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

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**Abstract—**The phase-controlled dc drive operation is well established, however, this paper investigates the operation of the separately excited dc machine in each of the four quadrants when fed by the system output used as feedback as in outer closed loop control and approaches control technique such as PI controller to improve power quality of single-phase dual buck converter. The armature control of the dc machine with constant load torque is undertaken in both clockwise and anticlockwise directions in the motoring and generating modes. The performance of the drive in each quadrant is compared with that of the conventional phase-controlled one. The simulation results indicate, at the ac interface the harmonic profile of the proposed drive fed by the improved power quality dual converter can be manipulated to enable use of more economical filters compared to those in the phase-controlled one.

**Key words—**AC-DC Buck Converter, Power Quality, Closed Loop, PI Controller, Steady State Error etc.

## I. INTRODUCTION

Although large amounts of ac power can be controlled economically by this phase control technique, it has several limitations due to the inherent characteristics. Due to the load variations the speed of the drive varies (variable power) such that total harmonic distortion (THD) increases, power factor and system stability decreases, and thus power quality cannot be maintained properly.

To overcome these drawbacks the essential variables are analyzed by feeding these variables back to the converter switches. Normally, dc output voltage of the converters is proportional to speed of the dc drive, this speed is used as feedback as in outer closed loop control and approaches the control technique such as PI controllers, are employed to provide fast dynamic response while maintaining the stability of the converter system over a wide range of operation. The concurrent control provides cost-effective, compact, and fast response of the IPQCs. Thus in this paper we are concerned about the power quality of four quadrant DC-drive without increase in the total harmonic distortion (THD).

In this paper, From the Power Quality point of view the four-quadrant DC-drive fed by a 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 conventional system. 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 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 speeds, PI controller for reducing steady state errors, Relational operator for generating gate pulses to Converter switches, the armature winding $A_1$ $A_2$, of the separately excited DC drive are fed by the separate dc source. The implemented technique expels the interest towards the performance investigation of the drive as it is less complex in implementing.

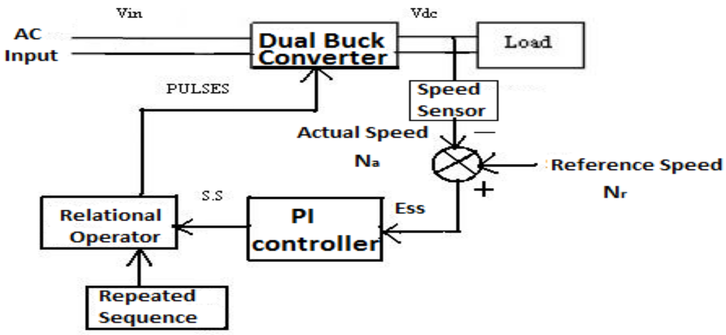


*Fig: 1 Block Diagram of closed loop control four quadrant DC-Drive*

## II. IDENTIFICATION OF PROBLEM

The problem of power quality in electrical systems, in general, is of great importance. Although large amounts of ac power can be controlled economically by this phase control technique, it has several limitations due to the inherent characteristics. Due to the load variations the speed of the drive varies (variable power) such that total harmonic distortion (THD) increases, power factor and 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).

## III. AIMS AND OBJECTIVES

In this paper a feasible solution for the improvement of power quality in a DC-drive, closed loop system is developed 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 factor can be achieved by this closed loop system.
- Easy and less time consuming for control.
- Qualitative & constant power can be supplied to the load.

## IV. 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 thyristors and diodes in series (two quadrant switches) which constitutes a dual buck converter. The four 2QSWs of set I are – T1D1, T2D2, T3D3, T4D4, and those of set II are – T1'D1', T2'D2', T3'D3', T4'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. The topology can, therefore, also be construed to be one with four 4QSWs and two limbs, with each limb having two 4QSWs. In Fig. , E = Induced emf in the armature and DFW = Freewheeling diode. The armature control of the dc machine with constant load torque is undertaken in both clockwise and anticlockwise directions in the motoring and generating modes.

