UNINTERRUPTIBLE POWER SUPPLIES AND ACTIVE FILTERS

Ali Emadi
Abdolhosein Nasiri
Stoyan B. Bekiarov

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To our families

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.

Contents

1

Uninterruptible Power Supplies

CONTENTS

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.

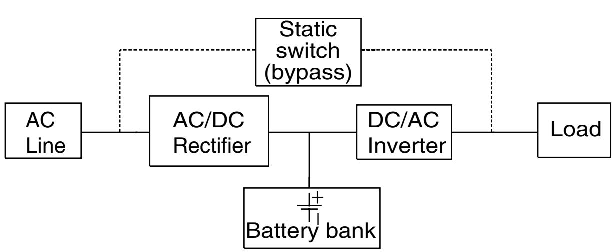

FIGURE 1.1
Block diagram of a typical on-line UPS system.

1.1.1.1.2 Stored-Energy Mode of Operation

When the AC input voltage is outside the preset tolerance, the inverter and battery maintain continuity of power to the load. The duration of this mode is the duration of the preset UPS backup time or until the AC line returns within the preset tolerance. When the AC line returns, a phase-locked loop (PLL) makes the load voltage in phase with the input voltage and after that the UPS system returns to the normal operating mode.

1.1.1.1.3 Bypass Mode of Operation

The UPS operates in this mode in case of an internal malfunction such as overcurrent. This mode is also used for fault clearing. It should be mentioned that the output frequency should be the same as the AC line frequency in order to ensure the transfer of power. In some cases, there can be a maintenance bypass as well. A manual switch usually operates it.

The main advantages of on-line UPS are very wide tolerance to the input voltage variation and very precise regulation of output voltage. In addition, there is no transfer time during the transition from normal to stored energy mode. It is also possible to regulate or change the output frequency [14].

The main disadvantages of this topology are low-power factor, high THD at the input, and low efficiency. The input current is distorted by the rectifier unless an extra power factor correction (PFC) circuit is added; but, this adds to the cost of the UPS system [2]. Because of this inherently low input power factor, the on-line UPS cannot efficiently utilize the utility network and local installation. The low efficiency is inherent to this topology because of the double-conversion nature of this UPS. Power flow through the rectifier and inverter during the normal operation means higher power losses and lower efficiency compared to off-line and line-interactive UPS systems.

Despite the disadvantages, double-conversion UPS is the most preferred topology in performance, power conditioning, and load protection. This is the reason why they have a very broad range of applications from a few kVA to several MVA. This broad range of applications brings a large diversity of topologies in on-line UPS systems [3]. Each topology tries to solve different specific problems and the particular choice depends upon the particular application. However, generally, there are two major types of double-conversion topologies: with a low-frequency transformer isolation and with a high-frequency transformer isolation. Figure 1.2 shows the block diagram of an on-line UPS with a low-frequency transformer isolation at the output.

In this configuration, there is an isolating transformer at the output, which operates at low frequency. This, of course, means a larger transformer. Therefore, this topology is used only in high-power ratings (>20 kVA), where the switching frequency is limited to less than 2 kHz. Apart from the large size of the isolating transformer, the drawback of this topology is high acoustic noise from the transformer as well as the reactor of the output filter [3]. This topology also has a poor transient response to the changes in the load and input voltage.

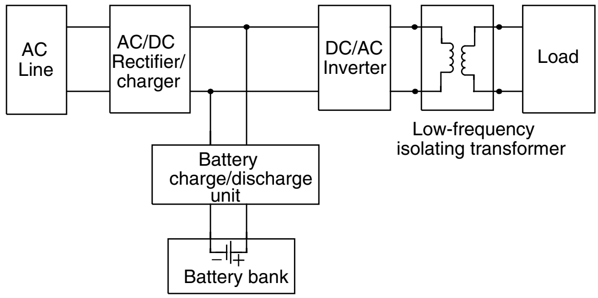

FIGURE 1.2
Block diagram of an on-line UPS with a low-frequency transformer isolation at the output.

