Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee:	Göran Andersson
Interview Date:	October 24, 2023
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Interviewer:	Julie Cohn, Daniel Molzahn, Sairaj Dhople, Line Roald, and Spyros Chatzivasileiadis. Rachel Harris was also present.

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Abstract:

Professor Göran Andersson describes his education Lund University, Sweden, his degrees in engineering physics, mathematical physics, and nuclear physics, and his professional experiences at ASEA (now ABB), the Royal Institute, and ETH Zürich. He explains his early focus on calculating system stability limits, the use of sparse matrices, and the role of computers, which had been little used for this in power systems engineering until the late 1980s. He mentions the configuration of the Swedish power system and the significance of the 1983 blackout. His research built on prior work by Peter Sauer and Russian engineers, and was supported by David Hill. He mentioned similarities in calculations needed for the US Strategic Defense Initiative. He describes his move to ETH Zurich in 2000 and a shift in focus to competitive power markets and integration of renewables. He describes the interactions between his academic research lab and industry – noting the importance of selecting research problems that will have an impact on real world issues faced by utilities and system operators. He discusses the importance of models of complex system, the limits of learning from systems

that are operating reliably, the ability to analyze data from real events, and the value of simplicity in methods and models that are ultimately adopted as standards. He stresses the pros and cons within any model. Discussing the integration of renewables, he notes that the old rubrics for controlling and optimizing systems depended on well-understood physics. With power electronics, and increased complexity, it is now more difficult to understand and conceptualize what is happening on power systems. We may have to "rewrite" our approach to stability. He speculates that social sciences will have important contributions to make to next generation methods of power control and optimization. He encourages new engineers to step back and thing about the overall purpose of power systems and to select research questions that will have a real impact. He closes by speculating on the intersections of power systems and other fields that address similar complexities, such as biological sciences.

Note regarding Transcript and Timestamps:

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

Transcript

Julie Cohn (00:00:02):

This is Julie Cohn. I'm conducting an interview with Göran Andersson on October 24th, 2023, online. Daniel Molzahn will assist with the interview as will Sairaj Dhople, Rachel Harris, Line Roald, and Spyros Chatzivasileiadis who are also participating and may ask questions as well. So, Dr. Andersson, during today's interview, we are especially interested in your early work on power systems control and optimization, and your perspectives on the history of particular methodologies. For example, the equal area criterion or the DC power flow approximation and how those methodologies frame contemporary approaches to grid control and optimization. But first, we'd like to begin with some introductory questions and some general background information about you. So, if you would be so kind, please describe your educational background and your professional positions in the field of power systems engineering.

Göran Andersson (00:01:04):

Thank you. And yeah, I'm glad to be here and I think this is a very interesting project that you are working on. So well, I—actually, my basic training at university, I'm not a power engineer. I studied here in Sweden in something at university called Engineering Physics, which is quite a broad field where we get the training in mathematics and control and physics. It's a little deeper than in other disciplines. And I decided to go for a PhD—and that was not in power, it was in something called mathematical physics—so I was a theoretician, and I made my PhD thesis in nuclear physics, actually. But it was very mathematical, and I was working quite a lot with matrices at that time.

(00:02:08):

And for a couple of months, I actually had a Swedish record of diagonalizing matrices to size. It was 1,024 by 1,024 matrix, which is peanuts to date. But then, in the late ‘70s, it was an achievement actually. Because the memory size of the computers and things like that, was not that impressive as today. So, but then when I finished the PhD, I was not really happy with physics that, I didn't see a very interesting career path in physics. And then I was contacted by an old friend who worked at the company ASEA, which then became ABB, and is now Hitachi Energy. And they were building up a systems group to work with system applications of high voltage DC. And they were looking for people that had a solid background in control and in computational techniques.

(00:03:02):

And I had a couple of other job offers too. But after quite some thinking, we decided to—I decided to take this job offer. And so that is where I really started to work with power systems, which actually was after my PhD. During my undergraduate education, we had courses in power. So, it was not a completely black spot for me, so to speak. So, I worked then with high voltage DC, as I said, and after a few years, I got in charge of a group called Systems Computation. And so, we developed the stability criteria for HVDC, and the different damping controllers for HVDC projects all over the world, in US and in Brazil and in Europe.

(00:04:31):

And I worked with that until 1986, I think. My PhD was 1980. 1986, they were looking for a professor at the Royal Institute of Technology in Stockholm in Power systems. I saw the call and I said, well, I'm curious who will get that? And then people started to approach me and said that you should apply, you should apply. And I did. And I got the position, much to my surprise, actually. And that—then I was at KTH or Royal Institute from 1986. I started in 1987 until 2000, when I got an offer to go to Zurich and ETH, where I stayed until my formal retirement in 2016. So that's roughly about my career in the field, so to speak.

Julie Cohn (00:05:52):

Thank you. So, during that time, what would you say were the most interesting or challenging problems you chose to tackle, once you had found yourself in the engineering position? <laugh>

Göran Andersson (00:06:09):

Yeah. Well, let me say, one thing that I think I saw very clearly was the role of computers that were not that much used then in the beginning of the 1980s. They were used—a lot of computations were done, but not to the extent that we see today. And the computational power and capabilities were not in the vicinity of what we have today. And that improved gradually and more rapidly during then the later decades. So that was it. It meant also that a lot of problems that couldn't be addressed and solved earlier then became available for—that we could develop good solutions thanks to the computers. And also, communication, if you're looking on real time controlling power systems.

(00:07:27):

And so, in the first problem we worked on in Stockholm, were quite a few students working on that, had to do with voltage stability in our systems. In 1983, 27th of December, there was a blackout of—in Sweden that—about two thirds of the country went black after an incident. And that was a voltage collapse, and that was something that was not studied that extensively up to that date. And there were other places in the world that had experienced voltage instabilities. So that was a very hot topic. So, we started to work on that. And we developed a few methods that were used during some time here in Sweden for calculating the stability limits for how much you could load the system.

