Aging Power Delivery Infrastructures

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Series Introduction

Power engineering is the oldest and most traditional of the various areas within electrical engineering. However, one unfortunate consequence of that seniority with respect to other technologies is that America's electric power infrastructure is quite old. As the electric power industry de-regulates and experiences increasing levels of competition, electric utilities find themselves under growing pressure to improve their bottom line financial performance as well as customer service quality. Yet they must struggle with power systems whose basic design was drafted more than a half-century ago, and that are composed of equipment that is often up to 60 years old.

Aging power delivery infrastructures present a dilemma for electric utilities, the electric power industry, and government. In order for our society to have electric service that is both high in quality and low in price, it must have both good electric systems and healthy electric companies. However, many of these electric companies are in an unenviable position. Modernizing their aging systems would require so much expense that they risk destroying their company's financial health and market viability.

Only by innovating, by taking a new approach and changing the way they plan, engineer, operate, and in particular, manage their systems, can utilities get both the system and financial performance they need. *Aging Power Delivery Infrastructures* discusses both the problems electric utilities face and the modern solutions that they can apply to improve their systems and customer service while keeping their financial performance at competitive levels.

As both a co-author of this book and the editor of the Marcel Dekker Power

Engineering Series, I am proud to include *Aging Power Delivery Infrastructures* in this important series of books. Marcel Dekker's Power Engineering Series includes books covering the entire field of power engineering, in all of its specialties and sub-genres, all aimed at providing a comprehensive reference library of the knowledge needed to meet the electric industry's challenges in the 21st century.

Like all the books in Marcel Dekker's Power Engineering Series, this one focuses on providing modern power technology in a context of proven, practical application, and it should be useful as a reference book as well as for self-study and classroom use. Unlike most books, however, this is non-technical, aimed at the non-engineer, as well as at those power engineers who need a quick, simple overview of de-regulation and how it impacts their role in the industry.

H. Lee Willis

Preface

This book is both a reference book and a tutorial guide on aging power delivery systems and the planning, engineering, operations, and management approaches that electric utilities can take to best handle the formidable challenges they face in working with an aging electric power delivery infrastructure. Electric power is almost unique among major public industries in one important respect: the quality and usability of its product is completely determined by the characteristics of the system that delivers it, not the way in which it is manufactured. America's aging power delivery systems mean poor power quality, frequent and lengthy outages, and frustrating challenges for the customers, the owners and the employees of electric utilities. They also mean poor financial performance for the electric utility companies themselves. Aging power delivery infrastructures degrade both customer service quality and corporate profit levels.

This book exists because the authors believe strongly that in order for our society to have the economical and reliable electric service it needs to sustain growth, it must have both good electric systems, and a healthy electric utility industry. In early 1994, it first because clear to us that the aging of power delivery systems throughout the U.S. was an important and growing problem which threatened the entire power industry. Although the visible symptoms caused by aging infrastructures – frequent and lengthy interruptions of electric service and rising repair and maintenance costs – were largely incipient at that time, projections of equipment age, system performance, and utility financial performance made it clear that the problem would grow exponentially. By year 2000 it would be a major problem. Events certainly proved this projection to be accurate. During the summers of 1998 and 1999, aging utility systems throughout the United States began to experience a growing level of operating problems that led to rapidly degrading customer service and public trust in electric utilities.

In the period 1994 through 1999, we devoted considerable effort, both personally and professionally, to the problem of aging power delivery infrastructures and its possible solutions. We are fortunate enough to be with a company that is arguably the largest and the strongest in the power industry. ABB's resources, technology, and particularly its international span gave us a platform from which to study and develop solutions that work. We used that support and capability to research the problem, to determine what it was under the surface. We collected a host of innovative and proven techniques for improvement from around the world. We developed ways of combining these so they work together, and we tested them until we were confident we knew what worked, what didn't, and why. This book summarizes what we learned.

We will freely admit that our efforts, which were both expensive and frustrating at times, were motivated in large part by the desire for the competitive advantage that comes from knowing how to solve an important, complicated, and poorly understood problem. However, the health and viability of the power industry are of great concern to us, for we are part of it, too, and our futures depend on its prosperity.

What did we learn? Most importantly, aging power delivery infrastructures involve much more than just aging equipment. As important as old equipment is, the problem is also very much the result of the outdated designs, constricted sites and rights of way, outdated engineering standards and methods, and traditional operating procedures being applied in a non-traditional world. The greatest barrier to solving the problem is not financial. Many of the traditional planning, operating, and managerial prioritization methods still in use by electric utilities are completely incompatible with the ways that utility executive management must manage the financial performance of their companies.