By increasing the switching frequency of the inverter above 20 kHz, these problems are solved, except for the size of the isolating transformer, since it is independent of the switching frequency. A topology employing a high-frequency transformer link can significantly reduce the weight and the size of the transformer [3, 16]. The use of high-frequency pulse width modulation (PWM) techniques can additionally reduce the size of the output filter. Figure 1.3 shows the block diagram of an on-line UPS with a high-frequency transformer isolation between the input and the output.

In contrast with the on-line UPS, which drives the load in the normal operating mode, off-line UPS provides power for the load in case of power outage, overvoltage, and undervoltage situations in the AC line.

1.1.1.2 Off-Line UPS

This configuration is also known as the standby UPS or line-preferred UPS [14, 15]. As shown in Figure 1.4, it consists of an AC/DC converter, a battery bank, a DC/AC inverter, and a static switch. A filter may be used at the output of the UPS or inverter to improve the quality of the output voltage. The static switch is on during the normal mode of operation when the AC line is alive. Therefore,

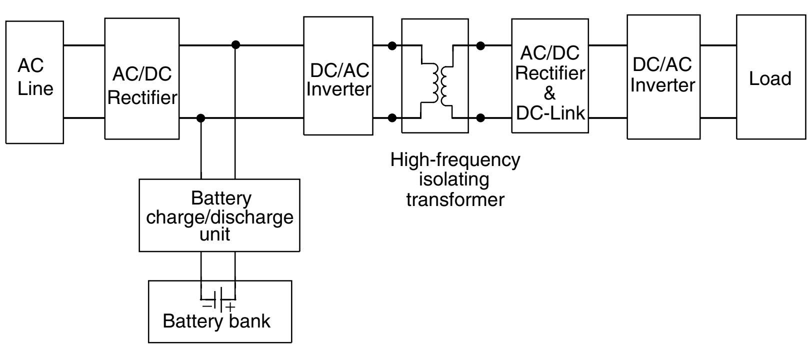

FIGURE 1.3
Block diagram of an on-line UPS with high-frequency transformer isolation.

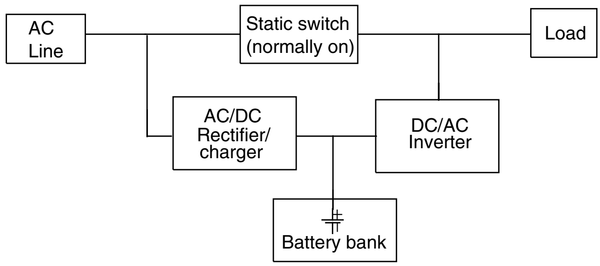

FIGURE 1.4
Block diagram of a typical off-line UPS system.

the load is supplied with power from the AC line directly without any power conditioning. The AC/DC converter charges the battery set. It is rated at a much lower power rating than the rectifier/charger in an on-line UPS since it is not required to meet the power demand of the load. This, in turn, makes the off-line UPS systems more reasonable than the on-line UPS systems. The inverter is rated at 100% of the load's demand. It is connected in parallel to the load and stays standby during the normal mode of operation. It is turned on only when the primary power is out of a given preset tolerance or is not available at all. During this mode of operation, the power to the load is supplied by the battery set via the inverter for the duration of the preset backup time or until the AC line is back again. The duration of the switching time depends on the starting time of the inverter. The transfer time is usually about ¼ line cycle, which is enough for most of the applications such as personal computers.

The DC/AC inverter is conventionally off in this mode. Therefore, an off-line UPS is not usually correcting the power factor. However, in the normal mode of operation, the DC/AC inverter may be used as an active filter to reduce the harmonic content of the line current or improve the power factor of the load. Further modification can also be made to reduce the harmonic content of the sinking current by the AC/DC converter when charging the battery. Yet, these increase the complexity of the system.

There are two operating modes for an off-line UPS system: normal mode and stored-energy mode.

