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Performance Analysis of Speed Controller for 3hp and 150hp Three Phase Induction Motors Being Used in Cable Industry Applications

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***Abstract* - In this paper, Performance analysis of speed controller for 3hp and 150hp three phase induction motors being used in cable industry applications is carried out. For this purpose, cable manufacturing industry (Ravicab Cables Private Limited) at Bidadi, Ramanagara district is taken into study. A 3hp 3Φ induction motor is used to pull the single core cable which comes out of diameter controller. Similarly, a 150hp 3Φ induction motor is used to pull the four single core cable to form a four core cable. Therefore, as far as this cable industry is concerned, these motors speed control is essential. If the speed of these motors is not controlled precisely, then these motors will run at a speed which is deviated from reference speed. Hence, single and four core cable manufacturing is discussed here. Moreover, performance of speed controller (PID) which is currently existing in this industry for 3hp and 150 hp 3Φ induction motor is analysed and various controllers are proposed (Fuzzy, Neural network, Neuro-fuzzy). Eventually, robust controller for 3hp and 150hp motors is identified using comparative performance analysis between various controllers.**
***Keywords:* Speed Controller, 3hp, 150hp, Single Core Cable, Four Core Cable**

I. INTRODUCTION

Ravicab Cables Private Limited is the cable industry which is located in Bidadi, Ramanagara district, Karnataka, India. In this industry, various induction motors ranging from 1hp to 150hp are used for the production of the single core and four core cable. However, here only 3hp and 150hp induction motors and its speed controller (Drive) is taken into consideration. Since 3hp motor is used to pull a single core cable during manufacturing, this motor and its drive is taken into consideration. Similarly, 150hp motor is used to pull a four single core cable to form a four core cable. Hence, this 150hp motor and its drive are taken into analysis. This industry is using PID [1-2] based speed controller to control the speed of 3hp and 150hp motor. Since PID based speed controller is used to control the speed of 3hp and 150hp motor, various drawbacks are occurred. Therefore, replacement of PID [8-9] controller with robust controller is necessary. In order to do the analysis of drawbacks of this speed controller (i.e. PID controller) for 3hp and 150hp motor, it is necessary to explain the single core and four core cable manufacturing. Moreover, this study is also useful to identify the novel robust controller [14-15] for 3hp and 150hp motor.

II. SINGLE CORE CABLE MANUFACTURING

Single core cable manufacturing is explained with the help of Fig. 1. In this figure 1, 3hp 3Φ induction motor is used to pull the single core cable once it's manufactured. After the diameter controller, water cooling truff is there to cool the single core cable which is in hot condition. Then spark tester is used to give the spark to the cable in such a way that cable has to get sufficient mechanical strength. Further, printer is connected to print the cable with the brand name of the company. Then 3hp capstan motor is used to pull the cable upto the take up machine. Here, 4m cable length is considered from diameter controller to the 3hp motor. Therefore, 3hp motor has to pull 4m cable along with the help of its speed controller (PID controller).

