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Identification of Robust Controller for 150hp 3 Phase Induction Motor

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***Abstract* - In this paper, comparative performance analysis of Neural network controller and Neuro-fuzzy controller for 150hp (Horse power) three phase induction motor which is used in cable industry (Ravicab cables private limited) at Bidadi is presented. Proportional integral derivative (PID) controller based voltage frequency drive (VFD) is used here to control the speed of 150hp three phase induction motor which is used in cable drawing process. Since VFD used in this industry is affected by several disturbances, robust speed controller is to be interfaced with the three phase induction motor. In order to identify and interface the robust controller, this paper deals with problem of the currently existing cable industry with real time data. Moreover this paper proposes two proposed controller to solve this problem. Performances of these two proposed systems are explained with the help of Simulation and comparison chart. At the end robust controller for this cable industry will be identified.**
***Keywords:* 150hp, Neural Network, Neuro-Fuzzy, Robust Controller**

I. INTRODUCTION

Induction motor is indispensable for diverse industries. Especially three phase induction motor is essential in controlling various processes of industries. Those industries are namely oil extracting mills, lathe machines industry, large capacity exhaust fans, crushers, hoists, cranes, lifts and cable industry. This paper deals about induction motor and its controller which is used in the cable industry at Bidadi. In this industry 1hp, 3hp, 5hp, 15hp and 150hp three phase induction motors are mainly used for various operations. In order to control these induction motors, PID controller based variable frequency drive is currently used by this industry [19]. This PID controller is severely affected by voltage fluctuations and nonlinear loads. Voltage fluctuations are voltage sag and voltage swell. Since this PID controller is affected by voltage fluctuations and nonlinear loads, it is too hard to operate this controller for the speed controlling purpose [20]. Therefore, in this paper two speed controllers are proposed. Neural network controller-based speed controller is proposed as proposed controller-I for the 150hp three phase induction motor [3]-[7]. Then Neuro-fuzzy controller-based speed controller is proposed as proposed controller-II for the 150hp three phase induction motor [9]-[11]. Robustness of these two proposed controllers is verified by doing comparative performance analysis between neural network and Neuro-fuzzy controller [18]. In this comparison chart, for various reference speeds actual speed will be represented. Besides superior performance of any one of these two proposed controller is identified at three reference speeds. In order to do these analyses in the effective manner, control system parameters such as rise time, peak time and steady state error is taken into consideration for analysis at various reference speeds and disturbance environment.

