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Optimization Analysis using Fuzzy Inference System for Robot Control

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Abstract— A Robotic control using DC-DC Dynamic FLC is analyzed in this article. When compared with the PID controllers and Mamdani FLC this advance use of Adaptive Neuro-Fuzzy Inference Systems for the control of the robot is very efficient. High DC supply voltage is excited at a very low time period in the proposed DC-DC Dynamic converter. In this theme, DC Robot control converter has two clamping diodes which shares one-half of the voltage input. The parametric quantities examined are voltage ripple, output power, rise time, settling time and peak voltage of 3L filter for the control of the Robot. The evaluation with the PI controllers and Mamdani with Adaptive Neuro-Fuzzy Inference Systems were analyzed by Mat Lab and inferred ANFIS system design has the good performance of the robot.

Index Terms— **D**irect Current (DC),Fuzzy Logic Controller (FLC), Harmonic Distortion, Phase Shifted (PS),Robot Control, Zero Voltage Switching (ZVS), Zero Current Switching (ZCS).

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1 INTRODUCTION

Technologists convoluted the conception of the low time period switching mode power supplies for high power application which employs DC-DC ZVS power converter. Hard switching and soft switching are the two different types of switching. In converters hard switching with an individual dynamic switch [1] -[2] has the major drawbacks of commutation losses.

In the soft switching converters [3] has ZVS or ZCS to achieve minimized switching losses and estimable efficiency. The voltage is zero just before turn ON is called Zero Voltage Switching (ZVS). On the other turn over if the current passing through switch is simply zero before turn OFF is called Zero Current Switching(ZCS). The switch conduct of power converter acts very fast and used for the drive optimization, electromagnetic interference, radio frequency interference and power dissipation issuances. In the high frequency power converter, the weight and size of the filter elements are reduced.

DC-DC Converters with PWM technique are applied in diligences like elevator, audio amplifier and UPS. By using dynamic methods of auxiliary switches the switching loss can be dispirited. An auxiliary switches rise the complexes of control circuits & main circuit this reason step down converter are desirable for high current & low voltage applications has been projected.

The primary controllers target is to achieve an estimable active response in DC-DC step down converter and to reduce the ripple content.There are numerous sorts of controllers grew to accomplish the attractive performances. The canonic PI controller proposes an uncomplicated affectation in processor circuit and it has a good operation [8]. In nonlinear load the functioning of PI controller is not acceptable. At present, numerous controllers exist which performs superior to PID controller. The execution of Sliding Mode Controller [9] is to thrust the system output to trace slidingline, design is simple but it meets composite control and varying switching frequency .

Recently Fuzzy Controllers have been the most preferred controller. The advantages of fuzzy controller are as follows:

a. There is no need of a model for controller design

b. Non-linearity can be managed easily

The transient and steady state response of FLC yields better performance than SMC. The structure of FLC is not as complex a SMC. Fuzzy design of Mamdani and Adaptive Neuro-Fuzzy Inference Systems to control the three level step down converter for PMDC Motor with three different filters has been explained in this paper. Speed control can be confined of 3 stages. The elementary footprint is a formal mastery of DC drive by PI controller. The second tone is by utilizing Fuzzy Mamdani. The third step is by Adaptive Neuro-Fuzzy Inference Systems. In Fuzzy system even under fluctuations there is no reduction in performance.

2 DESIGN OF ZERO VOLTAGE SWITCHING STEP DOWN DC-DC CONVERTER

The Fig. 1 & 2 shows three level cascaded buck or Step down converter and converter waveforms. During ON condition, switch conducts for the time period DT, diode & inductor becomes reverse biased, because of this inductor voltage is produced in the which is given as

$$VL = Vin - Vo$$

As the voltage of the inductor rises, inductor current also rises. Due to the inductive effect of energy storage positive inductive current continues through diode even when in the off condition. For timeperiod $(1-D)T$ the inductor voltage is equal to the negative output voltage as in [4]-[6]until switch ON condition.

