Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee:	Anjan Bose and Bruce Wollenberg
Interview Date:	May 26, 2025
Place:	Department of Electrical and Computer Engineering, University of Minnesota, Minneapolis, Minnesota.
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Keywords: Anjan Bose, Bruce Wollenberg, Bill Tinney, Gauss-Seidel, sparse matrix, General Electric (GE), Westinghouse, ABB, American Electric Power (AEP), Leeds & Northrup (L&N), Bonneville Power Administration (BPA), Eric Gross, Rensselaer Polytechnical Institute (RPI), IBM, Mike Adibi, Power Technologies, Inc. (PTI), Control Data Corporation (CDC), energy management systems (EMS), Power Industry Computer Applications conference (PICA), resource adequacy, Loss of Load Probability (LOLP), Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), analog computer, digital computer, Automatic Generation Control (AGC), Bureau of Standards, Bahman Hoveida, Open Systems International (OSI), Supervisory Control and Data Acquisition (SCADA), FORTRAN, John McDonald, Ned Mohan, MATLAB, 2003 Northeast Blackout, Midcontinent Interconnection System Operator (MISO), standards, IEEE Herman Halperin Electric Transmission and Distribution Award, IEEE Power & Energy Society Lifetime Achievement Award, Ian Hiskens, Fred Schweppe, Kevin Clements.

***Abstract*:**

Power systems engineers Anjan Bose and Bruce Wollenberg engage in conversation professional experiences and observations about changes in the electric power industry. They begin with a discussion of relationships between academia and industry. They recall that power meetings were dominated by industry representatives until deregulation, at which point industry people “disappeared from conferences.” They recall contributions by Bill Tinney and others who worked for utilities and the

excitement of meeting these individuals at conferences. Now the same organizations are dominated by academics. They describe the earlier international prominence of utility research and development teams and installations. Wollenberg recalls working at IBM and learning about digital computing used to run the American Electric Power (AEP) Company's power system and switching to power systems for his Ph.D. Bose and Wollenberg recall the shocked response of industry when Mike Adibi described using digital controls of Automatic Generation Control (AGC). The two recount a joke about this colleague and the phrase "bon appétit." Bose asserts that deregulation led companies to limit investment in research and development. He notes this has become especially problematic for addressing resource adequacy. Wollenberg adds that deregulation had some advantages for companies introducing new and more efficient generating technologies. They then turn the conversation toward decarbonization, raising questions about who is responsible for resource planning and how to address the intermittency of wind and solar. Bose emphasizes that traditional calculations for resource adequacy are no longer appropriate, but new calculations have not yet been developed. Wollenberg reflects further on the introduction of digital computing and control to power systems. He recalls the origins of Leeds & Northrup Company (L&N) and their manufacture of strip-chart recording instruments. He underlines the importance of changes in computing and new software development as drivers of change in power systems. Bose further explains that the introduction of Supervisory Control and Data Acquisition systems (SCADA) into power system control rooms led to a big shakeup in the industry. Software development companies overtook traditional instrument manufacturers in serving power industry needs. Wollenberg adds that it took 10-15 years for the industry to adopt energy management systems. The two trace computing evolution from programming load flow problems on very large computers to the speed and facility of using MATLAB on personal computers. Bose then distinguishes the work of academics, who focus on algorithms, from the work done in industry, which takes into account the full context of system operations. He notes that both he and Wollenberg had great working relationships with industry after they moved to academic institutions. They both reflect on the events and individuals that influenced their respective moves from industry to university settings. They recall a short course for control room operators and others from industry that they taught together at Arizona State. They further dissect the split between industry and academia, noting that utilities don't have the people who might engage in research, while academics have become narrowly focused on publication of research results. They talk briefly about AI and power systems and about the recent blackout on the Iberian Peninsula. Bose answers a question about resource adequacy and planning, noting that NERC standards are needed. He suggests that academics have not yet produced the algorithms needed to address the greater complexity in power systems today. Wollenberg discusses the difficult and lengthy process of producing standards. The two dwell briefly on the 2003 Northeast Blackout, the 2005 National Energy Policy Act, and the changing responsibilities of FERC and NERC. The share plans for participation in the upcoming IEEE Power & Energy Society meeting at which each will receive significant awards. They reflect on the origins of their professional and personal friendship. Wollenberg shares an anecdote about Ian Hiskens and the birth of one of his children, illustrating the way in which these professional friendships are longstanding. The two discuss a story about the first installation of an energy management system in Milwaukee, a competing claim by Commonwealth Edison in Chicago, and Wollenberg's role in the project. They recall Fred Schweppe's work on state estimation, and the difficulty of installing state estimators correctly. They close with discussion of an effort to write an algorithm to solve a problem with implementation of state estimators that was curtailed because computer memory was simply insufficient.

Note regarding Transcript and Timestamps:

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 (00:00:04):

This is Julie Cohn. I'm conducting an interview with Anjan Bose and Bruce Wollenberg on Monday, May 26th at the University of Minnesota. Sairaj Dhople will assist with the interview. Daniel Molzahn has joined us online from Georgia Tech University in Atlanta, Georgia, and there are some graduate students and additional faculty here as well. Doctors Bose and Wollenberg. It's delightful to have the opportunity to chat with both of you together. Your work in the power industry over several decades has no doubt resulted in many experiences that will be of interest to those within and beyond the industry for years to come. While Sairaj, Dan, and I have a few questions we'd like to ask, we also hope this interview will allow you to share some stories and ask each other questions as well. To begin with, I'd like to note that between the two of you, you've witnessed research in the power industry and manufacturing and in academic settings over a very long period of time. So, I'm curious to know how has the research relationship between those two sectors evolved over time?

Bruce Wollenberg (00:04:30):

That's an interesting point. When I first started, you'd go to a power meeting and the industry people were very, very nervous if too many academics presented papers. They didn't want academics chairing committees. And they wanted—well, in the beginning, you had to present your paper and get discussion, and then they would put that in the transactions. And so, I think you were—you remember that don't you?

Anjan Bose (00:05:16):

Oh, absolutely.

Bruce Wollenberg (00:05:17):

This antagonism between academics and people from industry. And that lasted until the '90s when the deregulation came in and suddenly the utilities didn't want to spend the money to send people. So, suddenly a lot of the industry people disappeared from the conferences and the academics always came in full force.

Bruce Wollenberg (00:05:52):

And so, they took over a lot of the committees and stuff like that. And many of the older industry people were biting their nails and just thinking, how on earth are we going to survive this? But that was, that's one of the differences. It wasn't so much a difference of—because the academics solved a lot of very important problems. But so did the industry. I mean, Bill Tinney introduced us to the Newton method and to sparse matrix methods, which just blew the lid off of a lot of work that had gone on for a long, long time with Harvey Happ and diakoptics and Nathan, no, not Nathan Cohn. What was his name? Kron. Gabriel Kron. Your dad didn't get into the power flow stuff. He was in controls. But on the other hand, there were a lot of very, very fundamental papers, I think of Brian Stott's papers on the decoupled power flow and so forth. So, as far as I was concerned, both sides, if you will, certainly contributed deep, deep insights into the power systems and how to solve problems. The first power flow was the paper—I used to remember their name—weren't they from Iowa State? Not Anderson and Fuad, but—

Anjan Bose (00:07:38):

Hale, Ward and Hale.

Bruce Wollenberg (00:07:39):

Ward and Hale. I think they were Iowa State.

Anjan Bose (00:07:42):

Yeah. They were at Iowa State

Bruce Wollenberg (00:07:43):

They wrote this paper, which I practically memorized when I was first at L&N. The so-called Gauss power flow— Gauss-Seidel power flow. And I heard Bill Tinney give his paper on the Newton power flow. And it was like an explosion. Suddenly everything else changed. Everything changed radically. And then Bill wrote dozens and dozens of papers over the next 20 years or so on sparse matrix methods and special applications and things that you could do. And he really advanced, so there were deep contributors from both sides. Wouldn't you say that?

Anjan Bose (00:08:40):

Yeah, I think when Bruce and I kind of started our careers in doing research, and doing things, I think it was a—sort of golden years of power engineering research, because industry did as much research, publishable, peer-reviewed research, as much as academia. In fact, they may have done more. And so we were, Bruce was in industry, so was I, when we got started. But I moved to academia. But we always went to these conferences where many, many of the papers were being presented by industry. And that's not just the GEs and the Westinghouses, or ABBs of the world. It was Philadelphia Electric, Pacific Gas and Electric, all the power companies—American Electric Power, they probably wrote more papers in those days than anybody else.

Anjan Bose (00:09:47):

And they were talking about actual applications on their own data, on their real-time data, on controls, on—and that was an amazing place. The conferences where these things were presented. For people like us, at a young age, learning from people like your father and, and Kirchmayer, and Bill Tinney, and all of these people, just amazing. And on top of that, the stuff that we talk about today, about open access and all of this, in those days, Philadelphia Electric would write the power flow and give it to everybody. Right?

Bruce Wollenberg (00:10:34):

Bonneville Power did too.

Anjan Bose (00:10:35):

Bonneville Power wrote the—give it to everybody. Not everything got, I mean, like Leeds & Northrup patented Nathan Cohn's controls and those kinds of things. So, there was a mixture, but the fundamental stuff were always free flowing.

Anjan Bose (00:10:55):

And—that did change in the '90s, and for the worse, because what they did was they stopped all of this kind of development of software, power flows, and things like that. Bonneville Power Administration, you can't even find their software today. In fact, the only people who keep up the Bonneville Power Administration transient stability program are the Chinese. They still use it. And none of us use it here. The whole thing has changed. And I would say it's not changed for the better. Once industry, especially the power companies, gave up all their R and D departments. If you now look at the conferences, they're mainly academic conferences. There's very little, and in fact, the people who should be putting out papers—like, Bruce has worked for Leeds & Northrup and then with the—now Siemens, but at that time was Control Data, and PTI—those papers and things were all being presented at a time. And now how many papers do you see from Siemens being presented anymore?

Sairaj Dhople (00:12:16):

So, it seems to me, if I'm just catching off of what Bruce said, that somehow deregulation was the turning point?

Anjan Bose (00:12:23):

Yes. The deregulation was a turning point, because I think what happened is that the regulators started to think that power companies shouldn't spend money on R and D. Because anything the power company spends goes into their overhead and has to be paid for by the customer. And they felt, and this attitude hasn't changed, they just can't put R and D into their—if you think of the dynamics of the situation, the vendors didn't care about that because they thought: "well, we'll do it all for the power companies that make money." Right? And that has continued to this day.

