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Neuro Fuzzy Inference System Controlled High Step-Up Gain DC-DC Converter

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ABSTRACT
DC motors are widely used in many applications including household applications, automotive and industry work house. These are considered as adjustable speed machines. DC motor is fed by a DC-DC converter. In order to avoid the use of transformer, a step-up high gain DC-DC converter is introduced here by combining the switched capacitor and regenerative boost configuration. Thereby it drastically increases the dc voltage gain and enhances efficiency. Neuro Fuzzy Inference System technique is adopted for controlling the speed of the DC motor which is a fusion of artificial neural network and fuzzy logic principle, and is based on Tagaki-Sugeno fuzzy inference system. With the help of controller the System performance has improved and has better performance in both transient and steady state response. The performance study is carried out with MATLAB/SIMULINK R2017a.

Keywords - DC-DC Converters, DC Motor, Neuro Fuzzy Inference System

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I. INTRODUCTION

PV based traction system employ DC-DC converters for boosting the pv output voltage to required levels. Modern traction system uses DC motors and traction application requires high voltage levels (500V to 750V), hence conventional boost converters and conventional speed control methods are inadequate. In solar and/or wind energy conversion system the generation voltage level is so far from grid voltage. After voltage source inverter (VSI) stage, a transformer is used to step-up the AC voltage which leads to increase system volume and losses, larger size and decreases overall efficiency. In past years, everyone searched to eliminate the transformer and presented cascaded multilevel converter [1],[2]. It leads to increase in the device counts, complexity in control and penalty on efficiency. However, the converter presented in[3] must operate at lower duty ratio to support for higher conversion ratio and deteriorates the performance under transient conditions. The switched capacitor (SC) converters are the most common answer to achieve unlimited gain. When the switched capacitors are combined with classic boost type, the DC-voltage gain improves exponentially. The switched inductor (SI) type converter[4] applied to reduce the current ripple and avoid the problems associated with pulsating current. The DC motors installed on board of traction rail vehicles are predominantly series motors, because their characteristics are the most suitable for meeting the requirements of the drive systems of the vehicles are motor current is big at small rotational speeds, which means, that the motor holds a very big start-up torque, which is very advantageous, because the required speed can be reached more quickly. The motor can be over twice overloaded for a short period of time, which allows for obtaining big startup torque. Motor torque is directly dependent on the motor supply voltage. Broad range of rotational speeds. The series motor is more robust, it is also more cost effective, and also cheaper and easier in maintenance. The dynamics of DC-DC converters are non linear and practical converter operation deviates from predictions because of problems related with the components like stray capacitance and leakage inductance etc.[5]. The traction operation is a non linear function. It is difficult to control in a manner similar to human operation. Robust and precise control and a number of efforts have been made to achieve the desired control[6]. The Controllers may be Proportional, Proportional Integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID), neural networks, Fuzzy Logic or any combination of these. A neural network offers the advantage being able to learn and adapt, however, neural network controllers consume more time as it initially takes time to learn about the plant. This work is based on the speed control of dc motor using neuro fuzzy controller. A fusion of neural network and fuzzy logic is used for developing the control. The fuzzy interface system is Tagaki-Sugeno-Kang fuzzy interference system. So for establishing efficient traction system a step up high gain DC-DC converter is presented with a adaptive neuro fuzzy interference system controller that produces the traction moment for light metro vehicles. The non linear characteristics of motors can degrade the performance of conventional controllers. So neuro fuzzy controller approach is a simpler quicker and more reliable over conventional techniques.

II. OPERATING PRINCIPLE

High step-up gain DC-DC SCRB converter contains two active switches S1,S2, inductors L1,L2 and diodes D1,D 2and D3. It also consist of capacitors C1,C2 and C3. The inductor L1 and capacitor C1 are used to perform boost operation. According to the proposed structure, the boosted voltage is regenerated and further stored into capacitor C2 and inductor L2. The energy stored C2 in L2 and is controlled by the switches. The fundamental principle of this converter is to regenerate boosted voltage using switched capacitor and inductor during on-state of the switches. Consecutively, it discharges the reactive elements energy at cascaded form during state of the switches. Therefore, this converter improves the DC voltage gain at an extreme level. Figure 1. shows a circuit of typical arrangement of the discussed high gain DC-DC SCRB converter.

