

Neutrally Clamped PWM Inverter

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Technical Field

The present invention relates to a pulse width modulated inverter and more particularly to a neutrally clamped pulse width modulated inverter.

Background of the Art

A known pulse width modulated (PWM) inverter includes a center tapped power supply with positive and negative terminals, the center tap being connected to neutral or ground. The positive and negative terminals are connected to a low pass output filter through respective switches which may be transistors or the like. The inverter switches are controlled to alternately conduct current to the output filter, the switches providing a pulse width modulated waveform to the filter, which in response thereto, provides an AC output which is applied to a load.

The pulse width modulated waveform applied to the output filter typically has a voltage swing of the rail-to-rail voltage of the inverter power supply over each half-cycle of the output. In order to provide the desired AC output, a very large output filter is typically required to accommodate the large rail-to-rail voltage swing of the pulse width modulated waveform from the inverter. Where the inverter is to be used in applications where weight is critical, such as on an aircraft, the use of such large filters is extremely undesirable.

Another problem with known PWM inverters is their capacity to accept regenerative currents. In applications where the load is reactive, the power supply of the inverter typically includes capacitors for

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accepting all regenerative currents. Even with a near unity power factor load, if the load current is continuous because of the output filter, the capacitors must still accept regenerative currents. The power supply capacitors must therefore be quite large, increasing the weight of the inverter which is undesirable for many applications.

Disclosure of the Invention

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The invention provides an inverter for providing an output voltage in the form of a pulse width modulated waveform to a filter having an AC output with positive and negative half-cycle, the inverter comprising a power supply with a rail-to-rail voltage thereacross, and further comprising:

coupling means operable during predetermined intervals for clamping the output voltage to be applied to the filter to ground to provide a pulse width modulated waveform having a voltage swing of one-half of the rail-to-rail voltage over each of the half-cycles.

The invention also provides an inverter which includes a first switch alternately conductive and nonconductive during the formation of the positive half-cycle of said AC output and a second switch alternately conductive and nonconductive during the formation of the negative half-cycle of said AC output, the clamping means being operable when both the first and second switches are nonconductive.

5 Preferably the PWM output voltage is established by a controlled first switch alternately conductive and non-conductive during the formation of the positive half-cycle of the AC output, and a controlled second switch alternately conductive and non-conductive during the formation of the second half-cycle of the AC output. The coupling means is controlled to be operable to clamp the output voltage to ground when the first and second switches are non-conductive, or to ground any regenerative load currents during intervals when those currents are regeneratively induced from the load.

15 The inverter of the invention preferably includes, as a clamping means, a bidirectional switch which, when turned on, clamps on the voltage to be applied to the inverter output filter to neutral or ground to provide a pulse width modulated waveform having a voltage swing of only one-half of the rail-to-rail voltage of the inverter over each half-cycle of the output. Such as bidirectional switch, when turned on, advantageously also provides a path to ground for any regenerative current flowing from the load so as to enable the regenerative current capacity of the power supply to be reduced.

25 In a preferred embodiment, the invention provides a DC to AC inverter comprising:
a centre-tapped DC power source with positive and negative terminals, the centre tap being connected to neutral;

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a filter for converting a pulsed input to a pulse width modulated AC output,

5 a first switch connected between the positive terminal and the filter, the first switch, when turned on, providing a positive input pulse to the filter,

a second switch connected between the negative terminal and the filter, the second switch, when turned on, providing a negative input pulse to the filter,

10 a bidirectional switch connected across said filter, the bidirectional switch, when turned on, providing a short circuit between the first and second switches and neutral, and

control means for controlling the first, second and
15 bidirectional switches, the control means alternately turning on the first switch and the bidirectional switch to provide to the filter one or more pulses having amplitudes which swing from zero to said positive voltage to provide the positive half-cycle of said AC output, and
20 the control means alternately turning on the second switch and the bidirectional switch to provide to the filter one or more pulses having amplitudes which swing from zero to the negative voltage to provide the negative half-cycle of the AC output.

