ENHANCEMENT OF A THREE PHASE INDUCTION MOTOR PERFORMANCE BY USING A NONLINEAR INVERSE DYNAMICS CONTROLLER

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SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of *Doctor of Philosophy in Electrical Engineering.

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STUDENT’S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at University Malaysia Pahang or any other institutions.

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TABLE OF CONTENT

DECLARATION

TITLE PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

B	Viscous constant
$d' - q'$	Rotor oriented, rotated coordinate system
d-q	Rotor flux oriented, rotated coordinate system
f	Friction coefficient
f_s	Sampling frequency
I_A, I_B, I_C	Phase A, B, and C currents
I_r	Rotor current space vector
I_{rd}	Rotor current vector in d- rotated d-q coordinate system
I_{rq}	Rotor current vector in q- rotated d-q coordinate system
$I_{r\alpha}$, $I_{r\beta}$	Rotor voltage vector in stationary $\alpha - \beta$ coordinate system
I_s	Stator current space vector
I_{sd}	Stator current vector in d- rotated d-q coordinate system
I_{sdc} , I_{sqc}	Stator current reference in rotated d-q coordinate system
I_{sq}	Stator current vector in q- rotated d-q coordinate system
$I_{s\alpha}$, $I_{s\beta}$	Stator voltage vector in stationary $\alpha - \beta$ coordinate system
J	Moment of inertia
L_M	Magnetizing inductance
L_s	Stator inductance
M	Mutual inductance, absolute value
M_e	Electromagnetic torque
M_{ec}	Reference electromagnetic torque
M_{eN}	Nominal torque
M_L	Load torque
m_s	Number of phase windings
m_{sr}	Mutual inductance
P_b	Pair poles
R_r	Rotor resistance
R_s	Stator resistance
S_A, S_B, S_C	Switching states for the voltage source inverter
T_L	Load torque
Ts	Sampling time

U_A, U_B, U_C	Phase A, B, and C voltages
$Us\alpha$, $Us\beta$	Stator voltage vector in stationary $\alpha - \beta$ coordinate system
U_v	Inverter output voltage space vectors
α-β	Stator oriented, stationary coordinate system
γ_m	Motor shaft position angle
γ_{sr}	Rotor flux vector angle
δ	Angle between rotor flux vector and stator current vector
δ_Ψ	Angle between rotor and stator flux vectors
ϵm	Torque error
$\epsilon_{\varphi s}$	Flux error
θ_{rf}	Rotor flux angle
φ_A, φ_B, φ_C	Flux linkages of the stator phase windings
φ_r	Space vector of the rotor flux linkage
Φ_{rd}	Rotor flux vector in d- rotated d-q coordinate system
$\Phi_{r\alpha}$, $\Phi_{r\beta}$	Rotor flux vector in stationary $\alpha - \beta$ coordinate system
φ_S	Space vector of the stator flux linkage
Φ_{sd}	Stator flux vector in d- rotated d-q coordinate system
φ_{sq}	Stator flux vector in q- rotated d-q coordinate system
$\Phi_{s\alpha}$, $\Phi_{s\beta}$	Stator flux vector in stationary $\alpha - \beta$ coordinate system
Ψsc	Reference stator flux amplitude
Ψ_{sN}	Nominal stator flux
Ω_k	Angular speed of the coordinate system
Ω_m	Angular speed of the motor shaft
Ω_{sl}	Slip angular speed
Ω_{sr}	Angular speed of the rotor flux vector

LIST OF ABBREVIATIONS

A/D	Analog to digital converter
ADI	Approximate Dynamic Inversion
CCNID	Current Control of Nonlinear Inverse Dynamic
C_{th}	Thermal capacitance
CV	Control variable
DC	Direct current
DFOC	Direct Field Oriented Control
DI	Dynamic inversion
DSP	Digital Signal Processing
DTC	Direct torque control
DTC-CSFC	DTC-Constant switching frequency controller
DTC-HC	DTC with the hysteresis controller
EKF	Extended Kalman filter
FCS–MPC	Finite control set–model predictive control
FL	Feedback linearization
FLC	Feedback Linearization Control
FOC	Field Oriented Control
GNID	General Nonlinear Inverse Dynamic
GTV-MPTC	Generalized two-vectors-based MPTC
hp	Horsepower
ID	Inverse dynamic
IFOC	Indirect Field Oriented Control
IGBT	Insulated-gate bipolar transistor
IM	Induction motor
INDI	Incremental Nonlinear Dynamic Inversion
IPMSM	Interior Permanent Magnet Synchronous Motor
kir	Iron-loss coefficient
LIM	Linear induction motors
MC	Matrix converter
MPTC	Model predictive torque control
NDI	Nonlinear Dynamic Inversion

NIDC	Nonlinear inverse dynamic control
NLD	Nonlinear dynamic
PI	Proportional integral
PNID	Partial Nonlinear Inverse Dynamic
PTC	Predictive Torque Control
PWM	Pulse Width Modulated
R%	Percentage ripple torque
RQ	Ride quality
Rso	Stator resistance at reference temperature
Rth	Thermal resistance
SDRE	State dependent Riccati equation
SMC	Sliding mode control
SOSMC	Second Order Sliding Mode Control
SPIM	Single-phase induction motor
SVM	Space Vector Modulation
SVPWM	Space vector pulse width modulation
T_{max}	Maximum torque
T_{min}	Minimum torque
Ts	Average temperature of the stator windings
T_{ss}	Steady state torque
UAV	Unmanned Air Vehicle
V/Hz	Voltage/Frequency
VCNID	Voltage-fed Control of Nonlinear Inverse Dynamic
V_{des}	Desired voltage
VF	Vector field

