ENHANCEMENT OF POWER QUALITY IN A CLOSED LOOP OPERATION OF FOURQUADRANT DC DRIVE USING DUAL AC-DC BUCK CONVERTER

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Abstract

This paper deals with the operation of the separately excited dc-drive in each of the four quadrants which is fed by symmetrical multi pulse modulated signal, leads to improved power quality by using single-phase, dual AC-DC buck converter. Here the armature control of the dc drive with constant load torque is considered in both forward and reverse directions in the motoring and generating actions. When a variable load condition occur the load voltage get changed, simultaneously other parameters such as torque, speed at load side and voltage, current profiles at source side get affected. Due to which there is lot of distortion in the sending end parameters. To overcome these drawbacks the essential variables are analyzed by feeding these variables back to the converter switches, which regulates the output voltage, fed to separately excited DC-Drive, which indicates that, at the ac interface the harmonic profile of the separately excited dc drive fed by the improved power quality dual converter is achieved using closed loop system.

Keywords: *AC-DC Buck Converter, Power Quality, Closed Loop, PI Controller, Symmetrical Multipulse Modulation (SMM) etc.*

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1. INTRODUCTION

The Four-Quadrant DC-Drive operation is extensively in practice. Due to increased use of improved power quality Dual AC-DC Buck Converter in a closed loop operation makes a compulsory investigation of the DC- drive when fed by the converter. In this paper From the Power Quality point of view the four-quadrant DC-drive fed by dual buck converter in closed loop operation is studied. In the armature control method of a DC drive at variable load conditions is considered in both the forward and reverse modes of operation. Performance characteristics of the proposed closed loop system in all the quadrants are compared with the single phase open loop dual buck converter fed four-quadrant DC drive. The simulation results focus that the performance analysis of the closed loop separately excited DC drive has better Dynamic response, better stability, improved voltage profile, improved power factor and also reduced harmonic distortions.

The pulse modulation technique adopted in the proposed system uses equidistant pulses for every half cycle (M) to obtain the response which can be continuously varied by changing the duty cycle (δ) of the equidistant pulses. The Block Diagram of Proposed closed loop four quadrant DC-Drive is shown in Fig: 1 which comprises of single phase step up transformer fed - dual AC-DC Buck Converter, error detector for comparison of voltages, PI controller for reducing steady state errors, Comparator for generating of gate pulses to Converter switches, the armature winding A1 A2, of the separately excited DC drive are fed to the separate dc source.

The implemented technique expels the interest towards the performance investigation of the drive as it is less complex in implementing.

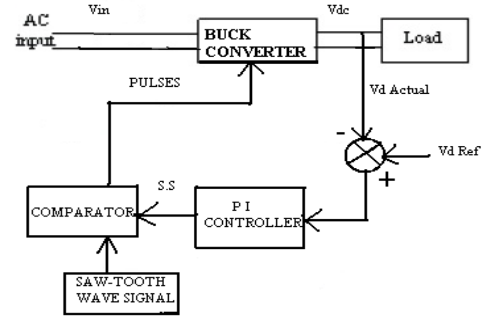

Fig: 1 Block Diagram of closed loop four quadrant DC-Drive

2. IDENTIFICATION OF PROBLEM

The problem of power quality in electrical systems in general is of great importance. Now a day's constant load can't be maintained properly on drives, due to the changes in the load on the DC-drive, the voltage and current profile has been drooped. Due to these load variations the speed of the drive droops from its constant speed at constant load condition simultaneously the load torque changes, total harmonic distortion (THD) increases, power factor, system stability decreases, and thus power quality cannot be maintained properly. Thus in this paper we are concerned about power quality of four quadrant DC-drive as main objective without increase in the total harmonic distortion (THD).

3. AIMS AND OBJECTIVES

In this paper a feasible solution for the improvement of power quality in a DC-drive using symmetrical Multipulse modulation (SMM) technique is developed in closed loop system using MATLAB-SIMULINK.

This System overcomes many of the drawbacks in the conventional system.

- Improvement in the dynamic response of the system.
- Constant load voltage can be maintained at variable load conditions
- Pure Sinusoidal (ripple free) voltage profile can be maintained at the source terminals.
- Ripples in Current profile at the source terminals can be reduced better than the conventional system.
- Close to unity power factory can be achieved in this closed loop system.
- Easy and less time consuming for control.
- Qualitative & constant power can be supplied to the load.

