Speed Control of Electric Drives Using Soft Computing Techniques

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ABSTRACT

The speed control of electric drives is a challenging engineering problem. The direct torque control (DTC) method is characterized by its simple implementation and a fast dynamic response. Soft computing techniques, viz., fuzzy control are ways for controlling a system without the need of mathematical model. It uses the experience of people's knowledge to form its control rule base. There are two techniques to control the speed of electrical drives. The traditional technique uses hardware by the knowledge of process and the tuning of controller whereas the dynamic model technique is a soft computing technique usually done by computer simulation before going for control hardware. This paper presents the implementation of intelligent ways to control the speed of synchronous motor and the induction motor. Direct torque control of induction motor and synchronous motor were implemented in MATLAB/SIMULINK. SIMULINK is the software for modeling, simulating and analyzing dynamical systems. It supports linear and non-linear systems, modeled in continuous time, sampled time or a hybrid of the two.

Keywords: *DTC, induction motor, speed, torque, flux*

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INTRODUCTION

Advanced control of electrical machines requires an independent control of magnetic flux and torque. For that reason, it was not surprising, that the DC machine played an important role in the early days of high-performance electrical drive systems, since the magnetic flux and torque are easily controlled by the stator and rotor current, respectively. The introduction of field-oriented control meant a huge turn in the field of electrical drives, since with this type of control the robust induction machine can be controlled with a high performance

Synchronous motors are now used in a wide variety of industrial applications. A majority of these motors are constructed with the permanent magnets mounted on the periphery of the rotor core. Here permanent magnets are buried inside the rotor core rather than bonded on the rotor surface; the motor provides mechanical ruggedness as well as the possibility of increasing its torque capability. By designing a rotor magnetic circuit such that the inductance varies as a function of rotor angle, the reluctance torque can be produced in addition to the mutual reaction torque of synchronous motors. The type of interior permanent magnet (IPM) synchronous motors can be considered as the reluctance synchronous motor and the permanent magnet synchronous motor combined in one unit. It is now widely used in industrial as well as military applications because it provides high power density and high efficiency compared to other types of motors.

When applied voltage to most of the DC motors is varied, they start exhibiting increase or decrease in their running speed. The major drawback of DC motors is that they require a switching process. AC motors however do not require switching process but the main drawback of AC motors is that we cannot adjust their speed easily, because of the close relation of frequency of line voltage with the speed of the AC motor. Another advantage of AC motors is that they don't require rectified DC supply [1–15].

INDUCTION MOTOR DIRECT TORQUE CONTROL

Advanced control of electrical machines requires an independent control of magnetic flux and torque. For that reason it was not surprising that the DC machine played an important role in the early days of high-performance electrical drive systems, since the magnetic flux and torque are easily controlled by the stator and rotor current, respectively. The introduction of field oriented control meant a huge turn in the field of electrical drives, since with this type of control the robust induction machine can be controlled with a high performance. Later in the eighties a new control method for induction machines was introduced: The direct torque control (DTC) method is characterized by its simple implementation and a fast dynamic response. Furthermore, the inverter is directly controlled by the algorithm, i.e., a modulation technique for the inverter is not needed. However, if the control is implemented on a digital system (which can be considered as a standard nowadays), the actual values of flux and torque could cross their boundaries too far, which are based on an independent hysteresis control of flux and torque. The main advantages of DTC are absence of coordinate transformation and current regulator absence of a separate voltage modulation block. Common disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up. These are disadvantages that we want to remove by using and implementing modern resources of artificial intelligence like neural networks, fuzzy logic and genetic algorithms. In the following paragraphs, we will describe the application of fuzzy logic in DTFC control. Fuzzy control is a way for controlling a system without the need for knowing the plant mathematic model. It uses the experience of people's knowledge to form its control rule base. There have appeared many applications of fuzzy control on power electronic and motion control in the past few years (Fig. 1).

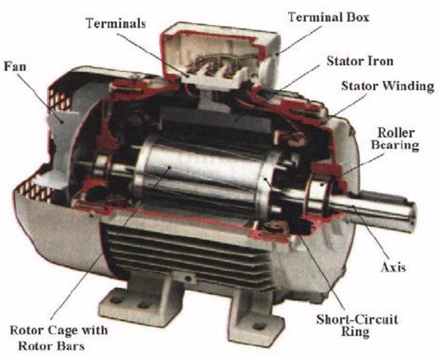

Fig. 1 Induction Motor Cross Section.