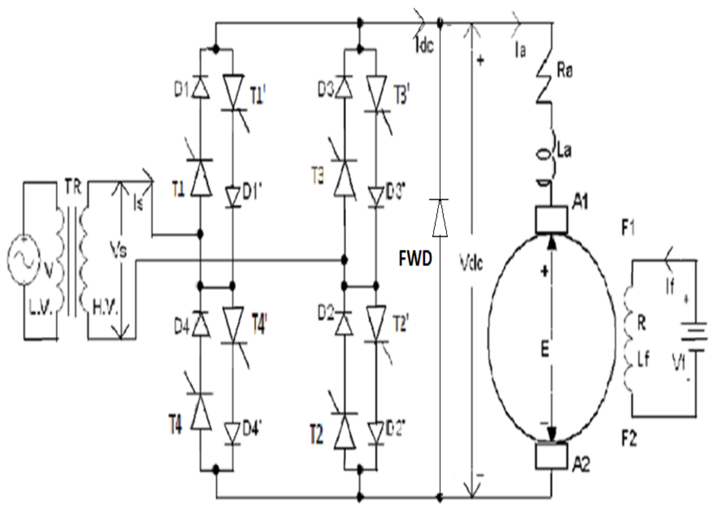


*Fig:2 Conventional single-phase, dual ac-dc buck converter fed four-quadrant, armature controlled, separately excited dc drive*

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

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

*Table:1 Switching States Of 2QSWs In The Dual Buck Converter*

The field winding terminals ($F_1$,$F_2$) of the DC drive are excited by a separate dc voltage source and the armature winding terminals ($A_1$,$A_2$) are connected to the dc side of the buck converter.

The operation of the dual buck converter in the rectification or inversion mode, corresponding to the dc machine functioning in the motoring or generating mode respectively, and in a particular quadrant in the speed-torque plane, shown in Fig. 3, is determined by the conditioning of the switching states of the thyristors of the two sets (I and II) of devices. In Fig. 3 the various parameters indicated are as follows:

TL = Load (external mechanical) torque.

TM = Electromagnetic (internal) torque.

Ω= Rotor (mechanical) speed

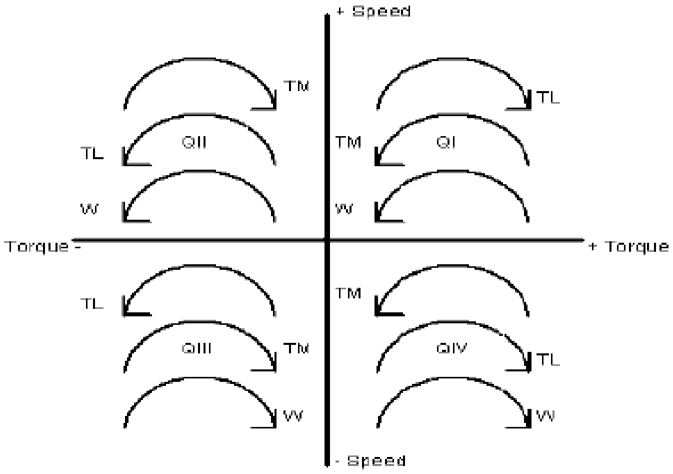


*Fig. 3.3. Speed-torque plane with the four quadrants demarcated*

Conditioning of Switching States of two Sets of thyristors in Dual Buck Converter the armature winding, A1A2, with reverse polarity across the dc link keeping the magnitude of its induced emf, E, greater than the amplitude of the transformer HV side voltage and imparting a phase shift of 180º to the gate switching control pattern of the set I or set II thyristors corresponding to the rectification operation in quadrant I or III to obtain inversion in quadrant II or IV respectively. The field winding F1F2 is connected to a time-invariant dc voltage source. The armature winding A1A2 is connected to the dc side of the dual converter.

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.

## V. SIMULATION RESULTS OF CONVENTIONAL SYSTEM BY PHASE CONTROL TECHNIQUE

The freewheeling diode is used in the phase-control model of the dc drive. Figs 3.2 and 3.3 depict quadrant I operation i.e. forward (anticlockwise, positive) motoring of the dc drive in which the ac side functions as the source delivering power to the machine via dc link for the delay angle, $\alpha = 0^0$. The electromagnetic torque and the speed are positive and, therefore, the power developed by the machine is positive indicating absorption of power by it.