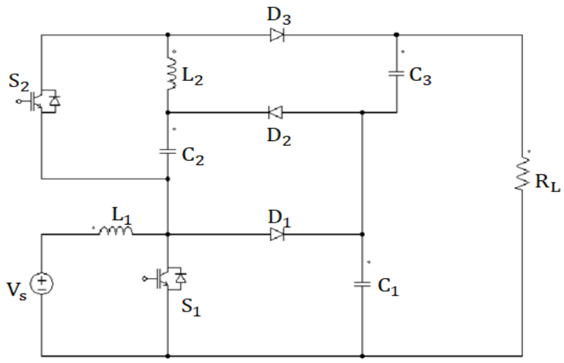

Fig. 1. Single stage transformer less dc-dc converter

1. MODES OF OPERATION

Mode 1: S1,S2 are ON -L1 stores energy and C1 gets discharged to L2 through switch S2. And C1 discharges to C2

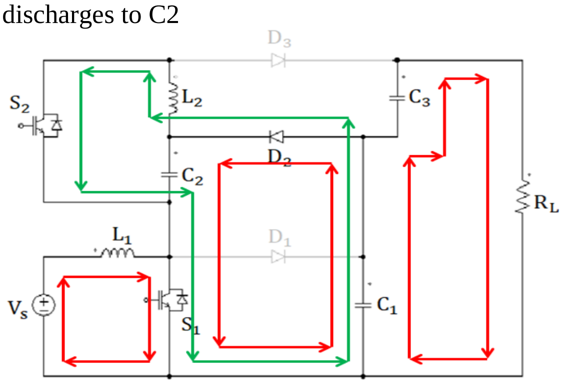

Fig. 2. Equivalent circuit of Mode 1

Mode 2: S1 is ON and S2 is OFF The inductor L2 and capacitor C2 gets discharges to the loads.

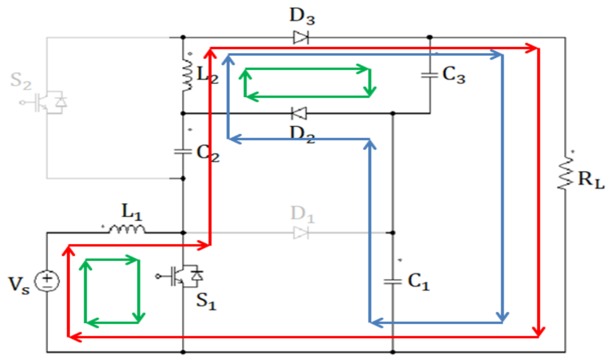

Fig. 3. Equivalent circuit of Mode 2

Mode 3: S1 and S2 are OFF-The stored energy in L1,L2 and C2 gets discharges to the loads. So the output voltage increases drastically.

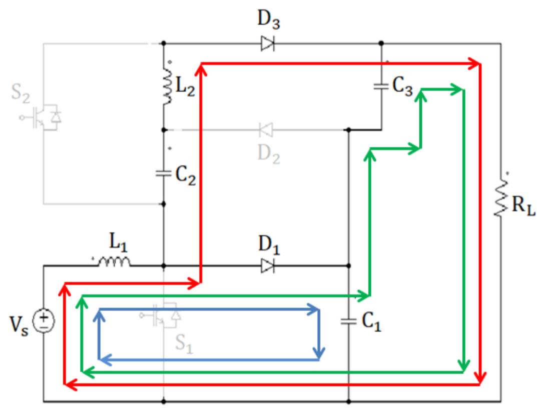

Fig. 4. Equivalent circuit of Mode 3

III. DESIGN METHODOLOGY

The relationship of the output voltage and input voltage converter is given by

$$\frac{V_{out}}{V_{in}} = \frac{2D}{1-D^2} \quad (1)$$

where and D is the duty cycle

The load resistance R0 is given by

$$R_0 = \frac{V_0^2}{P_0} \quad (2)$$

The values of inductors are

$$L >= \frac{V_0 * (1-D) * D}{(3+D) * f_s * \Delta IL} \quad (3)$$

where ΔIL is the 20% of input current.
Capacitances C1 = C2 = C3 .Assume voltage ripple ΔVout = 1.44 V.

