

A SIMPLE AND NOVEL MODULATION TECHNIQUE USED TO GENERATE SYMMETRIC THREE-PHASE OUTPUT VOLTAGE FROM SINGLE-PHASE SINUSOIDAL INPUT VOLTAGE

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Abstract: *In this paper, a new technique is presented in order to obtain three-phase AC output with variable magnitude, from a single-phase AC input. Two methods are presented here. In the first method the phase difference between the input and output voltage is not controlled whereas in the second method the phase difference is controlled to reach maximum voltage amplitude in the output. Using the second method symmetric three-phase output voltage with a magnitude greater than the single-phase input voltage can be obtained. First the general idea behind this technique is explained and its equations and constraint are derived. Then the switching topology is explained and illustrated. Finally, simulation results are presented and explained.*

Key words: AC-AC Converter, three-phase Supply, Switching, Induction Motor, Modulation Technique, matrix convertor

1. Introduction

Three-phase AC-AC converters are extensively used in driving and variable speed control of AC motors such as induction motor. Today, the inverter controlled variable AC motor is widely used in transportation, elevators, air-conditioners, and home appliances. The inverter can provide energy saving of the system, but it requires power semiconductor devices, and electrolytic capacitor. These elements cause the system to grow both in size and weight and result in more consumption of the resources [3]. Although these methods which are based on inverters, can successfully achieve the aim of variable speed control of AC motors, they need a DC

voltage source. Hence, the power converter topology is required for the high efficiency performance and the economic system design that doesn't require reactor and electrolytic capacitor [3].

AC-AC matrix converter is an array of power semiconductor switches that connects directly a three-phase AC source to another three-phase load. It can convert an AC power source with certain voltage and frequency to another AC load with variable voltage and variable frequency directly without DC link and bulk energy storage component.[2] The Matrix Converter (MC) has received considerable attention in recent years because of its appealing operational characters. The matrix converter introduced by Venturini and Alesinain 1979 is the most popular in the family of ac-ac direct converters [4], [5]. There are also other techniques based on inverters presented in [7 - 9]. AC-AC converters have many applications in induction motor drives. These converters are becoming popular due to the availability of better switching devices. However, real time implementation of such PWM switching algorithms can be difficult. It is shown that how AC-AC Matrix Converter (MC) theory [6-10] could be adopted to implement a SVM with minimal low order harmonics and no increase in the number of switches. Matrix converters provide a solution to the problem of converting AC power from one frequency to another. They have many advantages compared to the DC-link convertors [8].

In this study a new modulation technique is proposed and adopted to implement a single-phase to three-phase convertor AC to AC converter. This convertor uses the single phase AC input alongside a DC input obtained by rectifying the AC input to produce a symmetrical three phase output.

2. Methodology

Suppose that there are n voltages Available during time T to be applied to the output terminals (V_n). During this time, it's possible to apply n distinct voltage to output. T is divided to n time (t_n) and each available n voltages apply on output for t_n during T time, it can be assumed that the all input and output voltages remain constant during this interval (considering that T is very small). So T is divided into n pieces (t_n).

Considering what was mentioned the following equations can be extracted:

$$\sum_{k=1}^n t_k = T \quad (1)$$

$$m_k = \frac{t_k}{T} \quad (2)$$

$$\sum_{k=1}^n m_k = 1 \quad (3)$$

Where m_k represents the share of each mode during the interval T . ($0 < m_k < 1$)

$$\sum_{k=1}^n m_k V_k = V_{out} \quad (4)$$

Equation (4) states that the desired output voltage (V_{out}) is the mean voltage value during the interval T .

Now the only issue that remains is how to obtain m_k . Equations (3) and (4) are the only equations that exist but there are k unknowns. In fact any set of m_k that satisfies the equations (3) and (4) can be used to produce desired V_{out} at time t . An approach to finding m_k is that in order to minimize voltage ripple and harmonics, among all the available voltages only two of them closest to V_{out} are selected; one higher than V_{out} and the other lower than V_{out} . So all the other m_k are zero and equations (3), (4) are transmuted to:

$$m_1 + m_2 = 1 \quad (5)$$

$$m_1 V_1 + m_2 V_2 = V_{out} \quad (6)$$

Now with solve these two equations (5) (6) m_1, m_2 is obtained. Finally t_k can be found using equation (2).

