

**Algorithms & Power Systems Architecture:
Using Historical Analysis to Envision a Sustainable Future
Oral History Project**

Interviewee: Thomas Reddoch

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Interviewer(s): Julie Cohn, Daniel Molzahn, Sairaj Dhople, Jess Slater

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Abstract:

Thomas Reddoch, Manager of Energy Utilization at the Electric Power Research Institute (EPRI), discusses his education, his decision to pursue both power systems and systems theory, his early work at Gulf States Utilities, and his dissertation focus on load frequency control. He emphasizes the value of working closely with faculty. He describes working on transmission, load forecasting, protective relaying, and the importance of understanding power system fundamentals. He underscores the importance of a year spent with the Energy Research and Development Administration (ERDA), while he was on faculty at the University of Tennessee, during which a 1975 workshop in Henniker, New Hampshire brought together data modeling and control engineering, albeit without the benefit of today's advanced digital computing. He explains his dissertation focus on applying optimal control analytics to frequency control problems. He references the 1965 Northeast Blackout and the later utility adoption of digital control

centers. He stresses the importance of parallel developments in digital computing and power systems control, noting the example of matrix theory, which emerged in the 1930s, but could not be applied to power systems until the 1970s. He talks about early SCADA systems. He describes his four years at Oak Ridge National Laboratory. He talks about the advent of widespread use of air conditioning in southeast Texas and how that affected frequency control, leading, in part, to interest in controlling end use. Dr Reddoch describes his entrepreneurial experiences. He discusses his work with the Electric Power Research Institute (EPRI) that evolved from a focus on energy efficiency to electrification of new segments of the economy to workforce development. He reflects on his roles across multiple segments of the power industry, noting that he never worked for a regulator. He emphasizes the importance of regulation going forward, as more renewables are added to the grid, end users take on larger roles, and demand for electricity rises. He discusses the opportunities presented by using AI to analyze power systems, and the difference between physics-based models and data-driven methods. He dwells on the tendency to cling to old ways of doing things when emerging problems and new technologies call for new approaches. He gives an example regarding the 1970s research on wind turbines. He closes by reflecting on the importance of studying both system theory and electrical engineering to be well prepared for all the types of professional opportunities he encountered.

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.

Julie Cohn (00:02:44):

This is Julie Cohn. I'm conducting an interview with Thomas Reddoch on Tuesday, May 28th, 2024, online. Sairaj Dhople and Daniel Molzahn will assist with the interview. Jess Slater is also participating and may ask questions. Dr. Reddoch, during today's interview, we are especially interested in your early work on power systems control and how it later was carried forward into the various technology research endeavors in which you were involved. 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 electric power systems.

Thomas Reddoch (00:08:09):

I won't bore you with a total layout but let me share some things that I think might be relevant, at least in terms of how my perspective has evolved and something about how certain steps—at least in my own personal career—have advanced me along the way in an industry that has changed immensely. I went to undergraduate and [got] a master's degree from Lamar University. Back in the day when I went there, it was called Lamar State College of Technology; it's in Beaumont, Texas if you don't know that. And it's kind of important to put a few dates out—even though it does suggest how old I really am—but those dates benchmark certain calendar events. I completed my undergraduate degree in 1967.

(00:09:29):

So, I was an electrical engineer at Lamar—that's a relatively small school. We had like a graduating class of around 25 people, so that gives you a sense of size. But what this allowed one to do was to have a very intimate connection with the faculty. I always thought that was a special enlightenment for me, because, today, getting professor time can be a very cherished result. In those days—in the smaller environment—it was highly, highly interactive. And it was there that I really got my first introduction to electric power systems as a part of electrical engineering. And then, also off of that bachelor's degree, as I was working on my master's degree, I also had an opportunity to work with Gulf States Utilities. So, there was a period in there, about a year and a half, and it was my first really in-face engagement with electric power.

(00:10:43):

Again, I consider myself to have gotten several really unique breaks in the beginning, because I worked with the consulting engineer, the internal person at Gulf States Utilities—most unusual name, Howdy Sutton. Now, how much more southeast Texas can you get than that? A brilliant man. And for my first experience in the power industry, that was a really, really unique engagement. I got to work on an assortment of problems. None of those were in power system control at that time. But there were two project areas that I got involved with that sort of had a lasting impression. So, first of all, is high voltage transmission at the 500 kV level was just being introduced—and one of the first problems I worked on was with 500 kV transmission, you do have unbalance in the transmission phases.

(00:11:54):

And so, I got a really good dose of working with Howdy Sutton on how to analyze what that meant and how that impacted protective relaying. And then the second area was some load forecasting work. And one of the things that gives you an awareness of the kinds of control issues—albeit I don't think they quite compare with the things that we have today—but, in southeast Texas at that point in time, air conditioning had made a big inroad in the end-use area. And what would happen is that southeast Texas gets a lot of afternoon rain showers, and as a part of this load forecasting work, I was down in the dispatch center, and it was amazing to watch how quickly the load dropped off when a thunderstorm rolled through.

(00:12:59)

I mean, it was a fabulous experience. I'm looking at an old strip chart recorder—way before digital days—and on that strip chart recorder, you could just see how quickly the load rolled off and the adjustments they had to make in generation in order to get a balance. So, these early experiences, I think, really were special to me—first with the faculty, then that experience at Gulf States. Both of those specific events got me immersed early. And that was a time when a lot of people were exiting electric power—it wasn't the hot topic; there were other things that were starting to come along—so I got this first very, very unusual experience. Let me pause there. Julie, I may have elaborated a little bit long on that, but I thought that intro was kind of important.

Julie Cohn:

Yes. Thank you. We may circle back to those strip chart recorders at some point during the interview, <laugh> and the sudden popping off of load. So, following your master's degree, where did you head next?

Thomas Reddoch (00:14:19):

I went to Louisiana State University. It was a—I made it—this was another one of these momentous decision points—and what was significant about that is that I had narrowed down my choice to two schools for a PhD. I had to make a choice, and it was a tough choice, but I had a very specific criteria. And this allowed me to ultimately make the choice for LSU. The other school was Texas A&M University. So those were the two. I had fellowship offers for both, for doing my PhD work. And my ultimate choice was LSU because they had—in my judgment—a two-pronged attack. A) they had a great power system program, but they also had a strong program in general systems theory. And I really felt like that from my early intros, I wanted to be able to understand the fundamentals of electric power, but I also wanted to be able to acquire some tools and analytical methods that took me out to a broader systems assessment.

(00:15:45):

And that was my ultimate choice for picking LSU. I think if I had only been selecting on the basis of power systems, I think that Texas A&M's power system program was superior to LSU's, but I was really looking for the dual thread, and that took me there. And after I finished my PhD—my first formal job after my in-and-outs at Gulf States Utilities for a year and a half—I became a professor at the University of Tennessee in Knoxville. And that was my first job post graduate school, PhD level. And so, I was a professor at the University of Tennessee for about eight years.

(00:16:53):

And it's probably worth noting in the middle of that eight-year run—and two years in—I took a sabbatical. That's a little unusual; usually young faculty do not do that, but I got a chance to spend a year in Washington, DC with the forerunner of the Department of Energy. Many people don't know there was an organization ahead of that, but following the oil embargo in 1973, it became clear that the U.S. lacked a unified effort in energy. And so, what was done was a two-step process to formally organize energy activities for the U.S. under a single banner. And the reason being, things were scattered everywhere. And this original organization was the Energy Research and Development Administration. Terrible acronym, ERDA—it sounds like a disease, or something like that.

