Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee: Ian Hiskens

Interview Date: July 19, 2023

Place: Hyatt Regency Orlando, Orlando, Florida

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Transcriber:

Keywords: Ian Hiskens, Australia, Queensland, power systems, stability, algebraic singularity, energy function, network structure, power markets, Electric Power Research Institute (EPRI), Power Systems Engineering Research Center (PSERC), trajectory sensitivity, hybrid dynamic systems, operating engineers

***Abstract*:**

Ian Hiskens, Professor, Electrical Engineering and Computer Science at the University of Michigan, describes his educational background, professional and academic experiences and his research program. He names numerous collaborators including Pete Sauer, M.A. Pai, David Hill, Mark Laufenberg, Pete Kokotovic, Steve Wright, and Jim Rawlings. He discusses studying both mathematics and electrical engineering and later describes the value of integrating both fields. He explains his dissertation research relating fast forms of voltage collapse to algebraic singularity, energy function, network structure, and eventually stability. He discusses his early academic research on trajectory sensitivity and hybrid dynamic systems. He explains the challenges of finding research funding when many colleagues in this period [1990s] focused on market design. Dr. Hiskens explains that his earlier work for a transmission company in Queensland revealed the limits of available tools for conducting post-mortem analysis of trips and faults on the system. This led to his interest in trajectory sensitivity. He compares the work of operating engineers to the world of academic research and speculates about why it is difficult to bridge the two. He explains that operators still use analytical tools developed in the 1970s and operate systems conservatively while the work that he and others have done offer the means of understanding stability limits at a more fine-grained level. He describes a stability test in Queensland, before it was

interconnected with the rest of Australia (circa 1987), during which the operator allowed the researchers to manufacture a fault—which did not cause an outage—and produced real-time stability limit results. He speculates about the advantages of this real-time test—which cannot be done safely today—over simulations. He closes with thoughts about research directions young engineers should consider today.

Note regarding Transcript and Timestamps:

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

[00:01]

Mahbubul Bhuiyan: Good morning. Thanks for your important time, sharing with us for this interview. This is Mahbubul Bhuiyan. I'm conducting an interview with Ian Hiskens on Wednesday, July 19th, 2023, at the Hyatt Regency Orlando in Orlando, Florida. Dr. Daniel Molzahn, Dr. Sairaj Dhople will assist the interview and Dr. Julie Cohn , Sutanwi Chatterjee, and Rachel Harris, and a few other people present in the room, they may ask questions. During today's interview we are especially interested in your early work on generator control, frequency regulation and power flow optimization, and how your intersection with the industry changed over time. We'll begin with some introductory questions and general background information about you. So, please describe your educational background and your professional positions in the field of power system control.

Ian Hiskens: Okay. Educational background. So, my undergrad was at an institution that was called Capricornia Institute of Advanced Education, now called CQ University, which is a completely no-name, no one's ever heard of institute in my hometown of Rockhampton in Queensland. And I went there because my parents didn't trust me to go off to the big city. After about three weeks doing engineering, I decided it was boring so I did mathematics at the same time. They had no dual program, so I was actually full-time student in two different degree programs. I had two ID cards, it confused the administration no end, but anyway, that was fun. The mathematics group were a lot more interesting with camping trips to islands, with so much beer that the boat nearly sunk, way more interesting than the engineers. Anyway, so that's my undergrad Bachelor of Engineering and Bachelor of Applied Science in Mathematics. And then I did PhD at University of Newcastle in Australia.

So, I had a scholarship from the local electricity distribution company, which meant I was bonded to work with them for four years after graduation, which I got out of after two years. So, that entity was called Capricornia Electricity Board, which also no longer exists. And then I went and worked for the transmission generation company called Queensland Electricity Commission, which also no longer exists. So, I had quite an influence on all these organizations or something.

So, the reason I did engineering was my dad was an accountant in the electricity utility, and he said, "Engineers make more money, you are going to do engineering." Which is no longer the case actually but anyway, and he was a manager, and so, the place became known as Hiskens and Father.

So, that was distribution company, then I went and worked for transmission, initially in operations and then in transmission planning. And then while I was in transmission planning, they gave me 15 months leave to go and do a PhD. So, I did a PhD in 15 months.

Sairaj Dhople: They expected you to complete it in 15 months?

Ian Hiskens: Yeah.

Sairaj Dhople: One five or five zero?

