Identification of robust controller for 3hp 3Φ induction motor

H. Sathishkumar[1], S. S. Parthasarathy[2]
[1]Department of electronics, PET research foundation, P. E. S College of Engineering,
University of Mysore, Mandya, India
[2]Department of Electrical and Electronics, P.E.S College of Engineering, Mandya, India

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ABSTRACT

This paper deals about the identification of robust controller for 3hp 3Φ induction motor which is used in cable industry (Ravicab cables private limited) at Bidadi. In this cable industry 3hp 3Φ induction motor is used for cable pulling purpose. This industry is using PID (Proportional derivative integral) controller based VFD (Voltage frequency drive) for controlling the speed of this 3hp 3Φ induction motor. This VFD is not functioning well for the non linear load and disturbance environment. Therefore in this paper Neural network based speed controller is proposed as proposed controller-I for replacing the PID based VFD. Performance of the 3hp 3Φ induction motor is estimated when Neural network controller is interfaced with the motor. Then Neuro-fuzzy controller based speed controller is proposed as proposed controller-II for replacing the PID based VFD. Performance of the 3hp 3Φ induction motor is estimated when Neuro-fuzzy controller is interfaced with the motor. At last robust controller for the 3hp 3Φ induction motor which is used for cable pulling purpose is going to be identified by doing comparison chart between Neural network and Neuro-fuzzy controller.

Corresponding Author:

H. Sathishkumar,
Research scholar, Department of electronics, PET research foundation,
University of Mysore, PES College of Engineering,
Mandya 571401, India.
Email: gangulysathish@gmail.com

1. INTRODUCTION

Induction motors are playing an essential role in industries. Especially in the cable industry three phase induction motors are widely used for processes such as cable drawing process, cable pulling process. In this paper cable pulling process which is used in cable industry is mainly focused. In order to do this cable pulling process 3hp 3Φ induction motor is involved. This motor is presently controlled by PID controller based VFD [1]. While using PID based VFD for controlling 3hp 3Φ induction motor, actual speed is not exactly following the reference speed. Owing to the fact PID controller which is used in this industry is severely affected by non-linear load and disturbance signals [2-4]. Thus there is a necessity of replacing the PID controller by some other controller which has to work as a robust controller. In order to do this replacement initially Neural network is proposed for interfacing with the 3hp 3Φ induction motor [5-6]. Performance of this Neural network controller is formulated by using control system parameters such as rise time, peak time and steady state error. Consecutively Neuro-fuzzy controller is interfaced with the 3hp 3Φ induction motor instead of Neural network controller. Performance of this Neuro-fuzzy controller is formulated by using control system parameters such as rise time, peak time and steady state error [7-9]. Finally comparative performance analysis is made between Neural network controller and Neuro-fuzzy controller. This comparison chart result reveals the robust controller for the 3hp 3Φ induction motor which is used for the cable pulling purpose. In this comparison chart various conditions namely non-linear load and disturbance environment is involved for doing the effective analysis between the controllers. Besides non-linear load applied to the 3hp 3Φ induction motor shaft is splitted here into three parts namely no load (0Nm), half load (6Nm) and full load (12Nm). The cable manufacturing process as shown in Figure 1. Disturbance environment used here is voltage fluctuation such as voltage sag and swell. This voltage sag and swell is applied between the rectifier output terminals and the 3Φ inverter input terminals which are shown in the Figures 2, 3.

