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Direct torque control of induction motor using SVM-VSI .

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ABSTRACT

The theory of operation for the control techniques is presented. A mathematical model for the direct torque control of the induction motor drive is developed. A simulation model is developed in MATLAB/SIMULINK and is used to obtain the basic operation performance of the DTC induction motor drive.

In conventional direct torque control (DTC), the selection of flux linkage and electromagnetic torque errors are made within the respective flux and torque hysteresis bands, in order to obtain fast torque response, low inverter switching frequency and low harmonic losses. However, DTC drive utilizing hysteresis comparator suffers from high torque ripple and variable switching frequency. Space vector modulation is the strategy to minimize the torque ripple of induction motor in which, the stator flux level is selected in accordance with the efficiency optimized motor performance. In this work space vector modulation method is incorporated with direct torque control for induction motor drives. However, the direct torque control space vector modulation strategy is the calculation of the required voltage space vector to compensate the flux and torque errors exactly by using a predictive technique and then its generation using the space vector modulation at each sample period.

Keywords: Induction Motor; SVM-VSI; DTC; PWM.

I. INTRODUCTION

In industrial application, the electric motors play crucial role as heart of the system. Therefore, the best performance motor control systems contribute to a great extent, to the desirable performance of automated sectors by enhancing the production rate and the quality of products. In fact the performance of today's automated system is defined in terms of efficiency, smoothness and accuracy.

In recent years, the commercial applications of the Field-Oriented Control (FOC) of Induction Motor (IM) drives have greatly increased. A number of studies has been developed to find out different solutions for the control of the IM drives with two objectives, namely (i) fulfillment of the requirements for a precise and quick control of the motor flux and torque, and (ii) reduction of the complexity of the algorithms involved in a FOC.

A new technique for the torque control of induction motors was developed and presented by I. Takahashi as Direct Torque Control (DTC) [1]–[3], and by M. Depenbrock as Direct Self Control (DSC) [4],[5]. Since the beginning, the new technique was characterized by simplicity, good performance and robustness [6]–[16]. The basic scheme of DSC is preferable in the high power range applications, where a lower inverter switching frequency can justify higher current distortion. Differently from FOC, DTC does not tend to reproduce the electromechanical behavior of a dc motor drive but is aimed at a complete exploitation of the flux and torque-producing capabilities of an IM fed by a Voltage Source Inverter.

The DTC scheme is characterized by the absence of proportional integral (PI) regulators, coordinate transformations, current regulators and pulse width modulation signals generators. The name direct torque control is derived by the fact that, on the basis of the errors between the reference and the estimated value of torque and flux, it is possible to directly control the inverter states in order to reduce the torque and flux error within the prefixed band hysteresis band limit.

II DIRECT TORQUE CONTROL OF INDUCTION MOTOR

Unlike the traditional vector control, DTC doesn't require coordinate transformation, PI regulators, and PWM and position encoders. Hence, DTC is much simpler. Moreover, Both DTC and VC provide good dynamic response but DTC is less sensitive to the motor parameter variations [21]. The induction motor like performance is obtained in DTC drives. In DTC drives, the de-coupling of the torque and flux components is accomplished by using hysteresis comparators which compares the actual and estimated values of the electromagnetic torque and stator flux. The DTC drive consists of DTC controller, torque and flux calculator, and a Voltage Source Inverter. The basic concept behind the DTC of AC drive, as its name implies, is to control the electromagnetic torque and flux linkage directly and independently by the use of six or eight voltage space vectors found in lookup table. The voltage vector show in Fig.1.

In Direct Torque Control it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state.

The typical DTC includes two hysteresis controller, one for torque error correction and one for flux linkage error correction [21]. The hysteresis flux controller makes the stator flux rotate in a circular fashion along the reference trajectory. The hysteresis torque controller tries to keep the motor torque within a pre-defined hysteresis band. The control algorithm determines a control signal whose amplitude depends on the difference between desired and actual value.

This control signal can assume any value in a given interval. The three signals used in the control action of a DTC system are torque error, flux linkage error and the angle of the resultant flux linkage vector.

