# REDUCED-PARTS SINGLE-PHASE UNINTERRUPTIBLE POWER SUPPLY

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**Abstract – Reducing the number of switches and passive elements in uninterruptible power supply topologies not only reduces the cost of the whole system but also provides some other advantages such as greater compactness, smaller weight, and higher reliability. Generally, the largest cost reduction is achieved by reducing the number of switches employed in a converter power circuit. Another way of reducing the cost of converters is to use a topology that allows replacing active switches, such as IGBTs, MOSFETs, and thyristors, with diodes. Diodes are less expensive than active switches and apart from this, there is also a cost reduction from eliminating all the circuitry for driving active switches.**

**Keywords: uninterruptible power supply, pulse-width modulation (PWM), low total harmonic distortion (THD).**

## 1. INTRODUCTION

Uninterruptible power supplies (UPS's) are designed to supply clean and uninterrupted power to equipment in critical applications such as computers, medical/life support systems, industrial controls, etc. under essentially any normal or abnormal utility power conditions, including outages for up to 15 min. In order to be able to supply power in the absence of input to the power source, the UPS employs some form of bulk energy-storage mechanism. Most UPS systems use batteries, usually lead acid, for this purpose. Other schemes may employ the mechanical inertia of a large flywheel coupled to the shaft of a rotating machine or the stored magnetic energy in the field of a super-conducting coil. Maintenance-free gel batteries are the most widely used storage devices because of their portability and low-maintenance requirements. The conversion process between ac and dc storage is typically electronic, although some systems use rotating machinery in combination with solid state converters for this purpose.

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:

- Regulated sinusoidal output voltage with low total harmonic distortion (THD) independent of the changes in the input voltage or in the load, linear or non-linear, 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 two decades have resulted in a great variety of topologies and control strategies for UPS systems. The research has been focused mainly on improving performance and expanding application areas of the UPS systems. Reducing the number of switches provides the most significant cost reduction. Another form of cost reduction is to replace active switches such as IGBT-s, MOSFET-s, 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.

UPS systems are classified into three general types: static, rotary, and hybrid static/rotary. 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 are poor performance with non-linear 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.

## II. ON-LINE UNINTERRUPTIBLE POWER SUPPLY (UPS)

They consist of a rectifier/charger a battery set, an inverter, and a static switch (bypass). Other name for this configuration are inverter-preferred UPS and double-conversion UPS. Figure 1 shows the block diagram of a typical on-line UPS.

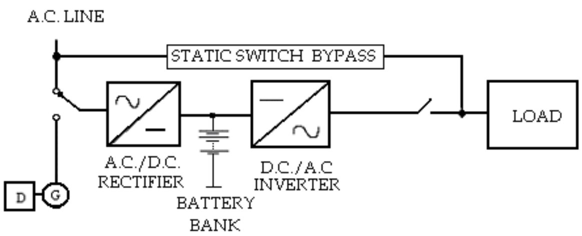



*Figure 1*
*Block diagram of a typical on-line UPS system*

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.

### *A. 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.

### *B. 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.

### *C. Bypass Mode of Operation*

The UPS operates in this mode in case of an internal malfunction such as over-current. 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.

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. 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 KAV to several MVA. This broad range of applications brings a large diversity of topologies in on-line UPS systems. 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.

## III. CONCEPT OF REDUCED-PARTS CONVERTERS APPLIED TO SINGLE-PHASE ON-LINE UPS SYSTEMS

A typical single-phase on-line UPS system based on full-bridge converters is shown in figure 2.

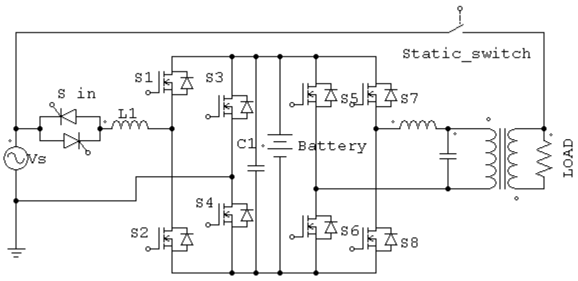



*Figure 2*
*Typical single-phase on-line UPS system based on full-bridge converters*

Applying the concept of reducing the number of switches to the UPS system based on full-bridge converters naturally leads to the UPS systems based on half-bridge converters shown in figure 3.

