SIMULATION OF IGBT BASED SPEED CONTROL SYSTEM FOR INDUCTION MOTOR USING FUZZY LOGIC

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ABSTRACT

This research paper presents modeling and simulation of fuzzy logic based speed control system for induction motor using PWM Insulated Gate Bipolar Transistor (IGBT) inverter as a switching device. The model is implemented on computer simulation using MATLAB/Simulink software with different Block Sets. Fuzzy Logic Controller is developed using fuzzy logic toolbox. The control design includes some rules. These rules show a good relationship between two inputs and an output, all of which are nothing but normalized voltages. The inputs to the controller are speed error, derivative of speed error means Change of error, and the output is Change of control. The errors are evaluated according to the rules in accordance to the defined membership functions. The membership functions and the rules have been defined using the FIS editor. The obtained Simulation results of MATLAB/Simulink in relation with electromagnetic torque and speed are given for effectiveness of the study.

Key words: Electromagnetic torque, Fuzzy Logic Controller, IGBT, PWM, membership functions.

1. INTRODUCTION

The use of Induction Motors (IM) has increased significantly from the day of its creation. They are mainly used in various industrial processes, robotics, house appliances and other similar applications. The reason for its amassed popularity is its robust construction, design simplicity and cost. [1]-[3] Induction motors are more reliable than DC motors.

Now days speed control of induction motor is very important because they are operated at different speed. Depending on application its speed will be selected. But the control of IM is complicated due to its nonlinear behavior and its parameters changes with
operating conditions. [4, 5] Hence in the last few years it has been studied, and various methods for the same have been developed. The Volts/Hertz control scheme is popular because it offers a wide range for speed control with good running performance. [5, 6]

Pulse Width Modulation (PWM) with flexible speed drive systems are mostly used in industrial applications for controlling where greater performance is desired. A number of Pulse width modulation systems are used for variable voltage and frequency supply requirement. Today there is a huge development in power electronics and semiconductor technology. This lead improvement in power electronic systems. Therefore different power circuits like inverters have become popular. [7]-[9] Variable voltage and frequency supply is achieved from inverter. Recently IGBT PWM inverters are widely used inverters, because of their improvement in harmonic quality at the output as compared to the other inverters. Now GTO devices are replaced by IGBTs because of their fast evolution in voltage and current ratings and higher switching frequency. [8, 9]

In the last few years, Fuzzy logic is popular in motor control applications due to its non-linearities handling ability and independence of the plant modeling. The fuzzy logic controller (FLC) operates in a knowledge-based way. Its control performance is less affected by system parameter variations. [9, 10] A fuzzy logic system uses linguistic if then rules based on systems qualitative aspects and expert knowledge.

This paper therefore proposes a simple alternative method for controlling speed of induction motor with PWM IGBT inverter, it uses only fewer values, rules, and decisions making. These rules are Linguistic, not numerical and cover great complexity.

This paper is organized as follows. In section 2 the aspects of IGBT PWM Inverter, V/f control strategy and its operational principle is presented. In section 3 the block diagram of system is described in detail. In section 4 design of FLC using membership function and FIS system is explained. In section 5 Simulink model of fuzzy logic controller and simulation results are discussed. In section 6 the main conclusions are outlined.

2. PULSE WIDTH MODULATION IN INVERTERS

2.1 IGBT PWM Inverter

For speed control of induction motor output voltage of an inverter must be adjusted by exercising a control within the inverter. Therefore this paper uses most effective method a pulse-width modulation control in inverter. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the simplest method of controlling the output voltage. This method is termed as Pulse-Width Modulation (PWM) Control. [11]-[14]

Generally power bipolar transistors and MOSFET’S are used for inverters to driving ac motors. An alternative inverter, insulated-gate-bipolar transistors (IGBT’s) is developed recently. [14] IGBT’s offers low ON resistance and need small gate drive power. A gate-drive circuit provides fast turn-on and turn-off, and adequate protection against overload/shoot through faults presented in IGBT. Snubbers are required to limit the stresses on the IGBTs at turn-on and turn-off. [14, 15]

