrote the book literally came from. So, Charlie Concordia, Edith Clarke, Mason, Kirchmayer, the list, they all worked at that group. And I was like, "I really have to consider working here." So, I was going to go work there for a few years and then go off into the rest of the world. And a few years turned into 37-and-a-half years. So, a bit of a corporate dinosaur in that regard. I had the same phone number for 37 years, which is kind of mind boggling. Over that time, I developed my, building on my undergraduate, or my training, became a bulk power systems dynamics person. So that's really my core expertise is how to make big power systems work better. Better being more efficient, more powerful point A to B, safer, cleaner, more reliable. Sort of the four pillars of power engineering.

(00:03:09):

And I spent my whole life doing applied research in that area. And that spilled into development of, sort of the topic for today, the development of algorithms, but development of hardware, identification of—so I spent a lot of my life looking to identify problems, challenges, maybe it's a better choice of words, that that hadn't manifested themselves yet. That the industry needed to anticipate. Part of that was as an advocate for GE. General Electric is a big equipment supplier, and part of my role there was to help the company, I don't think we used that language at the time but stay in front of the curve. So, what are our customers going to need that they don't even know that they will need, that GE could figure out how to make, and be ready when they need it. And that ended up being a very fertile environment. And I worked on cool problems for three-eighths of a century with great people. And so now I'm retired, independent consultant, and the world is so interesting that I can't bring myself to check out, so here I am.

Julie Cohn (00:04:40):

Thank you. So, can you help us understand the distinction between an EE and an EPE?

Nick Miller (00:04:47):

Yeah. So again, it's a point of pride. There was a separate department, its own chairman, at RPI, Rensselaer Polytechnic Institute, that had been founded by one of the giants of the industry—had a name that you'll still see around—Eric, E.T.B. Gross. And that department specialized in electric power. So, classes in surge phenomena, insulation design, economics of power system operation, protective relaying, the core skills. And that was, that was central to that discipline. I mean, I learned how to do circuit theory and the other good stuff that double E's do, but that was not the core of my work. So, a true focus on power engineering, and in extremely high demand. I mean, it was a good, economically, choice for me. The utility people, at the time, graduates with power degrees were in high demand.

Sairaj Dhople (00:05:59):

How big was the size of that department?

Nick Miller (00:06:01):

Relatively small. My master's class, I think, had seven or eight.

Sairaj Dhople (00:06:06):

And how many faculty? Do you remember?

Nick Miller (00:06:08):

About half a dozen.

Julie Cohn (00:06:11):

That's a nice ratio.

Nick Miller (00:06:15):

Yeah. Very well respected at the time.

Julie Cohn (00:06:21):

So, were there any other institutions that also offered that degree or was that unique?

Nick Miller (00:06:25):

Not that I know of. There were other schools at the time that had good, very respectable power programs. And some of those schools still have very respectable, world recognized places like Georgia Tech. But yeah, RPI was the gold standard for the US. I would say, "Who's best?" Those are funny things. Second, maybe only to Belgrade. Power program at Belgrade is the best in the world and has been for a century. Tesla's fingerprints left behind.

Julie Cohn (00:07:06):

So, what attracted you to that discipline?

Nick Miller (00:07:10):

I wish I could tell you that it was some sort of prescience on my part, but it was youthful indigence. My dad was a power engineer, very accomplished steam guy. Worked at [*GE*], in the glory days, the golden days of steam turbines developing bigger, higher temperature, higher pressure, high efficiency steam turbines. So, I kind of got to watch that. I grew up in the environment of engineers. So, there wasn't really any doubt in my mind I was going to be an engineer, just because like my dad life's pretty good. This is cool. So—and then a further gravitational attraction I decided I really actually didn't like mechanical engineering all that much. I thought I'd try power for the extremely pedestrian reason that my girlfriend's father was the chairman of the department. So again, one of the great, one of the big names in the industry is Allan Greenwood. So, he ran the Power Department. He's the author of the book on surge phenomena. If you studied surge phenomena, you probably used Greenwood. And he was to some arguable extent, the inventor of vacuum switchgear. So, I don't know, it's like, "This looks fine."

Sairaj Dhople (00:08:41):

Nick, can you say a little bit about the specific technologies that you worked on at GE? You mentioned controlling power flows over long distances. Can you say a little bit about that?

Nick Miller (00:08:49):

Sure, sure. About the time I came out of school, the industry was hitting one of these inflection points that happened sort of every couple of decades.

Sairaj Dhople (00:09:07):

What year was this?

Nick Miller (00:09:08):

1980. Anyway—yeah, so the expectation that we would, that a) that electric power consumption would continue in lockstep with GDP, which had been true for the preceding 40 years. The wheels were falling off that expectation, that, and becoming no longer true. So, the industry was in this strange transition of having been in a mode of build, build, build. It's like, we don't need this stuff. And it started to become uneconomic. So, all of that time there was this change in trajectory and the crumbling of the vertically integrated, completely regulated utility. So those—the bricks were starting to fall out of a wall at that time. And I—my first 20 years—watched that transition.

(00:10:09):

I lived through that transition from vertically integrated to competitive markets. And that had all sorts of knock-on effects in terms of: we're not going to run the system the way we did. There are participants that we—and I got to watch the stonewalling. It's like, "No, you can't do that to us, this is our turf." And that chipped away with the—with IPPs, right? It's like, it was a disease. So that happened. But as a system dynamics guy, we look at that and say the grid started getting used very differently and exchanges between adjacent areas, economic, and social incentives to massively increase long distance power transfer. So, I worked in the modeling and the dynamics of that. GE had and still has actually a first best in class reactive compensation business.

(00:11:18):

I did a lot of work on series compensation, shunt SVCs, controls thereof, how you can make—so I did a lot at work. For whatever it's worth, my research in voltage stability is the citation on my IEEE Fellow. That had, at that same time—so you got this dynamic of the mix of generation is changing, the ownership is changing, the way we're using the grid is changing. And there's all these new—that was about the time power system stabilizers, for example, right? Power system stabilizers, all the seminal development of power system stabilizers, application algorithms and stuff, all came from my group at GE: Swann, Larsen, Piwko, and de Mello. To be fair, the guys up the street at PTI and de Mello.