(00:18:00):

But ERDA was the transitional organization, and it was department level, which means there was not a Secretary of Energy in that early step—that came later. The negative of that is that you don't sit with the secretaries around the president of the U.S. in order to be in frontline strategy, so ERDA was this transition. I spent that year there; worked with a person that some of you might know from history—his name was Lester Fink. He was with Philadelphia Electric Company for more than 25 years, and he was chosen to be one of the key leads in the now re-scoped effort to put energy in a unified fashion for the US government. After two years, ERDA transitioned into the US Department of Energy, Les certainly continued his work, and just an example—energy work was scattered everywhere.

(00:19:07):

Some of it was in the Department of Interior, some of it was the Federal Power Commission, some of it was the National Science Foundation. And then we had, back in those days, the Atomic Energy Commission for nuclear. We just had things scattered everywhere: is it no surprise that there was not a unified effort? And again, I thought this was special for me because I got involved right at the front end. And it continued to reinforce why I thought this field of—I called it electric power exclusively then, which is now morphed into to a more general energy type perspective—these are, again, unique experiences for me that shaped a lot about how I later thought about processes. I can rattle through a couple of other post experiences but let me just pause again. Julie, I don't know if you want to explore, expand on any of these at this stage. Just what's your thoughts?

Julie Cohn (00:20:12):

What—well, can you tell us a little bit about what you worked on at ERDA during that year?

Thomas Reddoch (00:20:20):

Yes. And that steps back. I got to know Les Fink just before he came to ERDA, and then subsequent Department of Energy. I got to know him when he was really still at PJ—Philadelphia Electric—I don't wanna call it PJM yet; that's a later thing. And both my master's thesis and my doctoral thesis—both were focused on load frequency control—so at those two levels, that's when I really started to get involved in the area of control and management of the electric system. And here, most recently, within the last year, I beat some dust off both those documents because of some work that Julie—that you and I are doing in a mutual manner.

(00:21:30):

I went back to look at these documents and I think I discovered something really quite interesting. With this background, that's where I first met Les. He was involved. And there was this interesting workshop that was held the year before I went to ERDA. It was held in Henniker, New Hampshire, and it was a national meeting that set the tone for the research program that Les was gonna release at ERDA. I was chosen to be one of the presenters at that meeting, and I really presented on the topic of load frequency control. And so, what happened was post that meeting, that's when I took the sabbatical, and I went to ERDA.

(00:22:31):

And at that period, we were doing extensions of the work in the load frequency control area—today, we would call that automatic generation control. And the process of managing the very tricky balance between supply and demand. Again, when I think about where we are today, and I look back to that, it was relatively simple in those days because we had all central station power plants, and the only—what I'll call—issue to track was the load that was varying. In contrast to where we are today, when we can have supply variations, as well as load variations, making that problem a lot more difficult to solve. But that was the area I worked on. But I did also get one other special introduction when I was at ERDA.

(00:23:42):

And that is—I got connected with the Wind Energy program that was a separate area within ERDA. And they needed some help because they were first in the mid-seventies. So, this was in the—I may not have said the date, but the actual date was '74. In 1974, 1975, wind energy was just getting its first look. It actually came out of the National Science Foundation program, supported over to ERDA, and they were really looking to introduce wind energy as a power generating asset. So again, I got a great opportunity to be at the front end. That problem was interesting because it was trying to take the first of a variable resource and understand: how do you mix it in and make the grid still perform well?

(00:24:47):

How do you do planning studies with an intermittent resource? One of the tools that we used was an analytical tool—it was around at that time called PROMOD. It was the ultimate in planning tools, in terms of software, in terms of how people analyzed those situations; except, this business of an intermittent product didn't fit the model well. There was a lot of struggle trying to get this model to work well. So here I was working on my load frequency, automatic generation control analysis on my primary activity, and then I got this sidebar in wind energy. And I spent the next decade working on wind energy and that was pretty cool. Even when I returned back to the university, I continued that process. So that was again—I keep citing these one-of-a-kind, unique experiences, but I just considered myself fortunate to get these early, early exposures, and it shaped my attitude.

Julie Cohn (00:25:58):

I'm gonna see at this moment if either Daniel or Sairaj wants to jump in with a question, or do you want to wait 'til a little bit later in the interview? Because I think Dr. Reddoch has brought up some topics that I know are of interest to both of you.

Sairaj Dhople (00:26:15):

Julie, I can ask a quick question here—so Tom, just more of a clarification, could you say a little bit more about what aspects of load frequency control you worked on while at ERDA? And was that the big topic of the day? And was that what was keeping everyone excited?

Thomas Reddoch (00:26:38):

So, what Les Fink tried to do with this overall program was that he wanted to take traditional power system analytical methods, and he wanted to expand the analytics. So, he really wanted to dig into mathematical methods out of systems engineering and apply those to solving electric power system problems. His belief was that the system was gonna become more complex—well, his early vision of that clearly was correct—I mean, when we look at what we have today, it's a very complex system. So different than the—I hate to use the word—relatively simple circumstances at that point in time. So, what I did for my doctoral thesis was that I really did apply optimal control analytics to the load frequency control problem.

(00:27:57):

And that involved heavy modeling and really specifying control structures, and then essentially solving for the coefficients that would go with the various terms that made up that particular control structure. And what I did for my PhD thesis, I solved what I'll call the ideal case. And that would mean if you looked at what the key system variables were—I assume that you could make measurements on all those variables, bring those back, put all that into your control algorithm, and then guide the system. And there was little doubt when you looked at using those methods over traditional simple feedback systems, the controllability of the process was quite significant. Well, when I went to ERDA, we really wanted to take a look at what I would really call a suboptimal solution.

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And that is—you can't measure all of these things. You cannot necessarily—the communications technology at that time, you perhaps could not get information back quickly enough to truly implement

an optimum algorithm. So, the idea was: what can we do to get near optimum? How do we go to maybe some little simpler structures— better than what we had done with the then classic approach, which was largely either a simple proportional control—to really look at an optimal control where I could feed back a lot more information? We were doing some early advancement with sensors, so you could get some of these measurements. I think that—if I look at that and think back—it's probably communication was maybe the weakest of those links.

(00:30:23):

But bear in mind, we were not into the digital world much at all at this point; we're still doing everything in an analog fashion. And this is something that I want to emphasize because, recently, as I've looked back and I look at what I attempted to do in that ideal world, I think that it was impossible to implement that in an analog. However, as we move now in the digital world—let's get a date on that, that was 1973 that that dissertation was written, and here we are sitting out here more than 50 years later—and now, when I look at this, it required digital to make that happen. So, in a period of 50 years in my own professional career, I've watched how we've transitioned from rather primitive techniques, in terms of the analog world, to the power that digital unleashes. And certainly, in terms of measurement, what you can do with analytics, and how you can perhaps realize an optimum—or at least a near optimum solution.

(00:31:59):

Does that help?

Sairaj Dhople (00:32:03):

Yeah, absolutely. But just a quick follow up—so, do you feel like some of these optimal-control-based methods did take off? And are they implemented in power grids around the world today, or are they still—

Thomas Reddoch (00:32:19):

Yeah, I think—well, they're probably—the optimal solutions: probably not, because in a practical world, you can't measure all that information and get it back. So, it would be like: maybe you had, in a theoretical sense, 10 elements that you would be taking measured data from—probably not fully 10 from the ideal case—but what you would have is three or four of those. And with those additional pieces, what one would discover is that you could clearly hold excursions away from 60 hertz in a much more compact way. So, if you looked at the mean square error—for example, of what that frequency might look like—then those values would be smaller. So yes. But to really unleash that, we needed to be moving into the digital world to get that to happen.