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ABSTRAK

Pengurangan riak tork dalam motor induksi telah menjadi minat penyelidik sejak kebelakangan ini. Pengurangan riak tork mempunyai kesan yang jelas terhadap kecekapan motor induksi (IM). Ia meningkatkan kecekapan, memanjangkan jangka hayat dan mengurangkan kerugian dari penukaran alat ganti apabila digunakan di dalam industry pada sekala besar. Apabila mengambil kira kecekapan induksi motor (IM), kesan riak torque harus di ambil kira. Oleh itu, fokus utama tesis ini adalah untuk membangunkan kaedah Nonlinear Inverse Dynamic (NID) untuk mengawal induction motor tiga fasa. Tiga jenis (NID) iaitu General Nonlinear Inverse Dynamic (GNID), Voltage Control Nonlinear Inverse Dynamic (VCNID) dan Current Control Nonlinear Inverse Dynamic (CCNID). Kaedah ini adalah berorientasikan lapangan vektor ruang lebar (SVPWM). Pengawal dinamik songsang tak linear membatalkan sambutan tidak wajar motor induksi seterusnya meningkatkan prestasi. Pembatalan sambutan tidak wajar ini dicapai melalui persamaan matematik. Model matematik bagi motor induksi nyahgandingan bagi dua input diperolehi. Kemudian dinamik baru yang berasal daripada pelaksanan teknik pengawal dinamik songsang tidak linear(SHBN) yang dicadangkan songsang tak linear pengawal dinamik (SHBN) dihasilkan. Ia mempunyai kelebihan seperti kawalan tork yang cepat,riak tork yang minimum dan tindak balas kelajuan yang cepat. Kaedah yang dicadangkan diuji menggunakan motor aruhan 0.3 kW (IM) dan juga diuji dengan 100% ketidakpastian bagi pemegun, dan 20% pemutar rintangan daripada aruhan saling. Keputusan mengesah dan membuktikan bahawa sistem yang dicadangkan (NID) menghasilkan riak tork yang lebih kecil dan tindak balas tork yang lebih cepat berbanding kawalan konvensional linear suap balik(FLC) dan kaedah tork kawalan langsung (DTC) serta bebas dari tidak ketentuan parameter. Manakala, analisis ralat seperti ralat sensitivity, analisis ralat arus, analisis ralat model pengawal, analisis ralat pengukuran kelajuan, dan analisis kestabilan. Eksperimen dilakukan dengan menggunakan PMDC motor sebagai beban, computer sebagai platform sebagai antara muka kepada pengguna, cip DSP TMS320F28335 DSP sebagai papan pengawal, inverter, bekalan kuasa DC, pengekod, dan sistem merekod data. Kelajuan rujukan adalah 40 Rad / Sec dan beban tork yang digunakan adalah 0.8 N.M. Akhir sekali, objektif kerja disahkan dengan membandingkan kaedah yang dicadangkan dengan kerja-kerja terdahulu. Selain itu, kaedah yang dicadangkan telah mengurangan riak tork yang menjadi kebimbangan utama dalam tork kawalan langsung (DTC) dan skim kawalan suap balik linear (FLC) dan mempunyai kesan ke atas arus histerisis stator.

ABSTRACT

Decreasing the ripple torque in the induction motor has become a preoccupation of many researchers in recent years. It has many impacts on the effective performance of the induction motor (IM), increases efficiency, reduces losses and extends the life of its spare parts. As a result of the (IM)'s features which are robustness, economical, reliable and maintenance free, it is used in large-scale industrial applications. In general, when taking the induction motor performance, and the torque ripple into consideration, the impact is too significant to be ignored. Thus, this thesis focus on developing a new Nonlinear Inverse Dynamic (NID) method to control the three-phase induction motor. Three types of NID namely General Nonlinear Inverse Dynamic, Voltage Control Nonlinear Inverse Dynamic and Current Control Nonlinear Inverse Dynamic. These methods are based on field oriented with space vector pulse width modulation. The NID controller canceled a non-desirable response of the induction motor and enhanced the performance. This cancellation attempts by careful nonlinear algebraic equations. The mathematical model of induction motor and decoupling between two inputs were achieved. Then the desired new dynamic is derived from implementing the proposed NID technique that reserves some benefits such as fast torque control, minimum ripple torque, and fast speed response. The proposed methods were tested by 0.3 Kw IM and also tested with 100% uncertainty for stator and rotor resistances and 20% of mutual inductance. The high-performance minimum ripple torque operation of the closed-loop system was proved through simulation and experiment. The results are verified and proved that the proposed NID system achieves smaller torque ripple and faster torque response than the conventional feedback linearization control (FLC) and direct torque control (DTC) method and robust for parameters uncertainty. Whereas, several types of error analysis had been verified such as sensitivity error analysis, current errors analyses, controller model parameter error analysis, speed measurement error analysis, current measurement error analysis, and stability analysis. The experimental results are performed using programming torque device set as a load, the computer platform as the only interface to the user, the digital signal processor with model TMS320F28335 DSP chip as a controller board, inverter, DC power supply, encoder, and data acquisition systems. The reference speed is 40 Rad/Sec and load torque is 0.8 N.M are used. These, have all been successfully derived, analyzed, simulated, and practically implemented. It has been shown that the system closed-loop output error is equal to zero at all times and not just at steady state. Finally, the comparison of the proposed methods and other works have verified the objectives of the work. Also, the proposed method significantly reduced the torque ripple which is the major concerns of the classical hysteresis-based in DTC and FLC scheme and have an effect on the stator current distortion.

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