II. PROBLEM UNDER CONSIDERATION

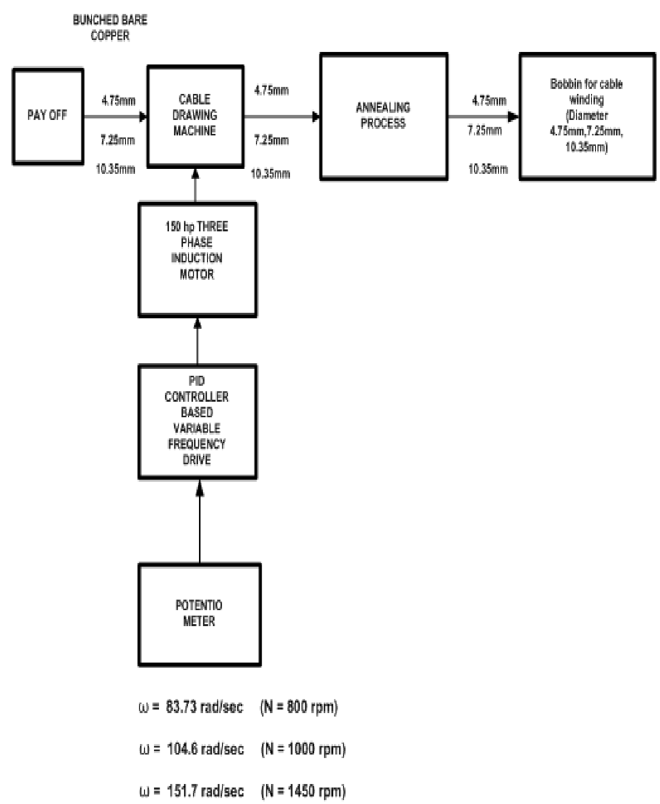

Fig. 1 Cable drawing process

Cable drawing process is shown in fig.1. This cable drawing process consist of various blocks namely payoff, cable drawing and annealing process. In this cable drawing process, cable payoff is used to deliver various diameter level bare copper such as 4.75mm, 10.35mm diameter. These various diameter cables (i.e. bare copper) are pulled by the cable drawing machine. This pulling torque of the cable drawing machine (i.e. pulley) is provided by 150hp three phase induction motor and it’s VFD. PID controller based VFD is used here to control the speed of this three-phase induction motor.

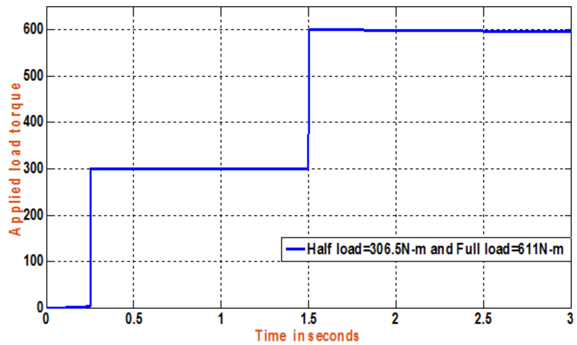

Fig. 2 Nonlinear load applied on 150hp three phase induction motor

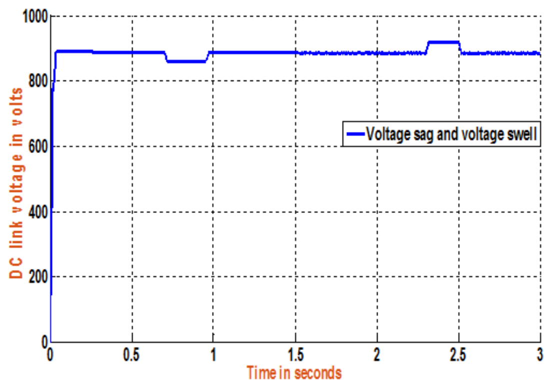

Fig. 3 Disturbance signals

This PID based VFD is suffering from various disturbance signals (i.e voltage sag and swell) and nonlinear load which is shown in fig.2 and fig.3. Here nonlinear load is the load which is applied on the 150hp motor shaft. This load is varied based on the diameter (i.e.4.75mm, 10.35mm) of the cable. It is considered that pulling of 4.75mm diameter cable as half load (i.e. 305.5mm). Similarly pulling of 10.35mm diameter cable as full load (i.e 611N-m) for the 150hp induction motor shaft. Moreover, during the half load and full load period, voltage drop, and voltage swell occurs respectively.

III. EXISTING CONTROLLER OF THIS CABLE INDUSTRY (PID BASED VFD CONTROLLER)

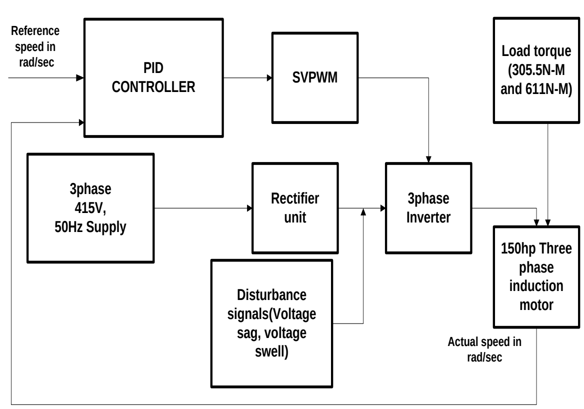

Fig. 4 Block diagram of PID controller for three phase induction motor

Block diagram of PID controller for three phase induction motor is shown in fig.4. If cable is not pulled by sufficient pulling torque, then annealing of the cable and winding of the cable in bobbin will not happen properly (fig.1). Annealing process is used to toughen the cable. If annealing process is not properly taking place, then cable loses it toughness (i.e. mechanical strength). Moreover, this strength less cable will be winded in the bobbin. This is the problem which comes during the time of usage of PID controller based VFD speed controller in this cable industry now. Equation of the PID controller is of the following form,

