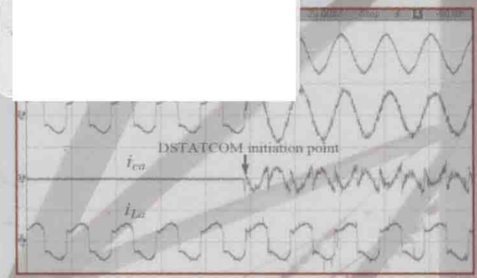

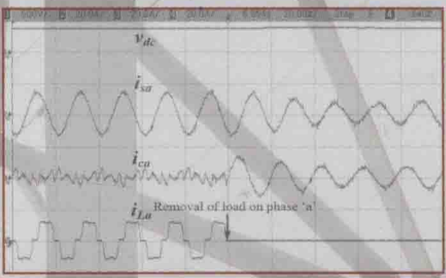

POWER QUALITY

PROBLEMS AND MITIGATION TECHNIQUES

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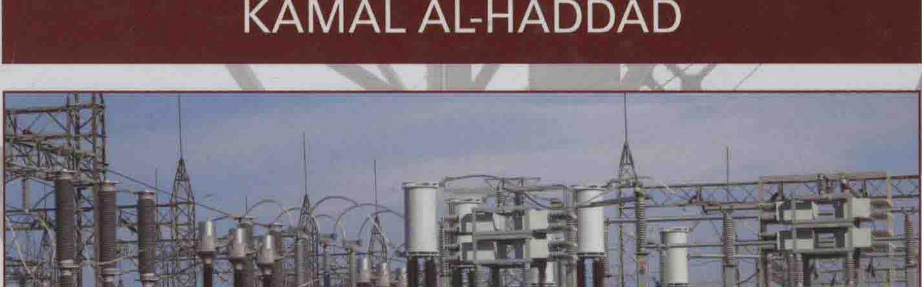

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POWER QUALITY PROBLEMS AND MITIGATION TECHNIQUES

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POWER QUALITY PROBLEMS AND MITIGATION TECHNIQUES

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This book is dedicated to our parents and families.

Preface

Due to the increased use of power electronic converters in domestic, commercial, and industrial sectors, the quality of power in distribution networks is deteriorating at an alarming rate. This is causing a number of problems such as increased losses, poor utilization of distribution systems, mal-operation of sensitive equipment, and disturbance to nearby consumers, protective devices, and communication systems. These problems are also aggravated by the direct injection of non-steady power from renewable energy sources in the distribution system. It is expected that in the next few years, more than 80% of AC power is to be processed through power converters owing to their benefits of energy conservation, flexibility, network interconnection, and weight and volume reduction in a number of equipment such as lighting, HVAC, computers, fans, and so on. In view of these facts, it is considered timely to write this book to identify, classify, analyze, simulate, and quantify the associated power quality problems and thereby provide mitigation techniques to these power quality problems that will help practicing engineers and scientist to design better energy supply systems and mitigate existing ones.

Motivation

This book is aimed at both undergraduate and postgraduate students in the field of energy conversion and power quality in more than 10,000 institutions around the word. The book aims to achieve the following:

- Easy explanation of the subject matter through illustrations, waveforms, and phasor diagrams using minimum texts, which is one of the most efficient methods of understanding complex phenomenon.
- Simple learning of the subject through numerical examples and problems, which is one of the most favorite techniques of learning by engineering graduates.
- To gain an in-depth knowledge of the subject through computer simulation-based problems, which is the most favored skill of today's young engineers.
- To get the confidence to find the solutions of latest practical problems, which are encountered in the field of power quality.
- To develop enthusiasm for logical thinking in students and instructors.
- To gain an in-depth understanding of latest topics on power quality in minimum time and with less efforts.

Focus and Target

This book is planned in a unique and different manner compared with existing books on the subject. It consists of rare material for easy learning of the subject matter and a large number of simple derivations are included in a simplified mathematical form for solving most of the power quality problems in analytical form and designing their mitigation devices. Aside from this, the book provides essential theory supported by a reasonable number of solved numerical examples with illustrations, waveforms and phasor diagrams, small review questions, unsolved numerical problems, computer simulation-based problems, and references.

In addition to undergraduate and postgraduate students in the field of power quality, this book will also prove useful for researchers, instructors, and practicing engineers in the field.

This book facilitates simplified mathematical formulations in closed form solution through calculation, computation, and modeling of power quality problems and designing their mitigation devices.

