Letters to the Editor

Comparisons of PWM and One-Cycle Control for Power Amplifier With Multilevel Converter

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Abstract—Based on the concepts of cascade multilevel converters and one-cycle technique, comparisons are conducted to characterize the distortion of the pulsewidth modulation (PWM) and one-cycle control methods that were applied to converters. Simulation results for the different control schemes are obtained in PSIM software initially to see the effect of one-cycle control different from that of PWM control. Through the comparisons, the advantages and disadvantages are identified for each method. The one-cycle scheme is better than PWM control in reducing undesirable harmonics and tracing dynamic waveforms. Simulation and experimental results are also provided to verify the conclusions.

Index Terms—Multilevel converter, one-cycle control, power amplifier, pulsewidth modulation (PWM).

I. INTRODUCTION

With the development of switching circuits and control strategies, it is increasingly possible to introduce power electronic techniques into the field of power amplifiers so that higher power rating and better quality can be obtained. In retrospect, multilevel converters were actively used to improve the performance of motor drives and power systems. An evident feature of this topology is to reduce harmonic components. Pulsewidth modulation (PWM) control has been usually used to eliminate harmonics, but there are still many unwanted harmonics existing under PWM control. One-cycle control that makes switched amplifiers acceptable has been developed for undesired harmonic rejection and distortion reduction. The nuclear idea of one-cycle control is forcing the switched variable exactly equal to the reference signal while PWM control makes the switched variable equal to the input signal in a whole period. In order to compare the two control methods experimentally, the contribution of applying them to the same main circuit is conducted. This letter presents a digital-signal-processor (DSP)-based control board and a nine-level cascade inverter as a power circuit that supports both control methods. Also, this letter describes the simulation procedure and experimental setup, and shows the simulation and experimental comparisons.

II. COMBINATION OF NINE-LEVEL INVERTER AND ONE-CYCLE CONTROL

One-cycle concept will be used to realize the modulation of the output waveform instead of PWM. The purpose of this concept is to reject unwanted harmonics and trace the transient waveforms well. The kernel is integrating the output until the integration value reaching
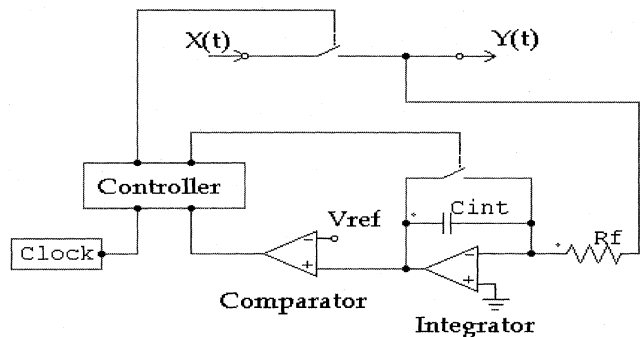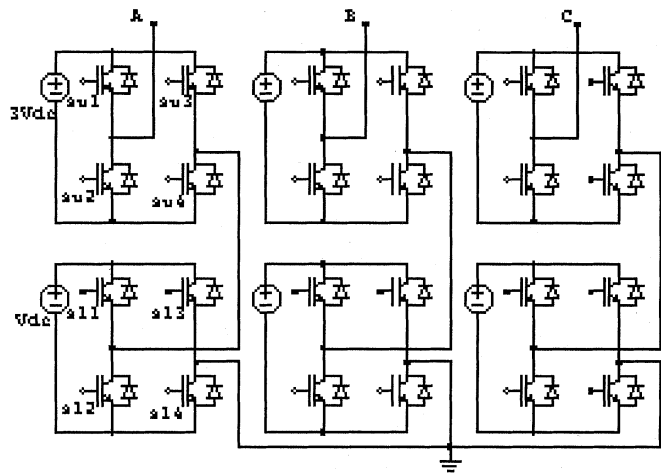
Fig. 1. One-cycle circuit.

Fig. 2. Novel nine-level three-phase inverter.

the reference signal. The key components of one-cycle controlling circuits are an integrator and a comparator, which are shown in Fig. 1.