(00:33:41):

So once again, I think that at the time I did that, the modeling methods were clearly out ahead of our ability to implement. And those—I think that early work was very timely. Really, when I went to ERDA, I mean, this is what hit me—it was all about the 1965 Blackout. [It] led to the first development of digital control centers for the industry, which emerged in the early '70s, and I think that that was some early recognition that we needed more information. If we had more information, we were gonna be able to do a better job. So as the digital age continues to advance, then we will have a better ability to manage the process overall. And that's almost a requirement now, because if we look at how renewable energies are changing the whole process, we need the power of digital to be able to manage this very, very complicated process.

Sairaj Dhople (00:35:15):

Thanks for sharing that, Tom. A theme that has repeatedly come up in our conversations with several of our interviewees is that: so many of these technologies are—I'm gonna borrow Julie's wonderful phrasing here—determinative in the sense that future solutions for better or worse tend to mimic those in the past. And it seems to me that you are sharing an example where the computing power changed from analog to digital. It was a lot more programmable, a lot more fast, but somehow the old ways of doing things—let's say for load frequency control—took a different name, but the method itself persisted.

Thomas Reddoch (00:35:57):

I think one of the things that was clearly missing—and this is really what the whole information process begins to support—in a conceptual sense, I think that these more complex structures where you're making measurements in multiple places in the system of some of the key system variables—enabling that process is really where the difference, I think, comes in. It is that clearly, more information; information that's accurate—and, by the way, information that is timely, because we have to be careful with latency in communication processes. If your communication process is not quick enough—the power system is a very dynamic beast—the system can very well be going up, and with delayed information, you thought that the signal needed to go down, and suddenly you discover you're going in the wrong direction. So consequently, understanding your communication process and the timeliness of that information, very, very vital in the overall execution. But the point being: in a digital world, we can make these measurements and we can really understand a lot better about how that process works. Speed <laugh> is crucial in this modern advancement.

Julie Cohn (00:37:49):

Thank you. Daniel, did you wanna jump in on this discussion, or—go ahead.

Daniel Molzahn (00:37:54):

Well, I had a question, kind of higher level, that you had brought up, that I thought was quite interesting. So you're saying, Les got all these people together, he had this program that he was putting in place to bring in the system engineering advances, so from your point of view: was most of the theory already there on the system side, and it was mostly a matter of applying it to power systems, or was it really a need to develop new theory? Or some mix of both? Or do you have a sense of how that balanced out?

Thomas Reddoch (00:38:30):

That's a relevant question in terms of understanding where we were. Analytical methods—which are really, from my perspective, very much derived from the mathematics ends of things—those analytical methods typically precede practical application. So, the types of analytics that was used in the late '60s, early '70s, was pretty fundamental stuff—simple feedback control, that was about it. I'll measure frequency, I'll see where it is, and I'll push the signal back, and I'm gonna have a mechanical governor that behaves differently than an electronic governor. And so, the analytical methods were pretty primitive. And yet it was a vast reservoir of analytics tools out there that were not being applied to the electric power industry. And with its growing complexity—and what is one of our strongest testimonies of growing complexity? Was the '65 Blackout.

(00:40:03):

We had a process that had been operated largely in a very manual way—literally, operators communicating with one another, making manual transactions—to where we had a system now that had so many modes of interaction because of the addition to the growing transmission system that really connected the various generating sites. So suddenly, now, you have an environment where there are a lot of interactions and understanding—without some deeper analytics—how these items are interacting with one another. That's in part how we got in trouble—just too many points of either failure or interaction to be able to simply manifest that in your head. You needed the power of tools. I like to give a—there's a really good historical example: matrix theory was developed in the thirties.

(00:41:15):

This is really interesting. Matrix theory was developed in the thirties, and we couldn't take advantage of that, but when digital computers came along, wow, what an application for matrix theory! And what it did is, it really began to reveal how you take a technique well ahead of its time and put it to really strong use. So, any type of transmission analysis—whether you were doing load flow studies or whether you're doing fault studies—all of those modeling processes used matrix theory very heavily. Which in truth, in the late '60s, early '70s, that's kind of old, but yet untapped, and certainly applied to the industry. So much of Les's program really focused on taking known analytical methods and applying them—even in the area of studying stability as well.

Daniel Molzahn (00:42:24):

Great. That's really interesting, and I really appreciate the analogy. That's a nice analogy. So, I do have other questions, Julie, but I'm happy to hold them until—as we go through the discussion. And happy to let you take back over, unless Sairaj has other questions.

Julie Cohn (00:42:42):

I'll ask a follow-on then. Was it your sense that Les Fink was sensitive to the opportunity presented by digital computing when he was pulling these people together to look at new ways to apply engineering systems theory to power systems, or maybe he had a hunch, but he hadn't articulated it, what was your sense of that?

Thomas Reddoch (00:43:07):

Visionaries come along—not very often in my mind—and Les, without a doubt, was well ahead of his time. He loved to have these young PhDs around him because he—I'm gonna use the following term—“only” had a master's degree. Yeah, he may have only had a master's degree, but he had a PhD in vision, I probably should say, in terms of being a forward thinker. I was confident that he did see the growing complexity that the system was coming under stress from, and that the '65 Blackout was so illustrative of the growing complexity, and that stronger assets needed to be brought to the table.

(00:44:10):

And I think his first belief was, let's look at analytical methods first, because—it is important to realize—digital was still very limited. Even by the time we got to 1980, digital was still very, very limited. And that was the same period that SCADA systems began to emerge—supervisory control and data acquisition. I always thought that in some respects that was a misnomer, because there really wasn't a lot of control, <laugh> it was mostly the gathering of information. And we try to clarify that a bit that SCADA is

primarily a data gathering activity, and it was among the earliest of things that we did digitally. And we didn't do direct digital measurements in those early days.

(00:45:16):

We used analog devices, and then we did A to D conversion in order to be able to get some of the digital information into process. But I think that he probably—this is speculation on my behalf—but I would surmise that he felt that the tools of implementation would come along if what we would do is bring these analytical methods forward where we could first demonstrate that you could do something in a positive way. And now, let's get a machine that will implement that.

Julie Cohn (00:45:59):

Thank you. Let's turn back just a moment to your professional path. You were at the University of Tennessee for eight years—I'm curious to know where you went next and why you made that decision.

Thomas Reddoch (00:46:15):

So, my next stop was Oakridge National Laboratory. I spent four years at Oakridge National Laboratory—and the reason being is that one of the things that I did when I was on my tour at ERDA. Many of you know that the US government typically uses National Laboratories as their vehicle for implementing a lot of their activities. And so, given this new emerging activity that this reorganization of ERDA, and then, again, later on, DOE—National Laboratories didn't have roles in this new energy play in the beginning. But National Laboratories have a great survival record, and the reason being is that when things shift in government, they're very astute and they already are on the move. There was a lot of scrambling to see: well, what National Laboratory was gonna get this electric systems activity?

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And certainly, Oak Ridge National Laboratory was one of those that was getting after it very, very quickly. And so, I got to know the guy that launched the program at Oak Ridge National laboratory. As a result of that, after I returned back to the university, he was eager to advance the program. And here I was, a guy that was in the early stages and knew a lot of the players, so we got together, and I really supported him up until about 1980. So, if we look at, again, a timeline—return to the university late '75, so '76, '77 on out to '80. He succeeded, and Oak Ridge became the lead laboratory for implementation of the programs. And then in 1980, he left, and he went out on an entrepreneurial's experience.