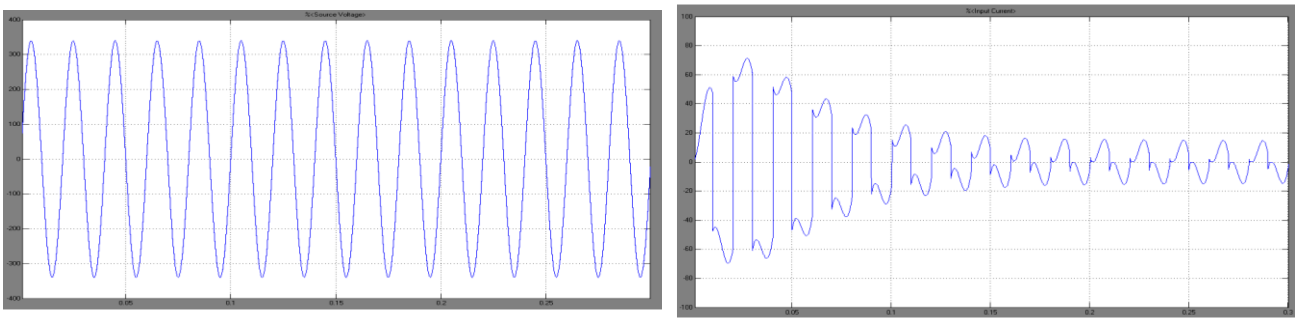

*Fig: 3.2 Quadrant I: H.V. ac side Voltage & Current for α = $0^0$*

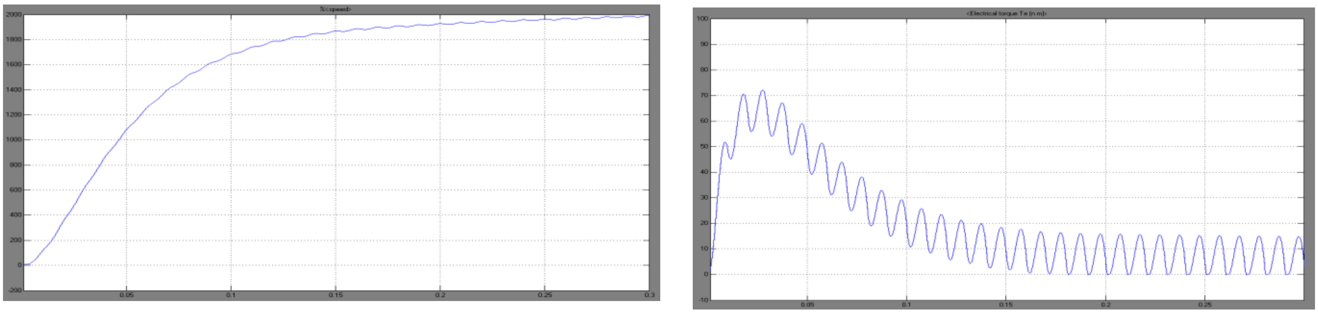

*Fig: 3.3 Quadrant I Speed and Electromagnetic Torque for α = $0^0$*

The characteristics of a DC drive in forward motoring mode (Q-I) is obtained using phase control technique for the delay angle, α= $0^0$.

Drawbacks:-

In this system, due to the load variations, the speed of the drive varies (variable power) such that total harmonic distortion (THD) increases, power factor and system stability decreases, and thus power quality cannot be maintained properly. But the dynamic response of the system & stability cannot be achieved properly.

