14th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2010, Mediterranean Cruise, 11-18 September 2010

CONTROL OF VOLTAGE SOURCE INVERTERS USING S PWM STRATEGY FOR ADJUSTABLE SPEED MOTORS

Sabrije F. Osmanaj
Faculty of Electrical and Computer Engineering
Fakulteti Teknik, Kodra e Diellit, Prishtinë, 10000
Kosovë

Rexhep A. Selimaj
Faculty of Mechanical Engineering
Fakulteti Teknik, Kodra e Diellit, Prishtinë, 10000
Kosovë

ABSTRACT
Sinusoidal Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance. Variable voltage and frequency supply to a.c drives is invariably obtained from a three-phase voltage source inverter. In this paper is used three-phase voltage source inverter which is carrier-based sinusoidal PWM. This paper analysis the theoretical and modulation form for control strategy and simulation results are presented by the different switching conditions. A three-phase motor is fed by a sinusoidal PWM inverter. The S PWM inverter is built entirely with standard Simulink blocks. Its output goes through Controlled Voltage Source blocks before being applied to the Asynchronous Machine block's stator windings. The machine's rotor is short-circuited. Its stator leakage inductance Lls is set to twice its actual value to simulate the effect of a smoothing reactor placed between the inverter and the machine. Simulation results are obtained using MATLAB/Simulink environment for effectiveness of the study.
Keywords: Voltage Source Inverter, Sinusoidal Pulse Width Modulation – SPWM, Carrier frequency, Asynchronous machine.

1. INTRODUCTION

Rapid developments in the field of power electronics (inverter grade thyristor, GTO thyristor, IGBT etc.) and miniaturization/mass production of control electronics (development of VLSI technology and microprocessor based digital control systems) have reached such a stage that variable ac inverter drives are becoming increasingly popular in today's motor drives. Presently, inverter drives meet not only weight and space constraints, but also are economically viable. S PWM is a powerful technique for controlling analog circuits with a processor's digital outputs. S PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. In ac motor drives, S PWM inverters make it possible to control both frequency and magnitude of the voltage and current applied to a motor. As a result, PWM inverter-powered motor drives are more variable and offer in a wide range better efficiency and higher performance when compared to fixed frequency motor drives. The energy, which is delivered by the PWM inverter to the ac motor, is controlled by PWM signals [1] applied to the gates of the power switches at different times for varying durations to produce the desired output waveform. Three phase voltage-fed PWM inverters are recently showing growing popularity for multi-megawatt industrial drive applications.

Single-phase AC can be constructed as induction motors, permanent magnet motors or synchronous reluctance motors. Thus, an auxiliary field has to be present in order to obtain a revolving air-gap field and electromagnetic torque with an average value different from zero. The solutions employed to create the auxiliary field assume either unsymmetrical stator windings or, supplementary impedances that can be fixed values or electronically controlled. A two-phase AC motor can have a configuration identical to the single-phase version of the motor, but the voltage applied to the windings terminals are independently controlled so that we have a two phase supply voltage system. As the AC mains are available as single or three-phase systems, a two-phase voltage system is realized through the use of inverters with different control strategies. The Pulse Width Modulation (PWM) makes the inverter output the waveforms made up of many pulses with certain rules and goals through supplying DC voltage for the inverter. Since it is the task for DC/AC switching mode [2] to produce a sinusoidal AC output voltage so as to make the flux linkage and frequency can be controlled with ease, PWM has become the soul of adjusting speed drive systems. In this paper, SPWM for three-phase inverter schemes are investigated to apply in single phase induction motor. Simulation results are obtained using MATLAB/Simulink environment for effectiveness of the study.

2. SPWM FOR THREE PHASE VOLTAGE SOURCE INVERTER

A typical voltage source inverter which we use in this paper is shown in figure 1. These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications, such as adjustable speed drives (ASDs), which are the most popular application of inverters. Static power converters [3] are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature fast transitions rather than smooth ones.

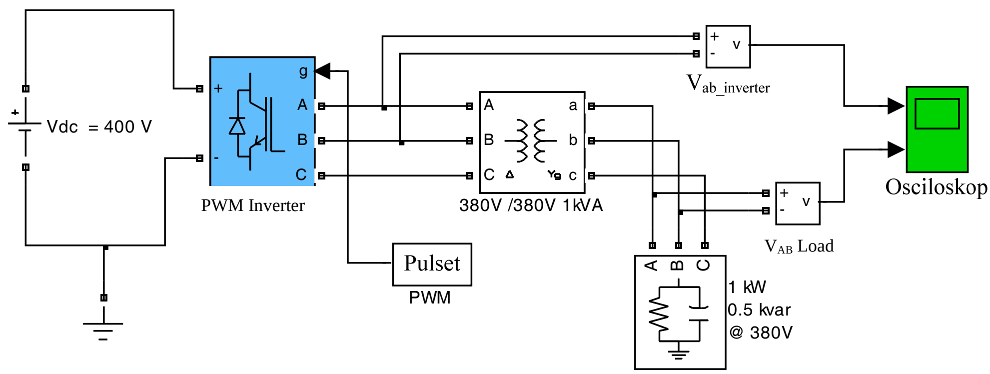


Figure 1. Basic three-phase voltage-source converter circuit.