(00:48:44):

He was late in his career, in his mid-sixties, and he always wanted to be an entrepreneur. And this was it, he broke—and when he did, the folks at Oak Ridge asked me if I would take the leadership of that program. And so, that's why I went to Oak Ridge National Laboratory. I led that program—it's called the Power Systems Technology Program, and I was the director of that, and I led that for four years, and worked a whole range of things. One oddball case in that mix was EMP, Electromagnetic Pulse, which in recent years we've had another run at that topic area. But actually, the most significant project I think I did at Oak Ridge was a project that had the name of the Athens Automation and Control Experiment.

(00:49:45):

That's a mouthful, but those kinds of things normally have a long name. Anyway, that project was the earliest stage of us beginning to really look at the end-use sector: what role might end use or managing the load [play, and] how might that influence the whole balance between supply and load? Now, that concept got its first intro in 1968. Detroit Edison was the first utility to actually put in air conditioner controls, so one-way primitive system. Well, what we were setting out to do in the late '70s—by the way, I didn't mention the name of the person at ONL, but his name was Hugh Long. We worked on this project, the reason being the DOE leader at that time—his name was David Moore—wanted to be able to control load.

(00:51:11):

He gave us this challenge, he says, "I wanna be able to manage these loads, and I wanna be able to do that from my office in Washington, DC." And I said, "Well, I'm not sure, David, we can do that," but we set out with an effort. And early distribution automation system-wide load control Athens is one of the local power companies of the Tennessee Valley Authority. And some of you may recall the event when Jimmy Carter did the famous fireside chat to push his energy conservation program? Well, when that was done, I watched Jimmy Carter make that speech, and the next day I go to Hugh and said, "Let's go propose to the then DOE guy that we actually implement the project." He gave us \$200,000 to launch the project, which I thought was a pretty—in that time

(00:52:14):

that was a nice sum of money. That project morphed into a \$15 million project—again, time span out to the early '80s—and what we basically did is that we put automation all over the Athens system. However, many of our devices—this'll make you cringe—were analog devices, and we had to go through an analog-to-digital conversion in order to get information into the digital computer. It was pretty primitive at that time. You just couldn't make digital measurements, you still had to make analog measurements. And that project was a foundational project without a doubt, probably my most valued contribution in that period. And after four years at Oak Ridge, it was time for me to do my own entrepreneurial thing. The first of those was, by the way, a consulting company; it was called Electrotek Concepts Inc. Somewhere back in the archives, you'll probably run across things about that. We started that company in 1984, and it was the

(00:53:45):

first of a little over 20 years of five entrepreneurial experiences. I did five startup companies between 1984 and, it spanned all the way out to 2007 or 2006, something like that—of which the first one was electric power systems, and the ones that followed were not. It was three guys that started this enterprise and we're really proud because we made the Inc. 500 lists about four years as one of the 500 fastest growing companies in the country at that time. I think now that list is 5,000 companies, not 500,

so it was a little different time; that was early in the Inc. experience. But that company, we had it about 10 years before we sold it.

Julie Cohn (00:54:55):

Before we get from your entrepreneurial efforts to EPRI, I want to see—I know Sairaj has to step away shortly—if he has burning questions to ask before he has to leave.

Sairaj Dhople (00:55:09):

None at the time, Julie.

Julie Cohn (00:55:11):

Okay. So, when did you join EPRI?

Thomas Reddoch (00:55:17):

So, I joined EPRI in 2007.

Julie Cohn (00:55:19):

Okay.

Thomas Reddoch (00:55:20):

After 20 years—I'm a guy now, I'm 61 years old, and I've decided that entrepreneurship is really for young people. <laugh> It's a really trying experience. I never imagined though, when I went to EPRI in

2007 that I would be there almost 16 years. I remember when I talked to a couple of guys—one of the past immediate past CEOs, Mike Howard, and now the current CEO, Arshad Mansoor. These were the two guys that I was dealing with in 2007, and they asked me if I would—and they were only in a subset of EPRI activities in Knoxville, Tennessee. And incidentally, I was a part of the launch team that got EPRI positioned in Knoxville. It started with something known as the Power Electronics Application Center, and it then later morphed into the EPRI Knoxville. And I told them, I said, "I'll do five years." Well, after 16 years, I would probably have worn out my welcome, it's probably time to move on, so that's when I joined EPRI.

Julie Cohn (00:56:52):

And what's been the focus of your work at EPRI?

Thomas Reddoch (00:56:56):

So, 16 years at EPRI is a long time in the sense that you need to be reborn several times if you're gonna be around 16 years. And there are probably at least three periods—I went in there originally to set up the energy efficiency program, which had been abandoned in 2004. And the reason being is that when the industry deregulated, the perception under the deregulated industry was that end use would be taken care of by markets—and only generation, transmission, and distribution needed to have a sustaining research element, and so EPRI slowly jettisoned off all their programs. Just to give you a little bit of perspective on that—in terms of how significant it was—in the late '90s, EPRI was a \$700 million R&D operation, and end-use technologies was over \$100 million of that \$700.

(00:58:22):

And when I joined in 2007, that program was \$5 million in size. That's the kind of shrinkage that occurred in the program itself. I guess the industry began to realize, maybe markets were not taken care of the end-use end. And especially with the growing role, in order to achieve load balance economically, rather than this being a system that generation follows load wherever it goes, maybe what we should do

is look at load and realize there is a part of load that can be managed. And you don't have to necessarily build endless generation and transmission, that you can shape the load and perhaps get a lower-cost configuration. And so that was my early assignment that then moved on out into areas of electrification. We started our early electrification efforts around 2012, and realizing that there were many end-use applications that, if you actually did them electrically, you could do them more efficiently. And that was one of the big drivers. And then the third phase—each these were about five- and six-year runtimes of things.

(01:00:14):

I never totally abandoned anything in energy efficiency, it was underneath that, but at EPRI, you really need to keep a fresh research agenda. And then [in] the last eight or nine years I've spent a lot of time in workforce development, taking modern developments and creating the workforce to go with that. I did that through a series of DOE projects that spanned—again, that nine years. It was a large effort—a \$25 million effort in the workforce development area.

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Daniel Molzahn (01:02:44):

So, Tom, you've really had just such a diverse career in academia, national labs, entrepreneurship, at EPRI, industry labs, and so one of my overall questions that I have is: how do you see the differences among all these different types of organizations evolving over time and the different roles that each have, and going forward in the industry, how do all these different groups work together to achieve our—sort of—overall societal goals, and have you seen that change over time? You were in academia, a while ago: do you see the role of academia changing? The role of National Labs changing? Just, I feel like you'd have a really unique perspective on all these different organizations.

Thomas Reddoch (01:03:37):

<laugh> That's an interesting observation: how was I jackrabbiting around to all these different things? But to begin with: why did I go to the university to begin with? And the reason being is that when I finished my PhD, I did—there were three specific interviews that I had: one was the University of Tennessee, which I ultimately chose that offer; the second was the University of Oklahoma, Norman; and the third one was Florida Power and Light. And the reason being, I was a little torn about what I wanted to do, although there was one—the swing vote, I think, was that I wanted to teach. And when that decision was made to go to the University of Tennessee, I did start off in a very much instructional role.

(01:04:52):

But I will say—my personal training enabled me to get into the research picture very, very quickly. And what happened is I went from being a full-time instructor to teaching—at best—one course a semester, sometimes one course a year, so I really, completely got transformed over. And part of that was born out of making that trip to ERDA and then subsequently working with Oak Ridge National Laboratory in terms of implementing the program. I really got over very much into the research into things, which means it kind of took me away from my original objective. And I got—when I was a second year as a professor at University of Tennessee—the Young Professor Award. And it was all based-on teaching, had nothing to do with research; it really was the teaching piece.