1.1.1.2.1 Normal Mode of Operation

In this mode, the AC line supplies the load via filter/conditioner, which, in fact, is not always required, but often exists. The filter/conditioner depends on the requirements of the particular load and the quality of the AC line power supply. The AC/DC converter charges the battery in this mode in order to provide backup power for the stored-energy mode of operation.

1.1.1.2.2 Stored-Energy Mode of Operation

When the AC line is beyond the preset tolerance or is not available, the load is supplied by the battery set through the inverter for the backup time or until the AC line is available again. The rating of the AC/DC converter has to meet only the charging requirements of the battery, which contributes to the lower cost of this UPS.

The main advantages of this topology are a simple design, low cost, and small size. The line conditioning, when there is such a feature, is passive and the technique is very robust. On the other hand, lack of real isolation of the load from the AC line, no output voltage regulation, long switching time, and poor performance with nonlinear loads are the main disadvantages.

The use of a three-winding transformer, as shown in Figure 1.5, can provide electric isolation for the off-line UPS. This technique has a high reliability at a moderate cost. The transformer allows limited power conditioning for the output voltage as well. The use of a Ferro-resonant transformer leads to a heavier UPS with a lower efficiency [15]. The disadvantages of off-line UPS systems limit their application to less than 2 kVA [3, 14, 15].

1.1.1.3 Line-Interactive UPS

In the 1990s, line-interactive UPS systems were presented [14]. As shown in Figure 1.6, a line-interactive UPS system consists of a static switch, a series inductor, a bidirectional converter, and a battery set.

A line-interactive UPS system can operate either as an on-line UPS or as an off-line UPS. For an off-line line-interactive UPS, the series inductor is not required. However, most of the line-interactive UPS systems operate on-line in order to either improve the power factor of the load or regulate the output voltage for the load.

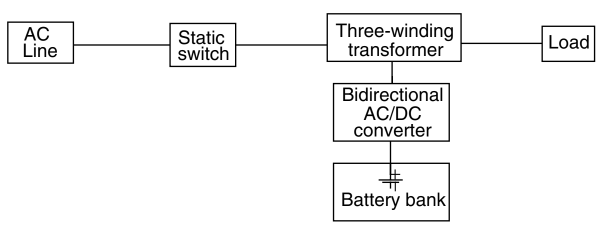

FIGURE 1.5
Block diagram of a typical off-line UPS using a three-winding transformer for electric isolation.

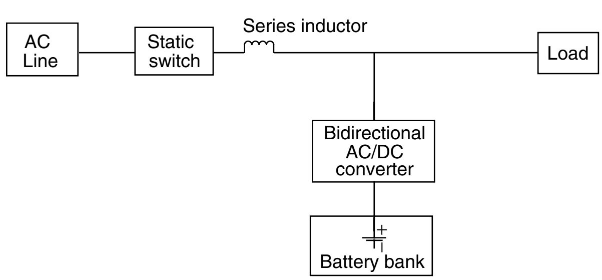

FIGURE 1.6
Block diagram of a typical line-interactive UPS system.

When the AC line is within the preset tolerance, it feeds the load directly. The inverter is connected in parallel with the load and charges the battery. It may also supply the reactive power required to keep the power factor close to unity or to regulate the output voltage [15, 17–20]. As mentioned, this power-conditioning function of the inverter is used only in on-line line-interactive UPS systems. We use the equivalent circuit for the fundamental frequency of a line-interactive UPS system, as shown in Figure 1.7, to explain the power-conditioning function of the inverter.

The amplitude of V_i is determined by the battery voltage and the modulation index m of the PWM converter. Hence, it can be adjusted independent of the AC line voltage. The shift angle δ, between V_1 and V_i, can be varied as well.