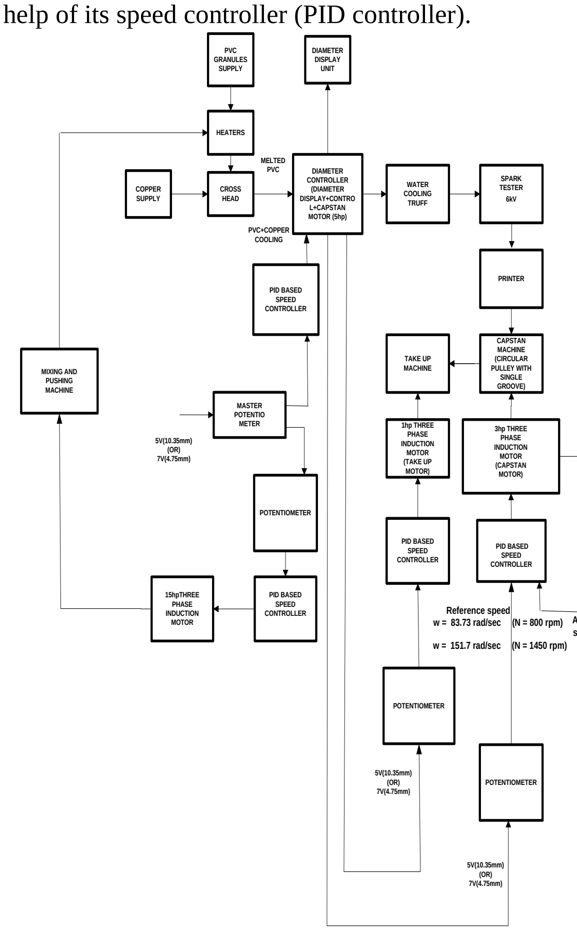

Fig. 1 Block diagram of single core cable manufacturing

There are two different types of single core cables are manufactured in this industry. If this industry wants to manufacture low diameter cable (i.e.4.75mm), then 3hp motor has to run at high speed (ω=151.7rad/sec (1450rpm)). If this industry wants to manufacture high diameter cable (i.e.10.35mm), then 3hp motor has to run at low speed (ω=83.73rad/sec (800rpm)).It implies that to pull the low diameter cable, low torque and high speed in required. On the other hand, to pull the high diameter cable, high torque and low speed in required. When PID [1-2] controller is used to control the speed of 3hp motor, actual speed is not varying w.r.t cable diameter.

Since this industry is using PID based speed controller for controlling the speed of 3hp motor, various drawbacks are occurred. Those drawbacks are,

1. Rise time, peak time and peak overshoot is more. Hence transient state performance is poor.
2. Steady state error and settling time is high. As such, steady state performance is poor.
3. As settling time (t_s) of the PID controller is high, response of the PID controller being used for 3hp motor is slow.

The above mentioned drawbacks of the PID based speed controller leads to replacement with robust controller for 3hp motor.

III. FOUR CORE CABLE MANUFACTURING

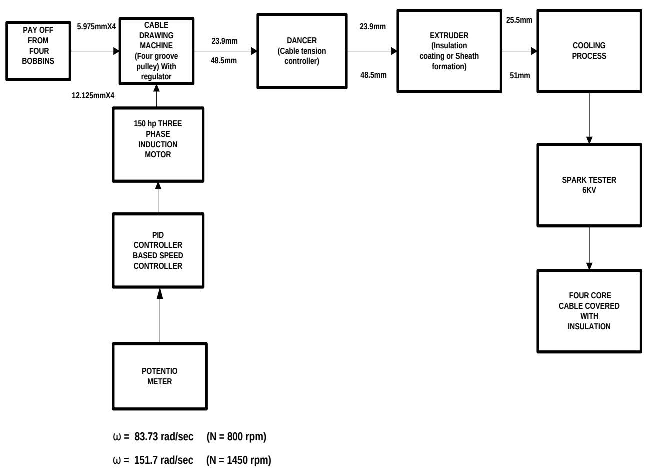

Fig. 2 Block diagram of four core cable manufacturing

In this Fig. 2, four individual payoff's are used to release four individual single core cable. Then four groove pulley which is connected in 150hp motor shaft is used to pull the four individual single core cable to form a four core cable. This four core cable is in the form of two different diameter's based on the requirement of manufacturing. In case this industry wants to manufacture low diameter cable (i.e.23.9mm), then 150hp motor has to run at ω=151.7rad/sec (1450rpm).On the other hand, if this industry wants to manufacture high diameter cable (i.e.48.5mm), then 150hp motor has to run at ω=83.73rad/sec (800rpm).Hence, role of the speed controller is essential. After the pulling process which is given by 150hp motor, dancer is going to be used to control the tension of the four core cable. Further, insulation coating will be given to the four core cable using extruder. Since insulation is coated over the cable, cable diameter will be in two different forms (i.e.25.5mm for low diameter cable and 51mm for high diameter cable).Then cooling process will be carried out for the four core cable. Moreover, spark test will be conducted to the cable using 6kv. Eventually, four core cable with insulation will be ready for commercial purpose.

