SENSORLESS STATOR FIELD-OREINTED DIRECT TORQUE AND SPEED TORQUE CONTROL FOR INDUCTION MOTOR BASED ON INTEGRATED HYBRID CONTROL SYSTEM.

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Abstract : In this paper, a novel chattering-free hybrid control (HC) algorithm is proposed for the torque speed and torque regulation of Induction Motor (IM). The HC is made up of the high-order sliding mode control (HOSMC) scheme and the adaptive dynamic program (ADP) control scheme, where HOSMC is developed for transient tracking, and ADP is responsible for steady regulation. The error band method is adopted to determine the switching rule between the HOSMC and ADP schemes. When the operation condition with strong disturbances happens and the tracking error exceeds the error band, the HOSMC scheme is chosen to be the main controller due to its characteristics of fast response and strong robustness. Under the control of HOSMC, the tracking error will converge to zero gradually. However, the undesirable chattering is generated by the discontinuous and high-frequency switching control action in HOSMC scheme. On the other hand, when the amplitude of the disturbances decreases and the tracking error enters the error band, the ADP scheme will replace HOSMC to be the control core such that the actual speed and torque will track the speed and torque reference without chattering or steady error. The main advantages of the proposed HC algorithm are that the chattering is eliminated by the ADP scheme, and the strong robustness is guaranteed by the HOSMC scheme. Real-time experiments in embedded platform are conducted to verify the efficiency and superiority of the HC algorithm

I. INTRODUCTION

In industrial fields, Induction Motor(IM)has been widely applied in motion-control applications due to its superior features such as compact package, high torque to inertia ratio and low noise . In the speed and torque control of IM, the traditional proportional-integral (PI) controller with appropriate parameters is usually selected as the control core when the operation condition is weakly influenced by the disturbances. It is a conclusion that the integral control in PI is indispensable to follow up a step reference signal or reject a step disturbance completely . However, on the high-precision and high-speed and torque industrial cases, the dynamic of IM is very sensitive to the complicated nonlinear system uncertainties and external disturbances. Therefore, it is difficult to achieve a satisfied tracking performance with the only adoption of the PI scheme . Recently, many advanced control algorithms have been well developed to deal with this problem, such as sliding mode control (SMC) , robust control, adaptive control , and artificial intelligence control . Among them, the SMC scheme is well-known for its strong robustness to various disturbances, fast tracking capacity and easy implementation in engineering .

Since the robustness of SMC is guaranteed by the selection of large switching gain, the chattering phenomenon is caused by the discontinuous and high-frequency switching control near the sliding surface . Furthermore, the chattering may excite the potential undesirable dynamics and is harmful to the mechanical structure in PMSM. Thus, many alternatives have been proposed to reduce or eliminate the effects of chattering. To the best of our knowledge, these methods can be classified to four kinds. The first one is the quasi-continuous control. The boundary layer is introduced to eliminate the chattering phenomenon completely by means of replacing the discontinuous control law with a continuous one, but the performance of disturbance rejection is sacrificed to some extent. The second one is to adjust the switching gain adaptively. In , the switching gain adapts to the variations of the sliding surface and system states, and both fast response and small chattering are achieved. In , the reaching-law-based switching gain tuning method is proposed, which allows chattering reduction on the control input while maintaining high performance in trajectory tracking. Li *et al*. utilize the extended state observer and disturbance observer to estimate and compensate the system disturbances, and the switching gain is only required to be larger than the bound of the disturbances estimation error which is usually much smaller than that of the lumped disturbances. Whereas, these control strategies are still discontinuous because of the existing high-frequency switching function.

The third one is the high-order SMC (HOSMC), where the high-frequency switching law is hidden into the high-order derivative of the sliding variable. In , a continuous second-order SMC is developed to suppress the chattering as the real output of controller is the integral of the switching law. In , the HOSMC law is designed to guarantee the stability of the observer and eliminate the chattering, so that smooth back- electromotive-force signals can be obtained without a low-pass filter. In

HOSMC, the switching gain should be larger than the derivative of disturbances. In other words, when the disturbances are step-shaped, the derivative of the disturbances will be relatively large. Moreover, the ideal continuous control law is unavailable in the discrete space of servo system of PMSM. Hence, the chattering in HOSMC is still unavoidable.