Ian Hiskens: One five, 15. Yeah. So, it took 18 months, but the final three months I was writing up and back in the job with three kids, at that stage. Yeah. So yeah, I went off to Newcastle, did PhD, came back. Again, I was bonded for three years or something like that. And then at the end of that I joined University of Newcastle, which did not make my transmission company particularly happy that they had invested 15 months. It was paid time off and then I left them. I still feel kind of bad, but I think it was the best thing to do. And then, University of Newcastle for a bundle of years, and then moved to … did sabbatical at University of Illinois, Urbana/Champaign. Enjoyed our time in Champaign, went back there as a visiting professor, and then to University of Wisconsin Madison as a tenured professor, and then to University of Michigan where I was an endowed chair.

Sairaj Dhople: So, why Illinois of other options, who brought you there at that time?

Ian Hiskens: So, you were in the [00:07] Pete’s and Pai’s <inaudible> and so as I mentioned when I was talking there for sabbatical, there was a choice between—so yeah, I knew Tom really well, Tom Overbye. I knew of Pai as I mentioned the other day, he was one of the three reviewers of my thesis, and he's obviously a great guy. I had met Pete earlier as well and so the choice was Illinois or to go work with John Anderson on sabbatical in Stockholm, and the deciding factor was that Pai was likely to retire at any moment. And if we didn't do sabbatical with Pai at that point, there probably wouldn't ever be another chance. Of course, Pai never retired, but we didn't know that at the time. The [00:08] other factor was with five kids, setting them up in school in Sweden when they obviously didn't speak Swedish was going to be a bit of a challenge. Whereas in Champaign/Urbana they vaguely spoke English, so that made that a little easier.

Mahbubul Bhuiyan: I'd like to take back in your PhD actually, nowadays people need four to five years to complete a PhD, how it went in 18-months?

Ian Hiskens: So, I do not multitask very well, but if allowed to focus then—back then at least I had the ability to be quite productive. I now look back on my thesis, I think, "Whoa." [00:09] But anyway, so there's no coursework requirements in the Australian PhD process. I did some courses, but that wasn't a requirement of the PhD. In the Australian system, it's purely judged on the quality of the thesis and so I wasn't buried in doing coursework. I could focus from day one on the topic of interest. And I got some unusual results, which I put down to a bug in my code. And I was sitting in a seminar, clearly not listening to the seminar, thought, "No, I wonder if it's algebraic singularity." And it was, and that became the theme of my PhD. So, [00:10] that turned into 320 pages of my thesis.

Mahbubul Bhuiyan: Can you tell us a little bit about your PhD work?

Ian Hiskens: It's a long time ago. It was pretty focused, I was working with David Hill, but he gave me a lot of freedom, which I really appreciated. For those who know me, I'm fairly independent, if someone tells me to do something, I'll do exactly the opposite. My wife knows that and knows how to work that now, so I had the freedom to work on whatever I wanted to work on with energy function related. So, the original theme was to explore energy functions, and it was quite a new topic and in particular sort of taking into account the network structure. And [00:11] that's when in kind of incorporating network into differential algebraic systems, we—I had discovered this algebraic singularity issue, related that back to load models with a conjecture, which Bernie LeSieutre later proved, worked with Pai and Pete. And the conjecture was pretty close, Bernie got a good proof out of it. So, that sort of led on to kind of relating fast forms of voltage collapse to this algebra singularity phenomenon. So, that was the extent of PhD. There are a few other things along the way relating eigenvalues or the sign [00:12] of eigenvalues of the dynamic system back to eigenvalues of the underlying power flow, a few things like that as well.

Sairaj Dhople: Why was stability and why were energy functions popular at that time?

Ian Hiskens: So, stability was an issue in the Queensland power system because it's a very long, thin power system, kind of in the USA equivalent, the Western system. And a few years prior, back in the good old days, we were allowed to do testing on the real system. And they'd done some testing on the interconnect between generation rich area in central Queensland and the load in the south. Opening breakers, looking at oscillations, had predicted behavior should be fine. [00:13] Starting with a relatively low load, opening breakers, everything was fine, then increasing the flow, and they predicted they should be able to increase the flow up to a certain level. And when they opened the breaker, they separated the system, not a good thing. But very interesting from an understanding system behavior. So, there'd been assumptions on load models up to that point, and that led to a lot of work on adjusting the load modeling. This is in the early eighties, so there was good deal of stuff going on.

Dominic Gross: So, what was more beneficial for your PhD, your engineering training or your math training?

Ian Hiskens: The math training. Well yeah, the engineering's necessary but not sufficient. [00:14] No yeah, it's necessary but not sufficient. It was a really fun time of … So, I still remember sort of a quote that I made that last month I couldn't even pronounce the word bifurcations, now I'm writing papers about it. So, it was a fun time of just exploring a lot of ideas, and there was a lot of work going on in nonlinear systems. And yeah, that was very, very new and interesting and exciting. So, that was really cool.