Structure

This book consists of 11 chapters. Chapter 1 gives an introduction on power quality (PQ), causes and effects of PQ problems, requirement of PQ improvements, and mitigation aspects of PQ problems. Chapter 2 deals with PQ definitions, terminologies, standards, benchmarks, monitoring requirements, financial loss, and analytical quantification through numerical problems.

In Chapters 3–6, passive shunt and series compensation using lossless passive LC components, active shunt compensation using DSTATCOM (distribution static compensators), active series compensation using DVR (dynamic voltage restorer), and combined compensation using UPQC (unified power quality compensator) are covered for mitigation of current-based PQ problems such as reactive power compensation to achieve power factor correction (PFC) or voltage regulation (VR), load balancing, and neutral current reduction and mitigation of voltage-based PQ problems such as compensation of voltage drop, sag, swell, unbalance, and so on in the single-phase and three-phase three-wire and four-wire loads and supply systems.

In Chapter 7, various types of nonlinear loads, which cause these power quality problems, are illustrated, classified, modeled, quantified, and analyzed for associated power quality problems.

Chapters 8–11 deal with different kinds of power filters such as passive filters, active shunt filters, active series filters, and hybrid filters to meet the requirements of various kinds of power quality problems such as current and voltage harmonic elimination, reactive power compensation, and so on caused by harmonics-producing single-phase and three-phase nonlinear loads. Moreover, these power filters are also used for elimination of voltage harmonics present in the supply systems.

The major strength of this book is its 175 numerical examples, 250 review questions, 175 numerical problems, 250 computer simulation-based problems, and 600 references in different chapters.

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Professor Al-Haddad would like to express his gratitude and high appreciation to his colleague and friend Professor Bhim Singh who is collaborating with him since 1995 on a continuous basis. This long time collaboration with Canada Research Chair in Electric Energy Conversion and Power Electronics (CRC-EECPE) led by professor Al-Haddad started with Dr Bhim Singh first visit to Montreal in 1995 as a visiting researcher, followed by invited professor position, adjunct professor member of the CRC, and since then it is a continuous work between the team from IIT Delhi and the CRC-EECPE researchers. Professor Al-Haddad also would like to express his gratitude to the following agencies who strongly supported this work: Canada Research Chairs (CRC), Natural Sciences and Engineering Research Council of Canada (NSERC), Fond de Recherche Nature et Technologies du gouvernement du Québec (FRQNT), ÉTS, and Groupe de Recherche en Électronique de Puissance et Commande Industrielle GRÉPCI. He also expresses his gratitude to his numerous hard working researchers, his brilliant dedicated graduate and undergraduate students, a long list of more than 150 names, his colleagues in the electrical engineering department as well as those from IEEE Industrial Electronics Society and equally important to his wife Fadia, and daughters Isabel and Joelle for their support.

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About the Companion Website

This book has a companion website:
www.wiley.com/go/singh/power

The website includes:
* Solutions to numerical problems

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Contents

1

Power Quality: An Introduction

1.1 Introduction

The term electric power quality (PQ) is generally used to assess and to maintain the good quality of power at the level of generation, transmission, distribution, and utilization of AC electrical power. Since the pollution of electric power supply systems is much severe at the utilization level, it is important to study at the terminals of end users in distribution systems. There are a number of reasons for the pollution of the AC supply systems, including natural ones such as lightening, flashover, equipment failure, and faults (around 60%) and forced ones such as voltage distortions and notches (about 40%). A number of customer's equipment also pollute the supply system as they draw nonsinusoidal current and behave as nonlinear loads. Therefore, power quality is quantified in terms of voltage, current, or frequency deviation of the supply system, which may result in failure or mal-operation of customer's equipment. Typically, some power quality problems related to the voltage at the point of common coupling (PCC) where various loads are connected are the presence of voltage harmonics, surge, spikes, notches, sag/dip, swell, unbalance, fluctuations, glitches, flickers, outages, and so on. These problems are present in the supply system due to various disturbances in the system or due to the presence of various nonlinear loads such as furnaces, uninterruptible power supplies (UPSs), and adjustable speed drives (ASDs). However, some power quality problems related to the current drawn from the AC mains are poor power factor, reactive power burden, harmonic currents, unbalanced currents, and an excessive neutral current in polyphase systems due to unbalancing and harmonic currents generated by some nonlinear loads.

