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Speed Control of a Three Phase Alternating Current Induction Motor Using Space Vector Pulse Width Modulation

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Abstract*—Sinusoidal pulse width modulation is a popular modulation for most alternating current induction motor. It only requires fewer calculations and is easy to implement. However, the shortcomings of using it are low DC voltage utilization, and poor inverter transmission capability. In recent years, there is an increasing trend and more research concentration of using space vector pulse width modulation in adjustable speed drives and renewable energy systems because it has better DC bus utilization, better performance, lower loss, lower ripples, and wide application range. This paper introduces space vector pulse width modulation and applies to speed control of alternating current induction motor. The three phase alternating current induction motor is reviewed based upon space vector representation. The development of space vector pulse width modulation and implementation to speed control of induction motor is done using Matlab/Simulink. The simulation is conducted by analyzing the response of stator current, stator voltage, speed, voltage, frequency, and the electromagnetic torque. Simulation results shows that space vector pulse width modulation which generates the voltage patterns at real time is able to control the speed of a three phase alternating current induction motor. It indicates the validity of space vector pulse width modulation in controlling the speed of a three phase alternating current induction motor (ACIM). In conclusion, the use and realization of space vector pulse width modulation has been validated by the Matlab/Simulink simulation experiment for controlling the speed of a three phase alternating current induction motor.

Keywords—Induction motor, Simulation, Space vector pulse width modulation, Speed control

I. Introduction

Alternating current induction motors which contain a cage are very popular in the variable speed drives. They are rugged, inexpensive, available in almost all power ratings, and can be manufactured at low cost [1], [2]. Another key feature is that the rotor does not have any moving contacts which eliminates sparking and highly reliable as its simple design has no brushes that could wear out. AC induction motor speed depends on the frequency of the AC input voltage and the number of poles in the stator windings [3]. The AC induction motors (ACIM) are available in single phase and three phase versions. Three phase is an ideal choice for the variable speed applications. Progress in the field of power electronics and microelectronics enables the application of the AC induction motors for high performance drives where traditionally only the direct current (DC) motors were applied [4]-[6]. Thanks to the sophisticated control methods. The alternating current (AC) induction motor drive offers the same control capabilities as high performance four quadrant DC drives. The drive application allows vector control of the AC induction motor running in a closed speed loop with the speed and position sensor coupled to the shaft. Nowadays, AC motors are widely used for variable speed drive. Therefore, a power inverter is more commonly used in order to produce a three phase AC output voltage from a constant DC link [5]. Since an AC voltage is defined by its amplitude and its frequency, these two parameters must be configurable. In order to control the output voltage and frequency, the pulse width modulation (PWM) with a variable duty cycle is used. With a sinusoidal modulation for driving the inverter only 78.5 % of the inverter capacity is used, whereas with the space vector modulation, 90.6% of the inverter capacity is reached [7], [8]. The general objective of this paper is to design and simulate the use of space vector pulse width modulation in controlling the speed of a three phase alternating current induction motor. The demand for the alternative energy solutions (e.g., wind energy, solar energy, ocean wave energy, etc.) are now being recognized as research trend worldwide in power engineering thus, the potential of space vector pulse width modulation (SVPWM) for speed control of variable drives is prevalent. Furthermore, in recent years, the Matlab software is commonly used by practicing engineers, researchers, scientists worldwide for modeling, simulation, as well as in doing experiments. The study would most benefit practitioners in the field of power electronics and the motor drives engineering. This paper is organized as follows. Section II describes the methodology for SVPWM in controlling the speed of ACIM (Matlab/Simulink). Simulation results are discussed in section III. A conclusion is finally given in section IV.

II. Methodology

The framework in Fig. 1 [17] illustrates the simulation flow process diagram. A simulation experiment is run to check the performance of the speed control. The simulation results are used to evaluate the performance of the system. As shown in Fig. 1. the simulation model of the whole system is built and invoked in the corresponding block diagram. The whole flow process is an open loop design. The parameters and constraints of the design are checked to run in the computer simulation experiment. The setup model of the system based upon the underlying theory of space vector pulse width modulation speed control of a three phase alternating current induction motor is analyzed, simulated, and results are examined.

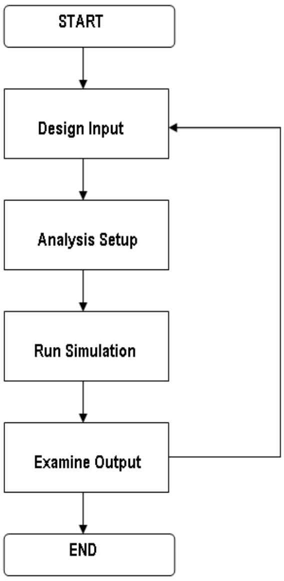

Fig. 1. Simulation flow process diagram [17].