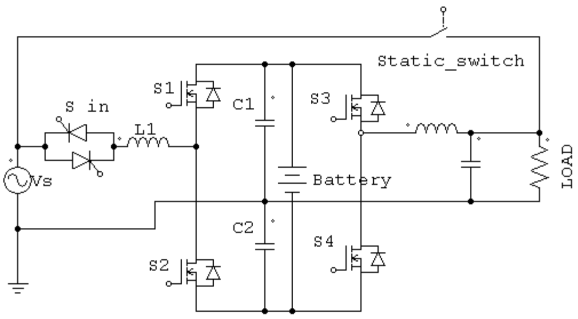



*Figure 3*
*Typical single-phase on-line UPS system based on half-bridge converters*

The UPS system based on full-bridge converters has some advantages over the one based on half-bridge converters, such as better utilization of the DC-link voltage, two times lower voltage stresses across the switches, and an option of zero state for the switches, which allows using more advanced control strategies. These advantages make the UPS system from figure 2 the preferable choice for medium and high-power applications. However, the disadvantage is that it has a large number of switches. It also requires an isolation transformer at the back-end, which is bulky, heavy and expensive. This is why the UPS system based on half-bridge converters from figure 3 is the preferable choice for low-power applications. It not only has two times lower the number of switches than the UPS topology from figure 2 but it also has a common neutral for the input and the output, eliminating the need for an isolation transformer.
One of the most important features of UPS systems is their reliability and availability. The component that influences these characteristics most considerably is the battery. As mentioned previously, there are two options for connecting batteries in UPS systems. The first is to connect them directly in parallel with the DC-link capacitors, which leads to several problems, such as: space, cost, reliability, and safety issues. The second is to add a bi-directional DC/DC converter. An on-line UPS system, based on half-bridge converters using a bi-directional DC/DC converter is shown in figure 4.

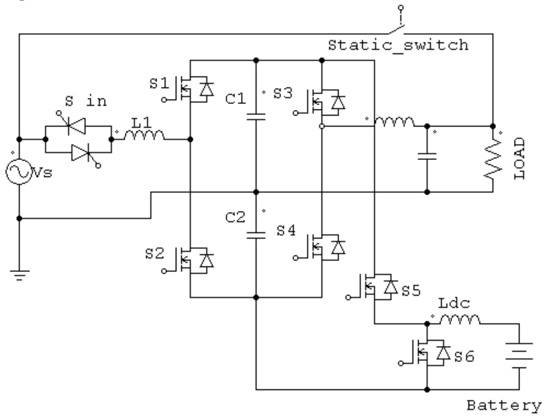



*Figure 4*
*Typical single-phase on-line UPS system based on half-bridge converters with bi-directional DC/DC converter*

During the normal mode of operation, the buck converter charges the battery bank and at the same time the power to the load is continuously supplied from the AC line through the rectifier, to the inverter, and finally to the load. Switches S1 to S5 are active, while switch S6 is idle.
During the stored-energy mode of operation, when the AC input voltage is beyond a preset tolerance, switch $S_{in}$ disconnects the UPS system from the grid. The DC/AC inverter and the battery bank maintain continuity of power to the load. Since the battery voltage is low, it first requires to be boosted to a high DC voltage for proper operation of the DC/AC inverter. Switch S6 is active during this operation mode as well as the inverter's switches S3 and S4. The rectifier does not work during this mode and its switches S1 and S2 are idle.

## IV. REDUCED-PARTS SINGLE-PHASE ON-LINE UPS SYSTEM

Careful consideration of the UPS system from figure 4 reveals that switch S6 can be eliminated, as long as the low battery voltage can be boosted to a high DC voltage. Taking advantage of the fact that the AC/DC rectifier is of a boost type and it is not in use during the stored-energy mode of operation, it is possible to eliminate switch S6 by charging the topology of the UPS system from figure 4 in such a way that the rectifier leg is used as a part of a DC/DC boost converter during the stored-energy mode of operation. Apart from eliminating switch S6, the use of the rectifier as a boost DC/DC converter during the stored-energy mode of operation relaxes the current rating requirements for the inductor in the DC/DC converter. As a result, the inductor is significantly smaller, lighter and less expensive. The proposed new single-phase on-line UPS system with a reduced number of switches is shown in figure 5.

