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SPEED CONTROL OF INDUCTION MOTOR USING ADRC CONTROLLER

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Abstract- The control of induction motors has been a primary concern of researchers. Proportional-integral-derivative (PID) control and direct torque control (DTC) have been proposed for induction motors [1-6]. However, the control of induction motors is still a challenging problem due to the following issues: 1) the dynamic system of an induction motor is highly nonlinear; 2) the rotor resistance varies because of heating. In this paper, a reduced-order active disturbance rejection control (ADRC) with reduced order extended state observer (RESO) is applied for induction motor control. The ADRC is employed for controlling a slip ring induction motor. All the three phases are assumed to be identical and symmetrically located with respect to each other.

1. INTRODUCTION

Currently the main types of electric motors are still the same DC, AC Asynchronous and Synchronous motors. But, since its invention, the AC asynchronous motor, also named induction motor, has become the most widespread electrical motor in use today. Induction machine (IM) has been the work-horse of industry due to its robustness, low cost, and less maintenance. The main advantage is that induction motors do not require any electrical connection between stationary and rotating parts of the motor. Therefore, they do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors [1]. Induction motors also have low weight and inertia, high efficiency and high over load capability. Furthermore, the motor can work in explosive environments, because no sparks are produced.

Induction motors have many advantages compared to DC machines and synchronous machines in many aspects, such as size, efficiency, cost, life span and maintainability. Low cost and ease of manufacturing have made induction machines a good choice for electric and hybrid vehicles. However, one must be able to achieve energy regenerative braking and be able to control the torque and speed of an induction machine at low speeds in order to use an induction machine in traction drives such as hybrid electric vehicles. Before going to analyze any motor or generator, it is very much important to obtain the machine in terms of equivalent mathematical equations [2], [3]. Traditional per phase equivalent circuit has been widely used in steady state analysis and design of induction motor.

Direct Torque Control (DTC) is an optimized AC drives control principle where inverter switching directly controls the motor variables: flux and torque. The measured input values to the DTC control are motor current and voltage [7]. The voltage is defined from the DC-bus voltage and inverter switch

positions. The voltage and current signals are inputs to an accurate motor model which produces an exact actual value of stator flux and torque. Motor torque and flux two-level comparators compare the actual values to the reference values produced by torque and flux reference controllers.

In the Direct Torque Controlled (DTC) method induction motor is supplied by a voltage source inverter [8]. It is possible to control directly the stator flux linkage (or rotor flux linkage, or magnetizing flux linkage) and the electromagnetic torque by the selection of optimum inverter switching modes. This selection is made to restrict the flux and torque errors within respective flux and torque hysteresis bands, to obtain fast torque response, low inverter switching frequency, and low harmonic losses.

Using the space-vector modulation (SVM) [9], instead of the DTC switching logic, provides higher control resolution and helps improving the drive's behaviour. Drives with SVM display excellent performance in terms of low torque ripple and quiet operation. The switching frequency results constant and the switching pattern can be further optimized. Attempts to combine the DTC with SVM have led to new schemes. Moderate torque ripple reduction is reported by using discrete SVM with predefined time intervals and extended switching tables. Linear proportional-integral (PI) torque and flux control using SVM is investigated and smooth operation was obtained in the steady state, but the robustness is low due to the linear control. The drawback of high current distortion, high torque ripple is eliminated in this method. But the control algorithm in this method is very complex compared to other control schemes.

A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point value. The

controller attempts to minimize the error by adjusting the process control inputs. In the absence of knowledge of the underlying process, a PID controller is the best controller. However, for best performance, the PID parameters used in the calculation must be tuned according to the nature of the system – while the design is generic, the parameters depend on the specific system. The main disadvantage of PID controller is PID can lead to the overshoot of output, and derivative of PID is not realized physically. The PID controller is often used in control of inductor motor; however, it is easily affected by the changes of the parameters of a system. To overcome this problems this paper presents a new concept called Linear Active Disturbance Rejection Controller (LADRC).