2. PROBLEM FORMULATION

Figure 1 shows the cable manufacturing process. Cable pulling process is one of the processes during cable manufacturing. In this cable industry various induction motors are used namely 1hp, 3hp, 5hp and 15hp. Among these motors only 3hp 3Φ induction motor is used to pull the cable. Without proper pulling torque cable cannot be taken out from the manufacturing unit. This manufacturing unit comprises of copper supply, cross head, diameter controller, water cooling truff and spark tester. Cable pulling unit comprises of capstan machine, capstan motor and its drives. This capstan motor is a 3hp 3Φ induction motor. Currently this cable industry is running the 3hp 3Φ induction motor by using this PID controller based VFD. While using this drive for controlling speed of three phase motor, VFD is affected by voltage fluctuations (i.e. Voltage sag and swell) and non-linear load. Therefore there is a necessity to interface robust controller with the 3hp 3Φ induction motor. Otherwise speed tracking performance would be poor. It leads to actual speed lacks from reference speed. In a closed loop system of cable industry, if actual speed is not able to follow the reference speed in a correct manner then desired output cannot be achieved by that system. Ultimately desired product of the cable industry (i.e. various diameter cables) cannot be obtained if actual speed lacks more from the reference speed. This is the problem which arises when PID based VFD is used to control 3hp 3Φ induction motor. Moreover Variable speed operation of the capstan motor is required when motor has to pull the various diameter cables namely 4.75 mm, 10.35 mm.

2.1. Capstan machine loading data

In Figure 1, the capstan machine is a circular pulley which is having a diameter of 12cm. This circular pulley is coupled with the 3hp 3Φ induction motor. Cable is coming out of the diameter controller after manufacturing. Distance between the diameter controller and the pulley is 4m. Hence pulley has to pull the cable which is having the length of 4m.

Case (i)

Cable is not coming out of the diameter controller (i.e. cable is not manufactured). Therefore capstan motor is running under no load.
Applied load torque on the motor = 0Nm

Case (ii)

Cable is coming out of the diameter controller via spark tester, printer to reach the capstan machine. In this case capstan motor has to pull the 4m cable with the diameter of 4.75mm. This 4.75mm diameter cable is considered to be half load for the capstan motor.
Equivalent applied load torque of 4.75mm diameter cable on the motor = 6Nm

Case (iii)

In this case capstan motor has to pull the 4m cable with the diameter of 10.35mm. This 10.35mm diameter cable is considered to be full load for the capstan motor.
Equivalent applied load torque of 10.35mm diameter cable on the motor = 12Nm.

In order to pull the high diameter cable (10.35mm), low speed (800rpm) with high torque of motor is required. On the other hand to pull the low diameter cable (4.75mm), high speed (1450rpm) with low torque of motor is required. However in this paper, both half (6Nm) and full load (12Nm) is applied on both low speed (800rpm) and high speed (1450rpm). Consequetively, actual speed of the motor is going to be verified with the reference speed (i.e.800rpm, 1450rpm) under no load, half load, full load conditions for both proposed controllers.

The following table reveals the poor speed tracking performance of PID based VFD when it is interfaced with 3hp 3Φ induction motor. In the Table 1, four different disturbance conditions are used for three different reference speeds. It is found that from the Table 1, speed tracking performance of this currently working PID based VFD is poor for various disturbance conditions. Therefore two proposed controllers are proposed for making the replacement of this PID based VFD. Besides it is recommended that each proposed controller has to be interfaced with the 3hp 3Φ induction motor separately and it’s performance has to be checked separately.