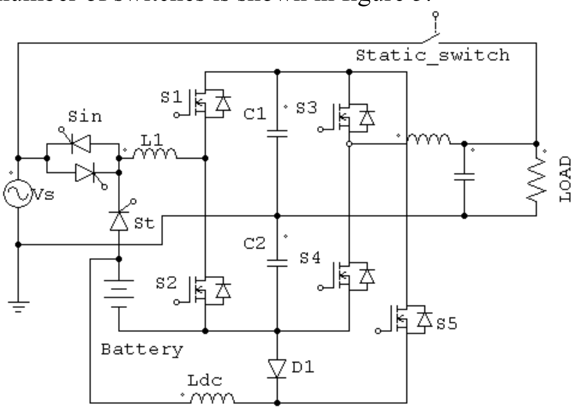



*Figure 5*
*Proposed new single-phase on-line UPS system with reduced number of switches*

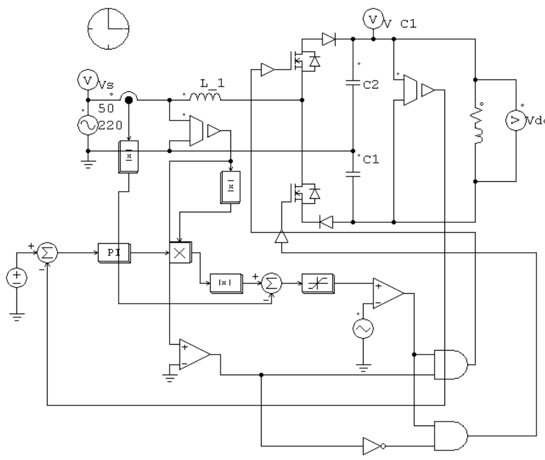
The new single-phase on-line UPS system, shown in figure 5, has a front-end AC/DC rectifier, with power factor correction capabilities, a DC/AC inverter, a step-down DC/DC converter, a battery bank, an input switch $S_{in}$, a transfer switch $S_t$ in the form of a thyristor, and a bypass static switch. The AC/DC rectifier consists of an input inductor L1, switches S1 and S2, and two electrolytic capacitors C1 and C2. The purpose of the rectifier is to keep the input current sinusoidal and in phase with the input AC voltage, while maintaining the required DC bus voltage at a level necessary for proper operation of the back-end inverter. The DC/AC inverter consists of a split DC bus, and switches S3 and S4, as well as an output LC filter. It operates in a high-frequency sinusoidal pulse width modulation (SPWM) pattern in order to provide a high-quality sinusoidal output voltage.
The front-end AC/DC rectifier work in the following way. During the positive half cycle of the input AC voltage, when switch S2 is on, the expression for the voltage across the input inductor L1 is derived from the second Kirchhof's law:

$$V_{L1} = L_1 \frac{di_s}{dt} = V_s + V_{C2} \qquad (1)$$

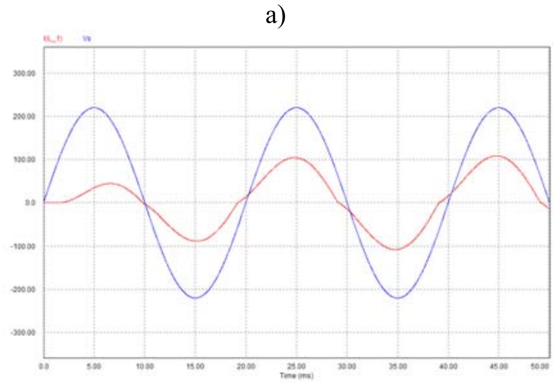
The voltage applied across the input inductor is positive; hence, the inductor current increases.
When switch S2 is turned off, the inductor current needs to continue flowing in the same direction. The only possible current path in this case is $V_s^+$ - $L_s$ – reverse diode of S1 – C1- $V_s^-$. The upper capacitor C1 is charged with the energy stored in inductor L1.
The voltage across the input inductor L1, is:

$$V_{L1} = L_1 \frac{di_s}{dt} = V_s - V_{C1}. \qquad (2)$$

Extensive computer simulations have been carried out, using PSIM simulation software. The input AC voltage Vs and current $I(L_1)$ in figure 6 show that the input current $I(L_1)$ is a sine wave in phase with the input voltage resulting in excellent power factor.




a)



b)
*Figure 6*
*Simulation Results*

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