A Novel Technique for Design & Implementation of DSP Based DC Drive: Applicable to Crane Hoist

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Abstract

This paper presents the design and implementation of novel technique for dc drive for crane application. In crane drive, it consists of three motors for three operations. For hoisting, bridge and trolley. The brief idea of crane drive for hoist application is discussed. This work presents the simulation results for proposed technique for different reference speed for forward as well as in the reverse direction. From the simulation results the speed response of the motor in the close-loop operation is observed. The novel technique with the independent armature and field current control is done for hoist configuration. The novel technique with controller is also implemented and tested with the prototype module using DSP (TMS320F2811). The results confirm the approach presented in this work. Main features and benefits for the novel technique are finally concluded.

Keywords bridge, crane, DC-DC converter, hoist, PWM, trolley, DSP.

1 Introduction

1.1 General

Application of the transport machines in automated production systems makes a new demand for their control systems simultaneously development of the control systems of electrical drives, basing on microprocessors and applying power electronic converters, enables to obtain better properties of the transport machines. In crane drives, the best performance was offered by dc motors, either as a rotating Ward-Leonard or static four quadrant control. The dynamic performance of the controlled dc motor is very good; this is obtained by controlling the torque and the field independently.

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In the part of the DC-DC chopper there are different power topologies are available like controlled rectifier, Buck chopper, H-bridge chopper, etc. In the crane drive application, the power topology must be decided with several considerations.

1.2 Basic Block Diagram of Crane Drive

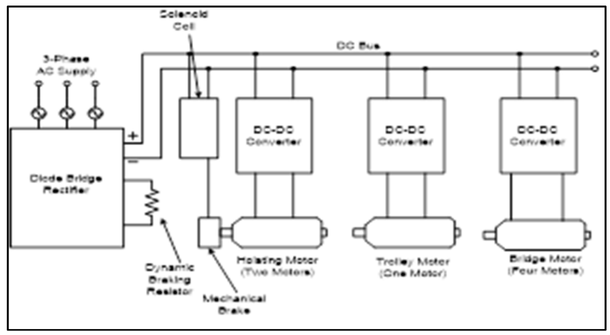


Fig. 1 Basic Block diagram of Crane Drive

As shown in fig.1 in the crane drive three motors are used for three different tasks one is for hoist mechanism second for trolley and third for bridge mechanism and for all of these motor operation three different controllers is used.

In this scheme each motor is controlled by input voltage control using DC-DC converter (chopper). For the speed reversal either armature voltage or the field reversal technique is sued.

2 Proposed Novel Technique for Hoist Configuration

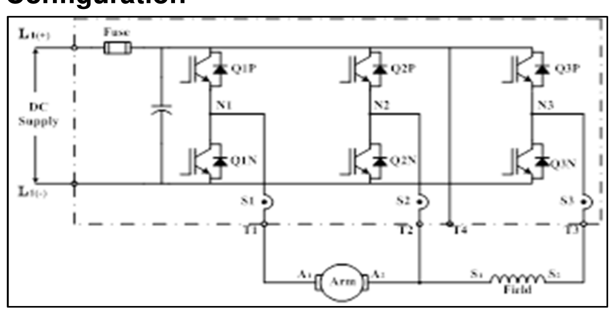


Fig. 2 Proposed Technique for the Speed Control of DC Series Motor for hoist configuration

Fig2 shows the power topology for the reversible dc series motor drive for hoist configuration; it supplies the motor current through terminals T1, T2 and T3 only. This allows some or the entire armature current to pass directly to the field winding when the torque is in the usual direction for balancing the load on the hoist. This substantially reduces the heating in the semiconductor devices that controls T2. This technique is able to give the four-quadrant operation, means it can produce either positive or negative torque irrespective of whether the motor is running in the forward or in the reverse direction. The controller is therefore able to absorb energy from the motor when it is providing torque in such direction as to decelerate a high inertia or when it is providing a braking torque during lowering of a heavy load. The efficiency of the controller is sufficiently high as it recovers some energy from the load and returns it to the dc supply.

