UNINTERRUPTIBLE POWER SUPPLIES AND ACTIVE FILTERS

Ali Emadi
Abdolhosein Nasiri
Stoyan B. Bekiarov

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Uninterruptible Power Supplies and Active Filters
Ali Emadi, Abdolhosein Nasiri, and Stoyan B. Bekiarov

Preface

In recent years, with the increase of nonlinear loads drawing nonsinusoidal currents, power quality distortion has become a serious problem in electrical power systems. Active filters have been known as an effective tool for harmonic mitigation as well as reactive power compensation, load balancing, voltage regulation, and voltage flicker compensation. On the other hand, uninterruptible power supply (UPS) systems provide uninterrupted, reliable, and high-quality power for vital loads. They, in fact, protect sensitive loads against power outages as well as overvoltage and undervoltage conditions. UPS systems also suppress line transients and harmonic disturbances. Applications of UPS systems include medical facilities, life-supporting systems, data storage and computer systems, emergency equipment, telecommunications, industrial processing, and on-line management systems. Generally, an ideal UPS should be able to deliver uninterrupted power and, simultaneously, provide the necessary power conditioning for the particular power application.

This book describes harmonic-producing loads, effects of harmonics, and harmonic mitigation methods using active filters. Different topologies of active filters and UPS systems, their applications, configurations, control methods, modeling and analysis, and stability issues are also comprehensively discussed.

Recent advancements in the area of power electronics have resulted in a great variety of new topologies and control strategies for active filters and UPS systems. The research has been focused mainly on improving the performance and expanding application areas of these systems. The issue of cost reduction has been attracting the attention of researchers. Reducing the number of switches allows one of the most significant cost reductions. A different technique is replacing controlled switches such as IGBTs, MOSFETs, and thyristors with diodes. Another approach for reducing cost is to develop topologies that employ switches with lower reverse voltage stresses and lower current ratings. This book addresses these new trends in detail.

Ali Emadi
Abdolhosein Nasiri
Stoyan B. Bekiarov

Biography

Ali Emadi received the B.S. and M.S. degrees in electrical engineering with highest distinction from Sharif University of Technology, Tehran, Iran. He also received his Ph.D. degree in electrical engineering specializing in power electronics and motor drives from Texas A&M University, College Station, TX, where he was awarded the Electric Power and Power Electronics Institute (EPPEI) fellowship for his graduate studies. In 1997, he was a lecturer at the Electrical Engineering Department of Sharif University of Technology. Dr. Emadi joined the Electrical and Computer Engineering (ECE) Department of Illinois Institute of Technology (IIT) in August 2000.

Dr. Emadi is the director of Grainger Power Electronics and Motor Drives Laboratories at IIT, where he has established research and teaching laboratories as well as courses in power electronics, motor drives, and vehicular power systems. He is also the co-founder and co-director of IIT Consortium on Advanced Automotive Systems (ICAAS). His main research interests include modeling, analysis, design, and control of power electronic converters/systems and motor drives. His areas of interest also include integrated converters, vehicular power systems, and hybrid electric and fuel cell vehicles.

Dr. Emadi has been named the Eta Kappa Nu Outstanding Young Electrical Engineer for 2003 by virtue of his outstanding contributions to hybrid electric vehicle conversion, for excellence in teaching, and for his involvement in student activities by the Eta Kappa Nu Association, the Electrical Engineering Honor Society. Dr. Emadi is also the recipient of the 2002 University Excellence in Teaching Award from IIT as well as Overall Excellence in Research Award from Office of the President, IIT, for mentoring undergraduate students. He directed a team of students to design and build a novel low-cost brushless DC motor drive for residential applications, which won the First Place Overall Award of the 2003 IEEE/DOE/DOD International Future Energy Challenge for Motor Competition. He is an Associate Editor of IEEE Transactions on Power Electronics and a member of the editorial board of the Journal of Electric Power Components and Systems, the international program committee of Power Generation and Renewable Energy Sources Symposium, the vehicle power and propulsion committee in Vehicular Technology Society of IEEE, and the organizing committee of the Annual Conference on Properties and Applications of Magnetic Materials. Dr. Emadi is the author of more than 130 journal and conference papers as well as three books including *Vehicular Electric Power Systems: Land, Sea, Air, and Space Vehicles* (New York: Marcel Dekker, 2003), *Energy Efficient Electric Motors: Selection and Applications* (New York: Marcel Dekker, 2004), and *Uninterruptible Power Supplies and*

Active Filters (Boca Raton: CRC Press, 2004). He is also the co-author of *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design* (Boca Raton: CRC Press, 2004). Dr. Emadi is also the editor of the *Handbook of Automotive Power Electronics and Motor Drives* (New York: Marcel Dekker, 2005). He is a senior member of IEEE and a member of SAE. He is also listed in the International *Who's Who of Professionals* and *Who's Who in Engineering Academia.*

Abdolhosein Nasiri received the B.S. and M.S. degrees in electrical engineering with distinct honor from Sharif University of Technology, Tehran, Iran. He also received his Ph.D. degree in electrical engineering specializing in power electronics and motor drives from Illinois Institute of Technology, Chicago, Illinois. He was listed in the Who's Who among students in American Universities and Colleges. He joined Baxter Healthcare Corporation in Deerfield, Illinois, as R&D electrical engineer in 2003 and, currently, he is working for ForHealth Technologies in Daytona Beach, Florida, as a senior electrical engineer. Dr. Nasiri has 15 journal and conference papers and is a reviewer of IEEE journal and conference papers. His Ph.D. dissertation was focused on configurations, modeling, and digital control of series–parallel active filter/UPS systems. His areas of interest include power electronic converters, integrated power converters, active filter and UPS systems, switching power supplies, and adjustable speed drives.

