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An Efficient Fuzzy Controller Design for Parallel Connected Induction Motor Drives

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ABSTRACT

Generally, an induction motors are highly non-linear and has a complex time varying dynamics. This makes the speed control of an induction motor a challenging issue in the industries. But, due to the recent trends in the power electronic devices and intelligent controllers, the speed control of the induction motor is achieved by including non-linear characteristics also. Conventionally a single inverter is used to run one induction motor in industries. In the traction applications, two or more inductions motors are operated in parallel to reduce the size and cost of induction motors. In this application, the parallel connected induction motors can be driven by a single inverter unit. The stability problems may introduce in the parallel operation under low speed operating conditions. Hence, the speed deviations should be reduce with help of suitable controllers. The speed control of the parallel connected system is performed by PID controller and fuzzy logic controller. In this paper the speed response of the induction motor for the rating of IHP, 1440 rpm, and 50Hz with these controller are compared in time domain specifications. The stability analysis of the system also performed under low speed using matlab platform. The hardware model is developed for speed control using fuzzy logic controller which exhibited superior performances over the other controller.

1 Introduction

Induction motors are used in many industries for most of their applications due to its strength and low maintenance requirement. In order to achieve maximum torque and efficiency, control the speed of an induction motor is more essential. Nowadays, the induction motor speed control is an important and interesting area for engineers. Generally, the speed control in an AC machine is more complex than DC machine but the complexity has been reduced by the advancement in power electronic devices and the controller. Of all the traditional controllers, PID and FUZZY controllers are very dissimilar in characteristics and also important for controlling the speed of an induction motor [1]. Earlier, scalar control method was used to control the speed of the induction motor but there was no decoupling effect in scalar control method which caused sluggish response. In order to avoid such problems, vector control method is implemented to achieve the desired speed control of the induction motor. Depending on the machine parameters, the flux and torque components are determined by indirect vector control method of an induction motor drive. It is advisable that those components are replica of the real parameters to attain decoupling control. But the signal of voltage is poor at low frequency and the ideal integration
have become difficult by DC offset in this method. The dynamic modelling of this AC motor is being
analysed by keeping the ratio between voltage and frequency value constant for the speed control [2].
For controlling the speed of an induction motor, stator voltage control method has been implemented
[3]. Using the neural network estimator, the speed of the induction motor with three phase has been
controlled by PI controller [4]. The voltage to frequency constant ratio with universal board is used to
control the speed of the induction motor [5]. The speed control of Induction motor is achieved by fuzzy
logic controller which provides better performance as it has the benefits of fuzzy control. The weighted
decoupling effect control method has also been implemented for controlling the induction motor speed
[6]. The auto-disturbance rejection controllers with digital signal processor have been implemented for
the induction motor speed control [7]. The three phase induction motor is controlled by the three phase
inverter with sensorless method using neural network backpropagation algorithm [8]. Control of
induction motor is achieved by sinusoidal pulse width modulated inverter [9-10]. Finally, the improved
control method such as fuzzy controller provides better performance than conventional methods. In this
paper chapter II delineate the different types of controller for induction motor speed control. Chapter III
describes the simulation circuits and the results of the induction motor speed control with and without
controllers. Chapter IV explains the hardware results of speed control of the induction motor with fuzzy
controller. Conclusion has been explained in Chapter V.

2. Speed Control of Induction Motor

2.1 PID Controller: PID controllers are extensively used in various applications for process control
in many industries. Mostly, mechanisations sector industries that required feedback operations
employ PID Controller which have been illustrated in Figure 1. The synthesis of proportional,
integral and derivative create a control signal. It modulates the output at the expected levels as
closed loop controller. Nowadays most of the PID controllers are organised virtually through
the microprocessors. PID controller trade by preserving the output in which, the error between
reference value and expected value is zero by feedback controller.

