THE ADVANCED SMART GRID

EDGE POWER DRIVING SUSTAINABILITY

SECOND EDITION

ANDRES CARVALLO
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The Advanced Smart Grid

Edge Power Driving Sustainability

Second Edition

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To Angela, Alexandra, Andres Josephe, and Austin Theodore.
—AC

To Barbette, Blake, and Wesley.
–JC

Foreword by Jon Wellinghoff

In my 40 years in the energy industry, we have seen innovation in the areas of generation technologies, renewable system production, smart grid implementation, storage, efficiency, demand response, and infrastructure security. The last 10 years though, have seen an acceleration, disruption, and adoption pace driven by unprecedented advances in policy, utility restructuring, technological innovation, and more active consumerism. One of the foundational transformations to help us reach the collective goals of less carbon, lower total cost of ownership, more efficiency, more consumer choice, more services, and more quality has been the advancement of smart grid technologies.

The Advanced Smart Grid: Edge Power Driving Sustainability by Andres Carvallo and John Cooper is a seminal work describing in great detail the vision, rationale, and journey of Austin Energy, the eighth largest public power utility in the nation, toward delivering cleaner, affordable, and more reliable power, coupled with superior customer service. This book also recounts the true story of the Pecan Street Project, now Pecan Street Inc., an initiative to build a smart grid laboratory within a living community to accelerate energy technology innovation and customer adoption. It does so while also giving us first the context of how our electric system evolved from the Edison and Tesla days, to the Texas vision of Pecan Street and, as they say, everything is bigger in Texas, which is where we should move forward to in the years to come.

I met Andres Carvallo in the halls of NARUC conferences in 2008, and our conversations on demand response and smart grid since then have always been ones of mutual fascination. Clearly, the work done by him and many others at Austin Energy have contributed in many ways to the shape of the electric industry today. Their early work built a much needed can-do attitude on how utilities must learn to balance keeping the lights on and energy costs low while striving to reduce carbon and become more efficient and sustainable enterprises (e.g., empowering customers, optimizing energy service delivery, and reducing water use).

From my days on the staff of the Nevada Public Utility Commission and later as a commissioner and then chair at the Federal Energy Regulatory Commission (FERC), Austin Energy always stood out to me as one of those early adopters leading national trends in policy and technology innovation. I can honestly say that following the journey of Austin Energy provides one with a stellar example of what it can be when it comes to a cleaner and more efficient power grid that strives to integrate emerging distributed energy resources such as solar, storage, and demand response into the distribution grid.

Between 2003 and 2010, Andres and his colleagues at Austin Energy turned the following definition of smart grid (SG1) into reality: "The smart grid is the integration of an electric grid, a communications network, software, and hardware to monitor, control, and manage the creation, distribution, storage and consumption of energy. The smart grid of the future will be distributed, it will be interactive, it will be self-healing, and it will communicate with every device."

They then progressed to the more ambitious definition of an advanced smart grid (SG2): "An advanced smart grid enables the seamless integration of utility infrastructure, with buildings, homes, electric vehicles, distributed generation, energy storage, and smart devices to increase grid reliability, energy efficiency, renewable energy use, and customer satisfaction, while reducing capital and operating costs."

In this book, one sees those definitions unfold as real live systems in an ever-advancing architecture that is methodically implemented by the Austin team. Andres Carvallo and John Cooper do a masterful job conveying to utility industry practitioners, regulators, and consumers alike a great episode in our country's energy evolution that should not be missed.