For the speed control of the motor Pulse Width Modulation (PWM) is used to produce an output voltage by controlling the duty cycle of the top and bottom IGBTs on each leg. The pulse frequency is typically 1 kHz, which is high enough for the inductance of the motor winding to act as a very effective smoothing choke. The current has a small amount of high frequency ripple but are substantially the same as if they had been derived from a smooth DC source.

Referring to the Fig.2, node N1, nodeN2 and node N3 are at the junction of IGBTs pair Q1P/Q1N, Q2P/Q2N and Q3P/Q3N, respectively of the DC/DC converter. When a hoisting operation is about to commence, with the load resting on the floor, the DC/DC controller modulates these three nodes at 50% in order that they are all at the same average DC voltage level, namely 50% of the DC supply voltage. Consequently, there is no current in either the armature or the field of the DC series hoist motor.

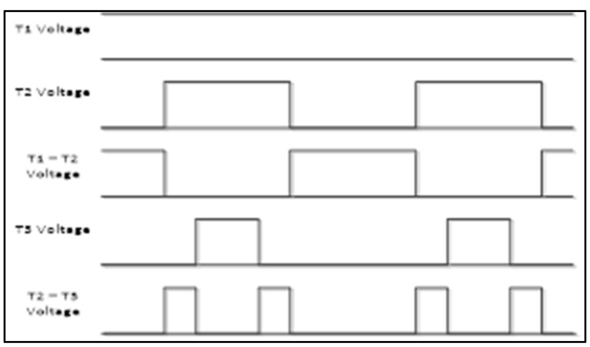


Fig. 3 Pulse Width Modulation Waveforms for hoist

Fig.3 shows the voltage pattern for the forward operation. Here in this technique Q1P and Q1N are used for deciding the direction the motor rotation. When Q1P is in on state the operation will done in the forward direction and when Q1N is in on state the operation will be done in reverse direction. When Q1P is ON the N1 node (T1 terminal) will come at the positive potential of the dc supply, which shows in the fig.1. Q2P and Q2N switches are modulated as per the required voltage across the motor armature. The voltage at the T2 terminal is decided by the modulation of these two switches. The voltage across the armature will be the difference potential at T¬1 terminal voltage and T2 terminal voltage. In the same way the difference between the T2 terminal voltage and T3 terminal voltage will appear across the field winding.

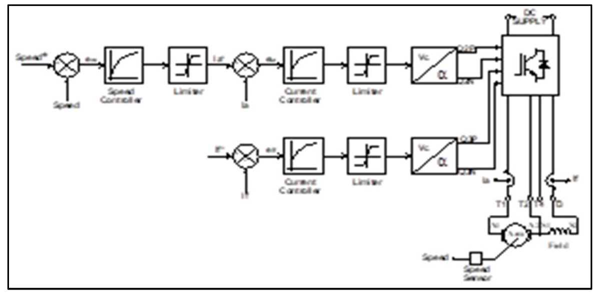


Fig. 4 Close-loop controller block diagram

Fig.4 shows the controller for the close-loop speed control of the dc series motor, which consists of outer speed PI controller followed by the inner armature current PI controller. The output of this series PI controller is compared with the 1 kHz carrier signal to generate PWM for the Q2P and Q2N switches. Other independent field current PI controller is used to balances the field current.

The output of the field current PI controller is compared with the 1 kHz carrier signals to generate PWM for the Q3P and Q3N switches.

3 Simulation of Proposed Technique for Hoist Application

To verify the proposed topology, it is simulated with the PSINM software tool with close loop PI controller as shown in fig.5. This fig shows only the power topology with motor connections and required sensors. This simulation is done with DC series motor with the rated voltage of 500Vdc, current of 10Adc, and speed of 1200rpm. The value of the armature resistance Ra = 0.5 · , field resistance Rf = 1 · , armature winding inductance La = 2mH, and field winding inductance Lf = 2mH. For the power topology IGBTs are used as switching devices with the switching frequency of 1KHz. PWM technique is used for the switching of IGBTs.

