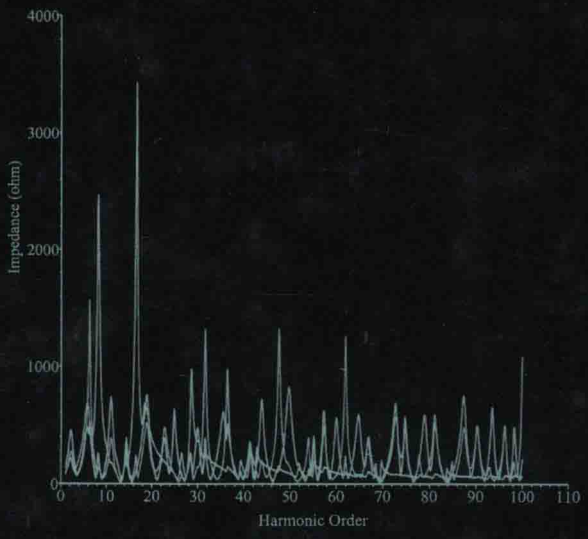
Power System Harmonics and Passive Filter Designs



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POWER SYSTEM HARMONICS AND PASSIVE FILTER DESIGNS

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FOREWORD

Dr. Jean Mahseredjian[1]

This book on power system harmonics and passive filter designs is a comprehensive resource on this subject, covering harmonic generation, mitigation, measurement and estimation, limitations according to IEEE and IEC standards, harmonic resonance, formation of shunt capacitor banks, modeling of power system components and systems. Harmonic penetration in the power systems, passive filters, and typical study cases, covering renewable energy sources – solar and wind power generation – are included. There are many aspects of harmonics discussed in this book, which are not covered in the current publications.

The following is a chapter-wise summary of the book content.

Chapter 1 forms a background on the subject of power system harmonics with discussions of harmonic indices and power theories. The coverage of nonsinusoidal single-phase and three-phase systems and popular instantaneous power theory of H. Akagi and A. Nabe, much used for active filter designs discussed later on in the book, leads a reader to understand the nonlinearity.

The second chapter on Fourier analysis, though much mathematical, paves the way for the applications to harmonic analysis and measurements with limitations of window functions. The examples given in the chapter help the readers to understand the transformations.

Harmonic generation from conventional power equipment, ferroresonance, and electronically switched devices, converters, home appliances, cycloconverters, PWM, voltage source converters, switch mode power supplies, wind farm generation, pulse burst modulation, chopper circuits, traction and slip recovery schemes, are well described in Chapters 3 and 4. A reader will find an interesting analysis of transformer modeling, third harmonic voltages in generators, and many EMTP simulations. Harmonics due to saturation of current transformers is an added feature. Chapter 4 is fairly exhaustive and includes harmonic generation from many sources of practical importance. The analysis and topologies of ASDs (adjustable speed drives) are well documented. Though the author provides some background, yet a reader must be conversant with elements of power electronics.

Interharmonics is a new field of research, and Chapter 5 is well written so as to provide a reader a clear concept of interharmonic generation and their effects. This is followed by a well-written work on flicker from arcing loads, arcing and induction

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furnaces, and tracing methods of flicker. The control of flicker through the application of a STATCOM followed by torsional analysis due to harmonics in large drives with graphics is one problem that is not so well addressed in current texts. The subsynchronous resonance in series compensated HV transmission lines and drive system cascades, with EMTP simulation results, will be of interest to special readers interested in this field.

Having discussed the generation of harmonics in previous chapters, Chapter 6 is logically placed to discuss the various strategies that can be adopted to reduce the harmonics at source itself, so that harmonic penetration in the power systems is avoided. This covers active filters, combination of active and passive filters, their controls, active current shaping matrix converters, multilevel inverters, THMI inverters and theory of harmonic reduction at source, new breed of matrix and multilevel converters, followed with the theory of the resultant of polynomials. Then, the demonstration of this theory and control of switching angles is demonstrated to reduce harmonic distortion to a very low level. Some sections of this chapter will need a prior understanding of many aspects of converters and their switching, and on first reading the mathematical treatment cannot be easily followed by an average reader. The author provides excellent references at each step for further reading.

The calculations, estimation, time stamp of harmonics are the first step before a model can be generated for study. The relevance of modeling angles of the harmonics, measuring equipment, transducers, analysis of various waveforms will be of interest to all readers, while probabilistic concepts, regression methods, Kalman filtering, and so on will be of special interest. The author provides fundamental aspects leading to these advanced concepts.

The effects of harmonics can be very deleterious on electrical power equipment, Chapter 8. Practically all power system equipment of interest, motors, insulation stresses, and traveling wave phenomena on drive system cables, common mode voltages, bearing currents, protective relaying, circuit breakers, and the like are covered. Of special interest to a reader will be derating of dry and liquid-filled transformers serving nonlinear loads, which at times may be ignored, resulting in overloads.

After this background is grasped, harmonic resonance in various forms is discussed in Chapter 9. The reactance curves, Foster networks, composite resonance, secondary resonance are illustrated, which are commonly missing topics in other texts.

The limits of harmonic distortions in Chapter 10 cover both, IEEE and IEC guidelines, with limits on interharmonics and calculations of effects of notching on harmonic distortions.