4. TOPLOGY OF CONVENTIONAL SYSTEM

The circuit shown below (Fig:2) Comprises of two sets of devices(Set I and Set II), each set comprises of four IGBT and diode in series(two quadrant switches) which constitutes a dual buck converter. The four 2QSWs of set I are – M1D1, M2D2, M3D3, M4D4, and those of set II are – M1'D1', M2'D2', M3'D3', M4'D4'. From the conventional converter topology it is clear that the two sets of 2QSWs that there are four combinations of two 2QSWs in inverse-parallel in the dual buck converter. Each of the inverse-parallel connection of 2QSWs constitutes of four-quadrant switches (4QSW) which provides control for turn-on and turn-off of current and voltage blocking in forward and reverse directions.

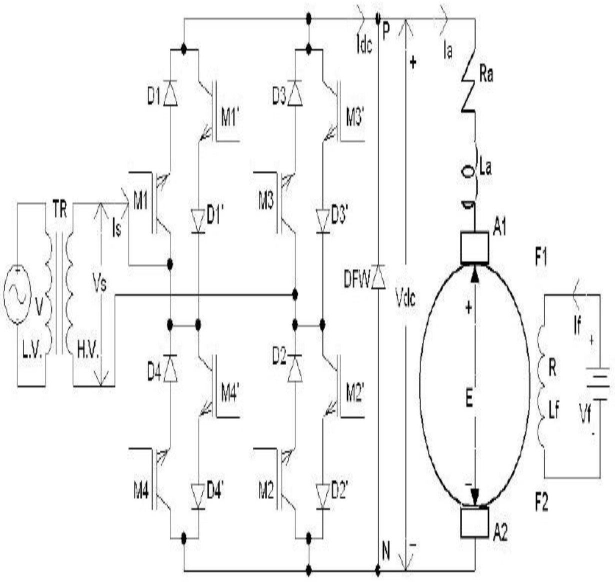

Fig: 2 Conventional single-phase, dual ac-dc buck converter fed four-quadrant, armature controlled, separately excited dc machine drive

In the Conventional system, operation of the dual buck converter in both the forward and reverse direction corresponding a DC-drive in both the motoring and generating actions are determined by the conditioning of the switching states of the IGBT's and are show in the below Table1.

Table1: Switching States Of 2QSWs In The Dual Buck Converter

Converter Operatrion /Mode	Quad (Q)	SET-I	SET-2
Rectification (Motoring)	I	SMM switching for a pattern	OFF
	III	OFF	SMM switching for a pattern displaced by 180°
Inversion (Generating)	II	SMM switching for a pattern displaczed by 180°	OFF
	IV	OFF	SMM switching for a pattern

The field winding terminals (F1,F2) of the DC drive are excited by a separate dc voltage source and the armature winding terminals (A1,A2) are connected to the dc side of the buck converter.

The source voltage is chopped into required number of the equidistant pulses for every half cycle (M) by symmetrical multipulse modulation (SMM). Due to these equidistant pulses the output voltage is practically free from even harmonics.

By varying the Duty cycle (δ) and number of equidistant pulse for ever half cycle, the magnitude of the fundamental component and that of the R.M.S value of the output voltage and its harmonic profile can be continuously varied.

Both the strategies (M constant, δ varied & vice-versa) have been implemented, to find the changes in the power quality parameters viz. power factor and THD on the AC side have been recorded and interpreted.

But on the DC side the constant load torque can be maintained at constant load conditions. At variable load conditions in this conventional system, constant load torque cannot be maintained .As a result of these ac harmonic profiles at the source side gets distorted. To overcome this problem in this paper, closed loop system is implemented.

5. SIMULATION RESULTS OF CONVENTIONAL SYSTEM BY SMM TECHNIQUE

In the multipulse modulation techniques as the pulses are of equal width and are placed equidistant from each other so that the usual reference and carrier wave control combination is not required for generation and are pre-defined by digital logic synchronized with a zero crossing detector output latched to the ac side first harmonics frequency.

