Algorithms & Power Systems Architecture:

Using Historical Analysis to Envision a Sustainable Future

Oral History Project

Interviewee: Mladen Kezunovic

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Abstract:

Dr. Mladen Kezunovic describes his educational and professional background in both Yugoslavia and the United States. He discusses an early Westinghouse project to develop the first digital substation. He notes that the second major advance in digital substation took place in Yugoslavia, where he was working at that time. He explains that the electromechanical protection systems in place before the 1970s could not react quickly enough nor flexibly enough to respond to advancing power system technologies in substations. He names several other engineers and companies in the United States,

France, and Japan that worked in this area. He talks about the synergy between energy management system development and digitalization of substations. He describes the three essential areas of expertise involved – power systems protection, digital technology, and communications. He explains that both precipitating events, such as blackouts, and advances in parallel industries, such as the emergence of microcomputers, trigger major innovation in power systems technologies. He reflects on lags in industry adoption of digital substations in the United States compared to areas with younger power systems. He notes that nearly all substations have digital relays, but few have all digital communication technologies between components. He discusses deficiencies in system monitoring noted in the wake of the 2003 Northeast Blackout and the adoption of synchrophasors, for which success was dependent on the emergence of GPS technology. He reflects further on the interplay between innovation on power systems and innovation in other fields. He urges engineers facing a new idea to “look at the beginning” in order to understand how many different approaches there were and why only one or two prevail. He discusses the development of guidelines, recommended practice, and standards, detailing the differences between CIGRÉ, IEEE, and the International Electrotechnical Commission. He describes the adoption of the IEEE Standard 61850 as an example, noting that there were errors in the timing of the original standard. He further describes the eventual coordination of different groups, the difference between proposals from IEEE and EPRI, the “battle” in the voting process, and the final reconciliation with adoption of 68150. He discusses big data and adapting machine learning and artificial intelligence approaches to a broad definition of relevant data for analyzing power outages. He reflects on the siloed nature of some academic work and the effect this has on workforce development for the power industry and offers cross-disciplinary experiences as a part of the solution. He discusses the introduction of renewables on the grid and challenges he foresees for adequately recording, synchronizing, and analyzing data. He urges engineers to flip the paradigm for power system analysis from making the system reliable to identifying the risks that lie ahead. He closes by reflecting on his numerous awards and recognitions and how they form a collage of the people and experiences he remembers over the decades.

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

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

Transcript:

Julie Cohn (00:00:02):

This is Julie Cohn. I'm conducting an interview with Mladen Kezunovic on June 10th, 2025, at Texas A & M University in College Station, Texas. Daniel Molzahn will assist with the interview, Dr. Kezunovic, during today's interview, we are especially interested in your early work on power system analysis and stability, and how it later was carried forward into standardized practice in the industry. We'll begin with some introductory questions and general background information about you. So if you would, please describe your educational background and your professional positions in the field of power systems.

Mladen Kezunovic (00:02:36):

Yeah. I graduated with an undergraduate degree in a foreign country, in Yugoslavia, as it happens to be, 1974, some time ago. And I did not have the background in power systems from the bachelor's degree. It was in control theory and control systems. I switched later on to the power system area, power systems area, in my master's and PhD, which I took over at the University of Kansas in Lawrence, Kansas from '76 to 1980. The turn of my career was circumstantial, in a sense, that while I was still a PhD student in Kansas, there was a project at Westinghouse in Pittsburgh. And that particular project, which I will describe a little bit in more detail, was seeking some engineers to support the project. I was doing work for PhD in digital substations on various issues there.

Mladen Kezunovic (00:03:53):

And this project was related to the first development of a digital substation. So somehow through publications and some other means, we connected, and they offered a position in Pittsburgh in 1979. So I moved there before graduating and joined the project. It turns out that this project really was the turning point in my career in two ways. One is I learned a lot because I was surrounded by a very special group of engineers and researchers. And secondly, the area that I was involved with grew significantly over the years. It's even a very important area today. So I had something to stay with, if you will, for, for almost the entire career. So that's the beginnings. So I like to claim that my career started with industry. And I can support that claim further by the developments later on in my career where I returned to the original country where I came from, and joined the company that was a flagship in the country—

Mladen Kezunovic (00:05:19):

35,000 employees, called Energoinvest—and worked there on the second generation of the digital substation development. So I was lucky to participate in a very short span in two major developments, the one in the United States, which was the first in the world, and then the one over there that was the next development. Eventually, making a long story short, I came back to the United States in 1986, joined Texas A & M, and did a lot of different projects and activities here, and continued the work in that area and in some other areas that are related, that I would like to talk about, that are important for the field. So that's, in a nutshell, how my career started and where I ended up eventually.

Julie Cohn (00:06:14):

Can you take us back to that project in Pittsburgh and describe what problem was occurring and why it needed to be solved?

Mladen Kezunovic (00:06:28):

Yeah, that's a very relevant historical question. Not just the fact that I was associated with that project. But what was happening is that as the digital technology—now I have to bring us all back a little bit to the development of computers and things like that. In the '70s, if you may recall, computers were of the size of cabinets, and more than that, but they were deployed in a lot of control situations, including power systems. So Westinghouse decided in 1970s to develop for the first time a digital protection system. Meaning a computer would do the protection in the power systems. And the system was deployed—developed and deployed at the Tesla substation—at Pacific Gas & Electric in 1970. The developer, the key lead developer, was George Rockefeller who published a few papers on that. The reason why they went digital is because prior technology was electromechanical, and solid state after that, meaning transistors and discreet components like that.

Mladen Kezunovic (00:07:54):

And those technologies were having limitations on how they can protect the system. It was limitation in how fast they can react. Protection requires fast reaction. It was an issue how they can be packaged. It was the issue of flexibility, how you can change things. None of this was available in the prior technologies. Digital technology has offered that. So the bottom line was you would have better protection at lower cost. That was the bottom line. However, that development was cumbersome in many ways because the computer technology was cumbersome. So the project that I was associated with was funded by Electric Power Research Institute. Again, it was the first project in the world. And the reason why they initiated that was because the microprocessor technology—the Compact VLSI technology, computer technology—was actually invented in the '70s, and the 16-bit microprocessors—Motorola and Intel—were introduced in 1979, right about when I joined the project.

