**Algorithms & Power Systems Architecture:**

**Using Historical Analysis to Envision a Sustainable Future**

**Oral History Project**

Interviewee: Janusz Bialek

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***Abstract:***

Janusz Bialek is Professor of Power and Energy Systems at Newcastle University, UK. In this interview, he begins by describing his educational and professional background. He describes his early work on power systems dynamics and stability and discusses his book on this topic, co-authored with Jan Machowski. He explains that as the industry transitions, the challenge will shift from small signal stability to large signal stability, driven by the transition from synchronous machines to inverter-based resources. He notes two big differences: the loss of inertia provided by synchronous machines – therefore offering a safety margin on the grid; and new types of self-sustained oscillation that are not well understood. He sees the transition as an opportunity to re-engineer power systems and mentions his participation with the Global Power System Transformation Consortium which is working on this. He discusses his interest in identifying system stability on future power systems. He discusses further his textbook and how it relates to the foundational text by Prabha Kundur. Bialek's discussion shifts to his work on markets and his collaboration with economists and later Russian mathematicians. He describes the Soviet-era power system as a top-down, very stable, very constrained, very strict system. He compares work in multiple countries, noting that in Brazil the system depends so much on hydro that it is inherently different from

other places. He describes the challenge of combining economic goals in electricity markets with the fundamentals of power system physics. He talks about his development of methods for power tracing, and their limited adoption by industry. He speculates about the need to provide power system services with IBRs, and how to build markets around this. He describes the current transition as "the biggest revolution since the war of the currents at the end of the 19th century." He closes by reflecting on his textbook as one of his most important lasting contributions to the industry.

Note regarding Transcript and Timestamps:

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

***Transcript:***

Julie Cohn (00:52):

This is Julie Cohn. I'm conducting an interview with Janusz Bialek on Monday, July 17th, 2023, at the Hyatt Regency Orlando in Orlando, Florida. Daniel Molzahn and Rachel Harris will assist with the interview. And we also have in the room several other people who are participating. And if they ask questions, I'll identify them later. But I will save us some time right now. So, during today's interview, we are especially interested in your work on generator control, frequency regulation and power flow optimization, and how your approach to address these topics has changed over the years. We'll begin with some introductory questions and general background information from you. So, if you would please, describe your educational background and your professional positions in the field of power systems.

Janusz Bialek (01:58):

Right. So, I'm Polish. I was born and educated in Poland. So, I got my first degree and PhD in Warsaw University of Technology, long time ago, PhD in 1981. So very long time ago in 19-, So I worked initially as a postdoc at the Warsaw University of Technology. In 1989, I moved to England, to Durham University to a lectureship, lectureship in England as equivalent of assistant professor. And then I progressed through the ranks. I was offered chair in electrical engineering at Edinburgh University in 2003, I think. I stayed there for a few years, then went back to Durham University, 2009, work again for a few years. I don't believe in staying too long, in one position, in one place; I moved around. Then I was offered a post as a founding director at the new university in Moscow called Skoltech, because at that time, Russia was trying to modernize itself. And they basically had the idea. They paid MIT lot of money in order to set up this new university called Skoltech. And I was hired to set up Institute for Energy Systems. So, I stayed there for a few years, got bored again. So, I returned to England when I joined Newcastle University, where I work now as a professor of power and energy systems, so this is in short—

Julie Cohn (03:26):

And so, it sounds like, throughout your entire career, you've been on the academic pathway.

Janusz Bialek (03:31):

That's right. Yeah. Yeah. I worked for a few months after PhD in industrial R and D outfit, but mostly, mostly I'm afraid I'm an ivory tower academic.

Julie Cohn (03:45):

We like ivory tower academics.  So let's turn now to questions related to your contributions to power systems dynamics and control. If you were to pick one or two of the most important technical problems you've tackled, what would they be?

Janusz Bialek (04:08):

Right. So, the issue of power system dynamics and stability and control is one of the main strands of my research. And I've done actually quite a lot of research in different, different areas, including economics as well. But I co-authored a book called Power System Dynamics and Stability with the main author called Jan Machowski from Poland. My good friend and now is the second author of that book, which is now in the third edition. I believe it's quite popular around different universities. And, well, contributions— So, what a number of problems related to dynamics. In the whole field has changed quite dramatically over the last few years because dynamics of power systems and control were related mostly to dynamics of synchronous machines, which have big rotating masses. And the stability problems were to do with electromechanical stability, which means relative oscillations of the different masses, hundreds of generators around the system.