(01:06:03):

But when that evolution took place, I left the university and went to Oak Ridge—first of all, the Oak Ridge opportunity came up—but one of the things I discovered is that if I'm gonna be in the research and development business, actually Oak Ridge was a far more powerful asset, especially if I was gonna be in the energy activity. So, that's why I left the university. I stayed on leave for about four years, <laugh> because I kept thinking I would go back, and I never returned to the university. I think, to me, that was the early transition where faculty today spend far more time on R&D than they do in teaching. And a lot of the teaching gets pushed down, the less experienced graduate students and the like. To me, that is a bit of a disappointment because I can tell you, if I go back to my time at Lamar—you may remember, I said this in the very beginning—

(01:07:08):

I had this unusual connectivity with faculty; I always thought that that provided the most unusual educational experience for me. And today, I think that some of the best minds in the university are focused on research, are not focused on teaching, and that has definitely been one of those changes. National Laboratories—they have been pretty consistent through time; they will float with the political picture—they have to, otherwise they don't survive. The good Department of Energy National Laboratories, though, they have great science people underneath, but they have leadership that keeps guiding that good scientific strength that sits underneath, they guide it to the current mission. And I clearly, from the very beginning, had entrepreneurial blood in me because things that I was trying to do very early in my career, was not stay with the current path, but to go an alternative path.

(01:08:28):

And I think that that inevitably leads one to wanting to try to do your own thing through an entrepreneurial experience. And so, when a guy that I met when I was doing my hitch at ERDA—his name was William T. Miles, went by the name of Bud—he was with a company called Systems Control Incorporated, which was one of the fast-emerging energy consulting companies in California back in those days. And what they were doing is that they were applying a lot of advanced analytical methods—that's part of how I got to know him. And then later he becomes my business partner, along with another fellow. And we were off to the races with Electrotek in 1984, and I began that 20-year plus run of wanting this alternate experience.

(01:09:39):

And so, I went through five companies over a period of that 20 years. And I mean, a lot of different things—everything from metal fabrication to building containment systems for nuclear waste to a plasma company—I mean, I had a lot of different engineering- and science-related fields. And then in the middle of all of that, even when I was at Electrotek, I did a sub-activity. I got involved with the launch of the Power Electronics Application Center that led to the formation of EPRI in Knoxville. That

was just one more of those experiences. But they all build together quite well. I think that if I look at EPRI, in some sense, when I ended up at EPRI—which was my last truly formal gig—then it was really applying everything else; it took everything that I knew before and rolled it into one entity. So, in some respects—I mean, it was an R&D organization, more like maybe the Oakridge National Laboratory experience—but the difference was the ONL experience was more focused on government; the EPRI experience was more focused on the electric industry proper. So, we had electric industry advisors in the ONL program, but at EPRI, we were working directly with the working directly with the industry. Although I will admit in my last six or eight years, EPRI did a lot more government work. So, I did—in my later years at EPRI—reach back to some of those experiences that I had with government heretofore and was able to advantage that.

(01:12:10):

I mean, I had three grant programs, or contract activities, that came out of DOE in this whole workforce development area that were really, really powerful. The first of those was really about: how do you take renewable technologies—this was a five-year program—and get them integrated into the traditional grid? That was our first five-year effort. The second five-year effort was really to take the area of digital systems and [see]: how is digital enabling us to achieve the integration? Because it was very clear, and it is very clear going forward, that digital is the great enabler of the whole solar technology and other clean technologies coming to the forefront. And then the third of those was hydrogen. And that activity is still going in my absence; it runs on for another two years.

(01:13:22):

So, when you look at all of those collectively, they were all about: how do we adjust the workforce? And one of the things that we used as an interesting model on that is that the earliest of the digital conversions was the so-called smart meter, the AMI interface. And I remember I had this discussion with the H.R. VP at Exelon, and their biggest issue was they had 3,000-meter readers, and their big question was: how many of those meter readers can we transform to the digital world? And what percent of these meter readers can we convert to other jobs? Otherwise, we have to terminate these people.

(01:14:27):

And so, training, retraining, and saving good, loyal people was an important part. That's the kind of complications that come. But we should recognize that, because remember, there was a great workforce that worked on horse and buggies that didn't have a place when the auto industry emerged, that used a different, whole body of technology. So, this business of taking workforce, and as we evolve—and one of the most interesting things about workforce development—there is something that's repetitive with all workforce advancement, and that is: every time we move forward, there's less human labor involved in the work process.

(01:15:25):

We're always reducing human labor, and we're advancing to some form of automation. And now that we're in this fourth industrial revolution, we see the impact of robotics and how robotics is, again, taking humans out of the loop—and [at] a minimum, meaning that the people that make it up have to have a higher skillset than just largely accomplishing things with their hands and [coordinating] with their [brains]—but actually moving out of the physical and moving more towards the intellectual end of things. That is the course of—you can look back in history as far back, and you just see this slow extraction of physical human labor as we move on with more and more advanced machines. And the computing age just enabled that more than anything else. Even though it looks like they're scattered, there was some madness to my stages of transformation in that regard.

Daniel Molzahn (01:16:40):

So, I was gonna ask you a quick follow up on the workforce development piece that I had meant to ask earlier—so as someone that, as a professor training students: do you have advice for students on looking forward, which areas to pair with power engineering? So, if you have students interested in power and energy, as you kind of see the developments coming forward—is it computer science? Or what pieces do you see as the most crucial?

Thomas Reddoch (01:17:11):

So, I don't think this has changed—the one thing that I'm convinced of—that advancing analytics is the most significant thing in my mind. When I say advancing analytics—analytical methods for solving problems—to me, that is the most significant thing because our systems are becoming more and more complex, and analytical tools will sit at the root of us being able to move forward. And it was just like that wacky decision I made back there—that I'm gonna go to LSU and not Texas A&M—and the reason being, they had the dual threat. And I think that I remain convinced that that was a right choice. What I'm not sure [of] is how, at that age, when I was that young—I, maybe, made a good guess, I'm not sure—but I believe sincerely, when I look over time, that's the sort of thing that transforms. And obviously, the whole digital analytics area is where we're headed, whether we're learning about AI being the next big analytical advancement. But the other thing that I've gotten progressively—I'm gonna make this as an honest admission—I'm struggling with this, I have spent 50 years using physical models to analyze processes.

(01:18:55):

And I'm looking at the emerging field of data-driven analytics that has nothing i do with the physical model, and it's all about interpreting the data. And in fact, the epitome of that I saw recently, is that I've been solving the transient stability problem, <laugh> since, I don't know, maybe 19-, 1975, '76, and that's always in my mind a very physical process. And I recently have been reading some of the new data-driven methods for doing stability analysis. Now that really—that is hard for my brain to process. It's part of that being that the physical process is implanted in my brain, and the notion that you would do that absent of the physical process—it's hard for me to grasp. But it's just recognition how analytical methods for more complex systems—we need the power in that. That is the best sidebar that can be put with in my mind. I mean, even the modeling methods: let's say you're trying to understand how a wind turbine array behaves—or I should say a wind turbine farm—in terms of how the wind flows over the whole farm and how that changes. That's a very complex modeling problem, and that's very, very significant.

Daniel Molzahn (01:20:33):

So, maybe one follow up on this as well—and then Julie, I should let you <laugh> continue the questions—but this is just very, very fascinating. So based on what you've seen throughout your career, and see looking forward: do you think the whole ecosystem—ecosystem in the sense of the DOE labs and universities and industry and EPRI and DOE itself, and kind of the whole ecosystem—is it set up well to integrate new analytical methods into practice, or was that better earlier in the day? Or is it still quite good? Or you think there's still challenges? Just, what's your perspective on this?