Daniel Molzahn: So, how much did you take from the sort of underlying mathematics separated from power systems? Was there a lot of work going on sort of in general non-linear systems work that you're able to adapt? Or was it really coming up with new theory for power systems independent from other fields?

Ian Hiskens: No, so the math—so there's—Hirsh [00:15] so his book on non-linear systems and then the Indian guy, what's his name anyway—

Sairaj Dhople: Vijay Saga?

Ian Hiskens: Vijay Saga? His book on non-linear systems, and there was in parallel some work happening in sort of the numerical analysis ideas as well. But yeah, Golibitsky and Schafer differential systems and stuff like that. So, there were some really—I can't even remember the names now, but back then I read the books. So, it was serious math that we were exploiting.

Sairaj Dhople: Was power engineering purely coincidental then? It seems like the scholarship got you into the program and you were a mathematician by heart.

Ian Hiskens: Exactly. Again, this is parental influence, which back then [00:16] had an influence. So, the premier university of Australia, Australian National University down in Canberra. So, I had all the early acceptance into ANU to do mathematics, and my mom and dad were like, "You'll never get a job in mathematics, why would you want to do that? You'll get a job in engineering; you're going to be an engineer." Like I mentioned, the first couple of weeks of doing engineering, which in first year there's a lot of math in that. There's some this mix of topics that are supposed to get you excited about engineering, and then there's the math background. The math background was way more fun than the engineering stuff. Anyway, so parental influence, that's why I ended up doing engineering. That's why I ended up at this little local college. Basically, my parents didn't trust me too, [00:17] but one of my good friends at high school—there used to be this statewide mathematics competition. And so, he won that statewide mathematics competition and did go off to Australian National University. And spent way more time hang gliding than studying and failed out and ended up being a math teacher in high school. A really good math teacher as you could imagine, but Steve Wright <inaudible>. Yeah, so Steve won the math competition two years later in Queensland. Yeah. So, Steve's another Queenslander, grew up four hours north from—didn't know him at the time, not until Madison.

Sairaj Dhople: So, how did you get in touch with the folks in Illinois? Did you meet them at a conference? Were you just aware of their work generally? [00:18] Had you met them before you made this cross-Continental journey to the corn fields in Champaign/Urbana?

Ian Hiskens: So, I think Tom was probably the first link, and Tom and I were both Christian. And there used to be an opportunity within the—back then it was summer meeting, winter meeting, and I went to winter. The first conference was in New York in the winter meeting in 1989, and that's maybe where I met Tom. I'm not exactly sure, but it was through that connection, this Christian group of engineers would get together at conferences. I remember meeting Pete, and at Pete's memorial I described that meeting of, this was a small conference at Deep Creek Lake, the first [00:19] of Les Fink conferences that

I went to. With all these luminaries, famous people, and here I was from country Queensland feeling completely overwhelmed. And Pete came up and sort of embraced me and introduced himself, I'm Pete Sauer, as in sauerkraut. I never heard of sauerkraut, but I took his word for it.

And then Pete sort of introduced me around and stuff like that. So, I knew Pete from Big Creek Lake and Tom, and I'm not sure when I first met Pai. I went to the Baltimore winter meeting in '96, I still remember chunks of ice floating in the harbor at Baltimore. Then from there I went [00:20] and visited Bernie in Boston and saw my first snow falling from the sky, and then visited Tom in Champaign and saw my first minus 40 Celsius and Fahrenheit, because they converge at that point. And then went to visited Chris in Madison, and that day still sits in the record book. It's the coldest 4th of February of record ever.

Sairaj Dhople: You brought great weather with you wherever you went.

Ian Hiskens: Seems like it. It was so cold the freeze eased, the pipes in Engineering Hall, that horrible building, they broke, they flooded the basement where all the computers were. I have a photo somewhere of water flowing out the entrance into where that statue of someone sits. Well, there was water flowing out of the doorway. [00:21] That was my introduction to Madison, and I ended up returning to Champaign and living in Madison. It's weird, I guess. What was your original question?

Sairaj Dhople: How did you meet them?

Ian Hiskens: Yeah, so that's how we met them, and I think probably I met Pai for the first time on that visit to Champagne in '96 face to face. Yeah. I remember being halfway, I'm sure I've told you, halfway between Everett lab and the Granger Library and thinking, I'm going to die. I was walking over the library, and I looked around and it was equally distant to both. I'm like, "I'm just going to die here. You won't find me for another three months until the winter eases." But we went back.

Daniel Molzahn: You had told me that Ann Arbor was a little bit warmer than Madison.

Ian Hiskens: Yeah.

Daniel Molzahn: When I moved there was [00:22] the polar vortex, and it was not warmer.