(05:16):

And it was well understood, well, relatively well understood. There are still outstanding problems, but at least small signal stability was, well, I think well controlled because there was a number of tools based on Eigenvalue analysis. Still, one of the unresolved problems in instability was large signal stability response to large disturbances. And number of methods. The simplest one is so-called equal area criteria, which works well for single generator, but number of attempts to generalize it into, into multi machine systems. And then the number of competing methods. And I think it's still unresolved problem.

(06:02):

However, now the whole situation is changing because synchronous machines are being increasingly replaced by the—by inverted based resources. Because wind and solar and batteries are connected asynchronously to the system by means of inverters, which transform DC to AC. And that changes completely dynamics of the system. And in short, we don't understand what's going on because it's completely new. So why traditionally it was, as I said, dynamics of the big masses, which were rotating and there was the oscillating with respect to each other. And that caused the oscillations. Now we have inverters which are programmable, which is a threat, a challenge, but it's also an opportunity. Because you don't, you, you don't have any longer those big masses which are kind of slow to control. You have inverters which you can control quickly. However, it also creates a threat.

(07:07):

There are well known problems like inertia, how—because those big rotating masses provided an inertia, which is like a margin, safety margin, if things go wrong, if you disconnect everything, those big masses will still rotate. They will provide for a few seconds a buffer, which you can do something. When you have inverters, there is no—those big rotating masses. The stored energy is only in capacitors, which is very little. And we have, and the—those inverters will have different characteristics. They all will be different, all kind of interactions. And over the last few years, there's a number of incidences of oscillations, self-sustained oscillations, which were arising out of nothing. So, it's a small signal stability problem. And they would disappear. And utilities are struggling to understand what's happening. And that's the main area of research for me at the moment, is how to tackle this new stability problem of the current and future power systems, which is inverter-based. It's—Power industry used to change very slowly since the beginning of the nine-, 20th century, end of the 19th century. So, there were changes would take decades. The progress was very slow. And suddenly now we are changing, seeing changes just basically year after year. And those problems I'm talking about it's not the future, it's what's happening now. And with many countries having zero-carbon targets around 2050, more or less, the timeframe on them will get even stronger.

(08:52):

And the system operators need, need tools to tackle them. And one of the things I'm involved in—it is a consortium called the G-PST, Global Power System Transformation Consortium. Which is an effort by system operators in leading countries which face those problems, which is from here is Texas and there's California. From Europe is Great Britain, Ireland, there's also Australia and Denmark. And I forgot about some others probably, and research community to tackle those problems. So that means it's not only stability, problem is just the question of re-engineering the system. So, as I said, those inverters are a threat, but it's a possibility, an opportunity to re-engineer the system. It's the biggest challenge since there was the war of currents at the end of 19th century, DC versus AC, Edison versus Tesla.

(09:55):

It was won by Tesla, AC. Now we are seeing to some certain extent going back towards DC. So, maybe Edison has his late victory after 100-years—more than 100-, 130-, 140-years. So, as I said, it's an opportunity to re-engineer the system, but to solve those problem, no one really understands what's going on. I'm involved in some attempts in the UK and the—the electricity system operators is struggling to understand, to model it. And it has, it can have very profound consequences to system stability, because the oscillation, things trip and it can cascade, now, the system and cause a blackout. So far, those incidents were local incidents which were contained locally. But it's a big threat.

(10:59):

It may, it may cause a systemwide collapse. So, you, you asked me about my contributions in system dynamics. I think one of the—my main contributions, I think, apart from the textbook is I work on identification of system model and system parameters, measurement-based. So normally you, to analyze that bit, you have models, and you analyze the models. But what if those models are unavailable or they're not? They don't know. You don't know them. It in the case of parameters. So, I've done some work on that. And then that's why I'm interested in, my main area of interest is system identification and methods of identification of system stability in the future system, where we may not know the parameters of the, of the inverters. Because one of the things that inverters are on, all different types, their models are not disclosed, because this is commercial sensitivity issues, and there are tens of thousands of them. So traditional methods will, the traditional models, so called EMT simulation models will not be able to process them. Even if you had exacting models of each individual model element, you would still not be able to simulate the whole system, because it'll be too big. EMT models and EMT programs require quite a lot of running time. That—they're pretty slow.