Mladen Kezunovic (00:09:08):

It was so early in the development that there were no boards, computer boards, designed yet. It was only chips. And so the Westinghouse took the effort of designing the boards and so on. And the development was called All Digital Substation Development. Now, I need to explain a little bit what it means in terms of the problem that it was solving. The power system, as you may know, consists of many connecting lines that are connecting, basically, the generation to the load. But these connections go through substations. That's where it's like switches, if you will. You can go from one line to another at this particular point, which is called substation. The equipment that is located in a substation, control and protection equipment, makes sure that this operation is smooth, that you get power from generation to the load. However, due to various circumstances in the power systems, whether deterioration of the equipment and whatnot, the various components may fail.

Mladen Kezunovic (00:10:19):

And those are carrying very high currents. So when there's a failure, which we called a fault, it has to be removed extremely fast from the system, that particular component. And protection relays are responsible for sensing that there is a fault and then issuing a command to switching equipment to remove that piece of equipment. And what was fascinating to me, and still is, that this happens in fractions of a second. So milliseconds. Not in seconds, but milliseconds. And so it was a high demand on the digital relay to perform all of these algorithmic parts in such a short period of time. But nevertheless, that system took off and was deployed at several substations. Incidentally, at the same time, there were similar developments, a little bit with a lag, at AEP, American Electric Power Corporation, with Arun Phadke and Jim Thorp and Mark Adamiak leading that effort.

Mladen Kezunovic (00:11:27):

So AEP had their own development. We collaborated with them. And then around the world in France, Électricité de France had some new developments at the time, a gentleman by the name of Pierre Bornard, who was in charge of that, at the substation that they developed—digital substation. And then there was a development in Japan at KEPCO, the company Kansai Electric was involved. So those were the first developments of the digital substations. Interestingly enough the first papers on digital protection came even before Westinghouse initiated the first project, the first paper that we were able to locate came from India in the 1967, 1968. And people may claim that there are other firsts, whatever they are, but it gives us a framework. When this started—it started in the late '60s. What is the significance of that in this context?

Mladen Kezunovic (00:12:40):

The significance is that the energy management systems, which are controlling the entire system, were conceived in a digital technology in the late '60s. The gentleman by the name of Dy Liacco invented basically energy management system as we know it today. And he worked at Cleveland Illuminating in Cleveland, Ohio. And his paper—seminal paper on this topic that was published in 1968—was envisioning that something may be digital in the substations. While we were, right after that, developing that, what he was anticipating maybe happened. So there's this synergy that builds up until today between the digitalization of substation and improvements in the functionality of the energy management system. This is both, by the way, the transmission and distribution. So that's really the gist of the problem, the way how it was addressed initially. Now, if you're interested, we can go a little bit through, fast forward, through the decades after that to see where we ended up, but I'll let you lead this discussion anyway you feel like.

Julie Cohn (00:14:05):

During that iteration of your work on digital substations, what was your role?

Mladen Kezunovic (00:14:11):

I was, at Westinghouse, what they call the systems engineer, which means basically the one that looked at different parts of that development and suggested certain requirements that needed to be met. Which by the way, was a very unique role because it gave me a chance to talk with every part of the team. The team was about 15 people or so. And I interacted with everybody on that, interestingly enough, a side comment, I also dealt with the subcontractors. And one, one of the subcontractors was Ed Schweitzer, who initiated Schweitzer Engineering, a very well-known and respected company. And he developed the first commercial digital relay that was successful and was carried over to the series of products they have today. And so that developed a special relationship with Ed Schweitzer and Schweitzer Engineering. And the other gentleman was Don Russell, from Texas A & M, that was responsible at the time for electromagnetic interference testing. So that was my role to coordinate outside—the contractors and to coordinate inside—the team efforts.

Julie Cohn (00:15:33):

Were there academic institutions involved, or was it all in the commercial—?

Mladen Kezunovic (00:15:37):

No, it was all in the commercial world. It was R and D, of Westinghouse, and the industry systems division, which was production line.

Julie Cohn (00:15:47):

Were there any particular utilities involved?

Mladen Kezunovic (00:15:49):

There were several utilities, I think I mentioned. The project incidentally was granted to two major companies, Westinghouse and General Electric. And the way how they handled it was that, when you have typically communication between two substations on that line—so one substation was developed by General Electric and one by Westinghouse. Interesting. By the way, it's worth mentioning that the project manager was Stig Nilsson from Electric Power Research Institute. A gentleman whom I respected very much for his leadership in this team, and then his knowledge and things like that. But yes, several utilities were involved in that development. It was deployed at their substations.

Julie Cohn (00:16:36):

Got it.

Daniel Molzahn (00:16:37):

And what was the expertise of all the people on the team? You mentioned some of that, but was it sort of—?

Mladen Kezunovic (00:16:43):

We had three, if you will, areas of expertise that we had to manage somehow. One was power systems oriented—protection requirements and things like that. The other one was digital technology. We had people that were experts in how to put the boards together, how to design reliable systems and so on.

Industry Systems Division of Westinghouse was serving many application areas like chemical plants and some other industrial applications. So we brought experts that didn't have anything to do with power, that were experts in the digital design. And the third one was basically communications. Because in digital substation, if it's all digital, you have components, relays and so on, and they need to communicate and coordinate. It was a very—again, you know—tight collaboration. I remember several patents that we filed at the time. We were questioning ethernet and token bus and things like that, that were emerging at the time, whether they are suitable for real-time applications and so on. So that gives you a flavor that it was not just power systems, it was different areas of expertise that were needed.

Julie Cohn (00:18:03):

From my understanding, the interest in this was—was it an evolutionary interest that the systems were growing, the technology being deployed wasn't fast enough for these bigger and bigger networks? Or were there precipitating events that drew attention, more attention, to this?