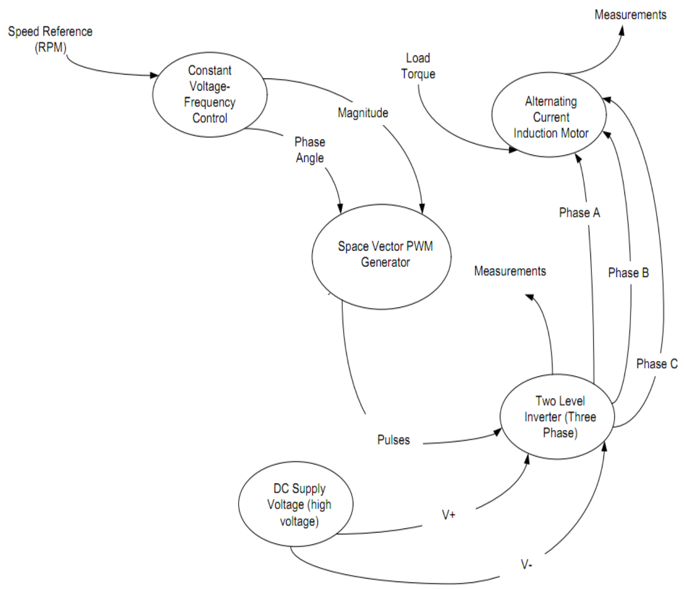

Fig. 2. Control sequencing diagram.

Fig 2. illustrates the control sequencing diagram of the whole system which are composed of space vector pwm generator, a constant V-Hz controller, inverter, and alternating current induction motor. A three phase squirrel cage induction motor rated at 3 horsepower, 220 V, 60 Hz, 1725 rpm is fed by a three phase MOSFET two level inverter connected to a DC voltage source of 325 V. The inverter is modelled using the universal bridge block of the Matlab/Simulink and the asynchronous machine by the AC Motor block. The stator leakage inductance is set twice its actual value to simulate the effect of a smoothing reactor placed between the inverter and the motor. The load torque applied to the motor shaft is constant and set to its nominal value of 11.9 N-m. The entire system is represented by open loop feedback control system consisting of the controllers, samplers, feedback systems, comparators, buses, constants, multiplexer, summers, adders, demultiplexers, gain blocks, look up table block, constant blocks, asynchronous machine such as AC motors, speed setting point, display, output sinks such as scopes, and input sources.

III. Simulation Results

The computer simulation is conducted and established the simulation model of space vector pulse width modulation on Matlab/Simulink. The reasonability and validity is testified by the simulation results, which would verify the effectiveness of the control strategy. Simulation method can be a thought way of designing and debugging the actual alternating current (AC) motors [18]. The space vector pulse width modulation speed control of a three phase alternating current induction motor for the control of various parameters is designed. The system is developed using the various toolboxes available in the library such as power system, power electronics, control systems, and signal processing toolboxes and from its basic functions. Series RC snubber circuits are connected in parallel with each switch device. The number of bridge arms of the MOSFET inverter is three and the corresponding snubber resistance is 10 kilo ohms while the snubber capacitance is set to infinity. The speed set point (RPM) had a step time of 0.1s with an initial value set to 1725 RPM and the final value is 1300 RPM. The voltage current (V-I) measurement is used to measure the three phase voltage and current in a circuit but when connected in series with a three phase element, it returns the three phase to ground voltages and line currents. The V-I block outputs the voltages and currents per unit value or in volts and in amperes. The corresponding voltage measurement is phase to phase and the signal label for the three phase voltage is Vabc_Stator while for the phase to phase current measurement is Iabc_Stator. The alternating current induction motor (ACIM) is characterized by a squirrel cage type of rotor with a stationary reference frame. The nominal power is 3x746 (2238) VA, nominal operating voltage is 220Vrms and the frequency of operation is 60Hz. The stator resistance is 0.435 ohms and the stator inductance is 2 x 0.002 henries while the rotor resistance is 0.816 ohms and the rotor inductance is 0.002 henries. The stator leakage inductance is set to twice its actual value to simulate the effects of a smoothing reactor placed between the inverter and the AC motor. The mutual inductance is 69.31mH while the inertia, friction factor and the pole pairs are given as 0.089 Joules (Kg/m^2), 0 F (N/m-s) and 2 pairs. The firing pulses to the inverter are generated by the space vector PWM modulator block of the SPS library where the chopping frequency is set to 1980 Hz and the input reference vector to magnitude and angle. This block generated the pulses for a three phase basic two level voltage source converter (VCS) consisting of a three half bridge switching devices MOSFET and it utilized the space vector pulse width modulation to generate firing pulses to the six switching devices of the converter as shown in Fig. 3. The firing pulse of the space vector pulse width modulation, of which the x-axis is set to auto range, is displayed. In Fig. 4 a different view from different angle of which the scale time x-axis is set to 0.001seconds. Speed control of the AC motor is performed by the constant voltage to the frequency (V/Hz) function block as shown in figure 2. An input port (rpm) coming from port 1 and feed from the speed set point block, saturation block for linearizing signals, the discrete rate limiter block, gain, look up table, discrete time integrator block, and the two output ports of the constant V/Hz control which is the magnitude (m) and the frequency (theta) of the stator voltages. Speed control of the AC motor is performed by the constant voltage to the frequency (V/Hz) block. The magnitude and frequency of the stator voltages are set based on the speed set point. By varying the stator voltages magnitude in proportion with frequency, the stator flux is kept constant. The saturation has a lower limit and upper limit parameters of 500 rpm and 1725 rpm. The discrete rate limiter limits the rising and falling rates of the signal of which the slew rates are set to +500 for rising and -500 for falling with an initial input of 1725 rpm.