(00:08:48):

Here is a lot of transfer from North, where the hydropower is, down to the south. It's very similar to what you see in western US in—where hydropower up in Oregon and Washington, and it's transported down to California. And there we got in contact with groups in US that were working on this topic. And both in industry and in academia. Pete Sauer in Illinois was working on this topic. Industry, was Prabha Kundur, he was in Toronto at that time. And there was a group in Vancouver where, I've forgotten the name of the university guy there, but it was at the BC Hydro. It was Yakout Mansour, was a driving personality in this endeavor. And we—so that was very stimulating both for me and the PhD students working on that.

(00:10:03):

So, we got involved in a lot of IEEE working groups and task forces on that topic. And that was—what we developed was a method to—what we looked as a stability measure was the minimum singular value of the power flow matrix, Jacobian, basically. And we had a little problem in selling that concept because many power engineers were not that familiar. They knew what eigenvalues were, many of them, but the minimum singular value was a little more, was an exotic animal to most of them. And actually, what happened was that Prahba Kundur and his group, they marketed more the eigenvalue. And the thing was, it turns out that for these matrices, which are almost symmetric, they are <almost> identical, the minimum singular value and the eigenvalues, or the smallest eigenvalues. So that was what we were working with. And that had also a nice connection to high voltage DC because many of the instability modes of the kind of technology that were used, were used then in the '80s and '90s, they are also related to voltage instability. So, we kind of showed that they were very similar and so we could use the same analytical techniques to model this.

Julie Cohn (00:12:03):

How did you persuade the reluctant engineers to pay attention to the work you were doing?

Göran Andersson (00:12:11):

Well, it was a very—in Sweden at that time, it was not that difficult because they had this blackout in '83, and they were very aware that they needed something more than they had at that time. And something new. And they had also quite the pressure from society because this blackout was, duration was quite high. It was up to seven, in some parts, up to seven, eight hours, and it was in the middle of the winter. So, it was dark and cold, and there was a report coming out that the, in Stockholm, that the pumps for the water supply system couldn't work. And if they don't work during a certain time, there are always leakages. You have to have a certain pressure. And if that pressure goes down, then water from outside can get in. Water that is contaminated. And that could be a disaster If that gets into to the water supply. They were lucky.

(00:13:33):

They managed to keep the water pressure out over the critical level. But if it had, blackout had been just one or two hours more, it could be really a catastrophe for the water supply in Stockholm. So, a lot of authorities, they put pressure on the utilities to solve this problem. So, and that was really nice because our group worked a lot of analytical techniques, but there were other things that should also be solved, load modeling and stuff like that. And there were other universities in Sweden like Chalmers and Lund, they did a lot of work on that. So, by the mid-’90s or something, we think that then we had a good solution that then was implemented with some modifications in the control of the Swedish system.

Julie Cohn (00:14:41):

So, for the non-engineer among us, who happens to be me, <laugh> how would you describe the practical difference for either system planning or in the control room that resulted from these changes?

Göran Andersson (00:15:00):

Yeah, for the planning. They got better models to do their simulations, and they also got criteria to look on these minimum singular values or eigenvalues. I think in the end, they switched it to eigenvalues, and that was a concrete measure of the distance to instability. And they also, what we also came up with were other indicators that some generators, their reactive supply was increasing above certain limits and things like that. Which then, for the online operation, what was very useful information for the operators, because they—in the online operation, there was no time to calculate these eigenvalues, or minimum singular values.

Julie Cohn (00:16:10):

Thank you.

Göran Andersson (00:16:10):

And it was also, which I think is important, perhaps not just to get a tool, but they got a better understanding of the problem. So, they knew what was going on, and that made them a little more confident about the operation and planning of the system.

Julie Cohn (00:16:38):

So, I have two follow-on questions in two different directions. One would be, if you, when you started working on this, what prior work were you building on?

Göran Andersson (00:16:54):

Yeah, if you take on the voltage stability, there was some preliminary work done by—then I would mention, I think Pete Sauer had some papers on that. And then there were Russians. The Russians had done a lot of work in this area. The problem was that they didn't publish in English, that most of the work was in Russian. And so, I think it was Venikov that first came up with this, that voltage stability had to do with the singularity of the power flow Jacobian. And it was not disseminated that much into the western countries. They had a lot of clever solutions in Russia or Soviet Union, I should say, then back in the ‘60s and ‘70s. But they were kind of isolated from the rest of the world in this respect. And there, I would mention David Hill—that many of you know that he—we work with him quite a lot on this voltage stability issue. So many of the papers we published together with him. We managed to get money from utilities here in Sweden so he could come and visit us. And he worked with us, and he also went to Russia or Soviet Union and discussed with power engineers there.

Julie Cohn (00:18:40):

So, did David Hill work as a bridge then between the separate groups of engineers who—whose ideas weren't crossing international borders very effectively?

Göran Andersson (00:18:53):

Yeah, he had been working on these things earlier and so we wanted to get kick started, so to speak. So, we managed to get him here. So, he was here for a couple of weeks, and then we worked intensely and he—were kind of co-supervising PhD students. That was very helpful.

Julie Cohn (00:19:22):

Yeah. That's very interesting because well, did that kind of technology knowledge exchange improve after the USSR disappeared? <laugh>

Göran Andersson (00:19:40):

No, I—well, what happened then was that: Russia collapsed more or less; All the engineers, they fled, they got out of the country—many of them at least.

Julie Cohn (00:19:55):

Interesting. Yeah.

Göran Andersson (00:19:56):

Yeah, yeah. There was some of the other people here around know Yuri Makarov that was, he was in St. Petersburg and he unfortunately passed away, was it last year or two years ago? And he was at—so someone can help me. He was at the Pacific Northwest Lab, I think when he passed away. And he was from St. Petersburg and then worked actually with David Hill in Australia, but then came to US. And so, he was one example of these guys that, they were trained in the old Soviet Union, but then they moved away when, in the end of—, beginning of '90s.