Sairaj Dhople (00:12:24):

Can you say a little bit more about that? Like, did they come out as a result of a problem that was being seen out in the field? Or did you guys forecast that that would be a problem?

Nick Miller (00:12:34):

History doesn't repeat, but it echoes. So, it's a useful bit of history, quite honestly. In the '70s, as generation was getting bigger and the system was getting more stressed, and as different power electronics technologies started to really infiltrate in places where they made sense, one of the places that—in some sense, power electronics became standard, and, besides DC, right? You've got DC and then kind of everything else was analog and electromagnetic. But excitation was a very early-on adapter of power electronics. It's an important part of the narrative because the power electronics, that allowed the excitation systems on synchronous generation to get faster, really fast, really energetic. And that had reliability and economic benefits in terms of improving the synchronizing strength. So, the generation could tolerate bigger disturbances. You could push power farther; you could get more power out. So, it was—these things—whenever there's these big changes, there's usually some economic, environmental motivation. So, in the '70s we were figuring that out, so it was college students still starting to watch that.

(00:14:09):

So that was in response to, in some sense, a problem, a constraint. I hate to call them problems on the system; we could do this better. The very—as I said, this echoes from what you heard it UNIFI and all the discussion about grid-forming inverters and stuff. The knock-on effect of that was that these extremely high-gain control systems were destabilizing. It's like, God, when have you heard that before? So, the destabilizing effect started to manifest itself when they'd have these big fossil generators, particularly in the western US, big fossil plants, modern, really high excitation systems. And things would sit in their bounds, and then they have system contingency, and they would go unstable. And the people like de Mello, look and say, "What is going on here?"

(00:15:08):

And they did the math and the modeling. They had enough system expertise and physical understanding of the problem. They say, “This is a control problem that needs some bleed.” And that was the genesis of power system stabilizers. We say, “We need another signal, besides voltage, coming in to modulate and modify the behavior of the excitation system, so they aren't destabilizing.” It's kind of grabbing the eigen value and hauling it to the left. So that's kind of the—that's the narrative. You got an opportunity. You got—you make a change, and that change has some unintended consequences and that's the next step.

Sairaj Dhople (00:15:50):

So, this came out of your group?

Nick Miller (00:15:52):

A lot of the—if you go, again, if you go back and look at the seminal papers, most of them are written by people from what was electric utility system in engineering and or PTI. Those guys have—I don't know if you know the history.

Sairaj Dhople (00:16:07):

Please share.

Nick Miller (00:16:08):

We always had like this kind of a Red Sox/Yankees relationship with PTI. PTI Was founded by a core of really very clever, very good engineers, and very good businessmen that got exasperated with the shackles of GE corporate environment. And they had a vision, especially the guy, Lionel Barthold was one of the, a name that you must encounter regularly, Julie, right? He's a giant of the industry. Lionel went and they packed up one day and they said, “Hasta la vista,” to GE and started PTI.

(00:16:52):

And they became obviously a powerhouse that produced power, PSSE. They hired brilliant people like John Undrill, and again, they had Paul de Mello and Wood and other guys that were, again, giants in the industry. And they did a software business. They competed with our GE software. They had a consulting business that competed with us. Went back and forth. And it was mostly good-natured. So, Schenectady became sort of a cluster of the power system engineering expertise that was, and is, arguably still quite important to the industry. There's this rivalry of, practically, siblings that was on for all my entire career. So, it's like we'd go compete against them and bid on projects and—but usually in a fairly civilized way.

Julie Cohn (00:17:48):

In terms of the solutions you were developing, did you, how did that competition play out? Because it would've been less likely to be in the bidding war and more likely in some other venue, I'm guessing.

Nick Miller (00:18:00):

Yeah, yeah. And I, let me leave the PSS stuff aside, that was important. And that became, that became code requirement. GE introduced ways to put it—it was a standard thing. It became a core piece of business to do PSS tuning whenever somebody ordered new things. That wasn't my—what I was doing. But at the same time, so to take a little step, maybe back closer to what I was doing, another piece of the world economic power texture, which ended up being personally important, was, in the '80s, the history lesson, the Japanese economy was absolutely booming. And Japan was, the Japan economy was going nuts. They were buying up Rockefeller Center, and it was like: “We're all going to just be servants to the Japanese economy”; was kind of this mentality. Not to be snotty about it, but it was just like, wow, this Japan economy in that time was just this juggernaut. The largest investor-owned utility in the world is Tokyo Electric power. And they are epically big. And in the '80s, they had—I'll put it nicely, they had gobboons of money.

Julie Cohn ([00:19:29]()):

That's a unit I'm not familiar with.

Nick Miller ([00:19:33]()):

Yeah, well, that's a, it's one of the more, that's a PG version of a couple other words, but yeah. So—and there's this—so there are a lot of corporate and cultural pride in being first. And one of the ways that manifested itself in, not in a negative way, TEPCO had huge research budgets. And so TEPCO's research budget was bigger than EPRI's. One company. And they built labs, and they were pushing, Japan was leading the way in these huge power parks, some of which came back to sort of haunt us. So, I did lots of work on Fukushima.

([00:20:27]()):

Went south. So that, but just, let's just talk about that. The net result of that was, Japan's got real space constraints, and they built these huge power parks that were remote from the urban centers of Tokyo, Yokohama. And they want to transport many gigawatts, many, many gigawatts into the city. So, they were doing work on UHV, thousand KV transmission. Very high voltage, very high power HVDC. Anyway, through a long sort of bit of good fortune, my group, through a mentor of mine at GE, who isn't known to the industry, but was very good to me, established a business relationship with the research people at TEPCO, and we would help them. So, my early work was looking at hybrid HVDC, EHV-AC parallel systems, and how you can control the DC and compensate the AC and get the power reliably and fault tolerant.

