REALISATION OF A SPEED ADJUSTMENT SYSTEM FOR SMALL THREE PHASE SQUARREL CAGE ASYNCHRONOUS MOTORS

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Abstract

With the quick development of technology, the reliability of power electronic devices has increased and costs have been significantly reduced. Depending on that, semiconductor based power electronics circuits have spread. Induction motors are very common all over the world and this motor has attractive in many applications due to robust and maintainless. But squarely motor has constant speed only can be changed by variable frequency in easy way. Sine based switching is a way to reduce harmonics signals in power control strategy. In this study, unique DSP based solid programmed microcontroller has been investigated to control small-power asynchronous motor (1.1kW).

Keywords: Induction motor, DSP, Sine-PWM, MC3PHAC

1. Introduction

Squirrel-cage induction motors are widely used in industry thanks to their advantages in terms of low cost, robustness and minimal maintenance necessities. Nowadays, the developments on complex control techniques allow manufacturers to design sophisticated inverter drives for these motors [1]. But these techniques bring both partly complex control systems and higher costs.

On the other side, in small-power, low cost applications like small pumps and fans, which needs speed control, optimum cost and performance conditions, must be met. These demands are low-harmonic content, low-cost and speed control in a wide operation range [2]. In this study DSP-based MC3PHAC chip has been used.

Abbreviations

$I_2^{'}$ Reduced rotor current

M_d (M_{maks}) Maximum torque

$R_2^{'}$ Reduced rotor resistance

V_1 Stator voltage

x_1 Stator Impedance

ω_s Stator angular speed

$x_2^{'}$ Rotor impedance in terms of stator

λ Rate between running frequency and nominal frequency

s Slip

E_{ag} Back E.M.F on stator

f_1 Stator frequency

f_2 Rotor frequency

φ_{ag} Magnetic flux in air gap

f Frequency

p Double pole

k Constant number

Motor Parameters

U=220V

I=4.4A

f=50Hz.

N=2770 rpm.

COS (φ)=0.87

P=1.1kW

2. V/F Control Theory

Synchronous speed and thus motor speed can be controlled by ac source frequency (f). Chancing frequency in induction motor control is common way to chance the speed. As shown Equation (1), counter *e.m.f.* of induction motor (E_{ag}) is proportional with frequency (f) and air-gap flux (ϕ_{ag}).

$$E_{ag} = kf\phi_{ag} \qquad (1)$$

In constant air-gap flux, E_{ag} can be made linearly dependent to frequency [3]. For low stator winding impedance ($R + j2\Pi fL_s$); E_{ag} is proportional with source voltage V_s. Thus constant air-gap flux can be written as Equation (2).

$$\phi_{ag} \propto \frac{E_{ag}}{f} \propto \frac{V_s}{f} \tag{2}$$

Air gap flux is controlled with frequency by adjusting source voltage. Air gap flux doesn't change as much as voltage ratio to frequency is constant. Breakdown torque of an induction motor can be expressed by Equation (3).

$$M_d = \frac{3pR_2^{'}(I_2^{'})^2}{2\pi f_{2d}} \tag{3}$$

Where, M is torque, R is rotor resistance, f is rotor frequency and I is rotor current. It can be seen that maximum rotation torque is independent from V_1 and f_1. Rotor current I2 can be expressed by Equation (4).

$$I_2^{'} = \frac{\lambda V_1}{\sqrt{(\frac{R_2^{'}}{s_d})^2 + (x_1 + x_2^{'})^2 . \lambda^2}} = \frac{V_1}{\sqrt{2}(x_1 + x_2^{'})^2} \tag{4}$$

Rotor current is directly proportional with source voltage V_1. Running area of induction motor up to nominal values is described as "constant torque area" and running area over nominal values is called "constant power area" as in Figure 1.