Using this technique, at a particular time, any output in the range of the available voltages can be obtained. Output voltages out of the range of maximum and

minimum of the available voltages cannot be produced and equations (3) and (4) will not come up with false results (such as m_k out of the range of 0 to 1). This is the constraint that limits the possible output voltages.

This method is used in order to generate a symmetric three-phase output voltage from one_phase input voltage. As shown in fig.2, 8 switches are used in the form of 2 H-bridge to produce one_phase output voltage. With using three of the circuit shown in fig2, three_phase output voltage is produced.

In this circuit two input voltages is used whereas the DC voltage is obtained from rectifying AC voltage. It is obvious that with this structure of switches the AC and DC voltage in seven modes can be applied on loads terminals. These possible voltages are $V_A + V_{dc}, V_A - V_{dc}, -V_A + V_{dc}, -V_A - V_{dc}, V_{dc}, -V_{dc}, 0$. Switching circuit topology is shown in fig1. For instance if $S_{a2}, S_{a3}, S_{a5}, S_{a8}$ are on, $V_A + V_{dc}$ appears on the terminals of load a, also if S_{a3}, S_{a4} or S_{a1}, S_{a2} and S_{a5}, S_{a8} are on, V_{dc} applied on load a.

In this case equation (1) to (4) can be represented as:

$$t_{+A+dc} + t_{-A-dc} + t_{-A+dc} + t_{-A-dc} + t_{dc} + t_{-dc} + t_0 = T \quad (7)$$

$$m_{+A+dc} = \frac{t_{+A+dc}}{T} \quad (8)$$

$$m_{-A-dc} = \frac{t_{-A-dc}}{T} \quad (9)$$

$$m_{-A+dc} = \frac{t_{-A+dc}}{T} \quad (10)$$

$$m_{-A-dc} = \frac{t_{-A-dc}}{T} \quad (11)$$

$$m_{dc} = \frac{t_{dc}}{T} \quad (12)$$

$$m_{-dc} = \frac{t_{-dc}}{T} \quad (13)$$

$$m_0 = \frac{t_0}{T} \quad (14)$$

$$m_{+A+dc} + m_{-A-dc} + m_{-A+dc} + m_{-A-dc} + m_{dc} + m_{-dc} + m_0 = 1 \quad (15)$$

$$m_{+A+dc} \times V_{+A+dc} + m_{-A-dc} \times V_{-A-dc} + m_{-A+dc} \times V_{-A+dc} + m_{-A-dc} \times V_{-A-dc} + m_{dc} \times V_{dc} + m_{-dc} \times V_{-dc} + m_0 \times V_0 = V_a \quad (16)$$