II. MODELLING OF INDUCTION MOTOR

In the control of any power electronics drive system(say a motor), to start with a mathematical model of the plant is required. This mathematical model is required further to design any type of controller to control the process of the plant. The induction motor model is established using a rotating (d, q) field reference (without saturation) concept. The power circuit of the 3-φ induction motor is shown in the Fig. 1. The equivalent circuit used for obtaining the mathematical model of the induction motor is shown in the Fig. 2. An induction motor model is then used to predict the voltage required to drive the flux and torque to the demanded values within a fixed time period[9]. This calculated voltage is then synthesized using the space vector modulation. The stator & rotor voltage equations are given by

$$\begin{aligned}
 u_d &= R_1 i_d + \frac{d\psi_d}{dt} - \omega_1 \psi_q \\
 u_q &= R_1 i_q + \frac{d\psi_q}{dt} - \omega_1 \psi_d \\
 u_{dr} &= R_2 i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_1 - \omega) \psi_{qr} \\
 u_{qr} &= R_2 i_{qr} + \frac{d\psi_{qr}}{dt} - (\omega_1 - \omega) \psi_{dr}
 \end{aligned}$$

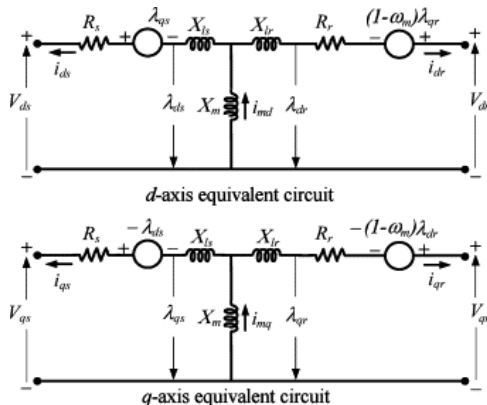


Fig.4 Equivalent circuit of induction motor in d-q frame

where u_{sd} and u_{sq} , u_{rd} and u_{rq} are the direct axes & quadrature axes stator and rotor voltages. The squirrel-cage induction motor considered for the simulation study in this paper, has the d and q-axis components of the rotor voltage zero.

By superposition, i.e., adding the torques acting on the d-axis and the q-axis of the rotor windings, the instantaneous torque produced in the electromechanical interaction is given by

$$T_e = \frac{3}{2} \left(\frac{P}{2} \right) \frac{L_m}{L_r} (i_{qs} \lambda_{dr} - i_{ds} \lambda_{qr})$$

III. ACTIVE DISTURBANCE REJECTION CONTROL

Active disturbance rejection control (ADRC) is Han’s way out of the robust control paradox [14-16]. The term was first used in [17] where his unique ideas were first systematically introduced into the English literature. Originally proposed using nonlinear gains, ADRC becomes more practical to implement and tune by using parameterized linear gains, as proposed in [18]. Although the ADRC method is applicable, in general, to n order, nonlinear, time-varying, multi-input and multi-output systems (MIMO), for the sake of simplicity, its basic concept is illustrated here using the second-order motion control problem in (1). The Active Disturbance Rejection Concept At this juncture, a more specific answer to (Q1) is that the order of the differential equation should be known from the laws of physics, and the parameter b is should also be known approximately in practice from the physics of the motor and the amount of the load it drives. Adopting a disturbance rejection framework, the motion process in (1) can be seen as a nominal, double integral, plant

$$\ddot{y} = u$$

Scaled by b and perturbed by $f(y, \dot{y}, w, t)$. That is, $f(y, \dot{y}, w, t)$ is the generalized disturbance, as defined above, and the focus of the control design. Contrary to all existing conventions, Han proposed that $f(y, \dot{y}, w, t)$ as an analytical expression perhaps is not required or even necessary for the purpose of feedback control design. Instead, what is needed is its value estimated in real time. Specifically, let \hat{f} be the estimate of $f(y, \dot{y}, w, t)$ at time t ,

$$u = (-\hat{f} + u_0) / b$$

reduces (1) to a simple double-integral plant $\ddot{y} \approx u_0$ which can be easily controlled.