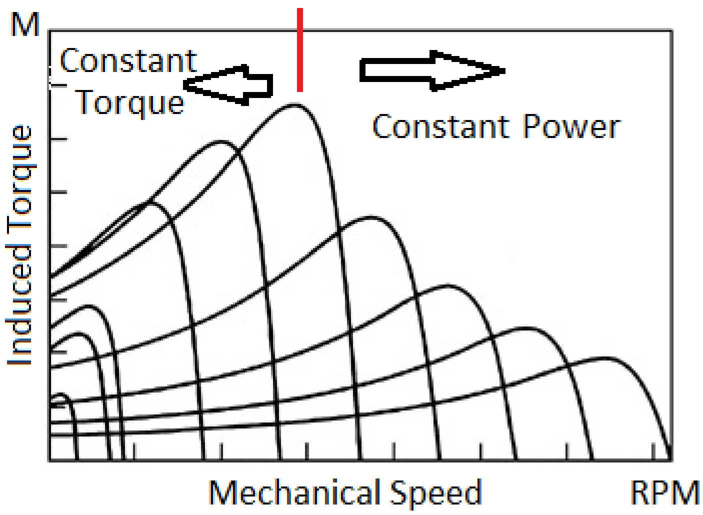


Figure 1. Speed-Torque curves

Induction motor has less torque in over speed running. In addition to less torque value, motor has much current and loses.

3. Low-Cost Basic Driver Structure

A simple control strategy for adjustable speed control, which provides the conditions above, is shown in Figure 2. This is the most commonly used AC/DC/DC inverter structure. Main AC source has constant voltage and frequency in the contrary, variable voltage and frequency are in need to change motor speed. In order to obtain variable frequency and voltage, main AC voltage source turn to DC source is filtered by capacitor. AC voltage can be turned to DC voltage using bridge diode structure and filtered by paralleled capacitor. Induction motor behaves as a generator when the motor is excited mechanically or when the motor set the lower frequency level from the upper frequency. Generated voltage makes DC bus level higher and makes driver stage broken. In order to protect the driver stage braking structure must be added [4].

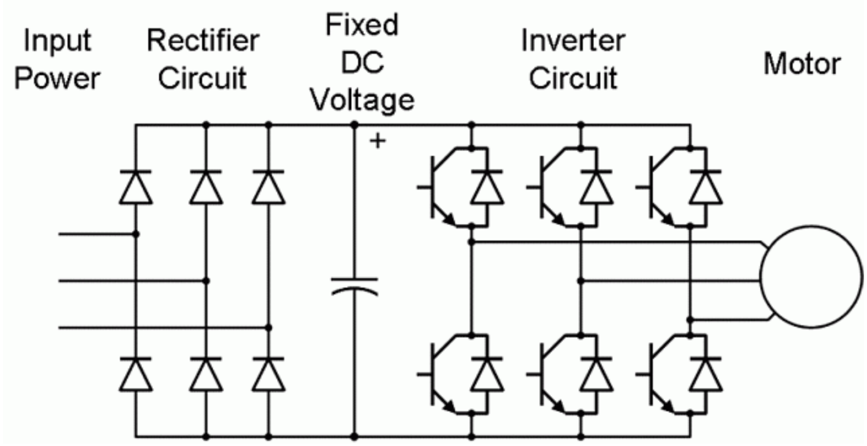


Figure 2. A typical AC motor driver structure

4. Generating Control Signals

MP3PHAC is monolithic motor control unit based on DSP signal calculation. In order to improve resolution, calculations were executed 32 bit data structure. Inputs and calculations of the PWM’s are shown Figure 3 for MC3PHAC.