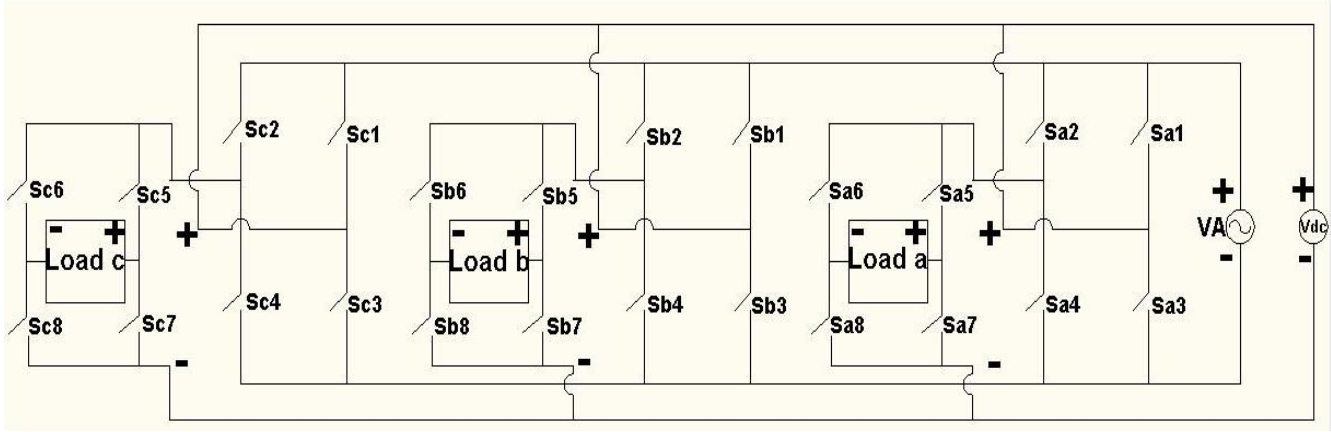


Fig. 1. Switching Circuit topology

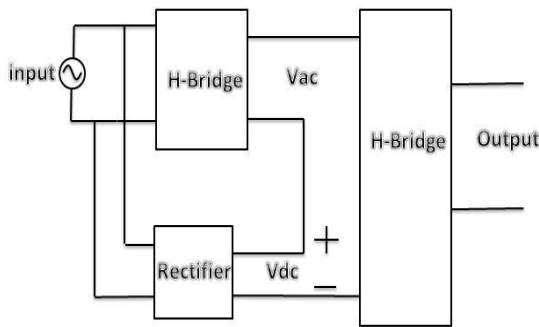


Fig. 2. Block diagram of circuit for producing one phase

The switching logic and equations for phase's b and c are the same as phase a and these three branches are working in parallel and in order to produce the three-phase output. As it was mentioned, output voltages cannot be produced if not within the range of available voltages. Fig4, illustrate this constraint, if the output voltage (yellow) is within blue area, it can be generated. Efficiency of this convertor depends on switching losses and amplitude of output voltage main harmonic.

Three-phase output cannot exceed area. There are two methods for producing output voltages. In one method the phase differences between the input and output voltages are not controlled. In this method maximum output voltage is equal to the DC input voltage value which in turn is the outcome of rectifying the AC input voltage (figure3, DC voltage is 308 volt).

In the second method the phase differences between the Input and output voltages are controlled which helps achieve greater maximum output voltages in comparison to the previous method. Figure (4) shows an example of this method. As it

can be seen in this figure the amplitude of the output exceeds the DC input voltage. To get the maximum possible amplitude in the output the minimum point of the envelope of the output voltages must occur at the same point as the minimum point of the envelope of all available voltages. Using this method requires the frequency of the output to be the same as the frequency of the input so that the phase difference between them remains constant at all times. In fig4 the amplitude of the AC input voltage is 308 (V) and consequently DC voltage is 308V as well.

So output three-phase amplitude is obtained 355 volt that is 47 volt bigger than input voltage. In this case

According to fig3 VA+DC and V-A-DC are also used to produce the output voltage. The maximum output voltage amplitude using the controlled phase method can be calculated as:

$$V_{out} = \frac{2}{\sqrt{3}} \times V_{dc} \quad (17)$$

2.1. Frequency limitation

As it was mentioned, if the output voltage (yellow) is within blue area, it can be generated. As shown in Fig4 all output voltage frequency can be produced because the output voltage is within the range of available voltage. It should be noted that output voltage frequency must be several times smaller than sample frequency ($\frac{1}{T}$), for example if sample frequency is 2kHz, output voltage frequency can be 200Hz, here there are 10 samples in every output voltage period time. it means that there should be at least 10 sample in every output voltage period time. Whatever the sample frequency is bigger than output voltage frequency, the harmonic of output voltage is become lower. Also there are hardware limitations in frequency switching.