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The invention allows the attenuation requirement of the inverter output filter to be reduced by at least 50% since the voltage swing of the pulse width modulated waveform is only one-half of the rail-to-rail voltage of
30 the inverter. Further, the power supply capacitors may be substantially reduced in size since they need not accept all of the regenerative current. The reduction in size of the output filter and power supply capacitors results in an inverter which is sufficiently lightweight
35 for applications where weight is critical.

Brief Description of the Drawings

Figure 1 is a schematic diagram of one phase of the neutrally clamped PWM inverter of the present invention; Figures 2A-E are waveforms illustrating the operation of the neutrally clamped PWM inverter of Figure 1; and Figures 3A-D are waveforms illustrating the operation of prior art PWM inverters.

Best Mode for Carrying out the Invention

10 The inverter, as shown in Figure 1, provides a pulse width modulated waveform at point A to a low pass output filter 10 which is comprised of an inductor 11 and capacitor 12, the filter having an AC output at point A' which is applied to a load 14. The inverter includes a
15 centre tapped power supply generally designated 16 having a DC source 17 connected to terminal 18 for providing a positive DC voltage, $+V_{DC}$, and having a DC source 19 connected to a terminal 20 to provide a negative DC voltage, $-V_{DC}$, the centre tap 22 being connected to
20 neutral or ground. The output filter 10 and load 14 are coupled between the neutral centre tap and the positive and negative power supply terminals 18 and 20 through a pair of series connected transistors 24 and 26 which are controlled to provide the pulse width modulated waveform
25 at point A. Diodes 28 and 30 are connected in parallel across the respective transistors 24 and 26 to provide a path for regenerative currents flowing in the respective directions of the arrows 32 and 34. The power supply 16 is provided with a pair of capacitors 36 and 38 which are
30 connected in parallel with the sources 17 and 19, the capacitors accepting a small amount of regenerative current as discussed below.

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The inverter includes a bidirectional switch 40 which is coupled across the output filter 10 to provide a short circuit thereacross, clamping the voltage at point A to neutral or ground whenever the switch is turned on. The
5 bidirectional switch 40 includes a transistor 42 and diodes 44, 46, 48 and 50 connected in a bridge. The collector of the transistor 42 is connected between the cathodes of diodes 44 and 46, the diode 44 having its anode connected to the neutral centre tap 22 and the diode
10 46 having its anode connected to point A. The emitter of the transistor 42 is connected between the anodes of the diodes 48 and 50, the diode 48 having its cathode connected to the neutral centre tap 22 and the diode 50 having its cathode connected to point A. When the
15 bidirectional switch 40 is turned on by the application of base current to the transistor 42, the switch can conduct current in either a first direction through the diode 44, transistor 42 and diode 50 or a second direction through the diode 46, transistor 42 and diode
20 48 to provide a short circuit across the output filter 10.

The inverter also includes a controller 52 for turning each of the transistors 24, 26 and 42 on and off so as to
25 produce a pulse width modulated waveform at point A which will provide the desired AC output from the filter 10 to point A' to be applied to the load. The

controller 52 outputs a plurality of control signals to the base of each of the transistors 24, 26 and 42 to turn the transistors on and off. An example of the respective waveforms applied to the transistors 24, 26 and 42 is shown in Figs. 2A-2C. From these waveforms it is seen that during the period of 0-180°, the transistor 24 is alternately turned on and off by the waveform of Fig. 2A; the transistor 26 is turned off; and the transistor 42 is turned on by the waveform of Fig. 2C whenever the transistors 24 and 26 are turned off. Similarly, during the period of 180°-360°, the transistor 26 is alternately turned on and off by the waveform of Fig. 2B; the transistor 24 is turned off; and the transistor 42 is turned on by the waveform of Fig. 2C whenever the transistors 24 and 26 are turned off.