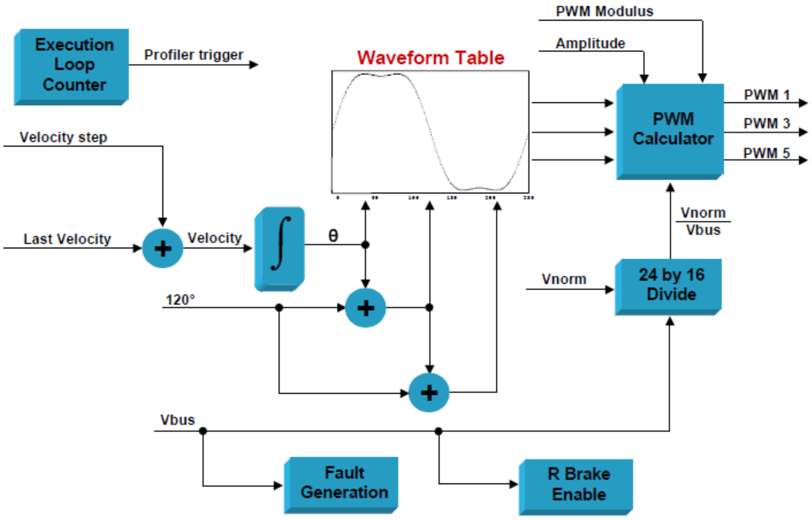


Figure 3. MC3PHAC block diagram for calculating PWM signals

Only calculations and wide data structure are not enough for generated signals to apply driver stage. There are control strategy and algorithm in need not to damage driver stage at any time. Sinusoidal pulse width modulation signals were generated via superimposing triangle and sinusoidal signal. Control algorithm does not apply signal which is smaller than 1uSec to driver stage to protect the driver stages. Another important situation is about starting control signals. Some driver stages include capacitor charge pump to driver MOSFET or IBGT to makes cheap the driver stages. For this structure, control signal must be started with low side signals. Figure 4 shows one leg's upper and lower transistors' driving signals. For the other legs are 120^{o} shifted forms of the same signals. Sinusoidal-based form of control signal also makes the stator current in sinusoidal form [5].

The MC3PHAC Motor Control Unit is a pre-programmed, variable-speed, three-phase ac device. It provides a comprehensive motor-control solution for use in many industrial, automotive, and home applications like low-horsepower HVAC motors, home washing machines and dishwashers, commercial appliances, process controls, pumps, and fans. This monolithic, intelligent unit contains the active functions required to implement the control portion of an open-loop, three-phase ac motor. With no software required for operation, an Internet-enabled system lets the motor be attached to a PC and controlled remotely. The unit is user-configurable for standalone or hosted operation.

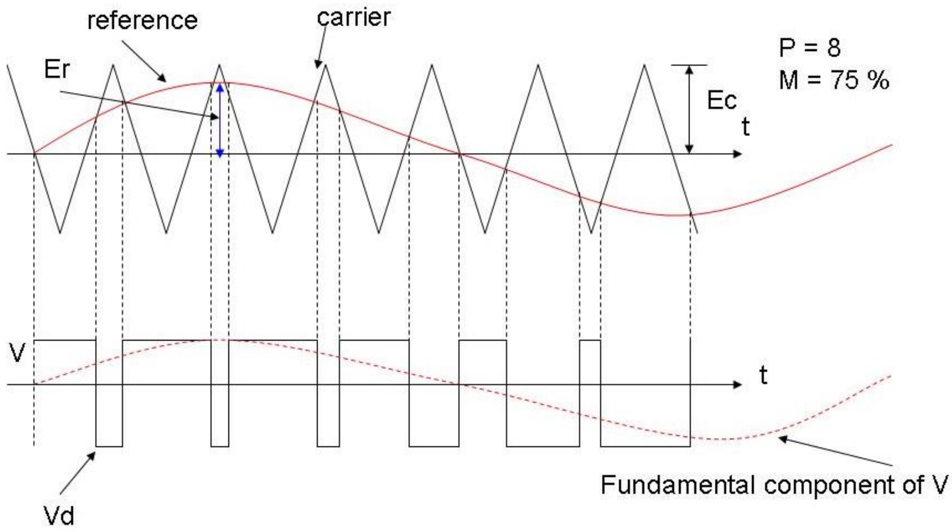


Figure 4. Generating control signal

The MC3PHAC features a selectable 50/60-Hz base speed and up to 32-bit high-precision internal calculations. Controlling the chip stand-alone or via a PC is possible. In this study MC3PHAC chip has been used as stand-alone and open loop as shown Figure 5.