Ian Hiskens: It's gloomier than Madison, Ann Arbor and Champagne kind of get this cloud cover, whereas Madison, it is that bit colder. It freezes the moisture in the atmosphere, I think, and so they have more sunny days in Madison.

Sairaj Dhople: So, was that sabbatical fruitful in terms of the types of problems you worked on?

Ian Hiskens: Yeah, absolutely was up until that point I'd been sort of continuing the energy function stuff leading into voltage collapse. So, by ‘97 when we went to sabbatical, no one was interested in energy functions, no one was interested in voltage collapse anymore. It was market stuff and who cared about that. So, it was sort of like [00:23] looking for what's new, let's explore some new ideas. And Mark Laufenberg had <inaudible> worked with Pai on trajectory sensitivity stuff growing out of work from Petar Kokotovic earlier work, and that seemed really cool. There was a lot of new directions to take that in, and so, that's where I started working on the trajectory sensitivity stuff, which is still kind of fundamental to a lot of the things I work on.

Sairaj Dhople: So, you seem to hint that there was much more interest in markets. Is this related to deregulation that happened at around the same time? And so, people assume that "Alright, all the physical stuff will fix itself, we just need to focus on the economics."

Ian Hiskens: Yes, I think so from a bias point of view, I think the [00:24] engineering side was too hard. So, people went off and did markets instead. Yeah, there was that evolution from vertically integrated into a market structure of some form post-Reagan, I don't know when Reagan was president here. But same thing happening with Margaret Thatcher and then markets evolving into the norm. There was some kind of weird things going on, but—there was no physics. You can't argue about the physics of power systems. You might argue about the interpretation for physics of physics. With markets, anyone had the ability to design a market, had their philosophy. So, you had all of these different market philosophies and who gives a stuff [00:25] about any of that.

Sairaj Dhople: But somehow you stuck to your area of work. Was it hard to do that in the face of all these competing other areas trying to get other people's attention?

Ian Hiskens: From a technical point of view, no. From a funding point of view, yes. There have been some very lean years of funding, but if you are persistent—no one's going to tell me what to do—I've got to fight through this. I can do that, the market stuff, but this is what I think is important to all work on it and find the funds from somewhere. Yeah. So, yeah, students wanted to do markets and things like that.

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Sairaj Dhople: And then was the environment in the USA very different from that in Australia? Did you suddenly find yourself in the place to do power systems controls?

Ian Hiskens: Yes and no. The environment's different in Australia, it's hugely bureaucratic and you can just burn endless hours fighting the bureaucracy or just doing the bureaucratic problem. In the USA there's way, way more autonomy. So, even when I came back to work as a visiting faculty, I was funded primarily off a PSERC grant. Well, I was offered grants that was funded by EPRI, I think. Anyway, [00:27] there was kind of this is the way we're meant to be going, but there was also enormous freedom to do what was interesting stuff. And that's the pattern of life in academia in the USA, it's this autonomy. And that's again, my independence comes through and that's what I really appreciate. That's how I get the work done, is not having to stuff around with all the bureaucratic stuff. That was the biggest difference, I think. So, in Newcastle, there were really sharp people doing really clever stuff. By that stage, David Hill had moved to Sydney University, so we weren't sort of collaborating quite so closely, which is good because if you're always doing work with your advisor, that doesn't lead to perception of good [00:28] outcomes anyway. So, moving to the USA certainly gave a clean break in that sense. But yeah, the independence, the autonomy is the sort of fundamental aspect that kept me here, not the weather.

Mahbubul Bhuiyan: Now we have a question related to your significant contribution in both frequency regulation and power flow, and what has been the most important technical problem you have taken?

Ian Hiskens: Well, I'm not sure it's power flow, I've never actually done anything in frequency regulation because it's not really been a hot topic, and so, I still think it's completely overrated actually. But anyway, I think, the most important contribution that I see is [00:29] in terms of developing trajectory sensitivity ideas for hybrid dynamical systems. That would be the topic that has excited me the most and gained most traction. So, why? Because the origin of the—exploring that topic came out of power systems, but one of the most highly cited papers in that topic is from the robotics community. And the ideas are used and useful in any hybrid dynamical system, which means hybrid dynamical system in the context of continuous dynamics interspersed with events and capturing that the event behavior. <inaudible> So, that robots, that's [00:30] robotics right there. It's power systems and it's a lot of other systems as well. The trajectory sensitivities in themselves provide gradient information for solving a whole lot of what are called shooting method problems, where you have some boundary value issue, and you can solve that using <inaudible> but the Jacobian involves these trajectory sensitivities. And so, it just opens up a whole range of things where you can embed dynamics and address questions like, let's find a limit cycle or let's find the boundary of and parameter space of safe region versus unsafe region things like that.

