

## Simulation Analysis of SPWM Variable Frequency Speed Based on Simulink

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**Abstract:** This article is studied on currently a very active field of researching sinusoidal pulse width modulation (SPWM) frequency speed control system, and strengthen researched on the simulation model of speed control system with MATLAB / Simulink / Power System simulation tools, thus we can find the best way to simulation. We apply it to the actual conveyor belt, frequency conversion motor, when the obtained simulation results are compared with the measured data, we prove that the method is practical and effective. The results of our research have a guiding role for the future engineering and technical personnel in asynchronous motor SPWM VVVF CAD design. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Simulation analysis, MATLAB/ Simulink / power system, Variable frequency speed control, Sinusoidal pulse width modulation, Asynchronous AC motor.

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### 1. Introduction

In today's industrial production, induction asynchronous motor has become the main form of electromechanical energy conversion, and their using number is more than the sum of all other types of motor [1]. Asynchronous motors in industrial applications, and even speed control system, can compete with the DC motor. Investigate the reason, there are several advantages.

1) Induction motor's robustness, reliability, low maintenance,

2) In particular, the production of squirrel cage motor is very simple. Without rotor winding, commutator, brushes, DC motor can avoid the wear problems. With out brush and electric arc, it can operate in poor security conditions.

3) It has a higher power density, higher maximum speed, and its rotor inertia is lower than the DC motor rotor.

But the induction motor also has its flaws, it is a nonlinear, multivariable strong coupling system. How to control them has been the focus of research in electric move industry. With the emergence of new power electronic devices, and smart power IC's available, as well as the development of modern control theory and computer science technology, researching direction has shifted to AC variable speed frequency control. Frequency control has a variety of methods, the paper has done in-depth study and simulation on the current sinusoidal pulse width modulation (SPWM) inverter which is active on researching field now. Using MATLAB / SIMMULINK simulation tools, we do priority research to speed control system simulation model.

## 2. Introduction of Asynchronous Motor SPWM VVVF System

An important conclusion in the sampling control theory: When the same impulse but different shapes of narrow pulse applied to the inertia link, the effect is basically the same. Sinusoidal pulse width modulation (SPWM) method is the theoretical basis of that conclusion, using equal altitude but not aequilate SPWM wave whose pulse width changes sinusoidally to equivalent with the sine wave (shown in Fig. 1) [2]. By controlling switching devices and cycle-off size of inverter circuit, we can change the frequency and amplitude of the sine wave.

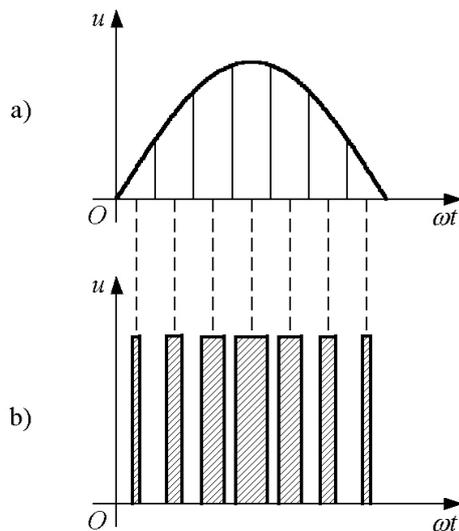


Fig. 1. SPWM wave equivalent sine wave.

The system diagram of SPWM indirect variable voltage frequency device has shown in Fig. 2. Firstly we turn frequency alternating current into direct current through the rectifier, and filters through the middle part, then convert the direct current into controlled frequency and amplitude of the AC through an inverter, which is also called AC - DC - AC VVVF device. Such apparatus, with no rectifier control devices, we can improve the input side of the power factor (power factor closes to 1), and reduce the impact of harmonics on the grid. The inverter part is completed once with SPWM VVVF inverter, simplifying the circuit structure; reducing harmonics, solving the motor torque ripple problems at low frequency section, and reducing the motor harmonic losses and noise [3].

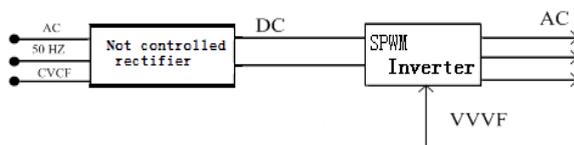


Fig. 2. SPWM VVVF indirect device.