Mladen Kezunovic (00:18:24):

It's always a combination. Throughout the history, you have—and I mentioned another add-on technology as we move on for digitalization of substations. But it's typically a combination of things. You know, you have a major blackout. We had one in '68, for example, and people start questioning what were the issues and so on. And again typically what comes back is the flexibility of the technology. Speed is very important in many ways. Which leads to the next generation of technology. Basically, that's how it happened. So it was the same here. There were issues with the blackout at the time, and they started looking at digital technology, and it wasn't quite there. There were many computers in that solution in 1970. So, they had to wait until the microcomputers came, which was the late '70s, early '80s. So it was a combination of things—something obviously hitting the limits, and something being offered by the technology. It is just a natural thing. It's just a matter of when things happen, but that's how they typically happen. Interesting.

Julie Cohn (00:19:40):

Thank you.

Daniel Molzahn (00:19:43):

Was there a lot of skepticism at the time that—was this project out there, that people didn't think this would be successful and it was a crazy idea? Or people thought this was the next thing?

Mladen Kezunovic (00:19:55):

Well, EPRI, Electric Power Research Institute, at the time, and now, it doesn't make decisions without probing the community quite a bit. So there was a support, that's how they generate the funds and everything else. There was a support to explore new technology. The skepticism is a different story in the sense that, whenever you have these developments, you are changing the mindset at the end of the day. And I need to tell you something that illustrates this, that is quite fascinating. This technology evolved—going fast forward with this—into something that is called 61850 today, which is all digital substation with a particular protocol. That is the 61850, is the protocol. And that technology has been accepted around the world in some areas where there were new developments of the power system—developing countries.

Mladen Kezunovic (00:21:02):

China at the time was a developing country and so on, and in many countries in Europe, not because they are developing, but because the vendors are very strong there. However, in the United States, it didn't pick up as much. And remember now, we started something in the late '70s, and today we may have 5% of the substations that are all digital in the United States. And the reason is, you may call it skepticism, I would like to call it customization. In United States, we are used to doing things differently from one to another because we have so many great engineers, and they are given the freedom to do that. And digital technology requires you to start generalizing and start standardizing and so on. And it carries a cost with it. And we are very cost-conscientious in the United States. So, combination of the "we like to do it our way, and we don't want to spend much money" is probably more of an impediment, if you want to call it that way, than skepticism, per se. It wasn't that somebody would say digital technology would not offer flexibility. I think people believed it would. It's just: "was it cost effective and how it's going to affect my particular way of doing things?"

Julie Cohn (00:22:34):

So was there partial adoption? You said only 5% of substations today are all digital. Was there some sort of partial?

Mladen Kezunovic (00:22:43):

Yes, there are. The original design electromechanical that goes back to the start of the power systems and protection, were discreet components. So, if you want to protect transmission line, you would not only have one, you would have multiple components to protect that—physical components, the digital technology, combine some of these functionalities into say, one box, but still there are multiple boxes. You're protecting transformers, you're protecting buses, you protecting whatever else is there. So it's discrete to start with. And the all-digital means two things. One is every component is digital. And the other one, they are interconnected through digital communications. So the partial deployment, which took United States by the storm, is that the digital relays were coming in as individual components. So if you go today to a substation, you will find digital relays in most of these substations. But all digital is more than that. It's communicating, coordinating all digital. And that is what is not picking up necessarily as much as individual components.

Julie Cohn (00:24:03):

Is that why it's kept you busy for your entire professional life?

Mladen Kezunovic (00:24:07):

Well, partially. I need to bring you to another interesting development, I believe, is that the all-digital substation meant that you would tightly integrate these components. Then we went discrete in deployment, with individual relays that are digital. Then we made a full circle. Lately everybody's talking about integrated digital substation. So we started with digital substation integrated, didn't pick up quite—because of all these reasons. Then we had discrete. And 50 years, I guess it took before we came to the centralized. So in my personal case, it was an interesting journey, because I started with integrated, and when individual components were done, I was involved with that. And when the integration started, I was like, "okay, I am, you know, back to where I was." So I had maybe additional knowledge that a lot of people didn't have, how that should be done.

Mladen Kezunovic (00:25:23):

So, yeah, it was something that kept me busy and involved. However, the second part of this journey, if you will, is what was coming next to this development. And I would like to talk about that briefly, if that's okay.

Julie Cohn (00:25:45):

Yes, please.

Mladen Kezunovic (00:25:47):

Another blackout, in August 2003, I believe it was, demonstrated—this was on the East coast—demonstrated that the monitoring of the system had deficiencies. The operators in this particular circumstance, there are many reports about that, what has happened, didn't quite see the behavior of the system. And so they were surprised by the dynamics of the system playing out the way they didn't expect—leading to the blackout. So after the analysis, it was concluded that the recordings—which are part, by the way, of the relays as well as some other equipment in the substation, like digital fault recorders—that the recordings were not synchronized across different parts of the system. And that was hard to line up, if you will, to understand the dynamics of the blackout.

Julie Cohn (00:26:51):

May I interrupt for a sec? So you're saying that they were—this recording might say it was 9:01, and this one would say it was 9:03, or something like that?

Mladen Kezunovic (00:27:01):

Yes, that's a part of it, which is the absolute time. So, absolute time doesn't change. It's absolute wherever it is as long as you keep the time differences. But the problem was, just to elaborate on that part, the problem was that the lining up of these recordings created an issue. Because if you record it here, and it's two hours different from there, you have to kind of line it up properly. And these recording devices didn't line it up. You had to do it manually. However, there was one other problem with the time synchronization. It is related to how you take what we call the samples of the waveform in the power system, which is current and voltages, that is different from absolute time. It's the synchronization of sampling, and it's related to the clock that exists in each device that drives the sampling and hold circuit, as it happens to be called.