Sairaj Dhople: What is the origin story to that line of work? Did it come out as an offshoot of your work instability analysis?

Ian Hiskens: So, I had this inherent interest in [00:31] stability of systems and that was the <inaudible> function ideas. But then I was talking with Pai about the work that he and Mark Laufenberg <inaudible> were doing, and that was just smooth systems and then thinking through, "Well, smooth systems are peaceful, but real power systems don't behave like that." And so, I guess it was sort of background in what industry days of, "Well, these are real systems. They have real complexities; they have real events interspersed and I want to do something that can be useful for real systems. So, how do we go about incorporating events? And that was the evolution of that.

Sairaj Dhople: And was your industry background instrumental in shaping the types of [00:32] problems you worked on?

Ian Hiskens: Yeah. When I was in industry, there was a range of different things, but one of the jobs that came to me in transmission planning was postmortem analysis of events. So, invariably there were lots of summer storms tripping out transmission, occasionally leading to some instabilities or whatever. So, it was sort of my job to understand from the limited amount of measurements that were available back then, what happened, what were the sequence of events. To do that kind of thing you're inherently using sensitivity information, but there was no way of computing those sensitivities, no formal way. So, you're just kind of trying things and that [00:33] built up a picture of behavior. So, yeah, when it became apparent that there were better ways of doing things, both from analytical point of view and then leading into numerics as well, and that was very appealing.

Daniel Molzahn: I think the other thing that your industry background gave you was a lot of credibility. I know when we worked on this phase unbalanced problem, you're able to talk to DoE and say, This is something we ran into in Queensland. Was that a common theme? Was your research able to say, "I've seen this in the industry, this is the right way to approach it"?

Ian Hiskens: Yeah, it was, and there was a credibility in the sense of I know what an industry engineers are going through, and they don't take lightly [00:34] academic questions. They're busy, they've got real problems that they're trying to address. Don't give me crap about your energy function stuff. So—

Sairaj Dhople: And yet you worked on energy functions?

Ian Hiskens: Yeah, I didn't get it into the operation room, and I was in operations for a number of years, but I wasn't successful in actually getting that into the control room.

Sairaj Dhople: Was that a motivation for you though, that you wanted to see it?

Ian Hiskens: It was, yeah.

Sairaj Dhople: Why couldn't you get it into the operations?

Ian Hiskens: It was just hard to package for operators to really understand. So, when I worked in operations, I was building security applications. My title was security applications engineer for EMS development, Energy Management System. Yeah, you [00:35] have all these clever algorithms that you have to dumb down for the operators and the operators getting paid three times as much as the engineers, but the engineers have to dumb things down so far for these operators to make any sense. And yeah, we didn't succeed in that taking off.

Sairaj Dhople: But was it scalable? Could it scale to continental scale grids? Could you compute things that they would have to be computed?

Ian Hiskens: So, back then Queensland was an island system physically expansive. The state of Queensland is probably about three times Texas or something like that. So, Texas is a little chunk. They think they're big, but not really. So, it was expensive, but it wasn't a big grid. Our maximum demand was probably [00:36] like four gigawatts or something like that. But that was spread over a very large area. And so numerically computationally, it wasn't a massive challenge. 300 nodes, 400 nodes, something like that was sufficient. So, computationally it wasn't a big deal, but it was how to package the information such that the operators could make use of it and such that you didn't scare the heck out of them all the time because something flagged as being a potential stability issue.

Julie Cohn: That's a really important point, I think. You were seeing instability at a level that would not have been visible to an operator then, but now can operators see instability at that fine grain?

Ian Hiskens: No, I think it's still just about as bad as it always was [00:37] in that sense.

Julie Cohn: But is it a real problem in terms of keeping lights on or is it a problem for other reasons?

Ian Hiskens: So, it's a problem in that systems get operated quite conservatively because no one quite knows where the boundary is. Except when they don't get operated conservatively and something fails, but the visibility is not there for where is that boundary in a real time sense.

Julie Cohn: But the boundary has moved, I would assume, in the last 20 years?

Ian Hiskens: Yeah, yeah, yeah. So, I think the state of the art, and I haven't really explored what's happening on the operator side of things. But I think in reality it's still a lot of offline studies that basically go to establishing nomograms, I [00:38] think is at least what they're called it in some places, BPA called them nomograms. So, these operational diagrams of you must keep the system within this region to ensure safety and the boundary of that region is produced from offline studies. So, if the online system is moved to a point that people haven't seen before, then they're very uncomfortable about that. But in terms of running dynamics in an operational environment there's a lot of contingency analysis, but it's based on steady state, running power flows and these things are going to be overloaded. But from a stability point of view, if this fault occurs under this condition, then this line might trip, or this generator might. I [00:39] really don't think there's much of that happening in the online environment, not in an automated way. There may well be opportunities for the operators to pass something back to the engineers who beaver away. Typically, a line trips, that puts the system potentially into a vulnerability, that gets set off to the engineers to say, "Hey, can we operate under this condition or not?" But in an automated every 10 minutes running through a bunch of dynamic contingencies, I don't think that's happening. Is that a status quo?