$$C >= \frac{V_{in} * (1-D) * D}{\Delta V_{out} * * f_s} \quad (4)$$

Input voltage Vin taken as 24V. Output voltage Vout taken as 720V. The switching frequency fs is 10kHz.
For a simple DC Series Motor
Vt=Terminal voltage, Va=Armature voltage, Vf=field voltage, ra=armature resistance, rf= field resistance, Lf= field inductance, La=armature inductance,Te =electromagnetic torque, Tl=load torque, J= rotors inertia, Bm= friction Coefficient, wr= angular speed

$$V_t = V_a + V_f \quad (5)$$

$$V_a = \left(r_a + \frac{dL_a}{dt}\right) I_a + \omega_r L_f I_a \quad (6)$$

$$V_f = \left(r_f + \frac{dL_f}{dt}\right) I_a \quad (7)$$

$$T_e = \left(J\frac{d\omega_r}{dt}\right) + B_m \omega_r + T_l \quad (8)$$

IV. SIMULATION RESULTS

Simulation parameters Single stage transformer less dc-dc converter is given in Table 1 below. An input voltage of 24V gives a output voltages of 720V The switches are MOSFET/ Diode with constant switching frequency of 10 kHz.

Table 1
Simulation Parameters

Parameters	Specification
Input Voltage (V_s)	24 V
Switching Frequency	10 kHz
Inductors L_1, L_2	4 mH
Capacitors C_1, C_2, C_3	10 μF
Output Voltage (V_{out})	720 V
Output Power (W)	100 W

1. SIMULINK MODEL OF CONVERTER

The Single stage transformer less dc-dc converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table 1 and the Simulink model is shown in fig.5.

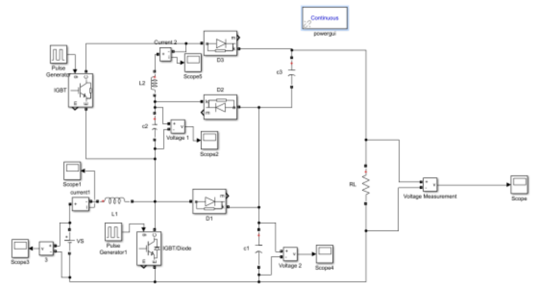

Fig. 5. Simulink Model

2. SIMULATION RESULTS

The simulation results of Single stage transformer less dc-dc converter are shown. It can be seen in fig.6. that the input voltage Vin is 24V. The input current or the inductor current IL1 103A with the ripple of 1A. The switching frequency is chosen to be 10kHz.

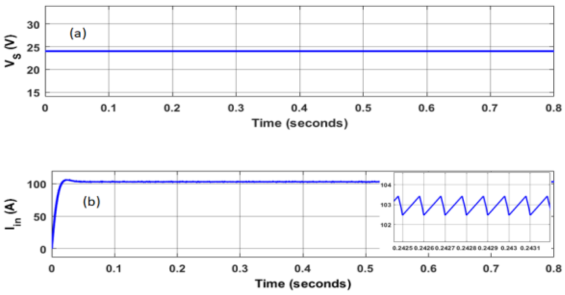

Fig. 6. Waveform of Input Voltage Vin Current Iin

As per fig.7. the output voltage Vout is measured as 710.25V and the output current 3.3A is and ripple current of 0.38A. Voltage ripple is 24.5V.

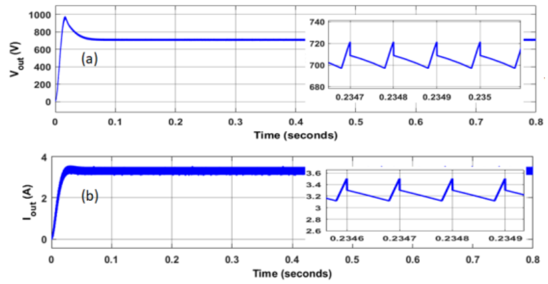

Fig. 7. Waveforms of output voltage Vout and output current Iout

3. SIMULINK MODEL OF HIGH STEP UP GAIN DC-DC CONVERTER FED DC SERIES MOTOR WITH NEURO FUZZY CONTROLLER

The high gain DC-DC Converter fed DC series motor with neuro fuzzy controller is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table 1 and the Simulink model is shown in fig.8.

