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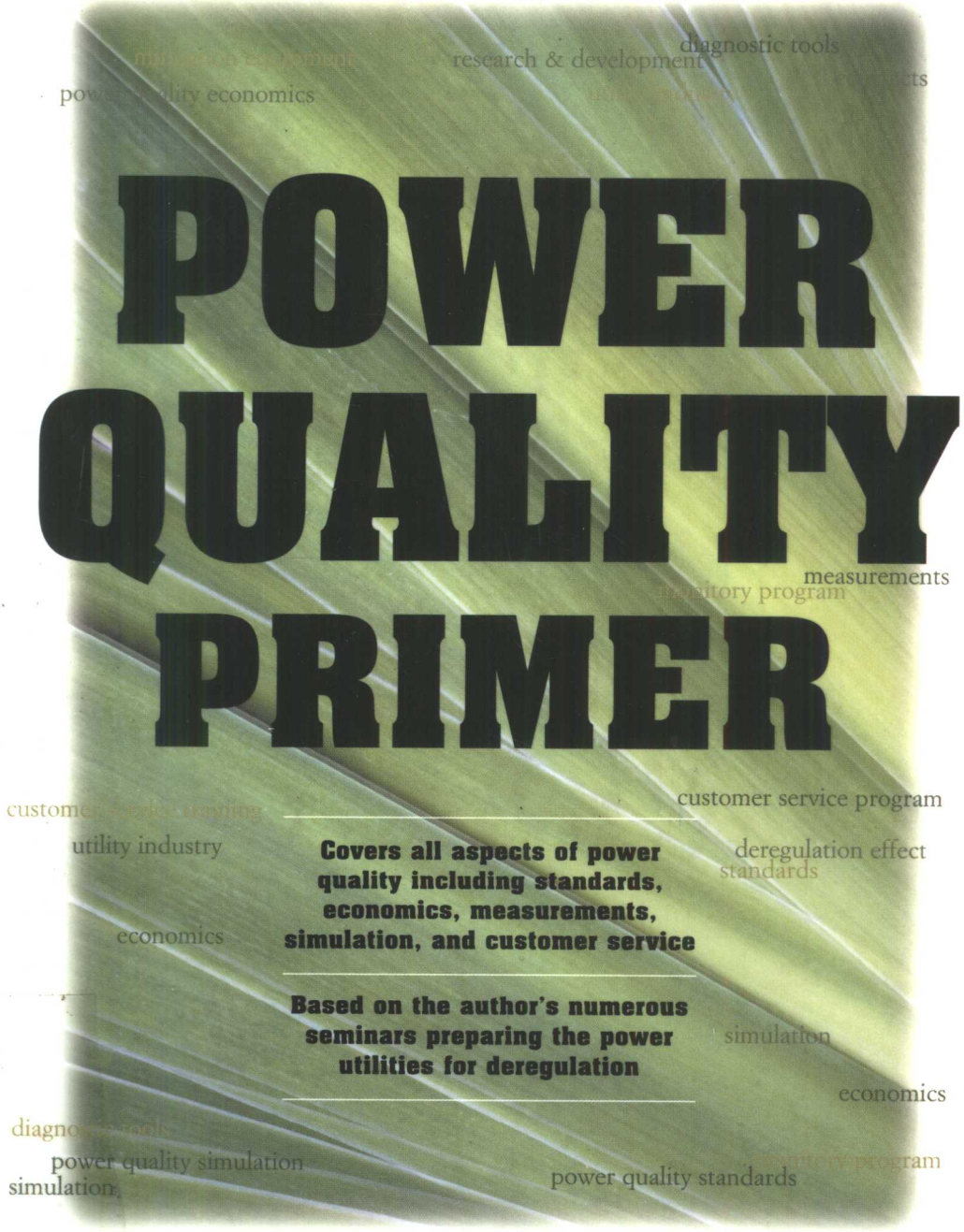

POWER QUALITY PRIMER

Covers all aspects of power quality including standards, economics, measurements, simulation, and customer service

Based on the author's numerous seminars preparing the power utilities for deregulation

BARRY KENNEDY

Power Quality Primer

Barry W. Kennedy

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FOREWORD

Deregulation of the electric power industry is making the quality of the power delivered a topic of increasing importance. It is no longer just an issue for a technical group within the utility that investigates unusual problems of interaction between the power system and customer facilities. It is a problem related to basic system design issues, system maintenance issues, investments that are required to protect equipment within customer facilities, and the implementation of new technologies. Unfortunately, no one has figured out who should be responsible for this power quality.