Tari Jung: Actually, there's an online dynamic that they run for northern region of MISO. That's kind of happening, I believe every like five minutes. So, it is integrated, but you're right that it's not a full picture in terms of where is it [00:40] unstable. Is it more a holistic view?

Ian Hiskens: There're certainly tools so, like Hsiao-Dong Chiang at Cornell sells product based on energy function ideas, and a few utilities have that in their control room. So, there are some tools, but not everywhere.

Sairaj Dhople: And then how was your interaction with the controls community at Illinois? Did you feel like you were in the best place ever surrounded by all of these control theorists as well? Did that help and inform the research that you were doing for power systems?

Ian Hiskens: So, I think for me it's not the mass of people, it's the individuals you can work with. So, Daniel Liberzon was doing early days for hybrid dynamical systems. Daniel was doing [00:41] a bunch of work in that field. So, I worked with Daniel a fair bit. So, Mark Sprong was doing robotic stuff and before he moved from there. So, yeah, there were various individuals that outside of the power group that I was connected with.

Daniel Molzahn: And you also mentioned Steve Wright at Wisconsin, was that how you started talking more with optimization folks, was through Steve or?

Ian Hiskens: Yeah, so somewhere along the way I started looking at model predictive control, which I guess was probably in Madison. And talking with Jim Rawlings, so Jim was chemical engineering and then he talked a lot with Steve. They did a bunch of work in MPC [00:42] from optimization point of view, and then I got involved in a bunch of that as well. I think there was a phase of sort of building optimization problems with time-domain simulation incorporated into that. That drew out of the trajectory sensitivity stuff because that gave it the gradient information to solve those types of problems. And then that sort of evolved into MPC talking with Jim Rawlings, <inaudible> Steve, yeah.

Daniel Molzahn: Yeah. I see.

Ian Hiskens: But yeah, talking with Steve is a mathematician, except he's now department chair and grumbling that he can't get anything done anymore. But I remember I was working on project with one of Jim's students, and we wrote theorem proof, and we're really happy about that. And then Steve took a look and just tidied [00:43] things up, it's like, "Yeah, that's really a whole lot better." And that's the difference between someone trained in mathematics versus someone who dabbles in mathematics. And I learned right then that I'm not a mathematician, I enjoy math, but I don't think like a mathematician, I think like an engineer who thinks he knows math, I think.

Mahbubul Bhuiyan: So, looking ahead to what extent do you see the solution we have now as appropriate for the future power system?

Ian Hiskens: So, it's hard to break into the real world of power systems. So, I work in dynamics and utilities across [00:44] the USA pretty much use PSSE, PSLF, some use Power World. They all are based on a form of <inaudible> integration, it's handy to do things that way because it's really simple. But ever since the seventies, other technical communities have moved on from there. The power system dynamics, the numerics live in the ‘70s and haven't moved on. When you come to trajectory sensitivity stuff, which industry could use a lot, it's incompatible with those really simple but stupid numerical integration techniques that are used. They have other issues of being not numerically [00:45] stable and all sorts of things. They are incompatible with systems that are stiff systems, which power systems have always been, but are becoming more stiff with inverter-based sources, right, Dominic?

When I was in industry, we were using PSSE, we moved to Eurostag, why they would call anything Eurostag, but that's the French right. And it's an enormous effort to port all the models over to a new simulation package. So, I understand why industry is still locked in the ‘70s from that point of view, but it limits the ability for industry to do so much. And that's a frustration because [00:46] I can show them how they could be assisted; I can show them how it would be trivial to solve some of the problems that they're working on, except that they don't, they're using these crappy numerical integration techniques. So, that's a frustration that probably will outlast more interest in power systems. But I'll write the book. I'll try and convince them; we'll see how we go.

Mahbubul Bhuiyan: Do you have any other questions related to this?

Daniel Molzahn: So, one question I have for you and what's your famous picture with discontinuation methods for power flow? Everyone uses shows as power flows are, so where was that motivation from to work on that and was that related to all the trajectory sensitivity work and the numerical [00:47] continuation ideas or how did that all fit in?

