Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee: Anjan Bose

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***Abstract*:**

Dr. Anjan Bose is a Professor in the School of Electrical Engineering and Computer Science at Washington State University. He is known for his work on control and analysis of large power grids. His research involved real-time modeling, state estimation, stability, wide-area monitoring, and communication systems for sensing and control. He has also been a technical leader and consultant to the industry on control center technology for communications and computation. In this interview, Dr. Bose describes his educational background and his early work at Control Data Corporation, first developing energy management systems, then developing operator training simulators. He emphasizes the importance of innovations in digital computing for advances in power systems. He describes using SCADA computers to run the operator training simulation. He explains the significance of the 1977 New York Blackout in triggering adoption of operator training simulators across the industry. He mentions

that the advent of computer workstations in the 1980s facilitated his work. He describes the competitive market for training simulators, the challenges in developing appropriate simulations, and the role of industrial psychologists in helping frame the simulations. Dr. Bose offers that his most important technical contributions have all been analyses that help the system operator. He compares the slower speed of improving algorithms to the ever-increasing speed of microprocessors. He shares an anecdote about early work at Consolidated Edison, and a mismatch between planned power flow and the amount needed due to extreme heat. He describes being a graduate student and meeting Bill Tinney, a renowned engineer with the Bonneville Power Administration, who developed the solution to power flow still in use today. He discusses the tension between academics and industry and the development of new algorithms and asserts that utilities have lost the incentive to innovate in this area. Dr. Bose closes by describing two conferences—PICA and PSSC—that began in the 1960s, as power companies adopted digital computers to do more and more sophisticated planning and operating functions.

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

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

Julie Cohn (00:00:09):

This is Julie Cohn. I'm conducting an interview with Anjan Bose on Tuesday, July 18, 2023, at the Hyatt Regency Orlando in Orlando, Florida. Daniel Molzahn and Rachel Harris will be assisting with the interview. Mahbubul Bhuiyan, Sutanwi Chatterjee, and Francis Bose are also in the room and may ask questions during the interview. So, during today's interview, we will be especially interested in your early work on energy management systems and how that work has since impacted power systems operations. But first, we'd like to ask some introductory questions about your background. So, Dr. Bose, if you would be so kind, could you please describe your educational background and your professional positions in the field of electrical engineering?

Anjan Bose (00:01:06):

So, I got my bachelor's degree in Indian Institute, Institute of Technology in Kharagpur in 1967. And then I came to the University of California Berkeley, where I got my master's degree in electrical engineering. And that was my first introduction to the electric power grid, even though I had taken some courses in it as an undergraduate. Because I had my research for my master's degree was in solving power flows. And the power flow algorithm was still not stabilized into what we use today routinely. This was still being experimented on in 1967. And anyway, after that I worked at Consolidated Edison Company, which is the power company in New York City, and I worked in transmission planning. And the transmission planning was just undergoing some changes at the time after the 1965 Blackout.

(00:02:35): And that's for all of northeastern US. And so that was the time when the analytical tools for doing transmission planning changed to computers. Digital computers and power flows were used, and transient instability was starting to be used, and the same thing had happened also in the generation planning area. And so, these were relatively new departments in the power company, Consolidated Edison Company. And so, I did that for two years and then I joined the PhD program at Iowa State University where my research was again in computer analytical tools. But this time it was more on transient stability. Finished my PhD in 1974. I worked for the IBM Scientific Center in Palo Alto, which was developing, again, transient stability programs with funding from the Electric Power Research Institute.

(00:04:08): I did that for about a year and then I taught briefly, one year, at Clarkson University as an assistant professor, after that. So, it was 1976 when I joined the Control Data Corporation in Minneapolis. They had a division that sold energy management systems. At that time, actually, there were no energy management systems in 1976, but they were in the process of building them and so were other vendors of control centers. Control Data Corporation built the first commercial EMS. That is, partial EMSs were built in-house by several power companies at the time, but we built and commissioned the first energy management system in the world at Wisconsin Electric Power in Milwaukee. And at that time, I was in charge of developing the applications programs that became the heart of the energy management systems.

(00:05:40): That is in 1960s, the control centers had become digitized. They were the SCADA system, the AGC system and so on, were already digitized in the sixties, but the new applications of state estimation, contingency analysis, optimal power flow, online power flow, these were all developed in the '70s. And by adding those to the control center, this new control center was called the EMS, the Energy Management System. And that name has stuck till today of all the control <laugh> are called Energy Management System, at least on the transmission side. And so that's part of the history. I think it was ‘78 or so when that first control center was commissioned. And then I think many others came in. Many of the other vendors jumped into the picture, and they were all making energy management systems at that point. And I left in 1981, late ‘81, more like 1982, Control Data and joined Arizona State University as an associate professor. And I stayed there doing research, and I continued my research in control centers and computer-aided analytical tools. And then I switched universities in 1993 to Washington State University. I've been there ever since.

