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A MULTILEVEL INTEGRAL CONTROL TECHNIQUE FOR REACHING HIGH OUTPUT VOLTAGE AND COMPENSATING NON-IDEAL DC INPUT EFFECT

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ABSTRACT

Output voltage and current of an inverter is based on the assumption that the DC input is ideal and ripple free. Indeed, DC input sources are not ideal and the ripple of the DC input can affect the output voltage and current. It can make low order harmonics that are severe to filter. On the other hand, by industry developing, high voltage inverters are mostly needed. This paper proposes a multilevel integral control inverter which can solve both non-ideal DC input and high output voltage problems. The technique is based on sensing the voltage of switches for feed forwarding and compensating the non-ideal effect of the DC input source, however, multilevel procedure is used to make a high voltage output. These two techniques are used for the first time together and the result is shown in this paper. A simulation of three-level diode-clamped integral control inverter has been proposed in this paper.

Keywords: multilevel inverter, integral control inverter, diode-clamped multilevel inverter.

INTRODUCTION

Non-ideal DC input can make low order harmonics and affects output voltage and current of inverters. Non-ideal DC input ripple can be controlled by using low frequency filters. As is shown in Figure-1, a low frequency filter is used to compensate the non-ideal effect of the DC input source.

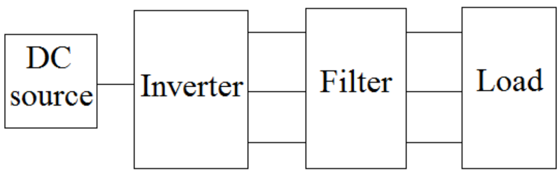

Figure-1. Compensating the non-ideal effect of a dc input source by using filter.

Using filters as a compensator is not efficient because filters are big in size and expensive. Therefore, new methods have been used to compensate this effect. In some articles a method called voltage integral control technique is used as a compensator [1-3].

Cascade H-Bridge multi-level inverters (CMLI) use several separated DC sources to synthesize desired stepwise output voltage waveform. In reference [4-5] the new topology of CMLI used as control technique. In this topology sets of full bridge modules are connected in series to generate controllable staircase output voltage waveforms. Each module acts as a conventional inverter to contribute three-level in the output phase voltage.

The ability of cascade multi-level inverters to obtain an almost sinusoidal waveform which its magnitude, phase and frequency are adjustable develops their applications in flexible AC transmission systems (FACTS), machine drives, active filters and interfaces of renewable energy sources and static compensators [6-8].

On the other hand, by industry developing, usage of high voltage inverters is increasing day to day. But power electronic switches can tolerate a specific amount of voltage. Though, some new techniques are proposed for generating high output voltage. Multilevel inverter (MLI) is a method for generating high AC output voltage [9-12].

In this paper, a method which can generate high voltage output and, also, compensate the non-ideal effect of DC input source is proposed. A three-level diode-clamped integral control inverter is simulated in this paper.

THE STRUCTURE OFVOLTAGE INVERTER USING INTEGRAL CONTROL

This structure is based on an integral control of output voltage in a certain frequency in order to ensure the sinusoidal volt-second without considering the DC input. Standard SPWM technique has an open-loop structure in which a switching pattern is used for comparing reference sinusoidal signal with a modulating signal. The integration can be changed by the ripple of DC input. Whenever the integrated DC input reaches the reference signal, it resets. Though the DC input can affect the pulse width. The PWM model using integral control is a function of non-linear DC input and the pulse width, generated by comparing with a sinusoidal reference, will lead to a sinusoidal volt-second output. Therefore, this modulator can compensate the DC input ripple and improve the voltage quality without any complex control circuit. In [1] single phase and three phase integral control technique inverters has been studied.

Single phase half bridge inverter

In Figure-1a, a closed-loop structure, a voltage sensor, detects the output voltage of bottom switch (Q_2) and a resettable integrator produces an ascending voltage - that contains information about DC ripple- which is compared with a sinusoidal reference.

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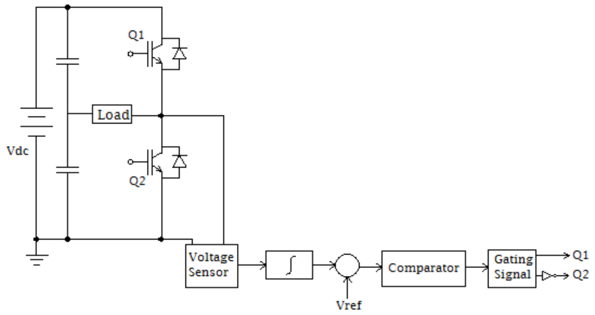

Figure-1a. Integral control for a half-bridge single phase inverter.