## VI. SIMULATION BLOCK DIAGRAM OF PROPOSED CLOSED LOOP SYSTEM

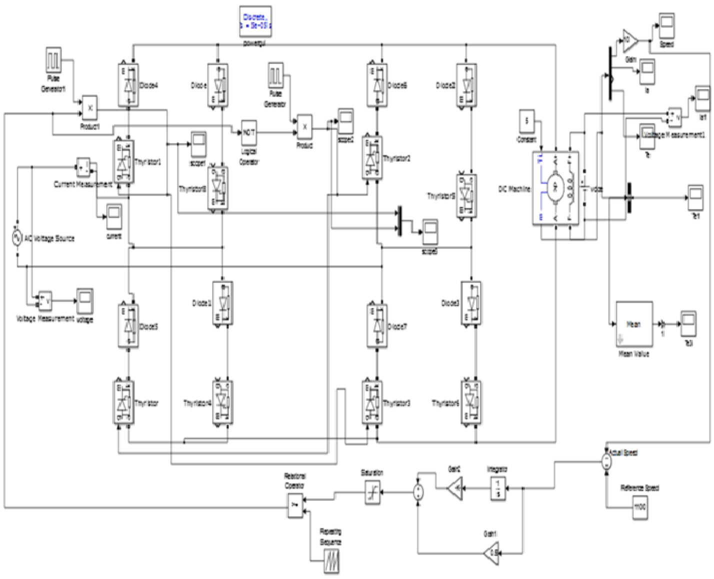

*Fig: 4. Closed loop Block Diagram implementation of four quadrant fed DC drive*

A New approach of closed loop fed four quadrant DC-drive using dual buck converter is implemented as shown 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) are 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 using a relational operator in order to generate the gate pulses required to turn-on & turn-off of the thyristor switches, these gate pulses are fed as feedback signal (modified gate pulses) to one pair of thyristor switches. The same feedback signal is fed to other pair of thyristor switches through NOT gate in order to compare the displacement of the signal supplied to the gate terminal of the switches for identifying both motoring and generating actions.

The armature control of the dc machine with constant load torque is undertaken in both clockwise and anticlockwise directions in the motoring and generating modes. The performance of the drive in each quadrant is compared with that of the conventional phase-controlled one. The simulation results indicate, at the ac interface the harmonic profile of the proposed drive fed by the improved power quality dual converter can be manipulated to enable use of more economical filters compared to those in the phase-controlled one.

## VII. 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 ($T_L$) always opposes the electromagnetic torque ($T_M$) But, in motoring mode $T_M > T_L$. This implies that in the motoring mode $T_M$ is the driving torque and therefore the drive rotates at an angular speed (ω) in the same direction as $T_M$. In the generating mode, $T_L > T_M$ i.e. $T_L$ is the driving torque and, hence, the drive rotates at an angular speed (ω) in the direction of $T_L$.

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 reversing of the armature current $I_a$ 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: Rm = 500p.u. Lm = 500p.u.
Vs= transformer H.V. side terminal voltage (r.m.s value)
Vdc = average value of dc voltage of the converter
For Vdc = 240V (rated armature voltage corresponding to δ).
Note:
Assuming that all power electronic devices and alternating voltage sources are to be ideal