Julie Cohn (00:20:59):

Thank you. Yeah, that's very interesting. And then the other direction I was curious about is, did you bump into many, many dead ends as you were developing your analytical approach to the singularity value? The minimum singularity value?

Göran Andersson (00:21:21):

Yeah. What I remember, you're kind of—to survive you forget about your—what your—where you do not succeed. But—I don't remember. We had one thing where we're—I think we made a contribution that is still used, was that when you reduce these matrices, you lose sparsity. They are not sparse anymore. But then there was a trick to solve that problem, and that was a very clever PhD student I had, his name was Thomas Smed, who came out with idea, there is something called generalized eigenvalue, or generalized minimum singular value, where you actually do not reduce the matrix. You keep the sparsity and then you can calculate it. And I think that that was a good trick that we were using at least, I think in power systems, for the first time.

(00:22:38):

Now in many areas, it's a standard technique to do it that way. But that was his contribution to this. But then you say, they are dense. What I remember was also to convene some of the older power engineers in the industry, that this was something that should be used. There is a skepticism against new things. Sometimes that's a sound skepticism. I think that <laugh> just because it's new, it's not necessarily good. And so, but some of the more influential of these engineers, I think we managed to, or succeeded to persuade that it was good. But there were others that perhaps not accepted it that much.

Julie Cohn (00:23:44):

How did you go about convening them? Was it through the normal conference, organizational activities or other kinds of meetings?

Göran Andersson (00:23:53):

Yeah, well, it was more meetings. We met at their office, and we showed cases and tried to then compare old methods and new methods and show what are the advantages with this and so on. Yeah.

Julie Cohn (00:24:13):

Did any of them offer critiques that gave you pause?

Göran Andersson (00:24:19):

Sorry, that gave us?

Julie Cohn (00:24:21):

I'm sorry, that made you, did any of them offer critiques that caused you to think, oh, maybe we're wrong? Or were they generally—?

Göran Andersson (00:24:29):

Oh, yeah. Oh yeah. Sure, sure. Critique in the sense that we had neglected things that are important out in the practical operation. As always, we kind of make models, mathematical models, and then we start to analyze these and compute things and et cetera. But it—quite often we have neglected important things in these models. And so, I think there was this interaction back and forth where they pointed out that you have to consider that. And then we had to do that and go back and <laugh> do our homework.

Julie Cohn (00:25:19):

That, I imagine this is something that may be coming full circle for you now, <laugh> with younger engineers. <laugh> I see that Dan has a question.

Göran Andersson (00:25:28):

Yep.

Daniel Molzahn (00:25:29):

Yeah. So Göran, this is really fascinating. And one thing I was wondering with this is, so I think if I understand correctly, in the ‘60s and ‘50s, there was a lot of effort. Everyone knew, in many different fields, not just power engineering, that sparsity was something that was very important in a lot of settings. Was it similar in the ‘80s and ‘90s when people were looking at these voltage stability problems that—were there kind of analogous problems in other fields that you were drawing on, or that many people were trying to solve kind of related questions to these stability problems, or this was very specific to power engineering?

Göran Andersson (00:26:06):

Yeah, it's a good question. I don't think I have [an] answer to that. There was, in the ‘80s, let me see, what was the name of this, that Reagan launched this big program called Star Wars, but it had another name flexible—you're too young to remember it, but that was a big effort to have kind of—

Daniel Molzahn (00:26:38):

I've read about this in books.

Göran Andersson (00:26:39):

And what you get then is what they call flexible structures, big mechanical structures that were kind of shields, and that they wanted to calculate the dynamics of these things. And then you get equations that are very similar to power systems, actually. Well, the name, what was the name of this big? It was a big defense—

Daniel Molzahn (00:27:14):

Oh, Strategic Defense Initiative? The SDI, is that—?

Göran Andersson (00:27:17):

SDI is the name. Yeah.

Daniel Molzahn (00:27:21):

I see. That's interesting. So, they had similar mathematical structures.

Göran Andersson (00:27:25):

Yup, yup.

Daniel Molzahn (00:27:26):

Did you work with, like, was that an active, connections between power engineers and, sort of, defense folks working on those questions, or these kind of pursued in parallel?

Göran Andersson (00:27:36):

I don't know, because that was a US project and that was highly classified <laugh> work going on. But they published things on numerical methods and so on, that power engineers looked at. That is, I remember that. Yeah. Definitely.

Daniel Molzahn (00:27:57):

That's very fascinating. Thanks. I appreciate it.

Göran Andersson (00:28:00):

Yeah. SDI was the name. Yeah, correct.

Julie Cohn (00:28:04):

And any other questions at this point?

Göran Andersson (00:28:10):

So well, I've talked a lot about the things that happened in Sweden, but then I moved to Switzerland and, we—there was more diversity of things we were working on. And Line and Spyros are aware of what they did. We, there, the stability issues was not that pronounced problem as in Sweden. What happened then in the power industry was that markets came in and so we worked on markets and then the integration of renewables was the next big topic that was coming in. And that was kind of—different aspects of that was the focus of our research there for many years.

Julie Cohn (00:29:16):

What were one or two of the—oh, I see Line has a question. Go ahead, Line.

Line Roald (00:29:23):

Yeah. Hi Göran. This is—it's very interesting. I wanted to ask, so given you—you mentioned that the stability problems were important in Sweden. I just wanted to ask, sort of the sense of place and where you are and your interactions maybe with national partners, whether that's industry or government agencies, how that has helped shaped your work.