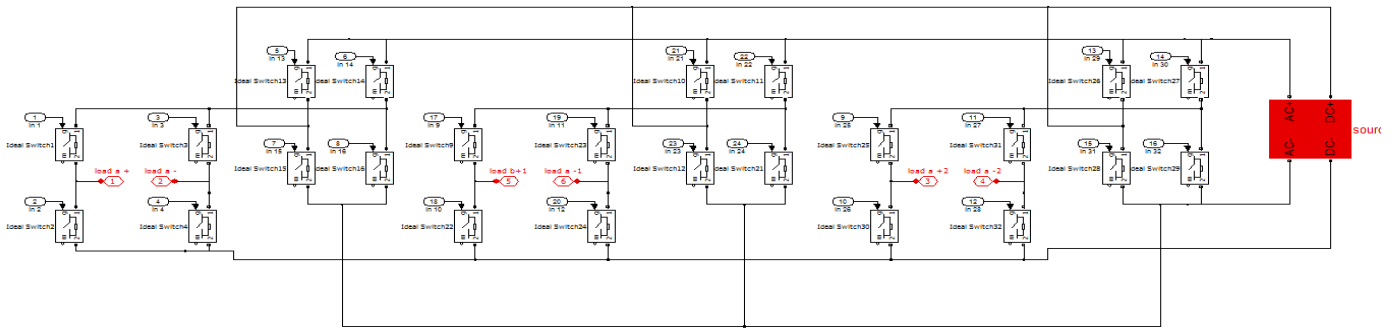


Fig. 3. Simulation Circuit

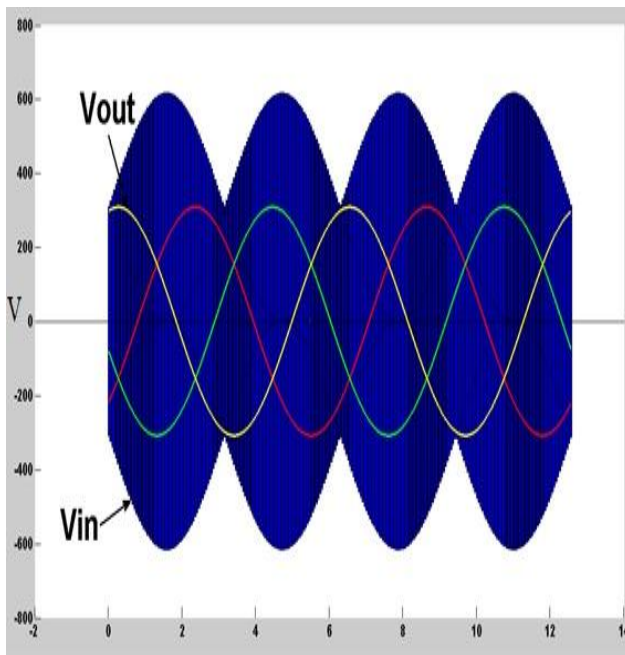


Fig. 4. Three_ phase out put voltage that can't be exceed blue area

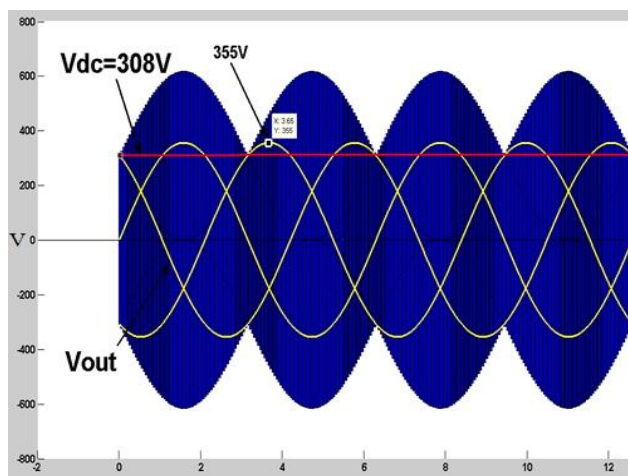


Fig. 5. Produced Three-phase output voltage (yellow plot) with controlled phase

Note that in all of the calculations and statements above it is assumed that the DC voltage on the capacitor terminals do not have any ripple. If the capacitor is not chosen properly, ideal DC voltage cannot be produced and the maximum possible amplitude for the output decreases.

3. Simulation

All simulations are performed with MATLAB Simulink, utilizing elements from SimPowerSystems™. Fig3 shows the topology of switches in Simulink environment. For two methods (controlled phase and uncontrolled phase), a set of simulations are performed to show results. For each method, Output currents, Output voltages, Spectrum of output voltages for each of the loads (a, b, c) are presented. Because of low pass filter loads, the harmonics of currents are eliminated. The following results are obtained using the first method (uncontrolled output phase) on an input with 308 volt magnitude and with 0 phase. In this method output voltages are lower than input voltage.

As shown in fig6, because of produced output voltage on three loads are lower than DC voltage (308 volt), V_{A+DC} and V_{-A-DC} not used to generate output voltage.

In figure7, 8, 9, it's observable that the main harmonics of output voltages is 50 HZ and magnitude of them is approximately 308 volt.

As shown in Fig10, Three-phase symmetric output currents are produced by three-phase symmetric output voltage.

According to fig11 with phase controlled, magnitude of output voltage main harmonic magnitude obtained.