## VIII. 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.

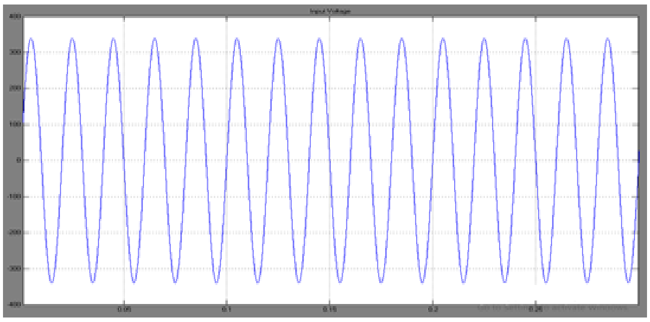

*Fig. 5 (a). Quadrant I H.V. ac side voltage*

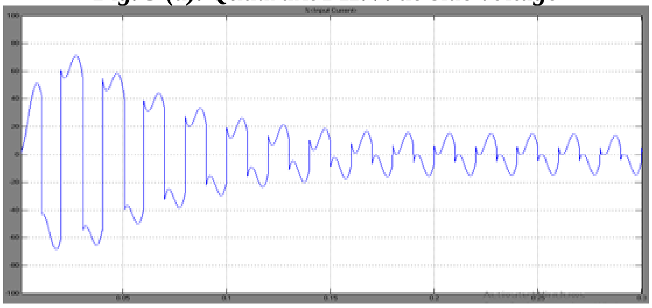

*Fig. 5 (b). Quadrant I: H.V. ac side current*

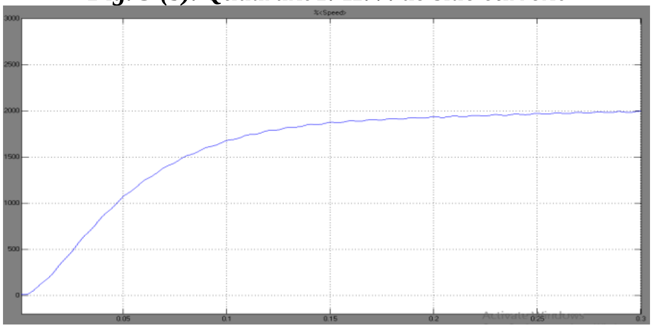

*Fig. 5 (c). Quadrant I: Speed*

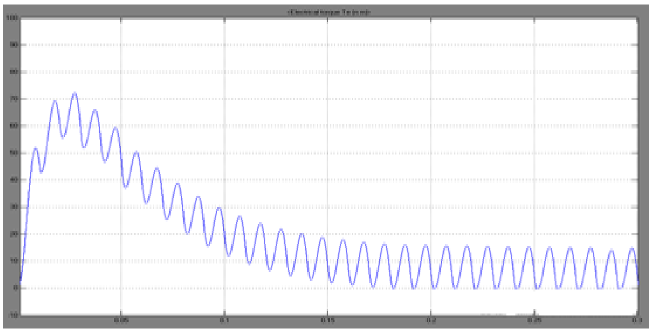

*Fig. 5 (d). Quadrant I: Electro magnetic torque*

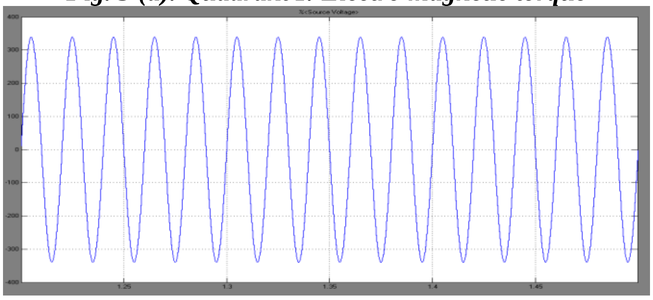

*Fig. 6 (a). Quadrant II: H.V. ac side voltage*

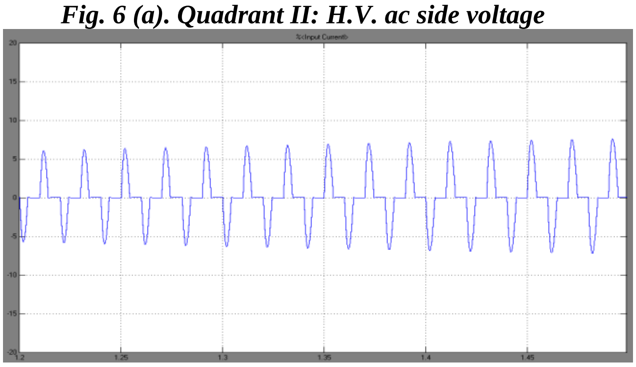

*Fig. 6 (b). Quadrant II: H.V. ac side current*