Julie Cohn (00:07:36):

So, it sounds like you've had, well, until the last maybe 40 years, you were straddling academia and industry for some length of time.

Anjan Bose (00:07:48):

Yeah, since ‘82. But because of my background with the Energy Management Systems, I kind of stayed my research in that area and continued. One of the things, for example, that we built, again for the first time in the world, was what we call an operator training simulator, the OTS, in Control Data Corporation. And the whole thing is dependent on the development of the computer field, because this is what was changing. The reason we went to, we were able to add applications like state estimation, contingency analysis and so on, is because that needed the ability of the computer to solve large sets of equations. And so obviously these large sets of equations, like a power flow would be solved offline.

(00:09:03): And this was already done in about ‘67, ‘68 timeframe when things started firming up offline that this is the best algorithm to use, and this is the way you implement it. And so, we took that experience and we said, Well, how can we do this online? And the big problem was that offline, we were using in those days, batch computers, rather large batch computers. And it so happened that Control Data Corporation, which is the company I worked for, was at that time, the leader in scientific computation. So, these were the people who today would be making the big computers with huge amounts of capacity, but Control Data started that. And the name I would mention is that Control Data's chief architect of computers was a man named Seymour Cray, who actually left Control Data later and formed the Cray Corporation, which is his own company.

(00:10:20): And Seymour Cray was kind of the guru of scientific computation, the leader in those days. But I never met Seymour Cray, but he worked in the bowels of the big corporation. We were on the power engineering side of things. But we used the latest computers from Control Data Corporation. And the idea was to take, to use these computers, to tie these computers into the control center and put them behind the SCADA systems, which brought in all the data and could do some small calculations. And then you could process this in the big processor. And the funny thing is today, it's the kind of computers which we thought were big and bulky, and could do fantastic things in those days.

(00:11:27): You can do it in your handheld phone today. But in those days, those computers required a lot of backup, meaning these had to be cooled with cooled water. You have to run them through these big machines to cool them because they got so hot. And so, you needed large rooms to set these things up in those days. But going back to my story on the training simulator, we had this idea, and it wasn't me personally, there were several other people working on this. And before we could use these big computers, these big computers in those days cost a million, 2 million, somewhere in that range. And for redundancy purposes, you never did controls with one computer, because if it failed, then the whole power grid will go down. <laugh>

(00:12:36): So, you had to have a backup. You had to buy two of these. The starting price of a control center, if you just take those two, is about $3 million right there. So, it was not uncommon to have a control room set up to be costing about $10 million in those days. And so only the big power companies could, could afford it. The small little ones couldn't afford an EMS system. But, when we started thinking of the training simulator, the idea is not new because pilots were already being trained in very early simulators already. So, we knew what, what it meant or what we had to do. The question was whether you could simulate the power grid in real time to be able to do this.

(00:13:30): And so, with these batch computers, even the big ones, it wasn't very easy to run, to simulate, we could obviously solve the power flow and even some dynamics, but you couldn't run it in real time. It was much slower then, and so we, strangely enough, these computers that ran the SCADA system, before we started using those big scientific computers, the computer that ran the SCADA system were specialized computers that was used mainly by the military for real time applications. And the difference is that they could interrupt their processing in between to do new things. And so, you could see that if a lot of data starts coming in, you have to kind of say, “I'll take this data first, and then this data next, and this data next.” And so, this is the way all computers work these days, it interrupts your pro-

(00:14:47): So, in those days, if you gave the computer a job to do, set of equations to solve, it had to do the whole thing first and wait for the next job. And so, it used to get that through and do it on the scientific computers. But these SCADA computers were actually better at handling these. So, we said, Is it possible to run a power flow on these SCADA computers? And we had nothing to do with this, but we had some very clever programmers who could program these real-time computers, and they said, Yep, we can run them. I mean, you give me the equations and I can set it up so that it can run these things. And so, we decided that we can run up to about a 60-node power system, a 60-busbar system on these little computers.

(00:15:49): They were only a few hundred thousand dollars each rather than a few million dollars each. So, once we got a power flow running on these things, well, now it can already run the SCADA. So that's not a problem. I've got the SCADA system coming in, in real time, I just have to keep up with the SCADA data rates and keep solving the power flow and the rest of it. So, it was a lot of clever programming needed to shoehorn everything like that into one small computer <laugh> in those days. And so just to finish up the story, we, in 1977, at a power engineering conference in Toronto, we unveiled this thing. And all the power engineers came and looked at it, and said, Oh, what a nice toy.