Jon Wellinghoff
Former chairman of the
Federal Energy Regulatory Commission
and partner at Stoel Rives

Foreword by Larry Weis

Andres Carvallo and John Cooper have written a thought-provoking and insightful book on smart grid and, in particular, its potential from leveraging the technology-rich world that we live in. In the 1980s when I was in distribution and construction management at a utility in the Seattle area, there were products being marketed with some built-in intelligence (e.g., electronic reclosers for circuits). Similarly, there were plenty of discussions in the industry about using information systems and communications technology along with our power equipment to help us implement "distribution automation" pervasively. So the ideas of automation had existed for a long time, but technology needed to catch up, become easier to use and manage, and become much more affordable. Over the last 10 years, technology solutions for automation have caught up, and *The Advanced Smart Grid: Edge Power Driving Sustainability* shares and embraces the opportunities that exist to use technology to change how we think of and operate the bulk electric systems and, in particular, how we deliver and manage products and services in partnership with our consumers.

When I came to Austin Energy in 2010, I knew that we were on the cutting edge of innovation. However, our delivery network was still behind. As part of our smart grid program, this year we launched, with the help of our partners, a brand new advanced distribution automation system (ADMS). We believe that our ADMS is unparalleled for large utility operations in the United States and that it will leapfrog us over many other utilities for years to come. Furthermore, we are advancing many of the ideas in this book into our thinking, specifically those about how to develop and leverage microgrids and those on how to advance the state of the art in home energy management.

While at a practical level we are still simply seen as providing the product of reliable and affordable energy to our customers, we have a great opportunity to further experiment in our wonderful urban service area with a lot of the ideas discussed in this book. We strive to be cleaner by deploying more renewables, to use more technology to automate, and to integrate electric vehicles and energy storage into the steady state physics of the grid seamlessly and affordably. I know with certainty that many big challenges lie ahead, and that while I do not get as much time to contemplate the future as my team does, Smart Grid evolution and the range of possible applications are intriguing and exciting things to think about.

Thank you Andres for your past work, for the time that we have spent collaborating on our vision of the future, for the fresh thoughts, and for the ideas presented in *The Advanced Smart Grid*.

Larry Weis
General manager and
CEO of Austin Energy,
Austin, Texas

Preface

Five years have gone by fast. Five years ago, we began work on *The Advanced Smart Grid: Edge Power Driving Sustainability* manuscript, fresh off our experience with Austin Energy and the Pecan Street Project. In the ensuing years, we've both enjoyed active engagement with our industry and passive observation, as the twin threads of grid optimization and edge power developed, closely tracking our observations in the first edition.

By early 2014, we noted that while our work had stood the test of time since its publication in 2011, it begged for an update in certain spots. So, we began reviewing our book for the second edition; it was something of a surprise but very gratifying to read our words set down in 2010 and 2011 and see that they remained timely three to four years later. In fact, the reasoning behind the advanced smart grid (Chapter 1), the fundamental components of the advanced smart grid (Chapter 2), smart convergence with other industries (Chapter 3), the case study of Austin Energy (Chapter 4), and the case study of the Pecan Street Project (Chapter 5) are timeless. The changes in the second edition are summarized as follows:

- Chapters 1–5: When we sat down to write, we found that some minor changes to Chapters 1–5 were needed, primarily edits to lend more precision where we saw room for improvement. Also, we moved any language that referred to specific dates or events to Chapter 6 to set up future editions.
- Chapter 6: The second half of Chapter 6, which covered smart grid in 2010, was quite dated, presenting us with a grand challenge; we spent months in consultation, struggling with how to cover all that had occurred from 2011 when the first edition was published up to the present. In the end, we decided that while grid optimization had progressed steadily, and would continue to do so, the compelling story was with our subtitle, Edge Power Driving Sustainability. It would be far more noteworthy to focus our attention in the second edition on distributed energy resources (DERs),so we devoted our efforts to a completely new second half focused on the disruptive impact of DER.
- Chapter 7: Our description of Smart Grid 3.0 (SG3) remained quite relevant, less focused on a snapshot of time like Chapter 6. We identified some gaps based on our maturing vision of the future, in particular updating the consumer maturity model; adding sections on electric vehicles (EVs) and energy storage (ES), positive energy buildings (PEBs), smart building/smart grid

convergence and on the Internet of things (IoT); as well as outlining likely industry structure for the SG3 era.