([00:21:43]()):

Some of that learning is still germane, and I still blow the dust off it today because one of the things that the US needs to learn: Japanese, being so space constrained, have, decades ago, mastered the art of putting, by American standard, insane amounts of power in very narrow power rights-of-way. Just like an order of magnitude higher power density. And I was always impressed with them. It was like, well, the Japanese are gold plating their system. I say, "Yeah, I don't think we have—." Nick's editorial opinion, which I'm happy to have go on record, is that we do very poorly. We have a century of practice that says, "Land's cheap. We can ride roughshod over the landowners. When we need more transmission, we're going to use more land up." And I am very strongly of the opinion that we can no longer tolerate that mentality and afford that indifference.

(00:22:56):

And there's lessons to be learned from the rest of the world on how to use the right-of-ways that we already have a lot better. And I think we have a societal obligation to do so. And we're doing better in this country. But Nick's, again, editorial opinion is we aren't doing anywhere near as well as we should be. And that's one of my elder statesman things. I go and talk to regulators and stuff and say, "You should be asking on every single thing that you approve: 'what's the power density and what did you do to maximize the power density,' because you owe it to the public to say, 'We did everything we could to use the land that we have in hand to the best.'"

(00:23:42):

Off that soapbox, back to TEPCO. So, we did all that. I did a lot of that work, and we established this fantastic relationship where we would come up with research ideas or they would have problems to say, "You know GE, you guys, your team, and—what do you think—what can you do to help us?" And we would work out research topics and they would fund us. And we worked together. And I did that for all of the '80s into the '90s, until the Japanese economy kind of turned around. This is going somewhere. One of the things is on August 23rd, 1987, it got to 40 C, 104-degrees Fahrenheit, in Tokyo, Yokohama. And the Japanese, the utility is highly prepared for that, right? So, there's a cultural thing, a blackout in Japan. Blackout is a bad thing here; blackout in Japan is a loss of face of epic proportions, right? So, they— so TEPCO was ready for this blazing heat, ready in all the traditional metrics that we understood. So, they had plenty of megawatts ready to go. And in the blazing heat of the afternoon, the grid collapsed. And Tokyo, especially Yokohama, went black for many hours on a workday when it was 40 C.

(00:25:31):

And that was, that was like an existential event for them. And we started working with them. And that was, to date, the biggest and most visible, whatever, voltage collapse that the industry had ever seen. So, voltage collapse is a standard part of the lexicon now. It was not in the '80s. It's like what the devil happened. And we worked—and that opened the sluice gates. So TEPCO was like, "We're working on this, but any help we can get—." So, they started throwing money at us. And we had—so this is algorithmics, so we started looking into the physics and whatever: "what had driven this voltage stability problem?" We started to understand it, and other people were working on it. It wasn't just us—Prabha Kundur was in the middle of that, right? Other giants, Charlie Concordia, were working on it. But yeah. So, we started to understand that they had failed to have the right amount, right flavor, right monitoring of reactive power control in their system.

(00:26:47):

And they had had gone off the end of the nose curve, which, "nose curve," that language didn't exist. Those images didn't exist. That was all developed, including by us, including by me. Not alone, but that was work I did. And that sort of—it's fed back. So, what do we do about this? This is not a transient stability problem. The one that drove the high excitation stuff from the earlier story where you get a fault, the system rips apart. This is a very different dynamic, much slower. It took many ones of minutes, up to almost tens of minutes for the system to come unraveled. So, this is maybe germane to the exploration here, because this is an algorithmic thing. At that time, and quite honestly still today, the workhorse tools, utility planning, are load flow. Load flow is a static tool.

(00:27:48):

It's a snapshot and it's a huge amount to be learned from. And there's good reasons why everybody uses that. And then the next piece of that puzzle, which was sort of the only game then, and it's still kind of true, sorry. Frankly, a little sorry to say, the world has to move forward in many regards. You did transient stability, you ran PSSE, you ran GEs predecessor to PSLF, and you would look at simulations. And simulations were meaningful for the dynamics of the phasor dynamics up to 10, 20 seconds. And then beyond that, those simulations aren't very meaningful. Because we didn't have the models or the algorithms or other kinds of stuff. This event was a dynamic event, but it was slow enough that it was lost in this no man's land between the tools. And we started to get our hands around what was going on.

(00:28:41):

We said, "How the heck are we going to simulate, and develop tools that will keep us out of the soup?" in a world where we had started to get pretty good understanding, but not perfect, it's still kind of—. So, one of the things we did at, with TEPCO funding—and at the same time EDF, France, kind of reached the same conclusion—we started doing a class of dynamic simulations that I'll call "extended term stability." That's what we called it then. It's different in each language. To try to fill that gap. So, to do dynamic simulations that were tractable. Remember this is close to 40 years ago now. So, we've got finite computing firepower, tractable for large systems over many ones or tens of minutes. So, huge development work on that. I personally used to write models and stuff.

(00:29:44):

We'll get to that when we talk about wind, wind plants, because that was kind of more recent history. But we built models of AGC, boilers, load tap changers, these things that operate in tens of seconds, but normally are either, they're either frozen or they're frozen, right? And those slow-acting things are the things that grab a system and drive it into slow voltage collapse. That's exactly what happened. So, we built all those models. Then you look at these things, and we don't have the computer algorithms. You can't run PSSE for 30 minutes. It's going to take a week and you're going to end up with a gigabyte of output, which you say today, "Well, what's the problem with a gigabyte?" A gigabyte was the total disc storage of all of Schenectady GE; that, it's like, no, it doesn't work this way.