(00:16:50): It has to have the same GUIs, the graphical user interface, as the operator will have in the control room. So, in those days, you didn't have LCD displays, you had scattered rate tubes. You had two or three CRT displays on one console, and we were using the same thing that we used for the SCADA system, so we unveiled this thing, and whole bunch of people came around and said, Oh, it's such a nice toy, it looks nice. And nobody thought it was useful for anything, <laugh> and we were trying to sell it as an operator training simulator. You sat down the operator—

(00:17:37): Because in those days, you see, if you don't have an operator training simulator, the only way the operator gets trained is on the floor. So you get a new operator, you put 'em on in the floor with the more experienced operators, and you learn both the grid itself, your power system, and you know that the generators are here, and this connected here, and the big loads are connected here, and you learn all of that, and you learn on the job. But the problem with on-the-job is the same problem why pilots went more and more to simulated training, is you can't have emergencies very often to get trained. So, if you have to wait six months for an emergency to occur, that's a lot of training time to actually get some experience in there.

(00:18:32): And so, you could kind of do these things with training simulators. It was a small thing, and it only solved 60-bus power system. And so, everybody said, Well, okay, yeah, nice. <laugh> And then in 1977, in May, that this conference was, in 1977, and in July of 1977, New York City blacked out, and we had an order for a training simulator within a month from Consolidated Edison Company, which is where I had worked already, and I knew the people there and so on. So that was the first very rudimentary training simulator. So, when it turned out that then, several other people bought training simulators, and we were not the only vendor with a training simulator; other vendors started coming up with their training simulators.

(00:19:45): And then EPRI, the Electric Power Research Institute, decided that they wanted to do something one step above. And what that meant is you should be able to run a full-size power, and that roughly means about, our target was a thousand buses, a thousand-node power system. That's what they wanted. And that was kind of an impossible task to run a power flow, a thousand buses, every second, let's say, to keep up with the real time.

(00:20:23): The SCADA frequency is about four seconds. So, you also are trying to do a very simple dynamic equation to calculate the frequency, which tells you the difference between the load and generation.

(00:20:54): And that drives the frequency itself. So, you had to do at least about one second because the time constants are about in a few seconds of the frequency dynamics. So, we had to figure out how to run the power flow every second. Luckily, the early '80s is when the workstation revolution occurred. And that solved two things. One is they were interruptible computers, so that was the start of the Interruptible computers. They were much cheaper than the humongous things that you had to run cold water through to <laugh> were all air cooled. So, what is happening is that the microprocessor chip industry is now rapidly moving ahead. And so, we could run these things on, they were called VAX computers, just prime and the companies like that.

(00:21:57): And that was when all the old control, all the old computer companies kind of went belly up. This is the time of Control Data where I worked, they went belly up and so did Honeywell, so did Borroughs, there was a whole bunch of computer companies, pre-workstation things. And they were known, by the way, in the industry as, as IBM and the Seven Dwarfs. Because IBM had 90 percent, 85- to 90 percent of the market, and the seven dwarfs divided the other piece. And they specialized, like Control Data was doing more scientific computing. Honeywell was making computers mainly for local control and so on. But they all couldn't keep up with the new computer companies that came in.

(00:23:05): And by that time, I left the company, but Control Data Corporation died like all these other ones. But the control center division that I worked for, it used to be called the EMS division, got bought up by Siemens. And even today, Siemens is the control center division of the Siemens Corporation, and they're still in Minneapolis. That division is. But to finish up the story on the OTS—the operator training simulator—when EPRI got involved. So, they funded a project that was won by Control Data Corporation still at the time. They won it. But they asked me, from the university, to be involved with development.

(00:24:09): So, we developed the engine, the power flow, and the transients and the stability and all of that for the insides of the engine. And that got done about 1990, finished and tested at Philadelphia Electric Company. And that was the OTS. And after that, for many years, that EPRI OTS was licensed by not just Siemens, but also ABB and being used around the world and some of the independent operator training companies. There were a couple of operator training companies. So, sort of started up third party, for the smaller power companies that didn't, couldn't just develop their own operator training and all of that. So, they started licensing this OTS technology from EPRI. And I'm not sure if people are still using that because so many years have gone by, and changes have been made. People who were using it as a licensee, they kind of develop things on top of that and so on.

Julie Cohn (00:25:23):

So, when you say real-time training, are the trainees pretending that they're operating a system, but they're getting the real-time data to do it?

Anjan Bose (00:25:35):

Well, they're not getting real-time data from the field. The data is all simulated. The simulation is producing data at real time.

Julie Cohn (00:25:45):

As if it were really the system operating.

Anjan Bose (00:25:46):

As if it was real-time.

Julie Cohn (00:25:47):

Yeah. And were you and CDC the only ones trying to come up with a workable training program at that time? Or were there competitors?

Anjan Bose (00:26:00):

No, this was a competitive business. At any given time, there were five or six EMS vendors. Ah, a couple of them will go out of business and a couple new would come in, and some would be successful and some not so successful. But at the period before the training, before EPRI got involved, the training simulators, we had the training simulator at CDC and ESCA Corporation, which was a new company; they had the other training simulator <Affirmative> and this was developed by a guy called Robin Podmore. And then ESCA got bought out by the French company.