- Glossary: Finally, we added a glossary with well over 100 acronyms and terms, acknowledging the tremendous challenge for a student of smart energy and smart grid to grasp this complex industry.

We anticipate publishing future editions as we track the progress of advanced smart grid optimization and the rising edge power economy, including the high drama of DER disruption and integration. With each edition, we'll improve our work where we can. In fact, it will likely be necessary to publish more frequent updates in this highly dynamic environment. It is a privilege and honor to find ourselves in the fortunate position to chart the progress of change in this vital industry, and we look forward to the fascinating journey of co-creation, commentary, and analysis.

Opportunity Meets Planning

The illustrious inventor Thomas Edison once said, "Good fortune is what happens when opportunity meets with planning." Throughout our careers as corporate athletes and entrepreneurs, we've examined complexity and explored ways to simplify it, ranging from addressing complex processes and concepts in technology and engineering, to finding the kernels of truth in government research and executive briefings in the legislative and regulatory arena. Lacking precedent, we worked through the complexities of utility processes, applications and systems, operational technology, information technology (IT), telecommunications, and power engineering at Austin Energy and identified a path to simplify and innovate to build the very first smart grid in the United States and then refined our vision with our work in the Pecan Street Project.

This book describes in detail our experience in designing and building the very first smart grid in the United States at Austin Energy—what we now call a first-generation smart grid, or Smart Grid 1.0 (SG1)—and in helping to design an energy internet at the Pecan Street Project (now called Pecan Street, Inc.) to evolve Austin Energy into a Smart Grid 2.0 (SG2) utility, which we've elaborated on to create our advanced smart grid vision. In these pages, we start with the vision that sprang from those unique experiences from 2003 to 2010; then we go back to share our local perspective in Austin (it is the "city of ideas," after all); finally, we share our observations of current events and our vision for the future, explaining what lies ahead for our industry and society.

Necessarily, we focus our story on the new power engineering concepts needed to drive this transition to a more rational approach to designing and operating an advanced smart grid—look for the "Power Engineering Concept Briefs" throughout. We also include use cases where it makes sense to communicate concepts more clearly. This is a highly complex industry on a good day, and as we set off on this fundamental industry and business transformation, it will only get more complicated. It pays to roll up your sleeves and get down in the weeds, as they say.

The remainder of this preface provides an overview of our approach, followed by a public acknowledgment of the many people who have helped us to get to where we are. We hope you enjoy this book and let us know what you think. We live in an interactive world now, and this will certainly be an iterative process. Together, we'll get this transformation right. We have to.

Chapter 1: The Inevitable Emergence of the Smart Grid

In Chapter 1, we draw a distinction between smart grids as they are described, designed, and built—what we term first-generation smart grids (SG1)—and second-generation smart grids, or advanced smart grids (SG2), which begin to emerge as a new understanding takes hold in this industry in line with the vision we have described in this book. First-generation smart grids start with an application, such as advanced metering infrastructure (AMI), and build a smart grid incrementally by adding more applications over time. In contrast, advanced smart grids start with smart grid architecture as part of a deliberate design that includes integrated Internet protocol (IP) network design, thereby positioning the smart grid to support any variety of applications as they become necessary or available.

We describe the electric grid as the most important of all the infrastructures we depend upon in our modern economy and society, going so far as to insert electricity at the base of Maslow's hierarchy of needs. We assert that it is inevitable that the grid will be upgraded to become an advanced smart grid because it is the quintessential infrastructure, but also because technology evolves to empower individuals at the edge over time; the electricity industry will follow similar trend lines described by evolution in the IT and telecommunications industries.