(00:30:39):

So, we developed algorithms using things like Runge-Kutta, variable time-step, which meant all the models, GENROU, and all those things needed to be completely restructured. And we built this—it's a cautionary tale on algorithms. We built this monster, and we did a whole bunch of work there, in the late '80s and early '90s. Say, what happened to that Nick? The answer is: we figured out what was important, and we figured out what was not important by doing that work. And it turned out that the important stuff's pretty simple and it doesn't need a whole lot of computing firepower. And it doesn't need that because those, those models took a lot of care and feeding. They were hard to build. You can just imagine that, right? We're having this conversation today on the other side of the spectrum with: you gotta do everything in EMT, right? Because we don't know what's going on.

(00:31:34):

This is echoing, today is echoing that past, except we were on the other side of that temporal boundary. And we did all sorts of work, and then finally came back, I said, "Look, there's a bunch of simple things that are all built into all operating centers now. They monitor the rate, the dynamic reactive power reserves over here at the operating center." Bonneville was the first one to do it, Bonneville Administration's the first one to do it in the US. They started doing it in the early '90s. Everybody does that. They know how many VARs they got. They know how, they know to watch those when they're doing contingency analysis and make sure that they all run out. And it's like, oh yeah, we figured that out. We don't need to carry around this ponderous baggage of modeling and algorithm. Nick's crystal ball says that we will get there with a lot of what we're struggling with UNIFI and other things, but we aren't there yet. So, you don't—you can't throw away the details until you know which details are important.

Sairaj Dhople (00:32:36):

I just want to take you back to one thing that you maybe hinted at. Well, I don't know if this was correlated or causal. So, is it safe to say that these nose curves became popular as a way to analyze the system after the Tokyo blackout?

Nick Miller (00:32:51):

I—one-to-one causality? It certainly was a contributor. There were some events in Europe that were more localized ones that happened in the US. Kundur did some nice work and published it. There's sections on that in the stability book. People like Carson Taylor is another giant in this space, if you encounter Carson, he's been retired for a while. Having said that, the—I don't see utilities doing a lot of that kind of nose curve. And I am, I'm doing research now. I haven't given that up, working with TELOS and others. I believe that that way of looking at the system is going to—is extremely important to us now in an inverter dominant system world. And we will be coming back again, future echoes of the past, won't be exactly the same. But it's not—there are utilities that do that, and they do QV curves as a way of testing their resilience. And that's quite useful. So, we pioneered a lot of that stuff then, and it's kind of had a chance to ferment—whatever—best practice.

Julie Cohn (00:34:21):

I'm going to interrupt and see if Dan has a question at this point?

Nick Miller (00:34:24):

Yes. Sorry Dan, I'm looking past you over there.

Daniel Molzahn (00:34:26):

No worries. I'm on the chair right now. I'm the head in the screen. Yeah, so this is super fascinating. First of all, very, very interesting. I love hearing this story. So, in the spring, I'll be teaching a class on power system stability and control and protection, these sort of topics. And we go through PV curves, and we talk about the nose point of the PV curve and voltage collapse and these things. And I'm planning on sharing this story or maybe this video with the students. And so, I'm wondering kind of the way that we present it now—at least the way that I think in a textbook—you would see this sort of work is reasonably straightforward and kind of intuitive that: you have this point, the voltage collapses.

(00:35:11):

You have too much power trying to flow over these corridors—you run out of reactive reserves. The story sort of is, I think, somewhat intuitive now. And so, I'm wondering if you can and you've done this a bit already, but maybe expand a bit on how challenging was it to get to this sort of boiled down story from this very complicated model? Like, what was the process you used to go from, “We have to simulate everything,” to, “Here's something I can put in a subsection of a textbook”?

Nick Miller (00:35:41):

This is a recurring theme, at least personally, and I think it’s a broader truth. You wrestle with these things, and you start to make connections. And so, one of the things that drove us, and we went down some rabbit holes—that's part of the discovery. One of the things that happened—that's part of the answer to your question—is that the world hasn't changed that much, right? You run a load flow that's out at or past the nose, right? And the algorithm doesn't solve. Just doesn't have a, because you're putting constant power boundary conditions in it. Got it. Right? And you walk out to the nose with your load flow and at some point, the algorithm—usually as you approach the load flow—starts to misbehave and you say, "That's it. I got this."

(00:36:43):

And then you look, you take that piece of information, and you look at what you observed in the field in some of these events, and you say, "They don't— first of all, they don't line up." And it's like, “What's going on?” And then you start to pull on that thread, and you found that, for example, the boundary conditions of a load flow are an approximation to reality. PQ boundary conditions are actually not very meaningful when the system is highly stressed like that. So they kind of—they started pulling on that and you start saying, "Well, we know in this other world that the loads are"—I'm just going to make it really simple—constant current, and all of a sudden if you take that mapping in PQ and map it to a current voltage space, all of those boundary conditions twist, and all of a sudden the nose goes away and it looks different.

(00:37:54):

And it was kind of that. It—now this is like, “Yeah, of course, Nick”; but it took us a while to get there. And we went, some of the rabbit holes we went down where we—you can draw a nose, right? You draw, you draw a nose curve, sorry, for my—<gestures>—my audience, right? And then you see my boundary conditions are power, right? That's a vertical line. It intersects the curve twice. The top part is the stable one, and the bottom part is nominally the unstable one. If you do the math, you say, "There's no attraction; this is the inverted pendulum on the bottom."

(00:38:35):

And then you look, and you say, "That's not—." The power system stayed there—for minutes. “What do I do with that piece of information?” And you find out, if I remap that so that I reflect the behavior of the loads served, you're coming into that boundary condition from the outside in. It's not quite a Nyquis criteria sort of thing, but it's, and then then the math says, "Oh, that actually is no longer an inverted pendulum. That's a stable equivalent." So, we went through those kinds of things to sort of get to the point. It's like, yeah, you can—a real power system. And I actually—one of the rather good papers, if I might brag, we did with right here with Puget Sound Energy. And they were looking at the challenge of pushing power across the Sierras into where we're sitting today on the 500 KV, series compensated.