(00:26:58): Alstom ran it, and now it's GE. So, they have always stuck to their own training simulator. They never bought, got the license from EPRI. So, they've always had their training simulator and they've always ran theirs. But not everybody built their own, because they had the EPRI training simulator available for licensing. They made all of this. In the West, there were those two major ones. In recent years, China has built their own and others. There's a European version, which as far as I know, not too many people are using, but the Chinese use their own made-up training simulators. But the training simulator, if you think of the bigger scheme of things in terms of large-scale operations of the power grid, the EMS is really the heart. I mean, that's where everything is done in real time in the real world.

(00:28:05): And the training simulator was a small piece. All EMS, if you go to any control center, they would say, Yes, we have another room over there where we do the training, and we have the training simulator. And the advantage of doing that is you can actually transfer data from the real system to this thing and simulate actual things that may have happened, or you say, last week we had this big disturbance, so let's kind of capture that and put it as a training scenario, which is very similar to actually what they do with pilot training, for example.

Daniel Molzahn (00:28:51):

Along those lines, would they do a lot of what-if scenarios of failures that, if you have 60 buses, you can maybe brute force a lot of possible failures? Would they do some sort of contingency scenarios offline and then use that to train the operators online?

Anjan Bose (00:29:07):

Well, the training simulator is basically another software tool. The only difference is you've got a lot of graphical user interfaces that can do it. But the other thing, and most people who have not kind of been in the training world don't realize, is that a training simulator requires a whole set of tools to be able to set up scenarios. So, one is to capture something that actually occurred, but if you're not within the control center environment, you have to make these things up. So, you say, "Well, so what will happen if I lost that generator? What would happen if there was a short circuit on this transmission line and the transmission line went out?" You can make up these scenarios.

(00:30:05): So, you need some tools to be able to create these scenarios. And then the more difficult thing, and now you have to start learning that most power engineers don't know. This whole idea of training, training effectiveness, what is it that you are training the operator for? You want the operator to make sure that all the voltages are within limits. Alright, so after you need to now create scenarios which will test the operator to do just that. Now you have to be able to create the scenario in such a way that the training is effective. Now, this requires a different kind of thinking. And basically, when I was developing the EPRI training simulator, we worked with a lot of industrial psychologists whose background it turned out was all with the military, they had worked with pilots.

(00:31:24): And then we learned that, well, it turns out that pilot training, the simulation of an aircraft, is a lot simpler than simulating a big power grid because there's only three equations in an aircraft for dynamics. <laugh> And the industrial psychologists, they didn't care. They said, Well, what is it that we are training for, if something stops working on the plane, how do you—if an engine stops, how do you recover, what are the things?

So, you have got to kind of explain to them, all right, so now you lose a generator, and then what are you supposed to do? I mean, then the AGC is working, some of the automatic stuff is already going on, which is also true in a plane. There are all kinds of things already underneath you that's already working. So, you have to know what is working, what is not working, and you have to intervene and do something. So anyway, an interesting thing for me professionally, because it was not just running power engineering equations <laugh> about people's behavior and that whole thing. So—

Julie Cohn (00:32:48):

Overall, looking back, what would you consider the most important technical problem you tackled?

Anjan Bose (00:32:57):

Well, since my work is more mainly on the operation side, the technical problems all ended up being some sort of an analysis that will help the operator. But when you're talking about analysis of a large power grid, there's no difference from simulating the grid or finding out. I mean, you have to kind of simulate the grid to be able to know what the answers are. So, so there's a lot of commonality between the things we were trying to do and maybe people offline are trying to do in the planning, on any other kind of analysis that they're doing about the grid. The only thing that was different in the operations area is there's always a time factor.

(00:34:09): There's no point giving the operator an answer two hours later. There are certain things you can't do even today, for example, this whole problem of scheduling the generation units, unit commitment. Which generators need to be turned on, which generators need to be turned off. Now, these are usually decided offline the day ahead or something like that, when you roughly know what the demand curve is going to look like for the next day. So, you say, "Well, this is when you're going to hit more than this generation, so this load." So, you're going to have to turn on another generator and you use some sort of optimization offline to be able to know what needs to be turned on and turned off.

(00:35:03): So now on the real time operations, this we would consider operations planning because you're talking about next day. So, there's a whole group of engineers who are doing nothing but thinking about how things are going to go next day. And when it's this hot, this is a real <laugh> tough time to say, "Well, are you gonna run out." So, there's a whole group of engineers in the operation center, in the control center, who are doing this operations planning for the next day or the next week or so on. But what happens is during the day, during operations itself, you'll lose a generator. You find that it's so hot that some pipe broke. They had to shut down the plant.

(00:35:57): And so now you are off the schedule. The optimal schedule is now thrown out the window because you never turned on that generator, <laugh> you can't turn on that generator anymore. So now you have to improvise, and there are tools now which says, well, I can do a whole 24 hours of optimization, and in the next five minutes to tell the operator what to do. So instead, you do much more approximate kind of a thing in real time to help the operator out. So those are the kinds of things you work for. The engineers who are working up tools for offline things don't have to worry about this time dimension that comes on. Those are issues that only the people who are working on the operation side will have to kind of be aware of.