A fuzzy logic controller was reported being used with DTC. However, the problem is that the rule numbers it used are too many which would affect the speed of the fuzzy reasoning. In this work, an approach to improve the direct torque control (DTC) of an induction motor (IM) is proposed. The proposed DTC is based on fuzzy logic technique switching table and the platform to perform the simulation by using SIMULINK. DTC is a method that has emerged to become one possible alternative to the well-known vector control of induction motors. This method provides a good performance with a simpler structure and control diagram. In DTC, it is possible to control directly the stator flux and the torque by selecting the appropriate VSI state. The main advantages offered by DTC are:

- Decoupled control of torque and stator flux
- Excellent torque dynamics with minimal response time
- Inherent motion-sensorless control method since the motor speed is not required to achieve the torque control
- Absence of coordinate transformation [required in field oriented control (FOC)]
- Absence of voltage modulator, as well as other controllers such as PID and current controllers (used in FOC)
- Robustness for rotor parameters variation. Only the stator resistance is needed for the torque and stator flux estimator

These merits are counterbalanced by some draw-backs:

- Possible problems during starting and low-speed operation and during changes in torque command
- Requirement of torque and flux estimators, implying the consequent parameters identification (the same as for other vector controls)
- Variable switching frequency caused by the hysteresis controllers employed
- Inherent torque and stator flux ripples
- Flux and current distortion caused by sector changes of the flux position
- Higher harmonic distortion of the stator voltage and current waveforms compared to other methods such as FOC
- Acoustical noise produced due to the variable switching frequency. This noise can be particularly high at low-speed operation

A variety of techniques have been proposed to overcome some of the drawbacks present in DTC. Some solutions proposed are: DTC with space vector modulation (SVM); the use of a duty-ratio controller to introduce a modulation between active vectors chosen from the look-up table and the zero vectors; and use of artificial intelligence techniques, such as neuro-fuzzy controllers with SVM. These methods achieve some improvements such as torque ripple reduction and fixed switching frequency operation. However, the complexity of the control is considerably increased.

A different approach to improve DTC features is to employ different converter topologies from the standard two-level VSI. Some authors have presented different implementations of DTC for the three-level neutral point clamped (NPC) VSI. This work will present a new control scheme based on DTC designed to be applied to an induction motor fed with a three-level VSI. The major advantage of the three-level VSI topology when applied to DTC is the increase in the number of voltage vectors available. This means the number of possibilities in the vector selection process is greatly increased and may lead to a more accurate control system, which may result in a reduction in the torque and flux ripples. This is of course achieved at the expense of an increase in the complexity of the vector selection process.

In DTC induction motor drive, there are torque and flux ripples because none of the VSI states is able to generate the exact voltage value required to make zero both the torque electromagnetic error and the stator flux error. The suggested technique is based on applying to the inverter the selected active states just enough time to achieve the torque and flux reference values. A null state is selected for the remaining switching period, which would not almost change both the torque and the flux.

Therefore, a duty ratio (δ) has to be determined each switching time. By means of varying the duty ratio between its extreme values (0 up to 1), it is possible to apply any voltage to the motor. Therefore, this technique is based on a two-state modulation. These two states are the active one and a null one. The optimum duty ratio per sampling period is a non-linear function of the electromagnetic torque error, the stator flux position and the working point, which is determined by the motor speed and the electromagnetic torque. It is obvious that it is extremely difficult to model such an expression since it is a different non-linear function per working point. Thus, it is believed that by using a fuzzy logic-based DTC system it is possible to perform a fuzzy logic-based duty-ratio controller, where the optimum duty ratio is determined with every switching period.

The suggested fuzzy logic system is divided into two different fuzzy logic controllers. The first one will act each time the selected active VSI state changes, being different to the previous one. The second controller will act in the opposite situation, which is when the active VSI selected state is the same as the previous one. These fuzzy logic controllers and their functionalities are explained in the following section.

Both fuzzy logic controllers use the centroid defuzzification method. The relation between different conditions in the same rule is determined by means of “and” operator. On the other hand, the relationship between different rules is done by means of “or” operator.

IMPROVEMENTS IN DIRECT TORQUE CONTROL

In the classical DTC, there are several

drawbacks. Some of them can be summarized as follows:

- Sluggish response (slow response) in both start-up and changes in either flux or torque.
- Large and small errors in flux and torque are not distinguished. In other words, the same vectors are used during start-up and step changes and during steady state.