Bruce Wollenberg (00:13:22):

Yeah. And you also began to have software companies. I mean, Siemens would—PTI with the PSSE is the most famous in that respect. But you began to have these companies doing software development. So, you can say that utilities kind of pass it. Ontario Hydro used to do that too. And it changed too. Ontario Hydro used to present lots of papers on—

Anjan Bose (00:13:53):

Oh, Ontario Hydro. BC Hydro. Even Manitoba Hydro was very, very active. And Hydro Quebec, I mean the Canadian companies—but the US companies were equally, at that stage, at least as well regarded. People came from all over the world, actually, to visit American Electric Power and Bonneville. Those were two major stops on the two coasts that people from Europe, Asia would come and find out what research was going on.

Sairaj Dhople (00:14:25):

And they were welcome.

Anjan Bose (00:14:27):

Oh, yes.

Sairaj Dhople (00:14:28):

Onto campuses. And it was all—

Anjan Bose (00:14:29):

Oh, yes, it was all open. It was all open. And this is completely—

Bruce Wollenberg (00:14:34):

Can I throw in a little personal story about American Electric Power? I was a co-op student as an undergrad for IBM. IBM had a lot of facilities in New York State. Their headquarters are in Armonk, New York, near New York City. And so, I was at an assignment in Poughkeepsie, New York. And honestly, I was bored out of my head. They never gave me that much that was challenging to do. And I would spend the rest of the summer or whatever semester I spent with them. And so, one day, this newsletter comes through about an IBM digital computer being used at American Electric Power to run their system. And what it was, it was a system built by Leeds & Northrup, but L&N built an analog computer, and then they had a digital computer that worked in tandem with it.

Bruce Wollenberg (00:15:31):

And I said, now that looks like something I'd like to do. And, literally, I said, no more computers. And I wrote a letter to Eric Gross at RPI and went into the power program. So that's how I got into power. And I'm so glad. When I look at what happened with IBM—they were just taking the rocket ship up, up into the stratosphere with their business in the '60s, '70s and '80s. And in the '90s, it got real rocky, and they began to have some layoffs and things like that, that they had never done. And they've never been—they've stayed in business, but they've never been as spectacular as they were in the '60s when I was working there. Once, the year that I started working for them, they hired 600 engineers. 600!

Anjan Bose (00:16:32):

Not so many in the power—I mean, their interest in power was always somewhat limited. I worked for a year for IBM right after my PhD. And it was an interesting place because IBM at that time was making more money out of power companies than any other. Of course, IBM had 90% of the computer business anyways. So, what they were selling computers to the power companies for was for billing.

Bruce Wollenberg (00:17:03):

Yep.

Anjan Bose (00:17:04):

Huge data-processing things. In those days considered huge data processing machines. But because they were also very much into research and so on, they kind of kept on telling the power company that they would like to do engineering-type stuff in the power companies. And one of the things I'm trying to remember the name of the Iranian guy who—

Bruce Wollenberg (00:17:31):

Adibi.

Anjan Bose (00:17:32):

Adibi.

Bruce Wollenberg (00:17:32):

Mike Adibi.

Anjan Bose (00:17:33):

Yeah. Mike Adibi was sort of in charge of this group in IBM whose task was to try and get IBM's computers sold on the engineering side rather than—and he came up—and one of his first presentations I remember—is to tell the conference that, "yes, AGC can be done with digital computers." And of course, people were shocked. I mean, everybody knew that AGC is an analog control. That's the way Nathan Cohn had invented it. That's the way it was implemented in every generating plant in the country. And they said, "how can—this thing that is sampling data—won't ever work. It'll go unstable. It'll go—." But of course, people figured out that it will work and it did work.

Bruce Wollenberg (00:18:34):

Yeah.

Anjan Bose (00:18:35):

But it was not IBM that did the digital AGC. They, they showed it work. But Leeds & Northrup, Control Data, everybody did it. They all, they all realized it once they knew it could be done.

Bruce Wollenberg (00:18:53):

Yeah. But L&N made the most I don't know what—reliable and stable analog computer equipment. And everybody wanted their analog computers to do AGC, and they did economic dispatch on an analog computer. I remember I took the course with—

Anjan Bose (00:19:18):

Yeah.

Bruce Wollenberg (00:19:19):

That's how they did it. And when I got to L&N, they were putting everything in digital. So, that was a big change. What would you say was the years of those changes? I

Anjan Bose (00:19:34):

I remember—

Bruce Wollenberg (00:19:36):

'70s? '80s?

Anjan Bose (00:19:37):

Early '70s. You see, just before the EMS came in, which was from the mid '70s on, you see, the early '70s was when both load frequency control and economic dispatch got completely digitized. And they could do it with the old SCADA system without bringing in the bigger calculating computers.

Bruce Wollenberg (00:20:06):

Yeah. IBM tried to build an EMS with IBM computers, and it just never really was too successful, was it? Yeah. IBM was not a process control company. They were a—well—an accounting company. Which,

Anjan Bose (00:20:29):

That's why they're called I-B-M as in "business machines."

Bruce Wollenberg (00:20:34):

Business machines. You're right. You're right. That's their name.

Sairaj Dhople (00:20:37):

You talked about being in industry at the same time before you made the switch to academia. Can you say a little bit more about that? Like where you guys were working, were you aware of each other? How did you first cross paths?

Bruce Wollenberg (00:20:50):

Hmm. I worked at Leeds & Northrup for seven years, from '66 to '74. And then I went to Power Technologies. Which is now part of Siemens. And while I was there, Ralph Masiello was at L&N too. And he left L&N, and he went to Control Data because they were going to get into EMS systems. So, they were very successful for quite a while. And so, Ralph did this study where he did a cost/benefit analysis of an EMS system.

Anjan Bose (00:21:29):

Oh, yes. I remember. That was later.

Bruce Wollenberg (00:21:30):

Yes.

Anjan Bose (00:21:30):

Yes. I was, I was still there.

Bruce Wollenberg (00:21:32):

You were still there. And that's where I met Anjan, I think, was during that period in the '70s.

Anjan Bose (00:21:35):

Yeah. You were at PTI, and I had joined Control Data in '76. You were already at PTI. But I think we met mainly at conferences.

Bruce Wollenberg (00:21:46):

Conferences.

Anjan Bose (00:21:46):

Those are the days when all of this was being presented, debated, at the general meeting.

Bruce Wollenberg (00:21:55):

I was so, so thankful, as I look back on my career, that I had people who took me to conferences. I had Walter Stadlin, from Leeds & Northrup. Did you ever meet him?

Julie Cohn (00:22:10):

I have, yes.

Bruce Wollenberg (00:22:10):

Yeah. He took me to—the first conference I went to was a Power Industry Computer Applications conference in 1967, a year after I had joined. And—just the little adventures that you have—this guy stood up and I looked at him and I thought, "oh, who let this hippie in here?" Long hair and a beard and everything? And he stands up and he says, "hi." He says, "my name is Mayer Sasson." Well, suddenly, my whole attitude—I'm glad I didn't say anything to anybody because he—I'd read his papers, his papers, and I followed him, and I went up and introduced myself. And then I became a pretty good friend of his for many, many years. For Mayer Sasson. Going to the conferences. I met almost, I mean, Mike Adibi. I knew quite well. Should we tell this story?

Anjan Bose (00:23:15):

Yeah. The joke?

Bruce Wollenberg (00:23:16):

The joke. Mike Adibi said that he was at a conference in France, and it is at a small college. He came into the cafeteria, and he is looking around for somebody he knows. He can't find anybody. He sees this Frenchman. So, he sits down and does this to him <gestures>. And the guy looks up at him and says, "bon appétit." And Mike thinks that's his name. So, he says, "Mike Adibi." And so, they ate. So, the next day he's sitting there alone, and the Frenchman comes in, and the Frenchman comes over and sits down and says, "bon appétit." And Mike says, "Mike Adibi." And the third day, Mike says, he asks somebody, and they said, "oh, no, no. Bon appétit. That's what the French say, 'have a nice dinner.'" "Oh!" So, the third day he's sitting there, and the guy comes in and he's waving, because he wants him to come over. And the guy comes over, and before he can say anything, Mike says, "bon appétit." And the Frenchman looks back at him and says, "Mike Adibi."

Bruce Wollenberg (00:24:27):

Now what would happen—Mike told me this—he said, "anytime I am introduced to somebody's wife at a conference, when they say, 'this is Mike Adibi,' they say, 'oh, you're the one that had the bon appétit joke!'" Sure enough. Now, this was in maybe '72 that I heard him say that joke. In 2010, we were at a conference here in Minneapolis. We're on the bus to go to some dinner, with my wife and Mike comes in and sits down. I said, "Ruthie, this is my friend Mike Adibi." And she says, right on cue, "you're the one with the bon appétit joke!" So that's a famous joke that went all over the power industry.

Anjan Bose (00:25:16):

Mike had lots of jokes.

Bruce Wollenberg (00:25:18):

He was a very humorous guy. He went and worked for the utility in Iran for a while, and then they had the revolution in '79. And he came back soon after that. And the rest of his career he spent doing a lot of work in restoration. He did a lot of the restoration studies. When you have a blackout, how do you get it back up?

Sairaj Dhople (00:25:46):

Did he receive his degrees in the US? What was his trajectory?

Anjan Bose (00:25:50):

I think he had a PhD from England, which was very common for Iranians to do that. And then he had gone back to Iran and then moved to the US and worked for IBM for years. And then the Shah of Iran, actually, himself, asked him to come in and be an advisor on the grid type of stuff, which is why when the Shah fell, he had to get out in a hurry.

Bruce Wollenberg (00:26:21):

Yeah, I can imagine. And he wrote a book too.

Anjan Bose (00:26:27):

Yeah. Lots of stuff.

Bruce Wollenberg (00:26:29):

He was a good friend. And then he had a long stretch where he wasn't around, and he was being treated for cancer.

Anjan Bose (00:26:40):

Oh, yes. He finally died, eventually.

Julie Cohn (00:26:44):

Let me take you back just for a moment to the 1990s. You mentioned one aspect of regulation that proved to be problematic for the utilities that invested in research and development. And that was regulators being unwilling to account for research and development costs in the rates that customers were paying. But that was also the era when various states were requiring companies to disaggregate their different activities, generation from transmission, from distribution. Did that also affect,

Anjan Bose (00:27:19):

Well, that's what deregulation meant. The basic part of deregulation was getting the generators out of the regulated part of the business. So that began. And that had lots of repercussions in my mind, which haven't been dealt with. I should say that, because they haven't been dealt with, we are still suffering from the R and D part. Was there something that the regulators did? Because they said, well, it's deregulated and this part is transmission and distribution, and how difficult can that be? So, let's just not do any R and D for—I mean, that kind of silly stuff. But the one area where it has really, really hurt is that we are now facing some real serious problems with resource adequacy, the shortage of generation, and this is appearing not in shortage of energy necessarily, but at times you don't have enough power available to meet whatever the demand is.