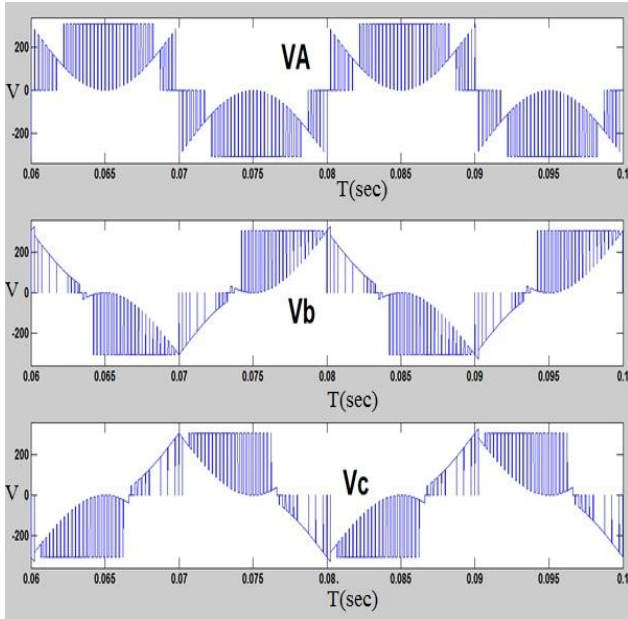


Fig. 6. Output voltages

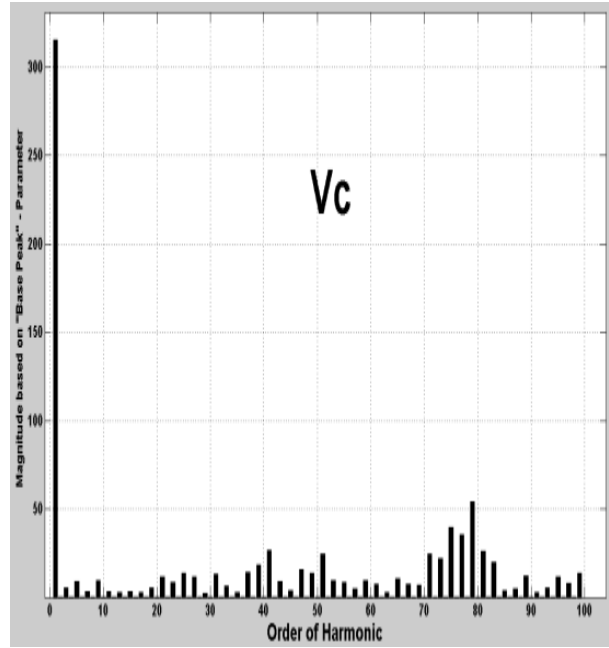


Fig. 9. Spectrum of output voltage c

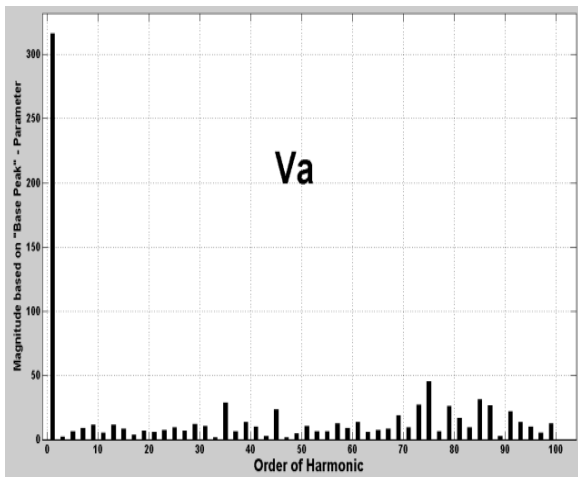


Fig. 7. Spectrum of output voltage

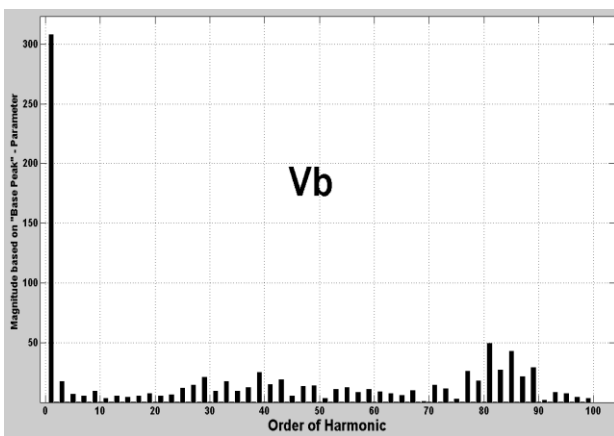


Fig. 8. Spectrum of output voltage b

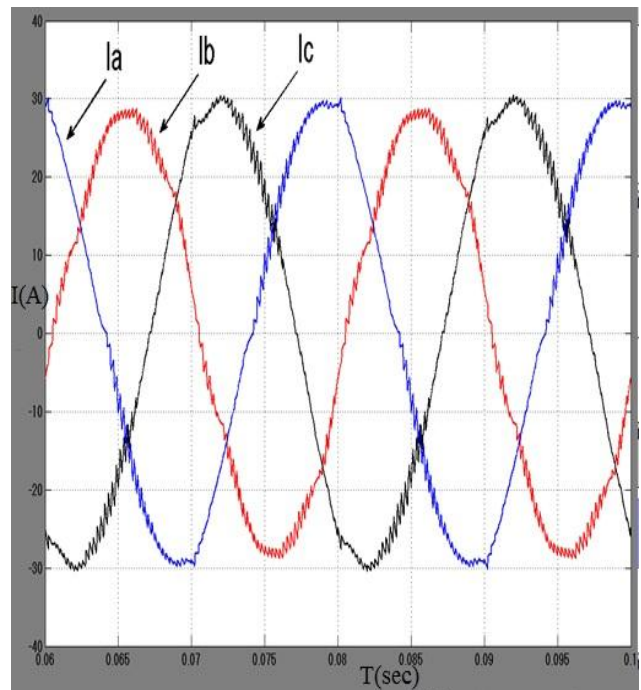


Fig. 10. Three_phase output current