The reducing degree of SPWM inverter output harmonic depends on the switching frequency of the inverter device, and the switching frequency is limited by the device switching time limit. Using IGBT, or P-MOSFET, the switching frequency can up to 100 kHz above [4], the output waveform has already been closed to a sine wave. Therefore, this device has become the most promising form. At present, for the requirements of high performance or small-capacity AC variable speed drive, the main use of this indirect SPWM VVVF AC motor apparatus for frequency control, i.e. asynchronous motor SPWM VVVF system.

## 3. MATLAB / SIMULINK Application in Motor Control System

MATLAB is popular simulation software now, we can get a new method to achieve electrical schematic diagram of the control system by Simulink and power system module library [5]. CAD can greatly improve the efficiency and reliability by using it. This article is based AC drive system as the research object, using the MATLAB / SIMULINK for SPWM controlled AC induction motor drive system to simulation analysis.

### 3.1. Simulink / Power System Toolbox

Simulink toolbox consists of a continuous module group (Continuous), discrete module group (Discrete), Functions and table module group (Functions & Tables), math module group (Math), non-linear module group (Nonlinear), Signals and Systems module group (Signals & Systems), the output module group (Sinks), input module group (Sources) and subsystem module group (Subsystems) and so on.

Power System toolbox is based on Simulink environment, covering electrical disciplines common basic component library. It consists of Power (Electrical sources), basic components (Elements), power electronics (Power Electronics), motor (Machines), connectors (Connectors), measurement (Measurements) this 6 module library components. According to the common needs, it can combine more complex modules, and add to the relevant module library. Matlab 6.0 above has additional module library. The control sub-module library has six pulse trigger, and three-phase sub-module library has three-phase full-controlled thyristor bridge modules, even additional motor sub-module library has AC, DC motor module and so on.

### 3.2. The Simulation of Phase Inverter Based on SPWM

SPWM modulation of the three-phase bridge inverter circuit has shown in Fig. 3. Simulation

methods are varied, we can get it by using different modules, but the principle is the same [6].

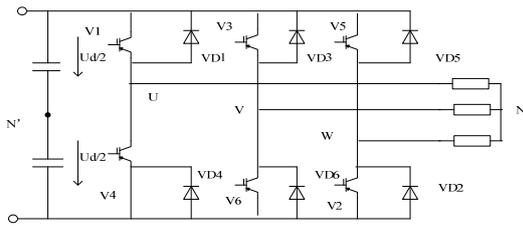


Fig. 3. Three-phase bridge SPWM inverter circuit.

1) The simulation model based on a logic module  
According to three-phase bridge PWM inverter circuit, we established the MATLAB / SIMULINK simulation model, the model diagram has shown in Fig. 4.

At the beginning of the simulation, various parts of the output waveform and numeric can be directly observed by the oscilloscope module. It is noteworthy that before running the system model, we should set reasonable relative error and step length in simulation parameters, so as to make the results of running simulation model more accurate.

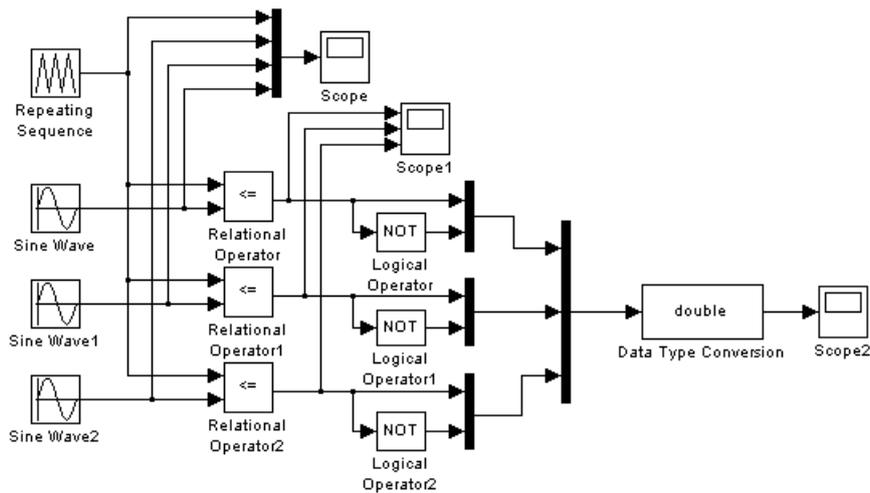


Fig. 4. Simulation model diagram composed of logic modules.