The flying or blocking capacitors C_1&C_2, two freewheeling or blocking diodes C_{d1} & C_{d2} of the proposal splits the voltage input

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$V_{DC}/2$ equally in the converter circuit. The power switches are Q_1 & Q_4 called leading switches which are placed outer. Q_2 & Q_3 are lagging switches placed inner side, and L_r resonant inductance for producing a zero voltage switching for Q_2 & Q_3. There are four blocking diodes or clamping diode D_5, D_6, [7] D_7, & D_8 in the converter.

In PWM ZVS converter phase shifted modulation is employed. The filter used in here is called Cascaded which is connected at output of the rectifier to reduce the ripple.

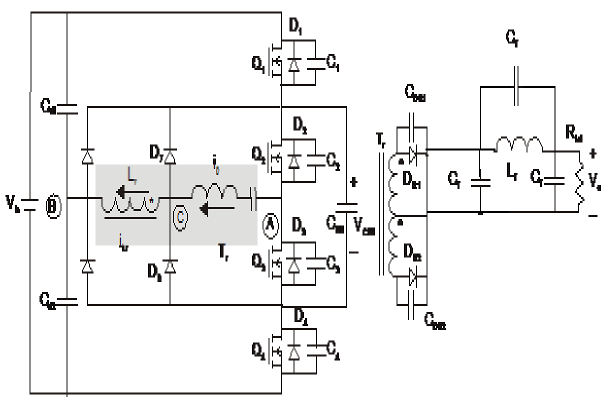

Figure 1. Proposed Cascaded Step down converter fed DC drive

When a high frequency is excited on the switches, current pulses produced are inductively transfered to secondary of the transformer as shown. Unidirectional current pulse of low voltage at secondary is produced. To avoid current reversal diodes at secondary transformer are connected.

A. *Analytical formulations of inductor voltage & current, output voltage*

$$\int_0^T VLdt = \int_0^{Ton} VLdt + \int_0^{Toff} VLdt \quad (1)$$

$$(Vin - Vo) \times DT + (-Vo) \times (1 - D)T = 0 \quad (2)$$

$$Vo = DVin \quad (3)$$

$$Vo / Vin = D \quad (4)$$

For a 100% efficient circuit $Pin = Po$, Therefore

$$Vin\,Iin = Vo\,Io \quad (5)$$

$$(Io/Iin) = (Vin/Vo) = (1/D) \quad (6)$$

For a step down converter, $IL = Io$

$$\Delta iL = \left(\frac{1}{L}\right)\int_0^{DT} VLdt \quad (7)$$

$$= \left(\frac{1}{L}\right)[\text{Shaded area } V_L \text{ (Area A)}]$$

$$= \left(\frac{1}{L}\right)(Vin - Vo) \times DT \quad (8)$$

$$iL,min = IL - (\Delta iL / 2) \quad (9)$$

$$iL,max = IL + (\Delta iL / 2) \quad (10)$$

The mean inductor current,

$$IL = Io = (Vo / R) \quad (11)$$

B. State-space generalized technique

State equation for switched network

$$X(t) = A_i\, x(t) + B_i(t), i = 1, 2 \ldots k \quad (12)$$

State Space generalized averaging equation,

$$X = \{\sum_{i=1}^{K} d_i A_i\}x + \frac{1}{T}\sum_{i=1}^{K} 1 \int_{t_{i-1}}^{t_i} B_i(\lambda)\, d \quad (13)$$

$$fs = 1/T$$

T = switching timeperiod,
fs = switching frequency,
fo= maximum frequency of Ai state matrix. and
B_i= control variable for bounded input.