The following figures are results of controlled phase method.

As shown in Fig11 using the phase controlled method, magnitude of the main component of the output voltage is approximately 355 (V) which is calculated from equation (17).

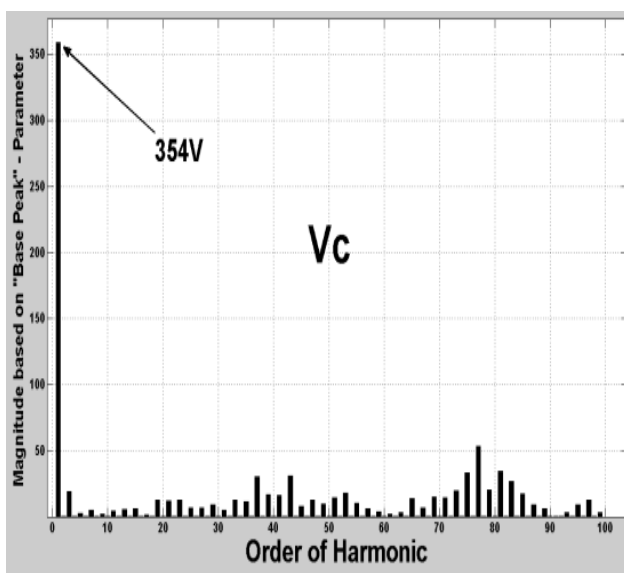
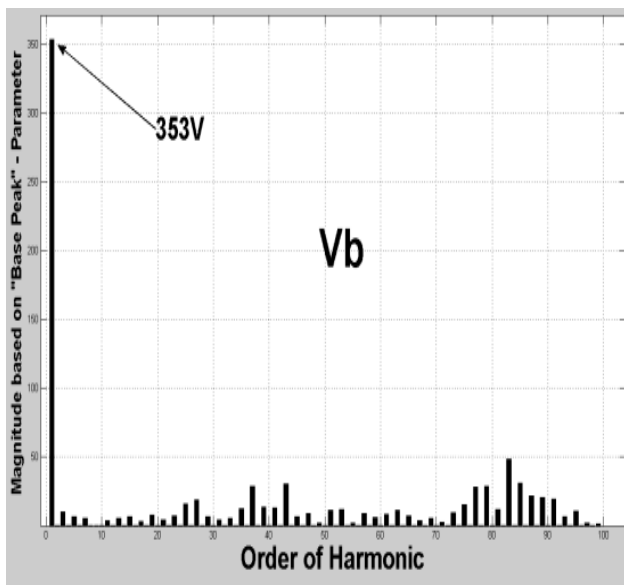
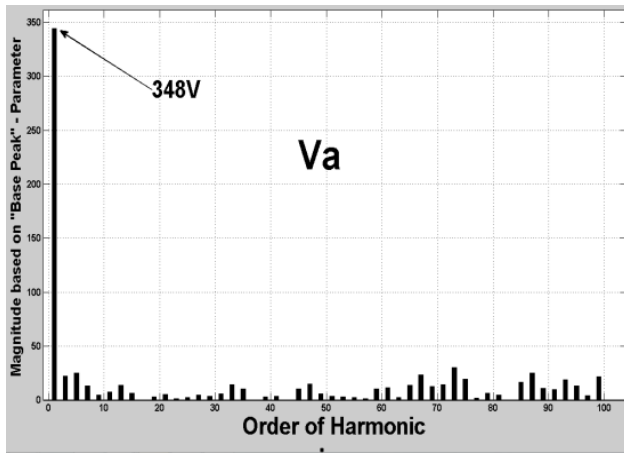