Since this industry is using PID based speed controller for controlling the speed of 150hp motor, various drawbacks are occurred. Those drawbacks are,

1. Rise time, peak time and peak overshoot is more. Hence transient state performance is poor.
2. Steady state error and settling time is high. Therefore, steady state performance is poor.
3. As settling time (t_s) of the PID controller is high, response of the PID controller being used for 150hp motor is slow.

These drawbacks of the PID based speed controller leads to replacement with robust controller for 150hp motor.

IV. IDENTIFICATION OF ROBUST CONTROLLER

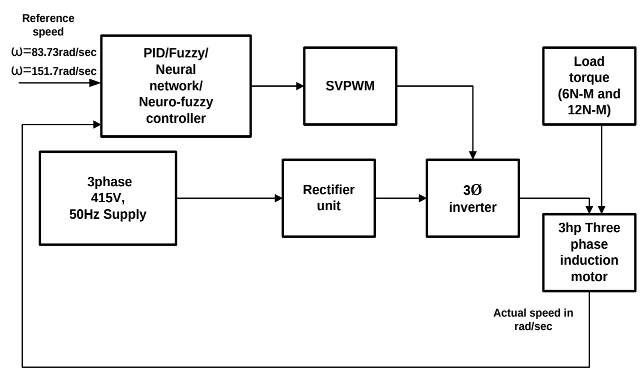

Fig. 3 Block diagram of robust controller for 3hp motor

Block diagram of robust controller for 3hp motor is shown in Fig. 3.In this figure, 3Φ supply is used to give supply to the rectifier unit. Then rectified DC is given to the 3Φ inverter. This 3Φ inverter is used to give variable AC supply to the stator of the 3hp motor w.r.t reference speed which is fixed based on cable diameter. Actual speed and reference speed are compared using speed controller. Then based on the speed controller output SVPWM (i.e. Space Vector Pulse Width Modulation) is operated. Further, pulse will be given to the 3Φ inverter. The equivalent load torque applied on 3hp motor is 6N-m for low diameter (4.75mm) cable. Similarly, the equivalent load torque applied on 3hp motor is 12N-m for high diameter (10.35mm) cable. In the place of speed controller unit, four different controllers (i.e. PID, Fuzzy, Neural network, Neuro-fuzzy) are used to identify the robust controller. Each and every speed controller which is mentioned above will be interfaced with 3hp motor individually in such a way that transient and steady state performance can be analysed. Finally, robust controller will be identified for 3hp motor.

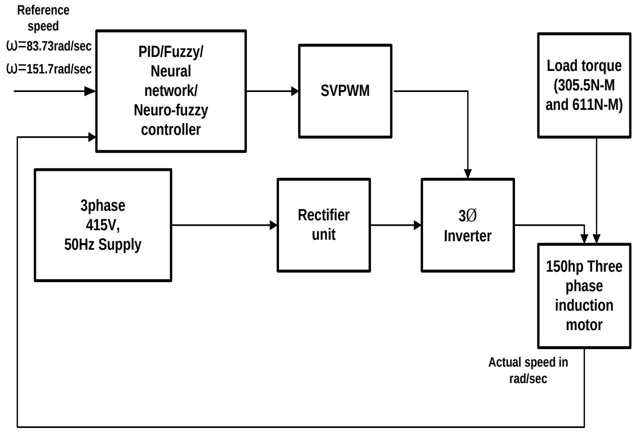

Fig. 4 Block diagram of robust controller for 150hp motor

Block diagram of robust controller for 150hp motor is shown in Fig. 4.In this figure, 3Φ supply is used to give supply to the rectifier unit. Then rectified DC is given to the 3Φ inverter. This 3Φ inverter is used to give variable AC supply to the stator of the 150hp motor w.r.t reference speed which is fixed based on cable diameter. Actual speed and reference speed are compared using speed controller. Then based on the speed controller output SVPWM (i.e. Space Vector Pulse Width Modulation) is operated. Further, pulse will be given to the 3Φ inverter. The equivalent load torque applied on 150hp motor is 305.5N-m for low diameter (23.9mm) cable. Similarly, the equivalent load torque applied on 150hp motor is 611N-m for high diameter (48.5mm) cable. In the place of speed controller unit, four different controllers (i.e. PID, Fuzzy, Neural network, Neuro-fuzzy) are used to identify the robust controller. Each and every speed controller which is mentioned above will be interfaced with 150hp motor individually in such a way that transient and steady state performance can be analysed. Eventually, robust controller will be identified for 150hp motor.