1.1 Existing System

In existing HC is formed by **MRAS and Fuzzy Logic Regulation** and Proportional and Integral **PI.** In this method rapid change in error and sudden accelerated error can be predictable. But slow tolerable state error cannot be predictable.

1.2 Proposed System

In proposed HC is formed by **HOSMC** and **adaptive dynamic program (ADP).** In this method rapid change in error, sudden accelerated error, slow tolerable state error can be predictable. So system stability and harmonic noise interference will be improved.

II. Research & Methodology

2.1 Literature Review

2.1.1 "Sensorless Stator Field Oriented-Direct Torque Control with SVM for Induction Motor Based on MRAS and Fuzzy Logic Regulation" by Abdelkarim AMMAR, Amor BOUREK, Abdelhamid BENAKCHA and and Tarek AMEID

Abstract— This paper deals with improvement of Direct Torque Control strategy for induction motor (IM) drive. Since the main disadvantages of the classical DTC are high torque/flux ripples and current distortion, this paper inserts the space vector modulation in order to reduce the ripples by maintaining a constant switching frequency. Besides, the fuzzy logic controllers will replace the traditional proportional-integral (PI) controllers for stator flux and torque regulation and to ensure an accurate reference tracking and a robust response against different uncertainties such as external disturbance and parameters variation. Furthermore, a stator flux based Model Reference Adaptive System (SF-MRAS) is designed as a sensorless algorithm for the estimation of rotor speed. This estimator can improve the performance of the controlled system by increasing its reliability and decreasing the cost of the speed sensor. The global control algorithm has been investigated via numerical simulation and real-time experimentation using Matlab/ Simulink with dSpace 1104 signal card.

2.1.2 "FOC and DTC: Two viable schemes for induction motors torque control," by D. Casadei, F. Profumo, G. Serra, and A. Tani, IEEE Trans. Power Electron., vol. 17, no. 5, pp. 779–787, 2002

Abstract : Field-oriented control and direct torque control are becoming the industrial standards for induction motors torque control. This paper is aimed at giving a contribution for a detailed comparison between the two control techniques, emphasizing advantages and disadvantages. The performance of the two control schemes is evaluated in terms of torque and current ripple, and transient response to step variations of the torque command. The analysis has been carried out on the basis of the results obtained by numerical simulations, where secondary effects introduced by hardware implementation are not present.

2.1.3 "Simple Flux Regulation for Improving State Estimation at Very Low and Zero Speed of a Speed Sensorless Direct Torque Control of an Induction Motor," by I. M. Alsofyani and N. R. N. Idris, IEEE Trans. Power Electron., vol. 31, no. 4, pp. 3027–3035, Apr

Abstract :This paper presents a simple flux regulation for a direct torque control (DTC) of induction motor (IM), to improve speed and torque estimations at low and zero speed regions. To accomplish this, a constant switching frequency controller (CSFC) is used to replace the3-level hysteresis torque comparator of a DTC IM. The DTC of IM utilizing CSFC (DTC-CSFC) retains the simple structure of a look-up table based DTC drive. With DTC-CSFC, constant switching frequency is maintained, and at the same, the flux droop problem that normally occurs in DTC with the hysteresis controller (DTC-HC) at low speed is solved; subsequently, the stator flux and torque estimations at low speed are also improved. In the proposed system, the speed feedback for the closed loop speed control is estimated using an extended Kalman filter (EKF), which requires heavy real-time computation. However, due to the simple structure of DTC-CSFC, small sampling time, hence large control bandwidth is possible. The performance of the speed sensorless DTC-HC and DTC-CSFC are compared experimentally under different operating conditions. With the improved stator flux regulation, experimental results of the DTC-CSFC showed a significant improvement in speed and torque estimations at very low and zero frequency operations.