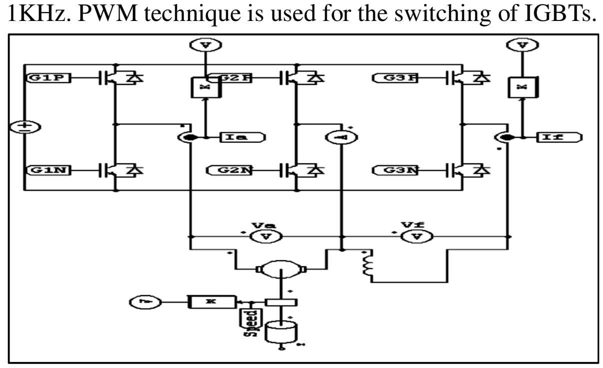


Fig. 5 Power Circuit of the Proposed Technique for hoist

Fig.6 shows the close-loop circuit components for simulations, it consists of speed PI controller, inner armature current controller and independent field current controller. The output of the armature current compare with the 1kz carrier signals and generated PWM is given to the Q1P and Q1Nc and the output of field current controller is also compared with same carrier signal and given to the Q3P and Q3N.

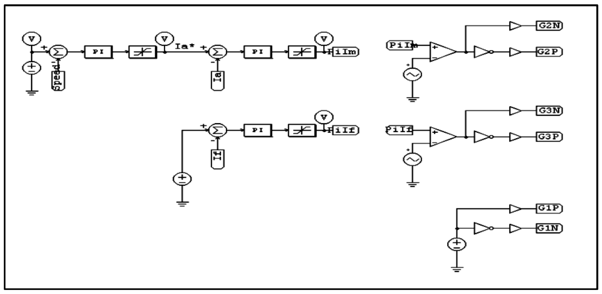


Fig. 6 speed of the motor with 1200-rpm reference

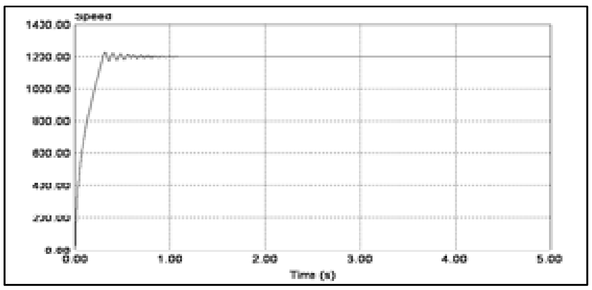
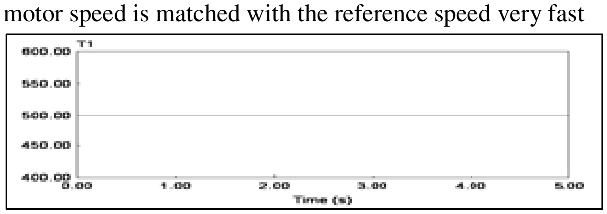
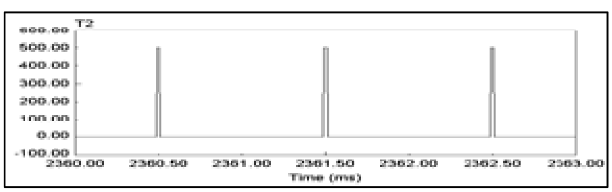


Fig. 7 speed of the motor with 1200-rpm reference

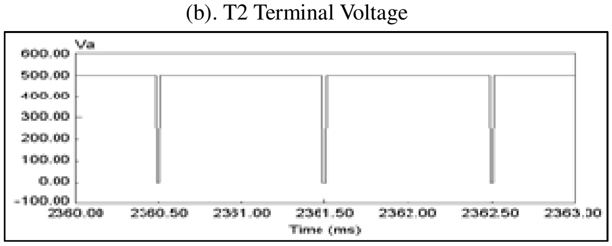
Fig. 7 shows the speed of the motor at the no load when the reference speed is set to 1200rpm, and it is observed that motor speed is matched with the reference speed very fast



(a) T1 Terminal Voltage



(b). T2 Terminal Voltage



(c). Voltage across Armature

Fig. 8 Armature voltage waveform for 1200rpm

Fig. 8 shows the voltage pattern for the 1200RPM reference speed and it also shows the voltage across the armature(c) is the difference between the (a) T1 terminal voltage and (b) T2 terminal voltage. And at the maximum speed maximum, the maximum voltage is available at the armature.