Thomas Reddoch (01:21:22):

I think we have an omen sitting out there intended to reinforce this whole analytical space. Just look at what we're doing with AI. So, we have an explosion of things in the AI space.

(01:21:47):

The application of the ability in the AI space to analyze data—it's all been empowered by our ability with the digital system to acquire data. So, these advances that we're seeing in AI—it's all about the fact that we can get vast amounts of data, and with large sums of data, this is how we're able to deduce certain things. Now, we may have some slick algorithms in order to be able to do that, but that is the difference: it's the quantity of data. And the reason being is that we've been fitting curves for a long time. I mean, I recently said, "Oh, well, you know what AI is? Oh, it's just a hopped-up regression algorithm." That's all it really is. I mean, we've had data, but we've had limited data, and we had very simple tools for being able to interpret that data. And what we would do typically is to try to fit an equation. Today, under AI, we don't exactly fit an equation—but what we do is generate information that allows us to interpret what's going on. So, I think analytics is live and well, and you can rest assured that AI is not the last stop—it's just the current stop.

Daniel Molzahn (01:23:35):

No, thank you. I appreciate the perspective.

Julie Cohn (01:23:37):

I want to ask you first—for the non-technical researcher who might access this interview—how would you differentiate between physical models and data-driven methods? Because I'm guessing you don't mean you have a mockup of a power system on your desk and you turn a switch at one end and see what comes out at the other. But that's what I think of when I hear physical model. <laugh>

Thomas Reddoch (01:24:07):

Yeah. A physical model means that, literally, you will use the principle of physics to characterize individual processes—things that are physical or governed by a set of physics laws. And we can talk about inertia, we can talk about speed, we can talk about acceleration. We have from physics, we're able to model these various things. We have these electrical components, and we have these physical equations where what we do is that we model those. And our best, our early shot at this was analog computers. Now, it's kind of interesting—I started off with analog computers; that's where I started. I spent a lot of time programming analog computers. And it was kind of interesting; what we basically did to do that was that the central module was really a series of feedback control loops where you emulated these equations. And this emulation of this physical process—the way I would do this is that I had an oscilloscope that was on the analog computer, and I saw the wave get generated as it went through the physical simulation. In a digital world, you're abstracting from the physical process to a digital representation.

(01:26:06):

These post-analytical methods, like AI, are generating huge amounts of data through direct measurement—not from really looking at the process, but just reading these sample points in the process. And it's out of studying, literally, these numbers that come spewing out that don't necessarily relate in any way. The connectivity between the numbers—there isn't an underpinning physical process; you operate truly in this digital world. Now, somehow, there is another group of people that, between the digital, you have to connect it back to the physical process. So, there is an unwind that does have to

take place in there somehow. Now, part of that's done in some direct digital circuitry. But the whole notion of analyzing what's going on—it's done totally in this abstracted world that has nothing to do with the physical process.

(01:27:30):

That's why these data-driven models—it's the data that's shaping the outcome. I remember earlier on when we started doing this digital analysis, the accuracy was not very good. These early digital models were not very good, and the reason being is they didn't have enough data in 'em early on. I remember we talked about doing some hybrid stuff—well, maybe you need some physical modeling to go along with this digital process—and what that would help do is help explain a couple of the phenomena, but we have moved well past that now. Now because we're able to generate so much data, then you don't need those crutches anymore; you can get at it strictly from looking at data. Again, very difficult for me to manifest in my brain, because you don't just discard that much familiarity and educational process about how important physics is in these processes to totally entrust it to the digital side—that it'll be okay.

Julie Cohn (01:28:50):

Interesting. Yeah. I wanna ask the question Daniel was asking—but in a different way. Some people describe what Daniel referred to as the ecosystem of the power industry as maybe a group of silos—where you have academics that do their kind of research, you have the National Labs that do a different set of research, you have regulators who don't do research but try to figure out other answers to other problems, and then you have the people who operate the system, the people who manufacture the objects that are used in the system. So, all of these different silos of expertise that together comprise what we think of as the power system. You've kind of had a toe in almost every one of those waters. And so, maybe a different way of asking the question is: are there silos? Were there silos? Is it changing? <laugh>

Thomas Reddoch (01:29:56):

The only one of those silos that I don't have time in is the regulatory one—although I have an ever-growing belief that, how important the regulatory part is. And I think it's probably more important today because we're undergoing so much change. I think that once, when we were in the steady state periods, the regulatory piece is not as significant. But given the way businesses are run, businesses sometimes now need motivation to be able to do something different. And I think about the regulatory processes, potentially that motivator that will move the power industry business in a direction that of adopting new things. I've always believed that—I still embrace the notion that fundamentals are crucial.

(01:31:11):

You normally get in trouble when you don't understand fundamentals. And universities and time periods get chastised because: you're only fundamental, you're not practical. But I always believe—and maybe it gets back to what I attempted to do with my dissertation—that ideal system that I worked on, which I realize probably will never, ever be implemented. We will continue to get more sophisticated with our structures because we can measure better, we can communicate better, we can analyze better; therefore, we can take actions that presumably are better. But what those do is that it gives you some sense of what you could achieve in a perfect world as opposed to what you might do in a real world, and it becomes a metric. So, I think these things have moved in and out over time.

(01:32:24):

I think the role, largely, of National Laboratories is still underpinning science. I still don't think about National Laboratories as delivering the knockout punch; I still think that comes really from industry. And at one time it was the equipment manufacturers that drove everything. I think consultants have a huge role because consultants are a little bit above the fray. And they're—in my mind— more critical to the process today than they once were. If you think back in the electric power industry, there was a time when GE and Westinghouse, they were synonymous with the industry—and they were the equipment suppliers. And then, what we saw with the digital age, we saw the computing world begin to enter into the equation. But people that can cut across all of those—which is really where the consulting industry

weighs in—I think is really, really powerful going forward in terms of getting new processes implemented.

(01:33:38):

I also think the electric industry, the utilities in particular, have become more conservative. I think they've become more conservative because the regulatory process, in many, many cases, kind of pushes that conservative view on things, because investor-owned utilities get rewarded by staying very much on track, which means their willingness to get to stretch is less, because it's safer to stay from a business standpoint, it's safer to stay to the midcourse. This is why I think, going forward, regulatory potentially plays a big role, because regulatory can be the reward to tell a CEO at a utility, "Oh, yeah, we probably should go out here and try this new thing, and we probably need to try it now." So, the roles keep shifting. But universities still—in my mind—are vital.

(01:34:52):

They're creating the next generation of products that are gonna go in and make up the industry. And to me, that is still the most valuable thing. And teaching the next advancements are crucial because, I mean, in 50 years, I could just see how ongoing advancements—either through technology and/or methods, analytical methods—it keeps changing. And the reason being, our processes are becoming more sophisticated, and we need more sophisticated tools. Nothing any more than digital—I mean, it's the great enabler. So, they all have roles. If I look at all that and say, "Where did the biggest change occur? Probably with consultants."

(01:35:49):

I think that it transferred more to the independent [resources] and not the equipment suppliers. Because if you go back to [the] '60's, '70s, '80s—equipment folks drove everything. And we've seemed to reach beyond that. And part of that is that it's not just about the power system hardware now—it's about the computing systems, it's about the information systems, the measurement systems—all those

other things that bring in different industry players. So, it's not dominated by the power hardware suppliers. However, one will say, when you can't buy a transformer, you have a problem. And that's, <laugh> that's where we are today. We're in a circumstance where our biggest problem is that we can't buy a transformer, or we have to wait 24- to 36-months to get one. And that is almost unheard of, but that's where we are.