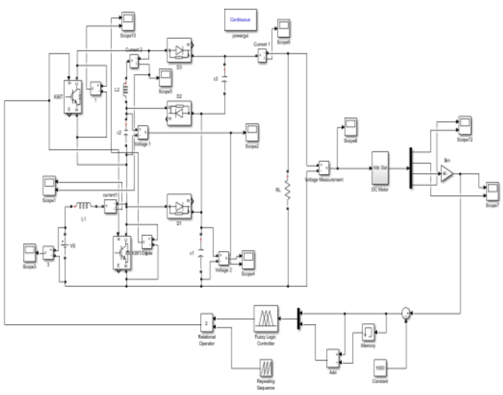

Fig. 8. Simulink Model

4. SIMULATION RESULTS

Table 2
Motor Parameters

Parameters	Value
Moment of Inertia (J)	2.83 *Kg.m2*
Friction Coefficient (B)	0.634 *N.ms*
Back emf constant (Kb)	0.6 *V/rad.s-1*
Armature resistance (Ra, Rf)	0.6 *ohm*
Armature Inductance (La, Lf)	0.006 *H*

Fig.9. demonstrates the MATLAB model of neuro fuzzy system structure. Furthermore, the operation and function of each layer has been outlined briefly Layer 1 shows that input parameter is actually connected to two nodes. Theses nodes are error and speed. The layer 1 generates the terms based on predefined MFs. Layer 2 is termed as firing strength layer which calculates the precision and adequacy of state in the previous segments. Layer 3 performs estimated values of triggering forces are standardized to effectively separate the triggering forces. Layer 5 adds the whole law ascribed to the output defining variables and transforms into a value utilizing the approach of summation with added weight.

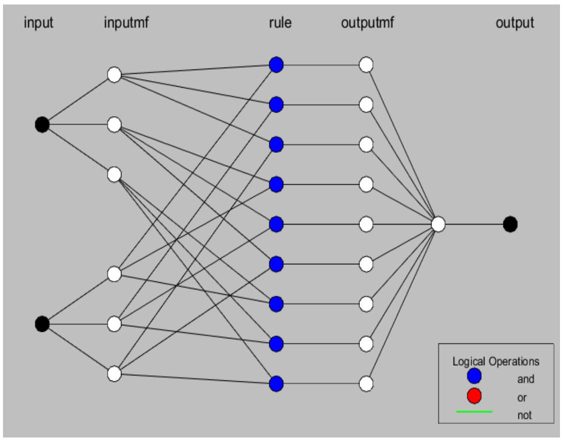

Fig. 9. Trained data and ANFIS Model in MATLAB

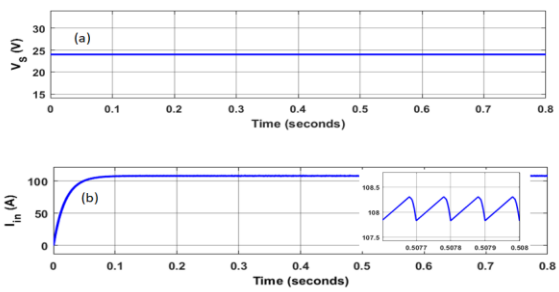

Fig. 10. Waveform of Input Voltage Vin , and Current Iin

It can be seen in fig.10. that the input voltage Vin is 24V. The input current or the inductor current IL1 108A with the ripple of 0.5 A.

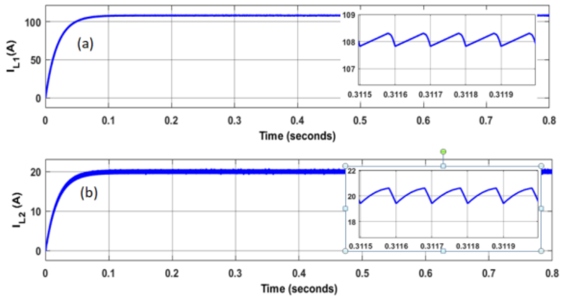

Fig. 11. Waveforms of inductor currents IL1 and IL2

Fig.11. shows the inductor current IL1 and IL2 and the zoomed version. The inductor current IL1 is measured as 108A with ripple current of 0.5A. The inductor current IL2 is measured as 20A with ripple of 0.95A.