When the transistor 24 is turned on during the formation of the positive half-cycle of the AC output at point A', the voltage at point A is approximately equal to the positive DC source voltage, $+V_{DC}$, ignoring any voltage drop across the transistor. When the transistor 24 is turned off and the transistor 42 is turned on, the bidirectional switch 40 forms a short circuit across the filter 10, current flowing into point A through the diode 50, the transistor 42 and the diode 44 to the neutral center tap 22, clamping the voltage at point A to approximately neutral or ground. The transistors 24 and 42 are alternately turned on to provide at point A a plurality of positive pulses such as the three pulses illustrated in Fig. 2D, to form the positive half-cycle of the AC output as shown in Fig. 2E. Because of the neutral clamp provided by the bidirectional switch 40, each pulse of the pulse width modulated waveform at point

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A has a voltage swing of only zero to $+V_{DC}$ over the positive half-cycle of the AC output.

When the transistor 26 is turned on during the formation of the negative half-cycle of the AC output at point A', the voltage at point A is approximately equal to the negative DC voltage, $-V_{DC}$, again ignoring any voltage drop across the transistor. When the transistor 26 is turned off and the transistor 42 is turned on, the bidirectional switch 40 forms a short circuit across the filter 10, current flowing through the diode 46, the transistor 42 and the diode 48, clamping the voltage at point A to neutral or ground. The transistors 26 and 42 are alternately turned on to provide, at point A, a plurality of negative pulses such as the three pulses illustrated in Fig. 2D to form the negative half-cycle of the AC output shown in Fig. 2E. Because of the neutral clamp provided by the switch 40, each pulse of the pulse width modulated waveform at point A has a voltage swing of zero to $-V_{DC}$ over the negative half-cycle of the AC output.

Prior art PWM inverters are similar to the inverter shown in Fig. 1 but do not include the bidirectional switch 40. Such prior art inverters are controlled by the waveforms shown in Figs. 3A-B wherein the two inverter transistor switches Q2 and Q3 are alternately turned on over each half-cycle, from 0-360°, so that one transistor is always on while the other is off. Controlling the two transistor switches as shown in Figs. 3A-B results in a pulse width modulated waveform, as shown in Fig. 3C, having a rail-to-rail voltage swing of $+V_{DC}$ to $-V_{DC}$ over each half-cycle of the sine wave output as shown in Fig. 3D.

The bidirectional switch 40 of the present invention, when turned on, clamps the voltage at the input to the filter 10, point A, to neutral or ground so as to reduce the voltage swing at point A to one-half of the rail-to-rail voltage over each half-cycle of the output. Because the voltage swing of the pulse width modulated waveform provided at point A is reduced over each half-cycle of the output, the attenuation requirement of the output filter 10 may be reduced by at least 50%.

The bidirectional switch 40 also provides a path to neutral or ground for any regenerative current flowing during the time the bidirectional switch is turned on. With an inductive load having a lagging power factor, regenerative current flows from the load in the direction of the arrow 32 during the 0-90° portion of the output waveform at point A'. Regenerative current also flows from the load in the direction of the arrow 34 during the 180°-270° portion of the output waveform. The bidirectional switch 40, when turned on, provides a path to ground for any regenerative current flowing from the load so that for an inductive load, the power supply capacitor 36 must accept regenerative current only when during the 0-90° portion of the output when the transistor 24 is on and the capacitor 38 must accept regenerative current only during the 180°-270° portion of the output waveform when the transistor 26 is on. Since the capacitors 36 and 38 do not accept all of the regenerative current, they may be substantially reduced in size.

The reduction in size of the output filter 10 and the capacitors 36 and 38 due to the operation of the bidirectional switch 40 results in a lightweight inverter which may be used in applications where weight is a

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critical factor, such as in an aircraft or the like. The neutrally clamped PWM inverter, although shown having a pulse width modulated waveform with only three pulses per half-cycle, may be used to provide any desired number of
5 pulses per half-cycle. Further, although the inverter is shown for only a single phase, the neutrally clamped PWM inverter will work for any number of phases.