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d (de/dt) \quad (1)$$

TABLE I INDUSTRIAL PID BASED VFD DATA

Proportional gain (K_p)	26
Integral gain(K_i)	39
Derivative gain(K_d)	0.09
Torque limit (N-m)	400

PID controller block parameters are shown in table I. This is the real time PID based VFD data which is taken from cable industry. It is difficult to handle the cable industry drawing process with this data. Therefore, this PID based VFD is replaced by proposed controller-I (Neural network controller). Besides this 150hp induction motor is interfaced with Neuro-fuzzy controller. Finally, robust controller for this cable industry is needed to be obtained by doing comparison chart between neural network and neuro-fuzzy controller-based simulation.

IV. PROPOSED CONTROLLER -I (NEURAL NETWORK CONTROLLER)

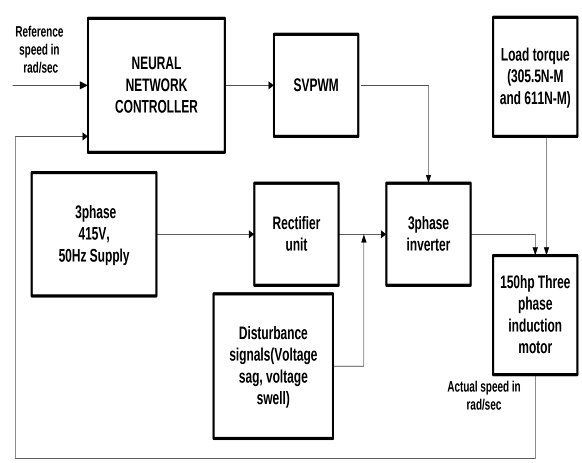

Fig. 5 Block diagram of Neural network controller for the three-phase induction motor

Block diagram of Neural network controller for the three-phase induction motor is shown in fig. 5. In this block diagram, neural network controller is the controller unit for the three-phase induction motor. This neural network controller gets two inputs. One input is reference speed and another one input are actual speed. Based on the error signal generated between these signals SVPWM (Space vector pulse width modulation) is operated. This SVPWM unit gives the required pulses to the three-phase inverter. Three phase 150hp squirrel cage induction motor gets the variable stator voltage from this inverter. Then actual speed of the motor is measured and fed back to the one of the inputs to the neural network controller. Moreover, three phase, 415V, 50Hz Ac supply is used as input supply. This supply is converted as DC supply via rectifier. Afterwards, rectified DC is added with the disturbance signals which are in the form of voltage sag and voltage swell (i.e. Equivalent voltage fluctuation in industry). Then this mixed rectified signal and disturbance signal is given to the input terminals of the inverter. Thereby inverter delivers the AC voltage to the motor.