(00:39:37):

And they wanted to—they were starting to look at this thing and say, "We're in the soup if we have a double circuit contingency on one of these 500.” It's like trying to get your hands around it. So, we work with them. And we use this massive tool to model this region. And we show it, and you watch the system and then you take that, and you map it into PV space dynamically. And sure enough, there's the world going out around the nose and down into the toilet and say, "Got it, those pieces fit together, so don't do that." And those—that's kind of the journey that we went through. And now everybody, you kind of—they may not articulate it that way, but you know not to do that. So yeah, it's like, you kind of beat on this thing with a sledgehammer and then you find out all you needed was a tack hammer. But that's part of the journey. So, did that help?

Daniel Molzahn (00:40:36):

That's really fascinating. I mean, I think that that's, that's perfect. That's exactly the, what I was wondering. I did have one other question, Julie. If you go back a bit, to much earlier in the discussion, you were talking about your graduating from RPI with this electric power engineering program. And I was just curious, how did that department—this electrical power engineering department—sort of interact with other groups, both at the university, in industry, and other places? Was it kind of really distinct from the kind of collaborations and intersections you would see in a more traditional electrical engineering department? Or was the fact that it was its own department really distinctive in sort of how it operated and how it collaborated?

Nick Miller (00:41:28):

That's an interesting—so I—at the risk of speaking ill of the dead, particularly my father-in-law, it was quite distinct, and proudly so. Some of the genesis of the department was funding from Phillip Sporn, who not only was a brilliant power engineer, but also was a brilliant businessman, managed to get himself stinking rich while he also changed the world. And he funded a lot as a vision. So that was American Electric Power, right? Which is like—that's the big dog. So that's the reason why. And there was always that. Now, so that's all. So, there's a sense of identity, a sense of partnership and service to the world power industry. There's lots of students from all over the world. So, in that sense it was open.

(00:42:24):

And—but the other part of your question, I will say, looking through the filter of the past, was—it was unfortunately disconnected, not utterly, but inadequately connected to all the other disciplines that were available at RPI. And particularly quite honest—and this is one of my soapbox items that I worry in UNIFI, ESIG, all of this—is not only do we need economists, so this is like, the RPI program was volts and amps, this is—there'll be a weenie here. Volts and amps are what's real. All this other stuff, we give you watts and vars, but money, that's like—other than make sure you make the equipment not too expensive, and that was myopic, even then.

(00:43:30):

And certainly—so that's unfortunate. I think the good power programs in other schools these days have much closer alignment with the business schools, other sorts of things, because they aren't separable, and they should never have been. The other part that we'd still like—next opinion, always a next opinion—is that we don't talk to, for example, the sociologists enough. So, I'm very much willing. It's like, what is it that makes people tick? Because you got engineers like me, it's like people are economically rational. They'll just do the least cost thing. And you know that that's garbage That's not the way people make decisions. And we keep learning that. And they put some price signal out there and everybody ignores it. And then all the power people sit around and say, “Well, what's wrong with these idiots? They aren’t responding to my price signal.” It's us that are the idiots and that exasperates me. So, the next—the current generation of power programs needs to be connected not only to the business schools, but to the social sciences, if we're going to be taking care of society the way we are obliged to be doing. Alright, another soapbox item.

Daniel Molzahn (00:44:50):

Nick, we appreciate that. I think we're going to pull some quotes from what you just said and put it in our next grant proposal with the historians here. So yeah, that's fantastic.

Julie Cohn (00:45:00):

Brian, did you have any questions?

Brian Johnson (00:45:01):

Yeah, actually I had a question. It's on a similar line here. Can you give me a clearer picture of how that unit at GE functioned and interacted? It sounds like in a way, your business model and that group was, you're selling research in a way. And I'd like to also know how that group related to other academics and the world at large. I'm just trying to get a picture of this.

Nick Miller (00:45:29):

Yeah, well it's, it is a good question. And again, maybe, to some extent, not to some extent, another point of pride. It was a pretty unique operation. All the history, not the history, withstanding, the history was important part of it. And Steinmetz—Steinmetz understood that the future of GE was more than just making widgets. It was being leadership. And he—so, the group started, I think its first name was Central Station Engineering, or something like that. But to answer your question, it was fraught, right? So, you had this corporate giant, right? GE still is, but at the time it was just an epically big company and made steam turbine generators, nuclear plants. Big stuff with big prices on it. And this little group of about a hundred people—which interestingly enough, it's been basically a hundred people for a century—never fit in like the MBA vision of the world.

(00:46:51):

There'd be a change in management, because that's one of the things that happens in the corporate world, and somebody come in and they'd have their org chart and it's like, "What is this? What is this little bubble over here? Who the hell are these people?" And then it is like, "Why am I bothering with this business that's ones of millions or whatever small on the corporate sense." And then the light would go off after they'd been at it for a while and say, "Oh, these are the guys—these are the people"— I'm actually quite proud of the fact that it's always been quite a diverse group, so it's not just guys—"that put the pieces together." And then they'd be like, "Oh, okay, yeah, you're valuable." But we were always independent from the businesses.

(00:47:44):

So, it became a very important piece of the puzzle from a credibility—and advancing the technical boundaries. We were never in the business of: "we're going to do a study to show you that what you need is something that GE makes." We never did that. And we kept our integrity that way. We would say, “This is your problem, this is the class of solution.” And if it was: “GE’s got a product that does,” that's fine, but a lot of times it would be, “There's nothing out there right now that really fits your needs.” And occasionally we'd be, “The other guys make this, and GE doesn't.” But that was serving the industry very well. So, you come back and say, “This is a need.” We would tell the corporate guy, business guy, say, “We see this coming; you should start working on a product that does XYZ.”