Julie Cohn (12:26):

Can you take us back to your earlier work, first before we come back around to the inverters again, to help us understand a little bit more about how you defined the dynamics and stability problem and how you approached solving it.

Janusz Bialek (12:46):

Yeah. So, there are many different definitions, stability. There was a working group which published paper about, different stability issues back in the '70s, I think. And this is modified in every few years. So, stability and dynamics. So, we are talking on the one hand side, I was talking mostly about electromechanical stability, stability of those rotating masses. But also, voltage stability which is much quicker. And so, there are those two main things, is essentially electromechanical stability connected to frequency stability, and voltage stability. So, one has to do mostly with real power. Voltage stability has mostly to do with reactive power. And to some extent they were treated as separate, because there's one thing about transmission systems: that you can separate real power and frequency from reactive power and voltage, but of course, there are interactions between them.

Julie Cohn (13:56):

And so—Tari, go ahead?

Tari Jung(13:57):

No.

Julie Cohn (13:58):

I was just curious. So were you developing models that looked at that intersection of the two or—

Janusz Bialek (14:06):

Yes.

Julie Cohn (14:06):

—treating them separately?

Janusz Bialek (14:08):

Yeah. So, as I said, in that book which we've published. There were a number of textbooks, and the most famous textbook is—was—written by Kundur, with a similar title, the Power System Stability or something, I can't remember. Anyway, it's like a bible. It's that thick. All the information is there. However, we found that the problem with that book is that it's a postgraduate textbook. So basically, you needed really first degree in electrical engineering and some knowledge in order to understand what Kundur was talking about. So, it—and it assumes a lot of knowledge. While we had a lot of people coming from the control background and from other backgrounds which didn't have the—that knowledge and the training, and they still wanted to work in that area. And they bring their own skills coming from—let's say—control background. So that's why we wrote a textbook. That means starting, trying to explain using simple models which are understandable based on fundamental physics without going into first degree in electrical engineering. How to explain those, and how to build that from the bottom understanding, on power system dynamics, issues, using those, those simple models. And then increasingly progress to the most complicated model. Models. So, we would see our textbook as a step before Kundur's.

(15:40):

So, once you understand our textbooks, you, you, you can study Kundur, which has everything right again about that, that old power system, which was synchronous machine based rather than the new, of course, Kundur died recently. And the—his textbook was written in the ‘70s, I think, or ‘80s.

Julie Cohn (16:00):

Did you have a question related to that?

Daniel Molzahn (16:04):

I saw Rachel nodding her head because she has Kundur's textbook on her desk. Yeah.

Janusz Bialek (16:08):

It is the bible—yeah, bible—everything is there. Yeah.

Julie Cohn (16:12):

When was it published? Do you know?

Janusz Bialek (16:15):

First, I think the ‘70s or ‘80s? No ‘80s or maybe or early ‘90s. Something. I actually don't know. No. Early ‘90s, I think.

Julie Cohn (16:22):

Okay.

Daniel Molzahn (16:22):

That sounds right.

Janusz Bialek (16:23):

Yeah. Early ‘90s, I think it was published. First edition of our textbook was '96. And now we are on the third edition, which was recently published. So, I don't know if you agree my, with my comments about Kundur's book that you really need the first degree.

Rachel Harris (16:43):

Yes.

Janusz Bialek (16:45):

Going on. It's very advanced. It's very good, but very advanced.

Julie Cohn (16:50):

So, it sounds like part of what you saw as a challenge was taking the complexity that is required to do the actual theoretical work, but making it accessible in steps, breaking down the underlying steps that hold up the theoretical approaches.

Janusz Bialek (17:11):

That's right.

Julie Cohn (17:13):

Were you also engaged in other types of research at that same time?