In this case the simulation parameters are: carrier ratio of 10, modulation of 0.8, the model adopts the variable under constant step-step type ode23tb algorithm simulation. Simulation waveforms have shown in Fig. 5-7. The result is the best of the results obtained by the algorithm.

see the system's modulation frequency and modulation size easily.

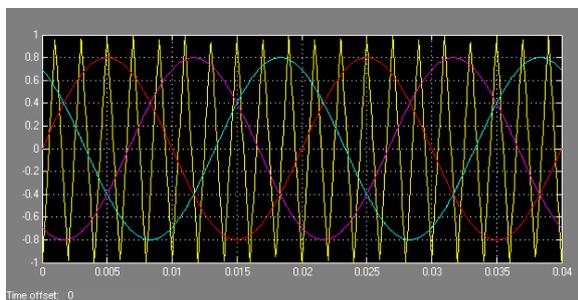


Fig. 5. Carrier and modulating waveform.

Fig. 5 illustrates the relationship of the three-phase sine and triangular between the carrier modulation. From Fig. 3, Fig. 4 and Fig. 5, we can

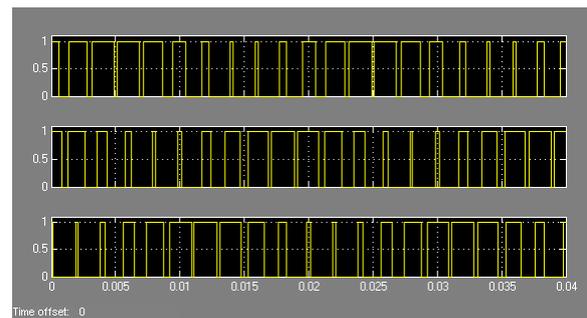


Fig. 6. Pulse waveform.

Fig. 6 shows the difference of three mutually 120° of each modulated sine wave and the triangular carrier wave of each phase obtained after the pulse sequence generated by the SPWM. Be apparent through Fig. 3, Fig. 4, Fig. 5 and Fig. 6, this three-phase pulse sequences are of the same shape, but the phase angle are different from each other between 120°.

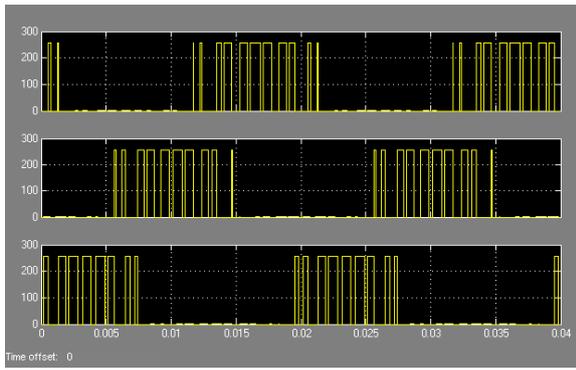


Fig. 7. Phase voltage waveforms.

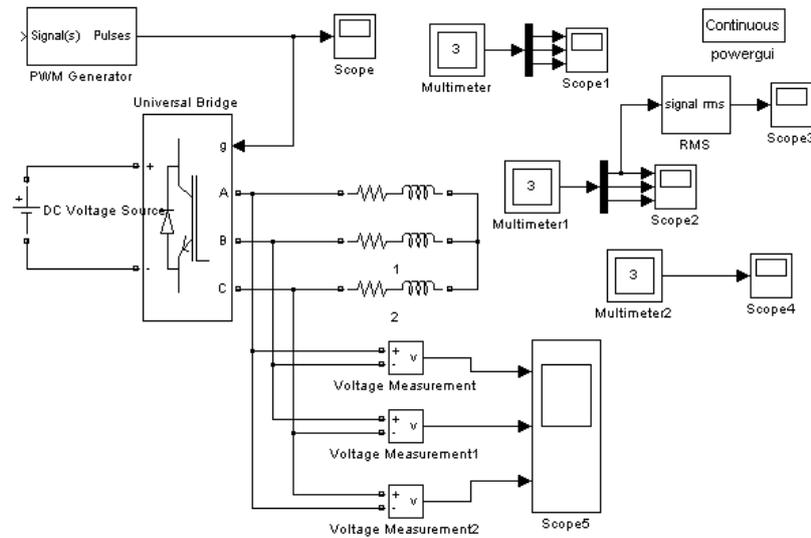


Fig. 8. The simulation model based on PWM generator module and universal bridge module.