V. SIMULATION RESULTS AND DISCUSSIONS

A. 3hp 3Φ Induction Motor at Reference Speed ω=83.73rad/sec

This reference speed is suitable to pull the full load. Therefore, full load simulation is shown here. However, for no load, any reference can be used. As such, no load operation is explained below using the reference speed ω=83.73rad/sec.

1. Case (i) At No Load

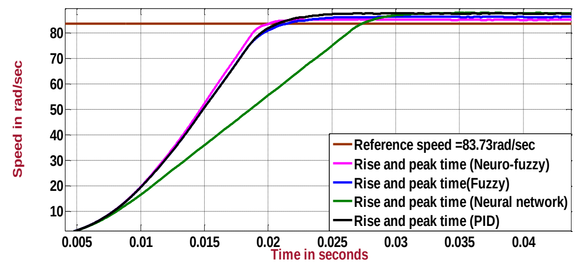

Fig. 5 Rise and peak time of the 3hp 3Ø induction motor

This figure 5 shows the rise and peak time of the 3hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. This measurement is made at no load for the reference speed ω=83.73rad/sec. During the time of no load, single core cable is not manufactured. Therefore, motor is not pulling the cable. From this figure, various parameters such as rise time, peak time can be measured. At the same time, peak overshoot is also calculated using the following formula.

Peak overshoot = First peak of the actual speed waveform – Reference speed.

Similarly, Rise time = Time taken for actual speed to reach 10% to 90% of the reference speed.

These rise time, peak time and peak over shoot are used to do the transient state analysis of the 3hp 3Ø induction motor.

TABLE I RISE AND PEAK TIME AT REFERENCE SPEED ω = 83.73 rad/sec

Parameters	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Rise time in seconds (t_r)	7.36sec	7.37sec	7.56sec	7.35sec
Peak time in seconds (t_p)	0.028sec	0.026sec	0.032sec	0.022sec
Peak over shoot	4.07rad/sec	2.47rad/sec	3.87rad/sec	1.87rad/sec

From the figure 5, rise and peak time measurements are made, is shown in the table I. From this table I, it is identified that Neuro-fuzzy controller takes low rise and peak time over PID, fuzzy, Neural network controller. As such, Neuro-fuzzy controller is suitable to handle the no load at this reference speed ω = 83.73rad/sec. Since Neuro-fuzzy controller takes low values of rise time, peak time and peak over shoot, its performance is better in the transient state over other controllers.

Steady state error of the 3hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used, is given in Fig. 6. From this figure 6, steady state error is measured at no load for the reference speed ω = 83.73rad/sec. The measured steady state error values are shown in the table II.

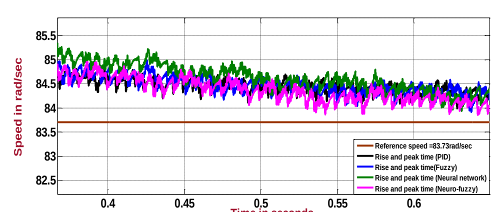

Fig. 6 Steady state error of the 3hp 3Ø induction motor

TABLE II STEADY STATE ERROR AT REFERENCE SPEED ω = 83.73 rad/sec

Condition	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Steady state error at no load	0.67rad/sec	0.37rad/sec	0.77rad/sec	0.27rad/sec
Settling time (t_s) in seconds	0.627sec	0.637sec	0.555sec	0.518sec
Response of the controller	Moderate	Slow	Moderate	Fast

Steady state error at no load for the reference speed ω = 83.73rad/sec is shown in the table II. Steady state error of the Neuro-fuzzy controller is 0.27rad/sec. This value is lower than other controllers. Therefore, it is found that Neuro-fuzzy controller reduces the steady state error over PID, fuzzy, Neural network controllers. Moreover, settling time of the actual speed waveform is also measured from Fig. 6. Neuro-fuzzy controller takes low settling time over other controllers. Hence, it is identified as the Neuro-fuzzy controller is the fastest controller over other controllers.