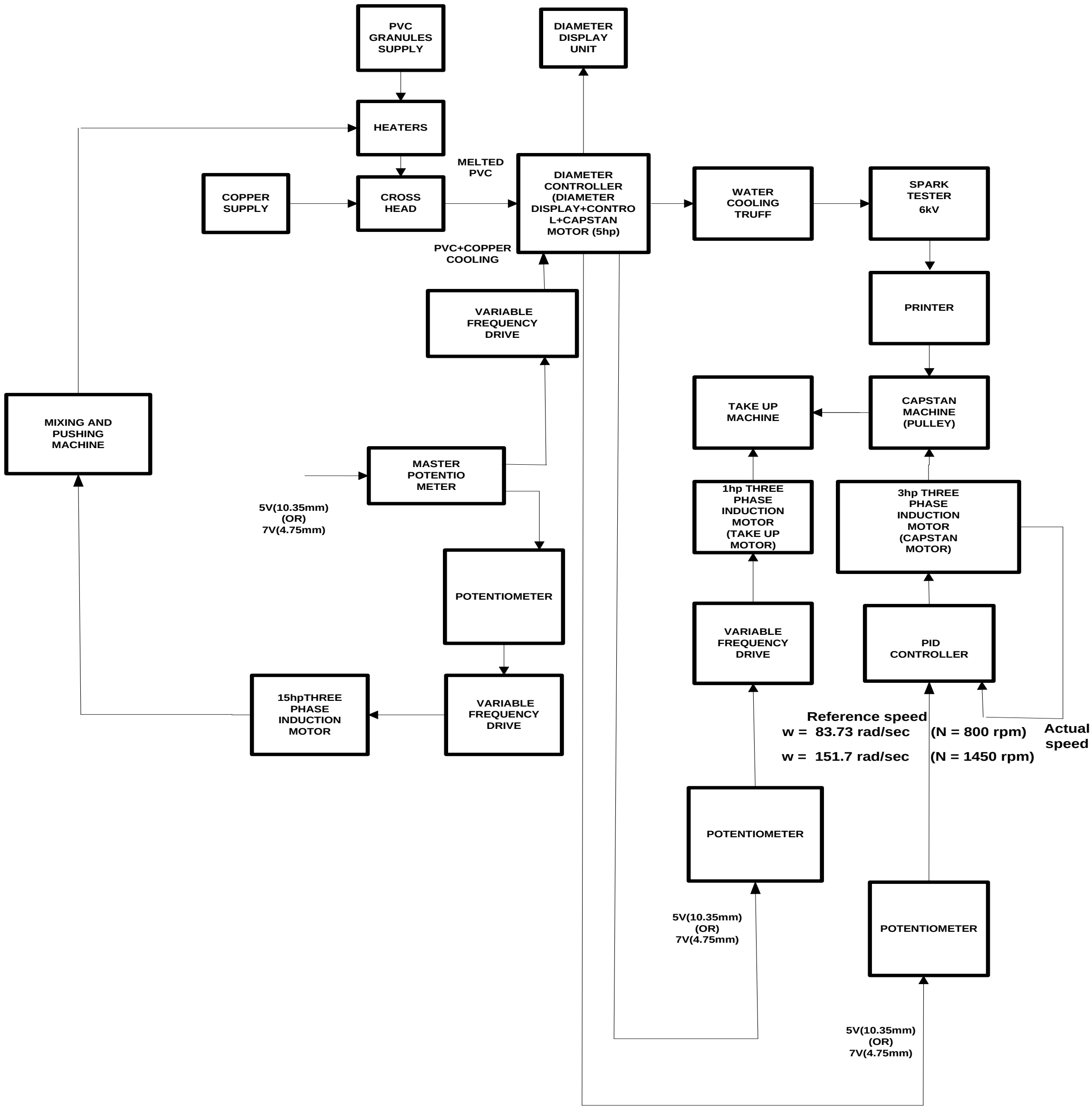

Figure 1. Cable manufacturing process

Table 1. PID controller based actual speed data taken from cable industry

Disturbance signals	Actual speed of the motor for the reference speed ω =83.73rad/sec	Actual speed of the motor for the reference speed ω =151.7rad/sec
Half load (6N-M) is applied to the motor at 0.25 minutes	ω =82.9 rad/sec (N=791.63 rpm)	ω =150.3 rad/sec (N=1435.25 rpm)
Voltage sag =27V is occurring between the time 0.7 min to 0.95 min	ω =82.6 rad/sec (N=788.77 rpm)	ω =149.9 rad/sec (N=1431.43 rpm)
Full load (12N-M) is applied to the motor at 1.5minutes	ω =81.9 rad/sec (N=782.08 rpm)	ω =149.6 rad/sec (N=1428.57 rpm)
Voltage swell =38V is occurring between the time 2.3 min to 2.5 min	ω =82.4 rad/sec (N=786.86 rpm)	ω =150.1 rad/sec (N=1433.34 rpm)

3. PROPOSED CONTROLLER-I (NEURAL NETWORK CONTROLLER)

In the Table 1, four different disturbance conditions are used for three different reference speeds. It is found that from the Table 1, speed tracking performance of this currently working PID based VFD is poor for various disturbance conditions. Therefore two proposed controllers are proposed for making the replacement of this PID based VFD. Besides it is recommended that each proposed controller has to be interfaced with the 3hp 3Φ induction motor separately and it's performance has to be checked separately.