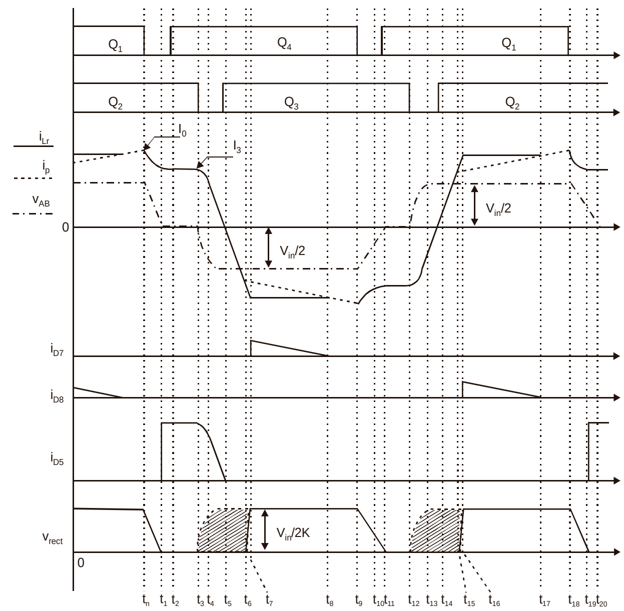

Figure 2.Waveform of converter

C. Mathematical Analysis of Resonant Circuit:

$V = L.di/dt + 1/C \int idt$ (14)

$V/S = (L.S+1/CS)\, I(S)$

$L\,[\sin\omega t] = \omega/S^2+\omega^2$

$i(t) = V\sqrt{C/L}\, \sin \omega t$

$i(t) = V/\omega L\, \sin \omega t$

Voltage across capacitor:

$V_C = 1/C\int idt\omega t$

$V_C = V\,[1- \cos \omega t]$ (15)

From the Fourier series of output of Full wave Rectifier we know that

$V0 = (2Vm/\pi)-(4Vm/\pi) \cos \omega t$ (16)

Similarly

$I0 = (2Im/\pi)-(4Im/\pi) \cos \omega t$

$I'rms = 4Im/3\pi\sqrt{2}$ (17)

$ZL = XL+XC||RL$

XC = Low value

RL = High value

Parallel combination of XC and RL is approximately equal to XC

Therefore ZL = XL+XC

ZL is approximately equal to XL, since XC is very less.

From equation (17)

$I'rms = 4(Vm/ ZL)/ (3\pi\sqrt{2})$

Substitute ZL = XL

$= 4Vm/(3\pi\sqrt{2}XL)$

$V'rms = I'rmsXC$

$= 4VmXC/ (3\pi\sqrt{2}XL)$

$r = V'rms/Vd$

$= 4VmXC/((3\pi\sqrt{2}XL)(2Vm/\pi))$

$r = \sqrt{2}/3*(XC/ XL)$ (18)

$L = 1/4\, \pi 2\, fr2C$ (19)

$\omega = 2\pi f$

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We know $r = \sqrt{2}/(XC/XL)$

$= \sqrt{2}\,(1/\omega C)/\omega L$

$= \sqrt{2}/\omega 2LC$ (20)

3.FUZZY LOGIC CONTROLLER

The different types of fuzzy inference system (FIS) are Mamdani, Takagi-Sugeno and Adaptive Neuro-Fuzzy Inference Systems. This research work provides the comparison of Mamdani FIS and Adaptive Neuro FIS. In Mamdani FIS the fuzzy sets are formed and the resulting fuzzy set is defuzzified to produce the output of the system. Adaptive Neuro FIS is a controller technique which train data automatically [13] -[16]. The three stages of Fuzzy Logic Controller (FLC) are

a. Fuzzification

b .Rule Decision Making

c. Defuzzification.

Fuzzification

Transformation of crisp data (non-fuzzy value) from the physical measurement in a fuzzy linguistic is called Fuzzification, i.e. Positive Big (+B), Positive Small (+S), Zero (Z), Negative Small (-S), NegativeBig (-B). Membership Function is assigning crisp input in terms of fuzzy form.

The (non-fuzzy value) crisp input is the primarily designed for all membership functions. Forward gain design is done by the scaling factor. The shape triangular, trapezoidal, bell or singleton is the different pattern for the Membership function(MF). Generally opted pattern for less computational operation time is triangular MF of 50% overlap with the neighbering MF.

Rule Decision Making

Rule Decision Making has Rule Table & Rule Evaluator [10] -[12]. The rules are presented in the rule table in relationship with input-output. The Rule evaluator decides which rules should be triggered as IF... THEN... with linguistic rule and has maximun of n inputs for 2n triggered rules.

Defuzzification

The last level is defzzification in which Fuzzy form has been converted into physical values by Mean Maximum Centroid Method.