Ian Hiskens: Yeah, so that precedes the trajectory sensitivity stuff. I think anyway, it's not really related. So early work again that Bernie and you continued, using continuation methods to find unstable equilibrium points. So, in energy function methods, you want to find the controlling unstable equilibrium point. It's one of many UEPs, how do you find the continuation. Continuation is one way of doing that, and you find all these interesting bifurcation phenomena. And in exploring that we came up with this sort of the donut shape and it was like, "Wow, different projections of it and one projection, it looks like a donut and [00:48] another projection it looks like an ellipse with the Star of David kind of thing in the middle of it. How can we explore that better? And it's frustratingly simple, it's just a three no network, but it gives rise to this unbelievable complexity. And so just played around with Matlab - it's easy to produce all the points that make up that surface, but it's harder to present the figure from those points. And it's probably one Sunday afternoon just kind of thinking, "Well, what if I did this or this and this and I popped the figure like, whoa, that's really cool." And so, the paper where that appeared, it appears in black and white and the color version's way cooler. But anyway, it was just looking at using continuation to trace the bifurcation boundary. [00:49] So, yeah, continuation to trace the power flow resolutions is one thing, but then actually tracing the points where the power flow Jacobian is singular was conceptually no more difficult. But implementation wise it was, so the paper is about that. And it was almost rejected.

Yeah, we all have our rejection story. It was presented at PICA, I think the last ever PICA conference. And then back then there was a pathway from the conference into the transaction. So, the paper was about singularity boundary, but this was a nice little figure that illustrated what those singularity boundaries looked like. No one ever looks [00:50] at the paper, but the figure caught on so that's not—but I lost the code for a decade. It was in the wrong direction or something, yeah, so there was this figure that I could not replicate that everyone was using, and I couldn't produce it anymore. It was not good, and then I was looking for something else and it was just poorly labeled. It was in the wrong direction. I came across it and I was like, "Oh wow, okay." I was really very happy about finding that piece of code. Should I find it again now? I'm not sure. It quite lost. Again, it's on my laptop somewhere.

Julie Cohn: I have a question about something you mentioned earlier in the talk. You described testing directly on the system, and I assume [00:51] that was the grid operator testing things on the system. Now everybody uses simulations. What's lost and what's gained?

Ian Hiskens: Yeah, so what's lost is that you don't have an indication of what the reality is until a disturbance actually comes along. And you can use disturbances, but if you are trying to avoid disturbances, you'd never get to know how the real system behaves. You're always imagining you'd know how it behaves. So, one of my bosses was a very innovative guy and still is, he chairs a company that's turning an old gold mine into pumped hydro storage. [00:52] I'm bit off topic, I'll come back, but there's two pits to this gold mine, and you can pump water uphill from one pit to the other and then run it down. And they're turning an old gold mine into—it's adjacent to a whole bunch of solar farms, wind farms, the company. So, he's chairman of that company.

Back then—he's a very persuasive guy and a very sharp engineer and was able to convince the organization and it was a very flat organization. So, me as a relatively junior engineer with kind of two steps away from the top of the organization. This guy was my boss, the innovative one, and then he was one step from the top of the organization. So, you literally would be talking with the people who were making decisions, very flat organization. [00:53] So, he was able to convince the organization to try these early tests on determining what the stability limit was for the interconnector between the generation area and the loads in the south. Later on, we implemented a very large static var compensator certainly relative to the fault level and these things were all kind of technical, but it was the largest in the world. And in the process of testing that, a lot of testing, I was the test engineer for the utility. The final test is, does this work under fault conditions? That's what it's there for, but if we don't test it under fault conditions, we'll never know. [00:54]   And so, we got approval to put a single phase to ground fault on 275 KV, which is, it's a pretty impressive thing to do. So, we did that, and it worked perfectly, it was all paper charts back then. We just see this beautiful response of this thing, so we all felt pretty happy about that. But the process for doing that, it was—we did the test at like 2:00 AM so that there was minimum load on the system. We rearranged all the generation across the entire system to maximize robustness and all of these things. And then there was the countdown, and someone remotely hit the close button. It was a circuit breaker with a cable connected to live 275 cable. We closed the breaker onto ground [00:55] and cleared it on the other breakers and watched the response of SVC, and it was beautiful, and we went back home and slept. The catch was the next morning we came back out and could not find this plot that had cost the organization some hundreds of thousands of dollars. And eventually—someone had put in the trash, and we found it in the trash. I was like, "This is the end of me."

Sairaj Dhople: When was this Ian?

Ian Hiskens: That was 1987.

Sairaj Dhople: Do you still see experiments of this type happening around the world or do you feel like this is all coming?

Ian Hiskens: No, that was the last one that I know of that happened on our system. Not that much longer it was interconnected with the rest of the Australian system or the rest of the east coast Australian system. And then approval levels became a real ordeal. I don't think [00:56] there's been any more tests, but there's been a lot more disturbances. So, you get measurements from the disturbances.