Block diagram of Neural network controller for the 3hp three phase induction motor is shown in Figure 2. Three phase AC supply 415V, 50Hz is used as input source. This AC supply is given to the rectifier unit which converts AC into DC. Then DC supply is fed to the three phase inverter via DC link capacitor. Moreover three phase inverter output is given to the three phase induction motor. Gate pulses which are required for the inverter is formed by comparing actual speed and reference speed. When actual speed is compared with the reference speed error is formed. This error signal is minimized with the help of Neural network controller.

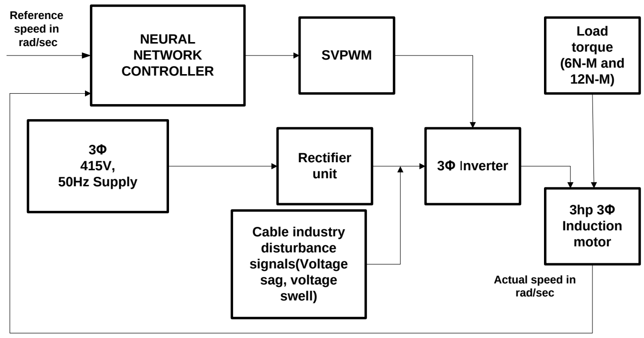

Figure 2. Block diagram of neural network controller for the 3hp three phase induction motor

The stator flux vector position is expressed as (1):

$$\theta = \tan^{-1} (\Psi_{qs} / \Psi_{ds}) \quad (1)$$

The stator current can be expressed as (2-10):

$$i_s = i_{ds} + i_{qs} \quad (2)$$

Electromagnetic torque $T_e = 1.5(P/2)L_m(i_{qs}i_{dr} - i_{ds}i_{qr})$ (3)

Stator reference flux linkage space vector position $\theta_e = \int \omega_e dt = \int(\omega_{sl} + \omega_r)dt = \theta_r + \theta_{sl}$ (4)

$$V_\alpha = V_d * \cos(\theta) - V_q * \sin(\theta) \quad (5)$$

$$V_\beta = V_q * \cos(\theta) + V_d * \sin(\theta) \quad (6)$$

$$\omega_{sl} = K_s i_{qs} \quad (7)$$

$$\omega_{sl} = (L_m R_r / \Psi_r L_r) i_{qs} \quad (8)$$

$$\Psi_r = L_m i_{ds}^* \quad (9)$$

$$i_{ds}^* = (1/L_m)\, \Psi_r^* \quad (10)$$

4. PROPOSED CONTROLLER-II (NEURO-FUZZY CONTROLLER)

Block diagram of Neuro-fuzzy controller for the 3hp three phase induction motor is shown in Figure 3. Neuro-fuzzy controller is used here as a speed controller for controlling the speed of 3hp 3Φ induction motor. Other blocks used in this block diagram are same as Figure 2. Both Neural network and fuzzy logic concepts are used to form the Neuro-fuzzy controller here.

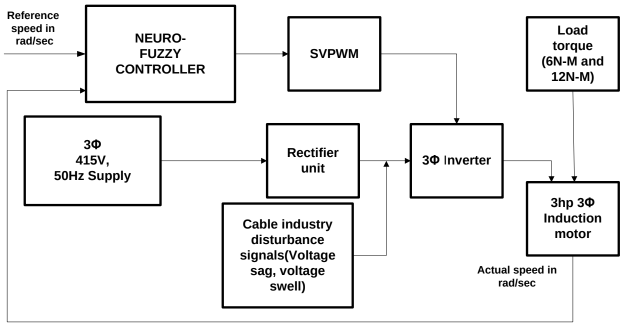

Figure 3. Block diagram of neuro-fuzzy controller for the 3hp three phase induction motor.