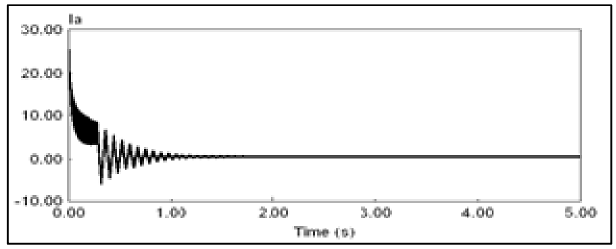


Fig. 9 Armature current

Scale: X-axis 1block = 1Sec, Y-axis 1block = 10A

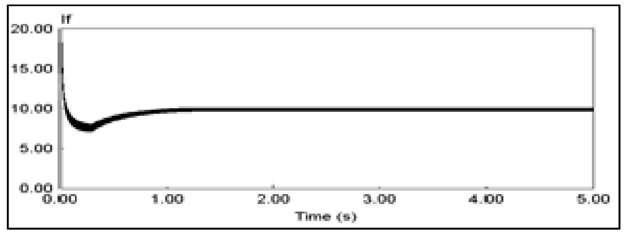
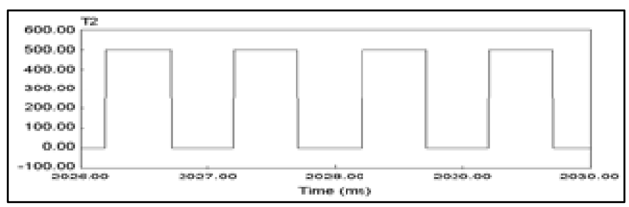


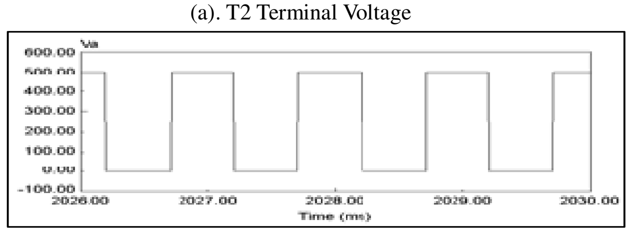
Fig. 10 Field current

Scale: X-axis 1block = 1Sec, Y-axis 1block = 5A

Fig.9 & Fig.10 shows the armature and field current respectively at the maximum speed and it shows that both the currents are independent with each other, so both the current can control independently. In the fig armature current shows very low because motor operates on no-load and as load increases armature current will increases.



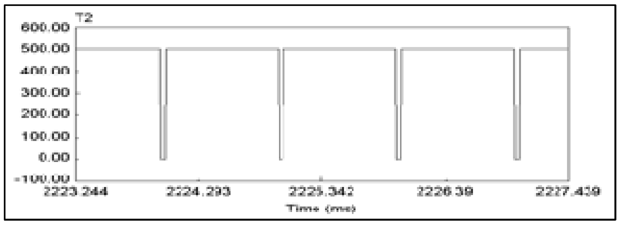
(a). T2 Terminal Voltage



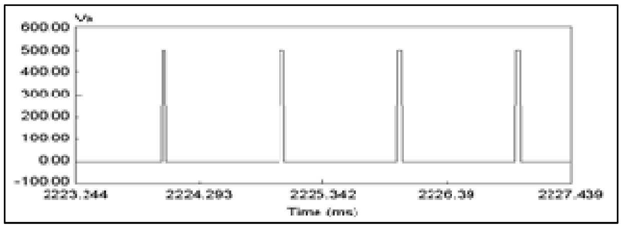
(b). Voltage across Armature

Fig. 11 Armature voltage waveform for 600rpm

Fig.11 shows the voltage pattern for the half speed reference, it shows that as reference speed decreases width of the T2 terminal voltage(a) waveform increases and the difference between the T1 and T2 terminal voltage decreases and as a result voltage across the armature(c) decreases, this shows that this follows the same pattern as discussed in the fig.2. At this speed also the field current is same as the maximum range and armature current is reduced.



(a). T2 Terminal Voltage



(b). Voltage across Armature

Fig. 12 Armature voltage waveform for 50rpm

Fig.12 shows the armature voltage waveforms for the 50rpm speed condition and it shows that at this speed very low voltage is available across the armature (b) and maximum modulation is there for the T2 terminal voltage (a).