This demonstrates the central idea of active disturbance rejection: the control of a complex nonlinear, time-varying, and uncertain process in (1) is reduced to the simple problem in (7) by a direct and active estimation and rejection (cancellation) of the generalized disturbance, $f(y, \dot{y}, w, t)$. The key difference between this and all of the previous approaches is that no explicit analytical expression of $f(y, \dot{y}, w, t)$ is assumed here.

The only thing required, as stated above, is the knowledge of the order of the system and the approximate value of b in (1). The bu term in (1) can even be viewed as a linear approximation, since the nonlinearity of the actuator can be seen as an external disturbance included in w . That is, the ADRC method applies to a processes of the form

$$\ddot{y} = p(y, \dot{y}, w, u, t)$$

of which (1) is an approximation, i.e., $p(y, \dot{y}, w, u, t) \approx f(y, \dot{y}, w, t) + bu$ success. Obviously, the of ADRC is tied closely to the timely and accurate estimate of the disturbance. A simple estimation such as $\hat{f} = \hat{\dot{y}} - u$ may very well be sufficient for all practical purposes, where \hat{y} denotes an estimation of y .

The Extended State Observer and the Control Law
There are also many observers proposed in the literature, including the unknown input observer, the disturbance observer, the perturbation observer, and the extended state observer (ESO). See, for example, a survey in [7]. Most require a nominal mathematical model. A brief description of the ESO of (1) is described below. The readers are referred to [14,19,20] for details, particularly for the digital implementation and generalization of the ESO in [20].

The ESO was originally proposed by J. Han [14-16]. It is made practical by the tuning method proposed in [18], which simplified its implementation and made the design transparent to engineers. The main idea is to use an augmented state space model of (1) that includes f , short for $f(y, \dot{y}, w, t)$, as an additional state. In particular, let $x_1 = y$, $x_2 = \dot{y}$, and $x_3 = f$, the augmented state space form of (1) is

$$\dot{x} = Ax + Bu + Eh$$

$$y = Cx$$

With $A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ b \\ 0 \end{bmatrix}, C = [1 \ 0 \ 0], E = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$

Note that $x_3 = f$ is the augmented state and $h = f$ is a

part of the jerk, i.e., the differentiation of the acceleration, of motion and is physically bounded. The state observer

$$\dot{z} = Az + Bu + L(y - \hat{y})$$

$$\hat{y} = Cz$$

With the observer gain $L = [\beta_1 \ \beta_2 \ \beta_3]^T$ selected appropriately, provides an estimate of the state of (9), $z_i \approx x_i, i=1, 2, 3$. Most importantly, the third state of the observer, z_3 , approximates f . The ESO in its original form employs nonlinear observer gains. Here, with the use of linear gains, this observer is denoted as the linear extended state observer (LESO). Moreover, to simplify the tuning process, the observer gains are parameterized as

$$L = [3\omega_c, 3\omega_c^2, \omega_c^3]^T \quad (11)$$

where the observer bandwidth, ω_c , is the only tuning parameter.

With a well-tuned observer, the observer state z_3 will closely track $x_3 = f(y, \dot{y}, w, t)$ The control law

