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IMPROVEMENT OF DIRECT TORQUE CONTROL FOR THREE PHASE INDUCTION MOTOR USING ARTIFICIAL INTELLIGENCE TECHNIQUE

BY

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ABSTRACT

Direct torque control (DTC) of an induction motor fed by a voltage source inverter is a simple scheme that does not need long computation time, can be implemented without mechanical speed sensors and is insensitive to motor parameter variations. In principle, the motor terminal voltages and currents are sampled and used to estimate the motor flux linkage and electromagnetic torque. Based on estimating of the flux position and the instantaneous errors in torque and stator flux magnitudes, a voltage vector is selected to restrict the torque and the flux errors within their respective torque and flux hysteresis bands.

In conventional direct torque control, the traditional proportional integral (PI) controller when used as a speed controller needs its parameters to be retuned every time the operating point is changed because of the induction machine behavior is highly nonlinear. In the first part of this thesis a fuzzy speed controller with modified voltage vector selection algorithm using artificial neural network is presented for adjustable speed DTC based induction motors driven using three level inverter. The three level inverter is used to modify the voltage vector selection algorithm because the voltage selection possibilities are enhanced since more inverter states are available. The full and intermediate voltage vectors are used to overcome the flux demagnetization problem associated with the low speed operation and at motor starting. Simulation results confirm the superiority of the presented controller in fast speed tracking capability over wide speed control range without affecting system stability.

In addition to the above in the conventional DTC, the selected voltage vector is applied for the whole switching period regardless of the magnitude of the torque error. Moreover, the selected voltage vector always cannot generate the exact stator voltage required to

obtain the demanded electromagnetic torque and stator flux linkage. This can result in high torque ripples.

In the second part of this thesis, torque ripple reduction algorithm using fuzzy logic control is proposed. This algorithm depends on varying the duty ratio of the selected voltage vector during each switching period according to the magnitude of the torque error and position of the stator flux. Moreover, another voltage vector selection algorithm modified especially for reducing the torque ripples is presented using three level inverter with artificial neural network as a voltage vector selector instead of conventional look-up tables. Simulation results justify the validity of the proposed method in reducing the motor torque ripples.

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LIST OF SYMBOLES

d^e , q^e	Synchronously rotating reference frame direct and quadrature axis component.
d^s , q^s	Stationary reference frame direct and quadrature axis component.
V_{qs}^s, V_{ds}^s	Stator voltage q^s,d^s axis component .
$V'_{qr}{}^s$, $V'_{dr}{}^s$	Rotor voltage q^s,d^s axis component referred to the stator side.
V_{qs}, V_{ds}	Stator voltage q^e,d^e axis component referred to the stator side .
V'_{qr}, V'_{dr}	Rotor voltage q^e,d^e axis component referred to the stator side.
ψ_{qs}^s ,ψ_{ds}^s	Stator flux q^s,d^s axis component .
$\psi'_{qr}{}^s$,$\psi'_{dr}{}^s$	Rotor flux q^s,d^s axis component referred to the stator side .
ψ_{qs} ,ψ_{ds}	Stator flux q^e,d^e axis component .
ψ'_{qr} ,ψ'_{dr}	Rotor flux q^s,d^s axis component referred to the stator side.
ψ_{qm}^s ,ψ_{dm}^s	Magnetizing flux q^s,d^s axis component .
ψ_{qm} ,ψ_{dm}	Magnetizing flux q^e,d^e axis component .
i_a , i_b , i_c	Stator phase a, b and c currents.
i_{qs}^s , i_{ds}^s	Stator current q^s,d^s axis component .
i_{qs} , i_{ds}	Stator current q^e,d^e axis component .
$i'_{qr}{}^s$, $i'_{dr}{}^s$	Rotor current q^s,d^s axis component referred to the stator side.
i'_{qr} , i'_{dr}	Stator current q^e,d^e axis component referred to the stator side.
i_{qm}^s , i_{dm}^s	Magnetizing current q^s,d^s axis component .
R_s , L_s	Stator resistance and self inductance.
R'_r , L'_r	Rotor resistance and self inductance referred to the stator side