Anjan Bose (00:28:43):

And this is come about because in those areas where generation was deregulated—now, I think most of you understand that the US has still has lots of areas where generation is not deregulated, including a large part of the west and a large part of the southeast. There, they follow the old rules. They're vertically integrated utilities. But in the other parts, thought was that if you deregulate generation, generation becomes not part of the power companies, and then the power companies buy from the generators, and much of what they will buy is—some of it will be long-term contracts and some of it will be day-ahead and real-time markets. Markets, right? So, but what happened in the process, what fell through the cracks, was generation planning. Okay. Until the nineties, everybody did generation planning. Everybody. And the power companies were responsible for making sure that they had enough generation available, whatever the demand was.

Bruce Wollenberg (00:29:57):

Yes.

Anjan Bose (00:29:58):

And this kind of went away. And the whole phrase, "generation planning," Became a bad phrase. It sounded—the economists who came in and did all the deregulation stuff to them, "centralized planning" was some sort of a communist plot. So, in fact, to this day, in these areas, they don't mention generation planning. They call it resourcing adequacy. We study resource adequacy because now they have to. But they still can't build anything.

Sairaj Dhople (00:30:40):

Do you still avoid—?

Bruce Wollenberg (00:30:42):

Yeah, I used to teach a course on reliability, and of course, much of the reliability studies were centered around generation reliability. And there were all these techniques to study how reliable your system is going to be. They started out with this one-day-in-10-years, which was the adequacy—

Anjan Bose (00:31:15):

Regulation—

Bruce Wollenberg (00:31:16):

Gold standard, if you will. And I don't know where—they must have made it up because I don't know that there was ever any analytical study behind coming up with that figure. And they decided to use that. And you could see how many generators—if your load was growing and so forth, how much generation you needed so that there was only one-day-in-10-years that you had an outage. And that meant a 24-hour period, which, anyway—. And you can't do that when you're not in charge of building. I mean, most utilities had departments that designed and managed the construction of power plants.

Anjan Bose (00:32:09):

Oh, yes, yes, yes. Of course. They had to build it.

Bruce Wollenberg (00:32:11):

So, I agree with Anjan. I will say this, however, the deregulation, I used to think it was an evil communist plot when they first started.

Anjan Bose (00:32:24):

It's the opposite.

Bruce Wollenberg (00:32:26):

But it had some advantages, I think. It gave—if people were to build a power plant that had better efficiency, they would be better situated in the market. And so, the desire to change came from the people outside utilities that could build more efficiently. And the typical power plants where you were—say, what they call combined cycle. Get behind me here on this one. Anjan, you had a plant that had a coal fired-boiler. And you took the boiler out and you ran a large gas turbine,

Anjan Bose (00:33:31):

Combined cycle—

Bruce Wollenberg (00:33:33):

250 megawatts or something. And then you took the output of that and ran it into a heat exchanger to create steam. And you kept the old boiler. You would generate in a high-speed unit and then capture the heat and run that on the conventional unit. And it ran the efficiency way up from the high thirties up into the fifties, right? Am I—the numbers? And so, a lot of that came through, but that's what the newer plants were doing. Now, utilities were converting, I know here in Minneapolis NSP, or now, Xcel, was converting their generators to combined cycle. But I think that the deregulation moves, there was a real

desire to have more efficient and so forth—. Whereas in the older scheme, there was wasn't that force to—

Anjan Bose (00:34:43):

That's true. Although—

Bruce Wollenberg (00:34:44):

Push the technology

Anjan Bose (00:34:45):

In the old, I mean, when you and I joined the industry, see the generators, the thermal generators were getting bigger, and that's how they got more efficient. Okay?

Bruce Wollenberg (00:34:57):

Yes.

Anjan Bose (00:34:58):

They were getting bigger, but that got in the way. You see deregulation happened in the '90s. Most of this technology—of combined cycles and things—were already starting to come into place by that time.

Bruce Wollenberg (00:35:16):

I agree.

Anjan Bose (00:35:17):

So, people were already going to go there. The thing that happened after the '90s was the whole interest in decarbonization. Okay? And this is where things got really hairy, because now you have, instead of large thermal central plants, you ended up with all this dispersed generation. And this—I'm going to get a little technical here. This made this generation planning process much more difficult. Because the way we would do generation planning is to make sure that you had enough capacity level, total capacity of all these large central plants.

Anjan Bose (00:36:04):

You added it together and you just had to make sure that it was going to be higher than the largest load that you can project for the next 10 years or 20 years. And that's how you planned your generation. And in the old days—I should tell you this also, what I started, my first job was in transmission planning at Consolidated Edison Company in New York City. And there were six of us doing transmission planning. We were running power flows and transient stability. And then there were six other guys sitting in the next cubicle who were doing generation planning, and they were doing the loss of load probability calculations, and we had to keep exchanging. One thing that people don't realize that you can't do transmission planning if you don't know what the generators are going to be.

Anjan Bose (00:36:54):

And you can't do generation planning if you don't know where the transmission is going to be. And we were constantly going back and forth, back and forth, trying different scenarios of transmission and generation combinations. And this is a very fundamental thing. You don't have to be an engineer to even understand this. But somehow this fell off the plates. Okay? What happened was the ISOs today are still in charge of transmission planning, but they have nothing to do with generation planning. So now, after Texas and California happened, suddenly FERC and NERC got awake, and then they said, "oh, now the ISOs will also be in charge of resource adequacy guarantees." Okay? They have to actually study, and they have to flag, 10 years ahead of time, that you're going to—but the problem has gotten a lot harder because of the transmission of the solar and wind. The difference is this, the thermal power plants were somewhere between 85-90% available. Okay? So, if you think of the reliability curve of this thing, this is 90% available. Right? And it <laugh>.

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Anjan Bose (00:39:59):

So, I was talking about why generation planning or resource adequacy has become so much more difficult today than it was before. It's because, as I was saying, before you only had to make sure that these generators—large generators that were 90% available all the time—that they had enough extra to make up for the 10% failures to get this probability of only losing the one-day-in-10-years. Alright? Now, what has happened is because the availability of solar and wind is in the 20-25% range, suddenly, you can imagine that the probability calculations have completely changed. And now the problem is not just finding out that you are not going to only fail during the peak times.

Anjan Bose (00:41:04):

You could fail during when there's not enough solar, not enough wind, all kinds of other thing. And then the storage, of course, gets more complicated. Although we are used to dealing with a certain amount of pumped storage, before. So, the problem is that now you can't just depend on doing calculations for the maximum demand times of the year. You have to actually check. In fact, as you know, California's worst conditions always occur at seven in the evening, because that's when the solar goes down, and the duck curve kicks in, and all this kind of stuff. So, now we are really facing issues of how do we calculate this? I mean, these are research issues, and I don't know that many people working on the research.

Bruce Wollenberg (00:42:02):

I have one PhD. My last PhD student.

Anjan Bose (00:42:06):

Is working—?

Bruce Wollenberg (00:42:07):

He left his job at Siemens and he's out at Sacramento municipal—SMUD—municipal utilities. And that's what he chose—was reliability. So, he is looking at—

Anjan Bose (00:42:17):

Resource adequacy—Yeah. So that's a very, very interesting intellectual problem as well. I mean, we as usual, in engineering, we always use brute force kinds of calculations to get at the fact that we don't know the analytical technique that's needed. So, people are using load for—what we call production costing methods—of doing 8760 hours-per-year scenarios, and things like that, to make sure that we don't miss some strange time in the middle of the fall that's going to suddenly give you some problem. Okay? And we are doing a lot of stuff like that, or—when I say we, "we" means as an industry, we're doing things like that. But real good analytical techniques and good software is still not very much available. And so, the problem hasn't gotten any simpler while we were not looking.

Julie Cohn (00:43:30):

Dan, I'd like to invite you to join our conversation if you would like to pose a question.

Daniel Molzahn (00:43:36):

One clarifying question, going back a little bit in the discussion.

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Daniel Molzahn (00:43:51):

Okay. Maybe going back a bit in the discussion, you were talking about sort of the industry being skeptical of this transition to digital control and you were doing sampling and—how would this be stable versus continuous analog control? So, I'm curious, was the theory developed for digital control at that time? Did people understand digital control? And it was just a matter of convincing the industry that this theory would apply in their context? Or there just wasn't theory for digital control and you just sort of were experimenting with things?

Anjan Bose (00:44:23):

Well, I just have one view of that. I was doing my master's in 1968, there was a course I took at that time, which was called Sample Data Control.

Sairaj Dhople (00:44:45):

This was in Berkeley, I think.

Anjan Bose (00:44:46):

This was at Berkeley, and we used the first book ever written on it by a guy named Eliahu Jury, who had done some of the first ones. And he had been able to use the Z-transform as opposed to the S-transform to do the calculations. It was obviously being thought of—about how can you do sample-data control? And the big question of course, in sample data is, if the sampling is too long compared to the time constant, you are going to lose it, right? So, the question was how fast does the sampling have to be done? And I think there were theories that developed in this early '70s, Shannon's theorem and so on and so forth, which kind of resolved the mathematics of it. But long before the mathematics was resolved, people were trying it anyways and making sure.

Bruce Wollenberg (00:45:47):

The group that I was in at L&N, my boss was Charlie Ross. I don't know if your dad ever mentioned him. But his group had a big analog computer, and they had a digital computer. So, they were building the first digital analog, digital AGC, and they would use the digital computer to control something that mimicked the generation process on the analog computer. And they were working on that for, I don't know, several years. But they got it, they got it running, and—

Anjan Bose (00:46:25):

What year was that?

Bruce Wollenberg (00:46:28):

So, I left in '74 and I'd—

Anjan Bose (00:46:30):

Yeah, '70,

Bruce Wollenberg (00:46:31):

Say '72, '73. They were working on a digital control for—and had a digital AGC. And it had a lot of advantages. Obviously. You could change the constants, at will. And you could do a lot of things. You could have it put out various reports for you. And digital had it all over analog, but—

Anjan Bose (00:47:01):

It is interesting, Dan, that many of these problems, of course, predate the solution by years. And we somehow managed to do the engineering in between. And there's lots of stories about these kinds of things. There were cases where people still ran the AGC part of it as an analog but did the economic dispatch by computer. Okay? But because the digital—everybody knows how to do that right from the beginning—but before the digital computer came in, they had to do the economic dispatch on the analog computer. So, there were all these kinds of things that

Julie Cohn (00:47:52):

Do you know when analog control was completely abandoned for AGC?