2. Case (ii) At Full Load (12N-m)

This figure 7 shows the rise and peak time of the 3hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. This measurement is made at full load for the reference speed ω=83.73rad/sec. During the time of full load (i.e.12N-m), 3hp motor pulls the high diameter single core cable (d_2=10.35mm).Performance of the various controllers can be identified when the motor pulls the full load. Further, from the figure 7, various parameters namely rise time, peak time can be measured and peak overshoot can be calculated.

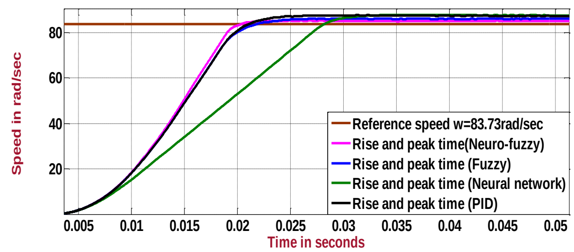

Fig. 7 Rise and peak time of the 3hp 3Ø induction motor

TABLE III RISE AND PEAK TIME AT REFERENCE SPEED ω = 83.73 rad/sec

Parameters	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Rise time in seconds(t_r)	7.68sec	7.68sec	7.70sec	7.63sec
Peak time in seconds (t_p)	0.0296sec	0.0207sec	0.0350sec	0.0204sec
Peak over shoot	3.87rad/sec	2.37rad/sec	3.97rad/sec	1.27rad/sec

From the figure 7, rise and peak time measurements are made, is shown in the table VII. From this table III, it is identified that Neuro-fuzzy controller takes low rise and peak time over PID, fuzzy, Neural network controller. Therefore, Neuro-fuzzy controller is appropriate to control the full load at this reference speed ω = 83.73rad/sec. Since Neuro-fuzzy controller takes low values of rise time, peak time and peak over shoot, its performance is better in the transient state over other controllers.

Figure 8 shows the steady state error of the 3hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. From this figure 8, steady state error is measured at full load for the reference speed ω = 83.73rad/sec. The measured steady state error values are shown in the table IV.

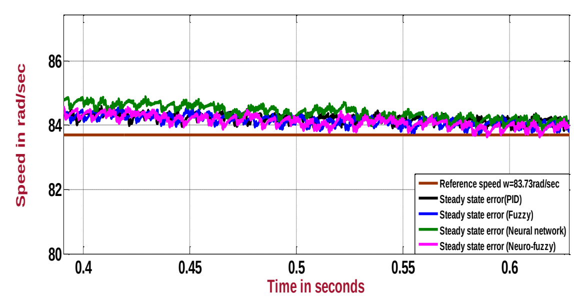

Fig. 8 Steady state error of the 3hp 3Ø induction motor

TABLE IV STEADY STATE ERROR AT REFERENCE SPEED ω = 83.73 rad/sec

Condition	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Steady state error at full load	0.11rad/sec	0.17rad/sec	0.67rad/sec	0.07rad/sec
Settling time (t_s) in seconds	0.625sec	0.606sec	0.541sec	0.504sec
Response of the controller	Slow	Moderate	Moderate	Fast

Steady state error at full load for the reference speed ω = 83.73rad/sec is shown in the table 4.Steady state error of the Neuro-fuzzy controller is 0.07rad/sec. This value is lower than other controllers. Therefore, it is found that Neuro-fuzzy controller reduces the steady state error over PID, fuzzy, Neural network controllers. Moreover, settling time of the actual speed waveform is also measured from Fig. 8.Neuro-fuzzy controller takes low settling time over other controllers. Hence, it is identified as the Neuro-fuzzy controller is the fastest controller over other controllers.

B. 3hp 3Φ Induction Motor at Reference Speed ω=151.7rad/sec

This reference speed ω=151.7rad/sec is suitable to pull the half load. Therefore, half load simulation is shown here.