Daniel Molzahn (00:37:00):

When you make algorithmic advances to make the real time problems faster solved, how much of that got fed back?

Anjan Bose (00:37:07):

It gets much of the advances in speed. If I think of the many years that I've worked in here, has not happened because, because clever engineers came up with better algorithms. It happened because the microprocessors got faster, <laugh> so I spent a large amount of my research life in academia solving the transient stability equations. And those are big and difficult and takes time. And you can never do those things in real time, even today unless they're very, very small systems. And we made all kinds of software betterment, and we'd write lots of papers, but by the time the papers came out, the computers were faster. <laugh> So yes, you are still getting a 10 percent better than the old algorithm, but nobody cares anymore, <laugh> because it's already been a hundred times faster, <laugh> so if you get 10 percent more than the hundred times faster—

(00:38:00): So, it's no big deal. <laugh> In fact, I warn people who are all doing algorithm research, watch out for this thing because reporting that your optimization is now 2 percent better, and you work five years of somebody's PhD life <laugh> to get that. By the time you went the paper route, 2 percent better would mean nothing. <laugh> I ran into this, and there was a period around 1990, when different computer manufacturers were coming out with parallel computers, and they had different designs. Some had designs, which had a shared memory, some had designs, which had message passing so that the memories were with each microprocessor, and you pass messages between them.

(00:39:44): And so, we were doing a whole bunch of research, and these computers were of interest in various different industries, not just in the power. And I remember we had come up with some algorithms that got some traction. Hydro-Quebec wanted to use ours, and they went and bought one of these computers, and they were not particularly expensive, but they were still a few hundred thousand dollars' worth of buying. And all those computer manufacturers went out of business. All the parallel computers went out of business because the computer manufacturer—what happened was that you basically have a generic parallel computer, that is, you have a bunch of processors, which are in series and parallel, and you have so much local memory, and you just do that, and you essentially optimize in the compiler. The compiler optimizes the algorithm, <laugh> the spreading of which processor does what becomes a clever compiler design.

(00:41:00): And so, the algorithm design doesn't have to anymore. So, that's one of the interesting things about trying to do work in the computer applications, is that by the time the computer field changes. Right now, you're hearing people talking about data science and AI and all this good stuff. The same thing will happen. These are people who haven't experienced this <laugh> because the AI technology will far surpass the ability to come up with clever algorithmic changes that you can in research. So, keep that in mind.

Julie Cohn (00:41:52):

Well, do you do, did you do collaboration with people building computers as opposed to people in the power industry also?

Anjan Bose (00:42:01):

No, not as much. Mainly because we keep up with this thing. Yeah. I mean, when these parallel computers were being built by different companies whose names now you can forget, but because they're gone. <laugh> But we would work with them. And the way we did the research was because all the national labs would buy these computers and would make time available on these different computers. So, I could sit in Phoenix, Arizona and run these things or wherever. And then, when somebody wanted to use one of these, like Hydro-Quebec, they actually bought one of 'em. So, I tell my PhD students that, just because you're having a lot of fun doing your research doesn't mean that it's going to end up being the big thing that you did. <laugh> Because, by the time 10 years goes by, nobody's heard of those computers.

(00:43:16): Nobody's heard of those architectures. It is still an exciting field, and as long as you're trying to solve the real problems outside. I'll tell you a story about my early days talking about, as I said, “What does the operator do?” So when I went to work for Control Data for Con Edison, I didn't have a PhD or anything, but I could run power flows and things, and they didn't have, in the control room, the ability to do a lot of these power flow calculations, meaning what everybody calls today operations planning, that is planning for the next day and the next day after that, that was actually in our group.

(00:44:13): We had the ability to run transmission planning, so we also did transmission operations planning. But we didn't have enough people to run things every week, and we couldn't even get turnaround times in those days to run power flows that fast. So, what we would do is we would plan or do the operations planning for next season, that is, this summer I would do next winter, and in the wintertime, I would do next summer. And then we would say, well, in the next summer, my peak load is going to be this much and this. These are the generators which are going to be out for maintenance or whatever, and this is how we're gonna run the power system. So, we do that, and then you'd come up with limits, what the operator can do.

(00:45:13): They said, Don't load up this line more than this amount, or don't run this generator more than so much. So, I remember one summer, I was sitting in my office, and it was a very hot day, and a call comes in from the operator. He said, “Alright, I've hit the limit. What do I do now?” So, I'm sitting, and it takes days, in those days, to run power flows. So, I can't run power flows to give him an answer. So, what I'm thinking as an engineer is, “Alright, so how much safety factor did I build in?” How did I come up with this number that I gave him? Because I knew there was some safety factor because I wouldn't be right on the dot for the answer, I got from my computer things.