In Figure-1a it is assumed that DC input voltage is ripple free. In order to simulate this ripple a low peak to peak AC voltage source is used after DC input. The gating signal of the IGBT switches, used in this circuit, is generated by feed forwarding from the bottom switch (Q_2) voltage. This procedure is generating a gating signal that depends on DC input voltage and its ripple, therefore non-linear effects of DC input source will be compensated. Gating signal circuit by integrating of the bottom switch voltage can include the information of DC input. The integrator used in this circuit can be reset externally and whenever the integrated voltage of DC input reaches the reference voltage, reset signal will be sent.

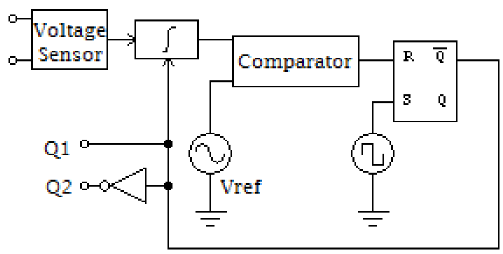

Figure-2. Gating signal circuit, feed forward from the bottom switch.

In Figure-2 integrated DC input and reference voltages are compared in a comparator, whenever these two voltages are equal the comparator sends a signal to a flip-flop. By receiving this signal, the S-R latch resets and toggles the gating signal. The square voltage source frequency is equal to the switching frequency and should be set manually. The integrator output waveform for a half bridge inverter is shown in Figure-3. Voltage waveform of bottom switch (Q_2) and gating signal of this switch are illustrated in Figure-4 and Figure-5, respectively.

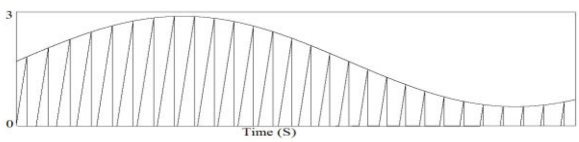

Figure-3. Integrator output waveform for single phase half bridge inverter.

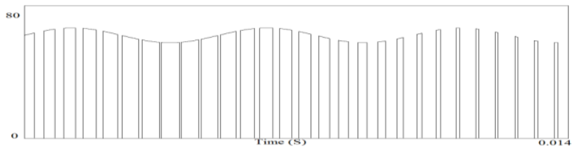

Figure-4. Voltage waveform of bottom switch (Q2).

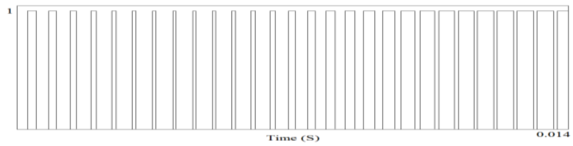

Figure-5. Gating signal of bottom switch (Q2).

Three phase inverter

In figure-6 a three-phase inverter is illustrated. In this circuit, DC input is 70V, switching frequency is 1980Hz, reference frequency is 60Hz, Gain of voltage sensor is 0.06 and DC offset voltage of reference is 2V with frequency of 200Hz.

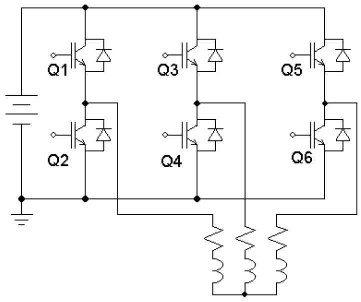

Figure-6. Three-phase inverter.

For generating the gating signal of each leg, voltage of bottom switch in each leg is used. Line-line voltage and line-line current waveforms of three phase load are shown in Figure-7, Figure-8, respectively.

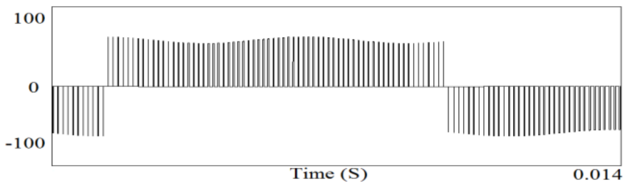

Figure-7. Line-line voltage of load waveform.

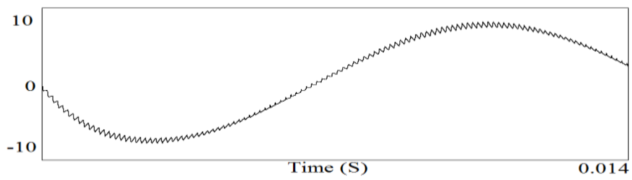

Figure-8. Line-line current of load waveform.