Mladen Kezunovic (00:28:08):

So if you don't sample at the same time, then what you calculate may not be synchronized either. So a new technology was proposed for wide deployment, which is called synchrophasor systems, with the units that are in the substations that are called phasor measurement units. They sample much higher than the relays and recorders. However, the vision at the time was that you would want to monitor what we call phases, which means the sinusoids, of current and voltage, which will give you the feel for the dynamics. The devices themselves have actually taken samples. So these phases were calculated and calculating these phases in the transient conditions when you have faults and so on, creates different errors. So this technology was a huge difference because everything was synchronized to the GPS global positioning system of satellites, for sampling. And the timing also was improved in terms of absolute time.

Mladen Kezunovic (00:29:24):

And the problem, however, was, they didn't know how to exactly fit that in the existing substation design and in the control systems. So these became, initially, standalone systems. And they were deployed through the American Recovery and Reinvestment Act in 2009 through the government share in the cost—50/50%—with utilities that wanted it. So, there was an impulse, and they were deployed. But immediately they created issues because of lack of integration. You had to kind of decide how that works together with the relays and recorders and control systems and so on. Over time, that improved, and I'll explain where it may be heading, the way it is. But that was another major, major development in the power system monitoring and control. The next step of this that everybody's trying to figure out is how to integrate two systems.

Mladen Kezunovic (00:30:45):

And I have my own vision about that, but a lot of other people are working on that issue. Incidentally, United States is not the leading country in number of PMUs deployed in the system. It used to be China. Now it's India. India has more than anybody else—than China, than United States. There are major deployment efforts in Latin America, and slowly it's coming into Europe. Incidentally, Europe is having blackouts. We had one in Spain just a few days ago. And I'm waiting for the report that will say that they need more phasor measurement units. So, that's another thing that may happen.

Julie Cohn (00:31:30):

You described two eras of adoption where it seems that a region that is significantly growing its power system is a more aggressive adopter than a country that has an older and more established power system.

Mladen Kezunovic (00:31:52):

Yeah, and that makes sense. Because when you are building new substations, the cost of deploying a new technology for digital parts for the control is less than going and refurbishing or retrofitting the existing substations. It's odd, but that's how it is.

Julie Cohn (00:32:11):

Do the digital relays completely replace the analog, or are they retrofitted?

Mladen Kezunovic (00:32:18):

No, you cannot retrofit in a sense of half of one and half of the other. But you can go and say, this transmission line should stay electromechanical, and this transmission line should stay digital. But the issue is that the vendors are phasing out the previous technologies, so you can't, so you cannot really get the support anymore. So I don't know exact situation in each part or each vendor, but I'm pretty convinced that if you have an electromechanical relay still, you're having difficulty maintaining them and things like that.

Julie Cohn (00:32:48):

Did you have a follow-up question?

Daniel Molzahn (00:32:49):

Yeah, maybe a somewhat tangential question, but—you had mentioned, I think it was 1979, that they first came out with the 16-bit processors. Right at the same time you were doing this first project. And then the PMUs, as you indicated, driven by GPS availability. Right? And so both of those seem like they were external to—it wasn't the power industry coming up with—?

Mladen Kezunovic (00:33:14):

No, it was power industry adopting this. And you know how it is; it's been like that for forever, so to speak. If you look at various major increments in what the power systems people are doing, it's either the math is driving something or, lately, for example, artificial intelligence may be driving something, and so on. But the core technology, computational technology, is really where the things are. And I include the sensors and timings and all of that, because that is part of the digital technology. If you look at this or your clock, your phone, you have that clock inside. You have that signal, GPS, inside whether this computer or—therefore the control equipment has it too.

Daniel Molzahn (00:34:07):

So were these things sort of foreseen in the power industry? Was it, both on the microprocessor side, the GPS side, and maybe other examples, were there sort of visionaries in the power industry that said, "oh, we could do this?" Or it was—?

Mladen Kezunovic (00:34:22):

There're always visionaries. I mean the way the world works, at least from what I can see, is you always have people saying that something may happen. The differentiation is whether it's going to happen or not or whether it has happened. If you go 50 years ahead. In this particular field, I mentioned several names there: George Rockefeller and, you know, Arun Phadke, Thorp, Eric Udren, for example, who works now for Quanta. He was on the team as well. Stig Nilsson. There are many, many others. But they felt that these flexibilities and the speed and all of that can be achieved by using these technologies. It was recognized widely that there are limitations. The question was how do we overcome the limitations? And those people were the ones that were able to maybe find the ways how to overcome that.

Daniel Molzahn (00:35:27):

Got it. I see.

Julie Cohn (00:35:31):

So, which technical challenges did you find most difficult to grapple with?

Mladen Kezunovic (00:35:40):

Well to me, you know, the—being in the power systems area in protection—the challenges always come from the changes in the power system due to some other reasons, like introduction of renewables right now, and inverters and so on. So how the protection is going to react. Is it going to be able to do the basic job, which is remove the faulted part as soon as possible? That's always the challenge. So now, the challenge grows as you start looking broader, saying, "well, I have normal operation of a power system, and I have faulted operation of a power system. So how those two relate?" Because in all of the blackouts, partial blackouts, which we call brownouts and so on, there was an interaction between the relaying and the control. So the challenge remains not only that it was there all the time, but it remains how to coordinate a distributed automaton, which is protection. It is localized, measures locally, exchanges some information with neighboring nodes, and acts on its own, versus control of the system that looks at the entire system, preserving stability and various other operational conditions. So coordination between the two, I think, is the challenge that I have dealt with and feel even today that it's growing in complexity and requires new approaches. And by the way, last 10 years, we are taking, my group is taking new approaches to that too.

Julie Cohn (00:37:29):

So, have there been other engineers whose work has paralleled yours or competed with yours?

Mladen Kezunovic (00:37:38):

Oh, many, many. I mean—

Julie Cohn (00:37:39):

Are there individuals who have gone—like—you've gone this way on how to address these problems and they've gone that way?

Mladen Kezunovic (00:37:47):

There are. The most interesting part when the new ideas come up is, and I always tell my students this, if you want to explore something new, look at the beginning of a given idea. Because at that time, many different things pop up. Over time, they settle to one or two approaches. And so, if you ask that question, and I bring it to the time when something was introduced, many people gave many different ideas. If you ask that question—past 10 years or 20 years—it settles to something that is one or two options. And yes, there are many people pursuing them, but they are not as diverse anymore—until the next time when a new idea comes about. For example, whether it's new or not from centralized substation to individual to centralized back.