2.2 Methodology

2.2.1 Hybrid Control Algorithm

It consists of two algorithms namely higher order slide mode control and adaptive control algorithm.

2.2.1.1 Adaptive control

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption; a control law is needed that adapts itself to such changing conditions. Adaptive control is different from robust control in that it does not need *a priori* information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing itself.

In general one should distinguish between:

1. Feed forward adaptive control
2. Feedback adaptive control

as well as between

1. Direct methods and
2. Indirect methods
3. Hybrid methods

Direct methods are ones wherein the estimated parameters are those directly used in the adaptive controller. In contrast, indirect methods are those in which the estimated parameters are used to calculate required controller parameters. Hybrid methods rely on both estimation of parameters and direct modification of the control law.

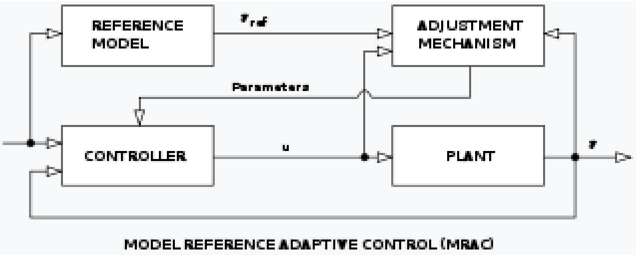


Fig 2.1 Model Reference Adaptive Control (MRAC)

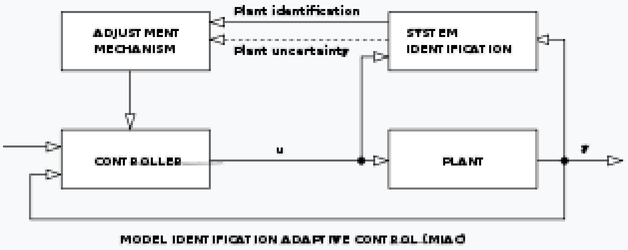


Fig 2.2 Model Identification Adaptive Control (MIAC)

There are several broad categories of feedback adaptive control (classification can vary):

- Dual adaptive controllers – based on dual control theory
  - Optimal dual controllers – difficult to design
  - Suboptimal dual controllers
- Non dual adaptive controllers
  - Adaptive pole placement
  - Extremum-seeking controllers
  - Iterative learning control
  - Gain scheduling
  - Model reference adaptive controllers (MRACs) – incorporate a *reference model* defining desired closed loop performance
  - Gradient optimization MRACs – use local rule for adjusting params when performance differs from reference. Ex.: "MIT rule".
  - Stability optimized MRACs
  - Model identification adaptive controllers (MIACs) – perform system identification while the system is running
    - Cautious adaptive controllers – use current SI to modify control law, allowing for SI uncertainty
    - Certainty equivalent adaptive controllers – take current SI to be the true system, assume no uncertainty

  - Nonparametric adaptive controllers
  - Parametric adaptive controllers
    - Explicit parameter adaptive controllers
    - Implicit parameter adaptive controllers
- Multiple models – Use large number of models, which are distributed in the region of uncertainty, and based on the responses of the plant and the models. One model is chosen at every instant, which is closest to the plant according to some metric.[2]

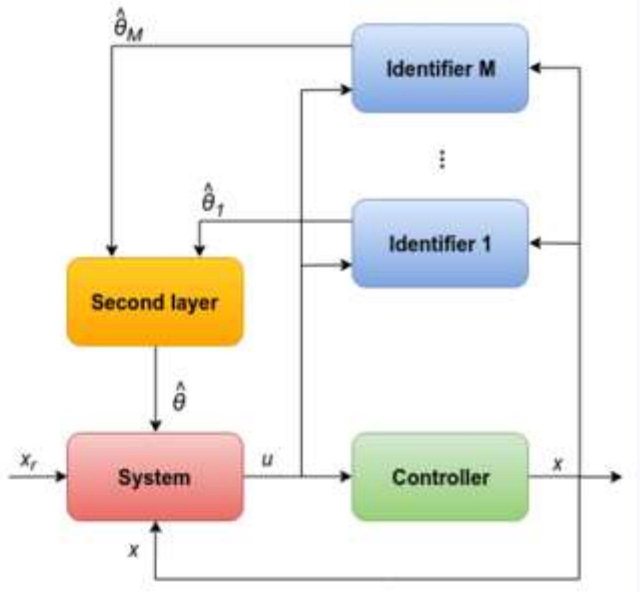


Fig 2.3 Adaptive control with Multiple Models

Some special topics in adaptive control can be introduced as well:

1. Adaptive control based on discrete-time process identification
2. Adaptive control based on the model reference control technique
3. Adaptive control based on continuous-time process models
4. Adaptive control of multivariable processes
5. Adaptive control of nonlinear processes
6. Concurrent learning adaptive control, which relaxes the condition on persistent excitation for parameter convergence for a class of systems.

Adaptive control has even been merged with intelligent techniques such as fuzzy and neural networks and the new terms like fuzzy adaptive control has been generated.

Application Of Adaptive Control

When designing adaptive control systems, special consideration is necessary of convergence and robustness issues. Lyapunov stability is typically used to derive control adaptation laws and show convergence.

Typical applications of adaptive control are (in general):

- Self-tuning of subsequently fixed linear controllers during the implementation phase for one operating point;
- Self-tuning of subsequently fixed robust controllers during the implementation phase for whole range of operating points;
- Self-tuning of fixed controllers on request if the process behaviour changes due to ageing, drift, wear etc.;
- Adaptive control of linear controllers for nonlinear or time-varying processes;
- Adaptive control or self-tuning control of nonlinear controllers for nonlinear processes;
- Adaptive control or self-tuning control of multivariable controllers for multivariable processes (MIMO systems);

Usually these methods adapt the controllers to both the process statics and dynamics. In special cases the adaptation can be limited to the static behavior alone, leading to adaptive control based on characteristic curves for the steady-states or to extremum value control, optimizing the steady state. Hence, there are several ways to apply adaptive control algorithms.

A particularly successful application of adaptive control has been adaptive flight control. This body of work has focused on guaranteeing stability of a model reference adaptive control scheme using Lyapunov arguments. Several successful flight-test demonstrations have been conducted, including fault tolerant adaptive control.

2.2.2.1 Sliding Mode Control or SMC

In control systems, **sliding mode control**, or **SMC**, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal (or more rigorously, a set-valued control signal) that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will *slide* along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a *sliding mode* and the geometrical locus consisting of the boundaries is called the *sliding (hyper)surface*. In the context of modern control theory, any variable structure system, like a system under SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes.

S=0, and the sliding mode along the surface commences after the finite time when system trajectories have reached the surface. In the theoretical description of sliding modes, the system stays confined to the sliding surface and need only be viewed as sliding along the surface. However, real implementations of sliding mode control approximate this theoretical behavior with a high-frequency and generally non-deterministic switching control signal that causes the system to "chatter" in a tight neighborhood of the sliding surface. In fact, although the system is nonlinear in general, the idealized (i.e., non-chattering) behavior of the system .