4. FUZZY STRUCTURE

The comparison of FLC inputs are mainly with error $e(k)$ of the speed within reference speed & actual speed of drive and secondly with fluctuation of error $\Delta e(k)$ that can been expressed as

$$e(k) = n* - n(k) \quad (21)$$

$$\Delta e(k) = e(k) - e(k-1) \quad (22)$$

Where, $n*$ is the reference speed, $n(k)$ is the actual speed at time k ,$e(k)$ is the error in time k , $e(k-1)$ is the error at time $k-1$.

The output Δu of the FLC will increase the voltage signal of duty ratio . The output signal is expressed in terms of error as

$$u(k) = u(k-1) + \Delta u \quad (23)$$

where $u(k-1)$ is the duty ratio of the k-1 time

The fuzzy system has been shown in Fig. 3.

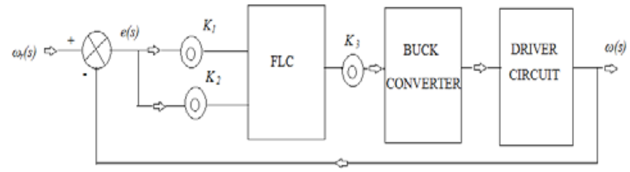

Figure 3. Fuzzy system for step down converter fed drive

The Fuzzy system incorporates three membership function(MF). The MF are 1. error 2. change in error & 3. control output for two inputs & one response.There five linguistic variables are PositiveBig (+B), PositiveSmall(+S), Zero(Z), Negative Small(-S), Negative Big (-B).The membership functions for error, change in error and control or trigger output are shown in Fig. 4,5& 6 respectively.

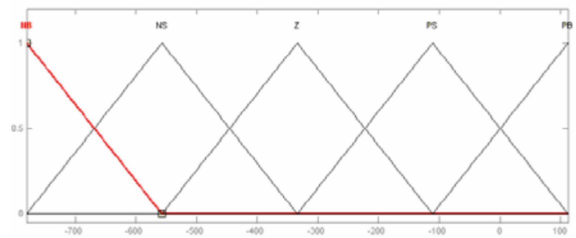

Figure 4. Membership Function - error

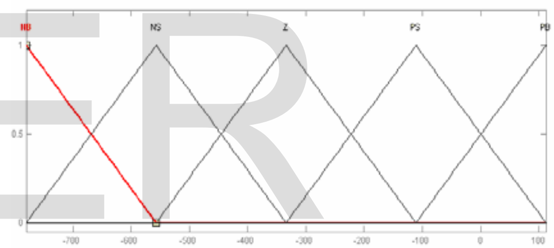

Figure 5. Membership Function - change in error

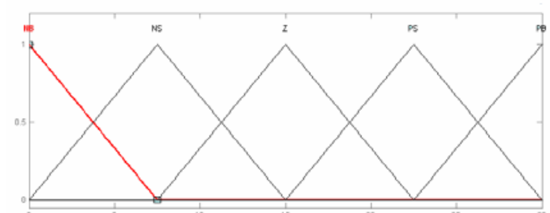

Figure 6. Membership Function – trigger or control output

5.SIMULATION RESULTS

The simulation examines the PID controller and Fuzzy system. The closed loop system with PID controller and FLC has been shown in Fig. 7 and 8 . Table 1 compares the PID controller and FLC. In Fig.9b. Speed output of the drive using PID controller [17] & [18] is shown. The speed output portends the operation of PID controller is not acceptable, though the drive acts quickly, the fault in steady state are heavy & there is steady state fluctuation. The motor load with open loop system been shown in Fig.9a. The drive response of Mamdani FIS has been shown in Fig. 10a.The drive response of the Adaptive Neuro FIS has been shown in Fig. 10b. Which responds rapidly & the fluctuations are reduced. Fig. 11,12 & 13 shows the ripple,response voltage &

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power. Fig.14 and 15 gives the voltage ripple and output power for three level capacitance, π and cascaded filter DC-DC converter. Fig. 16 shows Harmonic Distortion analysis. Table 2 compares voltage ripple & power response for three level capacitance, π and cascaded filter DC-DC converter. Table 3 gives the filter comparability of rise time, peak voltage & settling time for capacitance, π and cascaded DC-DC converter design.