Göran Andersson (00:29:54):

Yeah, that is very important I think to have as an academic researcher in our field, to have connections with industry that you work on real problems. And that you not, let me put it this way, that you get help to formulate the problem in such a way that they are, then, or could be useful for the industry. So, I think that is very important that industry is involved in this project, in this process. It's always necessary to get money from the industry to do the—<laugh>—the research, but it's also as important, I think, to get the input from the industries that they work on the right problem and they are formulated in a way that they could, if you solve them in a successful way, that they could then influence the development of the power system.

Julie Cohn (00:31:10):

Spyros, before I call on you, I have a follow on to that. So, did—was your personal experience, having worked in industry, important in how well you were able to translate back and forth between your academic work and things that were applicable in the real world?

Göran Andersson (00:31:29):

Yeah, I think so. I think it helped me to talk with people from industry and also to really listen and take their points of view into account. One has to understand that many of these people working in industry, that they have their problems, that they are working with them from all the day, from morning to evening, and it's not always that they have time to actually get into thinking beyond what they have on their desks, a particular day. And so, if they take the time and discuss with you, you should really use that time in effective way, try to kind of extract the information that could influence your research.

Julie Cohn (00:32:42):

Spyros, you had a question?

Spyros Chatzivasileiadis (00:32:44):

Yes. Thanks, Julie. It's actually a follow up on what you and Julie asked—and this related because in Switzerland—so the energy hubs was actually a concept that you introduced at work, right? The combined operation of electricity and gas networks. But did that come from the industry? So, was it through discussion from that, or was— could you come from academia?

Göran Andersson (00:31:11):

Yeah, well, I think the idea came from professor Frölich's group. He had that idea originally, and then we managed to persuade, it was ABB, and Siemens, and I don't remember the partners now, to support that work. And that later then came into this European Union project that you worked on. But I think the original idea was from us, from ETH. But to combine the gas and the heating and the electricity grid. I think that's an old concept. But the formalism with the energy hub came from us, if you can say that.

Julie Cohn (00:34:21):

So, within the two new fields that opened up as you arrived and began work in Switzerland - markets and renewables - were there one or two problems or challenges that especially occupied your attention and concerned you over many years?

Göran Andersson (00:34:44):

Yeah, it was the integration of renewables was then becoming the big issue and, different aspects of that, because that is—I think if you look now on power system research in Europe, I think, in US also, that is the dominating topic. Different aspects of that. It has new things, stability issues that are coming up. And so many of the things that we developed in the old days with stability, it has to be revisited and revised and complemented so it can cope with these new types of generators, PV and wind generators that are not like the old synchronous generators.

(00:35:45):

So, the areas, say stability, is something that is still there, but it has to be rewritten. Many of the rules and so on that we have used over the years. And another thing is the optimization that has then taken a more prominent role in power systems, I think. And that's due, first is we have computers, we can solve a lot or more problems. And new mathematical methods, new numerical methods have been developed. So more complex and bigger problems can be solved than earlier. And we want to cost-optimize things more.

Julie Cohn (00:36:38):

So, what would be an example of one of the older rubrics or algorithms that may no longer be appropriate in this new world of renewables, but that is still in use and requires rethinking?

Göran Andersson (00:36:53):

Yeah, I think that's a—the classical transient stability of a synchronous generator. You cannot use that in the same way as in the old days because you have this inverter-interfaced power sources. They will not react as the old generators. So, you have to revisit and perhaps change that. And the younger engineers here, they know more about this than I do, but that is my feeling, and I know people are working on this issues.

Julie Cohn (00:37:32):

Is this an example though, of something that older engineers might cling to while training younger engineers to work on it?

Göran Andersson (00:37:43):

Yeah, I think that it's necessary to actually revise this and rethink the—these old stability rules that were used in the old days. I—that's really necessary. Another thing is that, in the old days there were a few big generators in the system. Now there are numerous, many, many smaller generators, wind farms and PV and all that. And that requires different operational methods and strategies, I think. And earlier—

Julie Cohn (00:38:36):

Sairaj, you've got a question?

Sairaj Dhople (00:38:40):

Yeah. So just touching up on this. You talked about how physics and engineering physics played a big role in your formative years and how you went about picking problems and thinking about them. In the context of—let's say, renewables and power electronics—the physics part of it seems like we have gotten better at hiding away, right? And we don't appreciate these big mechanical masses that are, that are rotating and that did support the grid, and it was some somehow maybe easier to conceptualize and easier to understand. How big of a challenge do you think that this whole, sort of, black box approach to generation presents, going in the future?

Göran Andersson (00:39:32):

Yeah. If I understand your question, is that, you mean to conceptualize it to people, or to other engineers? It's getting more abstract. I can—I agree with you on that because the big generators, they were driven then by hydro turbines and steam turbines, and you could actually more see and feel the flow of power. But when you get power electronics, it's to get, getting a little more hidden, if that is what you mean. And—

Sairaj Dhople (00:40:19):

Yeah, I think, yeah, sorry, go ahead.

Göran Andersson (00:40:22):

Yeah, and that is a challenge to explain to people and also with power electronics and all these small generators, the complexity increases in the system. And complexity, per se, could be a problem to cope with. So perhaps you need methods to understand that better, because if you look at many of the blackouts that have happened, it's quite often that all these hidden failures in protections and control systems, and that—our control systems and supervisory systems, they do not work as they should. And that could then cause instabilities in the system. Whereas perhaps in the old days, it was more physically-induced instabilities by transient stability, voltage stability. You know the physics there much better, or can understand it much better than, if a lot of inverters start to behave in their own way or something like that—I don't know if you—I answered your question, but—

Sairaj Dhople (00:42:00):

Yes absolutely. And I guess to just follow up on that, do you see that our current way in which we think about these problems or we train our students to think about them, or the way we are engaging with industry, do you see that there are some gaps in how we could maybe do better to address some of these issues?