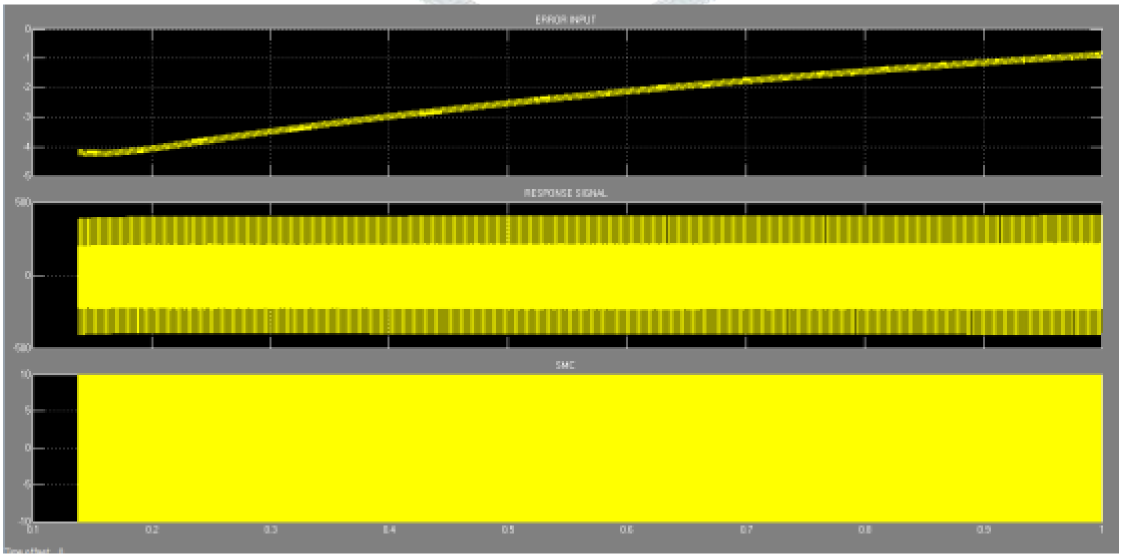
Intuitively, sliding mode control uses practically infinite gain to force the trajectories of a dynamic system to slide along the restricted sliding mode subspace. Trajectories from this reduced-order sliding mode have desirable properties (e.g., the system naturally slides along it until it comes to rest at a desired equilibrium). The main strength of sliding mode control is its robustness. Because the control can be as simple as a switching between two states (e.g., "on"/"off" or "forward"/"reverse"), it need not be precise and will not be sensitive to parameter variations that enter into the control channel. Additionally, because the control law is not a continuous function, the sliding mode can be reached in *finite* time (i.e., better than asymptotic behavior). Under certain common conditions, optimality requires the use of bang–bang control; hence, sliding mode control describes the optimal controller for a broad set of dynamic systems.

One application of sliding mode controller is the control of electric drives operated by switching power converters. Because of the discontinuous operating mode of those converters, a discontinuous sliding mode controller is a natural implementation choice over continuous controllers that may need to be applied by means of pulse-width modulation or a similar technique of applying a continuous signal to an output that can only take discrete states. Sliding mode control has many applications in robotics. In particular, this control algorithm has been used for tracking control of unmanned surface vessels in simulated rough seas with high degree of success.

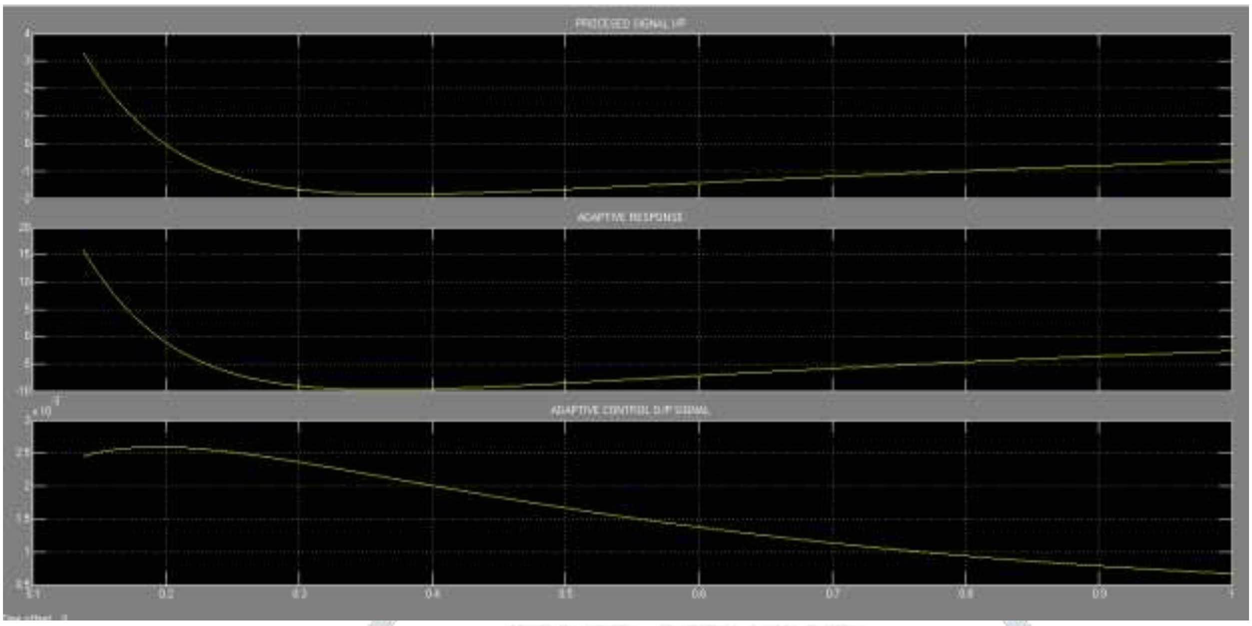
Sliding mode control must be applied with more care than other forms of nonlinear control that have more moderate control action. In particular, because actuators have delays and other imperfections, the hard sliding-mode-control action can lead to chatter, energy loss, plant damage, and excitation of un modeled dynamics. Continuous control design methods are not as susceptible to these problems and can be made to mimic sliding-mode controller