Janusz Bialek (17:17):

Yes. As I said, I work in a number of parallel streams. So, when I started my research career, it was '90s, and '90s was privatization of the electricity supply industry worldwide. So, I did quite a lot of work in parallel with this work on dynamics. I did quite a lot of work on designing of markets because that, that was the most interesting issue. And there was, there was some money available. Because essentially after privatization, the first thing they really did, they're cutting all the R and D as they're not interested in funding fundamental research, engineering research. It was all about markets, about my- making money. So over '90s, I did—most of my funded research was on, as I said, market related. Then the situation has changed in the early 2000s because, as I said, the fundamental system character, the characteristics started to change, and utilities started to understand that actually you do need to understand engineering side of the system. It's not all about economics. Other things as, as well. So, as I said, some on the dynamics side—I did the '90s publications on the design of, so-called power system stabilizers, which are used again to—it's one of the well-known phenomena, is so-called inter-area oscillations, between different regions of power systems, and again, are those rotating masses which start to oscillate against each other. So, I did some work on design of some of those PSS's, those power systems stabilizers.

(19:10):

And then on dynamic side, as I said, in the—kind of around 2010 and later I had those publications about identification of the dynamic system model, which is very mathematical because system identification is a, is a branch of control theories. It is very theoretical. It was actually one of the things which attracted me to going to Russia, to the Skoltech University, was that the Russians are well known for having excellent mathematicians. So, I started to collaborate with mathematicians in Russia. And there was a number of publications coming out from that strand of my research. And, as I said, now I'm trying to translate to move on to this new era of inverted-based resources rather than traditional synchronous machine-based models.

Julie Cohn (20:04):

I'm curious about something related to power systems in Russia, because it was my understanding that, unlike the United States and Europe and some other parts of the world, during, under the Soviet Union, the power system was developed under a very centralized model with very tight control from the top down and consistent control responses at every level that were dictated from the top down. Is that an accurate description?

Janusz Bialek (20:37):

That's accurate description of power systems around the whole world, not only in the Soviet Union. Basically the—this, the structure of the industry was, it was very centralized.

Janusz Bialek (20:48):

And it is called vertically integrated.

Julie Cohn (20:50):

Well, yes,

Janusz Bialek (20:51):

Across the whole supply chain, they had the full control of everything that's going on. Utilities had the full control,

Julie Cohn (20:58):

But in the United States, as different utilities interconnected, they sort of developed various ways to share power that were more and less centralized depending on which part of the country it was. But my understanding was that in the Soviet Union, it remained tightly controlled—

Janusz Bialek (21:17):

Yeah. It was tightly controlled—

Julie Cohn (21:19):

And centralized from the top down.

Janusz Bialek (21:20):

Yeah. That's correct. And—

Julie Cohn (21:20):

As a result, it was very stable?

Janusz Bialek (21:24):

Well, it, depending what —it's an actually interesting issue.

Julie Cohn (21:28):

Okay.

Janusz Bialek (21:30):

So, the old Soviet or Russian system—one thing you understand about Russia is a big country. So, it's geographically stretched through, I think, eleven times zones. It's huge. It's the largest country on, in the world. It's connected with one power system. And as every electrical engineer knows, that stretch causes problems because it basically stresses the system, long transmission distances cause all kind of problems. So right from the beginning, during Soviet times, they were facing those problems. So how to operate one integrated system in a, in a controlled way. So, for example, again, United States is split into essentially three interconnections. For more or less for that reason, that controlling one, connecting one country together would be very difficult to control. So that's why they have this east, west and Texas. In Ru-, in Soviet Union, in Russia. They still wanted to run it as the one system.

(22:33):

One of the reasons why—probably political—is that that's how Soviet economy used to work. So, they're facing a lot of constraints, how to run it. So, they developed, and actually, so their power engineering research was very good. It was not translated, people in the US didn't know about it, because of language barrier. And because there were, there were no contacts, but they were very good at what they were doing, so they were running the system actually very constrained, very strict system, in a quite stable way. However, the way they're doing it, they're achieving that stable way. They're quite ruthless about problems. So, for example, if there was developed, if there was some problems, the UES would, would cut out the whole region. Without, without, without any, any problem. And that would stabilize the situation. So, in the west, that would have—would not have been possible, just essentially to black out, I don't know, a whole region of the country.

Julie Cohn (23:33):

Yeah.

Janusz Bialek (23:34):

So that's why they claimed they never had a blackout, which is not entirely true because they did have local blackout. So, it's quite large areas would be just cut out in order to stabilize the whole system.