The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages should always be controllable. Pulse width modulation (PWM) is a method whereby the switched voltage pulses are produced for different output frequencies and voltages. A typical modulator produces an average voltage value, equal to the reference voltage within each PWM period. Furthermore, harmonic currents and skin effect increase copper losses leading to motor dating. However, the motor reactance acts as a low-pass filter and substantially reduces high-frequency current harmonics. Therefore, the motor flux is in good approximation sinusoidal and the contribution of harmonics to the developed torque is negligible. To minimize the effect of harmonics on the motor performance, the PWM frequency should be as high as possible. However, the PWM frequency is restricted by the control unit and the switching device capabilities, e.g. due to switching losses and dead time distorting the output voltage. The sinusoidal pulse-width modulation can be implemented using analog techniques; the remaining PWM techniques require the use of a microprocessor. Three-phase reference voltages of variable amplitude and frequency are compared in three separate comparators with a common triangular carrier wave of fixed amplitude and frequency (figure 2). Fig. 2, shows waveforms of carrier wave signal (Vc) and control signal, inverter output line to neutral voltage (VA0,VB0, VC0), inverter output line to line voltages (V_{AB}, V_{BC}, V_{CA}), respectively.

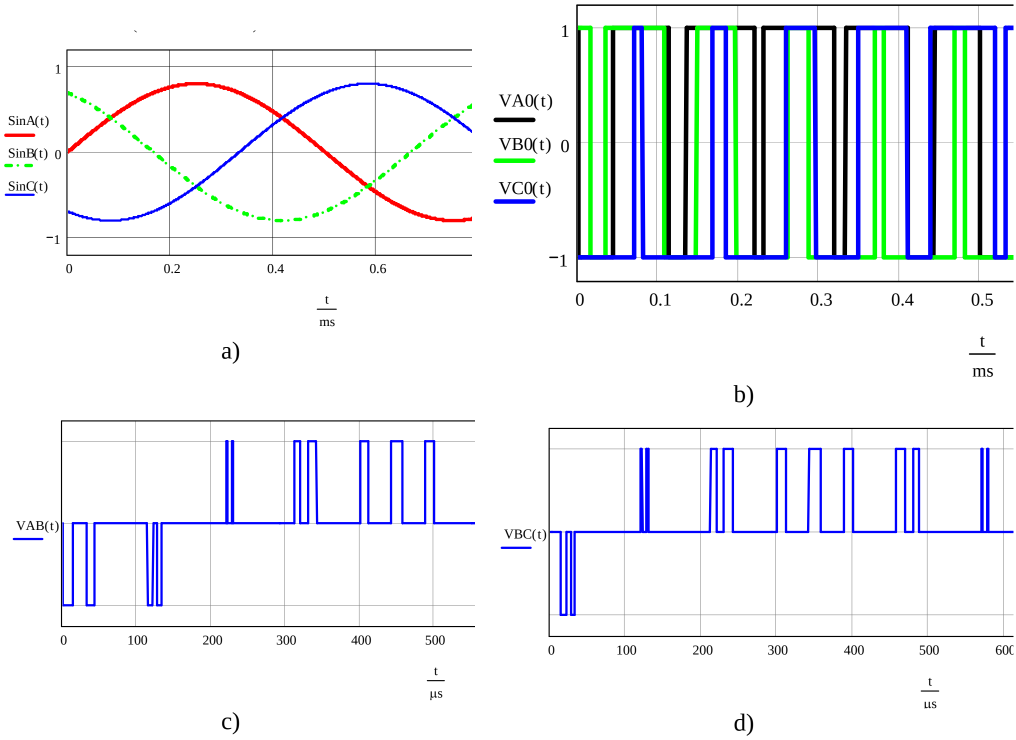
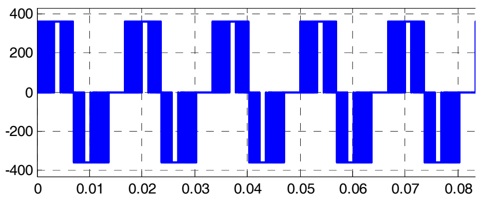


Figure 2. a) waveforms of carrier wave signal (Vc) and control signal,b) inverter output line to neutral voltage (VA0,VB0, VC0), c,d) inverter output line to line voltages (V_{AB}, V_{BC}, V_{CA}),

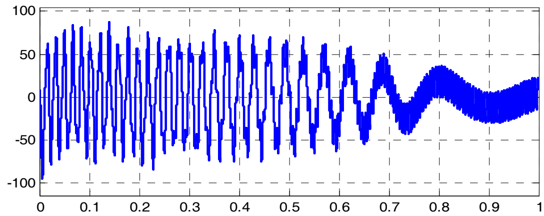
The S PWM is easy to realize in hardware by using analog integrators and comparators for the generation of the carrier and switching states. However, due to the variation of the reference values during a PWM period, the relation between reference and carrier wave is not fixed. This introduces sub harmonics of the reference voltage causing undesired low-frequency torque and speed pulsations. In contrary, software implementation provides sampled data during a PWM period (uniform/ regular sampling) and hence, the pulse widths are proportional to the reference at uniformly spaced sampling times. Compared to the analog implementation, the modulation with uniform sampling has lower low-frequency harmonics. Since the phase relation between reference and carrier wave is fixed, even for the asynchronous mode, the sub harmonics and the associated frequency beats are not present.