In order that the integrator works efficiently, time constant of integrator should be less than a particular quantity. Supposed that reference voltage and output voltage of integrator are like below [1]:

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$$V_{ref} = V_{bias} + V_m * Sin(2\pi f t)$$

$$V_{int} = \frac{K_s * V_{dc}}{\tau} * t$$

Output voltage of integrator should be always less than reference voltage, though:

$$Max\left(V_{ref}\right) < V_{int}$$
$$\frac{K_s * V_{dc} * T_{sw}}{\tau} > V_{bias} + V_m$$

Therefore:

$$\tau < \frac{K_s * V_{dc} * T_{sw}}{V_{bias} + V_m}$$

In this paper, the integrator time constant is 0.53^{ms}.

The frequency spectrum of line voltage and current of three phase load is shown in Figure-9.

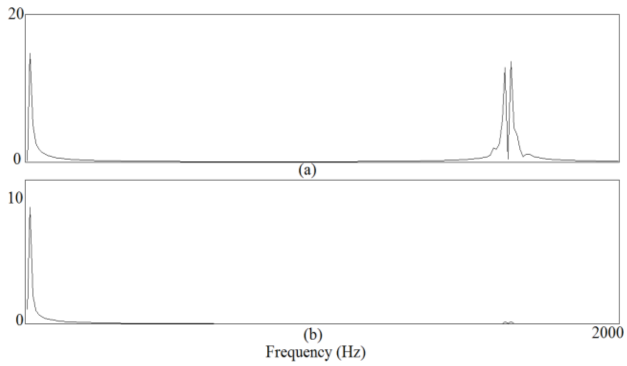

Figure-9. Line-line load a) voltage and b) current harmonic frequency spectrum.

MULTILEVEL INVERTER

Nowadays, high power inverter is needed more than ever in industry. The concept of multilevel converters has been introduced since 1975 [14]. Multilevel inverters have attractive features as below:

a) Generating voltage with very low distortion and also reducing dv/dt stresses.
b) Drawing input current in low distortion.
c) Producing smaller common mode (CM) voltage [8].
d) Working in basic and high switching frequency [9].

On the other hand, a multilevel inverter needs lots of switches, therefore, needs more gating signal generator circuits than a usual inverter and it makes overall system more complex and expensive. Multilevel inverters have three main types which are cascade H-bridge, diode-clamped, flying capacitor.

Cascade H-bridge multilevel inverter

Cascaded multilevel inverters (CMI) play an important role in recent years, especially in medium and high voltage applications, such as high-voltage direct current (HVDC), traction, electric power transmission system and wind energy interconnections because of its low witching frequencies and the capability to withstand high voltage.

Cascade H-bridge multilevel inverter requires less circuit parts comparison with diode-clamped multilevel inverter or flying capacitor multilevel inverter [4]. The number of possible output voltage levels is more than twice the number of DC sources [13]. Levels of series H-bridge inverters can be changed easily. But this inverter requires more DC sources than other multilevel inverters. In Figure-10 structure of a cascade H-bridge n-level inverter is shown.

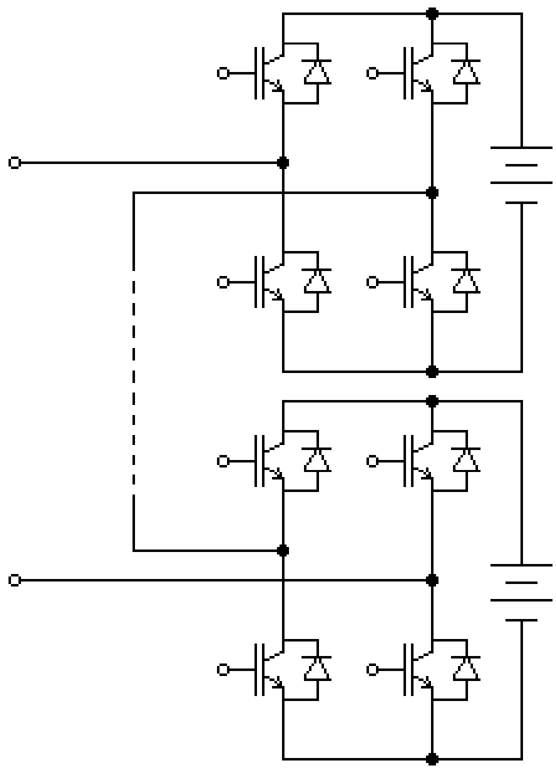

Figure-10. Structure of a cascade H-bridge multilevel inverter.