Julie Cohn (01:36:59):

So, we've taken up a good bit of your time—I'm gonna see if Daniel has more questions he'd like to ask—and I think Jess may have a question she'd like to ask.

Thomas Reddoch (01:37:12):

Okay. I'm cool.

Daniel Molzahn (01:37:13):

Sure. Yeah. I've at least one more question that I can ask. <laugh> So going back to pretty early on in the discussion, you had mentioned your early work where air conditioning coming into Texas was really a major change on the load side. And that seemed quite rapid and had a big impact on a lot of aspects of operation. And so, I'm wondering if there were any lessons that we could learn or analogies we could draw from that as we see electric vehicles, solar, batteries, or these other technologies that are coming on the system pretty quickly, but certainly inverter-controlled devices. And we're struggling to understand how to model and control them. And it seems like there's maybe an analogy there that we could draw some information from. I'm curious if you have a perspective on that.

Thomas Reddoch (01:38:11):

I think there are some similarities. It's kind of interesting—it was—air conditioning was probably one of the first big steps in electrification where it really impacted load. And there were certainly struggles with

that early on. And I think the reason is it came on pretty fast. And in those days, we didn't seem to have trouble building generation, so we were at least able to keep up with that. That was not a difficult problem to solve at that time. So, most of it had to do with really looking at the distribution system, and then ultimately the transmission system, because when the loads got large enough, then it began to influence transmission. But it was the distribution system that really had to change.

(01:39:22):

And the key thing was it changed the design criteria for the distribution system. And this, in itself, I think was the big deal. And that is the carryover lesson to what we're into now is that we have to abandon old rules of thumb. We have to abandon some of these protocols that we think are the only way that you could do it. And the reason being is that these loads have different shapes, in terms of what time of day they may peak. So, that also means that our operating practices have to change. So, our normal gut reaction is that, Oh, I've been doing it this way for the last 15 years, I'm gonna keep on doing it this way. And, what's incorrect about that—at least in my mind—is that you've got new apparatus with different features, and there's different shapes in the sense of what time of day, but also the capacity to energy ratio may differ.

(01:40:54):

You might have a peak capacity that you now use eight hours of the day as opposed to four hours of the day—well, that's a big deal. And the reason being is that one of the things that oftentimes is forgotten in the design process is that equipment is cycled in such a way that there's a period for it to cool. I like to pick on transformers, because transformers are a great example. The life of a transformer has to do with how much thermal exposure that insulation system gets, and that life expectancy of that transformer is: does it get adequate cooling periods? Well, as we begin to stack in these other loads that have different shapes that call for energy for longer periods, then that transformer doesn't get the cooling it needs, which means its lifetime is going to be different.

(01:42:04):

And this is an example of how you have to make these changes. And so EVs are an interesting, special case, because an EV can be both a source or a sink. That is, when you're charging the battery, then it's a sink. But now you have energy stored in a device that could be sitting there that you could draw energy out of—well, now that's a different critter. We don't typically have that, and we're having this as a quote, “as a load,” but has these bi-directional properties, as opposed to what I'll call a static storage device, which is really used in a very, very different way. Electrification in general. So, the single largest thing that we have that's facing us—and I think, if I remember correctly, between now and 20-, I think it's 2030, could be 2032—we're expecting 35 gigawatts of data centers.

(01:43:32):

Now why this monster load? Well, AI is part of that, but it is also part of the digitalization. That is a monster load. I mean, 35 gigawatts, that's a third of the size of the Texas grid—that's a lot of power; that is as large as TVA is. And I think TVA is maybe the fourth largest utility in the country—fourth or fifth, somewhere in there. These are huge loads that are coming onto the process, and old principles will not get it. Our need to make these changes are essential. So, and what did air conditioners tell us? By the way, when you focus on the problem, it's not like it's, does not have a solution, but what you just need to realize is that the future moving forward is gonna be different. Don't use old practices and start looking at new practices.

(01:44:43):

With the push for clean energy, the only way we get there is through electrification. The size of this increase is larger than when air conditioners came in to hit the system—we're looking at some seriously large numbers. And it's very difficult, today, to add generation; it's very difficult, today, to build new transmission. And it's the generation and the transmission—those bulk assets—that are essential to support the electrification movement. I look at that, it's a little bit unnerving. I won't say it's frightening, but it could get that way. But it's certainly unnerving—slow to add the bulk assets, rapid use of and growth of electrification.

Daniel Molzahn (01:45:46):

Maybe one quick follow up on this, Tom, is: did people at the time when air conditioning was really starting to come onto the system and make major changes, did everyone sort of agree as to what needed to be done, or recognize pretty quickly about, okay, we have to make these design changes and how we do design? Or was there, kind of, a lot of different groups that were trying to figure it out doing different things? How did you come to a consensus as to what needed to happen?

Thomas Reddoch (01:46:17):

I think that—so, what is probably a little different today versus then—today we accept the principle that we can manage consumption. By the way, we have information and communication control systems that will allow us to manage load. In those days, we didn't really—conceptually, managing load was not a part of the outcome. In those days, the attitude was: we're just gonna build more generation. Oh, load's growing? We're gonna build more generation. I think that early on there was a lot of overloads in the distribution system, but it didn't take long to realize. There was a guy I knew from Duke Energy—Mike Rowand is his name. I remember Mike; I was on a podium with him once, and he used the air conditioning example.

(01:47:26):

We were talking about electrification—actually, that session was around electric vehicles. And his comment was—this is not the first time that we had to look at how we were doing business. And he used the air conditioning example. We suddenly had this quick emergence and what we were forced to do is to go back and really review how it was that we were doing our designs and what our underlying principles for those decisions were. So, I think that what is clear is that those lessons learned from air conditioning should be new practices, new analytical methods—otherwise, we're gonna be in trouble.

Daniel Molzahn (01:48:21):

Great. No, that's really, really interesting. I find this discussion really fascinating. I did have one other quick follow-up question from the discussion earlier—then maybe I'll pass it over to Jess for other questions. But you mentioned early on that, early in your career, wind energy was really transitioning from National Science Foundation to ERDA: what did that transition look like? Was there a formal process in place where NSF said, We've done enough wind now; or, how did that happen?

Thomas Reddoch (01:48:55):

I think, as I recall, that because things were in such disarray with the whole energy circumstance—what I find rather interesting—it was the gasoline lines of '73 that told us that we didn't have an energy strategy. Nothing to do with electricity, by the way, but it was certainly energy. And so, it was recognition that we needed some kind of a coordinated plan. And I think that probably wind energy was with the National Science Foundation, because it was very early discovery from a science standpoint that what we could do is go from a windmill to a wind turbine, suggesting that what we were about to do is to deploy some serious analysis in the aerodynamics area in terms of: how should we go about designing, first of all, a blade that could optimize capture of wind?

(01:50:17):

And by the way, what wind speeds would we run this at? Would we try to build a structure that we could capture energy at a hundred miles an hour? Or <laugh> do we say, We're going to—once the wind speed gets over 40 miles an hour—gonna furl the blades and stop capturing. So, the whole process of—there was a lot of science that was coming, and that's probably why I was at NSF. And NSF—in my mind—always has been the theory out front, because their mission is more exploratory than necessarily building a practical machine. But I think that once a decision was made—we're gonna do central energy—those things were just moved by mandate. I don't know that it was a great amount of debate. We'll take what you now know, and we're gonna move this towards building a practical machine; we're not gonna be just investigating the science around wind industry.

Daniel Molzahn (01:51:39):

Got it. Now that's really interesting. Sounds like it was maybe some particular aspects of what was going on at the time in combination with the technology and just—interesting story.