4 Hardware Implementation of Dc Drive for Hoist

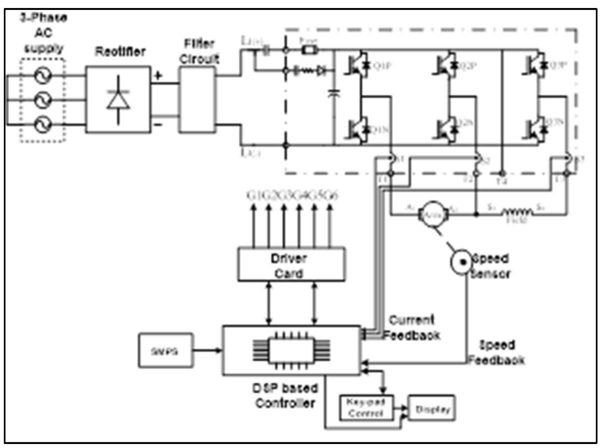


Fig. 13 Overall block diagram of DC drive using DSP TMS320F2811

To verify the proposed technique the actual experimental test is carried out on DC series, motor. The experiment is carried out with the help of 45KW rating prototype module. IGBT have a voltage rating of 1200V and current rating of 200A. For the close loop control the speed feedback is taken with the help of encoder, which gives 2500 counts per RPM. Dual current sensors having a current rating of 50A take armature and field current feedbacks. DSP (TMS320F2811) based control card is used as a controller as shown in fig.13.

DC series motor specifications:

Rated voltage = 230V dc, Rated speed = 1500rpm,

Rated current = 11.8A,

Armature winding resistance = 2.3ohm

Field winding resistance = 2.9ohm

5 Gate Pulse at The Output of Gate Driver Circuit using DSP (Tms320f2811)

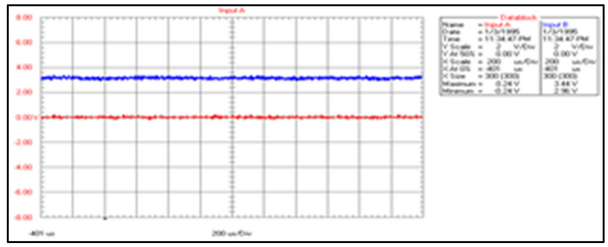


Fig. 14 Gate pulses for the IGBTs Q1P & Q1N

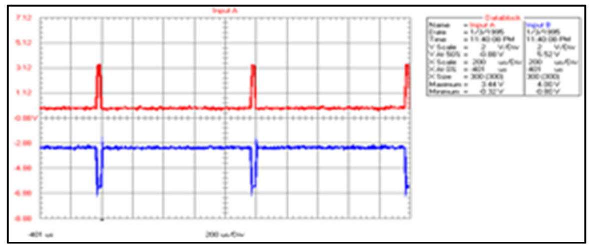


Fig. 15 Gate pulses for the IGBT Q2P & Q2N for 1200 rpm reference

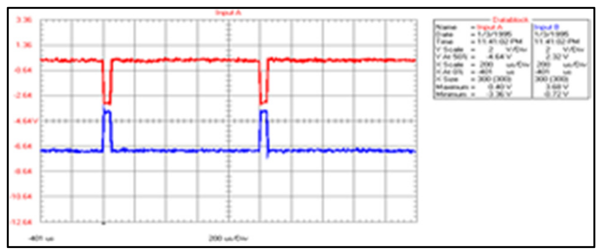


Fig. 16 Gate pulses for the IGBT Q2P & Q2N for 50 rpm reference

Fig. 14, 15 & 16 shows the gate pulses generated by the gate driver circuits for different IGBTs for different references speed. As shown in figure as reference speed decreases pulse width for the Q2P increases, which results; reduced voltage across the armature.