The H.V. side voltage in the SMM technique is controlled by the number of pulses per half cycle (M) and their duty cycle (δ).

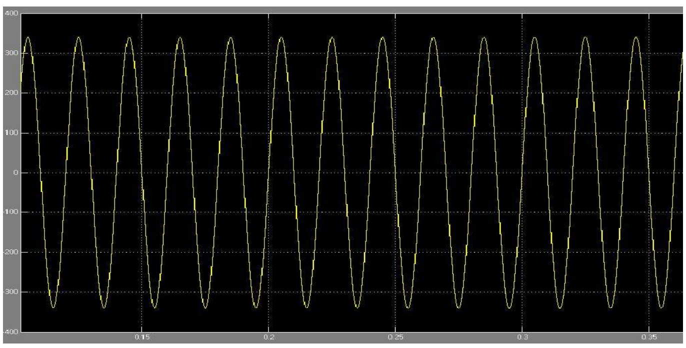

Fig: 3.1 Quadrant I: H.V. ac side voltage for M = 6 & δ = 0.8 (Voltage vs Time)

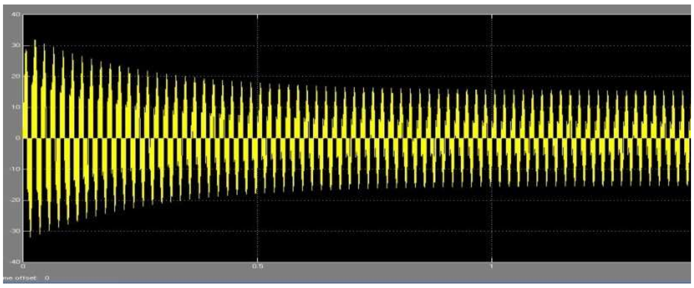

Fig: 3.2 Quadrant I: H.V. ac side Current for M = 6 & δ = 0.8 (Current Vs Time)

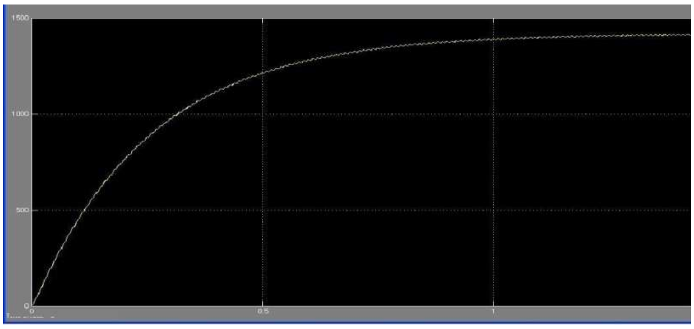

Fig: 3.3 Quadrant I speed for M = 6 & δ = 0.8 (Speed Vs Time)

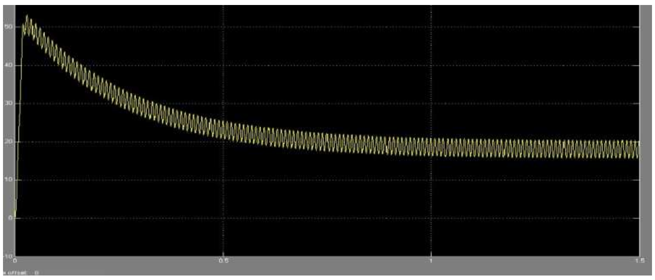

Fig: 3.4 Quadrant I Mean Torque for M = 6 & δ = 0.8 (Torque Vs Time)

The characteristics of a DC drive in forward motoring mode (Q-I) is obtained using SMM technique for M=6 and δ = 0.8 The duty cycle of the pulses has been kept in accordance with the armature voltage for each quadrant.

Drawbacks:-

In the Normal open loop system, with the increase in the load, Drive speed decreases, load voltage decreases automatically torque required to drive the dc-drive decreases due to which harmonics increases in the system as a result of this power quality can't be maintained properly. In the conventional system with the introduction of SMM technique, power quality can be maintained properly, but the dynamic response of the system & stability cannot be achieved properly.