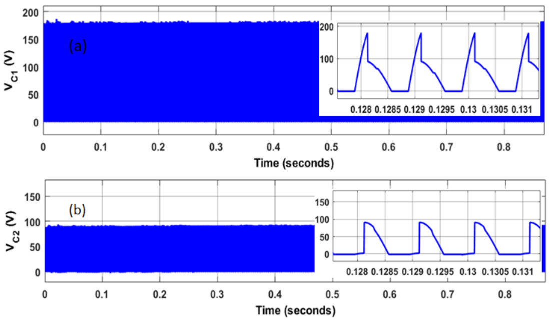

Fig. 12. Waveforms of capacitor voltages VC1 and VC2

As per fig.12. the capacitor voltages VC1 is measured as 180V and VC2 is measured as 90V.

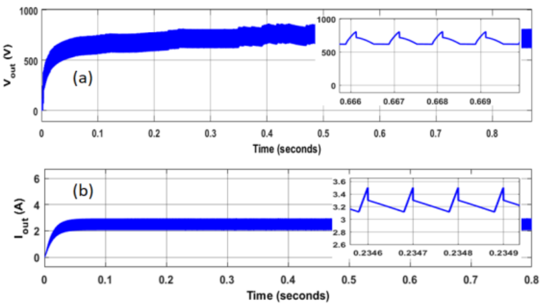

Fig. 13. Waveforms of output voltage Vout , output current Iout

Fig.13. shows the output voltage Vout and the output current Iout. Output voltage is measured as 721.25V and the output current is 3.25A with ripple current of 0.38A. Voltage ripple is 124.5V.

The motor performance of high step up gain DC-DC converter fed dc motor is obtained and shown in fig.14. The steady state speed is obtained as 1480rpm and the electromagnetic torque is 12 Nm.

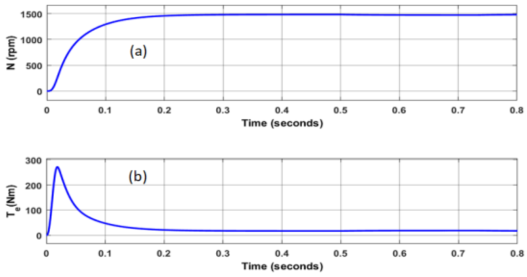

Fig. 14. Waveforms of speed N(rpm) , torque Te (Nm)

The controller contains 2 inputs and a single output. The input variables are error and speed. While the output for the controller is a constant. Due to the simplicity of calculation triangular membership functions are chosen for the controller. The membership functions for speed is shown in Fig.15. The membership function range is determined by trial and error during the process. And the approximation law of the controller used contains 49 rules. The input1 speed contains 7 membership functions NL,NM,NS,Z,PS,PM,PL where NL = Negative Large with a range of 895 to 1105, Nm = Negative Medium with a range of 1000 to 1210, NS = Negative Small with range of 1105 to 1315, Z = Zero with a range of 1210 to 1420, PS = Positive Small with a range of 1315 to 1525 and PM = Positive Medium with a range of 1420 to 1630 and PL = Positive Large with a range of 1525 to 1735.

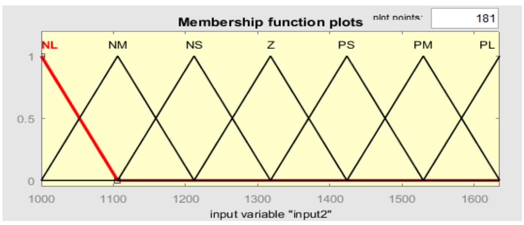

Fig.15. Membership function of speed

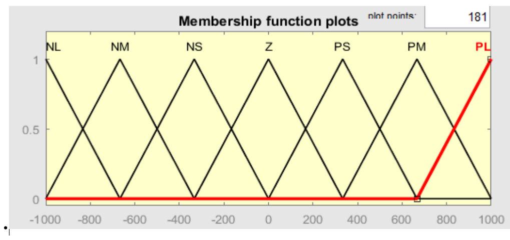

Fig.16. Speed error (e)

The membership functions for error is shown in fig.16. The membership function range is determined by trial and error during the process. Input2 error contains 7 membership functions

NL,NM,NS,Z,PS,PM,PL where NL = Negative Large with a range of -1500 to -750, Nm = Negative Medium with a range of -1125 to -375, NS = Negative Small with range of -750 to 0, Z = Zero with a range of -375 to 375, PS = Positive Small with a range of 0 to 750 and PM = Positive Medium with a range of 375 to 1125 and PL = Positive Large with a range of 750 to 1500.