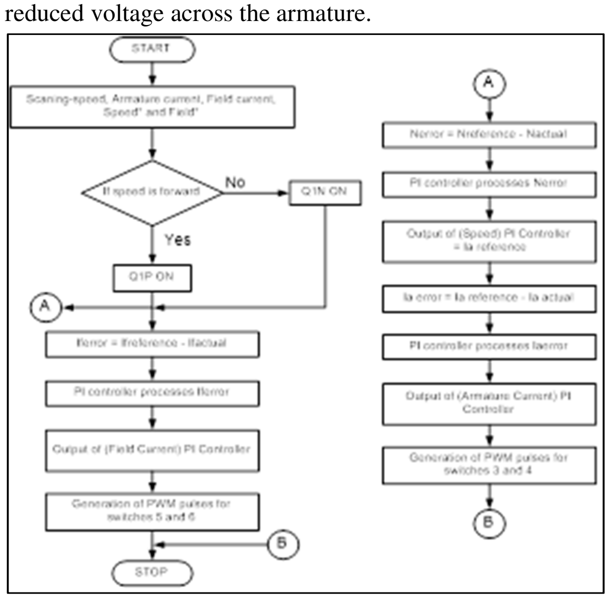
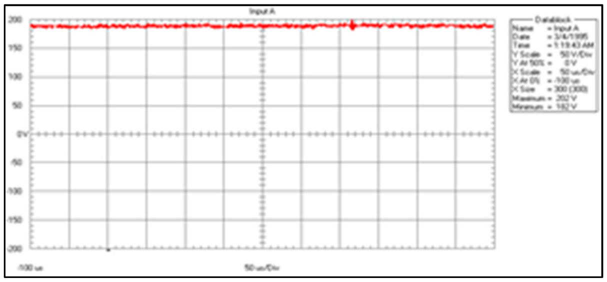


Fig. 17 Flow chart for PWM generation

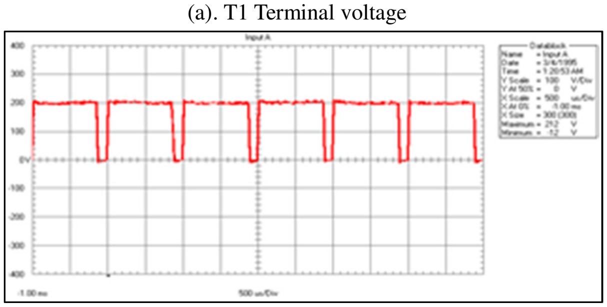
Fig. 17 show the flow chart to generate the PWM pulses for switches Q3P, Q3N, Q4P, & Q4N by satisfying different conditions for speed increasing and decreasing from close loop controller.

6 Experimental Results for Different Reference Speed Conditions

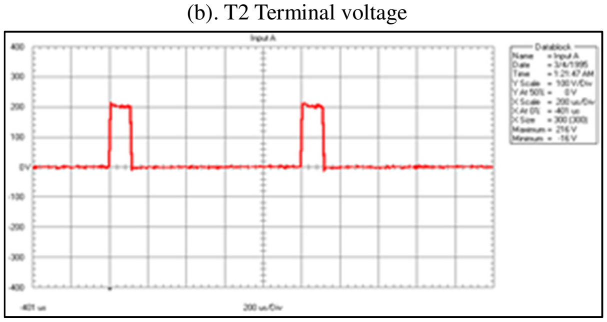
6.1 Experimental results for the 250RPM reference speed