6. SIMULATION BLOCK DIAGRAM OF PROPOSED CLOSED LOOP SYSTEM BY SMM TECHNIQUE

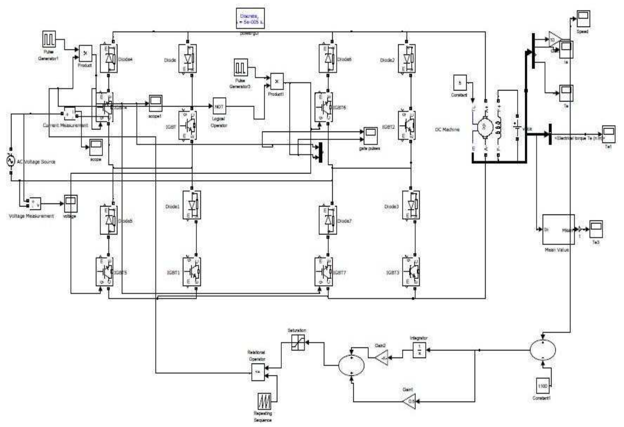

Fig: 4. Closed loop Block Diagram implementation of four quadrant fed DC drive.

To overcome the Draw backs in the conventional system. A New approach of closed loop fed four quadrant DC-drive using SMM Technique is implemented as show in the fig 4.
In the proposed system with the changes in load voltage, Speed of the DC-drive changes and this changed speed at the load terminals (drive output) is compared with the reference speed whose error signal is fed to a PI controller in order to compensate the instantaneous errors and improve the dynamic response of the system.

Steady state error signal (ess=0) is obtained as output of the controller, which is compared with the repeating sequence signal (saw-tooth) using a relational operator in order to generate the gate pulses required to turn-on & turn-off of the IGBT switches, these gate pulses are fed as feedback signal (modified gate pulses) to one pair of IGBT switches. The same feedback signal is fed to other pair of IGBT switches through NOT gate in order to compare the displacement of the signal supplied to the gate terminal of the switches for identifying of both motoring and generating actions.

In the conventional method the SMM technique is implemented by chopping the source voltage into required number of the equidistant pulses for every half cycle (M) & varying the duty cycle (δ) to maintain the constant torque at the load terminals under variable load conditions using armature control method.

In this paper the SMM techniques is implemented by varying the duty cycle (δ) of the gate signal which are fed from the feedback path to the IGBT switches .These pulses are varied based up on the load conditions. As the load voltage is directly proportional to the speed of the DC-drive. So, Speed is considered as input to the controller in the feedback path which are used to generate the gate pulses for the implementation of SMM technique.

7. FOUR QUADRANT DC- DRIVE SIMULATION IN CLOSED LOOP SYSTEM

The DC- drive parameters are considered to be positive in anti-clockwise and negative in clockwise directions respectively. The rotation of the DC- drive is said to be forward in the anticlockwise direction (motoring) and reverse in clockwise direction (generating). In a DC-drive the load torque (TL) always opposes the electromagnetic torque (TM) But In the motoring mode TM >TL. This implies that in the motoring mode TM is the driving torque and therefore the drive rotates at an angular speed(ω) in the same direction as TM. In the generating mode, TL > TM i.e. TL is the driving torque and, hence, the drive rotates at an angular speed (ω) in the direction of TL.

The armature control method of the dc machine is implemented by keeping the field excitation flux almost constant and by applying varying voltages to the armature winding. With the changes in the load conditions the duty cycle (δ) and the number of pulses per half cycle (M) varies, so as to ensure no adverse effect (In-adequate startup voltage, etc.). With the reversing of the armature current Ia the electromagnetic torque gets reversed. In this closed loop implementation there are No filters for mitigating of ripples on the dc link and harmonics on the ac side have been considered in the simulation model.

System Parameters:

The parameters of the separately excited DC machine considered in the simulation model are as follows:
Machine Rating: 5 H.P., 240V, 1750 RPM, V_f = 300V
Armature Winding: R_a = 2.581Ω, L_a = 0.028H
Field Winding: R_f = 281.3 Ω, L_f = 156H
Field-armature mutual inductance: La_f = 0.9483H
Total inertia: J = 0.02215Kg-m^2
Viscous friction coefficient: Bm = 0.002953Nm-S
Coulomb friction torque: T_f = 0.5161Nm
Initial speed: 1rad/sec
Transformer Rating: 10KVA, 50Hz
L.V.Winding: V_1 = 230V, R_1 = 0.002p.u, L_1 = 0.078p.u.
H.V. Winding: V_s =265V, R_2 = 0.002p.u, L_2 = 0.08p.u.
Core: R_m = 500p.u. L_m = 500p.u.
V_s= transformer H.V.side terminal voltage
(r.m.s value)
V_{dc} = average value of dc voltage of the converter
For V_{dc} = 240V (rated armature voltage corresponding to δ).
Note:
Assuming that all power electronic devices and alternating voltage sources are to be ideal.