But most important, there are viable, proven, and affordable solutions to the problem, solutions that provide results. Those, along with a thorough discussion of the problem itself, is the topic of this book.

This book is composed of three major sections based on technical focus. The first, consisting of Chapters 1 – 6, provides a series of tutorial background discussions on topics necessary to understand some of the subtleties of aging infrastructures and their solutions. The second set of Chapters, 7 – 9, looks at the various aspects of the problem, how they interrelate with one another and the many functions within a power system and an electric utility company. The third consists of seven chapters that look at various methods and technologies to solve the problem, leading up to a series of recommendations and guidelines for those who wish to put together a coherent and workable plan to deal with their

aging power delivery infrastructure challenges.

The authors wish to thank their many colleagues and co-workers who have provided so much assistance and help during the time this book took to put together. In particular, we thank our colleagues Drs. Richard Brown and Andrew Hanson for their valuable assistance and good-natured skepticism and encouragement. We also thank our good long-time business associates Mike Engel of Midwest Energy, Nick Lizanich of Commonwealth Edison, and Randy Bayshore of GPU, for their friendship, good humor and valuable suggestions. We also want to thank Rita Lazazzaro and Russell Dekker at Marcel Dekker, Inc., for their involvement and efforts to make this book a quality work.

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1.1 WHAT ARE AGING POWER DELIVERY INFRASTRUCTURES?

Many electric distribution utilities in the United States, Europe, and other countries around the world are experiencing problems in meeting their customer service quality targets, and in achieving the stockholder profit margin or government cost-control obligations they must meet. These problems are due to the fact that large portions of their systems consist of aging infrastructures. A power system composed of mostly old equipment near the end of its lifetime, configured in a layout that is itself quite old and not completely compatible with modern needs, produces reliability, maintenance, and budgeting challenges. If these challenges are not anticipated and brought under control, they will eventually overwhelm even the most effective organization.

As this chapter will discuss and the remainder of this book will show, aging power delivery infrastructures involve the complicated interaction of a host of managerial, operating, engineering, and design factors, some of which are subtle and obtuse in their impact. Due to this multi-faceted complexity, there is no completely satisfactory simple definition of this problem, one that will cover all situations. Some situations are unusual, a few even unique. But for the vast majority of electric utilities, an "aging power delivery infrastructure" can be described most simply as follows:

> An aging power delivery infrastructure is any area of the utility system with an average service age greater than the design lifetime of the equipment from which it is built.

It's Not Just About Old Equipment

This definition is not completely representative in one very important respect. It identifies equipment age as the active factor of aging systems and implying that it is the reason utilities have so many problems in older areas of the system. While equipment aging *is* an important factor, it is not the sole, and in many cases not even the primary factor at work in creating the service and cost problems that many utilities face. Three other major factors are involved. In all cases these other three are part of the problem and in some cases they are more important than the aging equipment. Still, overall equipment age, or "age of the system," is the simplest, most effective way to both characterize aging infrastructures and identify parts of a utility system that suffer from those problems.

Characteristics of an Aging Infrastructure Area

Situations vary, but most aging infrastructure problem areas have most of the same characteristics, which are:

- The area was originally developed, or last experienced a rebuilding boom, prior to the 1970s. Most of the existing system structure (substation sites, rights of way) dates from before that time.
- The majority of equipment in the area is more than forty years old.
- The system is well engineered and planned, in the sense that a good deal of concern and attention has been devoted to it. It fully meets the utility's minimum engineering criteria.
- The area is seeing steady but perhaps slow growth in load. It may be undergoing, or about to undergo a rebuilding boom.
- The area is plagued by above-average equipment failure rates. Overtime is high due to large amounts of unscheduled repair and restoration.
- SAIFI degradation leads SAIDI degradation by a few years. Although invariably both the frequency and the duration of customer service interruptions increase. Typically, frequency of interruption begins rising from five to eight years prior to big increases in SAIDI.
- When a major "event" such as a widespread interruption of service to customers occurs, it is due to a series of events that are quite unusual; or something truly bizarre. These can result in the failure of a relay/breaker. This normally would have caused only a minor

inconvenience, except that it failed during the brief time when the system was configured into a non-standard configuration in order to support the outage of some other unit of equipment – a contingency-switched mode where there was no backup.