Stoyan B. Bekiarov received his M.S. degree in electrical engineering in 1994 from Technical University–Sofia, Bulgaria. From 1994 to 2000, he was employed by the Grocvet-LTD, Bulgaria, as a Project Engineer. He received his Ph.D. degree in electrical engineering specializing in power electronics and motor drives from Illinois Institute of Technology, Chicago, Illinois, in 2004. Dr. Bekiarov is currently a Senior Engineer at C.E. Niehoff & Co. His interests include design and control of power electronic converters and systems, electric power management systems, and brushless alternators for military and heavy-duty automotive systems.

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Uninterruptible power supply (UPS) systems provide uninterrupted, reliable, and high-quality power for vital loads. They, in fact, protect sensitive loads against power outages as well as overvoltage and undervoltage conditions. UPS systems also suppress line transients and harmonic disturbances. Applications of UPS systems include medical facilities, life-support systems, data storage and computer systems, emergency equipment, telecommunications, industrial processing, and on-line management systems.

Generally, an ideal UPS should be able to deliver uninterrupted power while simultaneously providing the necessary power conditioning for the particular power application. Therefore, an ideal UPS should have the following features [1]:

- Regulated sinusoidal output voltage with low total harmonic distortion (THD) independent of the changes in the input voltage or in the load, linear or nonlinear, balanced or unbalanced.
- On-line operation, which means zero switching time from normal to backup mode and vice versa.
- Low THD sinusoidal input current and unity power factor.
- High reliability.
- Bypass as a redundant source of power in the case of internal failure.
- High efficiency.
- Low electromagnetic interference (EMI) and acoustic noise.
- Electric isolation of the battery, output, and input.
- Low maintenance.
- Low cost, weight, and size.

The advances in power electronics during the past three decades have resulted in a great variety of new topologies and control strategies for UPS systems. The research has been focused mainly on improving performance and expanding application areas of UPS systems. The issue of reducing the cost of converters has recently attracted the attention of researchers [2–15]. Reducing the number of switches provides the most significant cost reduction. Another form of cost reduction is to replace active switches such as IGBTs, MOSFETs, and thyristors with diodes. Not only are diodes more reasonable than the controlled switches, but there is also a cost reduction from eliminating gate drivers for active switches and power supplies for gate drivers.

Another way of reducing cost is to develop topologies that employ switches with lower reverse voltage stresses and lower current ratings, which means less silicon and smaller switching losses resulting in lower cost and higher efficiency.

1.1 Classification

UPS systems are classified into three general types: static, rotary, and hybrid static/rotary. In this section, we explain these three categories of the UPS systems.

1.1.1 Static UPS

Static UPS systems are the most commonly used UPS systems. They have a broad variety of applications from low-power personal computers and telecommunication systems, to medium-power medical systems, and to high-power utility systems. Their main advantages are high efficiency, high reliability, and low THD. The inherent problems related to static UPS systems are poor performance with nonlinear and unbalanced loads and high cost for achieving very high reliability. On-line, off-line, and line-interactive configurations are the main types of the static UPS systems [2, 14, 15].

1.1.1.1 On-Line UPS

On-line UPS systems appeared during the 1970s [14]. They consist of a rectifier/charger, a battery set, an inverter, and a static switch (bypass). Other names for this configuration are inverter-preferred UPS and double-conversion UPS [14, 15]. Figure 1.1 shows the block diagram of a typical on-line UPS. The rectifier/charger continuously supplies the DC bus with power. Its power rating is required to meet 100% of the power demanded by the load as well as the power demanded for charging the battery bank. The batteries are usually sealed lead–acid type. They are rated in order to supply power during the backup time, when the AC line is not available. The duration of this time varies in different applications. The inverter is rated at 100% of the load power since it must supply the load during the normal mode of operation as well as during the backup time. It is always on; hence, there is no transfer time associated with the transition from normal mode to stored energy mode. This is the main advantage of the on-line UPS systems. The static switch provides redundancy of the power source in the case of UPS malfunction or overloading. The AC line and load voltage must be in phase in order to use the static switch. This can be achieved easily by locked-phase control loop.

There are three operating modes related to this topology: normal mode, stored energy mode, and bypass mode.

1.1.1.1.1 Normal Mode of Operation

During this mode of operation, the power to the load is continuously supplied via the rectifier/charger and inverter. In fact, a double conversion, that is, AC/DC and DC/AC, takes place. It allows very good line conditioning. The AC/DC converter charges the battery set and supplies power to the load via the inverter. Therefore, it has the highest power rating in this topology, increasing the cost.

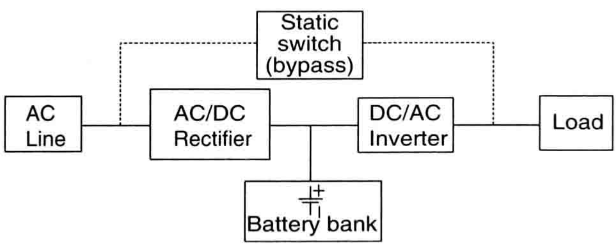

FIGURE 1.1
Block diagram of a typical on-line UPS system.