We assume that the AC line voltage V_1 is 100% of its nominal, and the output voltage V_i is 100% of its nominal as well. The shift angle δ is determined by the real power demanded by the load.

$$P = \{(V_i\, V_1) \sin \delta\}/j\omega L \tag{1.1}$$

The series inductor voltage drop is designed to be small under normal rated conditions — usually $\delta \cong 15°$. Hence, the power factor is very close to unity under these conditions: $\cos\varphi = \cos(\delta/2)$. The phasor diagram for this case is shown in Figure 1.8.

By assuming a pure resistive load, the inverter supplies only the reactive power necessary to compensate the reactive voltage drop across the series inductor. When the load has a reactive part, the inverter will compensate it

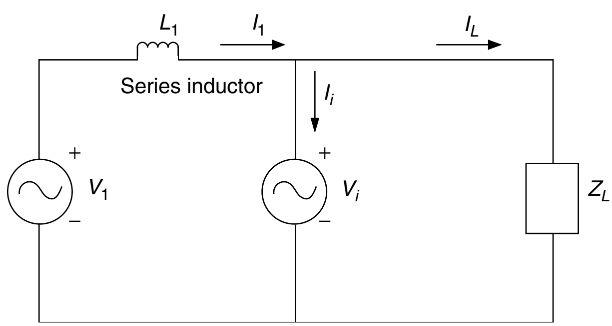

FIGURE 1.7
Equivalent circuit for the fundamental frequency of a line-interactive UPS.

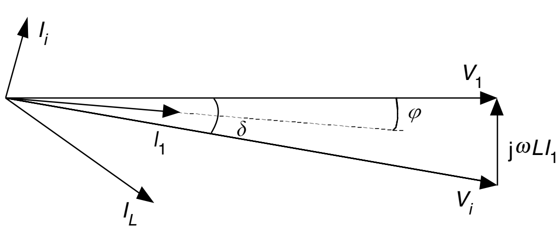

FIGURE 1.8
Phasor diagram for the equivalent circuit of Figure 1.7.

as well. In fact, current drown from the AC line is always sinusoidal and kept in phase with the AC line voltage.

The principle of the output voltage regulation can be easily understood with the help of the phasor diagrams in Figure 1.9. The inverter supplies reactive power for undervoltage and consumes reactive power for overvoltage situations. Since it is desirable to draw only reactive power from the inverter, it is obvious that the power factor deteriorates when a voltage regulation is implemented. When the AC line is not available or is beyond the preset tolerance, the inverter supplies the load with energy from the battery set. As a result, it is rated to meet 100% of the power demanded by the load and the power demanded for charging the battery set. The static switch is turned off to prevent back feed to the AC line.

There are two operating modes for a line-interactive UPS: normal and stored-energy.

1.1.1.3.1 Normal Mode of Operation

The power flow during this mode is from the AC line to the load. The bidirectional converter plays the role of a charger for the battery set. It can also keep the output voltage relatively stabilized and sinusoidal or improve the power factor of the load with a proper PWM control. The current taken from the AC line is mainly the current for the load. In fact, no additional harmonics are injected from the UPS into the AC line. This is an important advantage compared to the conventional on-line double-conversion UPS.

In order to enable better regulation for the output voltage during this mode, a bulk constant voltage transformer can be added to the output; however, it is heavy, large, and expensive [19].

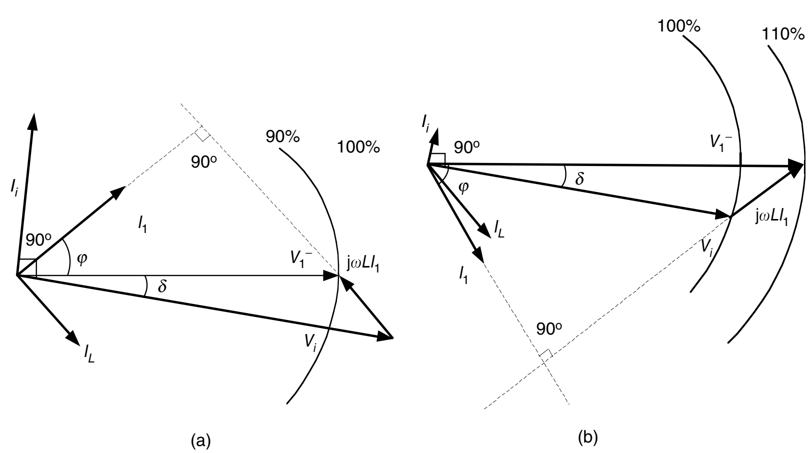

FIGURE 1.9
Phasor diagram for (a) undervoltage and (b) overvoltage situations.