5. RESULTS AND ANALYSIS

5.1. Simulation results of Neural network controller and Neuro-fuzzy controller at various reference speeds

Actual speed waveforms of the 3hp three phase induction motor is shown in Figure 4, Figure 5. These actual speed waveforms are measured at the reference speed ω =83.73rad/sec , ω =151.7rad/sec respectively. From this Figure 4, Figure 5 it is found that Neural network based speed controller is not making the actual speed waveform to coincide with the reference speed. However, actual speed wave form is almost coinciding with the reference speed waveform when Neuro-fuzzy controller is interfaced with the 3hp three phase induction motor.

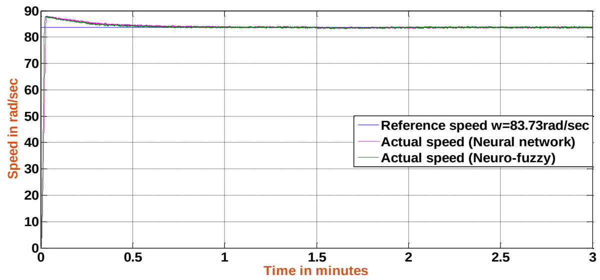

Figure 4. Actual speed of the induction motor when reference speed ω =83.73rad/sec

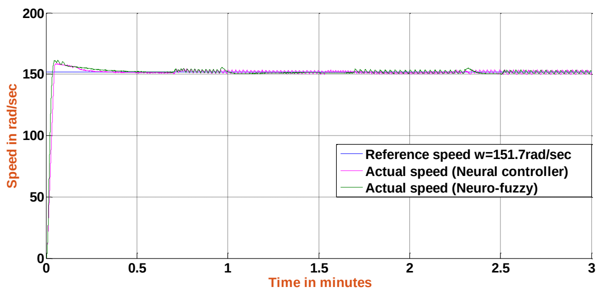

Figure 5. Actual speed of the induction motor when reference speed ω =151.7rad/sec

From Table 2, it is found that Neuro-fuzzy controller delivers superior speed tracking performance over Neural controller in the reference speed ω =83.73 rad/sec. From Table 3, it is found that Neuro-fuzzy controller delivers superior speed tracking performance over Neural controller in the reference speed ω =151.7rad/sec.

Table 2. Comparison chart for the reference speed ω =83.73rad/sec

Disturbance signals	Actual speed of the motor (Neural network controller)	Actual speed of the motor (Neuro-Fuzzy controller)
Half load (6N-M) is applied to the motor at 0.25 min	ω =84.53 rad/sec (N=807.20 rpm) (More than 83.73rad/sec)	ω =83.6 rad/sec (N=798.32 rpm) (Almost nearby ω =83.73rad/sec)
Voltage sag =27V is occurring between the time 0.7 min to 0.95 min	ω =84.12 rad/sec (N=803.28 rpm) (More than 83.73rad/sec)	ω = 83.3rad/sec (N=795.45 rpm) (Almost nearby ω =83.73rad/sec)
Full load (12N-M) is applied to the motor at 1.5min	ω =82.72 rad/sec (N=789.91 rpm) (Too lower than the reference speed ω =83.73rad/sec)	ω =82.9 rad/sec (N=791.63 rpm) (Slightly lower than the reference speed ω =83.73rad/sec)
Voltage swell =38V is occurring between the time 2.3 min to 2.5 min	ω =83.1 rad/sec (N=793.54 rpm) (Lower than the reference speed ω =83.73rad/sec)	ω =83.2 rad/sec (N=794.50 rpm) (Almost nearby ω =83.73rad/sec)