The IGBT Inverter combines the properties of both MOSFET’S and bipolar-transistors. It gives low saturation voltage and its voltage driven input. It uses very little drive power. It has two control terminals gate and emitter. The IGBT will turn-on when a voltage $V_{GE}$ greater than gate-emitter threshold voltage $V_{GEth}$ is applied between the gate and emitter. To turn-off the IGBT a resistance $R_{GE}$ is connected between gate and emitter, which provides a discharge path for the gate-to-emitter capacitance. The IGBT shows a large current fall time
at turn-off. The fall time consists of two different intervals, one of which is constant and the other is depends on $R_{GE}$. For smooth switching and to reduce the switching losses IGBT uses some additional networks. [15, 16]

![Power circuit Topology for IM](image)

**Fig1:** Power circuit Topology for IM

The configuration for IGBT PWM Inverter is shown in Fig.1. Normally, the voltage for the auxiliary winding is higher than that for main winding. The sinusoidal PWM signal, which is responsible for driving the IGBT inverter, was generated by Discrete PWM Generator.

### 2.2 V/f Control Strategy of Induction Motor

The induction motor’s speed-torque characteristic states that the induction motor draws rated current and provides the rated torque at the base speed.[17]-[19] The relation of Induction motor is given by following equation.

Stator Voltage $(V) \propto $ Stator Flux $(\phi)$ x Angular Velocity $(\omega)$

$$V \propto \phi \times 2\pi f$$

$$\phi \propto V/f$$ \hspace{1cm} (1)

In V/F control, variable frequency signals generated by the PWM control of an inverter and this signal is given to the Motor. In this the V/f ratio is maintained constant to get constant torque for the total operating range. As simply magnitudes of the input variables frequency and voltage are controlled, this is known as “scalar control”. For this type of controlling little knowledge of the motor is essential. In this type of control the torque developed is load dependent as it is not controlled directly. [18]-[20] The Table.1 show the parameter values used in proposed model.

<table>
<thead>
<tr>
<th>Table 1: Induction Motor Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stator resistance</td>
</tr>
<tr>
<td>Rotor resistance</td>
</tr>
<tr>
<td>Number of pole pairs</td>
</tr>
<tr>
<td>Stator inductance</td>
</tr>
<tr>
<td>Rotor inductance</td>
</tr>
<tr>
<td>Mutual inductance</td>
</tr>
</tbody>
</table>

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3. BLOCK DIAGRAM OF SYSTEM

The Block diagram of proposed system used for speed control of an induction motor is shown in Fig. 2. In the block diagram output of PWM inverter is the reference signal. The current speed of the motor ($\omega_m$) is compared with the reference speed ($\omega_r$), and provides speed error ($e$). This mechanism is called the feedback mechanism. Change-of-error ($\Delta e$), that is, the derivative of speed error ($e$) is computed and both ($e$) and ($\Delta e$) are fed to the fuzzifier for fuzzification. The inference system then processes these two fuzzy inputs using the fuzzy control rules and the database, which are defined by the programmer based on the chosen membership function. The obtained fuzzy output is defuzzified by the defuzzifier to give a crisp value, i.e. Change of control ($\omega_{sl}$), and it is applied as a input to the PWM Inverter. The PWM Inverter uses this input to generate a voltage whose frequency and amplitude can be varied by the Fuzzy Logic Controller itself via the above mentioned process. The voltage is fed to the auxiliary winding of induction motor which then runs with a speed which tends to follow the desired speed.

![Fig 2: Block Diagram of Fuzzy Logic Control System](image)

4. DESIGN OF FUZZY LOGIC CONTROLLER

4.1 Designing of Membership functions

The design of a Fuzzy Logic Controller (FLC) uses the membership functions. The membership functions are selected such that they cover the whole universe of discourse. The membership functions must be overlap on each other to avoid any kind of discontinuity with respect to the minor changes in the inputs. To accomplish greater control, the membership functions near the zero region must be narrow, and away from the zero region membership functions are wider which results the faster response to the system. Therefore, the membership functions for input and output variables are adjusted accordingly. After the selection of proper membership functions a rule base is created. It consists of a number of fuzzy If-Then rules according to the behavior of the system. These rules are similar to the human thought process, means here artificial intelligence is provided to the system.
The seven linguistic terms are used for two inputs and one output of fuzzy logic controller. These are as follows “NB” is “Negative Big”, “NM” is “Negative Medium”, “NS” is “Negative Small”, “ZE” is “Zero”, “PS” is “Positive Small”, “PM” is “Positive Medium” and “PB” is “Positive Big”. Membership functions for both input variables speed error (e) and Change-of-error (\(\Delta e\)) are shown in Fig.3 and Fig.4.

