ADVANCED MULTILEVEL UPS

to Delivering Green and Best-in-Class Power Quality for Critical Applications

Current and future demands in critical facilities are driving power quality technologies towards greener specifications. To achieve true green power quality for critical applications, this article reports an uninterruptible power supply (UPS) that features an advanced multilevel power converter. The proposed circuit design is very suitable for UPS applications and results in unparalleled double conversion efficiency (97%) and dramatic size/weight reduction. Critical facility engineers can benefit from the multilevel UPS to reduce cost of ownership, ensure availability and optimize project design. This article provides a discussion about multilevel converters and their benefits in UPS applications. Test results using a 750kVA-prototype confirm the improvement in efficiency and the high performance of this multilevel UPS.

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I. INTRODUCTION

A critical facility requires an environmental controlled room and space to accommodate various electronics equipments as well as a high availability power supply system. To meet the current and future requirements of this type of high-level infrastructure, the online double conversion UPS is the preferred solution due to its highest level of power quality and proven reliability against all types of line disturbances (voltage spike, sag, swells, noise, frequency variation, harmonic distortion, utility voltage and so on). On the other hand, this type of UPS usually exhibits lower efficiency when compared with other configurations such as the standby and the line-interactive technology. Nowadays, with the rising cost of energy and growing environmental concerns, critical facility engineers are more concerned with the cost of ownership and hence the UPS efficiency.

Recently, online UPS has featured transformerless design to reduce the efficiency gap between this technology and others. A transformerless design also promotes significant size/weight reduction that is also an important characteristic since some UPS systems are installed in expensive facilities such as data centers.

To further improve the efficiency of UPS systems without compromising the power quality, multilevel converters have emerged as a strong candidate for future circuit topology in high efficiency uninterruptible power supplies. This article discusses and examines the design and realization of an online double conversion UPS that features an advanced multilevel power converter. In comparison with a conventional design, the proposed UPS exhibits superior double conversion efficiency (97%) and dramatic size/weight reduction. In fact, the multilevel UPS constitutes an effective contribution to critical facilities by delivering high power quality and true green efficiency at the same time.

II. CIRCUIT CONFIGURATION

A single line diagram of a double conversion UPS is shown in Figure 1. In the normal operation, the AC power from the input line is converted into DC power and then the inverter converts this DC power back to a clean AC power to the load. Because the nature of this operation ensures unmatched protection against all types of power quality problems, the online double conversion UPS is the recommended solution for powering mission-critical facilities.

The novel type multilevel UPS described in this article comprises a PWM (pulse width modulated) AC-DC converter, a PWM inverter, a bidirectional chopper circuit, a DC-link circuit and input and output LC filters. In addition, this UPS has a transformerless design, which promotes reduction of losses and hence increases the overall efficiency. Commercial implementation of three-phase double conversion transformerless UPS has been reported previously [1]. In the proposed UPS, in instead of using a conventional two-level circuit topology, a multilevel configuration is employed to achieve higher efficiency in online double conversion UPS systems. To understand the benefits of the multilevel topology in UPS systems, a comparison of these two circuit configurations is shown throughout this Section.

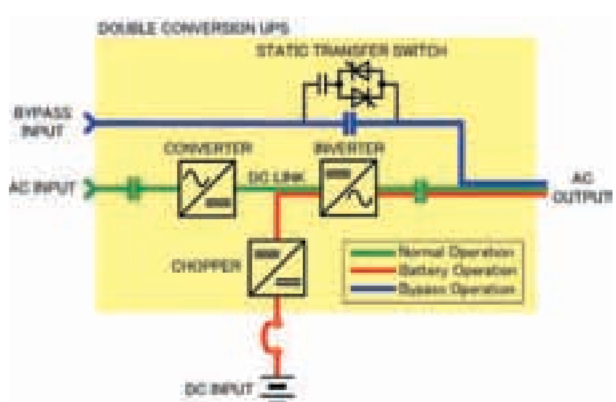

Figure 1 Single line diagram of a double conversion UPS.