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CLAIMS:

1. An inverter for providing an output voltage in the form of a pulse width modulated waveform to a filter having an AC output with positive and negative half-cycle, the
5 inverter comprising a power supply with a rail-to-rail voltage thereacross, and further comprising:

coupling means operable during predetermined intervals for clamping the output voltage to be applied to the filter to ground to provide a pulse width modulated waveform
10 having a voltage swing of one-half of the rail-to-rail voltage over each of the half-cycles.

2. An inverter according to claim 1 which includes a first switch alternately conductive and nonconductive during the
15 formation of the positive half-cycle of said AC output and a second switch alternately conductive and nonconductive during the formation of the negative half-cycle of said AC output, the clamping means being operable when both the first and second switches are nonconductive.

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3. An inverter for providing an output voltage in the form of a pulsed width modulated waveform to a filter having an AC output applied to a load, the inverter comprising:

25 a power supply that has a rail-to-rail voltage thereacross, and comprises means for accepting regenerative load currents; and

coupling means operable during predetermined intervals for clamping the output voltage to be applied to the filter
30 to ground and simultaneously providing a path to ground for regenerative load currents during said interval, whereby a pulse width modulated waveform is provided having a voltage swing of one half of the rail-to-rail voltage over each of the half-cycles, and a path to ground is provided for
35 regenerative load currents during the predetermined

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intervals to reduce the regenerative current coupled to the power supply.

4. An inverter according to claim 3, further including a
5 first switch alternately conductive and nonconductive to provide the positive half-cycle of the AC output and a second switch alternately conductive and nonconductive to provide the negative half-cycle of the AC output, the coupling means being operable during the intervals when
10 both the first and second switches are nonconductive.

5. A DC to AC inverter comprising:
a centre-tapped DC power source with positive and negative terminals, the centre tap being connected to
15 neutral,

a filter for converting a pulsed input to a pulse width modulated AC output,

a first switch connected between the positive terminal and the filter, the first switch, when turned on, providing
20 a positive input pulse to the filter,

a second switch connected between the negative terminal and the filter, the second switch, when turned on, providing a negative input pulse to the filter,

a bidirectional switch connected across said filter,
25 the bidirectional switch, when turned on, providing a short circuit between the first and second switches and neutral, and

control means for controlling the first, second and bidirectional switches, the control means alternately
30 turning on the first switch and the bidirectional switch to provide to the filter one or more pulses having amplitudes which swing from zero to said positive voltage to provide the positive half-cycle of said AC output, and the control means alternately turning on the second switch and the
35 bidirectional switch to provide to the filter one or more



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pulses having amplitudes which swing from zero to the negative voltage to provide the negative half-cycle of the AC output.

5 6. An inverter according to claim 5, wherein the control means turns the first switch on and off a number of times with the second switch turned off to provide the positive half-cycle of the AC output, the bidirectional switch being turned on by the control means whenever the first and
10 second switches are turned off.

7. An inverter according to claim 5 or claim 6, wherein the control means turns the second switch on and off a number of times with the first switch turned off to provide
15 the negative half-cycle of the AC output, the bidirectional switch being turned on by the control means whenever the first and second switches are turned off.

8. An inverter according to any of claims 5 to 7 wherein
20 each of said first and second switches are transistors.

9. An inverter according to any of claim 5 to 8, wherein the bidirectional switch includes a transistor.

25 10. An inverter according to claim 9, wherein the transistor of the bidirectional switch is connected to a diode bridge to allow current flow in either a first or second direction when the transistor is turned on.

30 11. An inverter according to any of claim 5 to 10, wherein the bidirectional switch, when turned on, clamps the voltage applied to the filter to neutral.

12. An inverter according to any of claim 5 to 11, wherein
35 the bidirectional switch provides a path to neutral for any

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regenerative current flowing during the time the
bidirectional switch is turned on.

13. A DC-to-AC inverter substantially as described herein
5 with reference to figures 1 and 2 of the drawings.
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