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Sliding Mode Vector Control Of Three Phase Induction Motor

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Abstract: Sliding Mode Control (SMC) is a robust control scheme based on the concept of changing the structure of the controller in response to the changing state of the system in order to obtain a desired response. A high speed switching control action is used to switch between different structures of the controller and the trajectory of the system is forced to move along a chosen switching manifold in the state space.

This thesis work presents a new sensor less vector control scheme consisting on the one hand of a speed estimation algorithm which overcomes the necessity of the speed sensor and on the other hand of a novel variable structure control law with an integral sliding surface that compensates the uncertainties that are present in the system.

In this work, an indirect field-oriented induction motor drive with a sliding-mode controller is presented. The design includes rotor speed estimation from measured stator terminal voltages and currents. The estimated speed is used as feedback in an indirect vector control system achieving the speed control without the use of shaft mounted transducers. Stability analysis based on Lyapunov theory is also presented, to guarantee the closed loop stability. The high performance of the control scheme under load disturbances and parameter uncertainties is also demonstrated.

INTRODUCTION

Power semiconductor devices constitute the heart of modern power electronic apparatus. They are used in power electronic converters in the form of a matrix of on off switches, and help to convert power from ac to dc,dc to dc and ac to ac at the same or different frequencies. The switching mode power conversion gives high efficiency; the disadvantage is that due to the nonlinearity of the switches, harmonics are generated at both the supply and load sides. The switches are not ideal, and they have conduction and turn on and turn off switching losses. Converters are widely used in application such as heating and lighting controls,ac and dc power supplies, electrochemical processes, dc and ac motor drives, static var generation, active harmonic filtering,etc. Although the cost of the power semiconductor devices in power electronic equipment may hardly exceed 20-30 percent, the total equipment cost and performance may be highly influenced by the characteristic of the devices. An engineer designing equipment must understand the devices and their characteristics thoroughly in order to design efficient, reliable, and cost effective system with optimum performances. It is interesting to note that the modern technology evolution in power electronics has generally followed the evolution of power semiconductor devices. The advancement of microelectronics has greatly contributed to the knowledge of power device materials, processing, fabrication, packaging, modeling, and simulation.

Vector control techniques incorporating fast microprocessor and DSPs have made possible the application of the induction motor and synchronous motor drives for high performance applications where traditionally only dc drives were applied. In the past such control technique would have not been possible because of the complex hardware and software required to solve the complex control problem. As for dc machine, torque control in ac machine is achieved by controlling the motor currents. However, in contrast to a dc machine, in an ac machine, both the phase angle and the modulus of the current has to be controlled, or in other words, the current vector has to be controlled. This is the reason for the terminology ‘vector control’. Furthermore, in dc machines, the orientation of the field flux and the armature mmf is fixed by the commutator and the brushes, while in ac machines the field flux and the spatial angle of the armature mmf require external control. In the absence of this control, the spatial angle between the various fields in ac machines vary with the load and yield unwanted oscillating dynamic response. With vector control of ac machines, the torque and flux producing current components are decoupled and the transient response characteristics are similar to those of a separately excited dc machine, and the system will adapt to any load disturbance or reference value variations as fast as a dc machine.

INDUCTION MACHINE CONTROL

Squirrel cage induction machines are simple and rugged and are considered to be the workhorses of industry. At present induction motor drives dominate the world market.

However, the control structure of an induction motor is complicated since the stator field is revolving, and further complications arises due to the fact that the rotor currents or rotor flux of a squirrel cage induction motor can not be directly monitored

The mechanism of torque production in an ac machine and in a dc machine is similar. Unfortunately this similarity was not emphasized before the 1970s, and this is one of the reasons why the technique of vector control did not emerge earlier. The formulae given in many well known textbook of the machine theory have also implied that, for the monitoring of the instantaneous electromagnetic torque of an induction machine, it is also necessary to monitor the rotor currents and the rotor position. Even in the 1980s some publications seemed to strengthen this false conception, which only arose because the complicated formulae derived for the expression of the instantaneous electromagnetic torque have not been simplified. However by using fundamental physical laws or space vector theory, it is easy to show that, similar to the expression of the electromagnetic torque of a separately exited dc machine, the instantaneous electromagnetic torque of an induction motor can be expressed as the product of a flux producing current and a torque producing current, if a special flux oriented reference is used.