(00:48:39):

But then we would get paid to do that. So, a significant amount of our revenue would be from outside customers, from utilities. And we did a lot of work with EPRI, later years—Department of Energy, as I said—TEPCO, so we covered our costs. So, the corporate scalpel never was motivated to cut off this appendage that nobody really understood. It was a delicate balance. But, for me personally, that was an incredibly stimulating and exciting environment, because it would be like, “We're doing real stuff.” We got a customer that's come to us with something that's like, “What the hell is happening,” or “What can we do about this as it's costing us a fortune, and the existing methods to fix the problem are uneconomic, what do we do about it?” So, there was a constant stream of doing new stuff, which maybe, let me fast forward because you've been asking all these questions. So, a few years before I joined GE in 1980, GE gave up on wind power and closed down the business. They couldn't figure out a way to make money at it. It was a classic: ahead of your time. So, this is one of these learning things that I've been through many times in my career: good ideas aren't sufficient, the timing is important.

(00:50:00):

So, the companies like Vestas in the US, the late '90s, you start to see California's building wind turbines and you're doing this. And the uniform utility view of that world was basically: these are curiosities, these are irritants, this isn't real stuff. And it started towards the end of the century to become apparent to some that this was a piece of the future that GE should take more seriously. And in 2002, GE—I forgot the year right, it's close enough anyway for this discussion—again, the world changes on the backs of individuals that have visions. And that's even true in the corporate world. So, there was a guy that was chief engineer at the RD center and had very good credibility within the company. He said, "We gotta do this. GE’s gotta get into the wind business."

Sairaj Dhople (00:51:15):

What was his name, Nick?

Nick Miller (00:51:16):

His name was Jim Lyons. And he convinced the corporate masters that this—and we bought a small company at fire sale prices; that was Enron Wind. And so, if you're students of history, you'll recognize the Enron name and around 2002 was when the wheels fell off. You say, "What the hell? Enron had a wind manufacturing business? How does that fit?"

(00:51:49):

And the answer is: I don't know how that got there, but it sure as hell didn't fit. And they had some good technologies. And that business was actually the very poorly executed merger of an American wind turbine manufacturer and a German. And they had taken, Enron had bought the two pieces, and slammed them together and GE bought some good basic technology, some very good basic technology and a whole lot of institutional organizational dysfunction, which GE, in its inimitable fashion, went in with a meat axe and hacked up and stuffed in some new people that had no idea what they were doing. And the whole thing was a carnival—sorry, editorializing. I get to say this too because I got to watch it—but again to Jim Lyons' and others' credit, they said, "Okay."

(00:52:51):

And that was a seminal moment for the power industry, because it's like, the big dogs, right? GE is now in the wind business, wake up, this is no longer a sideshow. And I don't want to denigrate a giant successful company like Vestas. Vestas is the biggest, but Vestas is huge by Denmark standards, huge by any rational standards, but it was peanuts by GE standards. So, this is GE and all of a sudden you see

Siemens waving, saying, "Oh right.” That was a really important piece of the piece of the world's “texture"—wait, is that the right word? I don't know, whatever—moving towards wind.

(00:53:33):

Enter Nick, because this is another point of pride for me in my career. It came in and within literally within weeks of the acquisition, I was working with the RD center in the new company and it's like: “how do you go to utilities to get these plants built?” And it's like, “how do they model the wind plants?” “Oh, that's secret, you can't tell them, right? All that stuff about the wind turbines is secret. You can't let anybody know how we run these things.” I had, at that point, 25 years of experience, 20 plus years of experience in modeling. And I made the case to GE management—so again, this is a point of pride for me, because I had the foresight to see this—and say, "If you are going to be taken seriously by the utility industry, you gotta play by their rules.”

(00:54:35):

And the industry isn't going to build a power plant that they can't model in PSSE. And they gotta see block diagrams. “Don't gimme this black box crap. You're not going to build that stuff on my system." And it's like, "Oh yeah, it's secret; you're going to give away the family jewels, man.” It's like this is a death sentence for your business if you don't do this. So, I lobbied within GE Wind at the time to say, "We gotta do this." So, one of the significant break points was the document of the team I led in 2003. You can still find the thing posted. It's modeling of GE 1.5-Megawatt Wind Turbines. And it's got block diagrams and data. And we deliberately structured it; my team deliberately structured it so it would look and feel familiar to utility people. So, if you go back to that, and you still see it in the IEEE, the DNA in the—even in the current IEEE models is recognizable from 20 years ago when my team built these block diagrams. And there's a block that's the generator block, right?

(00:55:54):

It's the moral equivalent of GENROU. And there's a block that's the electrical control; it's the equivalent of the excitation system. And there's a block that is the turbine; it's the equivalent of the turbine governor. And that was very deliberate to increase the comfort level for the utility. And it's full of simplifications. Those models had some limitations, and we knew that there were simplifications. But we used to go out and present these things and well, there's all sorts of other stuff in there. I said, "Look, I had a talk, I think—you have GE gas turbines on your system, right? You're utility guys. And here's the model, right?" What's the—what is it? GENROU? And it's got a GAST—sorry for talking in code, but those are the standard models—and say—so GAST, the model of the gas turbine has four state variables, about 10 parameters: it's a model of gas turbine.

(00:56:54):

The guys in the building next to me that designed the controls of gas turbines have models that are 3,000 state variables. You don't put that in. The industry has always accepted that these big system models have, are approximations to reality. And you, the pushback I would get, it's like, "oh no, no, it's gotta be perfect." Sound familiar? I was like, "No. It's gotta capture the stuff that's important to what you're studying and not have all the other crap in it." And that was a battle that I fought for a couple years. I mean, there was a few iterations on that. And quite honestly again, I'm kind of proud to have forced that through GE and it really made a difference to the industry. It's like, here's another model, here's another model. Now it turned out that we put it, listening to those voices. If you look and go back to that model, you'll see the turbine model that we proposed to the system, which is immensely simplified from the actual wind turbine controls, is crazy complicated. And in later years IEEE and people like Deepak [*Ramasubramanian*] and Abe Ellis said, "We don't need all that stuff." So, the turbine model that is standard in—standardized—is significantly simplified further. So, there's some learning there.

Sairaj Dhople (00:58:20):

So, Vestas and these other companies did not have similar models?