$$u = (-z_3 + u_0)/b$$

then reduces (1) to (7), i.e.,

$$\ddot{y} = (f - z_3) + u_0 \approx u_0$$

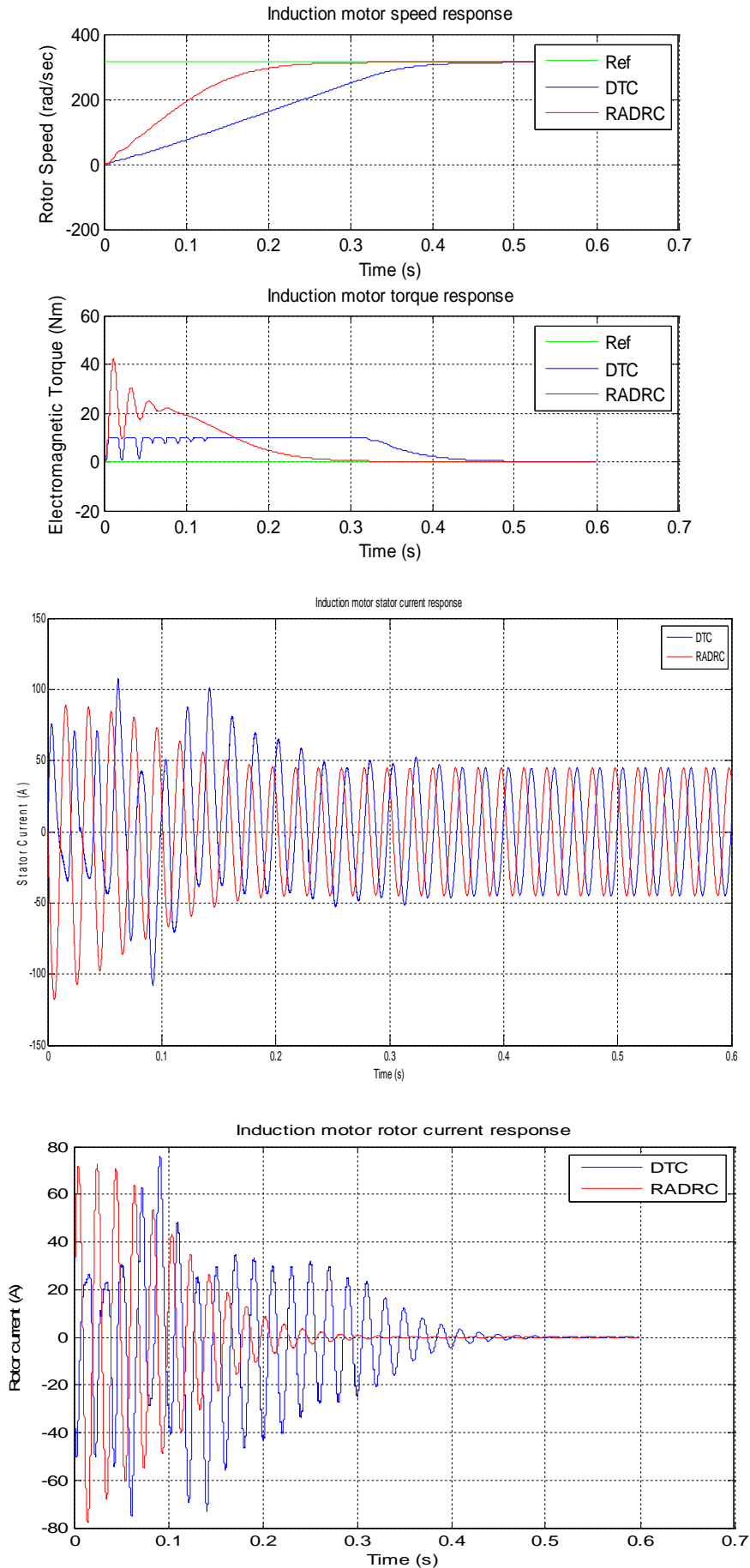
An example of such u_0 is the common linear proportional-and derivative control law

$$u_0 = k_p (r - z_1) - k_d z_2$$

where r is the set point. The controller tuning is further simplified with $k_d = 2\omega_c$ and $k_p = \omega_c^2$, where ω_c is the closed-loop bandwidth [18]. Together with the LESO in (10), (14) is denoted as the parameterized linear ADRC, or LADRC.

IV. SIMULATION RESULTS

The results validate the control structure proposed in this paper. Proposed control technique for the speed control of an induction motor is compared with the performance of the DTC of induction motor. Induction motor speed response and torque response shows that the performance of the ADRC control of induction motor is effective than the DTC of induction motor.



V. CONCLUSIONS

Active disturbance rejection controller (ADRC) maintains the advantages of PID because it is not depend on the accurate mathematical model of the induction motor [11], and it also can estimate and compensate the unknown internal dynamics and the external disturbance such as the change of the rotor resistance, so ADRC has better static and dynamic performances, strong robustness and adaptability. The main objective of this control technique is to obtain good dynamic performance.

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