![Figure 1. PID Controller](image)

**Proportional Controller:** Proportional controller gives response proportional to error of the current e
(t) by equating the expected value with original value. Proportional term is multiplied to the evolving
error value to find the desired output. The output of the controller is zero for zero error. If controller
gain Kg increases the speed response also increases. The block diagram of proportional controller
demonstrated in Figure 2.
**Proportional Controller:** Proportional controller has definite restrictions thereby it neutralizes the value between set point and process variable. This is eliminated by Integral controller and also the block diagram of proportional controller demonstrated in Figure 3. It removes the error at steady state until the error value vanishes to zero by integrating the value of error around a period of time. It supervises the tool by keeping the final output value in which the value of error flatten to zero. In the majority of the approaches, very high response of the speed is not important, however, proportional–integral controller is employed specially.

**Integral Controller:** Integral controller does not forecaste the desired value of error but once the set point is modified, controls the speed of the motor. This problem is rectified by derivative controller and its output is subject to change of error value with depends on multiplication of time and the Derivative constant which are illustrated in Figure 4. It improves the output of the system. The synthesis of these 3 controllers provide the valuable output of the system. The overall block diagram of induction motor speed control is presented in Figure 5.

**Derivative Controller:** Integral controller does not forecaste the desired value of error but once the set point is modified, controls the speed of the motor. This problem is rectified by derivative controller and its output is subject to change of error value with depends on multiplication of time and the Derivative constant which are illustrated in Figure 4. It improves the output of the system. The synthesis of these 3 controllers provide the valuable output of the system. The overall block diagram of induction motor speed control is presented in Figure 5.
2.2 Fuzzy Controller

The PID-controller is unable to recompense the changes in parameter it is a feedback controller with constant-gain and it will not transform to the different environment. The fuzzy logic is most suitable controller with nonlinearity. The error (E) and change of error (CE) are the input variables in fuzzy logic control which are given in Figure 6a. the membership function of fuzzy logic controller are depicted in Figure 6b. The rules for the speed control of induction motor in fuzzy logic control are illustrated in Table 1. The performance of fuzzy logic control depends on the shape and the types of membership functions of the rule base. Here triangular membership function is selected. They are very simple and robust in design as the realizations of a perfect model is not essential.
Figure 6b. Input and output Membership function

Table 1. Fuzzy rules for the proposed system

| Error | Change in error |
|-------|-----------------|
|       | nb     | Nm     | ns     | zero   | ps     | pm     | pb     |
| nb    | nb     | Nm     | nb     | nm     | nm     | ns     | zero   |
| nm    | nb     | Nb     | nm     | nm     | ns     | zero   | ps     |
| ns    | nb     | Nm     | nm     | ns     | zero   | ps     | pm     |
### 3. Simulation Results and Discussions

#### 3.1 The Induction Motor Speed Control without Controller

The Figure 7 demonstrates that no controller is connected and there is no feedback loop present to initiate a back response which means the voltage at end side can be regulated only if the supply voltage is changed but if there is any discrepancies in the input voltage state then the induction motor speed cannot be controlled. The above mentioned speed control is simulated and illustrated in Figure 7. Speed of induction motor without controller is shown in Figure 8. From the time domain analysis it is observed that the induction motor peak time is 2.2 seconds, delay time is 1.2 seconds, rise time is 1.6 seconds and settling time is 8.8 seconds in speed response of induction motor without controller. The transfer function of the above circuit shown above given as \( H(s) = \frac{11s}{22s^2 + 11s + 2} \). Here all the gains are taken to be equal to one. Frequency response for speed control without controller is demonstrated in Figure 9. Poles of the above transfer function \( S_1 = -0.25-168i \) and \( S_2 = -0.25-168i \) lies on left half of the S-plane which makes the system stable.

| pm | zero | Nm | ns | zero | ps | pm | pm | pm |
|----|------|----|----|------|----|----|----|----|
| ps | nm   | Ns | zero | ps | pm | pm | pb |
| pm | ns   | zero | ps | pm | pm | pb | pb |
| pb | zero | Ps | pm | pm | pb | pb | pb |

![Figure 7. Speed control of induction motor without controller](image)

![Figure 8. Speed response of induction motor without controller](image)
3.2 The Induction Motor Speed Control with PID Controller