In the design of passive filters, formation of shunt capacitor banks and their grounding and protection is an important aspect, Chapter 11. Often failures on harmonic filters occur due to improper selection of the ratings of unit capacitors forming the bank, as well as ignoring their protection and switching transients. The importance of this chapter cannot be overstated for a reader involved in harmonic filter designs.

The next step in harmonic analysis is accurate modeling of power system components and power systems, depending on their nature and extent of study, which is detailed in Chapters 12 and 13. These two chapters form the backbone of harmonic

analysis. The modeling described for transmission lines, transformers, loads, cables, motors, generators, and converters in Chapter 12 is followed by system modeling in industrial, distribution, and transmission systems and HVDC, which are the aspects that should be clearly grasped by a reader interested in harmonics.

Study of harmonic penetration discussed in Chapter 14 can be undertaken after the material in the previous chapters is grasped. Apart from time and frequency domain methods, the chapter covers the latest aspects of probabilistic modeling.

It may seem that in the entire book only one chapter, Chapter 15, is devoted to passive filters. However, harmonic filter designs may be called the last link of the long chain of harmonic studies. The chapter describes practically all types of passive filters commonly applied in the industry, with some new technologies such as genetic algorithms and particle swarm theories.

Lastly, Chapter 16 has many real-world studies of harmonic analysis and filters designs, including arc furnaces, transmission systems, solar and wind generation plants. A reader with adequate modeling tools and software can duplicate these studies and it will be a tremendous exercise in learning.

I conclude that the book is well written and should appeal to beginners and advanced readers, in fact, this can become a standard reference book on harmonics. Many solved examples and real-world simulations of practical systems enhance the understanding. The book is well illustrated with relevant figures in each chapter.

PREFACE

The power system harmonics is a subject of continuous research; this book attempts to present the state-of-art technology and advancements. It is a subject of interest of many power system professionals engaged in harmonic analysis and mitigation and the applications in the modern climate when the nonlinear loads in the utility systems are on the increase.

The book provides a comprehensive coverage of generation, effects, and control of harmonics. New harmonic mitigation technologies, detailed step-by-step design of passive filters, interharmonics, and flicker are covered. The intention is that the book can serve as a reference and practical guide on harmonics.

A beginner should be able to form a clear base for understanding the subject of harmonics, and an advanced reader's interest should be simulated to explore further. A first reading of the book followed by a detailed critical reading is suggested. The many real-world study cases, examples, and graphics strive for this objective and provide clear understanding. The subject of harmonics may not form a curriculum even for graduate studies in many universities. In writing this book, an undergraduate level of knowledge is assumed; yet, the important aspects with respect to connectivity of each chapter are not lost sight of. It has the potentiality of serving as advance undergraduate and graduate textbook. Surely, it can serve as continuing education textbook and supplementary reading material.

The effects of harmonics can be experienced at a distance, and the effect on power system components is a dynamic and evolving field. These interactions have been analyzed in terms of current thinking.

The protective relaying has been called "an art and science." The author will not hesitate to call the passive harmonic filter designs and mitigation technologies the same. This is so because much subjectivity is involved. Leaving aside high-technology research tools such as Monte Carlo simulations, the available computer techniques invariably require iterative studies to meet a number of conflicting objectives.

A first reading of the book will indicate that the reader must understand the nature of harmonics, modeling of power system components, and characteristics of filters, before attempting a practical filter design for real-world applications. Chapter 16 is devoted to practical harmonic passive filter designs and case studies including solar and wind generation. A reader can modal and reproduce the results and get a "feel" of the complex iterative and analytical procedures.

The author acknowledges with thanks permission for republication of some work from his book: *Power System Analysis: Short-Circuit Load Flow and Harmonics*, CRC Press.

J.C. DAS

ABOUT THE AUTHOR

J.C. Das is principal and consultant with Power System Studies, Inc. Snellville, Georgia. He headed the Power System Analysis department at AMEC, Inc. for many years. He has varied experience in the utility industry, industrial establishments, hydroelectric generation, and atomic energy. He is a specialist in performing power system studies, including short circuit, load flow, harmonics, stability, arc flash hazard, grounding, switching transients, and protective relaying. He conducts courses for continuing education in power systems and has authored or coauthored about 65 technical publications nationally and internationally. He is the author of the following books:

- *Arc Flash Hazard Analysis and Mitigation*, IEEE Press, 2012.
- *Transients in Electrical Systems: Analysis Recognition and Mitigation*, McGraw-Hill, 2010
- *Power System Analysis: Short-Circuit Load Flow and Harmonics, Second Edition*, CRC Press, 2011.

These books provide extensive converge, running into more than 2400 pages and are well received in the technical circles. His interests include power system transients, EMTP simulations, harmonics, power quality, protection, and relaying. He has published 200 study reports on electrical power system for his clients.

Related to harmonic analysis, Mr. Das has designed some large harmonic passive filters in the industry, which are in successful operation for more than 18 years.

Mr. Das is a Life Fellow of Institute of Electrical and Electronics Engineers, IEEE (United States), Member of the IEEE Industry Applications and IEEE Power Engineering societies, a Fellow of Institution of Engineering Technology (United Kingdom), a Life Fellow of the Institution of Engineers (India), a Member of the Federation of European Engineers (France), and a member of CIGRE (France). He is a registered Professional Engineer in the States of Georgia and Oklahoma, a Chartered Engineer (C. Eng.) in the United Kingdom and a European Engineer (Eur. Ing.) in the Europe. He received meritorious award in engineering, IEEE Pulp and Paper Industry in 2005.

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