Sairaj Dhople: So, it is a bit—I'm not able to find the right word, but ironic, right? It seems like we want to keep the system more safe, more reliable, more resilient, but we are not able to run the tests in order to make that happen versus the other way around. Would you say that that's an accurate statement?

Ian Hiskens: Yeah, what's ground truth for a power system? You can wait for the disturbances, but generally they're not the disturbances that you need to excite certain things that you really want to understand how they work. There are certainly disturbances like the Odessa one in Texas that highlights a number of issues that people have subsequently worked on. In the Australian context there's been some pretty infamous blackouts of South Australia, [00:57] but they persist in making decisions that will assist in providing more disturbances. So, there's no lack of capability of measurements of disturbances in South Australia for the foreseeable future. But yeah, it's sort of like, "Well if you can come up with a reasonable proposal that's safe, but there's always a risk. What if a circuit breaker doesn't open? If you put a fault on the system, circuit breaker doesn't respond as it should and that leads to some cascade. As soon as someone mentions blackout, they get wind of the fact that the utility actually caused the blackout. Then there's a lot of politics in that.

Daniel Molzahn: Do you think these sorts of physical tests are—is there a challenge if you wanted to them going forward, given that we have maybe [00:58] so much more uncertainty on the system, and it might be hard to replicate particular—you rebalanced everything so that it was as robust as possible. Is that possible in the future as a—

Ian Hiskens: I think it's possible. I, yeah, there is a risk factor, right? And it's about whether the management is going to cover you for that small risk that something could go wrong. And I think management doesn't have that confidence, and I think part of it is like if it's a vertically integrated utility like you basically were back then, then you can talk with generation and say, "Hey, we want to hold this test. It would be desirable to reduce generation here in favor of putting it closer to the load center in case something goes wrong." That was an easier thing to do back then because it's all the one organization. But now [00:59] who's responsible if MISO wants to do some tests, they've got to talk with ITC or, and generators, and someone in that process's going to say, No. So, you're not just trying, you're not just dealing with one entity anymore, you're dealing with the whole bundle and someone's going to pull <inaudible>. So, it's just much harder.

Mahbubul Bhuiyan: Is there any other thing we should know we didn't ask you, but you want to tell us?

Ian Hiskens: Yeah, I don't know. I was thinking through just kind of things that I've played around with over the time. Things like continuation methods which I didn't do much on, I've used them, but one of my colleagues back in 1984, we [01:00] were using continuation methods in transmission planning through a homegrown developed technique, which turned out to be what's called <inaudible> topic. But this colleague of mine invented this in parallel with others in the numerical analysis world, inventing continuation methods.

Sairaj Dhople: <inaudible> And who was this?

Ian Hiskens: Guy called Gary Price, really sharp guy, left the industry, disappeared, I don't know where. When you do a Google search on Gary Price, there's like a million of them around the world. When you do a Google search on Sairaj, unpopular smiling face, but there's some names that it's really hard to track down where they went. But yeah, a guy called Gary Price, and there's an IEEE paper on his work and talks about using it in industry. [01:01] So, that was 1984. I wrote an online state estimator that went online in 1983. So, these were the things that we were doing in our little isolated power system back then that other utilities took decades longer to implement. But the operators were using state estimation in 983 because it was easy to provide them with the information.

Mahbubul Bhuiyan: Yeah. It was interesting to hear you, but we are running out of time. Is there any last question if you want to ask?

Sairaj Dhople: Well, I'll ask you something that we've asked many others. Do you have any words of advice for the next generation of power engineers?

Ian Hiskens: Don't give up, even when the funding goes away, as it will at some point.

Sairaj Dhople: Oh no.

Ian Hiskens: Everything's a limit cycle. [01:02] Someone will come up and go markets or something or come along. I don't know, it's hard to predict funding going away because there are so many open questions at the moment. But they will, it will, the whole inverter-based stuff will become mundane and then what? But yeah, there's I don't know, there's a lot of interesting topics. Talk with industry but appreciate that industry has other issues that they're trying to solve. Yeah.

Mahbubul Bhuiyan: Okay. So, thank you so much. We appreciate your time. I think the experience you shared with us will contribute to the future. Thank you so much.

Ian Hiskens: Well maybe we'll see, a quote that relates to historians. [01:03] The calculus lecturer in my undergraduate, my first year and second year was an absolute crazy Canadian guy, and he would always be telling jokes. And one day he's like, "So—history repeats itself. It also mumbles." As I get older, I appreciate the whole repeating oneself and mumbling. So, I think I'm an example of history. So—

Sairaj Dhople: Thank you.

Mahbubul Bhuiyan: Thank you so much.

Julie Cohn: Thank you.

[End of Interview]