Anjan Bose (00:47:58):

It got abandoned over the years. And I heard this from Nathan Cohn. Because what would happen is that as they abandoned these things, the old L&N controllers were being decommissioned. And your father would get a call from this company, somewhere in the middle of Montana or something, saying, "we have these three, four controllers in our hydro plants, do you want them?" And I think your mother would say, "we don't want any more of these things in our garage." And Nathan said, "oh yeah, sure, I want them." I don't know if you remember these, but he had a collection of them even in his Phoenix garage, if you walked in there. These companies were so respectful of Nathan Cohn, they just wouldn't take this dirty little thing and just ship it. They would polish it. They used to be made of brass, and they used to look beautiful, and they would put a little plaque on it. And you even probably have some of those that are still in your garage.

Bruce Wollenberg (00:49:15):

She has them in her garden now.

Anjan Bose (00:49:17):

Throughout the '70s, these got swapped out.

Bruce Wollenberg (00:49:22):

What amazed me was that before they had operational amplifiers, what we call an analog computer, L&N built control systems with mechanical parts that were part of the strip-chart recorder. And they could set a set point, and the strip chart recorder would move. And so that would move the setting to call for more generation and up and down. It was strictly mechanical. I remember somebody telling us that the Pennsylvania Railroad had systems like that, that they had installed in 1910 or during the first World War, and they were still using them, they were that reliable. L&N—I was there at the 75th anniversary. And they started to have a lot of difficulty financially and so forth, and they were finally taken over in about another 10, 10 to 15 years. It didn't last to a hundred. But their equipment was always considered the epitome of design; and manufacture was so good that people could put it in, and it would be there for 30 or 40 years, like a lot of equipment in the power system.

Sairaj Dhople (00:50:48):

Can you say a little bit more about L&N. I mean, this has come up on so many occasions and in so many different contexts, like any ideas about where this company started, who set it up?

Bruce Wollenberg (00:50:58):

Philadelphia. When I was there, they had built a new facility outside of Philadelphia, North Wales, which is where your dad's office was. But once in a while, the main computer that I had to use, the digital computer for accounting, was in the old—which was way down off of Broad Street, North Broad Street someplace. And it was, I never felt safe walking around. But it was started by Morris E. Leeds, and I don't know who Northrup was. But your dad used to refer to him as Mr. Leeds, and apparently, he started with the first strip chart recorder. And you know how they ran it? It wasn't an electric motor, it was like a windup clock. You'd pull the chain, and this weight would come up, and then, as the weight went down, this thing would work.

Bruce Wollenberg (00:52:03):

So, it was all mechanical. And then they'd have these two contacts, and something would move the contacts and that would move the pen. And you could ink out the—power is going up and power is going—you could see it. And they would keep these strip-chart records. The paper. They would take it off and save it for, I don't know, decades—for what reason? As far as I know. The other thing that they did was to build a lot of equipment for standards. L&N was very big in working with the then Bureau of Standards and L&N made voltage standards and temperature standards that you could—measuring devices and equipment like that. I think the Bureau of Standards bought a lot of it. Whenever I would mention that I was with Leeds & Northrup to some people, they would say, "oh, yeah, we have some of their standards in our lab." So, I don't know exactly what started first. I never saw a written history of the company. Was there ever—do you know?

Julie Cohn (00:53:22):

There's one that was written, but I think it was in the 1950s. I've seen it at the Hagley Library in Delaware. But I had a question about, you said that financially the company was starting to have some trouble in the '60s?

Bruce Wollenberg (00:53:36):

Yeah.

Julie Cohn (00:53:36):

And it sort of took about 10 years for that to resolve.

Bruce Wollenberg (00:53:41):

They had a lot of projects that were way behind. And as we understood it, they don't tell the guys, the peons down here at the bottom. They don't tell them what's happening. But everybody pretty much understood that the company was this close to financial collapse. And at that point they were laying off people. And what I remember was that there was another company bought L&N eventually. And I can't remember the name of the company.

Julie Cohn (00:54:32):

Was it General Signal?

Bruce Wollenberg (00:54:34):

Could be, yeah. Yeah.

Anjan Bose (00:54:36):

That was in the late '70s, I think. Leeds & Northrup was still a competitor to Control Data.

Julie Cohn (00:54:44):

What I'm curious about though, I mean, obviously this was a company that had business that had nothing to do with the power industry as well as the power industry business. But do you think that the transition from analog to digital calculating and computing and controlling devices was part of the reason that this company became maybe, obsolete?

Bruce Wollenberg (00:55:09):

Yes, I would say, and I'll tell you my reason. Maybe Anjan has a different spin on it. But in my opinion, when they got into trouble, we'd get these projects that had lots of displays and lots and lots of software. And they were an accomplished company when it came to manufacturing, very, very beautifully developed and tested and so forth. But software, they didn't know how to manage large software projects. And that's when Control Data took over because they were a software—well, they were a computer company. Not that they managed it that well themselves. Really. There's one company in the industry, and it's right here in Minnesota—OSI, in my opinion is the only successful—was started by a guy who left Control Data, Bahman Hoveida, and he started OSI, and he became the most successful. He managed it in a way that—he was very low risk. If somebody wanted a new software application and he couldn't see that it was worth it, he would not bid it, not bid the whole job.

Anjan Bose (00:56:31):

But that was a later stage of things. I think OSI got started around 2000.

Bruce Wollenberg (00:56:38):

Yeah. But he was very successful, and he sold the company for $1.6 billion. I used to tell people, that's the only company I know that really made money.

Anjan Bose (00:56:51):

Money in software.

Bruce Wollenberg (00:56:51):

Yeah. And L&N didn't, CDC didn't. Well, GE was in it, and GE had trouble.

Anjan Bose (00:57:03):

Yeah, GE had trouble. And Westinghouse was in it, but they got acquired by ABB, and then Control Data got acquired by Siemens. So, there was a lot of turnover. But going back to the '60s, when the real going from analog to digital happened, this has nothing to do with the EMS software. This has to do with just the SCADA. Going from analog control rooms to the SCADA control rooms. That happened over the '60s. And there was a lot of shakeup at that time. Because people who were in the instrumentation business, like Leeds & Northrup and all of them, Westinghouse, GE, they were all doing strip-chart recorders and meters and things like that, hardwired stuff.

Anjan Bose (00:58:08):

And that big change going from hardwired meters and hardwired switches to this thing which required communication channels and RTUs, remote terminal units, at the generating stations, at the substations, and then full, in those days, cathode-ray tube displays, that was all new technology to all of these companies. So, that's when the new people got a chance to come in, because they knew how to design these analog to digital things, which they called remote terminal units. But they were digital. And then the communication systems had to be put in, which meant you had to have microwave guys in the company who understood somehow to run those up. So, there was a big shake-up during that time in the '60s that happened, and it kind of continued in the '70s. And then of course, people realized that computers are getting bigger and you can run state estimators and power flows and contingency analysis in the control room. So that put another big layer. Because Leeds & Northrup weren't in the computer business. Neither was Westinghouse for that matter. So, they had to go buy computers from somebody, and Control Data said, "well, we are really good at making these big computers, so let's see if we can push that."

Bruce Wollenberg (01:00:00):

And they would have these giant scientific computers. So, they could do—when I worked for Control Data, they used to talk about—they did a job for the Union—UBS—Union Bank of Switzerland, and it was a fiasco. They had promised too much and couldn't deliver. And it was a huge problem for them. I guess they had to go to court and so forth, so they didn't always have—but their power system, the energy management systems, took the entire market for about 10 or 15 years.

Anjan Bose (01:00:45):

I read that.

Bruce Wollenberg (01:00:45):

And then people wanted different architecture. They wanted what they called "open access," where you had a network and you had a lot of small computers communicating with each other.

Bruce Wollenberg (01:00:59):

And I remember, when I was at CDC, they had a unit commitment program, which is a huge application that's the one/zero—when do units go on and off. It's a big calculation. And somebody had copied it over in FORTRAN and gotten it to work on a Sun workstation, and the Sun Workstation beat this mammoth big Control Data computer. And that should have been—the management kept trying to sell the big ones. Because they made so much money on them, but they eventually had to just get out of that business.

Anjan Bose (01:01:38):

Many of these changes that affected the power industry, and the power control industry, happened because of changes in the computer industry. See, when we first did the EMS computers, or put the EMS applications on, we were using still these computers we were using to run the state estimation. These were still pretty much batch-oriented computers, and that got kluged enough to run these cases. But in what—it was '82, '83 when the Sun workstations came out? And that changed the whole picture because this was interruptible computers, so that they could just have streams of calculations coming into the process, and they could optimize the process and run it. And that changed the hardware.

Anjan Bose (01:02:45):

And in fact, that's when Control Data fell behind, because they were still trying to do their large computers. IBM had just entered the fray for a little bit, but their computers didn't work. But people like the free ones, like Leeds & Northrup at that time, I don't know if it still existed at that time, but Westinghouse and—what was the company down in down in Texas? Northrup? They all went to the Sun workstations almost immediately. And ESCA actually came out of the blue and formed, was a new company, 1979. And they'd just gotten onto the workstation. They never even went to the big computer.

Bruce Wollenberg (01:03:42):

And ABB was using DEC. The DEC computer.

Anjan Bose (01:03:49):

And they moved to the workstation.

Bruce Wollenberg (01:03:51):

We wrote software for Public Service Electric and Gas. And we did it on a prime computer because it had virtual store. That was a huge breakthrough. And the virtual store. And we did it all in Fortran. The programs were written in Fortran, and then we switched it over to VAX easily. And the VAX had virtual store, and we sold that to—there's a company, what's the company from Zurich, Switzerland? I can't remember. They were acquired by Siemens, but I can't remember. They were a company. [*Landis & Gyr*] John—what's his name? He was president of the IEEE. He's now with GE. You probably know his name as well as I do.

Daniel Molzahn (01:04:45):

John McDonald.

Bruce Wollenberg (01:04:47):

Pardon?

Daniel Molzahn (01:04:47):

John McDonald.

Bruce Wollenberg (01:04:50):

That's it. John McDonald worked for this company in California. And he bought all the software from PTI. That's where I first met John. And he ended up going over to GE for the rest of—

Anjan Bose (01:05:07):

You're talking about John Undrill?

Bruce Wollenberg (01:05:09):

No, John McDonald.

Anjan Bose (01:05:11):

John McDonald?

Bruce Wollenberg (01:05:12):

Was the president of IEEE.

Anjan Bose (01:05:14):

Yeah, he was.

Bruce Wollenberg (01:05:15):

John McDonald.