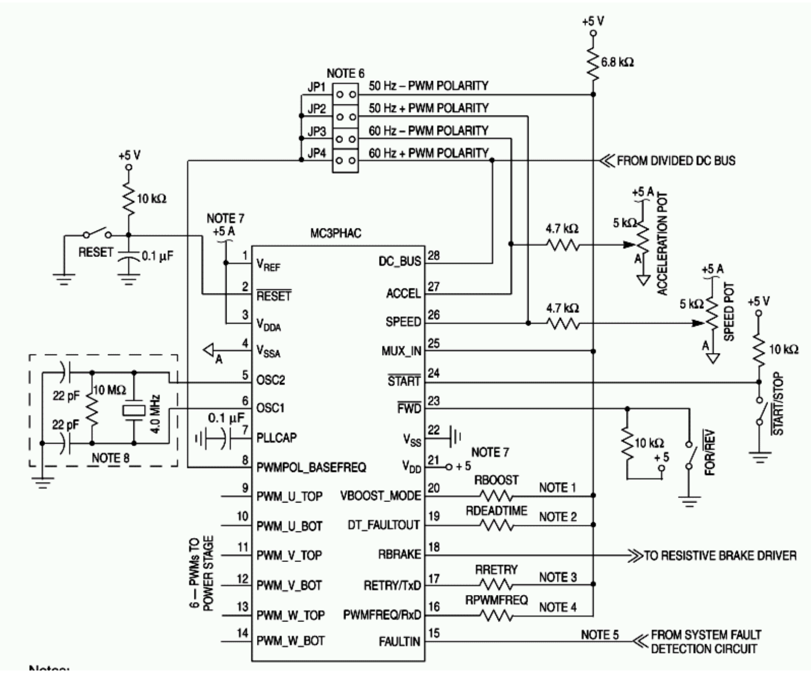


Figure 5. Typical application scheme for MC3PHAC without computer connection

Dead time, voltage boost, retry time features are available in the chip. For dead time adjustment, in the moment of turning on and off of the devices in the same leg a time gap should be given between two switching times, which is defined as dead time.

This short time can be adjusted via resistive or PC. Resistive adjustment graph is given in Figure 6.

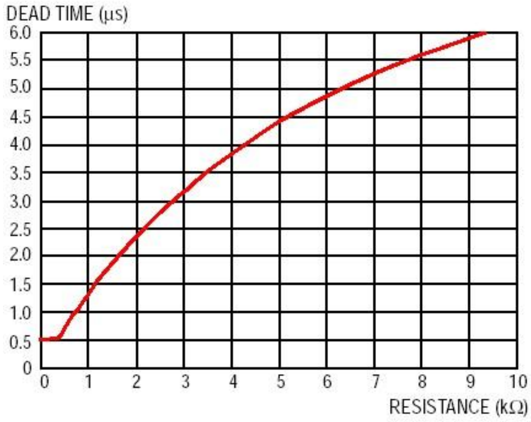


Figure 6. Dead-time adjustment graph

Retry option starts the motor again if the error like over-temperature or ground error has disappeared after a defined time.

In asynchronous motor control, copper losses must be compensated in low rotation speeds. For this reason V/f ratio is initialised from a value differing zero. This ratio changes for different motor characteristics. Initialising V/f ratio from a defined value is called "voltage boost". Figure 7 shows relations between programming resistor and boost ratio.