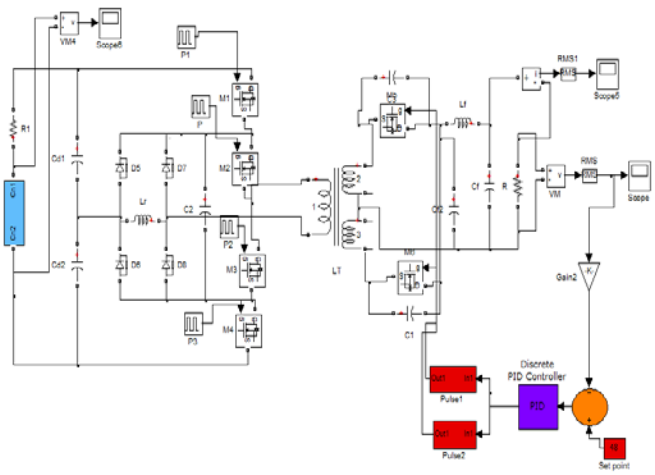


Figure 7. Closed loop system with PID controller

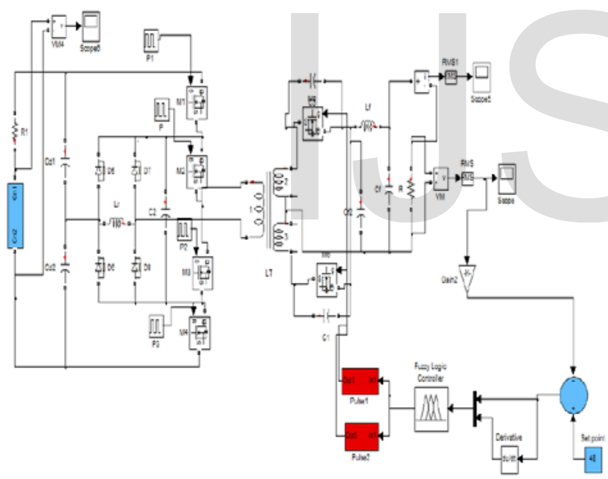


Figure 8. Closed loop system with Fuzzy controller

Table 1. Comparison of PID controller and FLC

Specifications	PID controller	Fuzzy Logic Controller
Rise time (t_r)	0.04s	0.02s
Setting time (t_s)	0.062s	0.03s
Peak time(t_p)	0.05s	0.03s
Steady state error(e_{ss})	5.8V	0.09V