Göran Andersson (00:42:26):

Yeah, well, I don't think I have a—kind of a general solution or quick solution to that. There was—some years ago something developed called complexity theory. I don't know if that has had any impact or what it actually can do, but when you interact, you have to be honest and present the problems. And also, be honest, to say when you don't have any solutions. That is also important. But it—this is very tricky, and I haven't thought so much about it. I must—

Julie Cohn (00:43:24):

Thank you—one thing we heard from other colleagues of yours from around the world who reflected on this differently, they didn't all have the same answer, but they all, many talked about being able to test their theories and models and analyses in some way, either on an analog system or on actual parts of a grid. And some saw value in this, others felt that the way we can model things today with our very high-speed sophisticated computers far exceeds the value of trying things on the physical grid or on a physical analog. Any, any reflections on that? Did you ever do that? And what are your thoughts?

Göran Andersson (00:44:17):

Yeah, I think it's a very interesting question. And I, and that is a tricky thing, thing with power systems is that it's very seldom you do full scale experiments. You can't do it because then you could endanger the stability of the system, and it could be very disruptive to society. So, we have to rely on models. That, there's no doubt about that. And my experience is also that when, so normally, and that is the way it should be, that the power system should be stable and just supply everything. Frequencies should be stable and voltages and so on. So, it's quite boring, actually. <laugh> You optimize this, the system and so on, but everything works. And then when it works as it should, you do not learn so much about it. <laugh> Actually, it's when something unforeseen happens, a big disturbance or something, then you get new information. And quite often you get information telling you that the models that you have used, they were not a hundred percent correct, so you improve your models.

(00:45:44):

There are many examples of that. That happened, going back to the voltage stability when they, what happened in Sweden then, 1983, when they simulated this in their models, the system was stable, but in reality it wasn't. So, there was a mismatch between the models and reality, and they found out what the mismatch was. It was to a large extent the modeling of the loads, the consumption, that had a certain voltage dependence that they didn't have. It was not modeled before that. And that was improved after that incident. And that happened at other places also, in US and in Japan, they had had similar problems in Tokyo, for instance. And also, at other of these big disturbances, you find out that the models do not work as—they're not perfect. So, it's impossible to have a complete model of everything. You should kind of appreciate and realize that. But we should have as good models as possible. And one should be aware of the limitations of the models.

(00:47:17):

But coming back to your question, if one should have a big analog model, I don't think that is possible anymore. Analog models were used into the 1980s for certain purposes. Particularly when these very fast transients, when you're down on milliseconds and microsecond scale for high voltage. But I don't think they are used anymore. And so, it's computer models that they are, digital models that we're using. But one should always, when all things that are not working as they should, then one should get the information. And that is, something that is much better today also, is the, to get good recordings of when something happens, on voltages and currents and so on. You have good time resolution. GPS, they are timestamped, so you know exactly when they're happening. So, at different places in the network, you can see what happens, and you could time-synchronize it. That is something that is really good.

Julie Cohn (00:48:46):

You mentioned optimization as an interesting problem, especially as renewables increasingly are part of the grid. Can you talk a little bit about how this was approached in the past and how one might need to be rethinking it now, or how your team rethought it in Switzerland?

Göran Andersson (00:49:07):

Yeah. Well, in the old days, as far as I know, the optimization was much simpler when it came to operational optimization. You had these merit-order curves, you know what power plants were the cheapest one, and you just put them online according to that. And you could do that because there was no market, it was a monopoly for the utilities. They were kind of, it was an optimization that was a cost minimization, that they were doing because the price was fixed more or less that the consumers had to pay. Optimization came in particularly when you had a hydro system because then you had a finite resource, with the water you had in your reservoir. When should I use it compared with using thermal hydro plants? So, I think that was the origin of more advanced optimization in power systems. And that came about here in Scandinavia. Norwegians did it and here in Sweden, and also in particularly in Western US where you have the hydro resources up in Washington and Oregon.

(00:50:46):

And that was—you have big units that were running. And they were, you had an—uncertainties in the water - how much it will rain and how much it will snow, et cetera, how much the, how, to what degrees or your reservoirs filled and so on. That was an uncertainty, but you could kind of, it was not that bad. They had pretty good data. But now when the renewables, like wind and PV, that is more fluctuating. And so, the forecasts error that you get, they are much, much bigger. So that means that the optimization is of another kind. That they are—you have to apply stochastic methods. And I think that Line, she's not here anymore with us. She's really doing that. And I think Dan also is into that to much higher degree. So, I think that is the new thing, that you need stochastic optimization. And you have also a lot of, more players in the field. You don't have these, just a few big power plants that are involved, but you have a lot of players.

Julie Cohn (00:52:23):

Dan, you have a follow up?

Daniel Molzahn (00:52:25):

Yeah, I do have a follow up on that. So that's a really interesting perspective, Göran, and it's interesting to hear the importance of the hydro/thermal systems in that context. But one follow up on that. So, I feel like we're kind of in this realm today, maybe similar to what you were describing in the ‘90s, where there was lots of different voltage stability metrics and people weren't—it took some convincing to figure out what is the right model for people to use for voltage stability. And I'm wondering if there's an analog to today where we have all these different uncertainty models of—do we use different flavors of stochastic optimization or robust optimization or chance constraints or scenario-based approaches, all of which are kind of getting at the same fundamental issues, but go about them in very different ways with different approximations and assumptions. Do you know, or do you happen to have any thoughts on going forward, any lessons learned from how we, sort of, consolidated around different operating procedures in the past that might be helpful for informing what we do going forward in this stochastic optimization problem?

Göran Andersson (00:53:36):

Well, I wish I had—<laugh> I think one has to be—you have to pursue all these different approaches and then in the end compare the results and one should always be aware that all methods have their pros and cons. There is nothing that is, have just pros. And so there is always a downside to everything. And then depending on the problem, one has to be honest and evaluate, which are the pros here and which are the cons, and where, which is standard, the heavier, where does it weigh over to one or another? And I think that is a principle that I learned many, many years ago by, when I was in industry, by an engineer, said that there are always pros and cons and you have to appreciate that and realize it. But when people say that solution, it has just advantages and no disadvantages. That's a lie. So, I think one has to read these different methods to evaluate the pros and cons and that could be situations where one method is the best and other systems or situations where another method is the best, and that has to be evaluated.