(00:46:14): So, he says, “Look, I'm gonna get by. <laugh> I'm doing some other things to get the loading down a little bit by changing the voltages and so on.” But he said, “Tomorrow is going to be hotter, so tell me what I'm supposed to do.” <laugh> That's what happened. And now, anything like that, the operator himself can press some buttons and get some answers, and that wasn't possible. So, things were slower, but I also learned a lesson to put in enough. <laugh> I find this story coming back to me all the time. I read the stuff in the newspapers. You open up any day now a newspaper, and they say, This region of the country is going to be so hot that they're already telling the customers to be careful, and we might have to shut off the lights. It's amazing how things don't change even with all the tools that they have today. Yeah.

Julie Cohn (00:47:27):

So, did you work with people who were, back in the '60s, developing the algorithms that you eventually programmed? Were you working directly with them as well?

Anjan Bose (00:47:38):

Well, I was part of that community. I knew all the researchers, and I've been very lucky because I started getting to know them very early in my career. It turned out, as a fresh master's student, not knowing anything about computers or anything, I ended up working on power flow algorithms at Berkeley. And the project was supported by two different companies, Pacific Gas and Electric and Bonneville Power Administration. Both these places had very brilliant engineers <laugh> and algorithm people that I could learn from. PG and E was right next to Berkeley.

(00:48:49): I would see those people quite often, and many of them were graduates of Berkeley anyway, but the Bonneville Power Administration, they were up in Portland, Oregon, and one day my professor says, "The project manager's going to come down and you need to have some slides ready." And like good graduate students, we had solved nothing, but <laugh> we had worked pretty hard. So that's what we told him. The project manager turned out to be a man named Bill Tinney. Now, everybody knows who Bill Tinney is, because he wrote the bible on the power flow. <laugh> So, he comes down there, and we know the name because he'd been writing papers on power flows. But we met him. There were two of us graduate students, and we made our presentations. Thinking back on it, he was so polite, and he was so nice.

(00:50:00): He said, "Oh, that's great work," and so on and so forth. <laugh> And he said, "Let me tell you a little bit about what we have done at Bonneville Power Administration." He got up on the board, and those days, it was all board and chalk and no computers. And the computers are in the computer lab, in the computer basement, computer center, two buildings away. So, he got on the board, and he started writing, and he had basically solved the power flow problem. And his method became the standard method that has been used ever since. And there are variations of his method, the Fast Decoupled method or something like that.

(00:50:45): But the basic Newton-Raphson method. And the amazing thing was that we were also trying to solve Newton-Raphson. And in fact, everybody in the world who was working on this problem was using Newton-Raphson, because everybody knew that Newton-Raphson was the best one to do. But we couldn't figure out how to run these huge, big matrices through Newton-Raphson. The computers weren't big enough. And Bill Tinney had figured out how to exploit the nature of the matrix. The matrix is what they call sparse, which means that most of the matrix is made up of zeroes. And he figured out a way on how not to have to multiply with zeroes a few million times, and which made it possible to then run it on this computer.

(00:51:46): So instead of talking about algorithms and their convergence, he talked about the sparsity of matrices, and we didn't understand any of it. We'd have to do with how you store a sparse matrix and how you manipulate a sparse matrix, which is what gives you the speed. And so, we had to all scramble and figure out what this means. From that day on, he knew me, who I was, we would exchange regular mails. There was no email in those days, He just died recently at the age of 99. And so, I started to get to know people of that caliber, who were at the very front end of research, because I was in the field. And that just made a big difference in terms of interest and encouragement.

Daniel Molzahn (00:52:53):

So, did people at the time realize that the way you make it sound is that you did that, the idea of exploiting sparsity was really the new, new concept. Was the thought that everyone knew you had to exploit sparsity?

Anjan Bose (00:53:07):

No, nobody knew, and in fact, what people don't know is Bill Tinney is the one who figured out how that sparse matrices could be exploited. And he became famous in the mathematics community. It is a bragging point for power engineers because at that time, IBM in Yorktown

Heights had a big research group, and there was a whole bunch of people doing nothing but algorithmic work because, in ’67, the thought was that computers are going to be mainly used for scientific computing. And doing algorithm work was the thing. Now, computers are used for everything but scientific computing. Only a few of us think about, people are sticking them into cars and <laugh> your toaster and everything else. <laugh>

(00:54:13): The use of computers has completely changed. But in those days, that was it. And IBM had huge numbers of PhD mathematicians working on algorithms, and the sparse matrices show up in many, many applications: civil engineering, anything you can think of has got sparse matrices. And so, these guys were all working on sparse matrices, recognizing that sparse matrices, but they couldn't figure out how to do it. And Bill Tinney sitting in a little cubicle in the bowels of the Bonneville Power Administration building in Portland figured it out, and he became famous in the applied math community.

Julie Cohn (00:55:06):

Did he ever talk about how the idea came to him?