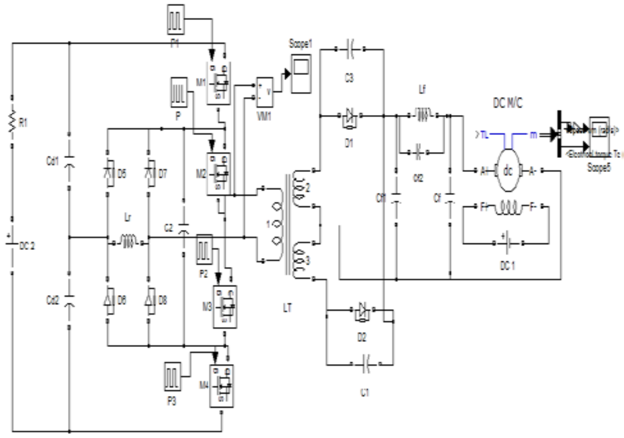


Figure 9a. Cascaded (3L_Cascade) open loop system with motor load

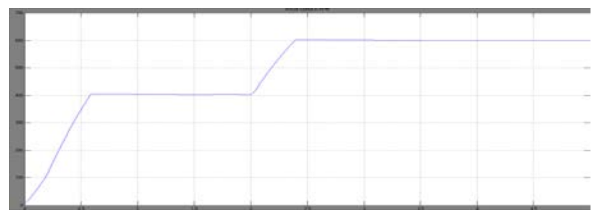


Figure 9b.Speed waveform for closed loop system with motor load

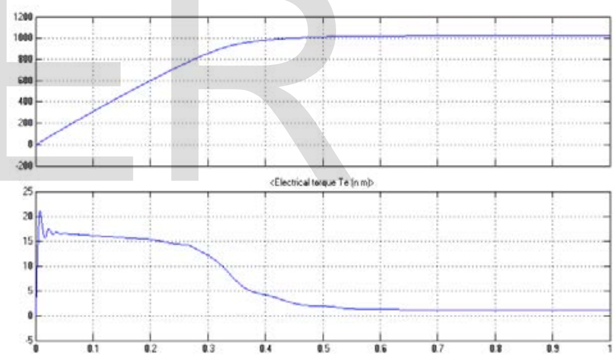


Figure 10a.Speed and Torque Response of 3L_Cascaded using Mamdani FIS controller

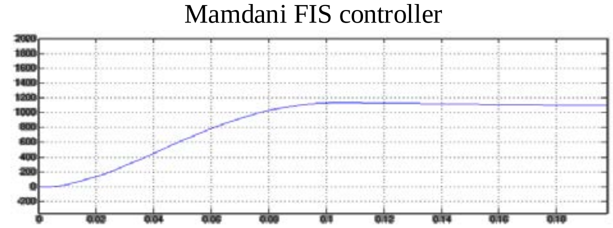
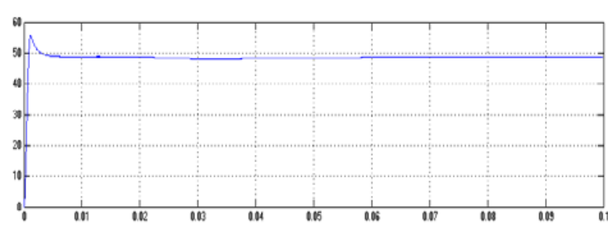
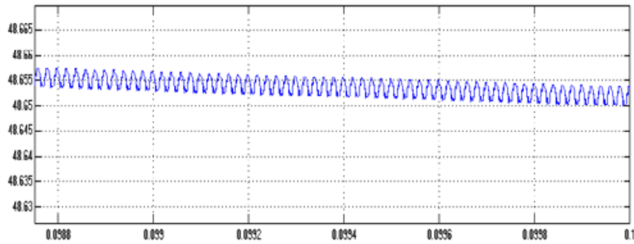


Figure 10b. Speed waveform of 3L_Cascaded using Adaptive Neuro FIS controller

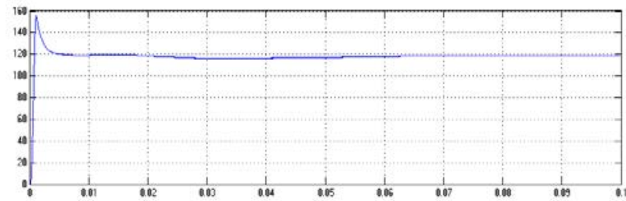


Voltage V Y-axis in volts Time period t X-axis in msec
Figure 11. Converter Output voltage of 3L_Cascaded



Voltage V Y-axis in volts Time period t X-axis in msec

Figure 12. Converter Output voltage ripple of 3L_Cascade



Voltage V Y-axis in volts Time period t X-axis in msec

Figure 13. Converter Output power of 3L_Cascade

Table 2. Comparison of capacitance, π and cascaded filter voltage ripple and output power of converter

3L_C=Three level converter with Capacitive filter

3L_ π= Three level converter with π filter

3L_Cas= Three level converter with Cascaded filter

Quantity	**Symbol**	**Units**	**3L_C**	**3L_ π**	**3L_ Cas**
Voltage Ripple	V ripp	Volts	0.017	0.007	0.004
Output Power	Po	Watts	113	120	124

Table 3. Comparison of capacitance, π and cascaded filter rise time t_r, peak voltage **Vp** , & settling time t_s of converter

Specifications	**3L_C**	**3L_ π**	**3L_Cascade**
Rise time (tr)	2.8e-4	4.6e-4	4.7e-4
Setting time(ts)	2.8e-3	3.4e-3	3.6e-3
Vp	12.5	6.5	5.1