- Things go bad a lot.

1.2 POWER DELIVERY, NOT POWER T&D

The authors have deliberately used the term "Power Delivery" rather than "T&D" throughout this book in order to make a point that is both crucial to success in dealing with aging infrastructures, but very often overlooked. The infrastructure involved in the issues being discussed here includes a good deal of the T&D system, but not all of it. In order to understand the problem, and appreciate how to solve it effectively, but at the lowest possible cost, a person must appreciate that both problems and solutions must be examined from the standpoint of function – what does the equipment involved do?

Modern power T&D systems can be divided into two parts, or levels, based on the function of that part of the power system under a de-regulated structure. In terms of the new de-regulated industry paradigm these are most easily distinguished as the wholesale level and the retail level. *The point of this section, and the focus of this entire book, is that the problems of aging infrastructure, as they impact reliability of customer service, are almost exclusively limited to the retail level.*

This is not to say that the wholesale power transmission level is unimportant. It is absolutely critical, and problems at that level can cause customer service interruptions. What is most important at that level, however, is system security, the continued ability of the system to remain "up and running." That is slightly different than reliability.

But frankly, the consumer does not care or even recognize the difference. Whether his lights are out because the wholesale grid cannot supply all the power needed regionally, or because a part of the local power delivery chain has failed and power cannot be moved to his site, the result is the same – he is without electric power. But this book is about understanding and fixing the problems caused by aging power delivery infrastructures, and eradicating the customer service quality problems they cause. In that context, the distinctions between wholesale and retail matters a great deal. The record shows that the problems caused by aging T&D infrastructures are limited almost exclusively to the retail level. The vast majority of customer service quality issues seen throughout the industry are created at this level, and the solution to those problems lies there as well. Problems at the wholesale level are generation shortages and transmission congestion – very serious indeed, but that is an entirely different set of concerns, and not involved with aging infrastructures.

The Wholesale Grid

At the top – closest to the generation – is the high voltage grid. This is often called the wholesale grid or the bulk power system. These names are particularly apt here, because they distinguish that part of the utility system from the power delivery functions associated with the customers – the retail level. The high voltage grid exists to:

1. Interconnect all generation to create a single regional system.
2. Provide economic dispatch capability for the system (traditional view), or open market access for every generator (de-regulated viewpoint).
3. Provide bulk power transmission capability throughout and across the region (from boundary to boundary).
4. Provide system security – the ability to tolerate the transient loss of any generator or unit of equipment while still maintaining a fully synchronized interconnection of the system and full capability to meet the needs for bulk transmission between regions.

Throughout the remainder of this book, the authors' will use the term "wholesale grid" for this part of the system. It is a critical element of the power industry, and to some people and from some perspectives, more important than the remainder. However, the wholesale grid is not connected to any energy consumers (except the few, large, wholesale consumers of electric power, many of whom are also merchant generators). Failures or other problems on the wholesale grid level do not cause poor electrical service at the retail level, whether that be defined as unacceptable voltage, high harmonic content, or lack of availability.[1]

The distinction between the power delivery system and the wholesale grid is one of function and exclusivity of purpose. While the wholesale grid is involved in getting power to the consumer, it exists mainly or at least in large part for other reasons (see list above). Furthermore, any one part of it may or may not be involved in delivering power to a particular consumer at any one moment. This is due *only* to decisions with regard to economy of supply that the electric Distribution Company or its customer energy service companies have made.

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[1] A good deal of attention is being given to the wholesale transmission level, and with good reason. It has its own set of serious problems. Among them are how to maintain interconnected security under open access when demand levels are high, and how to manage and alleviate congestion problems on the grid caused by highly localized demand-supply mismatches. Aging equipment is an issue in some of these cases, but not in most, nor is it in any situation the key factor of concern, in the authors' opinion.