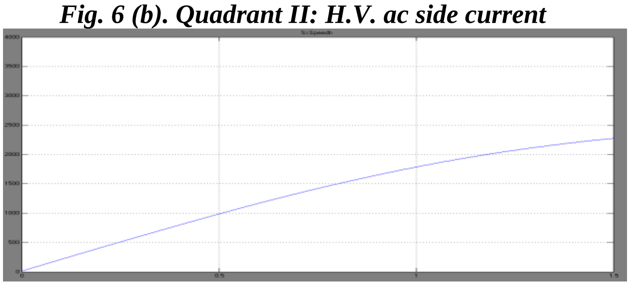

*Fig. 6 (c). Quadrant II: Speed*

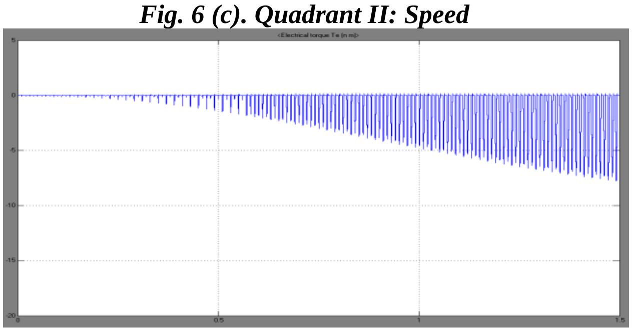

*Fig. 6 (d). Quadrant II: Electromagnetic torque*

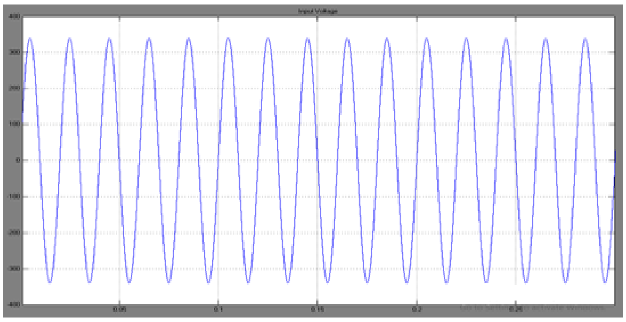

*Fig. 7 (a). Quadrant III: H.V. ac side voltage*

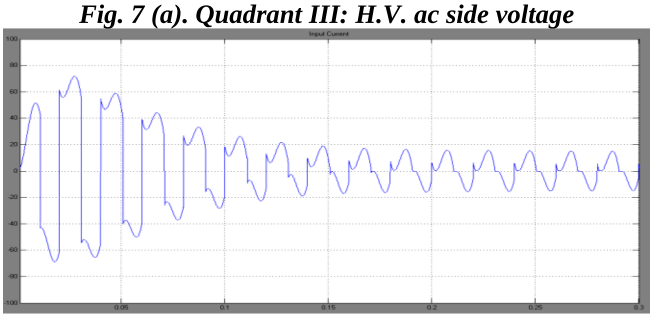

*Fig. 7 (b). Quadrant III: H.V. ac side current*

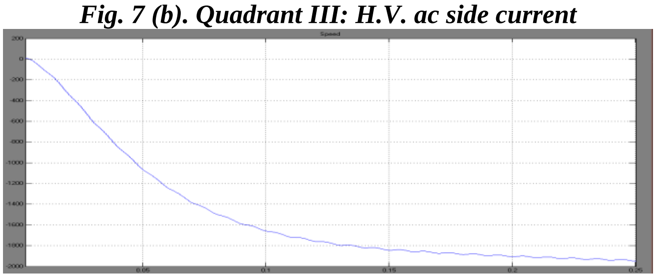

*Fig. 7 (c). Quadrant III: Speed*

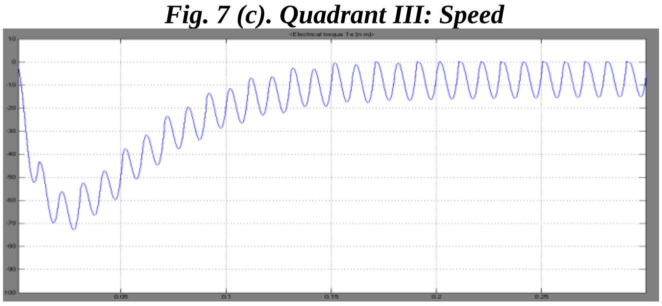

*Fig. 7 (d). Quadrant III: Electromagnetic torque*

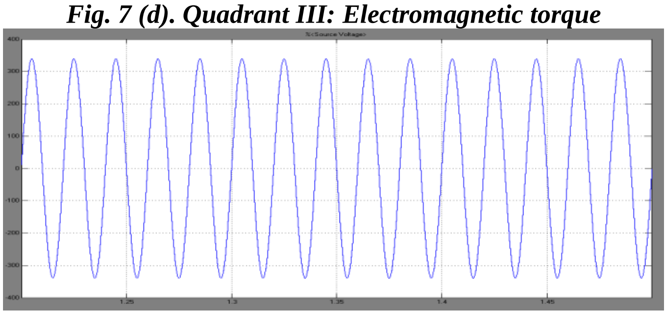

*Fig. 8 (a). Quadrant IV: H.V. ac side voltage*

 