One revolution is divided into six sectors. In each sector the DTC chose between 4 voltage vectors. Two of the vectors increase and other two vectors decrease torque. Another pair of vectors increase or decrease flux.

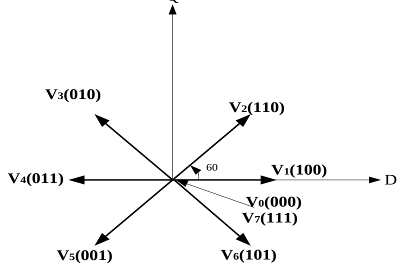

Fig.1. Eight Possible Voltage Space Vectors

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For each combination of the torque and flux hysteresis comparator state there is only one of the four voltage vectors which at the time compensate torque and flux as desired [22].

III TORQUE CONTROL STRATEGY IN DTC OF IM DRIVE

The instantaneous torque in terms of stator and rotor flux linkage is given by

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m(\overline{\psi}_s * \overline{\psi}_r)}{\sigma L_s L_r} \quad (1)$$

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m \psi_s \psi_r}{\sigma L_s L_r}\sin\delta \quad (2)$$

$$\psi_s = \psi_{qs} - j\psi_{ds} \quad (3)$$

$$\psi_r = \psi_{qr} - j\psi_{dr} \quad (4)$$

$$\psi_s = L_s I_s + L_m I_r \quad (5)$$

$$\psi_r = L_r I_r + L_m I_s \quad (6)$$

$$L_s = L_r L_s - L_m^2 \quad (7)$$

Where δ is the torque angle between flux vector ψ_s and ψ_r. If the rotor flux remains constant and stator flux is changed incrementally by the stator voltage V_S then the torque variation ΔT_e expression can be written as:

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{L_s L_r}|\psi_r||\psi_s + \Delta\psi|\sin\delta \quad (8)$$

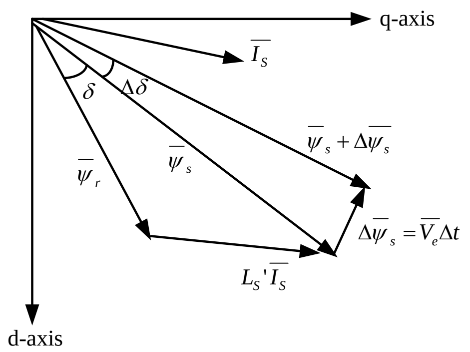

Fig.2. Stator flux, rotor flux & stator current vector on d-q axis.

As it can be seen form, if the load angle δ is increased then torque variation is increase. To increase the load angle δ the stator flux vector should tum faster than rotor flux vector. The rotor flux rotation depends on the mechanical speed of the rotor, so decrease load angle δ the stator flux should turn slower than rotor flux [21]. Therefore, according to the torque, the electromagnetic torque can be controlled effectively by controlling the amplitude and rotational speed of stator flux vector ψ_s . To achieve the above phenomenon, appropriate voltage vector are applied to the motor terminal. For counter-clockwise operation, if the actual torque is smaller than the reference value, then the voltage vectors that keep the stator flux vector ψ_s rotating in the same direction are selected. When the load angle δ between ψ_s and ψ_r increase the actual torque increase as well. Once the actual torque is greater than the reference value, the voltage vector that keep stator flux vector ψ_s is rotating in the reverse direction are selected instead of the zero voltage. At the time, the load angle δ decreases thus the torque decrease. Show in Fig.2.

IV. SIMULATION RESULTS

Recently, the high performance control of induction motors has been interesting to the researchers in industry, because the induction motor is the most commonly used machine and it advances in power electronics have made possible new control methods. Dynamic numerical simulation is very important to decide whether the new control design processes are valid and to avoid the mistakes early in simulations before actual real implementation. MATLAB/ SIMULINK have been a very powerful tool to model the electrical and the mechanical systems because of its simplicity. In this chapter, the dynamic simulation of induction motor is first performed employing the MATLAB/ SIMULINK. Direct Torque Control method on induction motors follows.