We are creating a new industry structure where there are many different entities with different responsibilities. The objective is to achieve deregulation of the electric power generation and realize the benefits of efficiency and innovation that result from competition. This is a good objective and consumers should benefit from this approach to generating power. However, there is still the problem of getting the power from these generators to the consumers. This involves a portion of the electric utilities that will still have to be regulated because putting in redundant systems for the transmission and distribution functions will never be the optimum approach for society. Regulation of the transmission and distribution portions of electric utilities ("the line companies") will have to consider power quality in some form. Regulators are already looking at the issues of reliability and consumers have already experienced reliability impacts associated with the new structure. Reliability is really just one part of the overall power quality issue—many other aspects of power quality can also have important impacts on customer operations. Many of these are quite complicated and involve interaction between the transmission system, distribution system, and even customer facilities.

What are these power quality concerns and how should we address them? When you are finished with this book, you should have a basic understanding of the important concerns. You will also understand that there is no simple method of dealing with them. Different customers

have different needs with respect to power quality. It would not be fair to increase the costs of distributing power to all customers to meet the power quality requirements of the most sensitive customers. These leads to the concept of differentiated levels of power quality, or "custom power." There should be many opportunities for individual contracts that define the power quality to be delivered for specific customers and regulation of the transmission and distribution companies should support this concept.

First of all, we need standards that define the basic requirements, the responsibilities of the different parties, and the methods of characterizing the power quality so that everyone starts at the same point. There are many different standards efforts under way, both in North America and internationally. This book will help you understand some of these important activities so that you can keep track of the developments and provide your input where it is appropriate.

Barry Kennedy had been involved in the power quality area for a number of years. His background in energy efficiency is particularly appropriate because many of the same devices that are appropriate for improving the energy efficiency of a facility also have important impacts on the power quality levels and concerns. For instance, adjustable-speed motor drives save energy and provide important advantages in controlling processes but they also can be very sensitive to small variations in the voltage supplied and they can introduce harmonic distortion which may affect other loads on the system. Our policies in promoting energy efficiency technologies must also address the associated power quality issues. Barry recognized this many years ago and managed a project for EPRI and BPA to develop a workbook that addresses these concerns. It is still one of the best references in the industry on this topic.

Barry's perspective on the problem should be valuable for many people. This book is designed to complement more advanced books on power quality issues and should become an important reference for everyone's power quality library. It should provide a basic understanding for the wide variety of people that may now be impacted by power quality issues—utility engineers, regulators, all types of customers, equipment manufacturers,and even politicians. In this sense, it fills a very important need for the whole industry.

Mark McGranahan
Electrotek Concepts

PREFACE

The term *power quality* seems ambiguous. It means different things to different people. So, what is power quality? Is power quality a problem or a product? It depends on your perspective. If you are an electrical engineer, power quality expert, or electrician, you may tend to look at power quality as a problem that must be solved. If you are an economist, power marketer, or purchaser of electrical power, you may look at power as a product and power quality as an important part of that product. Whatever your background, if you are involved in the sale or purchase of electrical power, you will benefit from this book.

I have designed this book to be a technical book for both a nontechnical and a technical audience. Electric utility staff can use this book as a reference. I have written it to help them understand how to compete in the new deregulated, competitive utility industry—not just on the price of electricity but through better customer service and power quality. It will also help utility engineers to provide better customer service to their customers. It will provide the consumer of electricity with important guidelines on how they can get better customer service and power quality from their servicing utility.

Four factors cause an increased need to solve and prevent power quality problems: (1) the increased use of power quality–sensitive equipment, (2) the increased use of equipment that generates power quality problems, (3) the increased interconnectedness of the power system, and (4) the deregulation of the power industry. All of these factors influence utilities' ability to compete with each other to gain new—and keep existing—customers. They also affect the consumers' end users of electricity ability to succeed at their business. Utilities can cause end users to experience costly disruption of production. I discuss each one of these factors in more detail in Chap. 1.