8. RESULTS & DISCUSSIONS

A. Simulation Results

The simulation results (Characteristics) of Four quadrant DC-drive in a closed loop system referring to Quadrant-I (forward motoring mode), Quadrant-II (forward generating mode), Quadrant-III(reverse motoring mode), Quadrant-IV (reverse generating mode) are shown below in figs 5(a-d),figs 6(a-d),figs 7(a-d), figs 8(a-d) respectively.

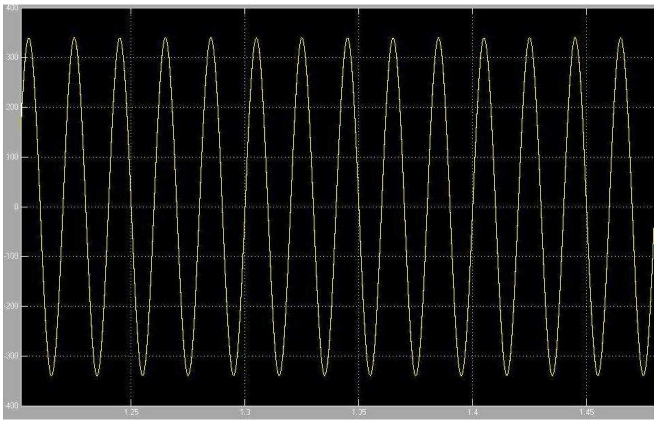

Fig5 (a) Quadrant I : H.V. ac side voltage

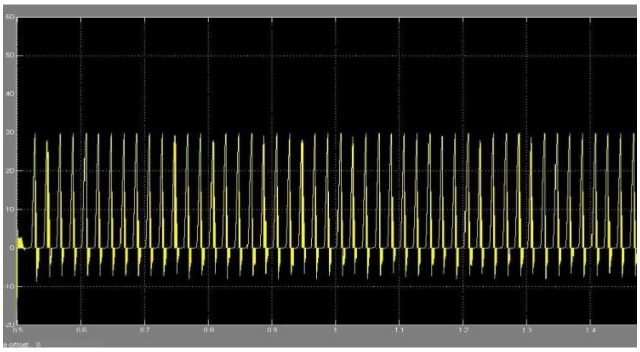

Fig5 (b) Quadrant I : H.V. ac side current

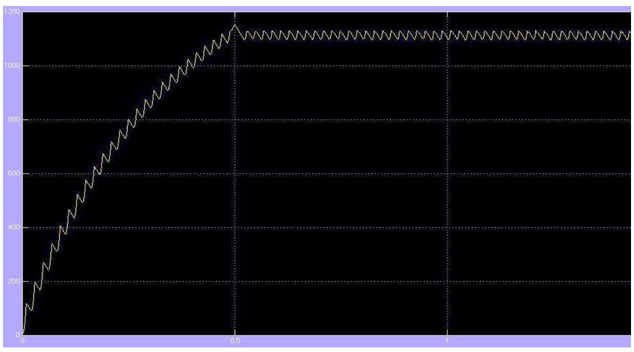

Fig.5(c) Quadrant I : Speed

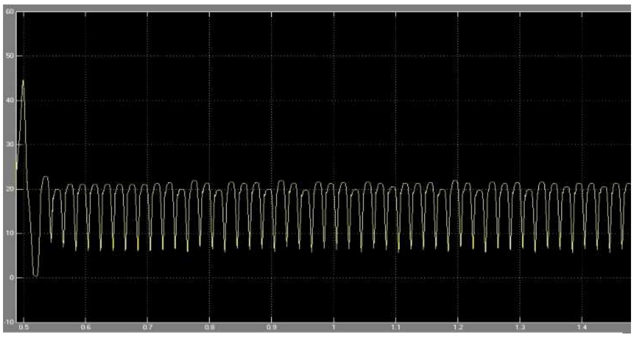

Fig5 (d) Quadrant I : Electro magnetic torque

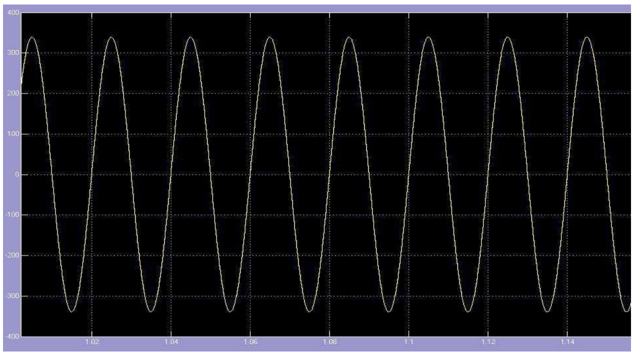

Fig.6 (a) Quadrant II : H.V. ac side voltage

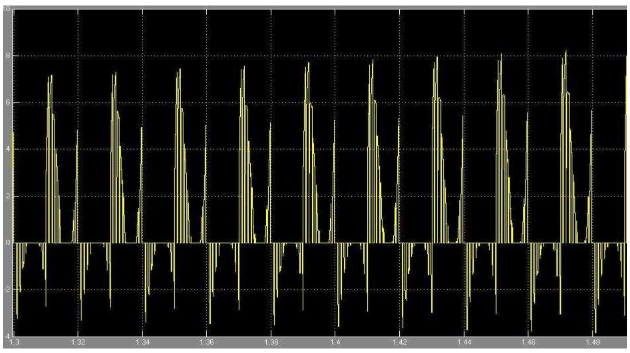

Fig.6 (b) Quadrant II : H.V. ac side current

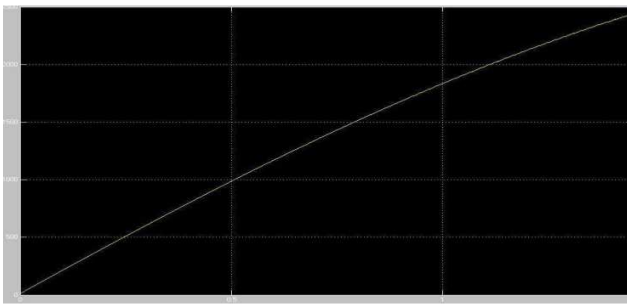

Fig.6 (c) Quadrant II : Speed

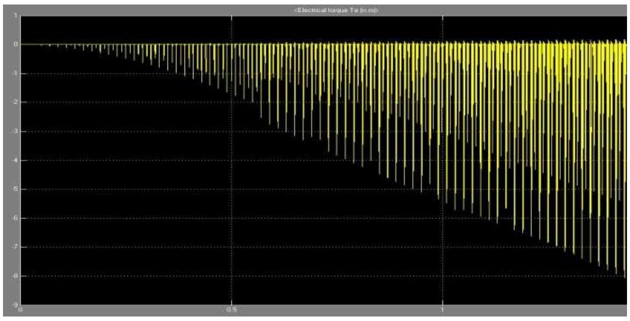

Fig.6 (d) Quadrant II : Electromagnetic torque

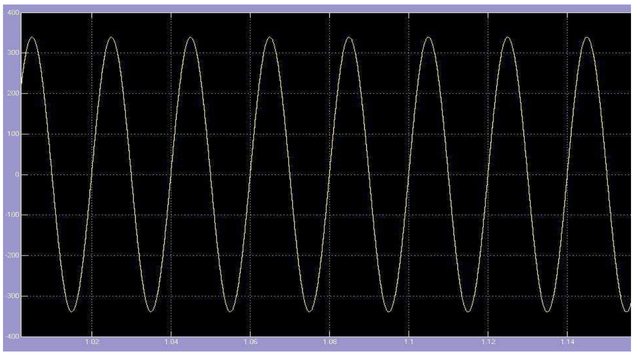

Fig.7 (a) Quadrant III : H.V. ac side voltage

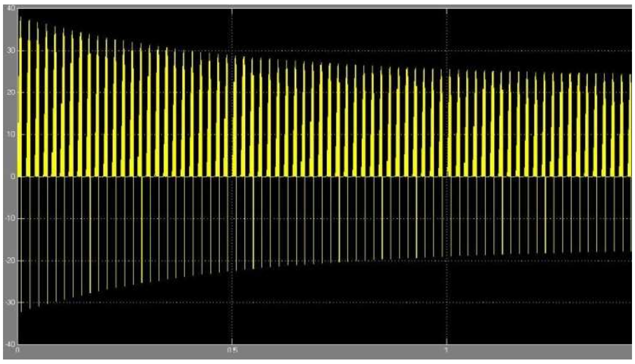

Fig.7 (b) Quadrant III : H.V. ac side current

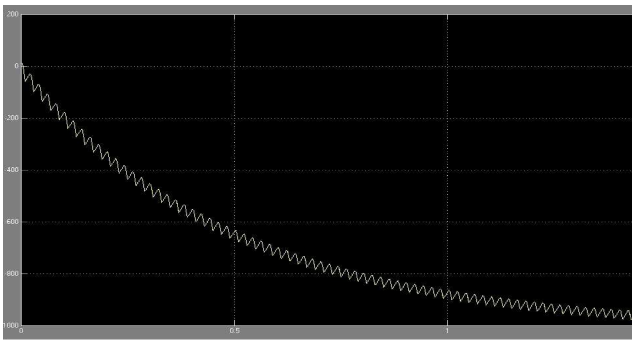