Since the main circuit has nine levels, there are more choices and difficulties for control implementation. While the power circuit fires, the control circuit limits the output within two adjacent levels in order to use one-cycle control principles. If the integration does not reach the reference value, the output is switched to the higher level. Once the integration reaches the reference, the control circuit switches the output to the lower level. Thus, the one-cycle control is combined with the nine-level topology in this application.

The comparisons between PWM and one-cycle control are set on a new nine-level converter. Fig. 4 shows the nine-level converter with two full bridges connected in series. When the nine-level converter is used for a power amplifier, it can reach high power with high efficiency and low harmonics distortion.

As seen from Fig. 2, insulated gate bipolar transistors (IGBTs) are chosen as switching devices for their high switching frequency. The lower full-bridge converter can produce three levels of $-V_{dc}$, 0, V_{dc}, and the upper full-bridge converter can produce $-3V_{dc}$, 0, $3V_{dc}$. Thus, appropriate switch combinations are able to engender nine levels such as $(+/-)4V_{dc}$, $(+/-)3V_{dc}$, $(+/-)2V_{dc}$, $(+/-)V_{dc}$, and 0. Note that each switch of the upper full bridge is only switched once per cycle, but each switch of the lower full bridge is switched several times per cycle.
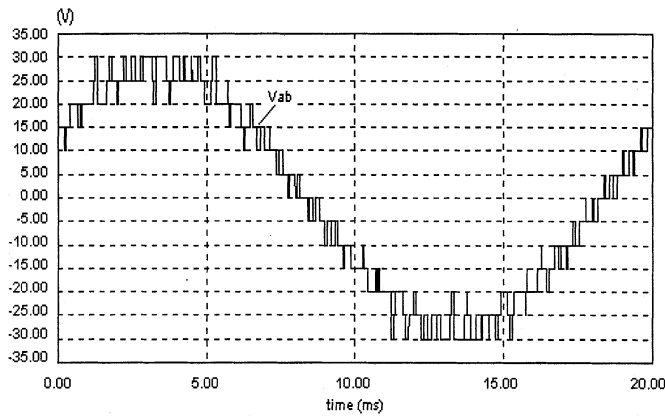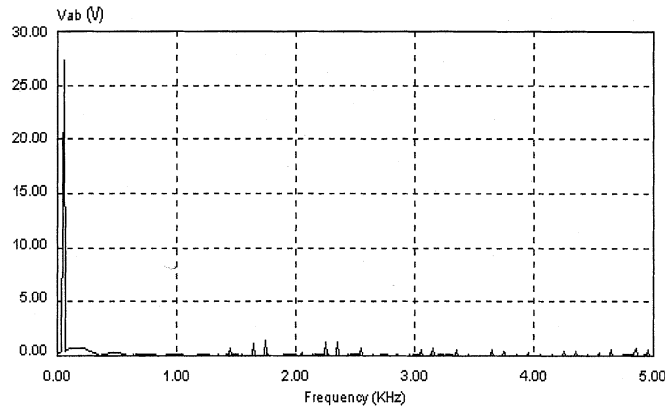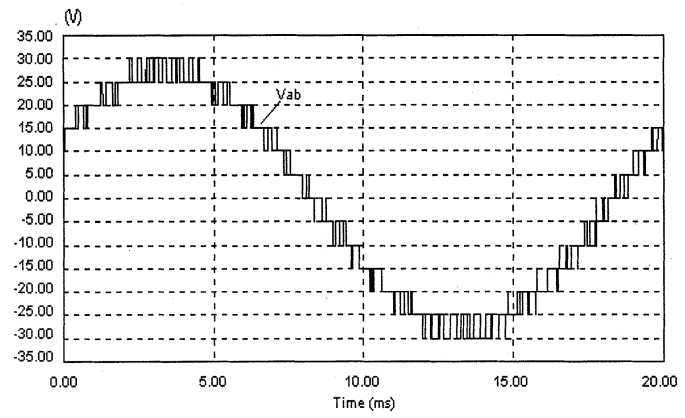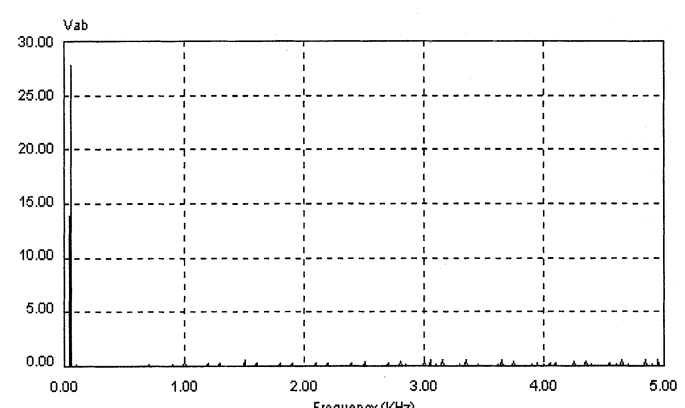
Fig. 3. Voltage waveform under SPWM control. (a) Line–line voltage waveform. (b) Harmonic spectrum of the line–line voltage.