Daniel Molzahn (00:55:16):

And where, where do you think those evaluations best take place? Are these, was this IEEE working groups and task forces? Are these the role of the ISO, the system operators and the federal regulators or who do you think is best positioned to make those assessments?

Göran Andersson (00:55:36):

Well, I think it's a multi-step process. It's, start off with researchers comparing the results. And that is what happened with voltage stability. We can draw the parallel with that. There were working groups in IEEE, and we had panel sessions where all the methods were presented and discussed. We tried to find out the pros and cons, et cetera. And it kind of, then, condensed down to a few methods that were worthwhile to use. And then I think different system operators, they picked up one that suited their system. And it should also be easy to integrate in their—the systems that they're using. So, I think that start off with a scientific - I don't like the word benchmarking - but some kind of comparison and evaluation. And honesty is very important here, because there is a risk here that it turns out to be a kind of a competition or popularity contest, which is the <laugh> best method. That's mine. But one has to kind of be a little humble and also identify the weaker points of what you're using.

Julie Cohn (00:57:17):

I see that Sairaj has a follow-on question. And then I have one as well. Go ahead, Sairaj.

Sairaj Dhople (00:57:20):

Yeah. So, I just wanted to follow up on that and maybe broaden that question just a little bit. And to maybe just pick your brain on what technologies or methods or tools you see as being determinative. And maybe I can explain how we have tried to define this term in our group.

There are a few methods—let's say, DCOPF, droop control, equal area method—Which—the slack bus, the per-unit system. Like we take this for granted, and these are sacrosanct and they somehow are never touched. And they have persisted through the years. Do you have any comments to offer on why there are these very sacrosanct methods that we all take for granted, maybe some pet ones of your own that you are either happy or unhappy about, and how you think that these should maybe change?

Göran Andersson (00:58:25):

Well, interesting question. I think that one reason why they are surviving is that they are quite simple and easy to understand, but still, they give a good insight into these problems. Take the equal area criterion and single machine infinite bus is—there is no real power system that looks like that, but still for transient stability, I think you get quite a lot of insight into what happens when you have these rotor oscillations in the systems. So, I think that is one reason why they are sacrosanct, or what term you used here, that they give a good insight. And if you take the DC power flow, it's simple, it's linear, and in many cases it's a very good approximation.

(00:59:37):

So, I think that's why it's survives. And perhaps, or what one should look for is, then, other such simple models then, in the new power system where you have all the renewables and so on, that could give the same insight as these simple models. I think they should be used. And, but if they are proven wrong, or they are not representative more in the power system, then they should not be used anymore. But I think that there is still some time until that is the case. If I answered your question, I don't know?

Sairaj Dhople (01:00:28):

Yes, thank you, thank you so much.

Göran Andersson (01:00:31):

I think that is, you need to have simple models, because we cannot—even if we compute big problems and big matrices and optimizations and so on, when you actually then design a solution of, I think most human brains must have simpler models to guide the thinking. You cannot look at a system with 10,000 buses or something like that. You have to have a more simple model that can guide your thinking.

Julie Cohn (01:01:16):

Thank you. Did you have a follow-on Sairaj or Daniel to that comment? If not, I have a different direction. Go ahead, Dan.

Daniel Molzahn (01:01:25):

No, no, I was just saying, I think that's really fascinating, so I appreciate the perspective on that.

Göran Andersson (01:01:32):

Yeah.

Julie Cohn (01:01:35):

So let me see if I can recollect my question. So, it sounds like a process in the past was somewhat, the individual researchers developed an approach to solve a problem. It was vetted through conferences, committees of IEEE, publications and so forth. Then particular system operators would adopt something because it seemed to fit their system. How much influence did any of those system operators ultimately have on, sort of, standardizing an approach across the industry? And were there particular ones that stand out in your mind as really being influential?

Göran Andersson (01:02:22):

Yeah, that is—I think that there are some more, some methods that are standardized or universally used. But I think a lot of systems that are in operation in power industry, they are more or less tailor-made for that utility. Because the systems are different. And they also have different preferences. And tradition is important, history of how, how the system has developed. But I think the core of many of optimization and operational methods, they are the same— state estimation for instance; that is used a lot. They, the core is more or less the same, but then they are adopted to different systems because they have their own requests or constraints or whatever. So, they, and I think that is when these big vendors that supply these systems, they have a computational core that is the same for many of these systems. And then they customize it, as I think they call it, for different systems so that they fit into it.

Julie Cohn (01:04:15):

And is there a pipeline from the academic/conference-based discussions around the core computational method and the adoption by a particular vendor? Or does it sometimes start at the vendor?

Göran Andersson (01:04:39):

Yeah, I think, these big systems, it's at the vendor, and there, universities do, is then to provide plugins to this system today. That to develop such a big system is for an academic institution is impossible. And so, it's kind of part of that system. And you can see that, go back to the voltage stability, that that was kind of a plugin to the stability assessment systems that they used here in Sweden. They had other criteria or other things they were looking on for transient stability, small single stability, and overloads and whatever they had in the system. So, we didn't kind of made a completely new system for them, but it was a plugin that was fitted into their system. I think that is quite often the case, what is happening in academia today. But that plugin could then trigger other activities and—<laugh> so it's hard to say who is kind of driving the development, but I think in the end is that the industry is—their needs is what is driving it.

Julie Cohn (01:06:06):

Did that look different from your perspective at a university in Switzerland versus your perspective at a university in Sweden versus your perspective at a utility in Sweden?