However, it is undoubtedly one of the achievements of Soviets, I—engineers that they managed to hold it all together over many, many decades.

Julie Cohn (24:01):

Thank you. Yes.

Daniel Molzahn (24:03):

I actually had a follow up on this. Just you, you've, you've been a researcher in so many different countries and different areas and you're involved in PSSC and other organizations like this as well, that have this broad geographic reach. How—have you seen different research styles or different research cultures across—how do power system researchers work in different countries? Is that something you've, you've seen big distinctions on? Or is it pretty similar?

Janusz Bialek (24:18):

I don't think, well, different countries have different problems, of course. But fundamentally, physics is the same, math is the same. So, I don't see a problem. As I said, back in the Soviet times, there was a different kind of mode of—in the Soviet from what I understand—so I talked to a lot of people over there; they have very advanced control techniques. Something which is in the US is called Special Protection Systems, SPS. Which was discovered, which is a lot of work on in the US the last 20 years. But Russians did it the last 50 or 60 years, because they had to do it. So, those, how to control the whole system and if something happens, how, how to keep it stable. So, there was this particularity of the Soviet system. But the rest of the world—in the—until the advent of renewables, basically the research problems were very, more or less the same. Frequency stability, voltage stability, transient stability are more or less the same. So, for example, transferring from Poland—I was educated in Poland to England, there's no problems, no problem for me.

(25:50):

And then, now the situation is changing, as I said, because there's just a number of countries which pursue very aggressive way of decarbonization. And they face those problems I was talking about with inverter-based resources. But many countries in the world, and actually the states as well, some of the states are very much where the—to the old system. So, it all depends on the country sense. So, if you have some systems which are more traditional, for example, like Brazil, well the—Brazil's already 90% hydro. It means they're renewable. So, their problems will be completely different because they will be dealing with hydro dominated system, which has different characteristics than, than other systems. So, I think it is more differences were more due to particularity of, and characteristics of different systems around the world rather than just style of research. Because, as I said, "Math is the same."

Rachel Harris (27:01):

I had a question on a bit of a different topic. What you had mentioned, you'd done work both on dynamics, and then you'd done some market economics work in the '90s, and then you said, but then they kind of realized that they needed to bring engineering back into the economics.

Janusz Bialek (27:17):

That's right.

Rachel Harris (27:18):

Could you talk maybe about the interaction between the market and the economics and the engineering problems and how they influenced each other?

Janusz Bialek (27:25):

Oh, this is a very good question. I can talk for hours about it, although there's no time. So yeah, it's basically the markets, the electricity markets in many countries were basically set up by economists and they didn't realize peculiarities of power systems: "Well, it is a market like any other utility, you can privatize it, and you can trade free." It doesn't work like that. And you really do need to understand fundamentals of power systems. So, I work a lot with economists, so mainly people at Cambridge University. There's a group with David Newberry and Michael Pollitt, which I think is one of the best groups in the world. And it's called EPRG group, Electricity- Energy, Power Regulation Group. And I spent quite a lot of time educating them about fundamentals of power systems.

(28:20):

So that's even—I was talking about our textbook being like a step before you, you go to Kundur. So that was even one level down, how, how to get, economists - have no knowledge of engineering, but are clever people, and they understand maths usually because economics is some branches of economic, economics are quite mathematical. How to educate them about, enough about characteristic of power systems. What is real power? What is reactive power? Why do you have constraints in the power system? And those kind of fundamental things. So, they can incorporate them into the economic models. So, it works. So initially the—those lot of examples, for example, gaming in electricity markets, because they didn't understand how people would behave. There was a lot of things they didn't understand. So, I think that was one of my contributions was probably just again, education of economists. So, I still work with them and just recently they ask me, they are writing a new textbook on deregulation, and they asked me again to explain to regulators how the future power systems will look like and what they need to understand. They don't want to understand everything. They want to understand what is important from the point of view of regulation. So, issues like inertia and others.

(29:50):

But apart on the pure economics, I did some work on so-called power tracing. Because there was, to do, how to trace the flow of power in the power systems. Also, on the design of the markets. There was a lot of issues regarding treatment of transmission losses, because initially they say, Transmission losses are little, so you can sweep them under the carpet; but no, on the margin they can be quite substantial. So, I did quite a lot of work on that.