V. PROPOSED CONTROLLER–II (NEURO-FUZZY CONTROLLER)

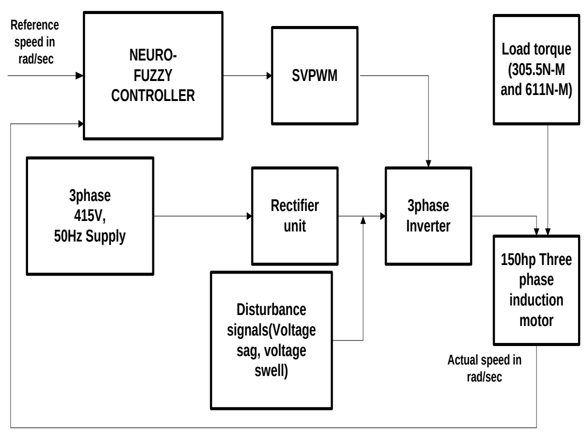

Fig. 6 Block diagram of Neuro-fuzzy controller for three phase induction motor

Block diagram of Neuro-fuzzy controller for three phase induction motor is shown in fig.6. In this block diagram, Neuro-Fuzzy controller is the controller unit for the three-phase induction motor. This Neuro-fuzzy controller gets two inputs. One input is reference speed and another one input is actual speed. Based on the error signal generation between these two signals (i.e. Actual speed and reference speed) SVPWM is operated. This SVPWM unit gives the required pulses to the three-phase inverter. Three phase 150hp squirrel cage induction motor gets the variable stator voltage from this inverter.

A. Design of Closed Loop Control of Three Phase Induction Motor

Inverse Park transformation:

Inverse Park transformation can be obtained using the following,

$$V_\alpha = V_d * \cos(\theta) - V_q * \sin(\theta) \quad (2)$$

$$V_\beta = V_q * \cos(\theta) + V_d * \sin(\theta) \quad (3)$$

Where, V_α, V_β are orthogonal stationary reference frame quantities

V_d, V_q are rotating reference frame quantities, this Inverse Park transformation is utilized during the formulation of the stationary reference frame quantities.

The stator flux vector can be estimated using the following,

$$\Psi_s = \Psi_{ds} + j\Psi_{qs} = |\Psi_s| \angle \theta \quad (4)$$

The stator flux vector position is expressed as,

$$\theta = \tan^{-1}(\Psi_{qs} / \Psi_{ds}) \quad (5)$$

The stator current can be expressed as,

$$i_s = i_{ds} + i_{qs} \quad (6)$$

Electromagnetic torque,

$$T_e = 1.5(P/2)L_m(i_{qs}i_{dr} - i_{ds}i_{qr}) \quad (7)$$

Stator reference flux linkage space vector position

$$\theta_e = \int \omega_e dt = \int(\omega_{sl} + \omega_r)dt = \theta_r + \theta_{sl} \quad (8)$$

Where, ω_{sl} is the slip speed in rad/sec.

ω_r is the rotor speed in rad/sec.

$$\omega_{sl} = K_s i_{qs} \quad (9)$$

$$\omega_{sl} = (L_m R_r / \Psi_r L_r) i_{qs} \quad (10)$$

$$\Psi_r = L_m i^*_{ds} \quad (11)$$

$$i^*_{ds} = (1/L_m)\Psi^*_r \quad (12)$$

The three-phase sinusoidal and balance voltages given by the following equations,

$$V_{An} = V_m \cos(\omega t) \quad (13)$$

$$V_{Bn} = V_m \cos(\omega t - 2\pi/3) \quad (14)$$

$$V_{Cn} = V_m \cos(\omega t + 2\pi/3) \quad (15)$$

$$V = (2/3)(V_{An} + \alpha V_{Bn} + \alpha^2 V_{Cn}) \quad (16)$$

$$V_\alpha = V_d * \cos(\theta) - V_q * \sin(\theta) \quad (17)$$

$$V_\beta = V_q * \cos(\theta) + V_d * \sin(\theta) \quad (18)$$

B. Simulation Results of the Neural Network and Neuro-Fuzzy Controller

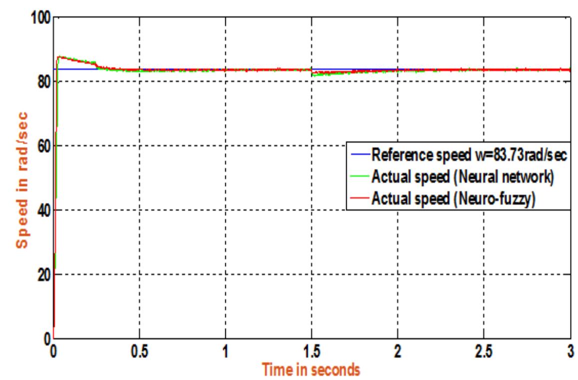

Fig. 7 Actual speed of the three phase induction motor when reference speed ω=83.73rad/sec