Fig. 11. Output voltage spectrum with phase controlled method

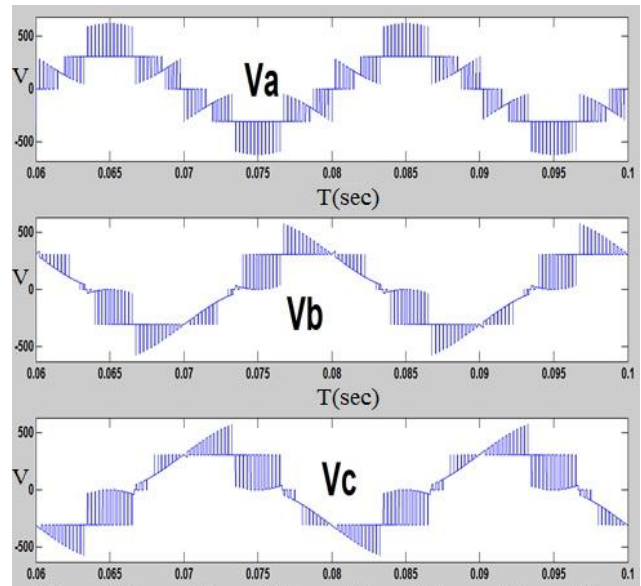


Fig. 12. Three phase output voltage

As shown in Fig12 because of produced output voltage on three loads are bigger than DC voltage (308 volt), therefore V_{A+DC} and V_{-A-DC} are used to generate output voltage.

4. Efficiency and Price

In [11] efficiency of matrix converter is explained and determine which matrix converter topology and switch configuration are the most efficient. In this convertor 24 switches are used and frequency switching ($1/T$) is 4000 KHz. Only the bi-directional switches are used to connect the power supply and loads, allowing higher-efficient operation than as in conventional AC Drives. Efficiency of this convertor is 95% that is obtained from simulation.

In classical inverter, with DC link, 12 switches are used to generate symmetric three-phase; also microprocessor that is used in matrix convertor should have high speed processing with high price. in inverters, output voltage is amplified with using bulk circuit but in this convertor without using bulk energy storage component and with less cost, symmetric three-phase output voltage with a magnitude greater than the single-phase input voltage, as shown in Fig 11, is obtained by controlling phase difference. According to explanation given, Efficiency of inverter is approximately as same as convertor.

5. Method implementing

This scheme can be implemented using Atmel@ARM@Processor to generate appropriate pulse signal of switches. Sampling process and

calculations time in Micro ARM caused a delay between sampled voltage and voltage applied on load. So calculated m_k has an error. In simulation this delay is ignored. To reduce this delay, code consume should be decreased and microcontroller should be used with high speed processor.

6. Conclusion

In this paper, two methods for generating three-phase output voltage from one-phase input voltage are proposed. In the first method the phase difference between output and input voltage not controlled while in the second method with control the phase difference of input and output voltage, three phase voltage that is bigger than one-phase input voltage is produced which is suitable for supplying induction motor. Simulation results confirm the idea of two methods. Symmetric Three-phase output voltage is generated successfully.

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