Daniel Molzahn (30:25):

So, I've read some of your works on those pieces. Do you know where those got adopted or are those in use? And how did that influence the conversation?

Janusz Bialek (30:26):

You're asking about tracing?

Daniel Molzahn (30:37):

I certainly know the tracing paper quite well. Yeah, but—

Janusz Bialek (30:40):

Well, there—this—well—tracing I think informed the debate about it, but tracing is an accounting method. So tracing is basically to—can you trace the flow of power? of electricity? flow of electricity? of energy from generators to load? So, for example, if we're sitting here, where does electricity come from to power this building. And the answer is physics. From the physics point of view, you can't. Because it's all connected together and it kind of comes from all the sources at the same time. But I developed a methodological tracing, which under certain assumptions you can do it, but it's an accounting method, so it's not a physics method.

(31:27):

You cannot say that if I change in that particular place, it will affect that way the—what happened over here. It's an accounting method which could be used, for example, how to judge people for losses, how to judge people for the, for the use of system. So, it informs the debate. And there was, that was probably my most, most cited paper. It has several thousands of citations. There were some attempts to implement it. And I think some of, some elements of this, of it, are implemented in a number of jurisdictions. But not, it hasn't been adopted for implementation as such, as far as I know. It was considered, but there was a debate about it.

Julie Cohn (32:11):

So, do you see those things changing in any significant—when I say those things, I'm being a little bit too general—but concerns about transmission losses, concerns about tracing, will those concerns change as the number of inverters reaches the millions on the grid?

Janusz Bialek (32:38):

Well, certain—

Julie Cohn (32:39):

Generation is so distributed?

Janusz Bialek (32:40):

But basically, that at the moment, I think that to go into the background, because we need to sort out the fundamentals. And fundamentals are, for example, one of the system services. Because synchronous machines provided—first of all, they give stability to the system because there are a lot of masses that continue to rotate if something happens. There's a lot of soft energy, which can be used. But also, they provided a number of services, by their physics. So, one is this inertia, and other things. So-called fault currents. So basically, fault currents are important for protection. If there is a fault, those generators produce more current, that current can be sensed, and protection can be activated. So, there's a number of services those synchronous machine provided free. By, by their nature, their existence, by physics. If you move to inverters, why you can program inverters to do that, but you have to pay them and you have to define new services.

(33:45):

So, there is a lot of effort around the world, especially in Great Britain, in the electricity system, operators, I think, clinic in that area. How to define the new system services for this new era of high penetration of inverter-based resources. The actual engineering—so they have—and one of the issues is they have too many of those services. And if they have too many, it's not good, yeah, because you have too many balls—juggling in the air and trying to catch all of them. So, but there are first steps. Some, someone has to do it. So, let's have fast frequency response, let's have long frequency, medium frequency response and et cetera, and et cetera, and et cetera.

(34:36):

So, there's a lot of effort of this. For example, I was talking about this G-PST, Global Power System Transformation consortium, how to define new services in the new system, which would be technology agnostic. So, no matter who provides them, no matter what technology is there, whether it's synchronous machine or inverters, or whatever, in order to keep the lights on, we need certain services. And it's a question how to do—how to define it. However, you can. It's a chicken and egg situation. You cannot define those services unless, and until you know what can provide them. So, the thing is, by breaking this chicken and egg situation, because the developers, the vendors will not develop those products, devices, which would produce those services, until they know what they are. But on the other hand, you cannot define them unless you know what they can do. So, one of the efforts is breaking the—as you say—the chicken and egg cycle.

Daniel Molzahn (35:45):

Do you know how much—? So, there's obviously major challenges with getting engineers, talking with the economists and building the first electricity markets. It seems like this is another sort of case where we have to get people to talk with each other along these lines. Are there lessons learned from the first time around in the '90s with this, that we could apply here?

Janusz Bialek (36:02):

Yeah, so—and so, as you rightly said, in the '90s it was mostly engineers and economists, which needed to talk to each other. And now I think you—they—you talk to economists, they usually understand what's reactive power, which is a great success. I think I have my little contribution to that. Now is—no one knows about the markets, what the markets will, will be. Because we are moving, the traditional markets were based on marginal cost per price, which was based on thermal generation, which cost, which had cost. You increase production, you increase the cost. But when you have renewable resources that have zero marginal costs, so there's a lot of debate going on, and there's economic debate, mostly, how to make those markets work with zero marginal cost. And, but I think, well, we know markets which work, for example, mobiles, which will only have the marginal cost of making call is zero, but people are making money from that.