1. Case (i) At Half Load (6N-m)

This figure 9 shows the rise and peak time of the 3hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. This measurement is made at half load for the reference speed ω=151.7rad/sec. During the time of half load (i.e.6N-m), 3hp motor pulls the low diameter single core cable (d_1=4.75mm).Here, performance of the various controllers are identified when the motor pulls the half load. Moreover, from the figure 9, various parameters such as rise time, peak time can be measured and peak overshoot can be estimated.

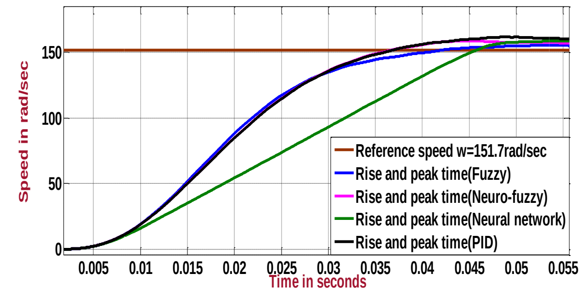

Fig. 9 Rise and peak time of the 3hp 3Ø induction motor

TABLE V RISE AND PEAK TIME AT REFERENCE SPEED ω = 151.7 rad/sec

Parameters	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Rise time in seconds(t_r)	9.28sec	9.27sec	9.76sec	9.16sec
Peak time in seconds (t_p)	0.050sec	0.053sec	0.055sec	0.045sec
Peak over shoot	9.8rad/sec	6.60sec	6.65rad/sec	6.4rad/sec

From the figure 9, rise and peak time measurements are made, is shown in the table V. From this table V, it is identified that Neuro-fuzzy controller takes low rise and peak time over PID, fuzzy, Neural network controller. Therefore, Neuro-fuzzy controller is suitable to handle the half load at this reference speed ω = 151.7rad/sec. Since Neuro-fuzzy controller takes low values of rise time, peak time and peak overshoot, its performance is better in the transient state over other controllers.

Figure 10 shows the steady state error of the 3hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. From this figure 10, steady state error is measured at half load for the reference speed ω = 151.7rad/sec. The measured steady state error values are shown in the table VI.

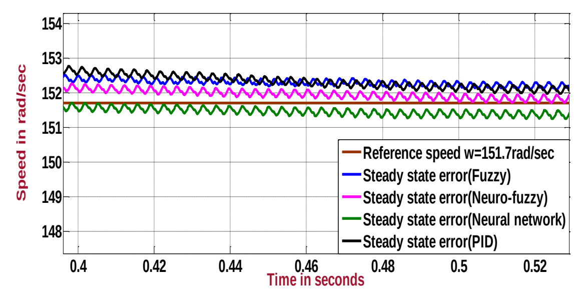

Fig. 10 Steady state error of the 3hp 3Ø induction motor

TABLE VI STEADY STATE ERROR AT REFERENCE SPEED ω = 151.7 rad/sec

Condition	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Steady state error at half load	0.4rad/sec	0.6rad/sec	0.3rad/sec	0.2rad/sec
Settling time (t_s) in seconds	0.48sec	0.49sec	0.50sec	0.47sec
Response of the controller	Moderate	Moderate	Slow	Fast

Steady state error at half load for the reference speed ω = 151.7rad/sec is shown in the table 6.Steady state error of the Neuro-fuzzy controller is 0.2rad/sec. This value is lower than other controllers. Therefore, it is found that Neuro-fuzzy controller reduces the steady state error over PID, fuzzy, Neural network controllers. Moreover, settling time of the actual speed waveform is also measured from Fig. 10.Neuro-fuzzy controller takes low settling time over other controllers. Hence, it is identified as the Neuro-fuzzy controller is the fastest controller over other controllers.

C. 150hp 3Φ Induction Motor at Reference Speed ω=83.73rad/sec

This reference speed ω=83.73rad/sec is suitable to pull the full load. Therefore, full load simulation is shown here.