Table 3. Comparison chart for the reference speed ω =151.7rad/sec

Disturbance signals	Actual speed of the motor (Neural network controller)	Actual speed of the motor (Neuro-Fuzzy controller)
Half load (6N-M) is applied to the motor at 0.25min	ω =150.9 rad/sec (N=1440.98 rpm) (Lower than the reference speed ω =151.7rad/sec)	ω =151.1 rad/sec (N= 1442.89 rpm) (Almost nearby ω =151.7rad/sec)
Voltage sag =27V is occurring between the time 0.7 min to 0.95 min	ω =150.5 rad/sec (N=1437.16 rpm) (Slightly lower than the reference speed ω =151.7rad/sec)	ω =150.7 rad/sec (N=1439.07 rpm) (Lower than the reference speed ω =151.7rad/sec)
Full load (12N-M) is applied to the motor at 1.5min	ω =150.1 rad/sec (N=1433.34 rpm) (Too lower than the reference speed ω =151.7rad/sec)	ω =150.3 rad/sec (N=1435.25 rpm) (Slightly lower than the reference speed ω =151.7rad/sec)
Voltage swell =38V is occurring between the time 2.3 min to 2.5 min	ω =150.4 rad/sec (N=1436.21 rpm) (Slightly lower than the reference speed ω =151.7rad/sec)	ω =150.6 rad/sec (N=1438.12 rpm) (Almost nearby ω =151.7rad/sec)

5.2. Simulation results of transient state analysis for Neural network controller and Neuro-fuzzy controller at various reference speeds

Rise time and peak time of actual speed of the induction motor is shown in Figure 6, Figure 7. From these figures, it is found that actual speed waveform is taking high rise and peak time when Neural network controller is interfaced with the motor. At the same time actual speed waveform is taking low rise and peak time when Neuro-fuzzy controller is interfaced with the motor. In Table 4, 5 rise and peak time values are depicted based on the measurements made at Figure 6, 7.

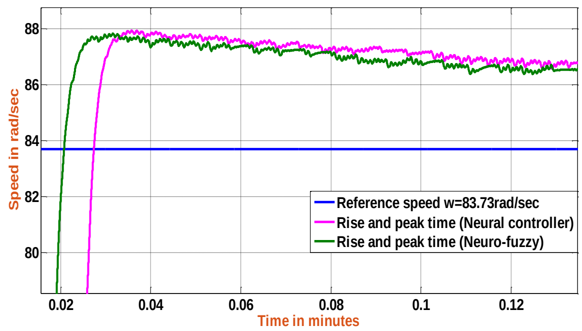

Figure 6. Rise time and peak time of actual speed of the induction motor when Neural and Neuro-fuzzy controller is used (Reference speed ω =83.73rad/sec)

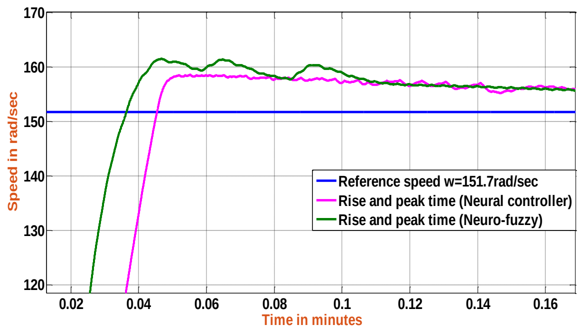

Figure 7. Rise time and peak time of actual speed of the induction motor when Neural and Neuro-fuzzy controller is used (Reference speed ω =151.7rad/sec)

Table 4. Transient state analysis in the reference speed ω = 83.73 rad/sec

Parameters	Neural network controller	Neuro-fuzzy controller
Rise time in minutes	0.0275	0.0200
Peak time in minutes	0.0360	0.0270

Table 5. Transient state analysis in the reference speed ω =151.7 rad/sec

Parameters	Neural network controller	Neuro-fuzzy controller
Rise time in minutes	0.046	0.037
Peak time in minutes	0.052	0.045

From this Tables 4, 5 it is found that Neuro-fuzzy controller reduces rise and peak time over Neural network controller in the reference speed ω =83.73, 151.7rad/sec.