Mladen Kezunovic (00:38:52):

So now, when it's centralized again, there are new ideas—popping up. And yes, there are many people. Some are from academia you know, Sakis Meliopoulis, for example, is leading some of that centralized substation work, but most of that gets consumed by vendors and consultants that take over and push. But just to give you a flavor, you know IEEE, for example, which is a major professional organization around the world, has societies. So we belong to Power Systems Society—Power and Energy Society, I guess, it's called now. And then there are committees. So, Committee on Protection has 300 engineers as members, and not everybody in that field is a member, but those 300 meet three times a year and contribute to this all the time. So if you look at that, that's kind of a substantial group, because protection is typically having one or two or three people in the utility company responsible for that. So yes, there are plenty of these innovative engineers that are constantly doing that, just in the United States, let alone in many other countries around the world.

Julie Cohn (00:40:23):

Would you say IEEE—those committees are one of the primary places that the ideas are—

Mladen Kezunovic (00:40:28):

As far as I can tell, there are two places—or two professional organizations—and I actively participated in both over the years. I think combined participation over a hundred years, I think! It's IEEE, and CIGRE, in Paris. CIGRE is an acronym that stands for High Voltage Systems, but they expanded now to distribution systems as well. Just to give you a flavor—membership of PES, Power and Energy Society, I believe is 45,000—something in that range around the world. CIGRE combined is about 20,000, 25,000, and they deal with all of the aspects of the power system. Maybe a little bit broader than PES. So those are the two drivers around the world in this area, I would say.

Daniel Molzahn (00:41:28):

You've mentioned, in the US, so many different utilities kind of doing things their own way. They wanted their own customization for your substation. How much at these IEEE protection meetings or CIGRE protection meetings, are people standardizing on different approaches and then customizing it for their particular application, or they're changing ideas and those ideas get customized or,

Mladen Kezunovic (00:41:51):

Well, the differentiation is this: CIGRE doesn't develop standards. So, their discussions are technical reports, recommendations. The other thing that is relevant in CIGRE is that most of the involvement is from the technical and management side. So they are required in their reports to give recommendations that the management may take and move things forward. In IEEE it's slightly different. In IEEE, it's mostly technical stuff, put out—whoever wants to use it, and standardization. So the standardization is an IEEE signature effort. And those are standards that are then recommended to the International Electrotechnical Commission, which drives most of the standards around the world. And so, in IEEE when you start a working group or whatever effort, task force, the first question is, are you going to develop a standard or are you going to develop a technical report.

[REMOVED FROM THE TRANSCRIPT]

Mladen Kezunovic (00:43:37):

So the first question is whether you want to develop a technical report or standards, and if you want to develop a standard, you have to get something that is called P.A.R.—Project approval or whatever—request to be approved to do that. And then you branch off into that. Now more specifically to your question, and the industry is trying to agree on things. And a lot of people don't know this, even in the professional community. I tell this to my students to be aware of—that standards are actually three-layer documents: standard, recommended practice, and guides. And standards are: it shall be; recommended–perhaps you should; and guides–you may. How stringent they are, it's different.

Mladen Kezunovic (00:44:39):

So the agreements can be at different levels. The agreements can be, "well, we will have a guide and we will kind of try to do that, but it's flexible." If you hit the standard, you have to do it, it becomes a norm that you have to observe. The problem with the standardization in general, which applies to everything in the power systems, but in this area as well, is that selection of the best time to develop the standard. Sometimes the standards are developed well ahead, which is good because you can reach agreements before people are entrenched in different things, but you don't know enough. So, your standards are not very good. They have to get changed. Or you wait until the practice is settled, and you call it a standard. And disadvantage is, whoever has the upper hand in settling something, has an upper hand in saying what the standard is.

Mladen Kezunovic (00:45:43):

So, it's not an easy decision. And it ties back to the cost. How much would it cost you to do one way versus the other way? I'll give you an example. When PMUs were introduced—and there were at least half a dozen vendors on the US market, and there was a standard, which by the way was developed ahead of time—I took an effort to test all of the PMUs to check how they comply with the standard. And I reported that to a major group. NASPI is the group, North American Synchrophasor Initiative. And the outcome was that not a single product met the requirements, not a single one. One was closer than the other. And what the outcome was is that the vendors went back and relaxed the requirements. So now everything met the standard. So, that gives you a little bit of a flavor that it's not an easy decision, what to standardize, when to standardize, how to standardize and so on. And while people are striving to do that, if you push it to an extreme, like this 61850, it becomes extremely expensive. Extremely expensive. And, you know, the question is: who can adopt it? And so on.

Daniel Molzahn (00:47:07):

Did that lack of meeting the original standard—at least for the synchrophasor requirements—did that cause technical challenges or technical problems for people?

Mladen Kezunovic (00:47:19):

Of course it does. We don't know whether it caused something material—in a sense of blackout or—we don't have that information. But we know that the measurements were not accurate as claimed. And so, that was an issue that needed to be sorted out.

Daniel Molzahn (00:47:51):

I have more questions, Julie.

Julie Cohn (00:47:55):

Okay.

Daniel Molzahn (00:47:58):

So, one—maybe going back to earlier in the conversation—and I think into this point as well, with especially the CIGRE international discussions. So how, especially back when you were first doing these initial digital substations, it sounds like there were different generations of technology that was being deployed in different areas—where, maybe in the US first, and you had mentioned in China and India and Yugoslavia, as another country. So what were the relationships among the engineering teams like at that time? Were you able—did you take it—did they know each other? They worked together? They gave advice to each other? Or these were pretty independent?