L_{ls} , L'_{lr}	Stator and rotor leakage inductance
L_m	Mutual (Magnetizing) inductance
T_m , T_L	Electromagnetic and load torque
ω_r , ω_m	Motor electrical and mechanical speed.
ω_e	Synchronous speed.
ω_{sl}	Slip frequency.
Θ_e	Angle of Synchronously rotating reference frame.
Θ_r	Rotor angle.
Θ_{sl}	Slip angle.
T_r	Rotor time constant.
γ	Torque angle.
J, B	Combined rotor and load inertia and viscous friction coefficient.
P	Total number of poles.
T_{ref}	Torque reference command.
ψ_{ref}	Stator flux reference command.
S_a,S_b,S_c	Three level inverter switches states.
H_{Te},H_{ψ}	Torque and Flux hysteresis comparator states
HB_{Te},HB_{ψ}	Torque and Flux hysteresis band width.
δ	Duty ratio.

LIST OF ABBREVIATIONS

AC	Alternating current.
ANFIS	Adaptive Neural Fuzzy Inference System
ANN	Artificial Neural Network
DC	Direct Current
DSP	Digital Signal Processor.
DTC	Direct torque control.
EKF	Extended Kalman Filter.
FOC	Field oriented control.
IGBT	Insulated gate Bipolar transistor.
PWM	Pulse width modulation
THD	Total harmonic distortion
PI	Proportional integral controller
FFT	Fast Fourier Transform

CHAPTER (1)

INTRODUCTION

1.1. General

In the past, DC motors were used extensively in factory automation areas where variable-speed operation with high performance at low speed was required, since their flux and torque could be controlled easily by the field and armature current. However, DC motors have certain disadvantages, which are due to the existence of the commutator and the brushes. That is, they require periodic maintenance; they cannot be used in explosive or corrosive environments and they have limited commutator capability under high speed operation [1]. These inherent disadvantages of DC motors have prompted continual attempts to find better solutions to the problem. An attempt has been made to use alternating-current motors instead of DC motors, which can have simple and rugged structural, high maintainability and economy; they are also robust and immune to heavy overloading. Their small dimensions, compared with DC motors, allows AC motor to be designed with substantially higher output ratings for low weight and low rotating mass [2-3].

Today, using modern high switching frequency power converters controlled by microcontrollers, frequency, phase and magnitude of the input to an AC motor can be changed and hence the motor's speed and torque can be controlled. AC motors combined with their drives have replaced DC motors in industrial applications due to their lower cost, better reliability, lower weight, and reduced maintenance requirement. Among the various AC drives systems, those which contain the squirrel cage induction motor have a particular cost advantage. The squirrel cage induction motor is simple, easy to build, rugged and is one of the cheapest machines available at all power ratings [2].

Variable speed or adjustable torque control of electrical motors drives are crucial component in modern industrial manufacturing processes. The application fields of flux and torque decoupling control of induction machines like field oriented control (FOC) [2&4] and more recently direct torque control DTC [5-6] have greatly increased in the areas of traction, paper, rolling mills, machine tools and steel industries where the high performance of the AC motor is required. FOC is based on the decomposition of the instantaneous stator current into two orthogonal components in the synchronously rotating reference frame. The two current components are controlled by a PI controller. Therefore, the dynamic response is relatively low and very sensitive to the motor parameters variation [2]. In the middle of 1980, a simplified variation of FOC known as direct torque control (DTC) for induction machine was developed by Takahashi and Depenbrok. In direct torque controlled induction motors drives, it is possible to control directly the stator flux linkage and the electromagnetic torque in a closed loop by the selection an optimum voltage vector through a predesigned inverter gate pulses look-up table to be applied to the machine stator terminals. The selection of the optimum voltage vector and hence the inverter switches status is made to restrict the flux and the torque errors within their respective hysteresis bands. Moreover, to obtain the fastest torque response and highest efficiency at every instant without using any internal current loops to overcome the drawbacks of FOC. The torque and flux are controlled in closed loop using flux and torque hysteresis comparators without using any internal current loops to overcome the drawbacks of FOC. DTC is simpler than field oriented control and less sensitive to the motor parameters variation, since the stator resistance value is the only machine parameter used to estimate the stator flux [5].

Nowadays, much research is still being done to improve the conventional DTC main disadvantages. The first and main disadvantage of DTC is the high torque and flux ripples [7]. The use of multilevel inverter instead of the conventional two level inverter