1.1.1.3.2 Stored-Energy Mode of Operation

In this mode, the bidirectional converter operates as an inverter and supplies the load with power from the battery set. The static switch disconnects the AC line in order to prevent back feed from the inverter. The duration of this mode is the duration of the preset backup time or until the AC line returns within the tolerance.

The main advantages of the line-interactive UPS systems are a simple design and, as a result, high reliability and lower cost compared to the on-line UPS systems. They also have good harmonic suppression for the input current. Since this is, in fact, a single-stage conversion topology, the efficiency is higher than that of the double-conversion UPS.

Its main disadvantage is the lack of effective isolation of the load from the AC line. The use of a transformer in the output can eliminate this; but, it will add to the cost, size, and weight of the UPS system. Furthermore, the output voltage conditioning is not good because the inverter is not connected in series with the load. In addition, since the AC line supplies the load directly during the normal mode of operation, there is no possibility for regulation of the output frequency.

The new series–parallel line-interactive topology, called delta-conversion UPS, can simultaneously achieve both unity power factor and precise regulation of the output voltage, which is not possible with a conventional line-interactive UPS. Its configuration is shown in Figure 1.10. It consists of two bidirectional converters connected to a common battery set, static switch, and a series transformer. The series bidirectional converter is rated at 20% of the output power of the UPS and it is connected via a transformer in series with the AC line. The second bidirectional converter is the usual inverter for a line-interactive UPS connected in parallel to the load and rated at 100% of the output power. The parallel converter keeps output voltage stable and precisely regulated by PWM control. The series converter compensates any differences between output and input voltages. It also controls the input power factor to unity and, at the same time, controls the charging of the battery. When the AC line is within the preset tolerance, most of the power is

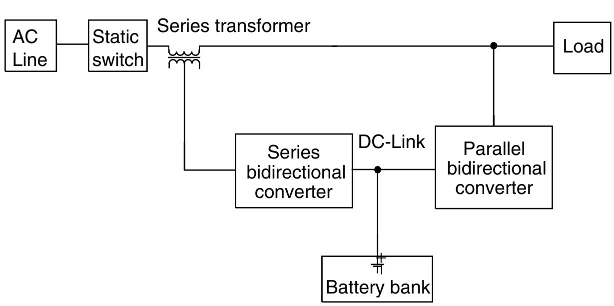

FIGURE 1.10
Block diagram of a typical series–parallel line-interactive (delta-conversion) UPS.

supplied directly from the AC line to the load. Only a small part of the total power, usually up to 15%, flows through the series and parallel converters. This power is needed to compensate for any differences between the input and the output voltages and to make the input power factor unity. Since an important portion of the power (about 85%) flows without any conversion from the AC line to the load, the efficiency of this UPS is relatively high. Therefore, the delta-conversion UPS is used in high-power rating applications, where the efficiency is a key factor. However, the complicated control of this topology limits its applications. Another disadvantage is the lack of electrical isolation of the load from the AC line.

1.1.2 Rotary UPS

A typical rotary UPS is shown in Figure 1.11. It consists of an AC motor, a DC machine, an AC generator, and a battery bank. Electric machines are mechanically coupled. There are two operating modes: normal and stored energy. During the normal mode of operation, the AC line supplies the AC motor, which drives the DC machine. The DC machine drives the AC generator, which supplies the load. During the stored energy mode of operation, the battery bank supplies the DC machine, which in turn drives the AC generator. The AC generator supplies the load.