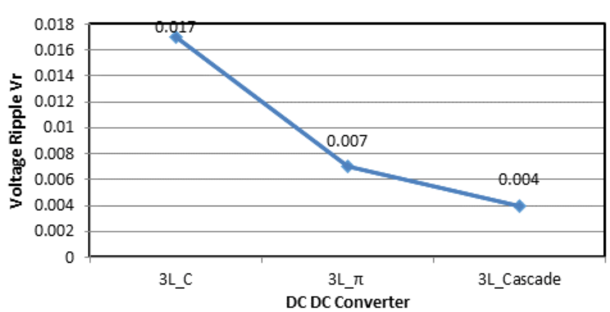


Figure 14.Output voltage ripple of DC-DC converter

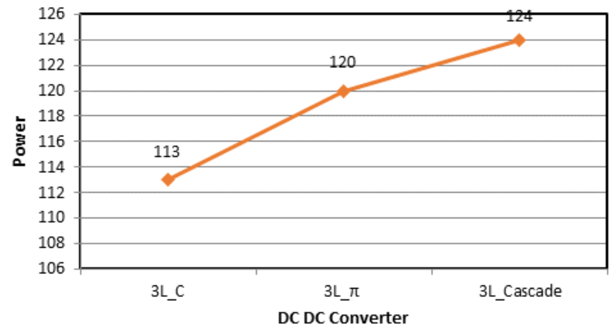


Figure 15.Output power of DC-DC converter

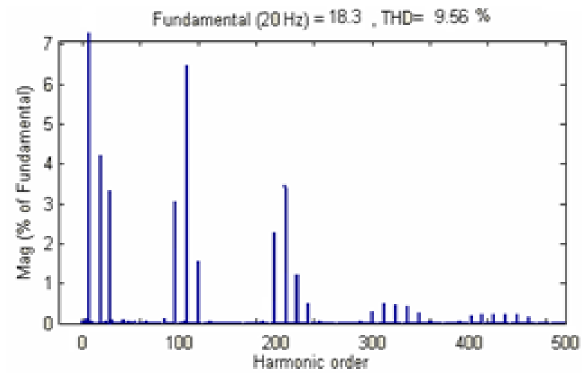


Figure 16.Harmonic spectrum for PID controller for Buck converter fed driver

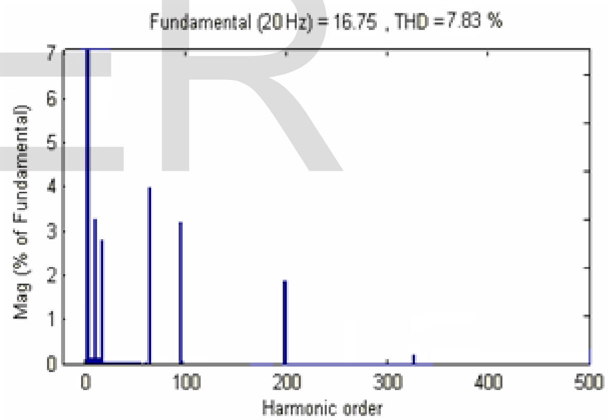


Figure 17.Harmonic spectrum for Fuzzy controller for Buck converter fed driver

The above comparison suggests the three level ZVS PWM DC-DC converter design with cascaded filter produce small ripple content in the response and gives up maximal power to the load. The operation of the permanent magnet DC motor is improved since the ripple current is reduced, which decreases the spacing.

Ultimately, it has been resolved that even when there is a small error, Adaptive Neuro-Fuzzy Inference Systems (ANFIS) performance has good response. The steady state error & oscillation can be weakened for the drive. The speed response curve of the ANFIS shows that it has the ability to maintain steady state for having long settling time. In Fuzzy system, the active response process upholds a steady state, where the settling time & the peak overshoot is less. Compared with Mamdani FIS the proposed Adaptive Neuro-Fuzzy Inference Systems (ANFIS) shows a robust characteristic. It can be generalized from the Fig.16 and Fig.17 that THD is decreased in case of ANFIS Fuzzy controller than the Mamdani & PID controller

6. PHYSIOTHERAPIC ROBOT

The purpose of this device is to compensate for a handicapped individual with a severe case of limited mobility within the upper limbs. The device is used to assist the client in reaching for his backpack, draped on the back of his wheelchair, and opening his laptop. The device will also aid the client in opening doors.