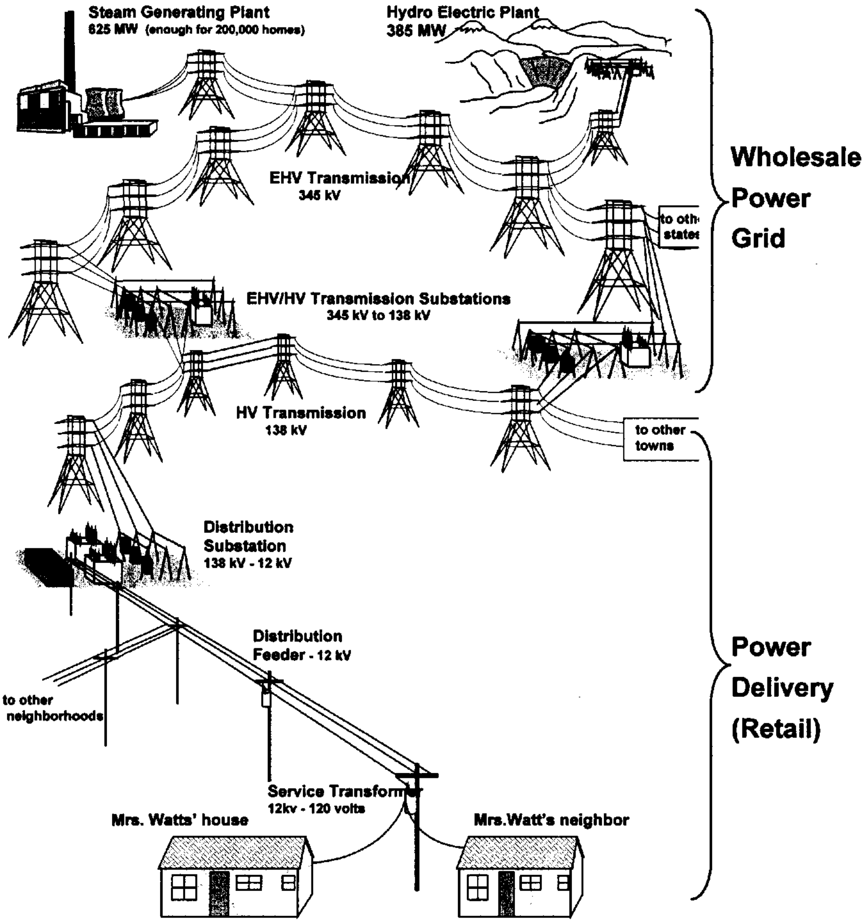

Figure 1.1 The electric power industry, including generation (now de-regulated), the high-voltage transmission network (the open-access wholesale grid), and the power delivery level, which consists of sub-transmission, substations, feeders and laterals, and the utilization voltage system leading to all customers.

The power Mrs. Rose uses to heat her home this week might come from parts of the wholesale grid north of her town, because the utility/service provider found a bargain with respect to generation located there. Next week it might flow in from the west, for similar reasons. This flexibility of flow at the wholesale level is not just considered "business as usual," it is in fact *a key design goal* of the wholesale grid (see number 2 in list above) and one important aspect that distinguishes it from the retail level. Factors, inefficiencies, and outright failures at the wholesale level most often affect market demand and supply economics and transmission congestion, not customer reliability. These are price, not reliability, issues.

Power Delivery: Getting Power to the People

By contrast to the wholesale level, retail, or power delivery, system exists *solely* to route power to consumers. It provides none of the functions, even in small part, listed above for the wholesale grid, but exists only because power must be routed to consumers if they are to buy it. Furthermore, and most importantly to this discussion, any particular consumer's power *always* flows through the same part of the delivery system, except on those rare occasions when there is a contingency. The power that Mrs. Rose uses each day is intended to *always* come through the same set of service drops, through the same service transformer, lateral branch, feeder trunk, substation switchgear, substation transformer, high-side switchgear, and substation transmission-level feed line. Only during an equipment failure will an alternate route be used for some part of this supply chain. During that time the utility may be willing to accept considerably higher than normal loads and lower-than-ideal power quality in order to maintain service.

> "Power delivery infrastructures," aged or not, are therefore those portions of the power system whose purpose is to deliver power to energy consumers. They are justified solely on the basis of the need to perform that function.

Power delivery is accomplished by an "infrastructure" that includes the power distribution system and a portion of what traditionally was called the transmission system. That portion of the transmission-level system is what was traditionally called the "sub-transmission lines – those lines that delivery power to distribution substations. Figure 1.1 indicates the portion of the power system identified as the power delivery system. This is normally the portion that falls under FERC's distinction of distribution, as opposed to transmission (Table 1.2).

From the perspective used throughout this book, the wholesale grid is part of the supply (generation system). Operating problems at that level can be serious and can potentially lead to widespread customer interruptions. In a few cases aging equipment and infrastructures may be a contributing factor.