3. SIMULATION RESULTS AND ANALYSIS

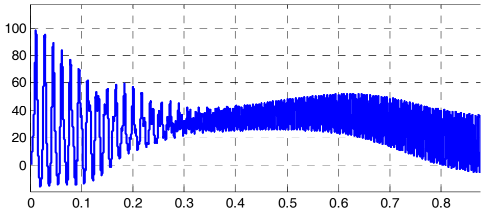
A three-phase motor rated 3 HP, 380 V, 1725 rpm is fed by a sinusoidal PWM inverter. The base frequency of the sinusoidal reference wave is 50 Hz while the triangular carrier wave's frequency is set to 2 kHz. This corresponds to a frequency modulation factor m_f of 40. The PWM inverter is built entirely with standard Simulink blocks. Its output goes through Controlled Voltage Source blocks before being applied to the Asynchronous Machine block's stator windings. The machine's rotor is short-circuited. Its stator leakage inductance Lls is set to twice its actual value to simulate the effect of a smoothing reactor placed between the inverter and the machine. The load torque applied to the machine’s shaft is constant and set to its nominal value of 11.9 N.m. The motor is started from stall. The speed set point is set to 1725 rpm. This speed is reached after 0.9 s. Take a look at the simulation parameters. The maximum time step has been limited to 10 microseconds. This is required due to the relatively high switching frequency (2 kHz) of the inverter. Observe that the rotor and stator currents are quite "noisy," despite the use of a smoothing reactor. The noise introduced by the PWM inverter is also observed in the electromagnetic torque waveform Te. However, the motor's inertia prevents this noise from appearing in the motor's speed waveform.



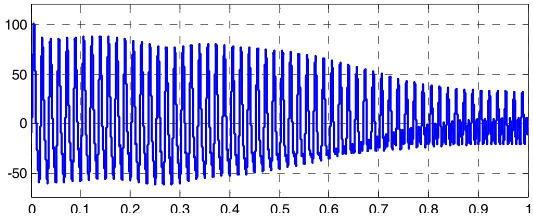
a) Waveform of voltage V_{ab}[V]



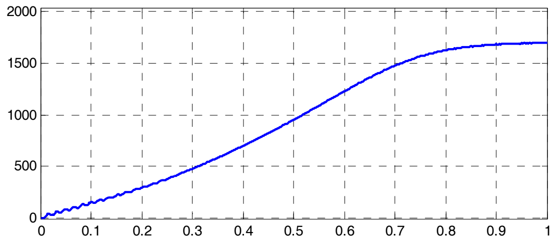
b) Rotor voltage waveforms, Ira [A]



c) Electromagnetic torque waveform Te [Nm]



d) Stator current Isa[A]



c) Speed (in rpm) of rotor

Figure 3. Response of Speed (in rpm) of rotor, stator voltage, frequency and Te versus time

4. CONCLUSIONS

These wave forms are the result of simulation conducted in asynchronous machine system. Based on waveforms submitted easily conclude priorities of static converters with harmonic SPWM control signal to load (especially if we refer to the graph of current).

For the six-switch inverter, the first harmonics occur around the carrier frequency (1000 Hz +- k*50Hz) whereas for the twelve-switch inverter harmonics are lower and appear at double of carrier frequency. As a result, the load voltage is "cleaner" for the twelve-switch inverter. If you now perform a FFT on the signal Vab_load you will notice that the THD is 4.1% for the six-switch inverter as compared to only 2.1% for the twelve-switch inverter. The graph (c) shows the machine's speed going from 0 to 1725 rpm. The graph (a) shows the electromagnetic torque developed by the machine. Because the stator is fed by a PWM inverter, a noisy torque is observed. However, this noise is not visible in the speed because it is filtered out by the machine's inertia, but it can also be seen in the stator and rotor currents, which are observed next.

5. REFERENCES

[1] Holtz, J. (1992). Pulse Width modulation – a survey, IEEE Transaction on Industrial Electronics, Volume 39, Page 1194-1214.

[2] Mohan, N.; Robbin, W. P. and Undeland, T. (1995). Power Electronics: Converters, Applications, and Design, 2nd ed. New York.

[3] Van der Broeck, H. W.; Skudelny, H. C. and Stanke, G.V. (1988). Analysis and realization of a pulsewidth modulator based on voltage space vectors, IEEE Transactions on Industry Applications, vol.24, pp. 142-150.