The performance of high step up gain DC-DC converter fed DC series motor with neuro fuzzy controller is analyzed by considering speed variation with step change in load and with stepped speed command. The results are shown in the following figures.

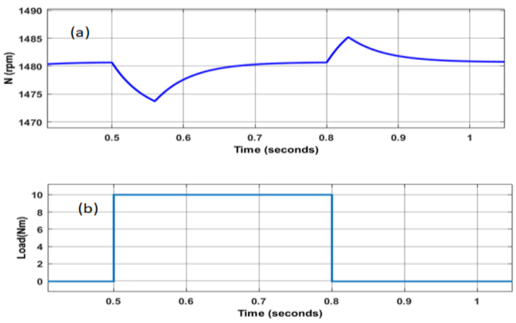

Fig. 17. Waveforms of (a) Speed N(rpm) of dc series motor with a step change in load, (b) Load(Nm)

Fig.17 shows the variation in speed with a step change in the load. The motor achieves desired speed in less than 0.4sec. While a load of 10Nm is applied at 0.5sec for 0.2secs. The speed of the motor gradually drops to 1474rpm and suddenly motor reaches its normal speed of 1480rpm with in 0.7sec. And 10Nm load is removed at 0.8sec. then there is a sudden rise in the speed of motor and it comes to 1480rpm within 0.2sec and remains constant to the desired speed. The reason is the rule base that have been set up earlier in the neuro fuzzy controller controls the value of speed output for DC motor.

The variation in speed with a stepped speed command is shown in Fig.18. The Command to increase the speed from 1500rpm to 1528rpm is given at 0.5sec. The speed of the motor reaches 1528rpm within 0.55sec and remains constant.

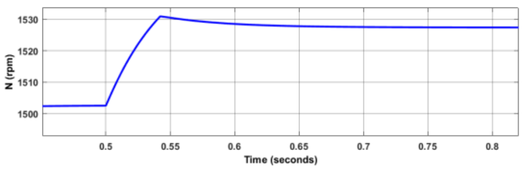

Fig. 18. Waveform of Speed N(rpm) of dc series motor with a step change in speed

V. ANALYSIS

The analysis of high step up gain DC-DC converter and high step up gain DC-DC converter with neuro fuzzy controller are carried out by considering parameters like voltage gain, efficiency, and duty cycle etc.

1. EFFICIENCY Vs OUTPUT POWER

Efficiency of a power equipment is defined at any load as the ratio of the power output to the power input. The efficiency is the fraction of the input power delivered to the load. A typical curve for the variation of efficiency as a function of output power is shown in fig.19. The converter efficiency is around 94.4% for R load. The converter efficiency is around 88 % for RL load.

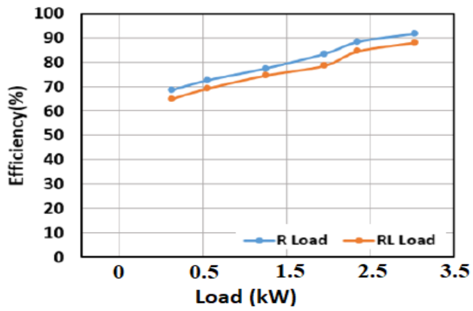

Fig. 19. Efficiency Vs Output Power

2. VOLTAGE GAIN Vs DUTY CYCLE

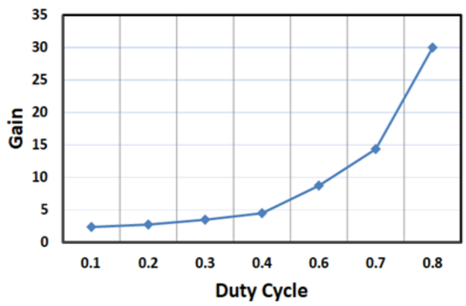

Fig. 20. Gain Vs Duty Cycle

The plot of voltage gain as a function of duty cycle is shown in fig.20. For any practical applications, the dc-dc converter must be operated at lower duty ratios to get maximum efficiency and the duty ratio can be extended up to 0.8. Beyond this duty cycle, the inductor core is saturated and generates noise in the circuit, which automatically degrades the performances..