Total 49 rules are written in the program according to the syntax provided by MATLAB. If-Then Rules used for the design of the Fuzzy Logic Controller are represented as follow:

1. IF (Error is NB) AND (Change in Error is NS) THEN (Change of control is NB)
2. IF (Error is NB) AND (Change in Error is ZE) THEN (Change of control is NM)

The table representing the rule base is as shown in Table 2.
Table 2: Fuzzy rule table for output ($\omega_{sl}$)

<table>
<thead>
<tr>
<th>ERROR</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>ZE</td>
</tr>
<tr>
<td>NM</td>
<td>NB</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>ZE</td>
</tr>
<tr>
<td>NS</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>NS</td>
<td>ZE</td>
<td>PS</td>
<td>PS</td>
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<tr>
<td>ZE</td>
<td>NM</td>
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<td>PS</td>
<td>PS</td>
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<td>PB</td>
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<tr>
<td>PS</td>
<td>NS</td>
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<td>PM</td>
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<td>PB</td>
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<tr>
<td>PB</td>
<td>ZE</td>
<td>PS</td>
<td>PS</td>
<td>PS</td>
<td>PM</td>
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<td>PB</td>
</tr>
</tbody>
</table>

4.2. FIS System

Now day’s Fuzzy Inference System (FIS) is magnificently applied for automatic control modeling. Mamdani’s fuzzy inference method is the most commonly used methodology.[21, 22] There are five parts of the fuzzy inference process first is fuzzification of the input variables, second is application of the AND operator to the antecedent, Third is implication from the antecedent to the consequent, Fourth is aggregation of the consequents and fifth is defuzzification.

5. SIMULATION MODEL OF SYSTEM AND SIMULATION RESULTS

Simulation diagram of proposed system is shown in Fig.5. The model is implemented using MATLAB/Simulink software with the Sim Power System, Simulink and fuzzy logic Block Sets.

![Simulation diagram of proposed FLC system](image)

Fig 5: Simulation diagram of proposed FLC system
Fig 6: Main Winding current of FLC Controller

Fig 7: Speed response of FLC Controller

Fig 8: Torque response of FLC Controller

Fig 9: The Surface Viewer of proposed system
The plots for speed, current, and torque for Fuzzy Logic Controller were observed and shown in Fig.6, 7 and 8. It can be seen from the above figures that while using the Fuzzy Logic Controller the settling time is less. FLC approaches the new reference speed faster. From the current plot, the same can be achieved. Fig.6 shows in the current plot the current is sinusoidal. But there is a distortion in the envelope before the machine attains steady state. Because at the time of starting the machine goes through the unstable region. Fig.7 shows the Fuzzy Logic Controller attains a steady state speed in small period, and, it is very much close to the reference speed. The torque plot is shown in Fig. 8. It illustrate that the Fuzzy Logic Controller gives oscillations during starting period and after that it gives smooth response. This is because motor provides a desirable response after some time as the controller first has to study and then adjust according to the data provided by the user. The Surface Viewer of proposed system is shown in Fig.9.

6. CONCLUSION

The performance of proposed fuzzy control system is satisfactory in relation to load torque variations when it achieves the reference speed. By using FLC we can avoid the numerical calculation involved in higher order systems. Fuzzy logic provides artificial intelligence to the controllers. This is not offered by the conventional controllers. After the simulation of the of the block diagram in MATLAB/SIMULINK®, it was found that the fuzzy logic controller used in the simulation worked quite effectively.

REFERENCES


AUTHORS DETAIL

Abhijit D. Ghorapade was born in Sangli, Maharashtra, in 1986. He graduated in Electronics and Telecommunication Engineering at the Shivaji University Kolhapur, Maharashtra, in 2007. He is a post graduate student of SCOE Pune from the University of Pune Maharashtra. His research interests are within the fields of Fuzzy systems, embedded systems and control.

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