(37:01):

So, it works. <laughter> So there are models that can give us, but let's leave that aside. So, what I'm—I'm not an economist. What we—regarding collaboration—did, the lessons from the '90s is, at the moment, the key challenge is the three legs, three branches, which need to work together. One is of course the traditional power systems, like myself, who understand power systems—the goal and dynamics. The second is power electronics, because all those inverters are just power electronics devices. And traditionally those two branches were, were kind of working separately, so power electronics. So, my phone reminds me about something.  And so the power electronics, the designing the inverters and power systems, and for me as a power system engineer, inverter is a black box with certain characteristics. I didn't want to know what's inside.

(38:03):

So now we do need to talk each other, because I need to understand what's in it, because otherwise I cannot sort out those, those issues of stability, for example, until, and unless I know what's the model, what's inside it, in that, I cannot do stability analysis. And the third branch is control theory because we are talking about multidimensional system and we have those thousands of inverters, and tens of thousands of inverters, how to put them together. So, they work together. You need very good control theory and there are very good control theorists. And the number of people around the world who are who are coming from the control background, who are interested. How to control that heterogeneous system with so many different devices? How to make sure that then basically things go right? So that's, that's like a triangle, which I see: traditional power systems, power electronics, and control theory. That's the main thing. And of course there are other things as well, but they are just three main branches.

Daniel Molzahn (39:15):

So, you think once those communities sort of sort this out, then it's a conversation with economists to define services?

Janusz Bialek (39:22):

That's right. Because there's, there's, there'll be too early to—there are some inputs. Well, for example, services. Once you define the services, you'd have to define the market. How will you provide those? How will you, who will provide those services? And for that, for that you need the market. But economists cannot enter this—the conversation—until we sort out what are those services. So that's why, as I said, they will come in a few years' time, although we need to keep up a conversation.

Julie Cohn (39:57):

Other questions on the technology side? I think you've actually already addressed to some degree a question I was going to ask, which was looking ahead, to what extent do you see the solutions we have today as appropriate for the future? But it—you've already answered this, I think.

Janusz Bialek (40:13):

I'm sorry, because—well, your interview, I understand, is about history.

Julie Cohn (40:17):

That's all right.

Janusz Bialek (40:18):

Well, I have—history is interesting, but I have bad memory, so I don't remember. I'm more interested what will happen in the future, than what's happened in the past. So, history is interesting for me as it informs the future.

Julie Cohn (40:32):

Yes.

Janusz Bialek (40:33):

What will happen in the future. So, we take lessons from the history,

Julie Cohn (40:37):

Yep.

Janusz Bialek (40:38):

To guide us towards the future.

Daniel Molzahn (40:40):

Actually, can I ask one follow-up on—?

Julie Cohn (40:41):

Yes, please.

Daniel Molzahn (40:42):

So, do you think—I'll try to tie both back to history and the future. So, at the time when we were kind of first working on these dynamics problems, did we have the fundamental mathematics that—we sort of understood the theory that—the underlying dynamical systems control theory, and it was a matter of mostly sort of applying it? Or was it that we needed to develop new methodologies?

Janusz Bialek (41:07):

You mean in the past?

Daniel Molzahn (41:08):

In the, well, in the past, and then what's your take on—

Janusz Bialek (41:10):

Well, in the past, as I said, "Kundur—everything's in Kundur."  So the models, the methods fundamentally were known—were well known. There's still certain elements, as I said, which people were working on that was, of course, research. But the fundamental—

Daniel Molzahn (41:30):

In Kundur's—they're in Kundur's book, but Kundur, did—I know Kundur was a genius. But did he come up with this himself or this was building off of the existing methodologies?

Janusz Bialek (41:40):

Of course, existing methodology. Of course, that research goes back, what, since the beginning of the power systems? And there were a number of textbooks and number of—and one was the famous one before Kundur, was Anderson, and I can't remember the other, and the other, his, his co-author. So, there were a number of textbooks which treated those problems.  Kundur put it basically, it's a refer—as I say, it's not a textbook, it's a reference book, so you put all the existing knowledge in one book.