Traditionally, utilities avoided involvement in power quality problems that occurred on a customer's system, and only got involved when their customers complained about power quality problems. Utilities would only

react to customer complaints. When they received a confusing complaint, they would first try to determine the cause of the problem and who caused it. Utilities in a competitive environment have found that this reactive approach makes customers unhappy. In today's electricity market, most utilities want to keep their customers happy and satisfied. At the same time, many utility customers expect high-quality power and cannot afford the cost and bother of power quality problems. Consequently, utilities have discovered that a proactive approach to power quality problems works better in satisfying and keeping their customers happy. Utilities and their customers have found the need to look at each other's side of the revenue meter when encountering power quality problems. Even though utilities cause many power quality problems, such as voltage sags, recent studies by research organizations, like the Electric Power Research Institute (EPRI), have found that utility customers cause 80 to 90 percent of their own power quality problems.

Many utilities and their customers have discovered the importance of solving and preventing power quality problems. They have found the need to prevent the cost of lost production caused by poor power quality. They have learned that they need to understand the cause and effect of power quality problems in order to prevent them. More and more utilities are working with their customers on the "other side" of the meter to help them solve power quality problems. Yes, both providers and purchasers of electricity need to know the causes and solutions to power quality problems. I have designed this book to provide both suppliers and consumers of electricity not only with a clear understanding of the cause and effect of power quality problems but also the solutions to those problems as well.

Several books about power quality are available, but none is dedicated solely to providing the reader with the solutions to power quality problems or help them to understand how to sell or buy power high in quality. Other books define the technical problems and solutions associated wth power quality, while this book is a power quality primer that will help both the provider and consumer of electrical energy to cope with the customer service and power quality impact of the deregulated electric utility industry. My goal in writing this book is to help providers and users of electricity to understand the basics of power quality. If you are new to power quality, you will find that Chap. 2 provides you with the necessary fundamentals on power quality theory, power quality variations, and power quality solutions. If you are familiar with power quality, you will find the later chapters on new power quality monitoring and diagnostic tools informative and valuable. And for both the beginner and advanced provider and user of electricity, Chapt. 3 provides a clear explanation of all the many and often confusing international and national power quality standards.

Power quality standards have been changing over the years. They will become even more important as the utility industry restructures and becomes more competitive. Chapter 3 discusses the various power quality standards developed by IEEE, IEC, EPRI, and other organizations. In addition to understanding power quality standards, you need to know how to solve power quality problems.

Chapter 4 outlines how to solve power quality problems. The various types of power conditioning equipment available on the market are presented, along with an explanation of how they can solve your power quality problem.

Because poor wiring and grounding cause many power quality problems (80 to 90 percent), Chapter 5 is devoted to identifying and solving wiring and grounding power quality problems.

I organized this book into logical steps to help you obtain easily the information you need to either develop a power quality program or just to understand power quality in general. I explain how to use this book in Chap. 1.

Whether you are a power quality expert or end user experiencing power quality problems, you need to decide how to use the many types of meters on the market today for measuring power quality. What meter should you use to solve your—or your client's—power quality problem? Just like doctors and their patients need to understand how to use instruments for diagnosing health problems, power quality experts and their clients need to understand how to use instruments for diagnosing power quality problems. You'll learn to understand how they work and how to use them from this book. Chapter 6 shows you the inner workings of power quality meters and how to apply them to solve your power quality problem. Not only will I show you how to use power quality meters but also how to determine what type of power quality meter is best for your situation.

Many utilities and their customers are looking for permanent power quality monitoring systems that allow them to respond quickly to power quality problems. Several systems are available today. Chapter 6 explains these systems and how to use them. Once you have determined the cause of power quality problems, you need to know what solution best fits your power quality problem. To help you to determine the various solutions available, I cover the technology and equipment being used to prevent or solve power quality problems in Chap. 4.

Many power quality problems are so complex that a computer simulation is required to solve them. Not only do computer simulations provide an opportunity to look at alternative technical solutions but they also allow you to evaluate the economics of various solutions. Then you can pick the solution that solves your problem with the least amount of cost. The various tools for power quality simulations and

how to use them, as well as the steps in performing a power quality survey, are discussed in Chap. 7.

Often, the analysis of power quality problems requires extensive experience in looking at the power quality signature obtained from your monitoring equipment and the ability to recognize the cause of the problem. This is not unlike a doctor looking at laboratory results and being able to identify the medical problem that is making you sick. Obtaining the necessary experience can be expensive and time consuming. Computer diagnostic tools developed by EPRI and others can be real assets in identifying and isolating a particular power quality problem. I present these tools and how to use them in Chap. 7.