Fig. 4. Voltage waveform under one-cycle control. (a) Line–line voltage waveform. (b) Harmonic spectrum of the line–line voltage.

III. SIMULATION AND EXPERIMENTAL RESULTS

The comparative results are derived from two origins: one is simulation in PSIM software, and the other is a real experimental set.

A. Simulation Results

The simulation results for different control can be seen in Figs. 3 and 4. The waveform under one-cycle control is apparently closer to a sinusoidal waveform than the output under PWM control. One-cycle control further improves the waveform on the basis of PWM control that can obviate most unwanted harmonics. This verifies the idea that one-cycle control can break the limitation PWM control has.

B. Experimental Results

The experimental results of the output under PWM control are shown in Fig. 5 and there is a delay of nearly 1 ms for a 110-Hz reference sinusoidal voltage. The output voltage has nine levels to approximate sinusoidal signals well while the modulation concentrated on the top step enforced the performance of multilevel inverters. Fig. 6 shows the experimental result of output under one-cycle control that demonstrates the fast dynamic response. There is almost no delay between the reference signal and the output. As to the waveform, the output voltage is better than that of PWM control because it seems smoother and has modulated steps besides the top step.

C. Fast Fourier Transform (FFT) Analysis

The results from FFT analysis for different output waveforms are shown in Figs. 7 and 8. It is obvious that the amplitude-frequency characteristic of one-cycle control is much better than that of PWM control.
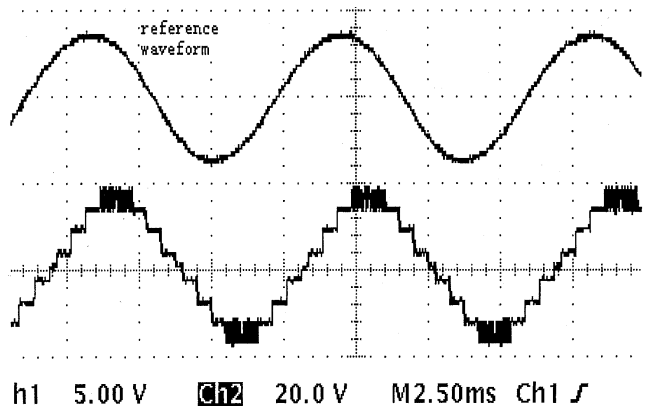

Fig. 5. Output waveform under PWM control.

PWM control still has some undesired harmonics such as 450 Hz for a fundamental frequency of 113 Hz. In the case of one-cycle control, the FFT result is smoother and has no harmonic contents in the PWM control.