SIMULINK MODEL OF DIRECT TORQUE CONTROL OF INDUCTION MOTOR

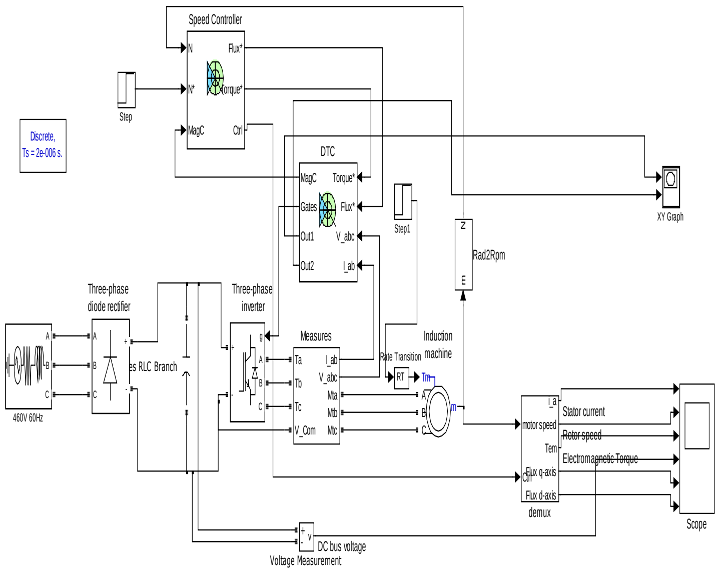

Fig.3. Simulink Model of Direct Torque Control of Induction Motor

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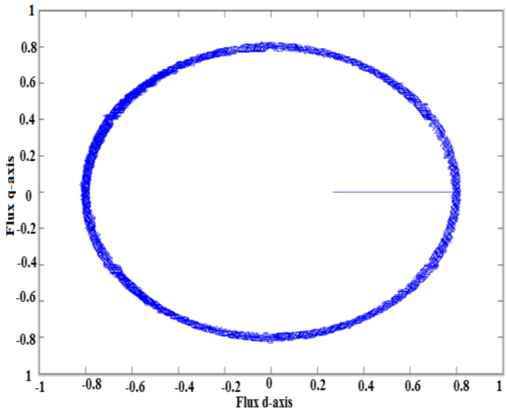

Fig.4 Stator Flux Circular Trajectory

Discussion of Fig.6 and Fig.7. Following cases has been considered.

(i) Speed change from 160 rad/s to 140 rad /s at 1 second.

(ii) Electromagnetic torque change from 120 N-m to 400 N-m at 1 second

Show in Fig.5 stator current, in Fig.6 rotor speed, in Fig.7 Electromagnetic Torque, in Fig.8 DC bus voltage, in Fig.9 Flux q-axis and in Fig.10 Flux d-Axis.