Nick Miller (00:58:22):

So, they did not do that. And we, and they were dragged, kicking and screaming just like GE was. It's like, you're not going to sell our stuff until you give us a model that we could see. But we were first, my team was first. And quite honestly, that was one of those things, again, as I said, a point of pride, that was really good for the industry, forcing that issue, brought it into the fold—this is another flavor of generation. And it was good for GE, because we set the tone and it was a significant—you can't monetize that, but it was a significant term. You'd have utility people out there. I remember—again, another point of pride—I was in an airport, I ran into this guy that had worked at New York ISO, was now at a utility in the windy part of the country.

(00:59:11):

And he goes, "Hey Nick, how good to see you!" And he goes, "Hey, we're closing the deal on a new wind plant here. And we scored the GE turbines; we got the good ones!" Cool. You live for those kinds of things in a competitive world. But that was partly because they knew how they were going to work, and we didn't get everything right. We—I didn't—my team did not anticipate connecting wind plants into 1.5 short-circuit ratio grids. But if you look back, those first-generation models had closed-loop voltage regulation. They had the frequency control stuff before they were being required. So, I led teams that were working on that too, and I would get pushback from GE.

(01:00:11):

It's like, look, here's a future that will make these plants really work well, particularly in the kind of lonesome expanses of the grid where: wind plants. It's like you gotta have, and wow, “well man, what could we charge for that?” It's like, what's it—how does my customer monetize that? It's like, yeah, the plant's going to work better and the grid's going to be able to build more wind plants. “Yeah, but that doesn't manifest itself as economic—as a price point on this project.” And that debate that, does that sound familiar? But there was enough wherewithal to sort of say, “We, GE, are not going to lead a race to the bottom, we want to set the standard for performance.” And they listened to me at times. And we did a lot of that stuff, and it was good. Turned out to be good business.

Sairaj Dhople (01:01:18):

What happened in 2002 specifically for them to acquire this business?

Nick Miller (01:01:22):

Well, I think again, there's—it was this guy, Jim Lyons, basically kept harassing people at corporate.

Sairaj Dhople (01:01:28):

And wind is going to be a thing?

Nick Miller (01:01:29):

This is real. You should spend some money and take—and you gotta—there's a little bit of corporate—I don't—culture, I guess, is the word I'm looking for. And big companies have to take gambles to stay in. Like, GE's doing all right? We're going to buy this. I think we buy companies regularly and kill them. I mean, that's corporate reality. And not, not deliberately kill them, but kill them out of—and then sometimes you do acquire things that it would be just a home run, say this fits, and off you go. It was that kind of thing.

Julie Cohn (01:02:05):

So, by the early 2000s, quite a number of states had adopted renewable portfolio standards. Did that influence decisions at a company like GE?

Nick Miller (01:02:14):

Yeah, yeah, for sure. This is a, this is a signal that there's going to be a market for things. And those RPSs were just starting to kind of—what is this? And the grid code, very early days of grid codes, were like, what? So, there was—

Julie Cohn (01:02:32):

Was there—to what extent was GE wrestling with the chicken and egg problem for wind? In other words, parts of the country that were really promising for wind development didn't have transmission capacity to make use of it.

Nick Miller (01:02:50):

There's always this—I would say that that particular aspect was not all that front and center in those early days. It was some mentality of cannibalizing the fossil business. GE made its big money, it still makes its big money, in many regards, in the fossil business. It's like, why are we doing this? These big kinds of issues that we're wrestling with now, where it's just saying, "This area is getting saturated." We weren't there at that point. Certainly, a lot of the work that I did on controls and stuff was more “Nick's shtick,” right? People don't like to live where it's windy. It's like, transmission systems tended not be robust and they weren't built, purpose built. It's like, how can you make it so that our customers can build a wind plant in a place where there's good wind and get the power out without getting crippled by the cost of transmission reinforcement?

(01:04:10):

But it was very, for many years, and it's still to some extent, very transactional. I don't think it was a holistic thing. But I'll pick up, let me pull out one thread because it's something that I was highly, highly involved with. And maybe a cautionary tale in terms of being ahead of time or not time at all. I published the first work on what GE branded “wind-free reactive power” in 2007 or '08. So, this is close to 20 years ago. And that's the idea that you can have the inverters stay active and effectively be STATCOMs while the turbine is stopped. And at the time, I lobbied GE, and I said, "Here's a concept here. This is a thing that would be value-added for our customers, that doesn't have significant hardware cost implications; it's brains."

(01:05:20):

Let's offer that after some develop—develop it as a product. With the, as it turns out, wishful thinking that there would be organized markets and other kinds of things to reward the plant owners for having that functionality and to get paid for providing a service. Here we are 20 years later and I'm still waiting for that. You see, that's a little discouraging. On the other hand, it ended up, this is germane to your first question, it ended up that GE actually sold that feature quite often. And the reason why they sold it is that at the interconnection study, the facility study, they said, "I want to put a hundred megawatts here out on this 161 KV line in the middle of nowhere." And managing the voltage is ugly. And if you're going to do this by the usual methods, you've gotta manage the voltage when the turbines stop. And you get these high voltages and it's like, you're going to have to pay for shunt capacitor banks or SVC or whatever. And say, "Ah, having this feature in the plant will avoid other capital costs to connect there."

(01:06:52):

I used to laugh too. So, this is a feature. That's a corporate way of saying that we charge for it, right? Unapologetic. And it didn't actually have much in the way of capital cost on the equipment. But see, it's true for lots of things you buy. When you buy a car, it's like all this stuff's built in. You want that switched, or not, that'll cost you—and GE did that. So anyway, what's the point? Transactional, localized and always some kinds, there's unexpected outcomes when you introduce a new technology at a business level as well as at a system dynamics level. That ended up being quite a successful thing and it became a competitive advantage, again for GE, because they could buy the turbines from GE and have that feature and have a cheaper interconnection, and frankly, a better behaving interconnection. It's the utilities that we have too. The voltage is good in the middle of the night when it's not windy and middle of the day when it's not windy, whatever.