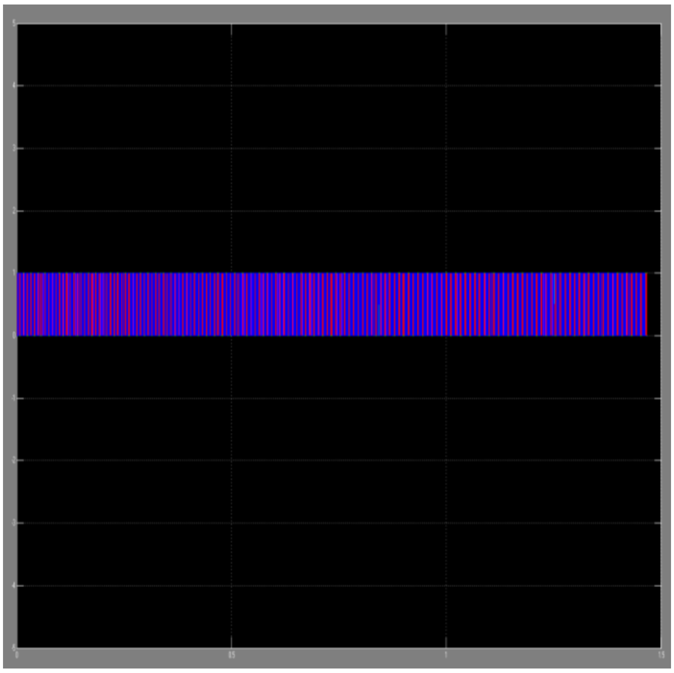

Fig. 3. Space vector pulse width modulation firing pulses (auto).

The element wise gain has a value of 2*pi*60/1725. The look up table performed linear interpolation of input values using the specified table data of which the vector values are 500, 1725, 2500 and the table data is [0.29 1 1] * 0.957. Extrapolation is done and this shall perform when values outside of the table boundaries occurs. The discrete time integrator is an accumulation of the input signal. The integration method used is the forward Euler type of which it has a gain value of one and the two output ports. The constant V/Hz is set as ‘m’ which indicates the magnitude that is feed by the look up table and ‘theta’ that is feed by the discrete time integrator. The signal block is composed of a phase locked loop (PLL), the selector switch, the filter, and the gain. Measurements of signals is obtain from the alternating current induction motor as well as from the signal bus voltage and current (V-I) measurements. The input port ‘m’ from the AC motor obtained numerous measurements such then as rotor measurements, stator and mechanical measurements. For the rotor measurements, the rotor current for phase A, B, and C, the rotor voltage and the rotor flux for d-q axis is measured. For stator measurements, the stator currents for phase A, B, and C, the stator flux, and stator voltage for the d-q axis is measured and lastly under with the mechanical measurements, the rotor speed, electromagnetic torque, and rotor angle were measured.