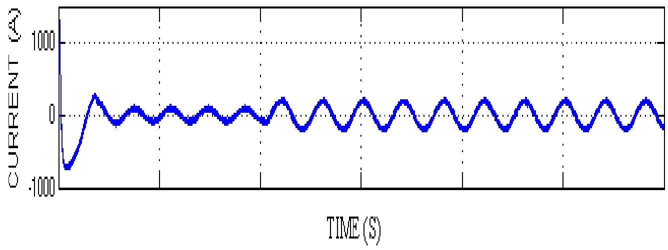

Fig.5 stator current

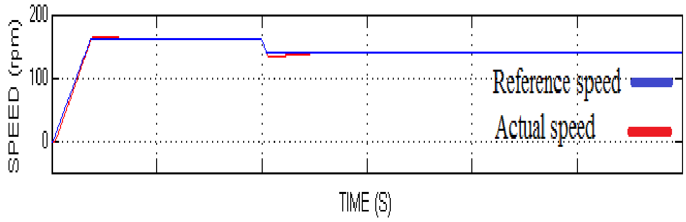

Fig.6. Rotor Speed

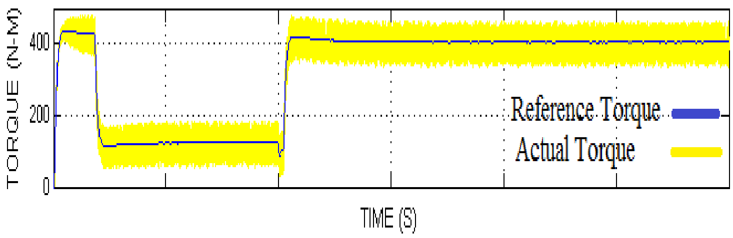

Fig.7. Electromagnetic Torque

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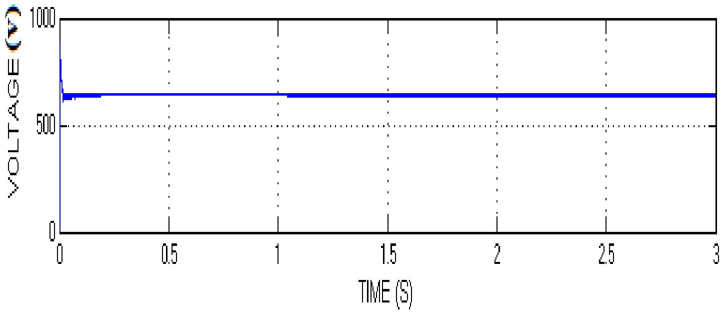

Fig.8. DC bus voltage

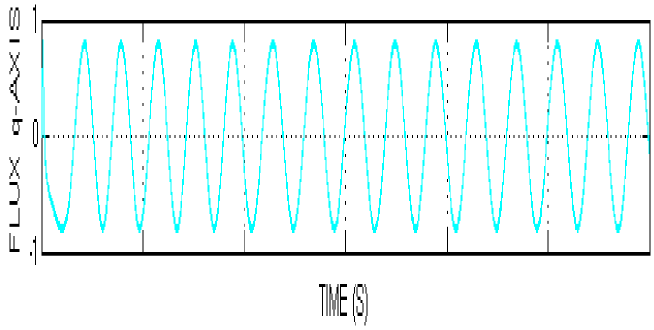

Fig.9. Flux q-axis

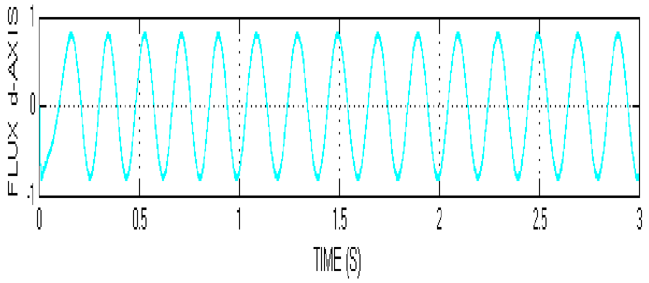

Fig.10. Flux d-Axis

Discussion of Fig.12 and Fig.13. Following cases has been considered.

(1) Speed change from 160 rad/s to 180 rad /s at 1 second.

(2) Electromagnetic torque change from 120 N-m to 400 N-m at 1 second

Show in Fig.11.Stator current, in Fig.12 rotor speed, in Fig.13 Electromagnetic Torque, in Fig.14 DC bus voltage, in Fig. 15 Flux q-axis and in Fig.16 Flux d-Axis.

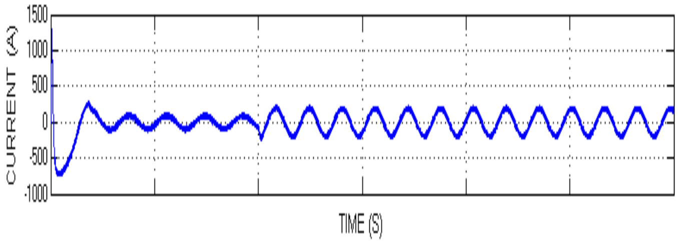

Fig.11. Stator Current

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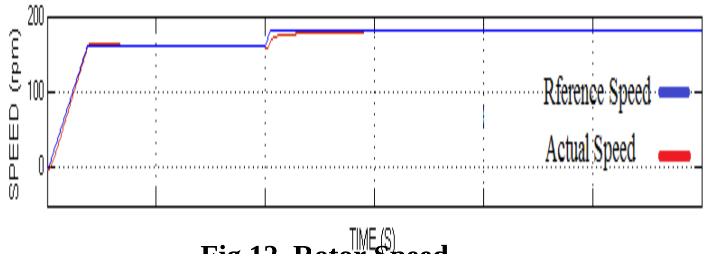