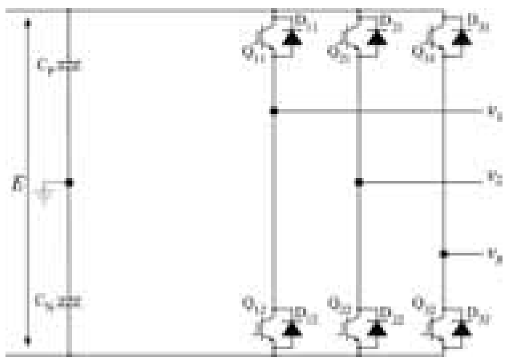

Figure 2 A two-level power converter.

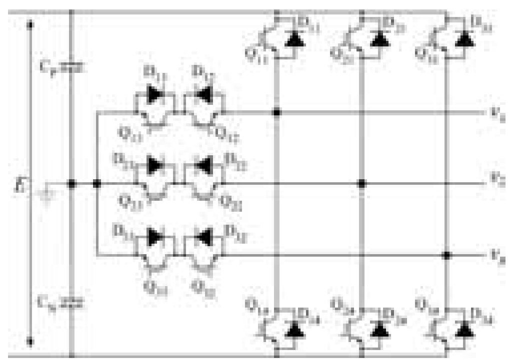

Figure 4 Advanced multilevel power converter.

Figure 3 Line-to-line voltage in a two-level converter.

Figure 5 Line-to-line voltage in a three-level converter.

A. Conventional Circuit Topology in UPS Systems

The conventional topology for power converters in UPS systems is the two-level configuration as shown in Figure 2. In this configuration, note that,

- the voltage stress on each switch can be as high as the DC voltage E;
- the voltage variation (dv/dt) at the terminals (v1, v2, v3) is equal to E (between –E/2 and +E/2).

Figure 3 shows an illustrative line-to-line voltage (train of variable width pulses) at the converter terminals of a power converter using a two-level topology. To obtain a clean sinusoidal waveform as required for UPS systems, filtering using bulky reactors is required to suppress high frequency components.

B. Multilevel Circuit Topology in UPS Systems

The arrangement of the switches in a multilevel circuit topology enables the access to intermediate potentials of the DC-link voltage. Many different topologies [2] have been proposed for this purpose including the neutral-point clamped (NPC) [3]; capacitor clamped [4]; and cascaded multicell [5]. This article introduces an advanced multilevel power converter that is very suitable for UPS applications. Figure 4 shows this advanced multilevel circuit in a three-level configuration i.e., each voltage terminal can output three different potentials (+E/2, 0 and –E/2). In comparison with a two-level power converter, there is a presence of a bidirectional switch that enables the output of the middle potential of the DC link voltage E. Additionally, thanks to the bidirectional switch, note that

- the voltage stress on each switch is the half of the DC voltage E;
- the voltage variation (dv/dt) at the terminals (v1, v2, v3) is equal to E/2 (between –E/2 and 0, and 0 and +E/2).

Figure 5 shows an illustrative line-to-line voltage at the converter terminals of a three-level power converter. Note that the resulting train of pulses tracks the sinusoidal waveform closer than in the case of a two-level converter. In addition, there is a significant noise reduction (acoustic noise and electromagnetic interference) due to the lower dv/dt at the converter terminals.

III. BENEFITS OF MULTILEVEL CONVERTERS IN UPS SYSTEMS

A. Size/Weight Reduction

The improvement in waveform synthesis by using a multilevel topology results in considerable size/weight reduction of UPS systems since this configuration requires a smaller filter to obtain a clean sinusoidal waveform. Figure 6 is a simulation result showing the inverter current waveform for: a) a two-level inverter with a 0.05 p.u. filter reactor; b) a three-level inverter with a 0.05 p.u. filter reactor; and c) a two-level inverter with a 0.10 p.u. filter reactor. Harmonic spectrum of the inverter current for each case in shown in Figure 7, where fs is the switching frequency. These results show