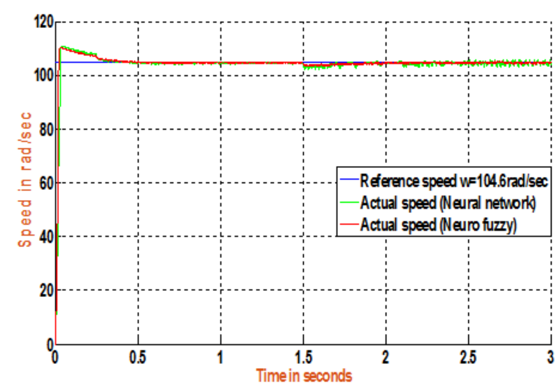

Fig. 8 Actual speed of the three-phase induction motor when reference speed ω=104.6rad/sec

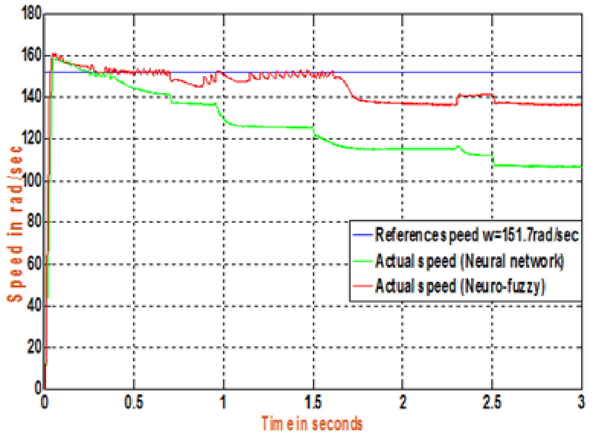

Fig. 9 Actual speed of the three-phase induction motor when reference speed ω=151.7rad/sec

Actual speed of the three-phase induction motor for various reference speeds is shown in fig.7, fig.8, fig.9. In this fig.7 shows the actual speed for the reference speed ω=83.73rad/sec, fig.8 shows the actual speed for the reference speed ω=104.6 rad/sec and fig.9 shows the actual speed for the reference speed ω=151.7rad/sec. Actual speed values taken from these figures are listed out in table II.

It is found that all actual speed values are higher for neuro-fuzzy based speed controller compared to neural network controller for the various disturbance signals and nonlinear loads.

TABLE II NEURAL AND NEURO-FUZZY CONTROLLER FOR THE VARIOUS REFERENCE SPEEDS IN RAD/SEC

Disturbance signals	Actual speed of the 150hp three phase induction motor at various reference speeds					
	Neural network (ω=83.73rad/sec)	**Neuro-fuzzy** (ω=83.73rad/sec)	**Neural network** (ω=104.6rad/sec)	**Neuro-fuzzy** (ω=104.6rad/sec)	**Neural network** (ω=151.7 rad/sec)	**Neuro-fuzzy** (ω=151.7 rad/sec)
Half load (305.5N-M) is applied to the motor at 0.25 sec	ω=83.45rad/sec (N=796.88 rpm)	ω=83.6rad/sec (N=798.32 rpm)	ω=104.7rad/sec (N=999.81rpm)	ω=104.95rad/sec (N=1002.19 rpm)	ω=143.3rad/sec (N=1368.41rpm)	ω=152.8rad/sec (N=1459.13 rpm)
Voltage sag =27V is occurring between the time 0.7 sec to 0.95 sec	ω=83.18 rad/sec (N=794.31 rpm)	ω=83.4rad/sec (N=796.41 rpm)	ω=104.5rad/sec (N=997.90rpm)	ω=104.65rad/sec (N=999.33rpm)	ω=136.65rad/sec (N=1304.43 rpm)	ω=145.6rad/sec (N=1390.37 rpm)
Full load (611N-M) is applied to the motor at 1.5sec	ω=82.7 rad/sec (N=789.72 rpm)	ω=82.9rad/sec (N=791.63 rpm)	ω=104rad/sec (N=993.12rpm)	ω=104.2rad/sec (N=995.03rpm)	ω=115.2rad/sec (N=1100.07 rpm)	ω=137.8rad/sec (N=1315.89 rpm)
Voltage swell =38V is occurring between the time 2.3 sec to 2.5 sec	ω=83 rad/sec (N=792.59 rpm)	ω=83.25 rad/sec (N=794.97 rpm)	ω=104.3rad/sec (N=995.99rpm)	ω=104.5rad/sec (N=997.90 rpm)	ω=112.2rad/sec (N=1071.43 rpm)	ω=141.2rad/sec (N=1348.36 rpm)