Fig.12. Rotor Speed

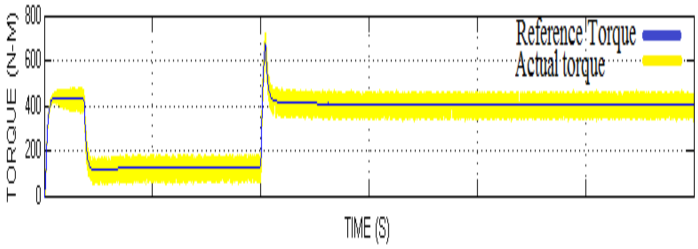

Fig.13. Electromagnetic Torque

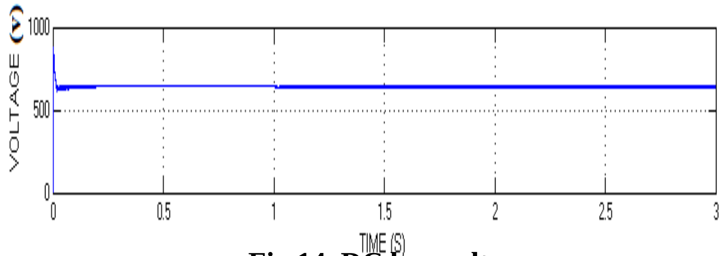

Fig.14. DC bus voltage

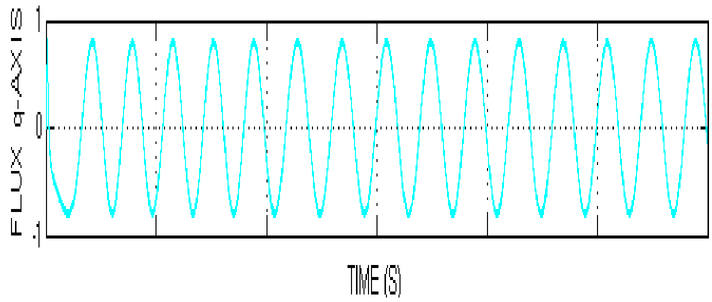

Fig.15. Flux q-axis

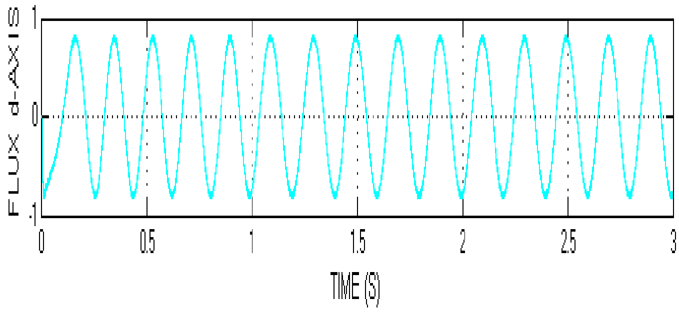

Fig.16. Flux d-axis

Discussion of Fig.18 and Fig.19. Following cases has been considered.

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(1) Speed change from 160 rad/s to 100 rad /s at 1 second.

(2) Electromagnetic torque change from 0 N-m to 120 N-m at 1 second

Show in Fig17 stator current, in Fig.18 rotor speed, in Fig.19 Electromagnetic Torque, in Fig.20 DC bus voltage, in fig. 21 Flux q-axis and in Fig.22 Flux d-Axis.