Diode-clamped multilevel inverter

All three phases in diode-clamped multi-level inverter require just one DC input source, though numbers of capacitors are reduced. The capacitors can be pre-charged as a group. This inverter can operate efficiently in low switching frequency [15]. But it requires a high number of diodes which causes problem in high-level inverters. In Figure-11 a structure of diode-clamped multilevel inverter is shown.

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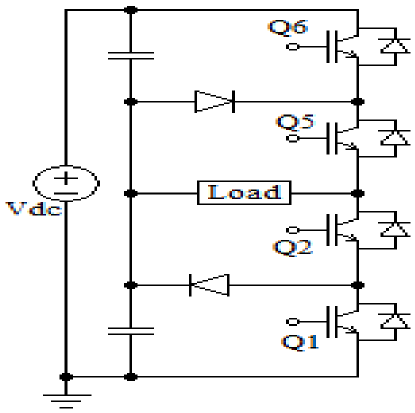

Figure-11. Structure of a cascade diode-clamped multilevel inverter.

Flying capacitor multilevel inverter

Topology of flying-capacitor multilevel inverter is the same as diode-clamped but capacitor is used instead of diode. The voltage of capacitors is adjustable by using phase redundancy. This inverter can control both active and reactive power, easily. On the other hand, the great number of capacitors makes this inverter more complex and expensive. Setting the capacitor voltages is not easy and switching utilization is not efficient for real power transmission [16-17]. In Figure-12 structure of a flying-capacitor multilevel inverter is shown.

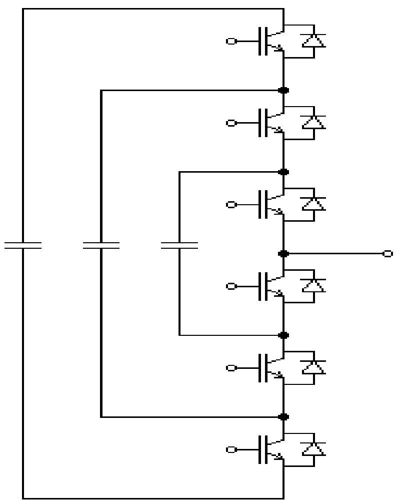

Figure-12. Structure of one leg of a flying-capacitor multilevel inverter.

THREE-LEVEL DIODE-CLAMPED INVERTER

Non-linear effect of DC input can be compensated by voltage integral control, also, to acquire high amount of voltage and power, multilevel inverters can be used. In this paper, a single phase and a three phase integral control three-level inverter have been designed. Diode-clamped multi-levels are chosen to be used. This type of multi-level inverter is better because of:

- Using diodes instead of capacitors
- Using just one DC input source
- Simple structure

Single phase three-level diode-clamped integral control inverter

In Figure-11 the structure of a single phase integral control inverter is shown. The circuit that is shown in Figure-13 is used for generating gating signals.

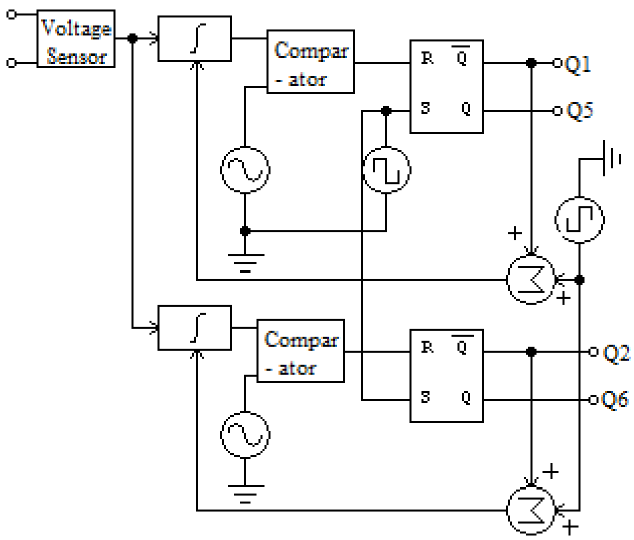

Figure-13. Gating signal circuit, feed forward from the bottom switch (Q_1).

In this structure AC reference source doesn't have any DC offset, though a square voltage source in a twice frequency of AC reference is used to be added with reset signal of integrator. The two AC reference voltages are in 180^o phase difference. Output voltage of integrator and reference voltage are shown in Figure-14. When the reference voltage is positive the gating signal circuit generates the gating signals for switches Q_1 and Q_5, however, when it's negative the gating signals for switches Q_2 and Q_6 are generated.