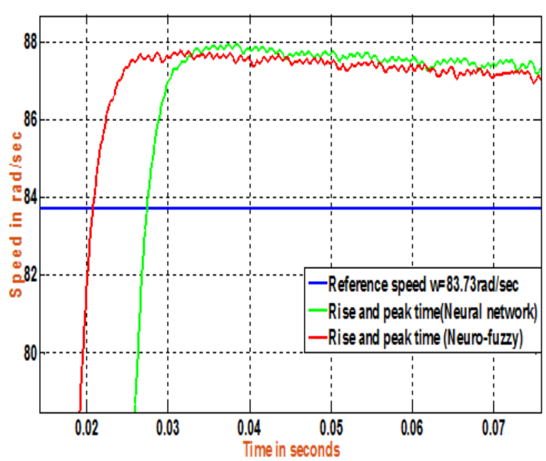

Fig. 10 Rise and peak time of the actual speed when reference speed ω=83.73rad/sec

Rise and peak time of the actual speed of the three-phase induction motor is shown in fig.10, fig.11, fig.12. Rise time and peak time values taken from these figures are listed out in table III.

It is found that rise time and peak time values are low for neural network-based speed controller compared to Neuro-fuzzy controller.

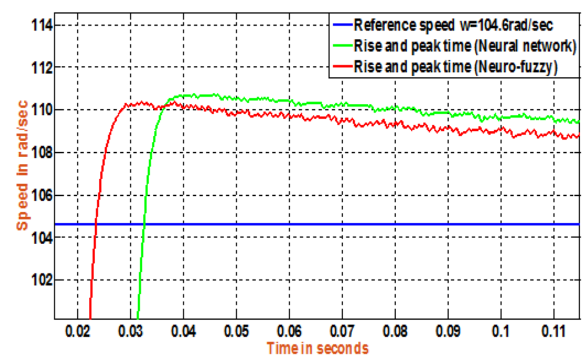

Fig. 11 Rise and peak time of the actual speed when reference speed ω=104.6rad/sec

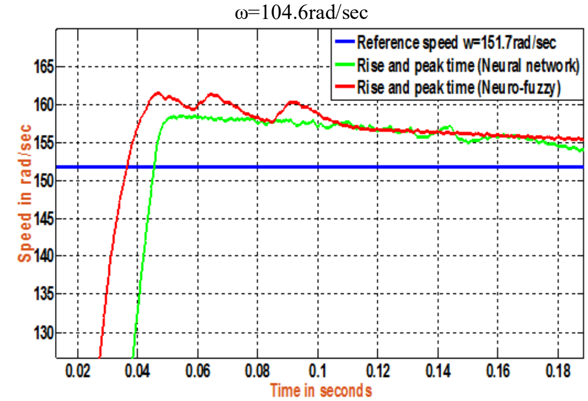

Fig. 12 Rise and peak time of the actual speed when reference speed ω=151.7rad/sec