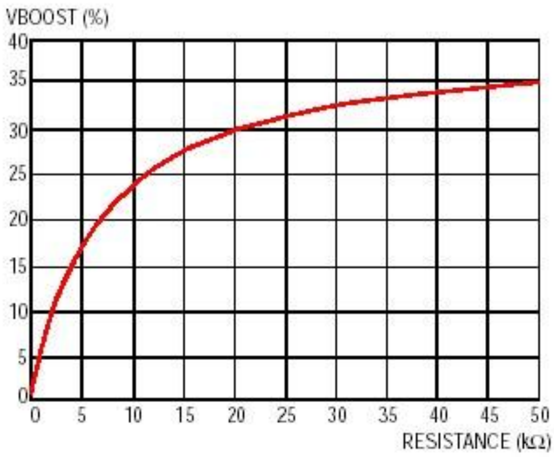


Figure 7. Voltage boost adjustment graph

5. Simulation and Implementation of the Circuit

The designed circuit consist a half-bridge rectifier, filter and an inverter that chops DC line voltage. The basic structure of the circuit is shown in Figure 2. The rectified ac voltage has been filtered with line capacitors and a dc voltage with minimum ripple has been obtained. The ripple in full-load is shown in Figure14 The obtained dc voltage has been chopped and converted to ac voltage whose voltage and frequency can be adjusted. As power devices IGBTs have been preferred. Over conventional BJTs and MOSFETs they have some advantages like not having second breakdown voltage and having very high input impedances. Their main drawback is the driving problem of the devices on the same leg [6]. This problem has been overcome by using a special driving chip (IR2235) for IGBTs and MOSFETs. The related circuit diagram is shown in Figure 8. IR series MOS-FET and IGBT drivers make driving circuits simple and useful.

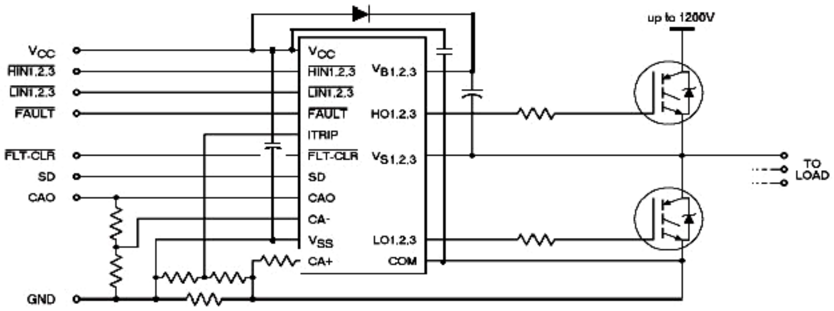
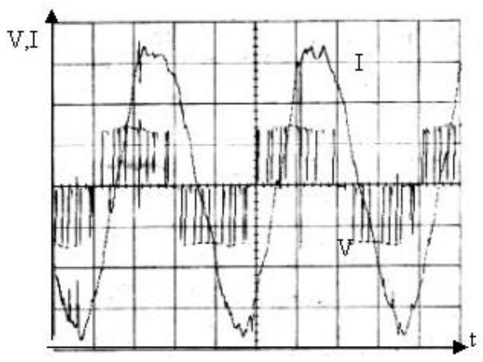


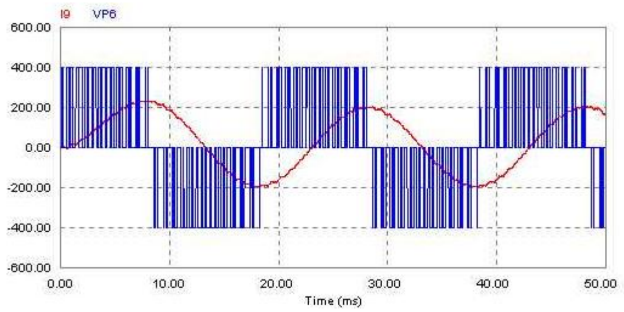
Figure 8. Scheme for IGBT driver unit

IGBT driver has 6 different outputs to drive 3-phase 3 half-bridge connection. Driving signals are TTL compliant. Observing DC line current on driver chip is possible [7]. Figure 9 shows one leg voltage and current waveforms at full load.