1. Case (i) At Full Load (611N-m)

This figure 11 shows the rise and peak time of the 150hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. This measurement is made at full load for the reference speed ω=83.73rad/sec. During the time of full load (i.e.48.5mm high diameter cable), four core cable is pulled by the 150hp motor. From this figure, various parameters namely rise time, peak time are measured and peak overshoot can be calculated.

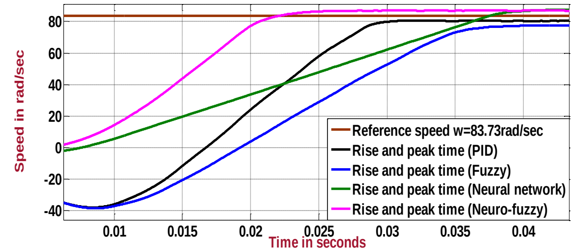

Fig. 11Rise and peak time of the 150hp 3Ø induction motor

TABLE VII RISE AND PEAK TIME AT REFERENCE SPEED ω = 83.73 rad/sec

Parameters	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Rise time in seconds(t_r)	0.015sec	0.036sec	0.020sec	0.010sec
Peak time in seconds (t_p)	0.033sec	0.040sec	0.045sec	0.027sec
Peak over shoot	3.23rad/sec	6.13rad/sec	3.77rad/sec	2.97rad/sec

From the figure 11, rise and peak time measurements are made, is shown in the table 7.From this table VII, it is identified that Neuro-fuzzy controller takes low rise and peak time over PID, fuzzy, Neural network controller. Therefore, Neuro-fuzzy controller is suitable to handle the full load at this reference speed ω = 83.73rad/sec. Since, Neuro-fuzzy controller takes low values of rise time, peak time and peak overshoot, its performance is better in the transient state over other controllers.

Figure 12 shows the steady state error of the 150hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. From this figure 12, steady state error is measured at full load for the reference speed ω = 83.73rad/sec. The measured steady state error values are shown in the table VIII.

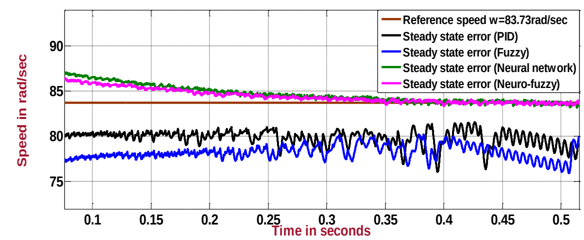

Fig. 12 Steady state error of the 150hp 3Ø induction motor

TABLE VIII STEADY STATE ERROR AT REFERENCE SPEED ω = 83.73 rad/sec

Condition	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Steady state error at full load	3.23rad/sec	5.03rad/sec	0.23rad/sec	0.13rad/sec
Settling time (t_s) in seconds	0.45sec	0.41sec	0.37sec	0.35sec
Response of the controller	Slow	Moderate	Moderate	Fast

Steady state error at full load for the reference speed ω = 83.73rad/sec is shown in the table 8.Steady state error of the Neuro-fuzzy controller is 0.13rad/sec. This value is lower than other controllers. Therefore, it is found that Neuro-fuzzy controller reduces the steady state error over PID, fuzzy, Neural network controllers.

Moreover, settling time of the actual speed waveform is also measured from figure 12. Neuro-fuzzy controller takes low settling time over other controllers. As such, it is identified as the Neuro-fuzzy controller is the fastest controller over other controllers.

D. 150hp 3Φ Induction Motor at Reference Speed ω=151.7rad/sec

This reference speed ω=151.7rad/sec is suitable to pull the full load. Therefore, full load simulation is exhibited here.

1. Case (i) At Half Load (305.5N-m)

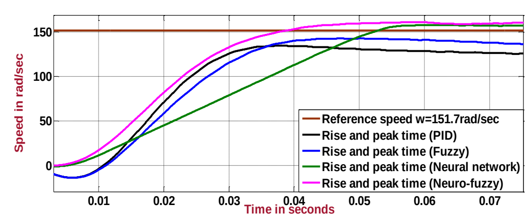

Fig. 13 Rise and peak time of the 150hp 3Ø induction motor

This figure 13 shows the rise and peak time of the 150hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. This measurement is made at half load for the reference speed ω=151.7rad/sec. During the time of half load, four core cable (i.e.23.9mm low diameter cable) is pulled by the 150hp motor. From this figure, various parameters namely rise time, peak time are measured and peak overshoot can be calculated.