In order to overcome the mentioned drawbacks, there are different solutions, which can be classified as follows:

- Non artificial intelligence methods, mainly "sophisticated tables."
- Predictive algorithms, used to determine the switching voltage vectors. A mathematical model of the induction motor is needed. Electromagnetic torque and stator flux are estimated for sampling period for all possible inverter sates. Then, the predictive algorithm selects the inverter switching states to give minimum deviation between the predicted value of the electromagnetic torque and the reference torque fuzzy logic-based systems [16–27].

PROBLEM FORMULATION

In this paper, the performance of two motors namely permanent magnet synchronous motor drive (3HP) and DTC induction motor drive of 200 HP is analyzed for different operating parameters as follows.

Permanent Magnet Synchronous Motor Drive (3HP)

In this circuit, a permanent magnet (PM) synchronous motor drive with a braking chopper for a 3 HP motor is used. The PM synchronous motor is fed by a PWM voltage source inverter, which is built using a universal bridge block. The speed control loop uses a PI regulator to produce the flux and torque references for the vector control block. The vector control block computes the three reference motor line currents corresponding to the flux and torque references and then feeds the motor with these currents using a three-phase current regulator. Motor current, speed, and torque signals are available at the output of the block.

Simulation Description

Start the simulation. Observe the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage on the scope. The speed set point and the torque set point are also to be calculated. At time t = 0 s, the speed set point is 300 rpm. Observe that the speed follows precisely the acceleration ramp. At t = 0.5 s, the full load torque is applied to the motor. You can observe a small disturbance in the motor speed, which stabilizes very quickly. At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases down to 0 rpm following precisely the deceleration ramp. At t = 1.5 s, the mechanical load passes from 11 Nm to − 11 Nm. The motor speed stabilizes very quickly after a small overshoot. Finally, the DC bus voltage to be regulated during the whole simulation period can be observed (Figs. 2–4).

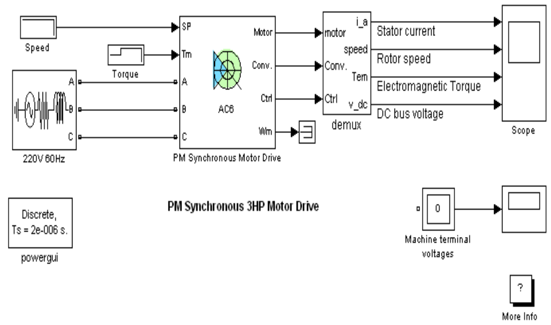

Fig. 2 Permanent Magnet Synchronous Motor Drive of 3 HP.

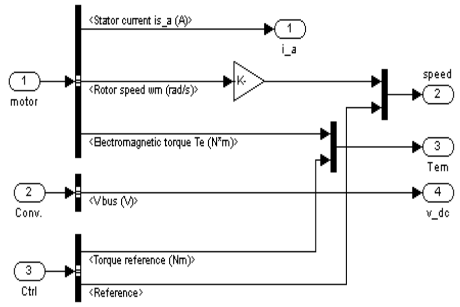

Fig. 3 Permanent Magnet Synchronous Motor Internal Architecture.

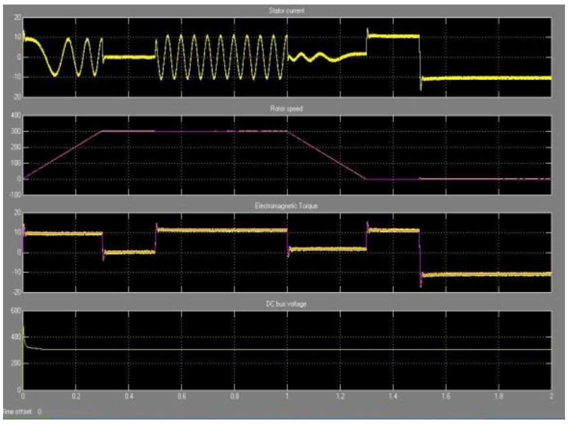

Fig. 4 Stator Current, Rotor Speed, Electromagnetic Torque and DC Bus Voltage Simulation Results.