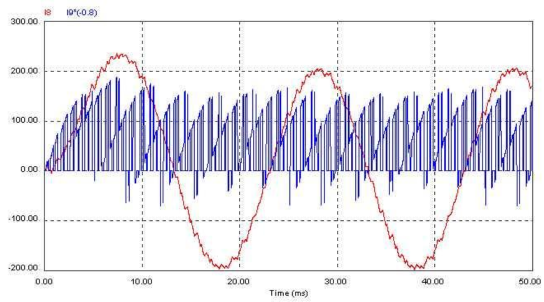
Current 1.8A/5msn Voltage 20V/5msn

(a)

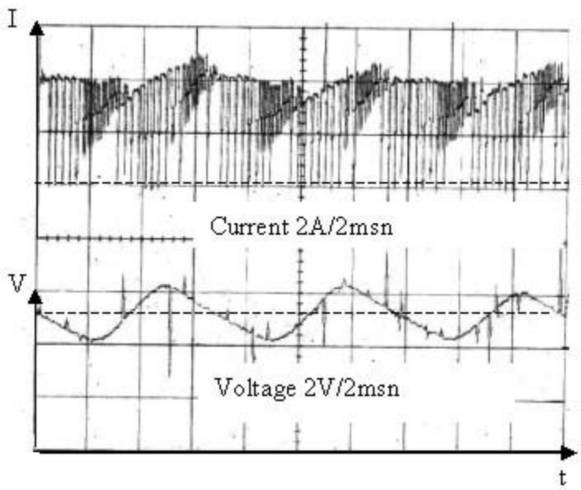


(b)

Figure 9. (a) The obtained waveforms of one leg voltage signal and same leg current (b) The simulated waveforms of one leg voltage signal and stator current observed on same leg.



(a)



(b)

Figure 14. (a) The simulated DC line current and stator current waveforms (b) DC line current and DC ripple extent. (Full load 1.1kW)

On the DC line current waveform resembles part of sine waves and superimposes all driver leg current. Figure 10 shows DC line current from application board and simulation program. On DC bus, capacitor has an ability to make voltage source of the driving structure due to capacitor capacity. Load current runs out the voltage level on the capacitor. And this event makes ripples on the DC bus voltage. Figure 10 b. shows ripple level related to load current at full load (1.1Kw).

6. Conclusion

In this study speed control of an asynchronous motor by means of V/f control has been implemented successfully. The generated signals have been isolated by optocouplers and applied to IGBTs through the IR2235 IGBT driver chip. Thus, sinusoidal-PWM signal generating microcontroller and source, which powers asynchronous motor, have been isolated from each other. In order to sense signals fast enough, a high-speed optocoupler model has been chosen. In circuit, 10MHz, 6N137 optocoupler has been used. IR2235 driver chip has 6 different outputs to drive 6 IGBTs. In case of over-current situation, it has its own error outputs independent from MC3PHAC. If desired, all PWM outputs can be shutdown independently. Because asynchronous motors behave like secondary short-circuited transformers, their starting currents may be between 4 to 8 times more than their nominal currents. The performance criterions on selecting IGBT are current and voltage ranges and 10µsn short-circuit durability.

As asynchronous motor has been controlled with PWM method, mostly voltage components of harmonics are available. Motor stator current component is rather close to sinusoidal form. Motor inductance also behaves as low-pass filter and higher frequency components become ineffective on the rotor. In order to prevent voltage harmonics to return back to utility, a filter has been added to ac source side whose high-cut frequency is higher than the third harmonic. Thus, ac source voltage's fundamental form is protected and electromagnetic interference to the utility is prevented.

In case of very accurate speed control demands, direct torque control or vector control has some important advantages. In applications where a range of 1-2% has no great importance, V/f method, which is also known as scalar control, presents a practical and optimum solution.

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