This apparatus will consist of three joints and a stable base. The arm will be segregated into to three distinct areas allowing for different ranges of motion depending upon the task being performed. In Fig 18. at the wrist, elbow and base three joints will be fixed. The upper and lower arms are separated by the elbow joint. With all joints, the primary three planes X, Y, Z axes will provide with a full 360 degree rotation.

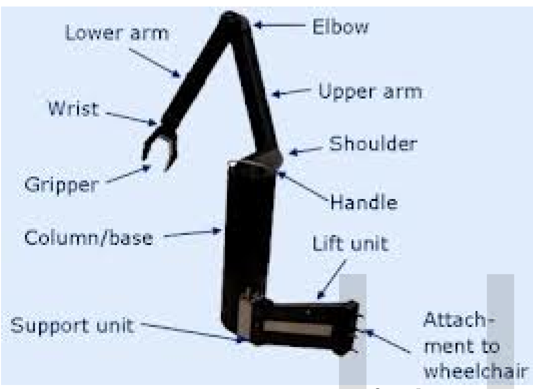


Figure 18.Parts Of Robotic Arm

Gripping device is connected to the wrist to do the clients activity. The assistive device will be able to meet most of the challenges in client's everyday life. The device will be designed to fulfill the tasks without him facing any hindrances due to the lack of muscle activity. While there are numerous products available on the market that serve as an assistive aid for people suffering with such conditions, the Robotic Arm designed is unique to client's specific condition of Athetoid Quadriplegia. According to research, Robotic Arms designed for challenged individuals have proven to be valuable.

The device that will be implemented for this design will be an assistive mobility device. This device will consist of a robotic arm shown in Fig.19 with multiple points of rotation. The base will mount to the end of the arm rest for the client's wheelchair. As a safety precaution, the velocity of the arm should never exceed 10cm/s. The stable device ie the DC-DC converter with fuzzy based system is used for controlled rotation about the shoulder which should not go above the velocity of 10cm/sec and will reduce the stress on the distal end of the mechanical arm.

7.CONCLUSION

The operation of proposed Robotic control of ANFIS is better than that of PID controller and Mamdani FIS [17] which has been proved in this article. The Mamdani and Adaptive Neuro-Fuzzy Inference Systems performance are similar but Adaptive Neuro FIS model works more efficient than Mamdani FIS. In a comparison done by the simulation of Fuzzy controller with conventional PI controller, the Fuzzy is a robust controller. The ANFIS Fuzzy system presents faster response with low lapse, small steady state error, reduced oscillation & short settling time.

In Comparison of capacitance, π and cascaded filter Fig.14 shows voltage ripple of the Cascaded filter has 0.004 ripple content, for three level step down DC-DC converter with Cascaded filter delivers maximal power to the load in the output as in Fig.15.

The improved performance of the drive is achived with ANFIS controller and cascaded filter. The reduce in size, ripple current and the energy loss is due to the cascaded filter produce good control of the robot.

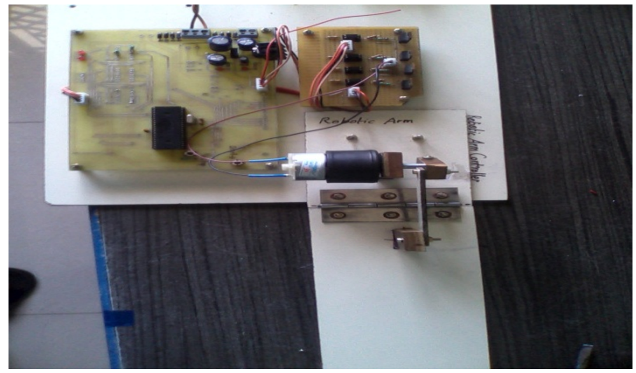


Figure 19.Physiotherapic Robot Module

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