Mladen Kezunovic (00:48:35):

Pretty independent initially, until people started publishing. And obviously you go to a conference and you find somebody else publishing and you talk with them about that. But the initial developments were sort of independent. Which means that there was a real need to do these things, because people wouldn't come to the same conclusion easily. What's interesting perhaps is that the coordination, which was primarily around standardization, was very intense. In other words, people didn't quite agree, because this was independent developments and you had to somehow bring them together, and people didn't agree on certain things. So, there was a standard that was proposed in IEEE on digital substation, led by EPRI based on the experience of these projects. And there was 61850 on the side. And there was a battle, literally, in the voting procedure: which one should take over? And 61850 prevailed, by one vote as it happens to be. And so you have these independent developments—you try to bring them together and you still have people that strongly believe that one or the other way is a better way. So that has to be reconciled, eventually.

Julie Cohn (00:50:00):

Did time tell whether or not 61850 was the correct—?

Mladen Kezunovic (00:50:04):

Well, it's difficult to tell because the other one didn't have a chance. So 61850 is what it is.

Daniel Molzahn (00:50:13):

So, I had at least two other kind of bigger picture topics, I was going to ask you about, Mladen. First of all, I want to make sure we have some time to talk—you said you had some perspective on future development, so I want to make sure we reserve some time for that. But maybe before getting to that, the other question I had for you was I know you've also been working at the forefront of this big data concept, and I introduced you for the survey paper several years ago at PSCC. How did that tie in with the digital substation ideas and the synchrophasors? Because it seems like synchrophasors are big data, but from what I understand, you've done a lot of other—

Mladen Kezunovic (00:50:55):

Bigger data. Yes. This is how it came all about. We were funded on the idea, which I will explain, in I believe it was 2011, and published the first paper to my knowledge in the world, introducing big data to power systems in 2013. By the way Santiago Grijalva was a co-author, Le Xie was a co-author, and myself. The idea came–I was the principal investigator. The idea came about from simple reasoning. I want to improve these things that you said, "what was the big challenge?" so that we don't get these outages and all of that. So how do I do that? And my thinking was, let's dig into the causes of outages and see whether we can grasp the causes. And then all of a sudden, it became clear, wait a minute, the causes are not just the grid. It's some other things, trees, weather, lightning, all kinds of other things.

Mladen Kezunovic (00:52:09):

So when we start looking at the sources of data that describe that, we were in the wonderland. We start realizing that so much data is out there that is related to the causes of outages that is not utilized. So the next question was, so how do we utilize it? Because the human perception and cognitive abilities are not there to correlate all of this, so it has to be automated. So machine learning and artificial intelligence came naturally. Now, I am—this is just a personal preference—I am very much involved in collaborative research across United States, across the world. And so I reached out to a gentleman at Temple University. His name is Dr. Obradovic, he's an expert in machine learning, artificial intelligence, and he didn't have anything to do with power systems whatsoever. He did this for health services and genomes— research on genomes, and atmospheric stuff, and so on.

Mladen Kezunovic (00:53:19):

So, I said, "I need your help because I don't know much about this stuff. We need to handle this data." Long story short, we are a very tight team now. Got funding from different sources over the years and produce some interesting results. So the point is this, and I'm going to paraphrase it in a kind of, ways we were thinking. The king in power systems was AC, after the battle of, with DC. It ain't anymore. It's a combination of AC and DC. The next king was storage. It is still the king, but it's expensive. We don't know how to handle it. How to dispose the materials and so on. The next king is weather. When you think about it, with renewables and everything, everything depends on weather: generation load, the behavior of the grid, everything. So, when you start looking at all of these things, you start broadening your view of data, actually.

Mladen Kezunovic (00:54:27):

And so, long story short, we started from that simple notion that the more data, the better. Simple notion to realize that, yes, you can get some better things. And I can give you an example of better things. You may try to predict outages. If you predict outages, the implication is that you have the time to prepare to mitigate. Therefore the impact would be less. It's like: they're going to attack us, let's get ready for that. When they attack, we are better than if they attack us, and we don't know what's going on. So yes, that was a big discovery, in closing, on that topic. The challenge, however, is that the techniques for machine learning, artificial intelligence are changing very quickly because they are driven by Google and Amazon and whoever, eBay, and whoever it is, and these people have resources and they just move forward. How the power systems people are going to catch up and use it for whatever it's useful for them, remains a challenge. So—

Daniel Molzahn (00:55:40):

Maybe a follow up on this, or perhaps a couple of follow ups. So, you had to be experienced in collecting lots of data, storing it, identifying what's useful, what's not useful in the context of protection systems, right? You're getting a lot of PMU data all the time. Was that expertise useful in this other context, with very different types of data?

Mladen Kezunovic (00:56:03):

Yes, it was, definitely, it was. Because there are generic issues there or issues that you have to deal with. It's management of data. And it's the computational power. Because all of these techniques, when you have large amount of data require resources that are high performance computing resources. Lately, what we are using, in the last few years, is the cloud—high performance, which is very elaborate. So when you start into that and you add more data and more diversity, you simply build on that experience and broaden your views of that. So it is useful, or was useful, when we started with one type, moving to the next or the next. It was useful.

Daniel Molzahn (00:56:53):

Got it. And then maybe one other follow up on this is, how much have utility companies today bought into this? I mean, I think everyone has an AI strategy, right? But is it specifically the sort of big data—?

Mladen Kezunovic (00:57:04):

They are, they are struggling—in a sense that it is totally different paradigm. But you know, the companies were struggling before. I mean, AC was a paradigm, very strong paradigm, with this DC coming in. Nobody knows exactly what to do with it. Eventually. But it is there. And so, all of these committees—standards, 2800 for example, on IBRs and, and so on, and for the distribution. So, my notion is better be there first and learn than be last and regret that you lost your opportunities. So I expect this to pick up. However, it is not going to pick up, in my opinion, if somebody is trying to solve small or simple problems with this. It has to be formulated as a solution, if it can be, to a major problem, because that catches their attention.