The rotary UPS systems are more reliable than the static UPS systems. However, they require more maintenance and have a much larger size and weight. But, they have many advantages making them desirable in high-power applications. One of the advantages of the rotary UPS systems is that the transient overload capability is 300 to 600% of the full load for rapid fault clearing. The transient overload capability for the static UPS systems is typically 150% for a short term. The performance of the rotary UPS systems with nonlinear loads is good because of the low output impedance. The input current THD is very low, typically 3% or less. The electromagnetic interference (EMI) is also low. The efficiency is usually 85% or higher [21, 22].

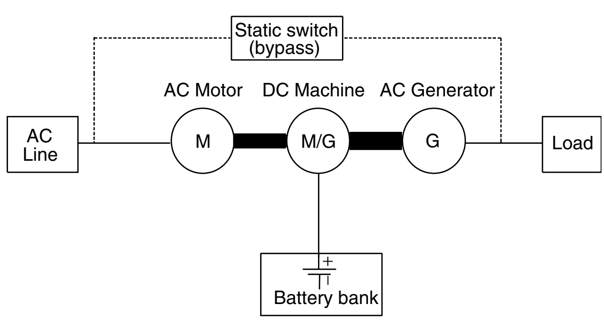

FIGURE 1.11
Block diagram of a typical rotary UPS system.

1.1.3 Hybrid Static/Rotary UPS

Hybrid static/rotary UPS systems combine the main features of both static and rotary UPS systems. They have low output impedance, high reliability, excellent frequency stability, and low maintenance cost. These are because of the missing mechanical commutator [21, 22]. In Figure 1.12, a typical hybrid static/rotary UPS is depicted. It consists of a bidirectional AC/DC converter, an AC motor, an AC generator, a battery bank, and a static switch.

During the normal mode of operation, the AC motor is fed from the AC line and drives the generator. The AC generator supplies the load. The bidirectional converter, which behaves as a rectifier, charges the battery.

During the stored-energy mode of operation, the inverter supplies the AC generator from the battery set through the AC motor. In fact, the bidirectional converter, which behaves as an inverter, drives the AC motor. The AC motor drives the generator supplying the load. When an internal malfunction in the UPS system occurs, the static switch (bypass) is turned on and the load is supplied directly from the AC line. However, since the AC line and output voltage are not synchronized, the transition is not transient-free.

The AC generator is started on utility power to avoid starting current overloads allowing the inverter to be rated for the normal operation. After the AC generator is on, the AC line is disconnected and the supply to the AC generator is given by the inverter. It is relatively easy because of the large inertia of the AC generator. This configuration has the advantage that the transfer from the AC line to the inverter takes place under controlled conditions instead of under fault conditions when different undesired conditions can influence the transfer. Another good point is that the inverter is always on, allowing no transfer time for switching to the stored-energy mode of operation [21].

The main advantages of this UPS over the static UPS include low output impedance, low THD with nonlinear loads, higher reliability, and better isolation. Hybrid UPS systems are usually used in very high-power applications, that is, several hundreds kVA.

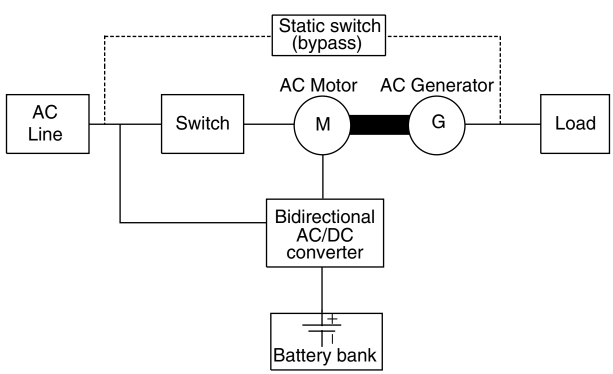

FIGURE 1.12
Block diagram of a typical hybrid static/rotary UPS.