Scalar control:

Scalar control, as the name indicates, is due to magnitude variation of the control variables only, and disregarding the coupling effect in the machine. For example, the voltage of the machine can be controlled to control the flux, and the frequency and slip can be controlled to control the torque. However, flux and torque are also functions of frequency and voltage, respectively. Scalar control in contrast to the vector control or field oriented control, where both the magnitude and phase is controlled. Scalar controlled drives give somewhat inferior performance, but they are easily implemented. Scalar controlled drives have been widely used in industry. However their importance has diminished recently because of the superior performance of vector controlled drives, which is demanded in many applications.

Vector or field oriented control:

Scalar control is somewhat simple to implement, but the inherent coupling effect i.e. both torque and flux are functions of voltage or current and frequency gives the sluggish response and the system is easily prone to instability because of high order system harmonics. For example, if the torque is increased by incrementing the slip or slip the flux tends to decrease. The flux variation is sluggish. The flux variation then compensated by the sluggish flux control loop feeding additional voltage. This temporary dipping of flux reduces the torque sensitivity with slip and lengthens the system response time.

These foregoing problems can be solved by vector control or field oriented control. The invention of vector control in the beginning of 1970s, and the demonstration that an induction motor can be controlled like a separately excited dc motor, brought a renaissance in the high performance control of ac drives. Because of dc machine like performance, vector control is known as decoupling, orthogonal, or transvector control.

Vector control is applicable to both induction and synchronous motor drives. Vector control and the corresponding feedback signal processing, particularly for modern sensor less vector control, are complex and the use of powerful microcomputer or DSP is mandatory. It appears that eventually, vector control will oust scalar control, and will be accepted as the industry standard control for ac drives.

SLIDING MODE CONTROL

A sliding mode control (SMC) with a variable structure is basically an adaptive control that gives robust performance of a drive with parameter variation and load torque disturbance. The control is nonlinear and can be applied to a linear or nonlinear plant. In an SMC, the name indicates the drive response is forced to tract or slide along a predefined trajectory or reference model in a phase plane by a switching control algorithm, irrespective of the plant's parameter variation and load disturbance. The controller detects the deviation of the actual trajectory and correspondingly changes the switching strategy to restore the tracking. In performance, it is somewhat similar to an MRAC, but the design and implementation of an SMC are somewhat simpler. SMCS can be applied to servo drives with dc motors, induction motors, and synchronous motor for application such as robot drives, machine tool control, etc.

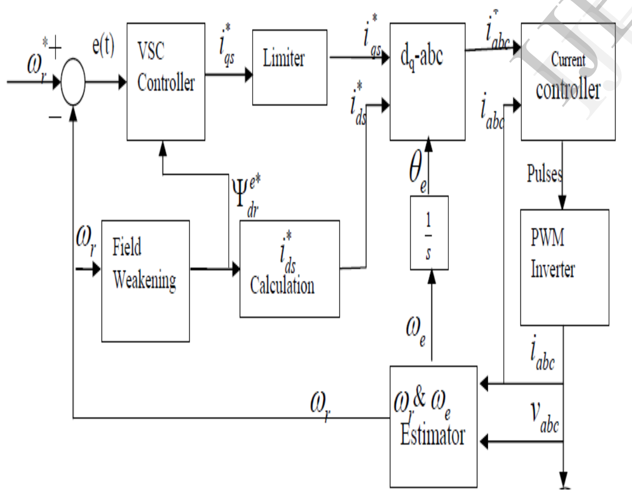
One particular approach to robust control controller design is the so-called sliding mode control methodology which is a particular type of Variable Structure Control System (VSCS). Variable Structure Control Systems are characterised by a suite of feedback control laws and a decision rule (termed the switching function) and can be regarded as a combination of subsystems where each subsystem has a fixed control structure and is valid for specified regions of system behavior. The advantage is its ability to combine useful properties of each of the composite structures of the system. Furthermore, the system may be designed to possess new properties not present in any of the composite structures alone.

In sliding mode control, the VSCS is designed to drive and then constrain the system state to lie within a neighborhood of the switching function. Its two main advantages are (1) the dynamic behavior of the system may be tailored by the particular choice of switching function, and (2) the closed-loop response becomes totally insensitive to a particular class of uncertainty. Also, the ability to specify performance directly makes sliding mode control attractive from the design perspective.