Anjan Bose (00:55:10):

Yes, he did. Like many of these people, he was modest about it, and he said, “Well, we were just fooling around with it.” <laugh> And that's probably right. He had a couple of other engineers in a small group of three people or something, and they kind of figured it out. Bonneville had a larger group of people who were working on various different things at the time. They were working on everything from HVDC transmission lines to all kinds of new generation, new substations, all kinds of things. So, it was an innovative place. They didn't mind having them. I think people have forgotten, but in those days when power companies wrote software, they gave it away.

(00:56:12): Now we talk about public domain, but they gave it away. And Bonneville's programs for power flow, for transient stability, for electromagnetic transients, these became the standard for half the country. The western half of the country use nothing else. They give it away, and they even maintain these things until much later. For 20, 25 years, this was the standard. And because Bonneville was available much more publicly than others, it spread all over the world. And in fact, they still have it running in China and the EMTP program, which he didn't do, but some other people did. And still somebody took it over, and they maintain it, and it's available free. But you pay somebody if you want it maintained.

(00:57:23): That was the way things worked. That's another thing, in the '70s when everybody started using power flows, all the power companies, there were two power programs, both free. One was Bonneville Power Administration, Western Interconnection used that. And the other was Philadelphia Electric, power flow, transient stability that was used by all of the Eastern Interconnection. And Philadelphia Electric's programs died first because PTI took over with their PSSE programs. They became a company. It was a new company, then, who wrote their own power flow. And then they started selling it, and they complained about the fact that power companies, regulated companies are not letting private companies to come into the picture. So, the Eastern Interconnection switch over to the PTI programs faster, but Bonneville's programs in the Western Interconnection persisted for much longer.

Rachel Harris (00:58:46):

So, it sounds like with power flow, a lot of innovation was happening in industry and not just in the academic setting. Was that also true for other applications, like state estimation or contingency analysis, that it was really driven by industry as well?

Anjan Bose (00:58:58):

Yes. If you think of how the things operate today, it's very seldom that things from academia migrate to industry. The main exception is Power World. The Power World program, because Tom Overbye, the founder, is still a professor. But even for Power World, what happens is that they use all this, all stuff that comes out of academia as they find fit, but they won't tell you what they're using. And it's all secret. What's in their algorithm is secret? And this creates a huge problem because much of the academic debate about whether this algorithm is better or that algorithm is better, is all theoretical because you say, “Well, optimal power flow is being used to clear every market in the US.”

(01:00:15): There's all this huge number of papers in academia thinking, my algorithm is better than your algorithm, but it doesn't matter because what matters is what PJM is using versus what MISO is using versus what SPP is using. And they have bought it from different vendors. And so, you have no idea if PJM's algorithm is better than MISO, because <laugh> they came from different, and they're all, both secret. So, nobody has a very good way of comparing these things. And if my algorithm is better than yours becomes an academic exercise. Yes, you try them on, you can try both algorithms on the same thing, and yours is better, fine, but who cares?

Julie Cohn (01:01:11):

So, would you attribute that to the transition in the industry? From the vertical monopolies to the competitive markets?

Anjan Bose (01:01:22):

I don't think that the competitive market has had anything to do with it, because the only place where there's a competitive market is in generation. So, transmission and distribution, what we consider the utility industry, is basically all regulated. So, you take the generation market and these guys, and that part is very competitive. But the competition is not what people would think that they come up with better generators. That's not where they make money, they make money in their bidding strategies. So, they're very innovative in that and very secretive. So, all these guys have big financial firms behind them who are continuously figuring out bidding strategies. And it's a trial-and-error method because what they do is they're looking at their history of what has happened to their bids compared to other people whose algorithms they don't know.

(01:28:38): So, they're developing their algorithms to guess how they can do better bidding than their competition. And these software that they develop is very creative and very competitive and very secret, so <laugh> the academic people are completely left out of it. <laugh> But the markets themselves create enough discussion among the academics. My personal opinion is that it hasn't really impacted the customer as much. Because it is kind of hard to argue because there are economists who are always saying that having generation deregulated, it may have made a big difference. And they're running all simulations, showing large amounts of saving. And what it boils down to at the bottom line is that, if, yes, the price of electricity has gone up, but if we didn't have the markets, it would've gone up more. Well, how can you disprove that? <laugh>

Julie Cohn (01:04:07):

So, the development of a wall between academics and industrial people, what do you attribute that to in the power flow area?

Anjan Bose (01:04:24):

I attribute that to the whole trend in the power companies, the utility companies, deciding over time that there is no incentive to do any innovation. And when I think about that, and I think about the time when I joined the industry, when I started working in this field, the difference is that the leadership of the power companies used to be made up of engineers. They worked themselves up into being the CEO and so on. And when we came to these kinds of conferences in the '70s, the CEOs were there. And it's kind of hard to explain because if you go to the plenary session on Monday morning, you'll find that the speakers are all CEO types, senior vice presidents and executives and from these power companies. But often they're not engineers, which is the way it is. So, in a sense, it's the same level of people they're attracting for the panel. But when the same panel, if I think of 50 years ago in the '70s, it would be the CEO of AEP, who would say that, Well, we are gonna put in another power plant in such and such place, or we are going to build in, They announced at a meeting like this that they're going to the 765 KV level, okay?