Today, the grid is brittle and challenged—in need of a new architecture. The way forward will be through a new design and overhaul to make it more resilient and even more robust. As the number of connected devices increases dramatically, the level of complexity in the grid will rise to the point where automated protocols are needed to maintain stability—and an Internet design will be required to enable the transfer of very large amounts of data and to ensure that the grid remains functional and continues to supply us with the power on which we are so dependent every minute of every day.

Chapter 2: The Rationale for an Advanced Smart Grid

In Chapter 2, we drill down to explore the impact that extending intelligence to the edge will have on utility network architecture, business processes, and organizational structure. The distributed control system (DCS) has traditionally been generation-oriented, in so much as the management system was comprised of a software program running on a dedicated computer providing directions to automatic generation controllers at one or more central generation units (i.e., power plants) to manage all the switches, boilers, and other devices through control systems, throttling the turbines up and down to maintain grid voltage levels within a specified tight band (60 Hz in the United States).

The rationale for an advanced smart grid is not hard to understand. In a sense, progress in grid management has been about gaining greater efficiencies through better control and better information. Pushing intelligence out into the grid, traditionally accomplished through independent appliances, applications, and networks, will become the purview of an integrated advanced smart grid. For that to happen, however, utility business processes such as annual departmental budget building must also be addressed. The shift from an industrial approach of long product life cycles, to a more IT-oriented environment implies not only managing a more dynamic product market, but also integrating with an IT department and considering the impacts on the greater ecosystem of interconnected devices and data.

Power Engineering Concept Briefs

The advanced smart grid will require departmental managers to coordinate like never before with IT staff on security, network strategy, interconnectivity, and network integration. Common databases will drive applications, minimizing the need for complex integration projects. The benefits and implications of a system rationale will be fully explored in Chapter 2, as planning for a new era of robust digital networks gets under way, where everything connected to the smart grid has become smart in its own way. The advance of technology will inevitably encroach upon traditional utility domains, bringing changes to the traditional utility business model and to the way a power engineer approaches grid management.

Chapter 3: Smart Convergence

Chapter 3 describes the ongoing opportunity for change that two megatrends present to every infrastructure that supports our modern ecosystem, from electricity, to telephony, to the Internet, to water, gas, and transportation. What are the two megatrends? First, ongoing analog-to-digital transitions are based on advances in digital technology driven by Moore's law. Digitization brings faster, cheaper, more powerful computing capabilities to edge devices that transform the potential of infrastructure design and operations. Complementing that trend is the second megatrend, advances in telecommunications and networking, driven by Metcalfe's law. As more wired and wireless technologies become available, infrastructures gain a tool to add digital devices and modernize their infrastructure operations. Furthermore, as all these infrastructures begin to transform themselves, they converge on each other, offering still more synergy.

Complementing this convergence of infrastructures is a convergence of business practices from other industries onto the electric utility infrastructure, perhaps best exemplified by the addition of warehouses and greater edge controls to the electric supply chain. Lacking effective storage or demand-side management options, the electric utility supply chain developed historically with an overwhelming reliance on supply-side solutions to keep voltage and VAR levels in harmony. Keeping the grid in balance is the overriding goal of the utility controller. However, with the addition of energy storage and maturing of demand response (DR), electric utility operators will see storage and demand-side management as valid alternatives to generation control—valuable new tools to keep the grid in balance.

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This chapter has perhaps the most comprehensive set of concept briefs of all the chapters, describing in detail how the convergence between infrastructures and the convergence of new concepts will work at the engineering level to bring changes to the grid. From a description of how to build a "thin" smart grid wireless IP network, to the detailed discussion of incorporating new digital tools into grid management solutions, these sections provide an engineering drilldown for the technically minded.

Chapter 4: SG1 Emerges

Chapter 4 tells the story of how the very first comprehensive, utility-wide first-generation smart grid came to be built in Austin, Texas, at Austin Energy, the city-owned electric utility that now serves over 420,000 residential, commercial, and industrial customers. The lessons learned in the smart grid journey described in this case study are fundamental to understanding the concepts in this book, which derive from the successes and lessons learned in Austin, in Texas, and in the United States from 2003 to the present.