The PID controller is used to regulate the output voltage from the boost converter. This controller gives an integrated controlled value of the voltage and reduces the harmonics to some extent. This controller also gives a nominal peak overshoot value of the voltage. This is further given to the induction motor to achieve the speed control. The only drawback of this controller is that it gives very high value of voltage and hence its usage is limited to high machineries only. This closed loop control is simulated using matlab Simulink and illustrated in Figure 10. The induction motor speed control employing PID controller is demonstrated in Figure 11. From the time domain analysis it is observed that the induction motor peak time is 3.1 seconds, delay time is 2.6 seconds, rise time is 3.9 seconds and settling time is 4.6 seconds in speed response of induction motor with PID controller. The transfer function of the circuit shown above is given as $H(s) = \frac{4+27s}{81s^2+29s+12}$ considering all the gains to be equal to 1 and the controller gain to be Equal to $\frac{1}{8}$. Frequency response for speed control with PID controller is demonstrated in Figure 12. Poles of the above transfer function $S_1 = -0.179+0.340i$ and $S_2 = -0.179-0.340i$ lies on left half of the S-plane which makes the system stable.
3.3 Speed Control of Induction Motor Using Fuzzy Controller at the Converter Side

The voltage from the photovoltaic (PV) panel is supplied to the boost converter which boost the magnitude of the voltage. This appropriate boosted output voltage is fed to the inverter which supplies two induction motor connected in parallel. The induction motor speed is controlled by controlling the MOSFET switch in the boost converter using fuzzy logic controller thus forming a closed loop. In this case the RLC series branch and the diode acts as switches that is connected to the MOSFET. These simultaneous turn on and off depending on the magnitude of the voltage being fed to the diode, the MOSFET turns on and off simultaneously. This producing a gate voltage which is fed to the inverter. This closed loop control is simulated using matlab Simulink and presented in Figure 13. The induction motor speed using fuzzy logic controller at converter side is illustrated in Figure 14. From the time domain analysis it is observed that the induction motor peak time is 2 seconds, delay time is 1.5 seconds, rise time is 1.7 seconds and settling time is 4.3 seconds in speed response of induction motor with fuzzy controller at converter side. The transfer function of the circuit shown above is given as $H(s) = \frac{s}{(1 + 49s)}$. Here all the gains are taken to be equal to one. Frequency response for speed control using fuzzy logic controller at converter side is demonstrated in Figure 15. Pole of the above transfer function $s = -0.020$ lies on left half of the S-plane which makes the system stable.

![Figure 13. Speed control of induction motor using fuzzy logic controller at the converter side](image-url)
3.4 The Induction Motor Speed Control using Fuzzy Logic Controller at the Inverter Side

The voltage from the photovoltaic (PV) panel is supplied to the boost converter which boost the magnitude of the voltage. This appropriate boosted output voltage is fed to the inverter which supplies two induction motor connected in parallel. The induction motor speed is controlled by controlling the inverter using fuzzy logic controller thus forming a closed loop. This closed loop control is simulated using matlab Simulink and demonstrated in Figure 16. Speed of induction motor using fuzzy logic controller at inverter side is shown in Figure 17. From the time domain analysis it is observed that the induction motor peak time is 0.85 seconds, delay time is 0.5 seconds, rise time is 0.7 seconds and settling time is 2.3 seconds in speed response of induction motor with fuzzy controller at inverter side. The transfer function of the circuit shown above is given as \( H(s) = \frac{s}{8s^2 + 12s + 4} \). Taking into consideration, all the gains will be equal to one and the controller gain to be equal to 0.2. Frequency response for speed control using fuzzy logic controller at inverter side is demonstrated in Figure 18. Poles of the above transfer function \( S_1 = -0.5 \) and \( S_2 = -1 \) lies on left half of the S-plane which makes the system stable.