TABLE IX RISE AND PEAK TIME AT REFERENCE SPEED ω = 151.7 rad/sec

Parameters	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Rise time in seconds(t_r)	0.025sec	0.024sec	0.036sec	0.022sec
Peak time in seconds (t_p)	0.035sec	0.047sec	0.064sec	0.032sec
Peak over shoot	18.1rad/sec	9.1rad/sec	5.9rad/sec	5.7rad/sec

From the figure 13, rise and peak time measurements are made, is shown in the table 9.From this table 9, it is identified that Neuro-fuzzy controller takes low rise time, peak time and peak over shoot over PID, fuzzy, Neural network controller. Thus, Neuro-fuzzy controller is capable to handle the half load at this reference speed ω = 151.7rad/sec. Since, Neuro-fuzzy controller takes low value of rise time, peak time and peak overshoot, its performance is good in the transient state over other controllers.

Figure 14 shows the steady state error of the 150hp 3Φ induction motor when PID, fuzzy, Neural network and Neuro-fuzzy controller is used. From this figure 14, steady state error is measured at half load for the reference speed ω = 151.7rad/sec. The measured steady state error values are shown in the table X.

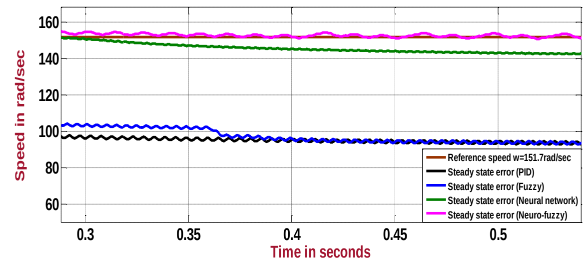

Fig. 14 Steady state error of the 150hp 3Ø induction motor

TABLE X STEADY STATE ERROR AT REFERENCE SPEED ω = 151.7 rad/sec

Condition	PID Controller	Fuzzy Controller	Neural Network Controller	Neuro-Fuzzy Controller
Steady state error at half load	55.6rad/sec	57.3rad/sec	9rad/sec	1.8rad/sec
Settling time (t_s) in seconds	0.38sec	0.44sec	0.50sec	0.30sec
Response of the controller	Moderate	Moderate	Slow	Fast

Steady state error at half load for the reference speed ω = 151.7rad/sec is shown in the table 10.Steady state error of the Neuro-fuzzy controller is 1.8rad/sec. This value is lower than other controllers. Therefore, it is found that Neuro-fuzzy controller reduces the steady state error over PID, fuzzy, Neural network controllers. Moreover, settling time of the actual speed waveform is also measured from Fig. 14. Neuro-fuzzy controller takes low settling time over other controllers. Therefore, it is identified as the Neuro-fuzzy controller is the fastest controller over other controllers.

VI. CONCLUSION

This study discusses about the operation of cable industry - Ravicab Cables Private Limited at Bidadi. This industry is manufacturing single core and four core cable. To manufacture the single and four core cable, 3hp and 150hp motors are mainly involved. Therefore, it is necessary to check the performance of currently existing speed controller (i.e. PID controller) which is used for 3hp and 150hp motor in this industry. Performance of this PID based speed controller is poor in the transient and steady state. As such, fuzzy, Neural network[10-12,14] Neuro-fuzzy controllers are proposed to replace the PID controller. Performance of these fuzzy [3-7], Neural network and Neuro-fuzzy controllers are verified in matlab. Since Neuro-fuzzy controller reduces rise time, peak time and peak over shoot, it is found that Neuro-fuzzy controller delivers good transient state response. Similarly, since Neuro-fuzzy [15-16] controller reduces steady state error and settling time, Neuro-fuzzy controller delivers good steady state response. Therefore, Neuro-fuzzy [13] controller is identified as the novel robust controller for 3hp and 150hp motors which is used for this industry.

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