Fig.7 (c) Quadrant III : Speed

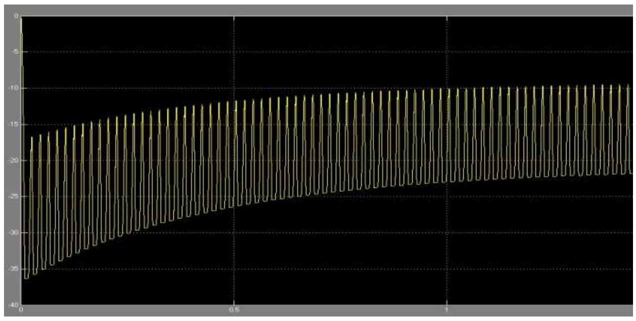

Fig.7 (d) Quadrant III : Electromagnetic torque

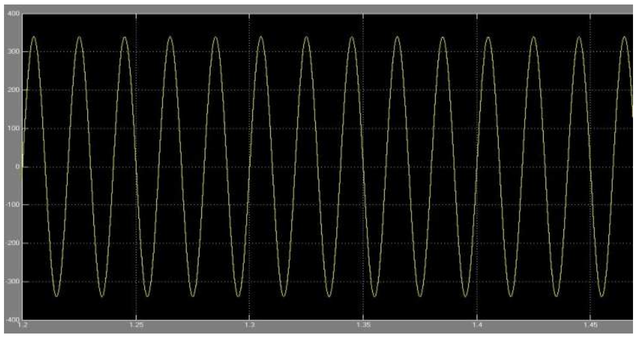

Fig.8 (a) Quadrant IV : H.V. ac side voltage

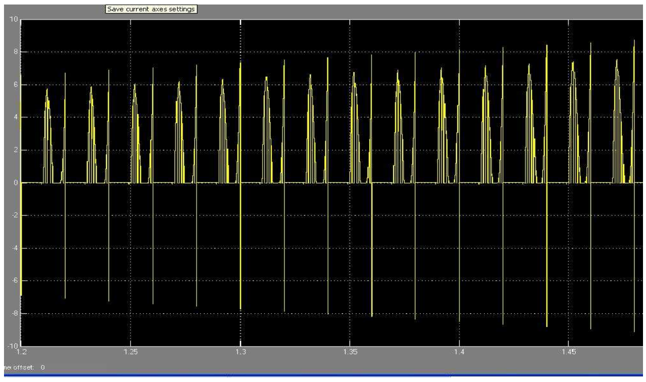

Fig.8 (b) Quadrant IV : H.V. ac side current

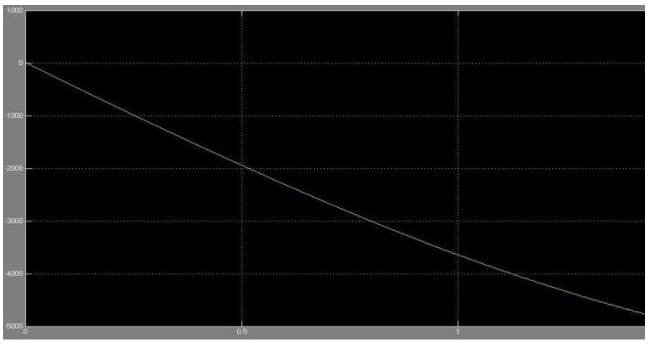

Fig.8 (c) Quadrant IV : Speed

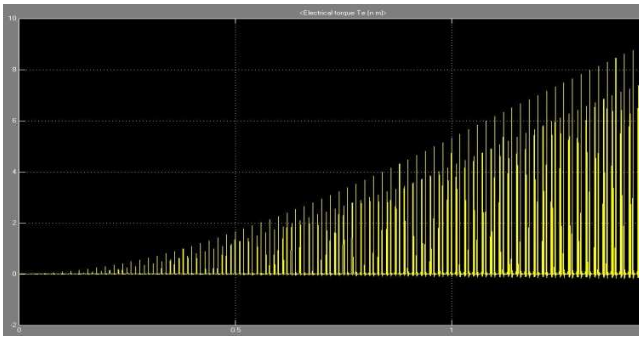

Fig.8 (d) Quadrant IV : Electromagnetic torque

From the figs 5 (a),6(a),7(a) & 8(a) it is clear that even under variable load conditions pure sinusoidal ac voltage is maintained at the input terminals of the IGBT bridge circuit due to Closed loop operation. In the fig5 (b) forward motoring , it is clear that the starting currents are low due to which relatively softer start is achieved and the magnitude of the starting torque is maximum fig5(d) because of the reduced voltage. As the current increases, speed increases and dynamic response is achieved fig5(c).

Similarly in the reverse motoring, High starting currents are obtained fig7 (b) due to which initial torque is low and further reaches to steady state fig 7(d). However in the both the forward and reverse motoring mode the stead state torque is same (Say 20 N-m).