Mladen Kezunovic (00:58:18):

For example, outages, yeah. Outages. If outages happen, it's not about major blackouts. There's a website that is monitoring all the outages in the country, 150 million metering customers. You can go to the website, click on every town, every area, and it will tell you what the outages are. There are always outages across the country. So that's a problem. And so, if you phrase it the way, "Hey, we will avoid this, avoid that, that costs this much money or, or lives or whatever," then it will, it will catch more attention. Unfortunately, the academic community that is driving some of this, these new theoretical things, do not have a feel for what is a critical problem in industry. And it creates a disconnect. We get a lot of publications or new ideas and whatnot that are addressing problems that are maybe—I shouldn't say not relevant—but far less relevant than what the technology deserves as a solution. So, that's an issue.

Julie Cohn (00:59:28):

Do you think that the scale of a problem you put forward—outages—is unique to power systems? Or are there other systems that, if the power systems community addresses this successfully with big data theory and application, it can apply, I don't know, to medicine to—?

Mladen Kezunovic (00:59:54):

Well, it's the other way around. They are already doing it. It's the other way around. You know, they're already doing it. If you're buying whatever from Amazon, you wouldn't believe what kind of a, you know, logistical outage analysis goes behind that. Interestingly enough, along those lines, I have some close relationship with the Carnegie-Mellon folks, and they developed outage, if you want to call it that way, or failure of the transistors in a very large-scale design that is applicable to power systems now. They probably have the optimal power flow convergence algorithm better than anybody else, perhaps. And so it's kind of: power system is not certainly necessarily feeding others, it's others feeding power systems mostly.

Julie Cohn (01:00:47):

Is that new for power systems?

Mladen Kezunovic (01:00:50):

What?

Julie Cohn (01:00:51):

Being a little bit behind the curve instead of ahead?

Mladen Kezunovic (01:00:54):

Well it depends how you look at it. You know, when the light came, it was certainly first. And they led everything else. They changed the production, the manufacturing, the whatever, you know. So the electrical system was a revolutionary solution. And maybe it goes into some other areas of revolutionary developments as we move on, because electrification is now penetrating other infrastructures, transportation, and there are 15 critical infrastructures. They're all affected by future electrification. So that's the next generation of how power systems may lead. But after these peaks, if you will, of invention, then the systems settle and they operate a particular way, and people don't risk. So it's a risk-averse industry. Others risk more, and then we grab from them, and then maybe we come to another peak of some sort. And that's maybe how it goes.

Daniel Molzahn (01:01:59):

Well, I also wanted to follow up on this thread with the sort of divergence between industry and academics. What do you think the underlying—what's your perspective on that? We've talked with several other interviewees about this, got different perspectives on where that came from. What's the implications? Possible solutions? Curious what your take on that is?

Mladen Kezunovic (01:02:21):

Well I am, right now as we speak, involved as a chair of a CIGRE working group on workforce development. And a major part of the report—we are just about to finish the report; I think it will come out at the end of the year—is this disconnect and how to bridge the disconnect. And so what the disconnect is, is that the industry moves in its developments very fast. And intrinsics of that are affecting fundamentals. So the fundamentals obviously are there. You can teach them and they are important. But fundamentals on their own are not going to solve engineering problems necessarily. They may advance science or something like that. And we need engineering problems, because the power systems are becoming more complex and outages are happening more rather than less and so on.

Mladen Kezunovic (01:03:20):

So we do need engineering problems. So that's the fact. That disconnect is the fact. The question is what to do about it. And I speak from this report, but it's kind of a consensus across the board. One is to get the faculty more attached to the industry through various means so that they get some feel for what's going on in industry. And the other one is to deal with something that is very difficult in academia. We claim as being open-minded and open to science, but we are more siloed than anybody else is. As an example, in order to solve the problems today, that I'm dealing with, I'm reaching to weather people in the geosciences—college of geosciences, working with them very closely. Behavioral economics people for this ancillary services—and things like that.

Mladen Kezunovic (01:04:23):

And many others in engineering. And that is not very common in academia. So another recommendation, if you will, is to try to get the students to get some kind of a cross disciplinary exposure. Now it's easier to do that at the graduate level. You know, you can have a degree in master's or PhD with some combinations, but undergraduates, it's very difficult. So we are also recommending that at least the undergraduate students also get more involved with industry, exposed, to get at least the feel that what they are learning is not the only discipline that those people are using. And so, this is, in a very broad sense, what the issues are. How to solve them exactly is not clear. And one key issue is that when you start going into advanced technologies, like, say data analytics, you have a situation where you graduate and Google grabs you and your salary is three times more than if the utility grabs you. And so where are you going to go? Not that everything is in the money, but you know, it's part of that problem. So it's a compounded issue that needs a lot of attention, I think, going forward.

Daniel Molzahn (01:05:49):

I was going to say, our colleague Sairaj who wasn't able to join this morning, always asks the question of what would your advice be for the next generation of students? It sounds like maybe this is your advice for the next generation of students.

Mladen Kezunovic (01:06:00):

Yes, it is. In general, it is. Get yourself—which is difficult—get yourself informed about what's out there as soon as you can. And I think it's—I shouldn't be talking about this because it's our internal effort here. I'm leading the alumni—we call it ACT, alumni collaboration team, where we trying to draw benefit from

8,000 alumni from this department in the last 20 years to help us to make these connections. But the students should develop that feel of exploring what's next for them to learn what to do as they are—which is difficult. You know, when I was deciding on my career, where to start, I was more interested in arts and film and theater than I was in electrical engineering. And I ended up, because my brother was an electrical engineer, so it's hard to decide what to do early on.

Julie Cohn (01:07:04):

It sounds like there must be a story there.

Mladen Kezunovic (01:07:06):

There is a very good story there. I don't know whether it's ready to be released, but there is a good story. I was attracted by, for some other reasons, to these other fields.

Julie Cohn (01:07:17):

Maybe in the next interview.

Mladen Kezunovic (01:07:18):

Maybe in the next interview, right.

Julie Cohn (01:07:21):

Yeah. So, if you'd like to take a few moments to look forward, we'd be interested in what you see as the challenges ahead and what of your past work will apply successfully and what you think may need a whole different approach.