The model uses Ode23tb algorithm under Variable-step type to simulate.

The simulation results of the model are shown in Fig. 9. From Fig. 9, we can obviously see that this is a three-phase pulse sequence of same shape but the phase angle is different of  $120^\circ$ , and the pulse sequence waveform is similar to sine wave.

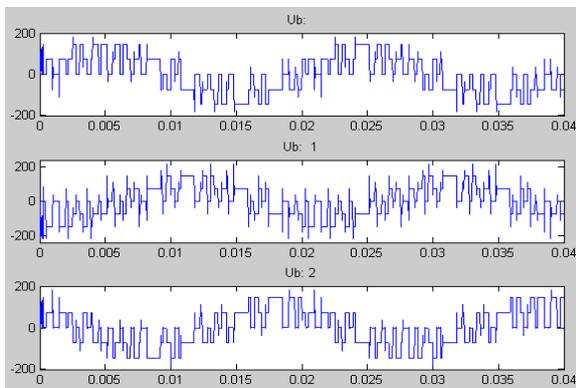


Fig. 9. The output voltage waveform.

Fig. 7 is the three phase line voltage waveform, which is corresponding to the three-phase inverter SPWM modulation principle, and it is relatively close to the sine wave. If the carrier frequency is further improved, the shape of the waveform will further close to sine wave.

2) The simulation model based on PWM Generator module and Universal Bridge module

This section describes the model (as shown in Fig. 8) which is mainly built by PWM Generator and Universal Bridge module. The parameter settings are as follows: The RMS measurement module sets the parameters of Fundamental frequency (Hz) to 50 Hz; DC voltage is set to 220 V; the three resistive inductive load are set to the same  $R=2 \Omega$ ,  $L=0.01 \text{ H}$ .

3) The simulation model based on basic module

Fig. 10 is a simulation model of SPWM waveform generator constructed by basic module. The model can be similarly divided into two parts: Sine wave generator and triangle wave generator. The frequency input signal  $f$  of the sine generator simulation model multiplies the sine wave  $2\pi$  gets the angular frequency  $\omega$ , then the  $\omega$  times the time variable  $t$  provided by the clock module, we can get the input there-phase sine wave generator (sin arithmetic module); the sine wave initial phase is provided by one constant module, the parameter is set to  $2\pi / 3 \times [0, -1, 1]$ , each phase is different between  $120^\circ$ . The triangular wave frequency is set by the constant module, it is set to 1650. The sine wave output by the sine module and the triangular wave output by the triangular wave generator (Math Function and Look Up Table combination) are selected by the Relay module after compare, we can obtain the SPWM wave the system desired. This model uses ode23tb algorithm under Variable-step variable step type to simulate [7, 8].

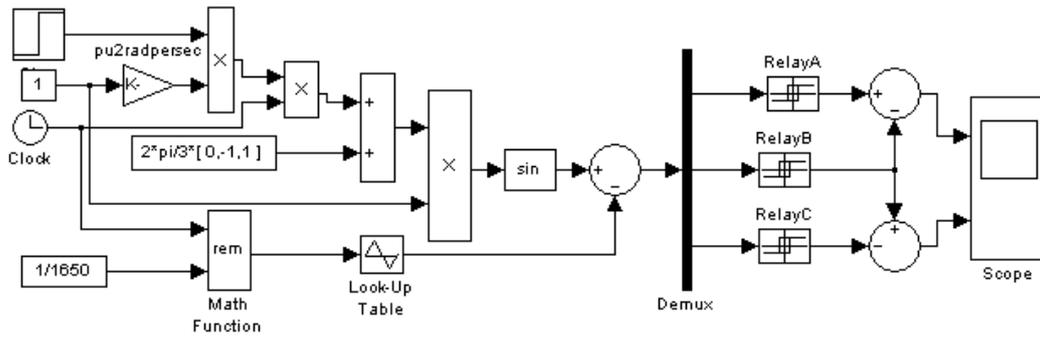


Fig. 10. The simulation model based on module of SPWM waveform generator constructed.

The simulation results of the model are shown in Fig. 11. It can get the same waveform which was got in the first two models. Obviously, we can see, the results are better than the second model simulation results when they are in the same algorithm.