Thomas Reddoch (01:51:51):

One of the interesting things is that—I think that one of the great early struggles was—what kind of generator should we put on this wind turbine that we're gonna generate electricity with? And the reason being is that there was an industry familiar option—it was called the synchronous generator—probably the worst choice from an energy standpoint, because what you've got is a variable input system, and you'd be a lot better off if you had an induction generator on that. Well, electric utilities, were not buying induction generators; electric utilities buy synchronous generators. So, I remember the program manager at the—was later DOE, because after my one year—remember I said I worked with him for a decade? And he had a really interesting philosophy.

(01:52:59):

He says—I show up at the front door of Mr. Utility and I knock on the door and say, "Hey, I'm here to sell you a new generator." And he says—first of all, he looks at me and he sees this wind turbine on my back, and he's looking at me like I'm a whack job, because we don't buy propellers here. And I say, "Oh, and furthermore, what I want you to do is change your whole industry practice and use this induction generator I have, because I can get more out of my propeller." "So, you're telling me I need to change my process in order to accommodate your uniqueness?" So, he says, "That sales mission will never work." So, what he chose to do is, "I'm gonna put a synchronous generator on this thing because the industry's familiar, and they may give me a chance."

(01:53:55):

And it tells you something about early adoption, even with digital systems—everybody tried to make 'em look like the analog system. And the reason was that people were familiar and comfortable with the

analog system. And yet, what would happen in the case of the digital world, is that you never got the power that digital was offering because you were watering it; you were downgrading it to make it look like the old stuff. This was the problem with the wind turbine—they forced synchronous generator on it to make it look like the industry practice, realizing that you're sacrificing energy production for the machine that I could get if I go to a induction generator—and today, a power electronic conditioned induction generator, essentially—so, this is a common fallacy. We introduce a new technology, we dilute it to make it look like the familiar in order to try to get in at market share, and then we slowly unleash the power that comes with the new technology. It's a very, very common practice.

Daniel Molzahn (01:55:17):

Now, this is, I think, a perfect example of the sort of story we were trying to capture in this project. So, that is really fascinating. We really appreciate it. So, I think I've taken a lot of time from questions, so I'm happy to turn to Jess or Julie—if you have further discussion topics.

Julie Cohn (01:55:41):

Sure. Thank you, Daniel. Jess, did you have a question you wanted to ask?

Jess Slater (01:55:45):

I did, which you touched on a bit throughout—but I wanted to ask it as a general question. So you spoke earlier about how part of the reason that you chose Lamar University over A&M was that Lamar had a curriculum that focused on the general/fundamental system theory and diverse analytic methods within general theory: how would you say this curriculum aided you within the many transitions within the industry, but more specifically, how did it help with dealing with resistance to change from those who did not have a good understanding of fundamentals, general system theory, and diverse analytic methods?

Thomas Reddoch (01:56:21):

There's probably two steps in me answering your question. So really, at Lamar, because of this intimacy with the faculty—I still assign enormous value to this—there's a couple of ways of looking at that. That also meant that when you went to the classroom, the worst nightmare—and I used to do this as a professor, that's terrible for me to admit this—but if you really want to get a student's attention, if the room is small enough where you can make really high-grade eye contact—when those eyes get focused on an individual, as a student, your first comment is, "Oh my God, he's gonna ask me a question <laugh>, and am I gonna be prepared to answer this question?"

(01:57:19):

Which means that in a small classroom, you couldn't hide either—I mean, you're really exposed. If you're in a classroom with 150 students, then you're pretty safe. You can just sit behind the person in front of you, and they can't even see your face. But what Lamar did is that they were really into teaching the fundamentals. The broader brush that I got with the systems analysis was really when I went to LSU—that's when that really got opened up. So, I think about my Lamar experience as being very much—even the master's thesis work, the course part of that—drilled on fundamentals of electrical engineering and/or electric power. And again, it was at LSU where I got this broader systems look.

(01:58:28):

I think that what I did at Lamar—I got introduced to enough to realize that there were these limitations. And just staying with the tools that the application area—which was electric power—was using, that there were more powerful tools out there. And those more powerful tools were the things that were embodied in the systems side. So, the way I like to think about that is: steeped in fundamentals of how the electric power process works, empowered with broader analytical methods to be able to manage the process of the electric grid in a more complete way and in a more capable way—not just complete, but capable as well. So, the analytics is very, very empowering, at least in my mind. Does that get most of what you were asking Jess?

Jess Slater (01:59:41):

Yeah. Thank you. I was wondering if—because on that other part of—did you ever see resistance from others who did not have those methods of—because you were saying that the analytical methods let you do things in a more capable way. Did you ever find resistance of people where you were saying, We should do this; and they were like, Absolutely not? Did you see resistance with people who didn't have that foundation like you did?

Thomas Reddoch (02:00:11):

The one thing you will get very, very consistently, is that you will get resistance to change. I don't care what it is that you're pushing—whether it's analytical methods or what toothpaste you use—people resist to change in general; that's the way humans are wired. Once we get comfortable in a space, it's very, very difficult to move to another one. What I always had hoped is that things that I would realize because of my adoption of these alternate analytical methods—I had always hoped that that would convince others that there is actually some value in trying these different techniques; that you do get insight into processes that you might otherwise not get just because you allowed yourself to get beyond your comfort zone.

(02:01:22):

A lot of job evaluation processes talk about goals that you should have. And ultimately at the end of the day, you get judged about achieving or not achieving your goals. But one of the things about it is, if you're looking for growth, what you do is that you have stretch goals. I mean, you can have easy goals that you make and you get to check the box, so to speak, but it's the stretch goals that really enable you to grow. So going to these other analytical methods allow you to stretch your mind. And hopefully, even though people might be slow to wanna make that move, but if they see others have some success by using those, then maybe that's not such a bad idea after all.

Jess Slater (02:02:27):

Awesome. Thank you so much.

Julie Cohn (02:02:30):

Thank you so much for giving us two full hours of your time. This has been really informative and useful information for our project. I hope it's been enjoyable for you.

Thomas Reddoch (02:02:42):

Oh, these are just natural sharings. This is the way that I see—I think I've been blessed in the fact that I've had these multiple experiences, and so many of those at the very leading edge of these areas that have emerged. And all it does is—at least in my mind—is affirm the fact that if you live in this technology world, and the analytics—I'll put right along beside that—it is not static. It is as dynamic as it could be, and unless you keep moving forward, you will become antiquated very quickly. It's alive. And I didn't say this in the beginning, but maybe this is a good way to wrap it up.

(02:03:46):

I've had two most unusual changes in the field, in electrical engineering and electric power. So first of all, I started in vacuum tubes—I was a senior electrical engineering student when transistors appeared. So, I had the most unusual experience: I had to learn vacuum tubes, and I had to learn transistors. Now, why is that so significant? Well, if you design with vacuum tubes, it's all about designing with voltage. If you design with transistors, it's all about designing with current. So, the way you design those circuits, philosophically, are quite different. But what this enabled me to do is to live in the two worlds: the vacuum tube world and the semiconductor world, which was the new thing. By the way, the transistor was invented in 1949, and it's transistor came to some form of glory around, I don't know, around 1965, 1966—and that was just a single transistor, let alone later integrated circuits that were thousands and millions of transistors. That was like one of those. And the other one is this transformation from analog to digital. So, vacuum tubes to semiconductors, analog to digital—those are revolutionary changes.

Julie Cohn (02:05:27):

Absolutely. And you're right. A great note on which to conclude the interview. Thank you so much.

[End of Interview]