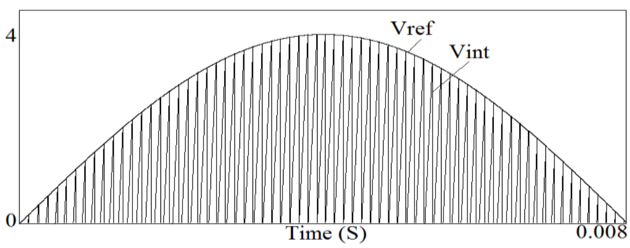

Figure-14. Integrator output waveform for single phase half bridge three-level integral control inverter Voltage of bottom switch (Q_1) is supposed to be sensed.

Three phase three-level diode-clamped integral control inverter

By using three single phase inverter and considering 120^o phase shift in each leg, a three phase inverter can be built. In figure-15 the structure of a three

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phase three-level diode-clamed integral control inverter is shown.

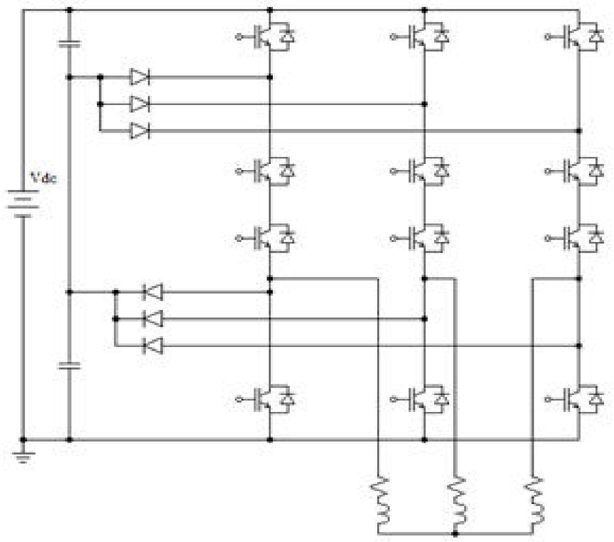

Figure-15. The structure of a three phase three-level diode-clamed integral control inverter.

Gating signal generating circuit of this three phase inverter is the same as a single phase one (Figure-13). For generating the gating signal of each leg, voltage of bottom switch of each leg is sensed.

Gating signals of the first leg is illustrated in Figure-15a.

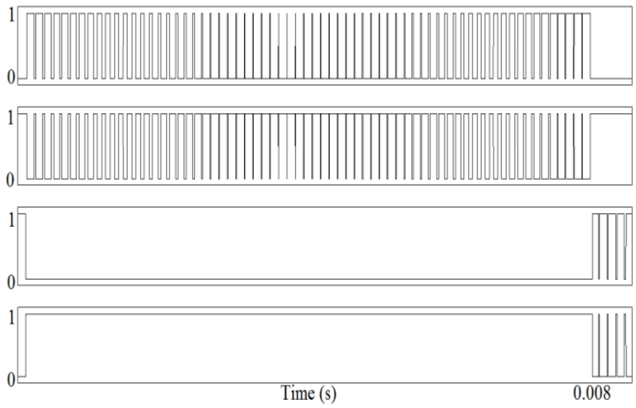

Figure-15a. Gating signals of the first leg of a three phase three-level integral control inverter; Q_1, Q_5, Q_2, Q_6 respectively.

If higher output voltage is needed, more levels of proposed inverter should be used. Each switch in this structure will tolerate a part of output voltage. In Figure-16 the output voltage and current are shown.

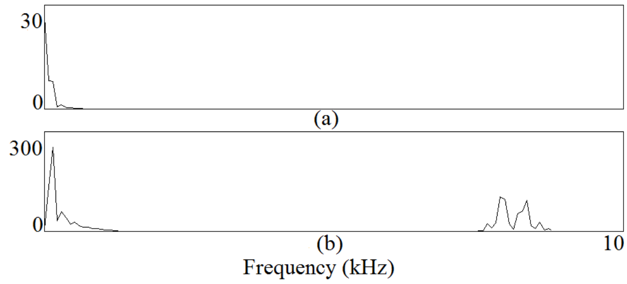

Figure-16. Waveforms of output load a) current and b) voltage.

Low frequency harmonics have very low amplitude and it tends to zero in high frequency harmonics. Frequency of switching is 8100 Hz.

CONCLUSIONS

In this paper, for compensating the effect of a non-ideal DC input source, however, generating a high voltage output two techniques are combined with each other and the result showed that it can be very efficient. A three-level diode-clamped integral control inverter has been designed and the output voltage and current waveform showed that the effect of DC input ripple has been compensated, however, the output voltage increased to a high amount of voltage by using more IGBT switches in a diode-clamped multilevel technique. The simulation of a single phase and three phase three-level diode-clamped integral control inverter had been performed in this paper.

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