IV. RESULTS AND DISCUSSION

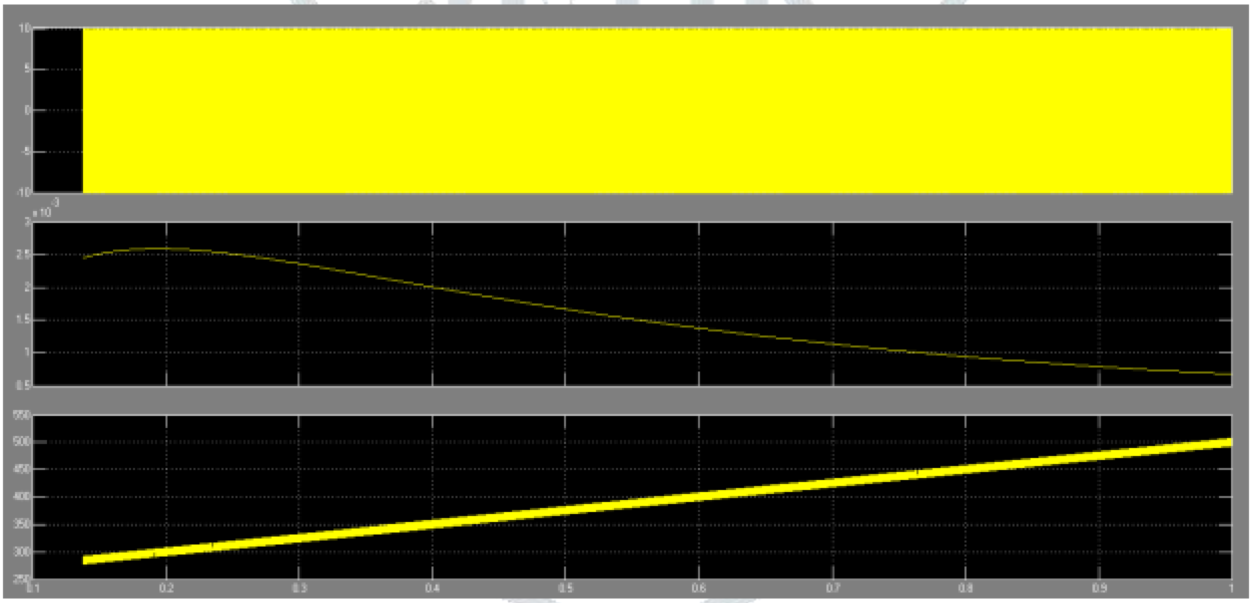
SMC CONTROLLER O/P



ADAPTIVE CONTROL O/P



PI O/P SELECTION



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