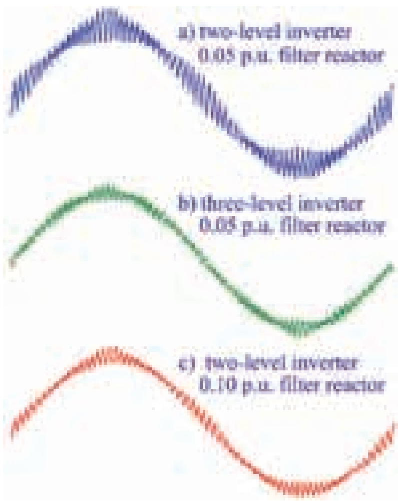

Figure 6 Inverter current for a: a) two-level circuit with a 0.05p.u. filter reactor; b) three-level circuit with a 0.05p.u. filter reactor; and c) two-level circuit with a 0.10p.u. filter reactor.

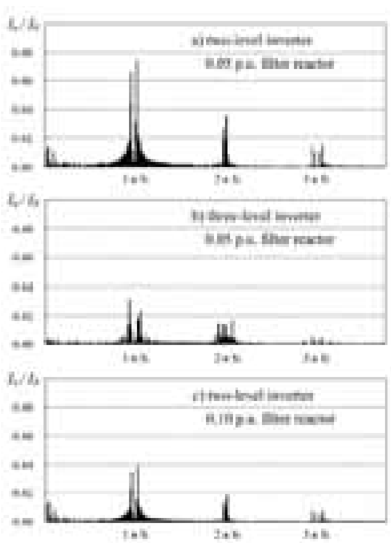

Figure 7 Harmonic spectrum of the inverter current for a: a) two-level circuit with a 0.05p.u. filter reactor; b) three-level circuit with a 0.05p.u. filter reactor; and c) two-level circuit with a 0.10p.u. filter reactor.

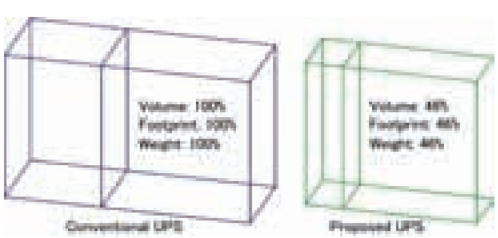

Figure 8 Dimensional comparison for a 750kVA UPS.

that a two-level converter requires a larger reactor to match the current ripple and harmonic spectrum performance of a three-level converter. In a UPS system, it implies a dramatic size/weight reduction. In fact, as shown in Fig. 8, overall volume, footprint and weight for a 750kVA unit are reduced by more than half in comparison with a conventional UPS with the same ratings. Therefore, multilevel UPS requires less space and infrastructure and ensures more room for maintenance and layout reconfiguration.

B. Higher Efficiency

Despite the fact that a three-level converter presents higher number of components, the overall UPS efficiency actually increases in comparison with the two-level topology. Since a UPS system operates at a high switching frequency, semiconductor losses are due mainly to the on/off operation of the power switches. In a semiconductor device like an IGBT, switching losses are a function of the switching frequency, the voltage across the device, the collector current, and the junction temperature. Thanks to the bidirectional switch, the voltage stress on the power switches is one half in comparison with a conventional two-level converter. Thus, for a given switching frequency, current and junction temperature, three level converters reduce the switching losses. As a result, in a typical UPS design, this advanced multilevel converter reduces the semiconductor losses about 40%. This reduction in losses contributes to the improvement in equipment reliability and long-term lifespan due to lower electrical stresses on power switches and lower heat rejection.

IV. TEST RESULTS

Typical test results of a 750kVA-prototype using the proposed multilevel converter are shown in Figures 9 and 10. The specifications of the tested UPS equipment are shown in Table I. Figure 9 shows the operation of the proposed UPS for an applied step load change. A rated load with unity power factor was switched on and off and the UPS output voltage is maintained constant. Fig. 10 shows the operation of the proposed UPS in the case of input power failure. Output voltage remains constant due to the backup provided by the DC power supply.