From the fig 6(b) the transient current are initially low and further increases with the increase in the current the torque increases in reverse direction and reaches to stead state torque fig 6(d). In the reverse generating mode, current shown in fig 8 (b) is similar to that of the fig 6(b) in forward generating mode. In both the forward and reverse generating mode the speed increases in their respective directions fig 6(c), fig8(c).

B. Discussions:

In the proposed closed loop system the SMM involved, in multiple switching of conducting devices within the relevant half cycle automatically based up on the load conditions and the speed of the DC-drive which are very important in implementing this technique. Low ripple content & harmonic free armature current, smooth load torque are obtained by placing freewheeling diode across the armature terminals. The self-commutating devices employed in the converter using SMM technique involve multiple pulses within a half cycle (M) so, the duration of each pulse in every half cycle is small. The duty cycle of the pulses is usually high ($\approx >0.5$) except, during starting, therefore, the off-time is low. With the increase in the loading , SMM technique provides improved power quality in terms of reduced THD of the ac side current (i, e if load increased, M & δ are high).

In comparison with the Conventional system the closed loop system maintain qualitative power with reduced harmonic distortion on A.C side, thus approximately Unity power factor is obtained. Under high load conditions In conventional system proper dynamic response cannot be obtained, but in this proposed closed loop system faster dynamic response is achieved for all load conditions by continuous monitoring of the drive speed.

CONCLUSIONS

In this paper a new proposed closed loop system with SMM technique for a separately excited dc machine drive in the four quadrants of operation has been analyzed for reduction of harmonic content, power quality improvement, faster dynamic response and system stability. The experimental results were found to be more improvised than the conventional system. The harmonic analysis reveals that unity power factor is achieved in the symmetrical multipulse modulation (SMM). However, in SMM technique, the Total Harmonic Distortion (THD) and harmonic reduction are achieved by changing the number of pulses per half cycle and the duty cycle automatically based on load variation and thus rendering easy filtration.

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