Anjan Bose (01:05:16):

Okay. He was—

Bruce Wollenberg (01:05:18):

Undrill was a big guy. Started his own company, and then he went back to GE.

Julie Cohn (01:05:27):

Sairaj or Dan, do either of you want to ask a follow-up question? If not, I wanted to change the direction.

Daniel Molzahn (01:05:33):

I had one quick follow-up on this discussion most recently. You mentioned, Anjan, that a lot of the changes in the industry were driven by the computer. The computer industry was driving changes. And so, I wonder what the academics were doing at this time. Because I imagine it was hard to get access, or to get the expertise and the hardware access to these state-of-the-art computers. And the story you just told was really a story about what was happening in the industry. What was going on with the academics at that point?

Anjan Bose (01:06:08):

As you can probably imagine, the academic research sort of always concentrated on algorithms, rather than anything to do with the architecture of the computers or anything like that. And also, things that got in the way of the industry people, like, how do you manage the data that has to flow inside the control room or from the SCADA and all of that? So those were never a concern about—the academics never picked up on doing things like that. So, it was all algorithms. The problem that academics had, at least when I first went to academia, which was '82, was that they didn't like the idea of having to deal with large data. I mean, a 1,000-node power system was considered to be too difficult. And so that's why, if you look at the papers from the '80s, they're all on 14-bus and 68-bus systems.

Anjan Bose (01:07:20):

Right? And for some reason there was a lot of resistance to this. And some of us that went to academia, Bruce, myself and so on, we were used to running large power systems and we didn't have any problems with it. One difficulty that many academics felt were getting in the way was nobody would give them the data. But usually, for people like me, and I'm sure, same thing with Bruce. If we went and talked to a utility, they said, "oh, for Bruce, let's give him the data. Let him sign this piece of paper (called an NDA)." And that was it.

Bruce Wollenberg (01:08:07):

You could get cases from people.

Anjan Bose (01:08:09):

Yeah. You could get base cases.

Bruce Wollenberg (01:08:11):

And the computing was usually big IBM—the universities had a big—some sort of central computer thing. Eventually, they may have had terminals around the campus, but the first ones that I did, I had a big box of cards that I would take over and, yeah, they'd run the cards through and maybe I would get some results the next day. There was—

Anjan Bose (01:08:36):

But that dates us, Bruce, because the cards disappeared around '72, 1972.

Bruce Wollenberg (01:08:42):

Once they got terminals. Yeah.

Anjan Bose (01:08:44):

Yeah. But people started getting—

Bruce Wollenberg (01:08:45):

I did my PhD thesis

Anjan Bose (01:08:47):

On cards?

Bruce Wollenberg (01:08:49):

On cards. At L&N. I ran it on their Sigma 5—a Xerox Sigma 5. And they let me use the computer there. Right. And I could punch cards on the old IBM 026 key punch in my sleep.

Anjan Bose (01:09:10):

But that's the thing, Dan, is that when things changed, it changed almost overnight. My PhD was in 1974. I was still doing cards at the time. But I went to work for IBM right after that, and I had a terminal right next to my desk, directly connected to the big 360. So, it just kept turning like that. And then, once these teletype terminals got replaced by CRTs, and then regular displays,

Bruce Wollenberg (01:09:55):

I did my first programs with a teletype terminal, and everything was stored on paper tape.

Anjan Bose (01:10:03):

Oh, yeah. That's what those were.

Bruce Wollenberg (01:10:04):

So, when you were putting updates in a program, you read the compiler in, and then you read the program, and then it punched a new version of your program, and then you put that in and compiled it, and then you did the loading of all the—it took an hour just to go from one change to the next, back and forth on paper tape. And they started out on a computer called an SDS, and then Xerox bought SDS, and they changed the computers to Xerox computers. Do you know why? Do you know what S-D-S stood for in the 1960s? The Students for a Democratic Society—militant group.

Anjan Bose (01:10:49):

Yes. Yes.

Bruce Wollenberg (01:10:51):

That's what they decided. We don't want the initials S-D-S. But that was a—I think that just stood for Scientific Data Systems or something. Anyway, they dropped that and they, they went to Xerox computers, and Xerox kept, kept the market for quite a while, until DEC came along, I would say DEC, and then after DEC was the workstations, the Sun workstations. And then eventually everything got really fast on PCs.

Julie Cohn (01:11:25):

So, both of you had this, these experiences in industry that were fairly wide-ranging and probably very compelling, what lured you back to academic settings?

Sairaj Dhople (01:11:41):

And did that happen at around the same time?

Anjan Bose (01:11:44):

No. I went first.

Bruce Wollenberg (01:11:47):

'82, right?

Anjan Bose (01:11:48):

'82.

Bruce Wollenberg (01:11:49):

And I was '89 when I left, I was out here in Control Data.

Anjan Bose (01:11:56):

Actually, I had left already Control Data when Bruce joined Control Data.

Bruce Wollenberg (01:12:02):

I joined in '84.

Anjan Bose (01:12:04):

We never overlapped.

Sairaj Dhople (01:12:06):

But it seems like you had many—

Anjan Bose (01:12:08):

Yeah, we knew each other by that time.

Bruce Wollenberg (01:12:10):

Yes. I would go down to Phoenix every year for this course.

Anjan Bose (01:12:16):

When I was still with Control Data.

Bruce Wollenberg (01:12:16):

Starting in, what, '83 or four.

Anjan Bose (01:12:20):

Something like that.

Bruce Wollenberg (01:12:20):

And we taught it until '92 or three, when it seemed that interest ran out. But it made a wonderful trip to Phoenix, Arizona in March. You can imagine coming from Minnesota. I took my wife with me just about every time. We loved going down there.

Anjan Bose (01:12:43):

But for me, most of my changes have been sort of by accident rather than anything else. I was doing just fine. I mean, actually it was a pretty exciting time when I left in '82, because the first EMSs had already gone in, and we were learning very quickly about how these things were actually going to be used in industry. I mean, it took many years before people understood that the state estimator doesn't do a lot, but the contingency analysis did a lot more and all of this kind of stuff. I left because my professor at Iowa State, who I did my PhD with, had moved to Arizona State University with the idea—they told him to come and build a power program and—

Anjan Bose (01:13:42):

And so, he kept twisting my arm and twisting my arm until I said, "okay, we'll do it." And it was sort of somewhat reluctantly we did that, because I was working here in Minneapolis, and my wife's family is all around here, so she wasn't too keen to go down where it's 120 degrees in the summertime. But it happened. And I never looked back. And I never thought that I would stay in academia for this long. I just got sucked into it, so to speak. The nice thing about academia is that you do make your own decisions on what you are going to work on. Whereas in Control Data, where I was basically in charge of what could be called an R and D group, they never called it an R and D group.

Anjan Bose (01:14:40):

We were developing new software and so I had to justify the salaries of all my people. And we were up to about 30 people total in our group. But of course, the reason that we had gone up to 30 people—we started with about 10 or so writing the state estimators and things—but then they said, "okay, now go put it into that control room over there." And then suddenly I needed more people who could do that part of it, because we were a moneymaking organization in here. So, I had to justify it. But it was very exciting in those days, given that a lot of this stuff was new.

Bruce Wollenberg (01:15:36):

I joined Control Data in '84 and just before I came out, a friend of ours back in New York State where I was working, showed me an article about CDC getting into rocky financial territory. And for the five years that I worked at CDC, almost every day I would get the newspaper, and I would go to the business section and say, "what are they saying about Control Data that—oh, here it is, CDC loses more." And CDC was really going downhill. And the energy management division was bought by Siemens in about '92 or so. But I had gone to the university. I just figured that it was time and then I was teaching at the university.

Bruce Wollenberg (01:16:41):

The first six months I was there, Ned Mohan called me up and asked me if I would teach a course for them in the—because Professor Albertson was away. And so, I came over and taught the course. When I came in this morning, it's the route that I used to take into the university. And everything went smooth until I got on University Avenue. And then I realized I couldn't turn. They wouldn't let you turn. They wouldn't let you turn. I had to come all the way down and come back. But anyway, I came and at one point, Albertson asked me if I would like to come. So, it was again—he didn't try to break my arm. He was just very polite about it.

Bruce Wollenberg (01:17:29):

But I thought it's time. It was just a wonderful change because I enjoyed working with students. I enjoyed the freedom of academic life and so forth. And I had Ned Mohan to work with, and he and I did a lot of projects together. Almost everything we did together, except for some of his power electronics stuff. But he and I did a lot of projects together. I was here 27 years. And the other thing that I realized this morning: when I made the decision to retire, was driving in. I said, I'm sick of driving in. It's 16 miles from where I live to get here. Most of the faculty all live around the university. I live out on the west side because that's where Control Data was. And then I took the job. I had a quite a—it was about a half an hour drive normally, but if it was raining, then it got to be an hour. And if it was the snow coming down heavily, it was two hours just to get in to the university.

Sairaj Dhople (01:18:52):

So, were you aware of Anjan's move?

Bruce Wollenberg (01:18:55):

Oh, yeah.

Sairaj Dhople (01:18:55):

At that time? Did you consult, like how was the interaction?

Bruce Wollenberg (01:18:58):

He went to Arizona State. And within a couple years you started this course.

Anjan Bose (01:19:02):

Yes, yes.

Bruce Wollenberg (01:19:03):

And invited me to come down and teach. I taught for all the years that the course was going and loved it.

Anjan Bose (01:19:13):

He even took it to other places, that course. Like Venezuela, remember, we—

Bruce Wollenberg (01:19:17):

You and I went to, he and I went to Venezuela, taught the course.

Anjan Bose (01:19:21):

Control centers, just every, everything to start from the basic SCADA stuff and go work all the way up to the EMS and everything.

Sairaj Dhople (01:19:30):

And who else started this with you guys?

Anjan Bose (01:19:32):

Well, I organized it and over the years—actually it started with Ralph Masiello coming down first, but then he deferred to Bruce. So, Bruce would come down—and other people we have had—I've had Brian. Brian Stott has taught in it. Robin Podmore has taught in it. But Bruce was one of the steady ones. He loved getting out of Minnesota in mid-March.

Sairaj Dhople (01:20:07):

This was like a week-long course?

Anjan Bose (01:20:08):

Yeah, it was a week long. We did it on our spring break.

Sairaj Dhople (01:20:15):

And you would offer this to control center engineers to get them trained?

Anjan Bose (01:20:19):

Yeah. So usually people would come—they all work with the EMS somewhere. They were all power company people. They weren't usually from the vendors. They were all, almost all engineers.

Bruce Wollenberg (01:20:29):

The only course I know of that, to my knowledge, is still running, and it started about in the early '90s. George Gross's course, what he calls transmission business school.