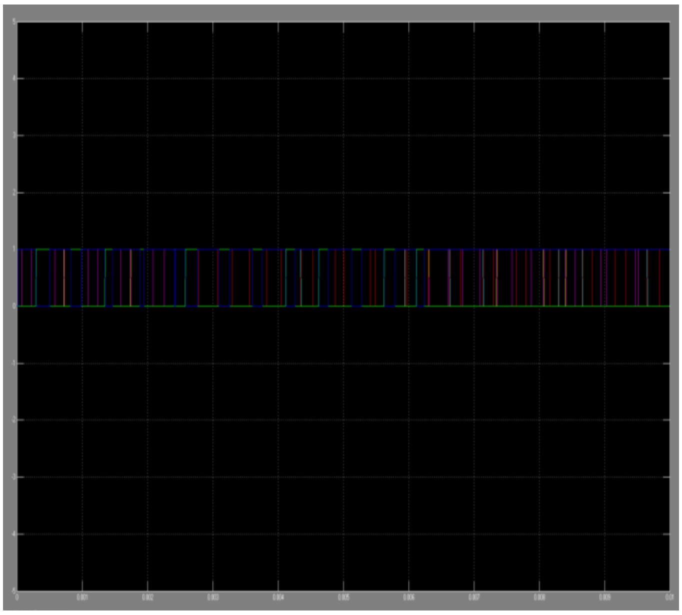

Fig. 4. Space vector pulse width modulation firing pulses (0.001sec).

The Vabc_Stator tag input port of the voltage and current (V-I) measurements feed the signal selector switch of which in this case, phase A is measured and evaluated under the output port 1 of the signals block. Phase A signal is used to feed the discrete second order filter with a cut off frequency of 2000 Hz and a damping factor zeta of 0.707. The alternating current initial input for magnitude is 1. The phase is 30 degrees and the operating frequency is 60Hz. The signal is then fed in the input of the phase locked loop (PLL) driven fundamental block and the element wise gain is set to 1/(220*sqrt(2)). The general discrete phase locked loop system is use to synchronize on a variable frequency sinusoidal signal of which the input signal is the normalized voltage and the output signal is three measured frequency in Hz. Ramp voltage varies between zero (0) and 2*pi synchronized on the zero crossing (rising) of the input signal and the output signal is either vector sine or cosine. The initial input parameters for the PLL are 30 degrees for phase and 60Hz for the frequency while the regulator gains Kp and the Ki is set to 120 and 2800 respectively. Terminator is use to terminate the signals in the ramp and to prevent warnings also regarding the unconnected output ports while computer simulation is running. The frequency is feed to the output port of signals block while the Sin_Cos of the PLL is fed to Sin_Cos tag of the PLL driven fundamental value block. The discrete phase locked loop (D-PLL) block computes the fundamental value of the input signal (input port) over the running window of one cycle of the specified fundamental frequency (freq port). The input port (Sin_Cos) is the two dimensional signal that provided the reference frame required for the computation and hence, returns the first and second output ports of the magnitude and phase, respectively. The initial fundamental frequency is 60Hz and the initial input magnitude and phase relative to phase locked loop in degrees is 220*sqrt(2) and 0 degrees respectively. Sample time (Ts) is measured as Ts*20. The element wise gain under the output of magnitude is 1/sqrt(2), which is fed to the output port of the signals block. Mechanical measurements are made in the design to glance the effects of space vector pulse width modulation in controlling with the speed of a three phase alternating current induction motor. The rotor speed and electromagnetic torque in the AC motor system is measured. The rotor speed signal in the element wise gain multiplier which has a value of 30/pi is measured in the output port 3. The electromagnetic torque is then directly measured at output port of the signals block. The input port labeled as Iabc_Stator coming from the voltage and current (V-I) measurements of the signal bus is input in the switch selector to measure either phase A, phase B, and phase C of the stator current. In this case, stator current phase A is chosen to measure and it is feed in the output port 2 of the signals block. The simulation is started with the initial motor speed of 1720 rpm, and the RMS value of the stator voltages is 220V at 60Hz. Notice that when the Vab_Stator (V) and Ia_Stator (A) waveform (Fig. 6.) reaches 0.1 seconds, speed began to changed. At 0.5 seconds, the speed in the revolutions per minute (rpm) changes from 1720rpm into 1550rpm (see Fig. 5.) and after 1 second the speed changes from the 1550rpm into 1300rpm. The stator voltage (Vab) varies after 0.5 seconds from the 220Vrms to 195Vrms and after 1 (one) second it changes from 195Vrms to 165Vrms. The frequency at initial state of 60Hz began to go down, and after 0.5s it is 53Hz, and again after 1 second, it is in 45.2Hz before it reaches the steady state. Every 0.1 second the speed continues to decrease reaching up to its final value of 1 second before it reaches the steady state condition of constant voltage to frequency control (V/Hz) of the alternating current induction motor of 165Vrms and 45.5Hz. The three phase source in the inverter is a combination of the three alternating voltages and currents displaced at 120 degrees which are connected to the stator of the AC induction motor. It also produces the rotating or revolving field that supplies the energy to the motor through induction. The rotor design is a squirrel cage type and the speed is obtained by means of a tachometer. The motor goes to a constant speed of 1300rpm, constant DC bus voltage of 165Vrms, and constant frequency of 45.2 Hz after reaching the steady state condition. Only the fundamental components is used keeping the complexity low but however providing relevant and significant information for controlling the speed of alternating current induction motor using SVPWM.