3. ARMATURE CURRENT Vs LOAD

The fig.21(a). shows the plot of armature current vs load of the DC motor. Armature Current is directly proportional to the load applied or torque. In dc series motors torque increases as the square of armature current. These motors are used where high starting torque is required.

4. SPEED Vs LOAD

The Fig.21(b). shows the plot of speed vs load of the DC motor also known as mechanical characteristics. It can be found that when load is low, speed is high and vice versa**.**

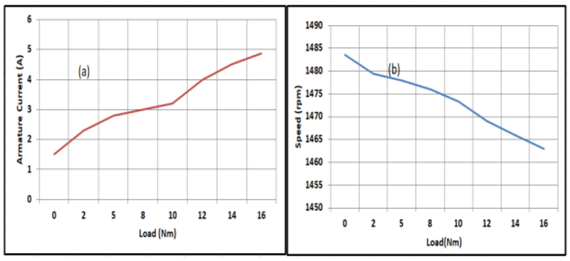

Fig. 21. (a)Armature Current Vs Load and (b) Speed Vs Load of DC Series Motor

5. COMPARISON OF NEURO FUZZY CONTROLLER AND PID CONTROLLER

Table 3
Comparison of neuro fuzzy and PID controller at no load

	Rise Time T_r (Sec)	Settling Time T_s (Sec)	Max Overshoot (%)	Peak Speed Value (rpm)
With PID Controller	0.113	0.637	27.414	2123
With Fuzzy Logic Controller (FLC)	0.35	0.35	0.00	1480

Table 4
Comparison of neuro fuzzy and PID controller at 10Nm load

	Rise Time T_r (Sec)	Settling Time T_s (Sec)	Max Overshoot (%)	Peak Speed Value (rpm)
With PID Controller	0.109	0.67	29.36	2059.4
With Fuzzy Logic Controller (FLC)	0.35	0.35	0.00	1480

In order to appraise the performance of PID controller and Neuro Fuzzy controller, a side by side comparison is built under no load and loaded conditions. Both systems give different output response which are illustrated above.

The Table 3 and Table 4 shows the comparison between the system performance of the Dc series motor fed by the single stage DC-DC converter with a PID controller and with the neuro fuzzy controller at no load and at 10Nm load respectively. At no load, with system reference speed of 1480rpm with PID controller, rise time is 0.113sec. The settling time is 0.637sec. For the overshoot(% OS), it is also shows a bad result, which is 27.414% . The peak speed value is 2123rpm. At the same time with system reference speed of 1480rpm with neuro fuzzy controller motor achieves a desired speed in less than 0.4sec. The overshoot is not appeared in the system. Peak speed value is 1480. At loaded condition, the rise time is decreased from 0.113sec to 0.109sec in the system with PID controller. And maximum overshoot is increased to 29.36% where are no overshoot in system with neuro fuzzy controller. The peak speed value is 2059rpm with PID controller. It is rated speed in neuro fuzzy controller. Speed remains constant.

VI. CONCLUSION

The high step up gain DC-DC converter fed DC series motor with neuro fuzzy controller achieves high voltage gain without the help of transformer and suitable for traction ap plication even when the input voltage is low from the solar PV panel sources. In order to avoid the use of transformer, step up high gain DC-DC converter is combining the switched capacitor and regenerative boost configuration. Thereby it drastically increases the dc voltage gain. In addition, it also dominates with fewer ripple content, which helps to elongate the lifetime of devices. Maximum efficiency of the converter is 94.4% with the duty cycle of 80%. Beyond this duty cycle, the inductor core is saturated and generates noise in the circuit, which automatically degrades the performances. Gain is observed as 30.14. It is observed that the neuro fuzzy controlled dc motor performs better than the dc motor with PID controller in terms of its faster settling time and absence of overshoot and its ability to maintain dc motor speed irrespective of the torque load applied.

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