Figure 14. Speed response of induction motor with fuzzy logic controller at converter Side

Figure 15. Frequency response for speed control of induction motor using fuzzy logic controller at converter side
The speed control of induction motor using fuzzy controller at inverter side provide better performance than without controller, conventional PI controller[11], PID controller and fuzzy controller at converter side. From speed response of conventional PI controller [11], the induction motor speed have more oscillation and then it reaches the settling time without oscillations at 9 millisecond only its very high when compared to the controllers used in the proposed work. The induction motor speed reaches the stable state rapidly by the fuzzy logic controller at inverter side because settling time is very less and steady state error also zero when compared conventional PI controller, PID controllers and without controller and it is shown in Table 2.
Table 2. Time domain analysis for speed control of induction motor

| Specifications | Without controller Speed in (ms) | With PID controller Speed in (ms) | With Fuzzy controller at converter side Speed in (ms) | With fuzzy controller at inverter side Speed in (ms) |
|----------------|----------------------------------|----------------------------------|-----------------------------------------------------|---------------------------------------------------|
| Peak time (Tₚ) | 2.2                              | 3.1                              | 2                                                   | 0.85                                              |
| Rise time (Tᵣ) | 1.2                              | 2.6                              | 1.7                                                 | 0.5                                               |
| Delay time (T_d) | 1.6                              | 3.9                              | 1.5                                                 | 0.7                                               |
| Settling time (T_s) (without oscillation) | 8.8                              | 4.6                              | 4.3                                                 | 2.0                                               |

4. Hardware Results and Discussions

Figure 19 depicts the block diagram of hardware implementation of fuzzy logic controller. Taking the practical cost into account only one induction motor is considered for hardware implementation. The voltage from the solar panel is boosted with the help of a boost converter. This voltage is further processed by using a PIC controller and a driver circuit to remove the harmonics and hence to get a variable speed output for the load on the induction motor even with constant or variable input voltages. The three phase inverter is used to power the three phase induction motors. Hence, the boosted dc supply is given to the inverter which converts the dc to the required ac supply. Driver Circuit TLP 250 is basically a MOSFET-driving circuit. It is a dedicated integrated circuit which is used to drive the MOSFETs in low side and high side configuration. DsPIC 30F2010 Controller is basically the heart of the circuit and is fuzzy controlled in this model. Hardware setup for speed control of induction motor is demonstrated in Figure 20. It controls the duty cycle using pwm technique with fuzzy controller thus controlling the speed of the motor.

![Figure 19](image-url)
On implementing the above hardware circuit for speed control of three phase Induction motor, the following output speed is obtained by varying the duty cycle using fuzzy logic controller. Of all the three push buttons, push button-1 is used to increase the duty cycle of the inverter, push button-2 to decrease its duty cycle whereas push button-3 is the RESET button which brings the circuit back to its normal state. On pushing the buttons, its performs pwm variations, which further modifies the duty cycle of the inverter and as a result, the speed control of induction motor is achieved. This complete phenomenon of speed control is achieved by variations of duty cycles. This can be repeated for different duty cycles using fuzzy controller and shown in Table 3. For the speed control of three-phase induction motor in open loop and closed loop, the ratio between voltage and frequency have to be maintained constant using fuzzy logic controller. Thus, we can conclude that control of speed in induction motors connected in parallel can be done effectively and efficiently Using fuzzy logic controller.

Figure 20. Hardware setup for speed control of induction motor

Table 3. Speed control of induction motor from the hardware setup.

| Input voltage in volts | Input speed in rpm | Duty cycle | speed in rpm |
|------------------------|--------------------|------------|--------------|
| 5                      | 200                | 0.25       | 211          |
| 5                      | 200                | 0.4        | 345          |
| 5                      | 200                | 0.75       | 600          |

5. Conclusion
The speed performance of an induction motor has been analysed with Fuzzy logic controller and compared the simulation results with the conventional PID controller. The performance of Fuzzy logic
controller has simulated and analysed at both inverter and converter sides. The inverter side analysis gives a better performance by comparing the converter side. The Fuzzy logic controller results are analysed in time domain and the results show that it gives improved performance. Specifically, the settling time and steady state error are very less by comparing conventional PID controller. Hardware setup has been developed for 1 hp motor with Fuzzy logic controller at inverter side and analysed the speed response. The hardware results are verified with simulation results.

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