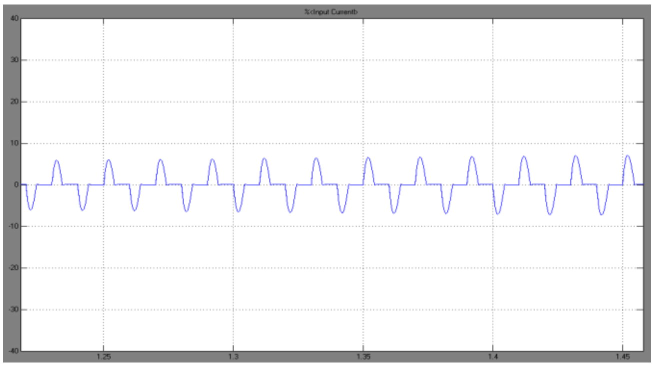

*Fig. 8 (b). Quadrant IV: H.V. ac side current*

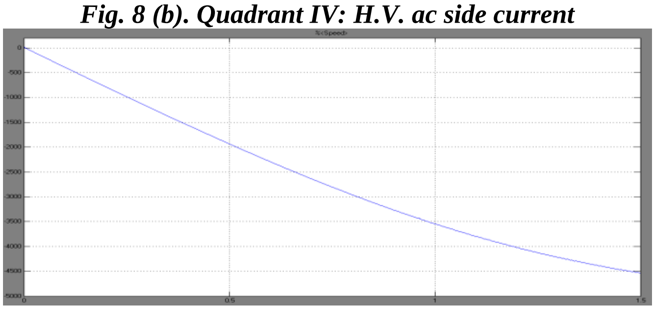

*Fig. 8 (c). Quadrant IV: Speed*

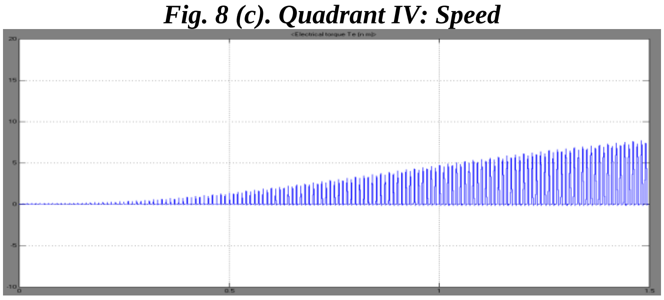

*Fig. 8 (d). Quadrant IV: Electromagnetic torque*

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 thyristor 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 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 duty cycle of the pulses is usually high (≈ >0.5) except, during starting, therefore, the off-time is low. With the increase in the loading, closed loop control provides improved power quality in terms of reduced THD of the ac side current.

It is clear that the THD of the ac side current generally decreases by giving feedback of the system output of drive through PI controller to the thyristor switches. The harmonic profile by FFT (fast Fourier transform) analysis of the ac side current for forward motoring is shown in Figs 9.0., the THD is obtained to be 35.5%.

In the conventional system the values of THD obtained to be 41% and, therefore, proposed system is better than phase control technique. However, this method neither can the harmonic profile be altered nor is harmonic mitigation and selective harmonic elimination inherent.

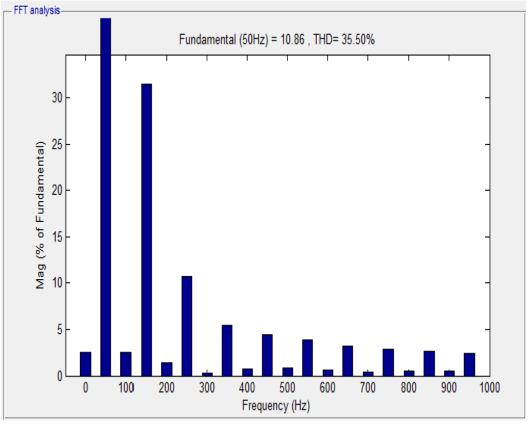


*Fig 9.0 FFT of ac side current for quadrant I operation*

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.

## IX. CONCLUSION

In this paper a new proposed closed loop system with PI control 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, and 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.

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