(01:06:07): And then nobody followed. They said, “AEP is the only one who has 765 kv in this country.” But this guy understood what goes in the 765 KV transmission in a substation. So that's the difference, because they were proud of moving the industry forwards, technically. None of the people, very few of the owners of the power companies, think that way because there doesn't matter what they do. Their profit margin is the same, so there is no incentive, and economists say that this is what was going to happen anyways. When the profit margin doesn't change, then there's no incentive. But when I think about it, I have to say that it must have been the pride of an engineer who did this thing, because an accountant's pride doesn't make your 10 percent or whatever. <laugh>

(01:07:15): So, I think that's the big difference. But also, the thing to remember is that this could happen, because in a way the power companies were very successful in moving the competition to the vendors, not the generators, to the vendors. So, you see where the innovation happened, where the ABBs and the Siemens, that's where innovation happened because they competed with each other. In the old days, it was GE versus Westinghouse, and now it's ABB and Siemens and Alstom or whoever else. And I think that made it even easier for the power companies not to worry about innovation. And it points to the fact that most power companies are shedding almost all their engineering functions. Even things that were sort of standard to do, like distribution substations. They're giving it to Black and Veatch or Burns and McDonnell, or somebody else, so that you don't have to worry about these kinds of details. Then finally, you become just a pass-through finance company. <laugh>

(01:08:42): I'm saddened by the whole thing that the power companies don't take any leadership, and I find it that when I go to a place like China, they're doing exactly the opposite. They're filling up their power company with PhDs, and you go into an operation center, a control center; they're maintaining their own software. They're developing, they're putting in their own software. They're not having to go to Siemens and say, Hey, the software is not working, can you fix it? They're able to do these things themselves. And then that keeps the vendors in line as well, because they said, No, we don't want this.

(01:09:37): You've gotta do it this way because this is the way I want to operate my grid <laugh> And so, it's a very different kind that you see is happening. And the reason China can do it that way, it shows in both sides. They have incentives because again, their engineers want to do better and so on. But see, the result, the technology in China is moving ahead. 10 years ago, 15 years ago, we would say, They're copying our stuff. They have nothing left to copy there. They've gone past.

Julie Cohn (01:10:23):

We've taken up quite a bit of your time and I know you have other responsibilities here today, so I'm gonna see if there's any final question anybody wants to ask.

Daniel Molzahn (01:10:35):

If we have a minute. If you'll indulge me, I know you've explained this to me before, but one of the stories I really appreciate that you've told us this history of PICA versus PSSC and these different power conferences. I think it fits in a little bit with what you were just describing. Can you summarize that again? What's the role of these conferences in—

Anjan Bose (01:10:55):

In the '60s, I would say, when the computer started being applied to the power grid, and the power companies were ahead of every other industry in applying computers. So, these people started thinking about having conferences on it. So, there were specialized conferences set up. One was called the Power Industry Computer Applications. That was set up in the US as part of the IEEE. And so, some of the people like Bill Tinney and so on were involved with that. And this was before my time. I really started getting involved in the '70s after my PhD. They started doing a similar conference in Europe called PSCC, the Power Systems Computation Conference, that you know very well.

(01:12:01): But they had completely different characteristics. The ones in Europe were run by a few top big-name professors from the European university. Here it was more of an IEEE thing. And there were a lot of industry people involved because those were the people from GE and Westinghouse and all the software vendors. And they were all involved in setting up, including professors. And so there were different characteristics, but the idea was the same. To push the analytical aspects of applying computers to—the history is the PICA, the conference here, and then I got very involved with PICA, and I was on the board and I ran a couple of the conferences and so on, deteriorated when the leadership of the Power Engineering Society decided that PICA wasn't big enough because it was limited to about 400 people because it was very specialized.

(01:13:10): But people would talk about what they had done with the control centers. And industry actually participated quite a bit. But the Power Engineering Society decided it wasn't big enough. And so, they changed the name of it and started a bigger, which flopped and didn't work. Because it wasn't focused enough, and it just started to look like another general meeting. And they killed it finally. So, it doesn't exist. PSCC continued, but it has also changed in quality. It has stayed very much an academic conference. And so that part hasn't changed, but it's now become the main conference in the world that is focused on computer applications to the power grid. But it is pretty much academic. And I kind of regret the PICA thing because that was where the vendors would actually come and talk about things, and that's kind of gone.

Julie Cohn (01:14:25):

Thank you. Well, thank you so much for spending time with us this morning. It's been a real pleasure, and we greatly appreciate it, and we wish you the best for the remainder of this conference.

Anjan Bose (01:14:37):

Thank you. So, yeah, when my age, you just have stories too.

Julie Cohn (01:14:46):

I feel we could have sat here all day.

Anjan Bose (01:14:48):

Yeah. Right.

[End of Interview]