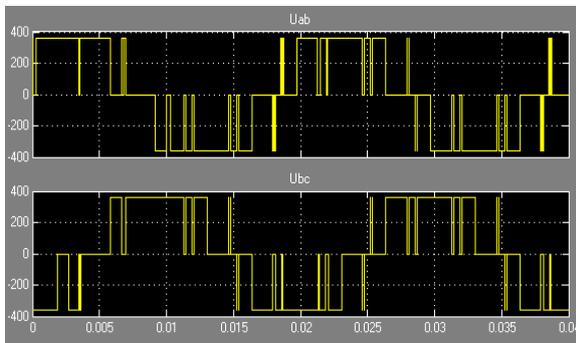


Fig. 11. The output waveform based on module of SPWM waveform generator constructed.

#### 4. Simulation research of SPWM Variable Frequency Speed Control System

The conveyer belt of the bale press in a cotton mill uses frequency conversion motor. A type of YP2100L2-4 three-phase asynchronous motor, its rated values are 380 V, 1430 r/min, 2.2 kW. The system's working process is as follows: First, get the symmetrical three-phase AD through the transformer from the power grid, and then provide power for the electric motor after three-phase uncontrolled rectifier, filtering and the inverter under SPWM control mode.

Asynchronous motor is a high-level, non-linear, strong coupling of multivariable systems. In the study of the mathematical model of asynchronous motor, we usually make the following assumptions [9, 10]:

a) Ignore the space harmonics, supposing that the three-phase windings are symmetrical in space, and each is different between  $120^\circ$  electrical angle, which produces a magnetic momentum in the spatial distribution by sine law; the distribution of the magneto motive force produced by them is as the sine law in space;

b) Ignore magnetic saturation, considering that the self-inductance and mutual inductance are constant

c) Ignore the core loss;

d) Do not consider the influence of the frequency variations and temperature variations to the winding resistance.

#### 4.1. Modeling

According to the results of the preceding chapter, we can see that the SPWM waveform generating first and third method is more ideal, we use in modeling algorithm is ode23tb algorithm step type under the optimal algorithm, the best way in the first method to produce SPWM wave is ode23tb algorithm under Fix-step fixed step type, therefore, we select SPWM waveform generator model as the basic modules simulation model to build system model. Firstly, package the model as shown in Fig. 10 of the subsystem, and then model as shown in Fig. 12. The output of SPWM frequency signal generator is the Simulink control signal. To drive motor, we must use controlled voltage source module in the power module to get AC voltage to control the operation of a motor. SPWM variable frequency control signal generator and a voltage controlled current source module are shown in Fig. 12 of the connection, you can get three-phase AC voltage of driving motor. Asynchronous motor parameters:  $P_N=2.2$  kW,  $U_1=380$  V,  $f=50$  Hz,  $R_1=0.435$   $\Omega$ ,  $R_2=0.816$   $\Omega$ ,  $L_{11}=4$  mH,  $L_{12}=2$  mH,  $L_m=69.31$  mH,  $J=0.089$  kg/m<sup>2</sup>,  $p=2$ . Asynchronous motor output signal measuring device model. The system outputs a phase current, speed, and torque signal. The velocity signal increases by 2 times, just to make separate output signal, easy to see. In this system, the induction motor actual speed is  $n = \omega \times 30 / \pi$  (r / min). A frequency control circuit has only one given link, the system simulation model uses the signal module to achieve the step, an initial value of 50 Hz, at 1.0 s step to 25 Hz, by varying the frequency of the sine modulation wave signal to achieve the system frequency, thereby achieving speed. The system uses asynchronous modulation, when changing the frequency of the sine wave modulation, the triangular carrier frequency keeps unchanged.