Göran Andersson (01:06:19):

Yeah, no, I think it's pretty much the same and one should also say that in many projects that were done at the university were also that industry wanted to test it, to test ideas, new ideas. That had a problem and then there was an approach to solve it. And they gave them a project to university, to us, and we tested it, and they could use it or if they don't want it, to use it or that was up to them. Because with research, it's always that you don't know what will come out in the end. You have your expectations and your forecast of what it will be, but you don't know for sure. So that is according to Einstein, the definition of research. If you <laugh> know what comes out, it's not research anymore, so—

Julie Cohn (01:07:33):

Thank you. So, I think in this final section I'm gonna ask a question. I suspect Daniel and Sairaj might also have some, and then at the end I'll see if you have other topics you'd like to reflect on before we conclude. My question is this, so you've done a lot of work on blackout postmortems, and I'm curious to know what you think might be really significant research directions to pursue going forward based on the kinds of findings you uncovered in your work previously?

Göran Andersson (01:08:17):

You mean particular concerning this blackout postmortems or in general?

Julie Cohn (01:08:27):

Whichever you would prefer to speak about at the moment. <laugh>

Göran Andersson (01:08:30):

<laugh> Yeah.

Julie Cohn (01:08:33):

I think about blackouts, but you may find a different set of topics, more, more cogent.

Göran Andersson (01:08:38):

Hmm. No, well, we don't want blackouts in the system, but—<laugh>—but I think there is a lot, particularly if we're looking on dynamics and stability issues, there is a lot you can learn from the postmortems on the analysis. And a lot more today than earlier, or perhaps I should say that you have a lot more measurements and registrations; you have all these PMUs over the system, and you can get a lot more information, and better signal processing methods available. And so, you can do a lot. So, I think that is, could be very fruitful, but you must have a blackout; <laugh> otherwise you can't do it. And you should not trigger any blackouts, or—<laugh> so I was following work done here because there was a near blackout here in Sweden a couple of—when—it was in April. And I followed what they have done at the grid company here, and it's really amazing all the data they have and how they could, with this timestamping, actually see: what is the cause, what caused that, and what was the reason and origin and things like that. That is really amazing what they can do.

Julie Cohn (01:10:23):

Yeah, it sounds like the parallel development of computing capability and data gathering capability are significant for future directions in this field.

Göran Andersson (01:10:33):

Yeah, yeah. But still there, I want to say that physics is important. <laugh> That is what is governing the system. I don't think that this, that you should go too much into, to data modeling and things like that. There is—you can improve your physically-based models with that, but completely data-based models. I think that's a dangerous path to go because we have—the physics is quite simple, what we have in the power system, actually—the complexity is the big issue here.

Julie Cohn (01:11:23):

Spyros, Sairaj, Rachel, or Daniel, do you have any final questions you'd like to ask?

Daniel Molzahn (01:11:30):

So maybe I'll start with one. So Göran, I'm curious about your perspective going forward, because you, so you, with your background, you were in more mathematical physics and mathematic or engineering physics. You had come from a background with a different field and worked across lots of different fields with lots of different communities. And you described how different communities have had impacts—the economists, for instance, with the markets in the ‘90s sort of thing.

(01:11:59):

I'm just curious about your perspective. If you had to guess what's the next big field that will kind of have an impact on power systems, maybe in the same way that the economists did in the ‘80s or in the ‘90s, and the mathematicians and sort of applied math folks that you're describing with matrix theory in the ‘80s and ‘90s for, like, is there another field that you see on the horizon as gonna come—<laugh>—come have a big impact on the industry?

Göran Andersson (01:12:30):

Yeah, I wish I could. I could speculate on this. First, let me say that I'm really amazed how power engineers have educated themselves during the years with new things. Like when—the markets came, then power engineers, they dived into economics and some were very good at this and other fields also. So, I think it's a, by nature, a multidisciplinary field, power engineering. And I think that's why I found it amazing also that there's a lot of different things. It's physics and it's controls. It's systems theory, optimization, you name it. And one thing that I think is, I don't know if it'll come, but I would be very glad if people are looking more on connections to society.

(01:13:41):

The behavior of people in the system and of consumers. It's the next step, so to speak, that in the, if you go back into 70s, 80s, there were loads in the system. That was something that was—<laugh> the power went into loads and power engineers didn't care so much about what it was. That, then, it started with market openings and the liberalization, or whatever you call it, that it's consumers. But consumers are living in a social context which is then interacting with the power system. And I think that is something that will count. It's not so mathematical, but the social sciences, I think, would be an interesting thing. And I wouldn't be surprised if that will take a more prominent role in power. Perhaps not in power engineering as we define it, but in the design of power systems, the function of the power system.

Daniel Molzahn (01:15:04):

That's really fascinating Göran. And I'm, it makes me also happy to know we're hanging out with the right people if on a, on an engineering and history project, it's—<laugh> that's a good sign.

Göran Andersson (01:15:14):

<laugh>. Yeah. And one—I should have said one thing when I—at the very beginning—why I went into power engineering. I got this job offer. I had other job offers too, and also from the defense industry. And, I'm not an active pacifist, but I found it much more human oriented, to work with power systems than with defense system. So that's one reason why I choose to this career to go to power engineering, because it's for the benefit of mankind, I think. <laugh>

Julie Cohn (01:16:07):

And we appreciate that. <laugh> Sairaj, did you have another question? Any other final questions you wanted to ask?

Sairaj Dhople (01:16:16):

Sure. I'll ask a question that I've asked several of our interviewees. Any words of advice for the future generation of power system engineers?