Daniel Molzahn (42:13):

So, I guess that's my question: is—do we have that, that basis today that if someone—if the next Kundur came along and it's—just compiled everything we know, do we have—?

Janusz Bialek (42:25):

It's too early, as I said, we're still developing theory of those new power systems. We are—it's a bigger—it's the biggest revolution. I keep referring to it as the biggest revolution since the war of currents at the end of 19th century. And to be honest, as a start of this revolution, we don't know. We just don't know. We don't have tools; we don't have methods. We have no idea what's happening. So, the next Kundur will have to wait at least 10 years, maybe 20 years, until all those methods will develop. Unfortunately, I'll be retired by then.  I'm almost retired now. So—but you know, for young people,  it's probably the most exciting time in power systems.

Julie Cohn (43:15):

How much do you think the theoretical work can proceed without real life tests on power systems?

Janusz Bialek (43:26):

Well, the answer is obvious—just—well, one informs the other.

Julie Cohn (43:31):

Yeah.

Janusz Bialek (43:31):

So, I was talking today to people, and they, basically, say of control theory— I was talking to—I think you know—Dominic Gross, and how was his control theorem? You know, he deals with equations, but he's told me that he has developed a theory and he's working with people who will develop a test tree, will test it. Because at the end of the day, it's all about engineering. It's about reality. You need to test it. But first you have to think about it. You can't go blind and build something if you don't know where you're—you know the saying: If you don't know where you are going, you might not get there, so you need to know where you're going. And that's the role of the theory to analyze the system. A control theory, complexity theory, all, all kind of backgrounds, theoretical backgrounds which tries to make sense of the new power system, determine the direction. And once you know the direction, you can build things to test it. But at the end of the day, yeah, but one informs the other.

Julie Cohn (44:39):

Yeah. I guess the reason I'm asking the question is that you and others have said that we're moving very, very quickly; at a much faster rate than we did over the last hundred years.

Janusz Bialek (44:52):

Correct.

Julie Cohn (44:53):

And so, we—and the theory kind of evolved along with the system over the course of the 20th century to some extent. But can it evolve within five years?

Janusz Bialek (45:06):

Well, it's not a blank sheet because I said at the moment, "Is this what I'm saying? Control theory"? I've worked with mathematicians, with control theorists, with operation research people, with graph theory people. Because I—if you look at graphs, for example, electrical networks are graphs, and people have been working on those problems for decades. There are very advanced tools. So, I personally believe that there is theoretical knowledge out there in the community, in different communities, not in power system community. So, it's the question of adopting that knowledge. That's why I'm working with mathematicians. That's why I'm working for control theorists, because when I'm talking to them, they—I explained to them the problem. Oh yeah, yeah. There is a method which deals with that. So, it's not a blank sheet. It's not a question of totally developing new theories, adopting the existing theory, adopting the existing theoretical tools to the realities of the power system. So, that's why I'm saying it's very important to talk to those guys because I don't have mathematical knowledge to develop those new tools. I need to talk to those people or experts in it and they'll develop those tools together with me.

Julie Cohn (46:27):

Any other questions anyone would like to ask? One closing question we sometimes offer is: if you wanted a general audience to walk away with one important thing to remember, or know about the work that you've done, what would it be?

Janusz Bialek (46:45):

About my particular work?

Julie Cohn (46:46):

Yeah.

Janusz Bialek (46:47):

Well, as I said, "History is history." I'm still—I'm intrigued about these new problems, which I'm working on right now. And I hope I will, I'll make some contributions, which will stay after I've retired. So far, my—I think my—probably the contribution which counts most is the textbooks, as I said, because that's what stays behind; that's what people are using. So, if I see that young people are using those books, that's one. That's a pleasure. Because I wrote, I don't know, 100, 200 papers. No one will read them in 50 years' time. I hope some elements of the book will still be still relevant.

Julie Cohn (47:43):

Thank you.

Janusz Bialek (47:44):

Oh, thank you very much.

Julie Cohn (47:45):

It's a real pleasure I hope you enjoyed it.

Janusz Bialek (47:46):

My pleasure. I enjoyed it.

*[End of interview]*