TABLE I. SPECIFICATIONS OF THE TESTED UPS EQUIPMENT

AC Input	Voltage	480V +15%, -20%
	Circuit configuration	3-phase, 3-wire
	Frequency	60Hz ± 10%
	Power Factor	Greater than 0.99
	Current harmonic distortion	Less than 3% at 100% load
AC Output	Voltage	480V
	Circuit configuration	3-phase, 3-wire
	Frequency	60Hz ± 0.01%
	Rated Load Power Factor	Unity
	Voltage regulation	Less than 1%
	Voltage transient response	2% (100% step load)
	Recovery time	Less than 20ms
	Voltage distortion	Less than 2% for linear loads Less than 5% at non-linear loads
	Overload capability	125% for 10 minutes 150% for 1 minute
DC Input	Voltage range	400 – 540V

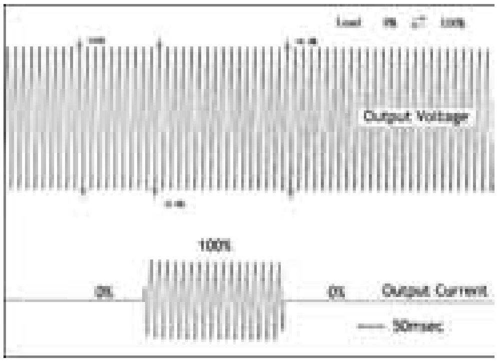

Figure 9 Output waveforms for a step load change.

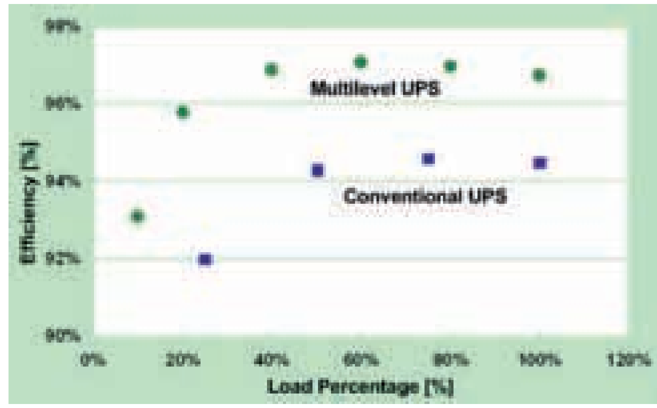

Figure 11 Efficiency curves for a 750kVA UPS.

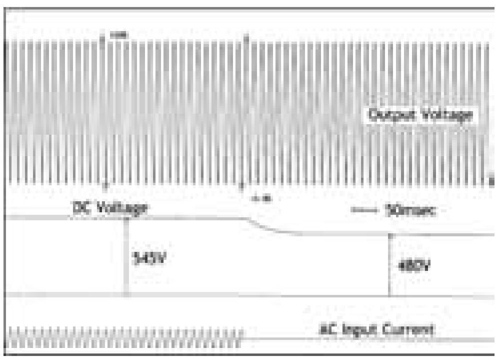

Figure 10 Output waveforms for an input power failure.

Double conversion efficiencies of the proposed UPS are shown in Figure 11. In comparison with a conventional UPS, the proposed UPS exhibits a superior efficiency (97%) due to the circuit topology and transformerless design. Note that even for light loads (around 10%) the efficiency of the multilevel UPS is higher than 93%. Thus, the proposed UPS is also suitable for redundant multiple module system where the individual load in each UPS is below 100%.

V. CONCLUSIONS

Critical facility engineers can benefit from the green characteristics of double conversion multilevel UPS to reduce cost of ownership, ensure power availability and optimize project design. The multilevel UPS features higher efficiency due to the substantial reduction of the semiconductor losses and magnetic components. In addition, a multilevel UPS exhibits a dramatic size/weight reduction leaving more room for maintenance and layout reconfiguration Test results confirm the green energy conversion and the high performance required for mission-critical facilities.

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