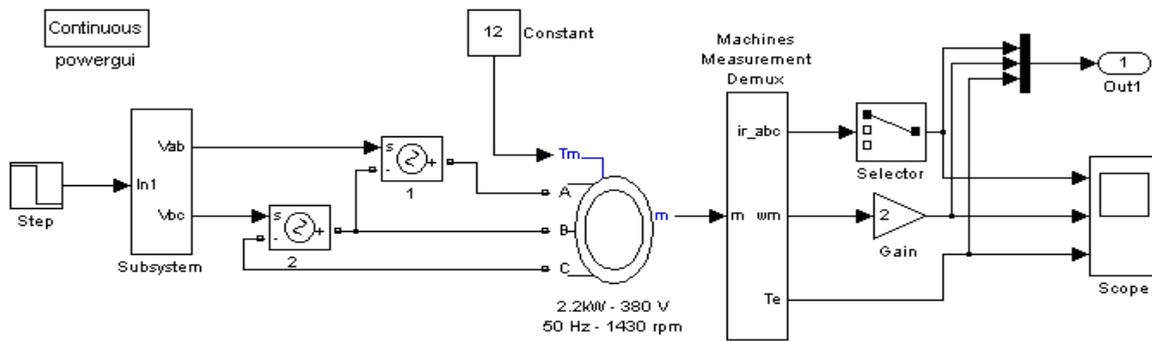


Fig. 12. SPWM VVVF system simulation model.

## 4.2. Simulation Results and Analysis

The simulation results of the A-phase current, speed and torque of the SPWM Frequency Control System are shown in Fig. 13, we can see that, when starting, the current of the asynchronous motor is large, and as the speed increasing, the current will gradually decrease, when the speed is stable, it is minimum and remained stable. This is because that when starting, its slip ratio is large, while the equivalent impedance of the motor is very small, therefore, the start-up current is large; the time when the motor is running normally, the slip ratio becomes small, and the equivalent impedance of the electric motor is great, thereby limiting the rotor current.

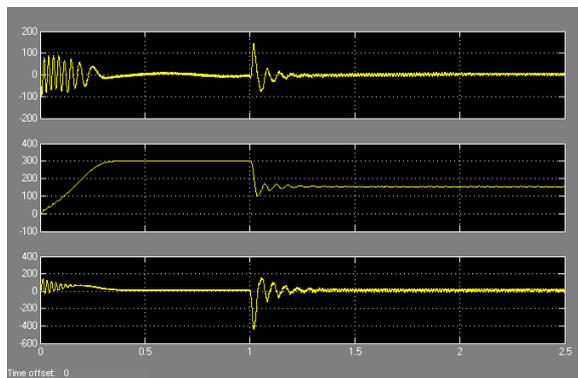


Fig. 13. The curve of current, speed and torque based on SPWM VVVF system

The output torque are as shown in Fig. 13 waveform of asynchronous motor, torque motor VVVF system at boot time increases, and the load torque unchanged, rotor speed. With the rise of rotational speed, the rotor current is gradually reduced, the torque ripple decreases, but its value is still higher than the load torque, stable operation and motor, namely speed, load torque and output torque to balance again. Because the control system is the SPWM asynchronous modulation. The asynchronous modulation, carrier frequency is constant, with the increase of carrier frequency modulation wave, will increase

the ratio of  $N$ , the harmonic component is reduced, so the high speed motor torque ripple. On the contrary, the motor in the low speed running state, the carrier will be less than that of  $N$ , the harmonic components increase, leading to large torque ripple. And, because the motor has the effect of inertia, no pulsation in speed waveform, so the speed waveform is smooth. From the above analysis, the conveyor belt for motor in constant torque load in low frequency, reduce the torque ripple and noise, improve performance of the system in low frequency.

## 5. Conclusions

We tested the asynchronous motor variable frequency speed regulation process (50 Hz-25 Hz) by selecting data which is the same with simulation parameters. The current, speed and torque curve are shown in Fig. 14. Comparing with the current, speed and torque curve of the simulation diagram, we found that, not only the change trend, but also the speed of dynamic response is the same.

Practice has proved that the simulation model constructed by the basic modules has the advantages of simple structure and high precision mathematical model. We can prove the validity and practical applicability of the method by comparing the simulation results with measured data. The research results have great effect on guiding CAD design in SPWM VVVF system for the engineers.

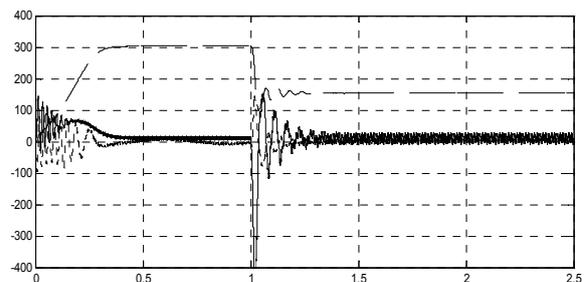


Fig. 14. The measured curve of current, speed and torque based on SPWM VVVF system.

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