IV. CONCLUSIONS

1) One-cycle control is better than PWM control in improving waveform quality. Simulations and experiments show that one-cycle control can suppress the perturbation yielded by the dc source and abate the undesired harmonic contents which exist under PWM control to make output closer to the reference signal.
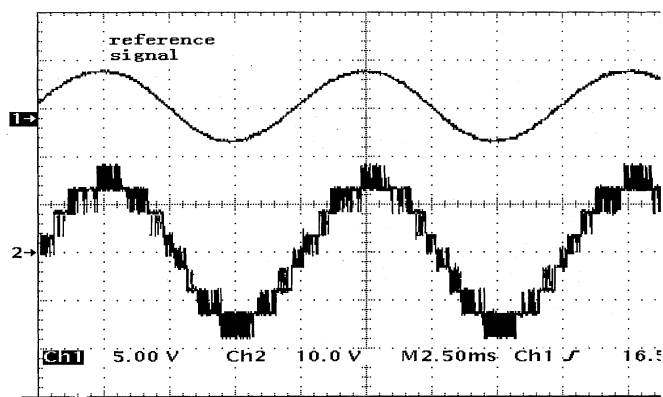
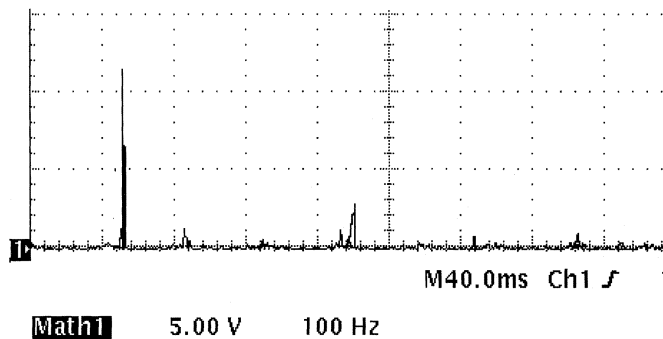Fig. 6.   Output waveform under one-cycle control.
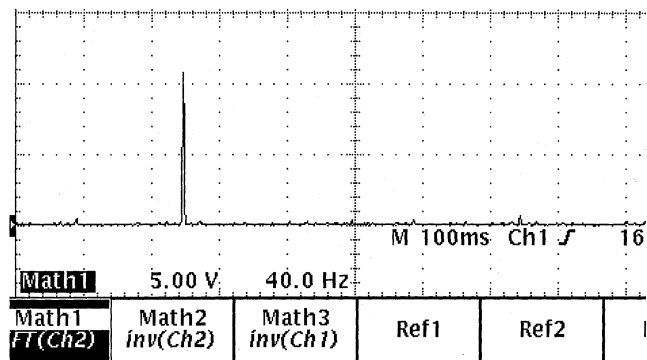

Fig. 7.   FFT result of PWM output.

Fig. 8.   FFT result of one-cycle output.

2) One-cycle is better than PWM control in tracing transient waveforms. Through the experiments, one-cycle control shows its better performance than PWM control in the dynamic response. There exists shorter delay between reference signal and output than that in the PWM control.

3) One-cycle is more general than PWM control. One-cycle control can approximate arbitrary waveforms that can be dc, ac, or those strange waveforms without any regulation such as transient fault voltages in power systems. PWM control depends on the modulation signal requiring specific consideration. The generality of one-cycle control is also tightly connected to its high-speed response.

4) One-cycle is more complex than PWM control in hardware. To realize the algorithm of one-cycle control, a high-speed inte-

grator, either digital or analog, should be used. However, PWM control does not need any integrators.

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Loss Minimization in Vector-Controlled Interior Permanent-Magnet Synchronous Motor Drives

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Abstract—An efficiency optimization method for vector-controlled interior permanent-magnet synchronous motor drives is presented. Based on theoretical analysis, a loss minimization condition that determines the optimal d-axis component of the armature current is derived. Selected experimental results are presented to validate the effectiveness of the proposed control method.

Index Terms—Adjustable-speed drives, efficiency optimization, interior permanent-magnet (PM) motor, loss minimization.

I. INTRODUCTION

Improvement of permanent-magnet (PM) motor efficiency is a most important priority, hence, several control methods have been proposed in order to reduce the loss of PM motor drives and improve their performance. This can be realized by an online control of the d-axis component of the stator current (I_d). In surface PM motor drives, copper loss is minimized by keeping the d-axis component of the stator current equal to zero ($I_d = 0$) [1], [2]. Thus, a maximum torque-per-ampere current control is accomplished. Since the "$I_d = 0$ control" prevents the demagnetization of the PM, it is often employed in interior PM motor drives. However, in "$I_d = 0$ control" method the reluctance torque is not produced. Contrarily, reluctance torque can be produced by controlling the I_d current according to load conditions. Thus, the I_d current that provides maximum torque-per-ampere current ratio in interior PM motor drives, is a function of the I_q current and opposes the excitation field of the PM [1]–[4].