A typical permanent magnet synchronous motor of 3 HP, 512 segments having 0.85 reminent flux and saturation flux of 1.2 is controlled by artificial intelligence (AI) techniques. Further, an induction motor of 200 HP, 500 rpm is taken up and is controlled by fuzzy logic.

DTC Induction Motor Drive (200 HP)

In this circuit, a direct torque control (DTC) induction motor drive with a braking chopper for a 200 HP AC motor is used.

The induction motor is fed by a PWM voltage source inverter which is built using a universal bridge block. The speed control loop uses a proportional-integral controller to produce the flux and torque references for the DTC block.

The DTC block computes the motor torque and flux estimates and compares them to their respective references.

The comparator outputs are then used by an optimal switching table which generates the inverter switching pulses. Motor current, speed, and torque signals are available at the output of the block (Fig. 5).

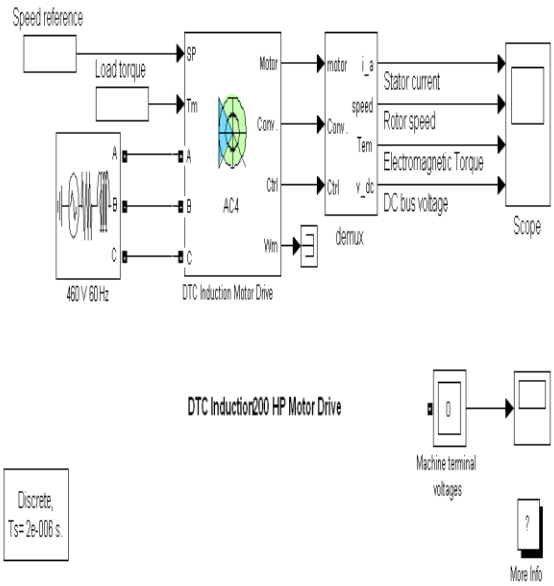

Fig. 5 DTC Induction 200 HP Motor Drive.

Simulation Details

Start the simulation. Observe the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage on the scope. The speed set point and the torque set point are also shown. At time t = 0 s, the speed set point is 500 rpm. Observe that the speed follows precisely the acceleration ramp. At t = 0.5 s, the full load torque is applied to the motor shaft while the motor speed is still ramping to its final value. This forces the electromagnetic torque to increase to the user-defined maximum value (1200 Nm) and then to stabilize at 820 Nm once the speed ramping is completed and the motor has reached 500 rpm. At t = 1 s, the speed set point is changed to 0 rpm. The speed decreases down to 0 rpm by following precisely the deceleration ramp even though the mechanical load is inverted abruptly, passing from 792 Nm to − 792 Nm, at t = 1.5 s. Shortly thereafter, the motor speed stabilizes at 0 rpm. Finally, the regulation of DC bus voltage during the whole simulation period is noted (Fig. 6).

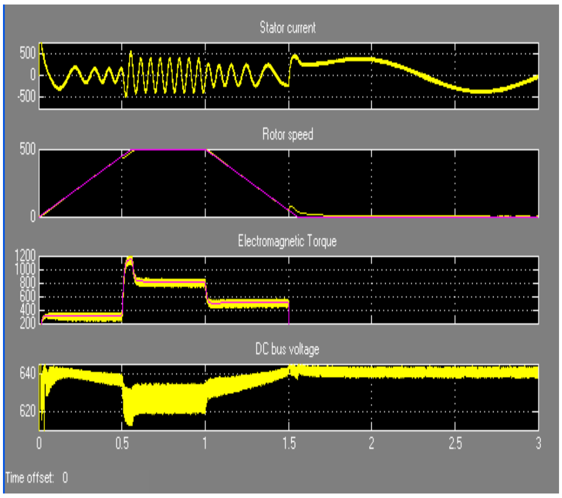

Fig. 6 Stator Current, Rotor Speed, Electromagnetic Torque and DC Bus Voltage Simulation Results.

CONCLUSIONS

Permanent magnet synchronous motor and direct torque control induction motor have been simulated using MATLAB.

It is investigated that in a typical permanent magnet synchronous motor of 3 HP, 512 segments having 0.85 reminent flux and saturation flux of 1.2 better control can be achieved by artificial intelligence (AI) techniques. Further, a direct torque control strategy has been implemented on induction motor of 200 HP, 500 rpm. It is evident from the simulation results that the evolutionary computing techniques can reduce error namely electromagnetic torque and flux error.

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