5.3. Simulation results of steady state analysis for Neural network controller and Neuro-fuzzy controller at various reference speeds

Steady state error of the actual speed is shown in Figure 8, 9. Steady state error is the error which is the difference between the actual speed and reference speed. From the Figure 8, 9, it is found that Neural network controller based speed controller is producing more steady state error when it is interfaced with the 3hp 3Φ induction motor. However, Steady state error is low when Neuro-fuzzy controller is interfaced with the 3hp 3Φ induction motor. Measured steady state error values are represented in the Table 6, 7. From the above Table 6 and Table 7, it is found that steady state error is minimized by Neuro-fuzzy controller over Neural network controller.

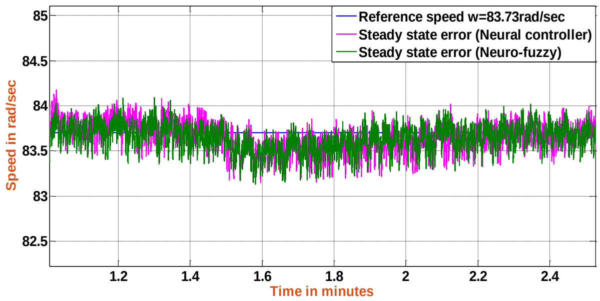

Figure 8. Steady state error of the actual speed when Neural and Neuro-fuzzy controller is used (Reference speed ω =83.73rad/sec)

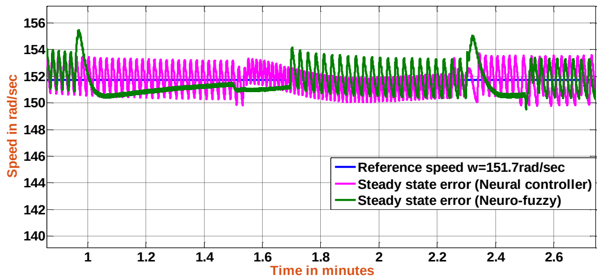

Figure 9. Steady state error of the actual speed when Neural and Neuro-fuzzy controller is used (Reference speed ω =151.7rad/sec)

Table 6. Steady state analysis in the reference speed ω =83.73 rad/sec

Parameters	Neural network controller	Neuro-fuzzy controller
Steady state error at half load before 1.5min	0.60rad/sec	0.27rad/sec
Steady state error at full load after 1.5min	0.53rad/sec	0.23rad/sec

Table 7. Steady state analysis in the reference speed ω =151.7 rad/sec

Parameters	Neural network controller	Neuro-fuzzy controller
Steady state error at half load before 1.5min	1.1rad/sec	0.6rad/sec
Steady state error at full load after 1.5min	1.2rad/sec	0.7rad/sec

6. CONCLUSION

In this cable industry a 3hp 3Φ induction motor is used for cable pulling process. This industry is currently using PID based VFD for controlling the speed of the 3hp 3Φ induction motor. This VFD is affected by non-linear load and disturbance signals. Therefore this paper proposes two controllers (Neural and Neuro-fuzzy) for the replacement of PID based VFD. Eventually it is identified that from the various comparison chart, Neuro-fuzzy is the robust controller for this cable industry.

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BIOGRAPHIES OF AUTHORS

H.Sathishkumar received the B. E degree in electrical and electronics engineering from Sona college of technology, Salem and M. E degree in Power electronics and drives from Kumaraguru college of technology, Coimbatore. He is currently pursuing Ph. D degree in Electronics from University of Mysore. He is currently working as assistant professor in MVJ College of Engineering, Bangalore. His research interest includes Electrical machines and drives, soft computing techniques, Power electronics converters and robust control.

S. S. Parthasarathy received the B. E degree in electrical and electronics engineering from National institute of engineering, Mysore and M.Tech degree in power electronics and drives from IIT Kharagpur. He received his Ph.D degree in advanced control engineering from IIT, Madras. He published papers in 50 international conferences and journals. He is currently working as professor in P. E. S college of engineering, Mandya. His research interest include Power electronics, Advanced control engineering and signal processing.