Sliding mode control is an efficient tool to control complex high-order dynamic plants operating under uncertainty conditions due to its order reduction property and its low sensitivity to disturbances and plant parameter variations. Its robustness property comes with a price, which is high control activity. The principle of sliding mode control is that; states of the system to be controlled are first taken to a surface (sliding surface) in state space and then kept there with a shifting law based on the system states. Once sliding surface is reached the closed loop system has low sensitivity to matched and bounded disturbances, plant parameter variations.

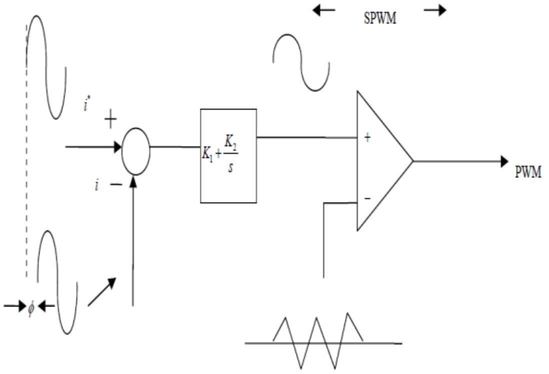
Sliding mode control can be conveniently used for both non-linear systems and systems with parameter uncertainties due to its discontinuous controller term. That discontinuous control term is used to negate the effects of non-linearities and/or parameter uncertainties.

BLOCK DIAGRAM OF SLIDING MODE FIELD ORIENTED CONTROL



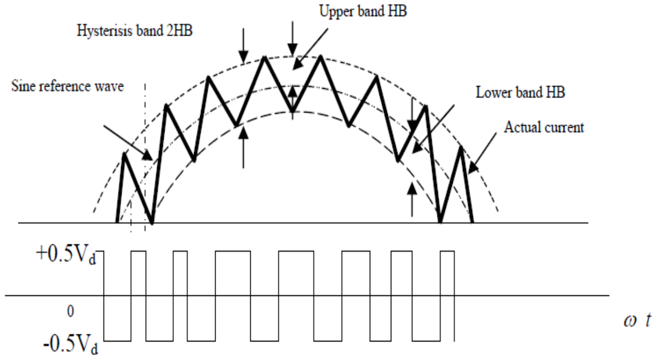
CURRENT CONTROLLER

The block current controller consists of three hysteresis band current PWM control. It is basically an instantaneous feedback current control method of PWM where the actual current continuously tracks the current command within a hysteresis band.



Hysteresis band current control PWM

The control circuit generates the sin reference current wave of desired magnitude and frequency and it is compared with the actual phase current wave. As the current exceeds the prescribed hysteresis band, the upper switch in the half bridge is turned off and lower is turned on. The output voltage transitions are from +0.5Vd to -0.5Vd, and the current start decay. As the current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. A lock out time is provided at each transition to prevent a shoot through fault. The actual current wave is thus forced to track the sine reference wave within the hysteresis band by back and forth switching of the upper and lower switches. The inverter then essentially becomes a current source with peak to peak current ripple, which is controlled within the hysteresis band irrespective of Vd fluctuations.



Principle of hysteresis band control

RESULT AND COMPRATIVE STUDY

In this work the rotor speed estimator is based on stator voltage equations and rotor flux equations in the stationary reference frame. Here a variable structure control which has an integral sliding surface to relax the requirement of the acceleration signal, that is usual in conventional sliding mode speed control techniques. Due to the nature of the sliding control this control scheme is robust under uncertainties caused by parameter errors or by changes in the load torque. The closed loop stability of the presented design has been proved through Lyapunov stability theory. Finally, by means of simulation examples, it has been shown that the control scheme performs reasonably well in practice, and that the speed tracking objective is achieved under uncertainties in the parameters and load.

CONCLUSIONS

Sliding Mode Control (SMC) is a robust control scheme based on the concept of changing the structure of the controller in response to the changing state of the system in order to obtain a desired response. The biggest advantage of this system is stabilizing properties are preserved, even in the presence of large disturbance signals. The dynamic behavior of the system may be tailored by the particular choice of switching function and the closed-loop response becomes totally insensitive to a particular class of uncertainty.

Also, the ability to specify performance directly makes sliding mode control attractive from the design perspective. One of the problems associated with implementation of SMC is Chattering which is essentially a high frequency switching of the control. Chattering in torque & speed may large, but can be minimized by small computation sampling time higher pwm frequency & minimizing additional delay in feedback signal.

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