Deregulation and restructuring of the electric utility industry will have an effect on power quality. What will the restructured utility industry look like and how will it effect power quality? Deregulation's effect and other future trends, described in Chap. 9 provide you with the structure of the new utility industry and how it will affect power quality.

Changes in technologies and the structure of the power industry will make the need for continuous power quality training essential. Chapter 9 is devoted to the type of training available today from utilities, EPRI, IEEE, and consultants, along with the steps for developing your power quality training if you so choose.

Once you have examined the various components that make up a power quality program, you are ready to develop your own power quality program. Your program could include any of the modules I discuss in Chap. 9. I have tried to present to you with the parts of a power quality program in modules to allow you to create a program that meets your needs.

The cost of power quality problems and solutions needs to be evaluated not only from the utility's perspective but also from the utility customer's perspective. The economics of power quality programs need to be evaluated as well. In Chap. 8 I show you how to evaluate the cost of power quality problems, solutions, and programs.

Can power quality be treated as a business? Whether you wish to sell power quality as a service bundled with your power rates or as a separate unbundled service, you need to develop a business plan. In Chap. 9 I discuss how various companies are treating power quality as a business and how to write the technical components of a business plan for a power quality, industrial, or commercial organization.

Deregulation and restructuring the electric utility industry will make the use of power quality contracts imperative. These contracts will not only involve agreements between the servicing utility and their customers but also between power consumers, transmission and distribution companies, power quality servicing companies and their customers, and between generators and their customers. I discuss how to write these contracts in Chap. 9.

When the utility industry becomes deregulated, users of electricity will need to evaluate their supplier of power not only on the basis of the power cost but also on power quality. How to evaluate providers of power quality services, and transmission and distribution services, is the subject of Chap. 9.

Research and development of new tools for diagnosing and solving power quality problems is constantly changing. New technologies that result in power quality problems will require new methods for diagnosing them. I discuss the status of research and development in Chap. 9.

What are the future trends in technology and organizational structure in the power industry? How will these trends affect the end user of electricity and the utility industry? I look into my crystal ball and present in Chap. 9 what I think will be the important trends in power quality.

In order to help you sort through the jargon and technical language in the power quality and electric utility industry, I provide an extensive glossary of terms and abbreviations. Often you might have a desire to do further research on power quality. To meet that need, I provide a bibliography that includes references to several Internet web sites that deal with power quality.

You, the users and providers of electricity, benefit from the selection and operation of a power system that provides power that is high in power quality. You have the data on the cost of power quality problems and the cost of power quality solution to make the decision that benefits you and your customers. With this book, you have the knowledge and methods for evaluating the cost effectiveness of power quality solutions that meets your needs to serve your customer and save money.

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Barry W. Kennedy

Credits

Contents

Chapter

1

Introduction

It's Friday. Your boss gave you a deadline to have that report done by close of business. You're almost done with the report. So you don't bother to save it. Then your computer "freezes." You're upset. You take a deep breath, say a prayer, and reboot your computer. You've lost several hours of work. You may have lost a promotion and certainly a chance to impress your boss. You decide to work overtime and vow to back up your material more often. You're not alone. What may have been an annoyance to you and your boss multiplied many times has become a costly problem throughout the United States and the world. In many cases where offices and factories have become dependent on the smooth operation of computers, a single outage can be very costly. For example, a glass plant in 1993 estimated that an interruption of power of less than a tenth of a second can cost as much as $200,000, while for a computer center that experienced a 2-second interruption, it can cost $600,000 and a loss of 2 hours of data processing. According to *Science* ("Editorial: Magnetic Energy Storage," October 7, 1994), costs due to power fluctuations in the United States range from $12 to $26 billion. Consequently, the United States market for power quality services and equipment has grown to over $5 billion in 1999. Figure 1.1 shows how the cost of power quality disturbances have increased over the last 30 years.

Electrical power engineers have always been concerned about power quality. They see power quality as anything that affects the voltage, current, and frequency of the power being supplied to the end user, i.e., the ultimate user or consumer of electricity. They are intimately familiar with the power quality standards that have to be maintained. They deal with power quality at all levels of the power system, from the generator to the ultimate consumer of electrical power. They are not the only ones who need to be aware of power quality.