These power quality problems cause failure of capacitor banks, increased losses in the distribution system and electric machines, noise, vibrations, overvoltages and excessive current due to resonance, negative-sequence currents in generators and motors, especially rotor heating, derating of cables, dielectric breakdown, interference with communication systems, signal interference and relay and breaker malfunctions, false metering, interferences to the motor controllers and digital controllers, and so on.

These power quality problems have become much more serious with the use of solid-state controllers, which cannot be dispensed due to benefits of the cost and size reduction, energy conservation, ease of control, low wear and tear, and other reduced maintenance requirements in the modern electric equipment. Unfortunately, the electronically controlled energy-efficient industrial and commercial electrical loads are most sensitive to power quality problems and they themselves generate power quality problems due to the use of solid-state controllers in them.

Because of these problems, power quality has become an important area of study in electrical engineering, especially in electric distribution and utilization systems. It has created a great challenge to both the electric utilities and the manufacturers. Utilities must supply consumers with good quality power for operating their equipment satisfactorily, and manufacturers must develop their electric equipment either to be immune to such disturbances or to override them. A number of techniques

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have evolved for the mitigation of these problems either in existing systems or in equipment to be developed in the near future. It has resulted in a new direction of research and development (R&D) activities for the design and development engineers working in the fields of power electronics, power systems, electric drives, digital signal processing, and sensors. It has changed the scenario of power electronics as most of the equipment using power converters at the front end need modifications in view of these newly visualized requirements. Moreover, some of the well-developed converters are becoming obsolete and better substitutes are required. It has created the need for evolving a large number of circuit configurations of front-end converters for very specific and particular applications. Apart from these issues, a number of standards and benchmarks are developed by various organizations such as IEEE (Institute of Electrical and Electronics Engineers) and IEC (International Electrotechnical Commission), which are enforced on the customers, utilities, and manufacturers to minimize or to eliminate the power quality problems.

The techniques employed for power quality improvements in exiting systems facing power quality problems are classified in a different manner from those used in newly designed and developed equipment. These mitigation techniques are further subclassified for the electrical loads and supply systems, since both of them have somewhat different kinds of power quality problems. In existing nonlinear loads, having the power quality problems of poor power factor, harmonic currents, unbalanced currents, and an excessive neutral current, a series of power filters of various types such as passive, active, and hybrid in shunt, series, or a combination of both configurations are used externally depending upon the nature of loads such as voltage-fed loads, current-fed loads, or a combination of both to mitigate these problems. However, in many situations, the power quality problems may be other than those of harmonics such as in distribution systems, and the custom power devices such as distribution static compensators (DSTATCOMs), dynamic voltage restorers (DVRs), and unified power quality conditioners (UPQCs) are used for mitigating the current, voltage, or both types of power quality problems. Power quality improvement techniques used in newly designed and developed systems are based on the modification of the input stage of these systems with power factor corrected (PFC) converters, also known as improved power quality AC–DC converters (IPQCs), multipulse AC–DC converters, matrix converters for AC–DC or AC–AC conversion, and so on, which inherently mitigate some of the power quality problems in them and in the supply system by drawing clean power from the utility. This book is aimed at providing an awareness of the power quality problems, their causes and adverse effects, and an exhaustive exposure of the mitigation techniques to the customers, designers, manufacturers, application engineers, and researchers dealing with the power quality problems.

1.2 State of the Art on Power Quality

The power quality problems have been present since the inception of electric power. There have been several conventional techniques for mitigating the power quality problems and in many cases even the equipment are designed and developed to operate satisfactorily under some of the power quality problems. However, recently the awareness of the customers toward the power quality problems has increased tremendously because of the following reasons:

- The customer's equipment have become much more sensitive to power quality problems than these have been earlier due to the use of digital control and power electronic converters, which are highly sensitive to the supply and other disturbances. Moreover, the industries have also become more conscious for loss of production.
- The increased use of solid-state controllers in a number of equipment with other benefits such as decreasing the losses, increasing overall efficiency, and reducing the cost of production has resulted in the increased harmonic levels, distortion, notches, and other power quality problems. It is achieved, of course, with much more sophisticated control and increased sensitivity of the equipment toward power quality problems. Typical examples are ASDs and energy-saving electronic ballasts, which have substantial energy savings and some other benefits; however, they are the sources of waveform distortion and much more sensitive to the number of power quality disturbances.

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