TABLE III TRANSIENT STATE ANALYSIS AT VARIOUS SPEEDS IN RAD/SEC

Parameters	Neural network controller (83.73rad/sec)	Neuro-fuzzy Controller (83.73rad/sec)	Neural network controller (104.6rad/sec)	Neuro-fuzzy Controller (104.6rad/sec)	Neural network controller (151.7rad/sec)	Neuro-fuzzy Controller (151.7rad/sec)
Rise time in seconds	0.027	0.021	0.033	0.023	0.045	0.036
Peak time in seconds	0.034	0.026	0.04	0.03	0.052	0.047

Fig. 13 Steady state error of the actual speed when reference speed ω=83.73rad/sec

Fig. 14 Steady state error of the actual speed when reference speed ω=104.6rad/sec

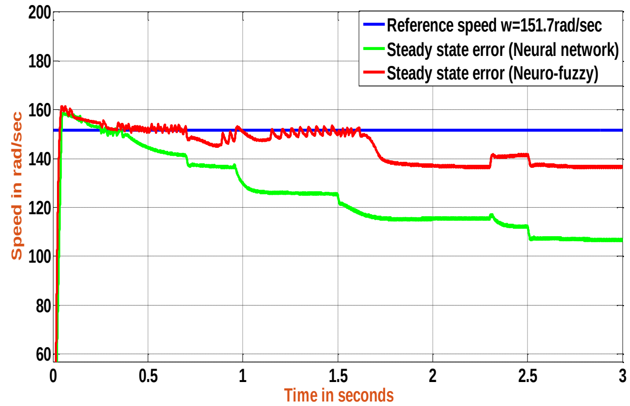

Fig. 15 Steady state error of the actual speed when reference speed ω=151.7rad/sec

Steady state error of the actual speed of the three-phase induction motor is shown in fig.13, fig.14, fig.15. Steady state error is the difference between the reference speed and the actual speed. Steady state error taken from these figures is listed out in table IV.

From this table IV, It is found that Neuro-fuzzy controller based speed controller reduces the steady state error significantly over neural network controller.

TABLE IV STEADY STATE ANALYSIS AT VARIOUS SPEEDS IN RAD/SEC

Parameters	Neural network controller (83.73rad/sec)	Neuro-fuzzy Controller (83.73rad/sec)	Neural network controller (104.6rad/sec)	Neuro-fuzzy Controller (104.6rad/sec)	Neural network controller (151.7rad/sec)	Neuro-fuzzy Controller (151.7rad/sec)
Steady state error at half load (Before 1.5sec)	0.63rad/sec	0.27rad/sec	0.5rad/sec	0.3rad/sec	25.7rad/sec	4.2rad/sec
Steady state error at full load (After 1.5sec)	0.53rad/sec	0.33rad/sec	1.4rad/sec	0.8rad/sec	44.3rad/sec	15.2rad/sec

TABLE V CABLE DRAWING MOTOR NAME PLATE DETAILS

HP	**150**	**kW**	**111.855**
Rated voltage	415V	Full load	286.05A
Power factor	0.85	Efficiency	80%
Frequency		50Hz	
Poles		4	
Stator resistance R_s		0.435 Ohms	
Stator inductance L_s		0.004 H	
Rotor resistance R_r		0.816 Ohms	
Rotor inductance L_r		0.002 H	
Mutual inductance L_m		0.06931 H	
Inertia		0.089	

VI. CONCLUSION

Cable industry at Bidadi is taken into study. In this industry various three phase induction motors are used. However only 150hp motor which is used for cable drawing purpose is taken into consideration.PID based VFD is used still now in this industry. This PID controller based VFD is affected by non-linear load and disturbance signals. Therefore, in order to do the replacement of this drive two controllers are proposed. Neural network controller is initially interfaced with the 150hp motor. Performance of this Neural network controller is analyzed with the help of simulation. Then Neuro-fuzzy controller is proposed as proposed controller-II. Performance of this Neuro-fuzzy controller is also analyzed with simulation work. At last comparison chart has been made between these two proposed controllers. When comparing the simulation results of neural network with Neuro-fuzzy controller, it is found that Neuro-fuzzy controller performance is good as neural network controller. Therefore, robust controller for this cable industry is identified as Neuro-fuzzy controller.

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