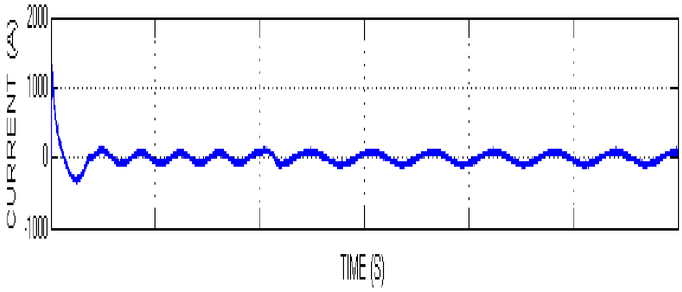

Fig.17. Stator Current

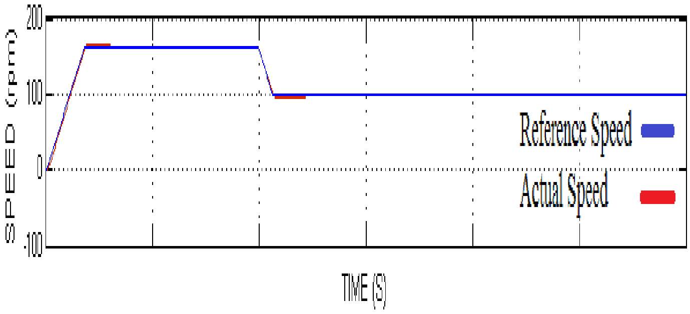

Fig.18. Rotor Speed

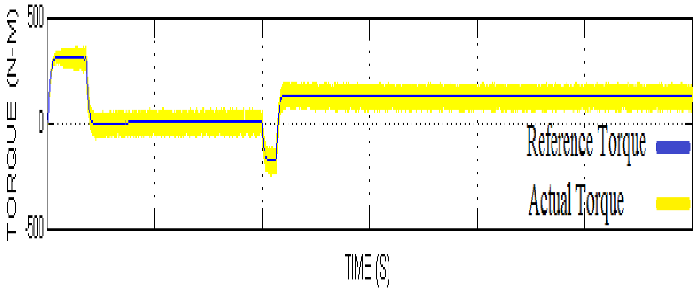

Fig.19. Electromagnetic Torque

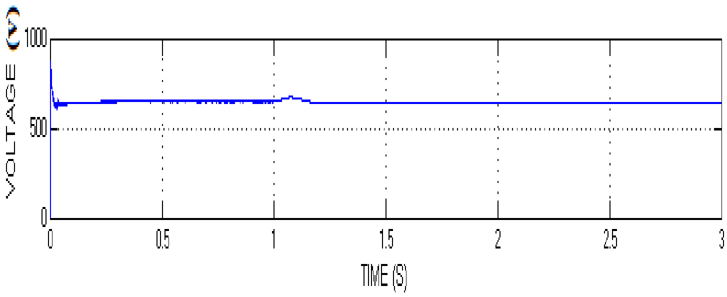

Fig.20. DC bus voltage

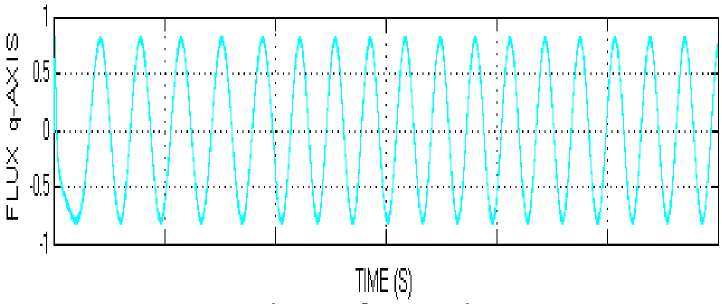

Fig.21. Flux q-axis

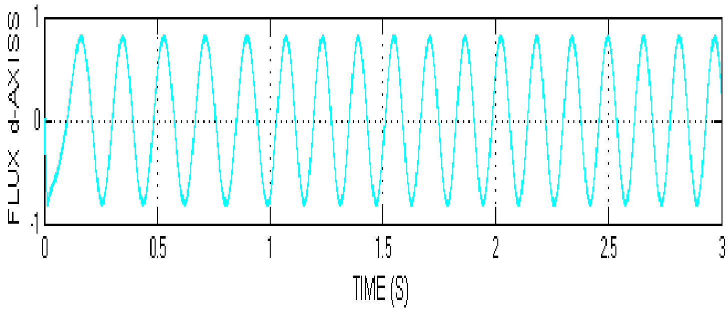

Fig.22. Flux d-axis

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