IV. Conclusion

The design and simulation of space vector pulse width modulation in controlling the speed of three phase alternating current induction motor is presented. Computer simulation experiment is performed and implemented in controlling the speed of a three phase alternating current induction motor. The results of simulation show that space vector pulse width modulation generates the voltage patterns at a real time and able to control the speed of a three phase alternating current induction motor. The use and realization of space vector pulse width modulation has been evaluated by computer simulation experiment for controlling the speed of the three phase alternating current induction motor and the performance obtained is good in the results of the simulation. However, the space vector pulse width modulation control algorithm theory is very complex and the actual implementation requires a high power and high speed DSP processor for the desired switching frequency.

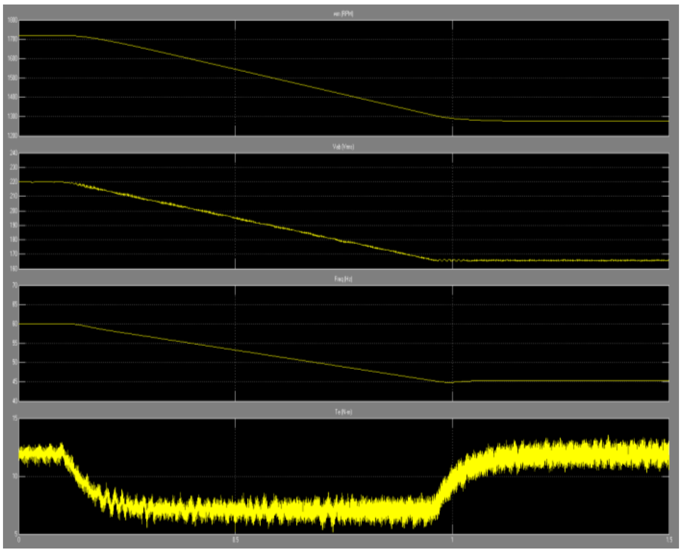

Fig. 5. Speed, voltage, frequency, and electromagnetic torque measurements.

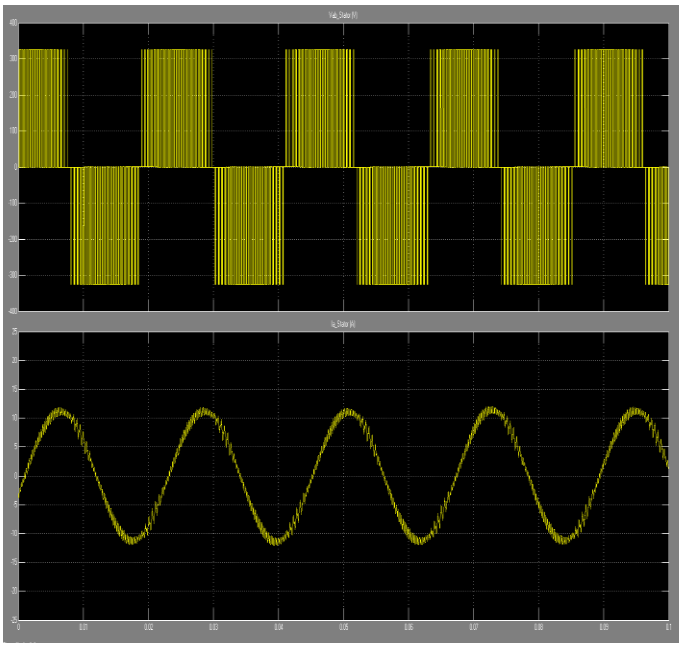

Fig. 6. Stator voltage and stator current measurements.

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