Powers and compensation in circuits with nonsinusoidal currents

Leszek S. Czarnecki

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To my wife Maria
The “Driving Force” behind this book

Preface

Electrical circuits and systems provide the “blood” - the electric energy for our homes, commercial buildings, and technological processes. This energy costs. Even if it comes from unlimited energy reservoirs, such as rivers flow, wind, sunlight, sea waves, or geothermal processes, its “harvesting” is not for free. It costs. This “harvesting” can deteriorate or even damage our natural environment. Moreover, the priceless resources of the Earth, such as coal, crude oil, or natural gas are wasted to produce electric energy. Therefore, with the increasing social concern about it, we should use it as sparingly as possible. Also, the improvement in the effectiveness of electric energy transfer becomes more and more important.

We cannot deliver this energy to customers without losses thus much more energy has to be produced than consumed. The difference between the produced and the consumed energy, meaning the energy wasted as losses, is the lowest when the voltages and currents are sinusoidal, without any phase shift. In three-phase circuits, they should be, moreover, symmetrical. In such a situation there are also the lowest demands as to the capability and the cost of the energy transmitting equipment.

Sinusoidal, symmetrical currents that are in phase with the supply voltage a drawn only by balanced purely resistive loads supplied with a symmetrical sinusoidal voltage, however. Only three-phase electrical heaters draw such currents. Electric energy is too expensive for wasting it for heating, however. Other common loads do not draw currents that are in phase with the supply voltage. These currents do not have to be, moreover, sinusoidal, and symmetrical.

The phase shift between the supply voltage and the current can be eliminated, sinusoidal waveform and the current symmetry can be restored by compensators. The knowledge of the power properties of circuits with nonsinusoidal and/or asymmetrical currents is necessary for such compensator development.

Students at university courses on circuits are taught mainly about electric powers and compensation when voltages and currents are sinusoidal. At the same time, the LED or fluorescent bulbs, computers, printers, TV and audio equipment, microwaves, or induction stoves draw currents that are very far from sinusoidal ones, however. Distribution systems supply very high-power rectifiers in chemical plants and power electronics-driven variable speed drives in the manufacturing process and transportation. From loads in our homes up to ultra-high power metallurgic plants with power electronics-driven crushers, mills, and arc furnaces, the power is comparable sometimes to one million population cities, electrical loads cause current distortion and asymmetry.

This book is to provide solid fundamentals for circuit analysis and development of compensators that are to operate at nonsinusoidal voltages and currents in the presence of the load imbalance. Such analysis provides reliable conclusions as to energy flow-related physical phenomena in such systems, which in turn create a well-founded basis for developing methods of compensation. Before that, the credibility of various opinions on energy flow-related phenomena and compensation methods should be verified and misconceptions identified. Therefore, a substantial part of this book is dedicated to the critical analysis of existing interpretations of power-related phenomena and their conclusions upon compensation.

The book is dedicated to scientists, engineers, graduate and undergraduate students interested in energy flow in systems saturated with power electronics converters, renewable sources of energy, or interested in microgrid development. Such systems are usually not very strong and consequently, they are susceptible to voltage and current distortion and asymmetry. The assumption that voltages and currents in such systems are sinusoidal and symmetrical can result in substantial errors.

Investigations on power properties of circuits with nonsinusoidal voltages and currents have more than a century-long history, with hundreds of scientists involved and several “schools” that explain power phenomena and define power quantities in such circuits in different ways. Mutually conflicting conclusions regarding the possibility and methods of compensation, have been drawn in these investigations and disseminated in the power engineering community. Different quantities have been suggested to be regarded as reactive, apparent, or other powers. These “schools” differ also concerning the physical interpretations of power-related phenomena in electrical circuits. Some of them and their effects are misinterpreted. For example, the opinion, which is very common in the electrical engineering community, that energy oscillations between energy sources and customer loads are responsible for the degradation of the effectiveness of energy transfer, is one of the most remarkable misinterpretations. Even the presence of such oscillations is controversial.

The book presents a detailed analysis and interpretation of the various, energy transfer-related phenomena and their effect on the methods of compensation in circuits with nonsinusoidal and asymmetrical voltages and currents.

Leszek S. Czarnecki

BIOGRAPHY

Leszek S. Czarnecki, IEEE Life Fellow, A.M. Lopez Distinguished Professor at Louisiana State University, Titled Professor of Technological Sciences, granted by the President of Poland. He received an M.Sc., Ph.D., and D.Sc. degrees in electrical engineering from the Silesian University of Technology, Poland. For two years he was with the Power Engineering Section, of the National Research Council (NRC) of Canada, as a Research Officer, and for two years with the Electrical Engineering Dept. at Zielona Gora University, Poland. In 1989 Dr. Czarnecki joined the Electrical and Computer Engineering Department of Louisiana State University (LSU), Baton Rouge. For developing a power theory of three-phase systems with nonsinusoidal and asymmetrical voltages and currents and for methods of compensation of such systems he was elected to the grade of Fellow IEEE in 1996. Development of the Currents' Physical Components (CPC) – based power theory which explains all physical phenomena that specify power properties of electrical systems and creates fundamentals for compensation in circuits of any complexity, was the major professional Dr. Czarnecki's contribution to electrical engineering, for which he was nominated to the IEEE Proteus Charles Steinmetz Award. Dr. Czarnecki was decorated by the President of Poland, for his public activity in the United States, aimed at the acceptance of Poland in NATO, with the Knight Cross of the Medal of Merit of the Republic of Poland.

Involved in mountaineering and underwater photography. He climbed, without oxygen support, Lhotse (No. 4 in the World) in the Himalayas (8350m); the main ridge of the Ruwenzori in Africa (19 summits of the average high of 5000m), Kilimanjaro, and Mt. Kenya; traversed on ski (500km) Spitsbergen in the deep Arctic; climbed in Alpes and Andes; climbed solo McKinley, the highest mountain in North America, and traveled to Antarctica.

E_mail: lsczar@cox.com, lczarn1@lsu.edu, Internet Home Page: www.czarnecki.study

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