The chapter describes the initial assessment, efforts to realign IT processes and gain organizational buy-in, and communication of a new, more comprehensive vision. Key to the transition were institutional tools such as a technology governance plan, a technology leadership team, customer steering committees, a project management office (PMO), an enterprise architecture council, a technology security council, a disaster recovery Council, and an enterprise data council, which together took the utility on an evolutionary journey from technical anarchy to standardization, increasing productivity and instituting proactive control.

Power Engineering Concept Briefs

Any advanced smart grid project needs two things above all else. First, it needs project funding, which can be found in part from system rationalization that eradicates wasteful IT spending and frees up cash to fund strategic initiatives like an advanced smart grid project. Second, organizational buy-in is needed from other departments, achieved by improved communication, better service, and cross-functional experiences.

Chapter 5: Envisioning and Designing SG2

In Chapter 5, we tell the story of the Pecan Street Project, a unique community project in Austin, Texas, whose goal was to envision and design an energy internet, essentially an advanced smart grid, launched in late 2008 and continuing on to 2013 as an ARRA-funded U.S. Department of Energy (DOE) Smart Grid Demonstration Project, then as an independent research company. The project was informed by the experiences at Austin Energy from 2003 to 2009 in building a pioneer first-generation smart grid. Weekly brainstorming over 25 weeks allowed the diverse teams to evaluate and imagine the next generation of the smart grid, which proved immeasurably valuable to the authors, offering keen insights to help define the essentials of the advanced smart grid vision outlined in this book.

The Pecan Street Project, named for a main cross street in downtown Austin, began in 2008 with an idea for clean energy–led economic development. By harnessing community input, the project founders hoped to capture the imagination of the nation and steer clean energy companies to locate and grow in Austin and central Texas, creating a new focal point for economic development to complement the semiconductor and Internet business foundations of Austin's new age economy. While the jury is still out on the success of that primary goal, the 200-person team did succeed in laying the groundwork plans for a new clean energy ecosystem, whose central tenet is the importance of integrating the water and transportation infrastructure with the power infrastructure. Beyond that level of integration, the project also emphasized the importance of integrating the community into the decision and planning process, since so much of the DER equation depends on an informed and motivated citizenry to move beyond niche applications into mainstream adoption. Throughout this book, DER is a term that includes DR, distributed generation (DG), electric vehicles (EV), energy storage (ES), and appliances and systems with built-in energy-efficiency (EE), collectively the new energy technologies that comprise both the supply and demand sides of "edge power"; the Pecan Street Project discussion expanded the term beyond supply-side technologies to include DR and EE.

Four key elements emerged in the storyline of Phase One of the Pecan Street Project: first, the need to integrate technology, specifically the emerging DER technologies, but also water technologies; second, the emerging need for a new business model for utilities to replace the 100-year-old model of distributing commodity kilowatt-hours; third, the need to integrate and motivate the energy consumer into the energy ecosystem; and fourth, the need to channel regulatory and legislative policy to accommodate all the necessary changes (all these have become key trend lines in the 2014 energy debate documented in Chapter 6).

In what we then called Phase Two, the nonprofit Pecan Street Project organization used DOE grant money and local funding in a three-year study of an energy Internet neighborhood at a new urban style neighborhood located on the site of the old Mueller Airport in central Austin. Pecan Street has since rebranded itself as a research network linking a neighborhood with intense DER penetration with UT's mainframe computers.

Power Engineering Concept Briefs

The Pecan Street Architectural Framework, and all the other elements of the Pecan Street Project process offer tremendous lesson plans from the power engineering perspective, discussed in detail in this section.

Chapter 6: The National Perspective on Smart Grid

In Chapter 6, we pause from describing our local journey on the path to a smart grid in Austin at Austin Energy and the Pecan Street Project to set the context at the