Göran Andersson (01:16:29):

Yeah, well. <laugh> I think one should be listening to industry needs or, what— Perhaps industry is a little too narrow, but the role of the power system in the social context. This is more on a higher level than just talking about algorithms and numerical methods and so on. But I think it's important now and then to think about: what is the whole aim, the whole purpose of our work. And when you work is to—selection of projects and so on—to work with things that you're really convinced that they will have an impact or have the possibility or potential to make an impact on the system. And the—there is this—I think Dan and I discussed in an email, this paper by Les Fink that is now a famous paper. <laugh> Dan, you have it. And which is—the title is "Solution of Non-Problems versus Non-Solution of Problems" <laugh> which was written [in] 1980. And so, I think you—Dan, you have the reference.

Daniel Molzahn (01:18:21):

Yeah, I, and in fact, I—we both have that reference, and then we also ran away, I think both Sairaj and I and bought the book that—

Göran Andersson (01:18:30):

Okay.

Daniel Molzahn (01:18:30):

The proceedings that you had mentioned. It was very fascinating work and obviously Les Fink was really insightful in that article. It is really a great article to read.

Göran Andersson (01:18:44):

Yeah, so, I think that I, many of my students have read it because I <laugh> distributed it, and I think there is a lot of good advice and insights in that paper.

Julie Cohn (01:19:05):

Thank you. Rachel or Spyros, anything else?

Spyros Chatzivasileiadis (01:19:11):

I can have one, one follow up, because we discussed so far how industry actually influences our work and we need to be learning what industry needs, and also how we have actually learned very fast from other disciplines and used these kind of insights for power systems. What could be our impact to other disciplines? So, is this a two-way road?

Göran Andersson (01:19:42):

So, if I, under- you said that what could be the impact of power systems on other disciplines?

Spyros Chatzivasileiadis (01:19:49):

Yes, exactly.

Göran Andersson (01:19:50):

Yeah. I haven't thought so much about that. So, you mean our methods that are developed that could be used other, yeah, I don't—

Spyros Chatzivasileiadis (01:20:10):

Sorry. I don't know. Maybe it's also could be the way of thinking how we deal with complexity and renewables. I don't know, to be honest. I don't know what the answer is actually. That's why I asked.

Göran Andersson (01:20:23):

Yeah, no, yeah. Complexities in telecom systems, the biological systems, and in many other systems, and there might be generic methods that could be used, or some generic thinking. And—but I cannot say anything definite on that, but I wouldn't be surprised if one could find something. And [it's] important it's also to try to interact with engineers and researchers from other disciplines. And that is kind of a risk I see that people get more and more specialized today. That you do not interact with other—there was an article in Nature, I think one or two years ago about this, that it used to be more common that people, researchers, they read papers from other disciplines, but that is not the case anymore. You just, which is understandable. If you should be competitive and do research, it's a full-time job. You don't have the time to, kind of, read a paper from another discipline. Which is bad, because you could get some new ideas from that and also perhaps influence other disciplines.

Daniel Molzahn (01:22:12):

Göran, maybe to ask a quick follow-up on that. Were there, any of the work that you look back on throughout your career, that you have done? Was there anything where there was another discipline or another paper and another discipline you read where you're like, that was really insightful and I can see the parallels in power engineering or kind of had an impact on your thinking?

Göran Andersson (01:22:33):

Yeah, I remember we, on this SDI, with these flexible structures, we read some papers then. And I'm not sure that we got some very new bright ideas from it, but we got some insights on how the power systems worked, or there was a parallel to these flexible structures.

Daniel Molzahn (01:23:04):

Got it. That's, that's really, really interesting. It's an intersection I would've never guessed as a—that's—I just never would've thought that that would be a spot.

Göran Andersson (01:23:15):

It was because these many projects, SDI, a lot of control people were involved in that. And so, it was actually with interaction with the control people that they said, they looked on, when we talked to them, the power systems. Well, your equations look very familiar to what they are doing in these flexible structures. So, you have—should have a look on that. And we did and I cannot say that we got some very drastic or revolutionary new results by looking on that. But we saw that they sometimes had solved the same problems that we do in power engineering in the same way. So that was kind of, then, verification that we were not that stupid, <laugh> other people had done the same thing. <laugh>

Daniel Molzahn (01:24:18):

<laugh> Were—are there—sorry to keep following up on this, but were there any similar kind of projects you see going on today that, if you had as much time to sit down on the—I guess in Sweden, it's what—in the mountains and read? or the beach and read? What would be your topic of choice to read from another field today?

Göran Andersson (01:24:44):

Yeah. Perhaps systems biology. Interesting. There you have also a lot of interacting entities, cells and et cetera. They're connected in various ways, and it is kind of—a cell is kind of [an] energy hub where you have then different, you have the blood flowing and other fluids, and you have the interconnection sometimes by nerves, which is electrical. And so that would be interesting. I don't know if it would give you something but would be curious to see.

Daniel Molzahn (01:25:34):

That's very interesting. It reminds me yesterday I was talking with some supply chain researchers and they said, A power grid is just a supply chain for electricity. And I said, well, a supply chain is just a power grid that moves physical things. <laugh>

Göran Andersson (01:25:50):

<laugh> Yeah.

Daniel Molzahn (01:25:52):

So that's—it's interesting that systems biology, that's quite fascinating. Hmm. But thank you.

Julie Cohn (01:26:01):

Dr. Andersson, are there any topics you were hoping to talk about today that we haven't touched on yet?

Göran Andersson (01:26:09):

No, I don't think so. We have talked a lot and I, no, nothing particular just to say that I do not regret that I chose <laugh> this field <laugh> to work in <laugh>—not at all. That was—had been fascinating from the very beginning. And I think also it's a lot of very dedicated people that are working in the field that have—has a common goal to supply energy, electricity, to customers, and also feel that it's very important that the electricity supply system is kind of the backbone of our society. So, it's important that our good people working with these topics.

Julie Cohn (01:27:22):

Thank you so much. And on that note let me express my appreciation to all the interviewers, but most especially to you, Dr. Andersson, for taking time to talk with us about your life and your profession.

Göran Andersson (01:27:25):

Yeah. Oh, my pleasure.

[End of interview]