Anjan Bose (01:20:42):

Yeah. That's still running today.

Bruce Wollenberg (01:20:43):

It's still going. I taught that for about 22 years. And finally, when I said, George, it's time for me to hang up my—and one of my students, Anthony Giacomoni, is now at PJM, but he's teaching the stuff that I did.

Anjan Bose (01:20:59):

That was the business of transmission, but this one was just all control centers.

Bruce Wollenberg (01:21:06):

It was really just to help people in the deregulation areas: what's the business of an electric utility?

Julie Cohn (01:21:16):

Was your course an unusual opportunity for people who spent their time operating power systems to spend time with people who thought about how they should operate power systems? I mean, the academic and the control room person? Was that an unusual combination?

Anjan Bose (01:21:33):

Well, the reason people would come to do it is that, if you go to a control room, you'll find that the operators at the desks are usually people with no degrees. They come out of the unionized field experience and so on. And then the engineers are essentially taking care that everything is running right. So, they have to know a little bit of how the SCADA works and how the EMS works and the software and hardware. Before they call the vendors themselves to come and fix something, they have to make sure everything is running. And many of these engineers were hired not as, with a lot of power engineering background. Let alone the level you need to understand, say a state estimation algorithm or something.

Bruce Wollenberg (01:22:29):

You're right. But they weren't power engineers.

Anjan Bose (01:22:31):

Yes, they weren't. So, this would be a sort of a one-week crash course. They didn't have to know algorithms. They didn't have to know how to write algorithms. They just need to know what are the different pieces.

Bruce Wollenberg (01:22:44):

Power education, I would say, when I was in school, even when I was an undergraduate in the '60s, people said that they had to take a course in machines, but they didn't take anything else. And the power program was in the master's level. And they would look down on it. They would say, "oh, no, I'm not going to get into power. It's all that old machines." And you'd go to a machines lab—it's these ugly, old, dusty, big honking machines that are this big, this <gestures>. And I was always scared to death of getting electrocuted around those machines. They were so big and powerful. A lot of people looked down on power and machines as—and I would say it was that way. So, many electrical engineers never had anything. Maybe they had something about three-phase in some circuits course, but that was it.

Bruce Wollenberg (01:23:46):

They never had a thorough course in power systems. The University of Minnesota did. They had a course, well, eventually we had a whole curriculum for undergrads. We had a course that covered power system analysis. We had a course that covered relaying. We had a course in design. And then, they became the level that you could take it as a graduate or a senior. And so, we had a sufficiently good power program. I went to school in the power program at RPI, and we had those courses too. But I think that so many schools—the power programs were few and far between, whereas if you wanted to study computer design or electronics of some sort, that was everywhere.

Julie Cohn (01:24:52):

So, when would an electrical engineering student first encounter an algorithm?

Bruce Wollenberg (01:25:03):

Good question.

Anjan Bose (01:25:04):

Early on. Meaning—an algorithm means that you have a process, a computer process of solving some equations, right? So that's an algorithm. What has happened is that you start introducing algorithms now, earlier and earlier. Before, if you taught the second circuits course, all the problems had to be done by hand. Right? Now you can do that by hand. And you can say, well, and here's a CAD circuit design algorithm that you could try out, and then you suddenly give them something with 13 different things on the circuit.

Bruce Wollenberg (01:25:58):

When I was teaching here, and I would say this was true for many years, I would try to get the students to write a program in MATLAB. I was telling people that MATLAB was God's gift to electrical engineers. And it really is. Going from assembly language to FORTRAN and then going to MATLAB is up on the ceiling. It was just really, and I would try to get them—and I'd have students say, "I came here to learn how to be an electrical engineer, not a computer programmer." They resisted it. They didn't want to bother writing programs. They didn't want to know software. Which I thought was just absolutely crazy. I said, "sooner or later, you're going to want to be able to write programs to do certain things." And they said, "well, I'll get a computer." [*computer programmer*]

Bruce Wollenberg (01:26:49):

You're in a company and you need something. You don't just go get somebody to do it. He's busy doing something that he's got to do. You should do it yourself. And partly that was—the faculty here decided that—I used to say they should teach a course in the first term sophomore year, that taught MATLAB, taught how to use spreadsheets to do calculations, and maybe get into some of the circuit simulator programs. SPICE, wasn't it one of them? And they said, "no, no, we'll just mix that in with all the rest of the courses." And they didn't mix. And the students didn't learn. The students would get out, and they didn't know how to write a line of code. It was ridiculous. My opinion. When you had a language like MATLAB, which—complex numbers, no trouble, matrices, no trouble. Everything is built in. So, you can write some very sophisticated stuff. And the students—. When I gave an exam, I would give a problem and then I would solve the problem with a MATLAB program, and I would just give them the program as the solution. I figured, you're going to have to learn how to read this, there it is. So—

Julie Cohn (01:28:19):

Dan, would you like to ask any more questions?

Daniel Molzahn (01:28:24):

So, I had kind of one question circling back to the beginning of the conversation. And that was, there's discussion about the relationship between industry and researchers and academic settings, or other communities. So, the discussion earlier was that maybe deregulation had impacted how that relationship had evolved. Is there a path that you would see towards getting back to something where we have folks at the equivalent of an AEP or BPA that are doing work and publishing it and interacting with the academic community and coming to conferences—is there a path back to that world? Or maybe another way to ask this is, is there any parts of the world that are doing it better? Where there that relationship is stronger?

Bruce Wollenberg (01:29:22):

I've always been impressed with the people from Spain, for example. They have some people with their utilities that write some very, very good papers—do you experience that too? The Spanish people don't seem to have thrown that out. Of course, they just had a big blackout the other day. So, they need—. But I don't know that there is. When deregulation came, I remember we had this thing here at the university called the University of Minnesota Center for Electric Energy. And we got money from [*the electric companies*]—and we tried to do problems, and we gave lectures to them. And the guy from Xcel Energy, or then NSP, was the head of their research group. And all of a sudden, he wasn't there anymore. Once the deregulation came, they shut down all that. All that development went away. Now, at the same time, if they needed some specialized software, they could buy it from one of several companies, like PTI or, what are some of the software companies? ABB.

Anjan Bose (01:30:38):

Siemens.

Bruce Wollenberg (01:30:39):

And Siemens. And EPRI had a branch that tried to do that within EPRI. But I don't see that utilities have gone back to development and that kind of thing. They're there to be part of the process. They do engineer and so forth, but they're not there to develop new software. I don't think they do any research at all. That was what EPRI was supposed to do.

Anjan Bose (01:31:19):

But I think, Bruce, that you're right, that the utilities have lost the ability to interact with academia at the research level, just because they just don't have the people. But where there can be a much tighter connection between the industry is between the vendors and the consultants.

Bruce Wollenberg (01:31:45):

Yes.

Anjan Bose (01:31:47):

And academia. But I'm afraid that the academic research has kind of gotten themselves into a bubble that they're having trouble penetrating. And I get asked this question by young assistant professors all the time, "how did you get your software being used by other people? Nobody wants to use my software." And I said, "well, you've got to want to use your software to do something, not just write a paper that my software is a 3% better optimizer than yours, because nobody will care about 3% betterment in optimizing."

Anjan Bose (01:32:39):

And I think there's a kind of thinking that has gone on in academia, which is very, very hard to break now because academia now is kind of worldwide. And there's a whole group of people that are handling these journals, that put out these papers, and you've got a kind of a feedback loop, which says, okay, if you get it into this journal, it'll be cited so many times.

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Anjan Bose (01:34:09):

Continuing the thought on industry, academic research. I think the two points I will make is that you've got to have some relationships with industry, and however you do it, most of the power programs have figured out certain ways of reacting, interacting with industry. And then see if you can develop them to a point where they're interested in what you do. People get confused between the fact that, yes, even power companies who are not doing any research, they want to know how AI is going to impact their lives. Alright? But actually, none of the academics know how AI is going to act, what's going to impact our lives. We're still trying to figure it out. But we know that we can use certain methods of machine learning or something in certain algorithms. So, we try to do that in academia. But usually, from the academic side, one has to think of a more holistic way of looking at the problem.

Anjan Bose (01:35:28):

And that's one of the advantages that Bruce and I had, because we immersed in industry in the beginning. So, nobody came and said, "I need a better algorithm." Right? They said, "I have a problem, come and fix it for me." Right? So, that's the difference. That's the difference. You have to understand the problem in their terms, not the way you have formulated the problem in academic terms or in mathematical terms or in physics terms, but with all of the others. Now, you may not have to solve all of them, but if you solve a few of them, then the industry will jump in and say, all right, if you can do that part, I can do this part. And we can do things together.

Anjan Bose (01:36:21):

And that is missing at the moment. What really concerns me is that I'm seeing this happening worldwide, because journals are now worldwide, the journal papers are all worldwide. And so, there's a kind of a community growing, which is all focused in on the academic side of the research and not on the application side of the research. And this is a sort of a two-way deal, which needs to be—I mean, if you look at Power Globe today, there's still people speculating about what happened in Spain with the blackout. And what is happening is that these kinds of conversations actually muddies the issue more than it actually does solve anything, right?

Anjan Bose (01:37:27):

So, we have to have some way of communicating these things, information, communication, not just that: Hey, let's just speculate and do these things without—. Dan and I were at the PSERC meeting last week, and one of the members of PSERC is RTE, which is the transmission people from France. And they made a nice presentation, although they said, well keep it secret because this is politically sensitive. But they could see what was happening from their end of the tielines, okay: when their tielines opened up and why it opened up, from their end. It didn't tell us what happened in Spain, but it told—and there has to be a lot more openness on the industry side as well, for these kinds of things. So that's not a very good answer, but we have to keep working at it, because otherwise it's just not going to—by separating ourselves so much, it's not good.

Julie Cohn (01:38:41):

Did anybody else in the room want to ask a question?

Tari Jung (01:38:45):

I had a question, but it's maybe a little different direction. Is that okay?

Julie Cohn (01:38:48):

Yes, of course.

Tari Jung (01:38:49):

I have a follow-up question for you, Professor Bose. You kind of mentioned about the loss of load study a little earlier. I actually happen to be an engineer for MISO—done that for about five years now passing on. But I just think there's connection between—there is like acceptance that resource adequacy, especially as a balancing authority who can't really do any generation, we still basically have to develop the standards that we're communicating with the generation partners to actually bid on it. And I'm kind of curious in terms of the research efforts that we would have to put up, we, I think have a lot more increased interest to talk to academia now because of the complexity that—we're like, "oh, we don't know how to do this generation portion, necessarily. Well do you see that type of increase in interest on your end as well?