Mladen Kezunovic (01:07:39):

Well, you know, there are different angles to this. One is by personal contribution that I may be able to make. I am at my, I should say, end of my career, but getting closer there. So I don't know how much more impact long-term impact I can make. But my students certainly can. They are graduating, they are very well positioned. And then there's another angle to it, which is the view that I have about where the things are going. And I don't like to, in general, talk about long-term things like 20 years, because I don't think anybody knows what's going to happen in that timeframe. But I certainly see where the industry has to go. Doesn't have a choice. According to me. Right? Incidentally, I also have a private firm for over 30 years that is doing development, and lately consulting, for almost a hundred customers worldwide.

Mladen Kezunovic (01:08:42):

So I give this advice to them as well. The introduction of renewables, which is a trend that cannot be stopped, it can be kind of paused or moved this or that way, but it's something that is going to come to us. Directly means more DC in the AC system. And that is really hard to deal with. It affects controls, affects protection, affects many things. And so the existing controller and protection systems—monitoring, control, and protection systems—are not going to be sufficient. It's going to have to change. So the question is how. And it's a long story. It has many facets, but there are some simple notions along those lines. More data will have to be used. That's along the lines of this machine learning, artificial intelligence. The recording in the system that happens through remote terminal units of the energy management system, relays, PMUs, and so on, will have to be merged. And the way it's going to happen, I think, is that the PMU, as we call it today, becomes a relay, becomes remote terminal unit, becomes everything. In other words, that technology—synchronized sampling—is the technology that is across all of the substations.

Mladen Kezunovic (01:10:22):

That in itself, plus the data, additional data, will help develop new applications and new algorithms for control and new monitoring capabilities and so on. So, my area is control and protection. Monitoring is a part of that. So that's how far I span in my thinking, on how the control and protection should look like in order to manage the system so that we don't fail. Because the failure of the system, as I said, in the future where electrification expands, is going to be causing other infrastructures to fail. So it's a harder impact than now. Now, I want to close with one topic that is dear to my heart in the last few years. It is the approach to the analysis of the power systems. I think it should be risk-based analysis. In this outage prediction, the risk is predicted and mitigation is an optimization process to reduce the risk.

Mladen Kezunovic (01:11:37):

We talk about risk, but not as much as about reliability and resilience. I call them three R's. Reliability, resilience, risk. Reliability is very established. It's been around forever. It has approaches and it's well recognized. Resilience is a nebulous term. People are interpreting it any way they want, no standardization on that. And no particular meaning behind that, except for individual explanations—what they mean by that. The risk can tie the two. The risk analysis can tie the two. We were able to analytically tie the two through the risk analysis. And the notion of the risk is that something can go wrong. That's the notion of the risk. The utilities don't like that notion, because they like the notion that everything is going to be good. No reason to believe that it won't. I think the paradigm needs to flip. Everybody, including utility regulators, legislators should look at this system saying, "it's very complex. It surely can fail. Of course, we're going to do everything so that it doesn't. Therefore, let's quantify the risk mitigation measures, and so on, to reduce the impact of the risk." So I would like to close this discussion here with that notion. One side is technology and control systems and this and that. The other one is how we view the system from the analysis standpoint. So I said what I believe is over there, but on the analysis is the risk.

Daniel Molzahn (01:13:25):

So is it, building on that a little bit, what you're suggesting is a lot more stochastic modeling—?

Mladen Kezunovic (01:13:32):

Probabilistic views of—for example, is it better to tell you that the outage may occur, with 70%, or not to tell you anything? You know, you would probably want to say, well, if it's 70%, I want to be aware. If it's 10%, I don't know. So that is not in conflict with anything that we are doing. It is just the additional decision-making tool.

Daniel Molzahn (01:14:03):

And do you think we have the right expertise in the room, in the metaphorical room, to answer those sorts of questions? Or is that—we need some other communities?

Mladen Kezunovic (01:14:10):

I absolutely think that we need to reach out to other communities that are experts in this.

Daniel Molzahn (01:14:19):

Which ones in particular?

Mladen Kezunovic (01:14:20):

Well, if it's in my field, it's data analytics people. If it's in a more theoretical, it's probabilistic analysis/stochastic analysis people, mathematicians, if you will. So somewhere in there is where we should be. And the obstacle, however, that we are dealing with is the mindset. You know, when you go to utility company and you try to predict outages as an example, they would say it's great. But when we, after 10 years, have a product that we can put out, they are not sure who should deal with that product? Which department should deal with it? Is it asset management? Is it you know, protection? Is it control? Who is it that should be the owner of that particular technology? And where should it fit in the legacy solution? And so, those are the obstacles. But my simple thinking is, "hey as I said before, you can get to it and learn, or you can just be smashed with something really bad and change your mind after that and seek out help." So anyway, that's the view I have on all of this for whatever it's worth.

Julie Cohn (01:15:44):

I'd like to, before we close, I'd like to ask you about one other thing. You're sitting in front of a wall of acknowledgements, awards, medals. I wonder if you have any reflections on what those things represent?

Mladen Kezunovic (01:16:02):

Well, I have two or three reflections on that. It feels good when you receive one. After a while you maybe even forget exactly the circumstances, but what you do remember is the people you interacted with. So all of these recognitions, whatever they are, carry, to me, carry a memory of a particular group that I was associated with. And that's the beauty of being able to—being blessed basically—to go out and socialize, if you will, in many ways with bright people that do things. So, whenever I receive one, as I said, I may feel good, but at the same time, I feel guilty that, hey, somebody else should have gotten it, because those people that I associated will, most of them, deserve it.

Mladen Kezunovic (01:17:01):

So it's a little bit of both. But it's a sort of a humility at the end of the day, you know? "Yeah, we did that. But okay. You know, many other people helped." And so on. So yes, they mean a lot. But as I described, you know, pretty much as a collage of different experiences and interactions and so on over the—.

Julie Cohn (01:17:27):

I think that's a lovely note on which to conclude. Thank you very much.

Mladen Kezunovic (01:17:31):

Thank you, by the way, for this opportunity. It's fun.

[End of interview]