Julie Cohn (01:08:02):

Your research group operates in a really unique space, because you're within a corporation, but you can, you have a lot of latitude in the types of questions you choose to answer or investigate. What would you characterize as the pros and cons of being in that unique space versus being in a university-based research organization?

Nick Miller (01:08:33):

I can answer that. This is what I wrestled with. First of all, the pros, which from a personal point of view, and also from an institute, from a—what's good for the society is, and it's still true today, I'm not plugged into that anymore, is the people that are still in that group. So, one of the current grand masters that future generations are going to look back to is a guy that's here in Seattle named Sebastian Achilles. And Sebastian runs the core. And he—and the engineers, young engineers, so he's got a team, are privy to the most intimate reality of the technology. They know what's going on in the heart of the equipment and where its weaknesses are, how it performs. How, at a level that is absolutely impossible for a university academic to get to.

(01:09:42):

This stuff is secret. “Now we can tell you, but we'll have to kill you.” And that's a real event. So, like this latency thing that I talked about, right? That stuff is—they are right there. And that has enabled that team to continue to make innovations that aid the industry at a level that you just couldn't get as an independent or an academic. So that's the plus side. Minus side is always the perception that you're part of this big corporate thing and you're there to represent—you're there to sell me GE'S widget, not whatever; we can't trust you with the gory details of a Siemens widget because you're the bad guys.

(01:10:39):

And there were times, many times in my career when it was like, now we can't use you guys. We need to go to an independent. We need to go to PTI, before PTI was Siemens. We need to—and really good consulting houses. And also one of the best in the world, in Nick's opinion, is Electranix, right? Dennis Woodford's group and Andrew Isaacs and stuff. And those guys have thrived in that: “we are independent and skilled so that you can have the secrets from multiple places come in and be handled competently and secretly.” And that was always a challenge. To my mind, that's kind of the biggest. In general, I'm very supportive of academic research and the kinds of stuff that are going on in UNIFI, whatever. The role of the Department of Energy, the role of research groups.

(01:11:38):

That is to be going a little bit farther afield and asking some of these impertinent questions. Asking some of the blue-sky questions. Like what if what we just take all this stuff and shovel it aside and do, you know, blue sky blank paper? We didn't have the luxury to do that too often. It was really too expensive and—there's very much a role, a healthy role for asking the impertinent questions at the academic level. The challenge for academics is always to—at the same time that they're going to field is to stay grounded, and to stay current. It's like—there's this time lag. And I see work done in power electronics, in academia, and say that "you got assumptions that have been technically obsolete for years, built into your models, because you're not paying attention." So that's the risk on that side, and time and money gets wasted with bad oversimplifications or bad information.

Julie Cohn (01:12:58):

We have about five minutes left. And I know that there are probably other questions people are wishing to ask. Jess, would you like to—?

Jess Slater (01:13:10):

I have three questions, but I know we're short on time, so I'll ask the one that benefits me. So, you mentioned the importance of including social scientists, like sociologists, how do you envision this collaboration to look like? And what outcomes would you hope to achieve through that sort of interdisciplinary approach?

Nick Miller (01:13:29):

The short answer is: "I'm not sure." But I'll give you a longer answer, because that's what I do. There are places that I could see a little bit more narrowly. There's some real value. And one of the things, another one of Nick's soapboxes, is that the old paradigm of the power industry is: customers are acts of God and they are kind of unknowable and uncontrollable. And our mission as a utility, as the power industry, is to serve them electricity no matter what. We don't have the luxury of that ridiculous bouillon. And the future means that customers, whatever that word means anymore are going to be active participants in every piece. And they're going to respond to policy and they're going to respond to economic signals. And that was my earlier thing. So, the collaboration there is, we need better research on understanding what makes people tick. And there's good stuff out there, but the power industry ignores most of the good stuff, and the fact that there's first adapters and all that, I don't know all the language that goes with that. But the notion that customers are some monolithic thing is a completely garbage. And any sociologist will know that. And utility power people just like, "Yeah. Customers." It's like, a singular noun. So that's the need. How that conversation takes place? I don't know, but it needs to. It needs to get framed.

Jess Slater (01:15:19):

Thank you.

Julie Cohn (01:15:21):

Thank you so much for sharing your perspective on so many aspects of the work you've done for all of us for a long time. Sairaj has a usual closing question, so we'll use that to finish out the interview.

Sairaj Dhople (01:15:38):

This has been very educational. And in that spirit, do you have any words of advice for future generations of power engineers?

Nick Miller (01:15:46):

Oh, yeah. Make your own luck.

Jess Slater (01:15:53):

So, I have that question, but more specific. So, reflecting on your experiences navigating the evolving economic landscape over your own career, what key lessons have you learned—and we can skip that part if you want—but what advice would you offer to students aiming to adapt to the current economic shifts within the power industry?

Nick Miller (01:16:15):

I think it fits with these different questions and my criticism of my experience at RPI. There isn't enough power people learning some of the fundamentals that I learned. So, to some extent that's problematic. When I add on top of that, they need to have the economics, and they need to have the sociology pieces. And they need to look at the reality that the industry is changing and come into it with the—with a view towards—that they want to be part of this change. And recognize that there's opportunities; you've got a chance to make the world better.

(01:17:02):

And it will—one of the—it is a service industry and everybody, including the old geezers like myself, that really make a difference, get it. We are in the business of serving the society that we are part of. We really aren't in the business of making money or doing anything else. We have a societal obligation to make this work, to make it clean, safe, economic, and reliable. And there's an army of people in this industry to get up and live that. And as a young person, it's like, "yeah, this is a community that I want to become part of." It's a lot more than volts and amps. So that's the advice.

Julie Cohn (01:18:03):

That's a perfect note on which to conclude the conversation. Thank you so much. We really appreciate your time.

Nick Miller (01:18:10):

Lots of fun. I love to talk.

[End of interview]