Anjan Bose (01:39:45):

When I see my end, I think the academic research community is just maybe starting to think about it, but because it is this thing about loss of load probability and how you calculate it, and things had kind of become stagnant. But suddenly, because the ISOs have all been trying to work on this, suddenly there's a lot more interest in the National Academy and NERC. We had a joint workshop—and MISO people came to it—about what to do about this thing. And there were some recommendations and things, but ultimately, as you pointed out, certain standards have to come out. NERC standards have to be developed, which will supersede the standard one-day in 10 thing, because the one-day-in-10 has sort of lost its meaning right now. Because there's no way to pinpoint, let's say, the duck curve problem in that one-day-in-10 kind of calculations which we were used to doing.

Anjan Bose (01:41:00):

So, we've got to come up with new methods. So yes, there is increasing research, but of course it's like the fact that the sight of the guillotine clears your mind—because now, all the ISOs are thinking, "well, we may be like California tomorrow." Right? And not have enough power in the evening.

Tari Jung (01:41:27):

I'm kind of curious, because the channel of—I guess how these things like push through, in your examples throughout, it's like, "okay, they're utilities, they're vendors, they're consultants." But then, like you said, at the end of the day, okay, the standards have to actually be updated for anything to change.

Anjan Bose (01:41:44):

Yes.

Tari Jung (01:41:44):

Which none of these people really are bodies of—updating that kind of standard that would come to the balancing authorities, right? So how do we make that circle?

Anjan Bose (01:41:54):

Well, you are right, that it is a sort of a circular situation, because reliability—as Bruce was saying, talking about reliability—FERC is in charge of reliability, right? FERC doesn't—has basically given that job up to NERC, right? And NERC actually—to make these standards—have to go through their process, which is very stakeholder-driven. Alright? So, they have got to go through that. So, there's a lot of convincing to be done in all of this. But I'm separating out the process of determining what level of generation adequacy you're going to get. The process of determining that from the algorithms you need. And the reason—because the algorithms are not there. And the academics are behind in trying to get, jump into it. We need the academics in that area—all the probability distributions, all the Montecarlo methods, or whatever you're going to use to develop the software that is needed to make sure that you don't have a lot of frequency—. You need to, instead of just saying LOLP, the loss of load probability over 10 years, what you need is: what is going to be the frequency and duration of your outages?

Anjan Bose (01:43:24):

And that requires a different kind of calculation.

Bruce Wollenberg (01:43:28):

A lot more details.

Anjan Bose (01:43:29):

A lot more details. A lot more details. But you see, people get hung up on computations. Right now, my position has been that there's no shortage of computer power. There's a shortage of brain power, but not computer power.

Julie Cohn (01:43:46):

Did you want to add anything, Bruce?

Bruce Wollenberg (01:43:51):

I had a great point, but I forgot it! I was going to ask a question. Does NERC create standards that are just for utilities? Or do they, are they what we call a standard-setting body now?

Anjan Bose (01:44:13):

Yes. Yes.

Bruce Wollenberg (01:44:14):

A standard setting body—the standard has to be voted on. And anybody who is considered knowledgeable can join in the voting on it. So, they do that for NERC. NERC—

Anjan Bose (01:44:27):

They have their own process, which is different from the IEEE process, for example.

Bruce Wollenberg (01:44:30):

When we had the blackout in 2003, I was on a legal case. I was an expert witness for First Energy in Ohio. And there was this—these lawyers that kept talking about NERC standards. And I finally looked at my own attorneys at a private meeting. I said, "NERC standards are not standards. They're NERC suggestions." They didn't have standards setting, but they do now, I gather, because there's—the reason I used to tell people NERC is here and they're telling you what to do. And behind NERC is this monster called FERC. With unbelievable powers to club you over the—I mean, they can put presidents of utilities in prison if they don't do what they're supposed to. And they have real power.

Bruce Wollenberg (01:45:31):

They're the government. And so, I said "now NERC it's not just—." But they do take that process. Do you remember when we were in IEEE meetings that was going to do a standard for AGC?

Anjan Bose (01:45:53):

Yes.

Bruce Wollenberg (01:45:53):

And it went on for years and years and years. And it just finally died. It just never got done. Standards are—because somebody wants to have a certain thing that benefits their business and other people don't. So, there's that give and take. So, standards are very hard to come by. And they take a long period. I think that NERC—well, the very first student whose committee I was on, and I was his advisor, Mark Lauby is a senior vice president of NERC.

Bruce Wollenberg (01:46:34):

And he did a lot of algorithm development on his own when he was working for the power company, right around here, for MAPP they called it. And he did a lot of that work on it. So, he knows what algorithm development—I don't know how much NERC does any of that. They should be getting people to evaluate algorithms and suggest—think of what—i's in FERC. Every year they have a meeting in the summer that has to do with the development of optimal power flow. Don't you get the invitations? I get the invitations that—I've never gone.

Anjan Bose (01:47:19):

Is that from NERC or is that from FERC?

Bruce Wollenberg (01:47:22):

FERC. It's from FERC.

Anjan Bose (01:47:23):

Yeah, yeah, yeah. I do.

Bruce Wollenberg (01:47:23):

They have a big two- or three-day meeting about optimal power flow. I'm thinking that NERC should have a meeting to talk about reliability and the various standards that they want to see and how can we enforce them and what kind of algorithm development is needed. But FERC was able to push that for, I mean, they go into deep details about optimal power flow, and they have lots of—

Anjan Bose (01:47:54):

Oh, on the FERC thing. Yeah. So, let me put that in perspective a little bit. You brought up the 2003 blackout. It was after the 2003 blackout, the 2005 Energy Policy Act was passed by Congress, which shifted the reliability responsibility to FERC. Alright? So, FERC became in charge in 2005 of reliability, which meant that NERC was no longer kind of in charge. But FERC didn't have enough expertise. So, they went and contracted out—or formed what they call ERO—reliability, energy reliability, Electricity Reliability Organization. And they appointed NERC to be the ERO. Okay? And that was when all they became a standard-setting body and all of that—which was already in the works for them to become a standard-setting body. But they didn't change very much their stakeholder process of developing these standards.

Anjan Bose (01:49:22):

Okay. Having said that—that's still pretty much the same. All the power companies and the big power companies, the ISOs, they're all members of this standard-setting process. But aside from that, the big issue that you are bringing up, Bruce, is that neither NERC before, or FERC today, or the FERC/NERC combination, they don't actually specify algorithms. See, they will say, you must meet these standards. You must meet the loss of load probability of one-day-in-10. You must meet the N-minus-one standard.

Okay? But the fact is, nowhere does it say that you have to run a contingency analysis program using Bruce's algorithm.

Bruce Wollenberg (01:50:16):

They don't specify how you determine whether you're going to make it.

Anjan Bose (01:50:20):

Yeah. You've got to show that you are somehow making it.

Bruce Wollenberg (01:50:22):

Let me say, they just look at the results.

Anjan Bose (01:50:26):

They just look at the results.

Bruce Wollenberg (01:50:27):

They take all the records and say, "oh, you had an outage here for three hours and you had this and that." And then they tally it up. They don't get into the business—

Anjan Bose (01:50:36):

The nitty gritty. And they said, "well, that's up to the vendors to come up with the algorithms and the software and so on and let MISO and so on to determine—." I've had this argument over and over again with people like Mark Lauby, and I said, "you have to—"

Bruce Wollenberg (01:50:51):

Not really. Yeah.

Anjan Bose (01:50:53):

"You have to be, you see—you can say that you can use any algorithm you want as long as you show it. But there has to be an understanding of what it is." Okay. So now if you look at the NERC, they will from time to time come out with best practices about how to meet these standards, right? Which becomes de facto algorithms. But now you see the problem has gotten deeper because of the change in the problem itself with all the renewables and the storage devices and all of this kind of stuff.

Anjan Bose (01:51:26):

And the standards haven't changed. So, they're still showing that they're good for the probability of one-day-in-10 loss. Right? And they're obviously, the algorithms they're using are probably not adequate enough. But NERC has to stay an arm's distance from that, saying that, "well, I can dictate this is the algorithm." So, this workshop that we had between NERC and NAE organized, it basically says, "Hey, we have to look at Monte Carlo methods. We have to look at frequency and duration of outages. We have to do—." But again, this is not the algorithm. And I don't think they will ever say, "you've got to use this algorithm." But I think what will end up being is that just like power flows and optimal power flows that we use for transmission planning, contingency analysis, there will be standard practices that will come up.

Julie Cohn (01:52:46):

Sairaj, you had a slightly different topic you wanted to pursue as we reach the end of the interview.

Sairaj Dhople (01:52:52):

Yeah. It's a privilege to have both of you here. It's quite a coincidence, right? And it seems like you've had many points of intersection over the years, over the course of your careers. I was wondering if you would share some thoughts about your relationship: When it started. Did you think that after all these years you'd be sitting together and recounting these stories and maybe organizations or events that helped you cultivate that relationship and keep it alive? And just some thoughts along those lines?

Anjan Bose (01:53:33):

We don't have that many years left to do that.

Bruce Wollenberg (01:53:34):

No. I think that—do you still go to the PES meetings?

Anjan Bose (01:53:41):

Oh, yes.

Bruce Wollenberg (01:53:42):

I don't.

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Bruce Wollenberg (01:54:36):

I haven't been to the meetings. And now I have to go to the meeting this summer. I'm getting this award. And they said that I have to come and make some remarks. And so Sairaj, it's his fault. Because here I am, sitting there blissfully happy, and suddenly he tells me I've got this award. And then IEEE says, you have to come to one of the meetings. So, he and I are going to go fly down together.

Anjan Bose (01:55:19):

The Halperin Award?

Bruce Wollenberg (01:55:20):

Yeah. I went through the whole list of all the Halperin Awards. I know many of the people that have, of course, gotten them. And anyway, Anjan is one of the few people that I—I mean, you're here to see Francy's family. So, he'd come here to see Francy's family, usually in the spring, often. He'd often come over to my house and have dinner or, or lunch, or something, or Sunday dinner or something. We'd have him over. And so, we kept our friendship going. And then we had—Anjan, was it a year ago? Or is it two years?

Anjan Bose (01:56:09):

I don't remember.

Bruce Wollenberg (01:56:11):

At the restaurant up on—

Anjan Bose (01:56:12):

Yeah, yeah, yeah.

Bruce Wollenberg (01:56:13):

University—

Anjan Bose (01:56:14):

With Mohan.

Bruce Wollenberg (01:56:15):

I think just the fact that Anjan was in town, and we'd try to get together. For many years. We'd get together and my wife and Anjan's wife got to know each other. She used to write the most unbelievable Christmas letters. My wife—I'll leave it at that. But his wife would write these wonderful, wonderful letters at Christmas. And anyway, so, we were close as families. So that kept us close for these many years. But I know I'm going to go to that meeting. I'm practically thinking that when I get there next summer, it's in July, to put a big card on a lanyard around my neck that says, "please tell me your name first" or something. Because I will have people come in, "hi Bruce, remember me?" And I'll just go, "ah." But it's a long time that I haven't—a lot of these people I haven't seen—a lot of them have passed away. I keep a list of my, of my Power Society friends that have passed away. It's, it's getting to be quite a long list over the last—

Anjan Bose (01:57:39):

And more frequent

Bruce Wollenberg (01:57:40):

And more frequent, yeah.

Anjan Bose (01:57:42):

So, you are coming to the Austin meeting then.

Bruce Wollenberg (01:57:47):

Yes. And so are you.

Anjan Bose (01:57:49):

Yeah. I'm going to be there.

Bruce Wollenberg (01:57:50):

You're getting an award, you're getting a PES, was it a—

Anjan Bose (01:57:53):

So, I reflect on this at my age—reflect on these professional friendships. Friendships that grew out of the fact that you were working in the same field and you ran into each other often. Bruce and I never worked in the same place, but we ran into each other often enough, and we read each other's papers, and I can probably even —I have stories I tell about some of the work that Bruce had done on De-FACTS and that have kind of influenced a lot of people, but influenced me as well. These friendships are kind of special because they're more than just another electrical engineer. There's intellectual kind of connections at various levels that helps the things. So, I reflect on that a lot. And there are lots and lots of stories about—just not Bruce and I, but Bruce and I and all the other people, kind of our generation of people who worked on similar things and how—the zigzag route of what got accepted and what didn't, and what—this is all kind of fun to think about it.

Bruce Wollenberg (01:59:31):

Yeah. You run into people. I had an experience where—I'm trying, what was the prof? Who was the professor at Michigan? He had a chair.

Anjan Bose (01:59:47):

Oh

Bruce Wollenberg (01:59:49):

He was from Australia.

Sairaj Dhople (01:59:51):

Ian Hiskens.

Bruce Wollenberg (01:59:52):

Oh, Ian Hiskens was in Australia, submitted a paper, and I was in charge of getting the papers. And he kept emailing me. "I have to know so I can buy my ticket if I'm going to be able to present." And he also dropped the fact that his wife had just had a baby. Okay. So, this is about '91 or '2, or '3, or so. So about five years ago—by the way, I had to be the one to tell him that the paper wasn't accepted. And I said, "go back and enjoy your new baby, really hold the baby and wonder at God's grace that gave you another beautiful baby." And so, he invited me to come and be on the committee of one of his students about five years ago. And he invited us all to his house for dinner.

Bruce Wollenberg (02:00:49):

The boy that he had was there. And I said, "when were you born?" And he said, "'93." And I said—I told him the story about his father. And I said, "I hope he turned around and wasn't too depressed. The fact that you were born, he could stay there and be with you." And so, I got to meet the baby! But Ian—you have ties with people through unbelievable—I mean, there's a lot of people that I met and talked with and did a lot of things with for years. And now I haven't seen them in 20 years because I haven't been going to power meetings. So, I'm hoping I can recognize some of them.

Anjan Bose (02:01:39):

So let me tell you the story because it has kind of an L&N involvement in it. I wrote to somebody, or some group that—the first EMS was actually installed by Control Data at the Wisconsin Power Line, in Milwaukee, in 1976. So, I get an email back saying that can't be, we had our state estimator running in our control center in 1975 or '74. So, I'm thinking, how can that be? And this would—

Bruce Wollenberg (02:02:31):

<Joseph> Wrubel from Public Service Electric and Gas. Is that who?

Anjan Bose (02:02:34):

That wasn't it, but it was Public Service Electric and Gas. It was somebody else who wrote this thing.

Bruce Wollenberg (02:02:40):

We put a state estimator in there.

Anjan Bose (02:02:42):

Yeah, but it wasn't a real state estimator.

Bruce Wollenberg ([02:02:44]()):

No, it was—oh, you're thinking of Commonwealth Edison in Chicago?

Anjan Bose ([02:02:49]()):

Yeah, yeah, Chicago.

Bruce Wollenberg ([02:02:50]()):

What we did was we had the

Anjan Bose ([02:02:52]()):

Kluged up a power flow.

Bruce Wollenberg ([02:02:54]()):

Well, we had a power flow, which started with the breaker position, right. And built the bus model, right. That then the power flow used, I think that was the first one of those. And then we had a way of—Jay Britton, from ESCA, he devised this method of putting a constraint into a Newton power flow, right? So, we had the area, they knew what the area interchange was, so you could specify that and that would set the power—

Anjan Bose ([02:03:23]()):

Outside power.

Bruce Wollenberg ([02:03:24]()):

So, we did it., But we called it a state estimator, and we know darn well that it—

Anjan Bose ([02:03:28]()):

You knew that it wasn't a state estimator, but it was called a state estimator. So, this guy had—we kind of went back and forth and I said, "tell me what was in there." And they said—and because I know that they weren't using the algorithm that everybody accepted as state estimator. But I haven't mentioned the story to you, but I figured you had something to do with it.

Bruce Wollenberg (02:03:50):

Oh, yeah.

Anajan Bose (02:03:52):

It was a closed-up power flow that they called the state. estimator

Bruce Wollenberg (02:03:57):

Well, it was really a real-time power flow.

Anjan Bose (02:03:59):

Yeah. It was a real-time power flow.

Bruce Wollenberg (02:04:00):

Is what we should have called it.

Anjan Bose (02:04:03):

We called it the real-time power flow during the time the state estimator was being developed. We all called it a real-time power flow. And it was because what's his name from MIT—.

Bruce Wollenberg (02:04:16):

Fred Schweppe—

Anjan Bose (02:04:19):

Fred Schweppe developed it, and he was from the controls community, and he called it a state estimator. And then it stuck after the rest of us had—

Bruce Wollenberg (02:04:27):

I still remember Fred Schweppe presenting that at one of the power meetings. And it was the most—what he said was, if you take all the data and you put it into a power flow, it doesn't match up. It does—it solves the power flow. Something doesn't match the measured. And there's all these errors all over the place. And they wanted him to solve that problem. And he realized that it's the same problem as tracking a missile with radar, where you get noise in the radar and the angle isn't perfect and the distance isn't perfect, but you can get a statistical idea of where the missile is. And so that's why he used it. I think that was a state estimator.

Anjan Bose (02:05:14):

Yeah,

Bruce Wollenberg (02:05:14):

Was a missile tracking—

Anjan Bose (02:05:15):

That's what they called it, a state estimator.

Bruce Wollenberg (02:05:17):

He had done that. So, he had applied it to power systems, and it was just—the state estimator became—but for years they couldn't get a good algorithm. They had this, ESCA had this, not ESCA, well, the people from ESCA had this algorithm. It really didn't work.

Anjan Bose (02:05:37):

No. The column filtering algorithm never did work. But AEP had developed a lines-only algorithm. Which had enough redundancy in it that it did work. But then they realized by adding the nodal injection that—

Bruce Wollenberg (02:06:01):

But putting state estimators in became a real effort to get it working. Because, whenever we put it in at Public Service Electric and Gas, they said they would get this error at this substation. They sent somebody out and the guy came back and said, "well, guess what? The meter was backwards." Things like that. They said that the connection was wrong.

Anjan Bose (02:06:27):

That's another thing that most people don't realize today, is that when we were putting in the first state estimators, you had to tune state estimators to work. I mean, even today, that's true. But in those days, you see, you took the measurements coming in—there were lots of measurement errors like that, which was not the small measurement errors that you expected the state estimated to correct. But big errors, like you got a negative flow on this thing.

Bruce Wollenberg (02:07:03):

Backwards.

Anjan Bose (02:07:03):

And I think the first 10 years of state estimation implementation went in just cleaning up measurements at the substations.

Bruce Wollenberg (02:07:15):

It took a long time. I remember at Public Service—and then I talked to people from other utilities. The same thing. We had to, when we were putting it in, we ran into it, we called it the ""zero injection problem. If you have a bus that has no load of generation on it, and the state estimator solves and tells you that you've got 130 megawatts of load on the bus, well there's no load there. So how can this be? And so how do you, how can you force—? And that's when we went to the—

Anjan Bose (02:07:44):

Did you invent that? Who wrote that first one? The constraint of the zero-injection bus?

Bruce Wollenberg (02:07:50):

We wrote a paper and talked about it, but it was solved by these guys in Waterloo. [*Ontario, Canada*]

Anjan Bose (02:07:56):

Oh, oh, yeah.

Bruce Wollenberg (02:07:57):

And the–what do you call it? What? It's—Joe Biden effect has overcome me again—the method of solving the equations.

Anjan Bose (02:08:14):

Yeah. With the constraint—.

Bruce Wollenberg (02:08:16):

No, but it's what—there's a method that's based on orthogonal decomposition. That's what it's called. And they showed with orthogonal decomposition, you could put a weight on that measurement that would squeeze it down and make sure that every—and so we tried writing that algorithm, but we didn't have enough memory in the computer. I had a great deal of difficulty because of that. But that became the standard—the orthogonal decomposition.

Anjan Bose (02:08:54):

Yeah. But orthogonal decomposition was also used for much of the observability stuff. And that—what's his name from Worcester Poly also used.

Bruce Wollenberg (02:09:08):

Kevin? Kevin Clements.

Anjan Bose (02:09:10):

Kevin Clements used that for actually cleaning up a lot of other stuff than the zero injections.

Bruce Wollenberg (02:09:15):

Yeah. No, he helped us develop our state estimator programs. Kevin.

Anjan Bose (02:09:20):

Yeah, that's right.

Bruce Wollenberg (02:09:20):

He was very active in it.

Julie Cohn (02:09:25):

We've had you talking for better part of two hours

Anjan Bose (02:09:30):

That's what old people like to do. Talk about—reminisce about—

Bruce Wollenberg (02:09:35):

We can go all day, if you want that.

Anjan Bose (02:09:35):

People get tired of our stories.

Julie Cohn (02:09:39):

We're not tired yet. But I think we should take a break. I think it's only fair. This has been interesting.

Anjan Bose (02:09:46):

See you later, Dan.

Daniel Molzahn (02:09:50):

We really appreciate your time, Anjan and Bruce. Super, super interesting discussion. And sorry I can't be there in person, but this was a lot of fun.

Julie Cohn (02:10:00):

Okay. Thank you.

[End of interview]