(a). T1 Terminal voltage



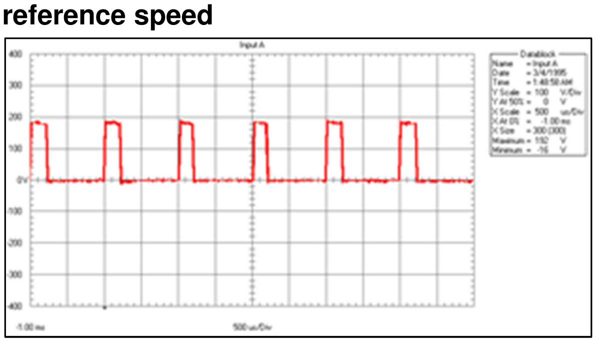
(b). T2 Terminal voltage



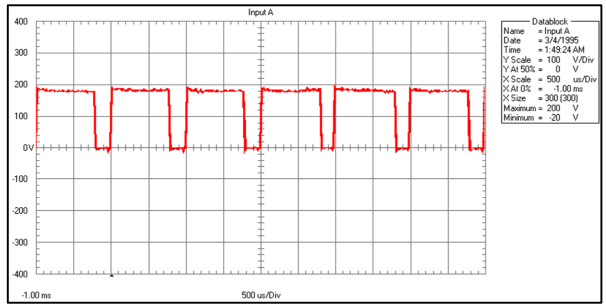
(c). Voltage across armature

Fig. 18 Voltage across armature for 250RPM reference speed

6.2 Experimental results for 1000RPM reference speed



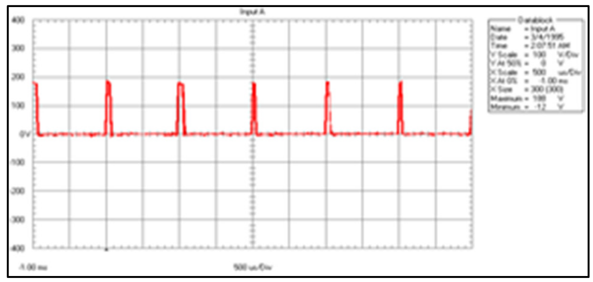
(a). T2 Terminal voltage



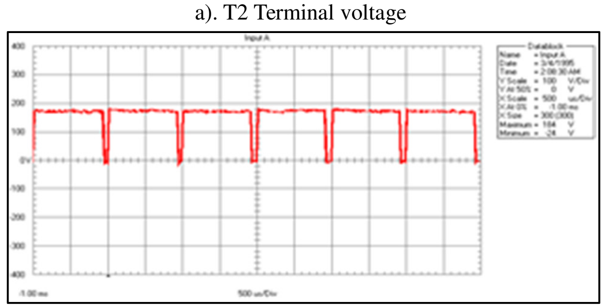
(b). Voltage across armature

Fig. 19 Voltage across armature for 1000RPM reference speed

6.3 Experimental results for 1750RPM reference speed



a). T2 Terminal voltage



(b). Voltage across armature

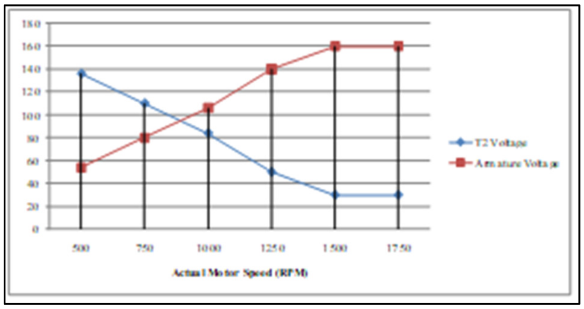
Fig. 20 Voltage across armature for 1750RPM reference speed

Fig. 18, 19 & 20 shows the experimental results for 250RPM, 1000RPM & 1750 RPM reference speed respectively.

Table 1 Armature Voltages for Different Reference Speed

Reference Speed (RPM)	T1 Voltage (V)	T2 Voltage (V)	Armature Voltage (V)
250	190	167	23
500	190	136	54
750	190	110	80
1000	190	84	106
1250	190	50	140
1500	190	30	160
1750	190	30	160

Table. I show the armature voltage for different reference speed and it shows that as the reference speed increases the voltage across the armature increases and the voltage at the T2 Terminal decreases and the difference between the T1 terminal voltage and T2 terminal voltage is appeared across the armature.



Graph. 1 T2 terminal voltage and Armature voltage for diff. Ref. Speed

Graph I. show the relation between the T2 terminal voltage and reference speed and it is verified from the graph that as the reference speed increases T2 terminal voltage decreases.

Table 2 Comparison of Actual and Reference Speed

Reference Speed	Actual Speed (50% Load)	Actual Speed (75% Load)	Actual Speed (100% Load)
100	100	100	97
200	200	100	197
300	300	299	298
400	400	400	398
500	500	499	500
600	600	600	600
1000	1000	1000	1000
1100	1101	1100	1099
1200	1201	1199	1200
1300	1301	1300	1300
1600	1601	1598	1600
1700	1701	1700	1700
1800	1801	1800	1800

7 Conclusion

After discussing all the basic required features of the crane drive it shows that for the particular crane application it requires fast dynamic response in the forward as well as in the reverse direction, for dc motor it gives good dynamic response when it is control with independent speed and torque control. So, it requires independent armature and field current controller. The proposed technique is able to control independent armature and field current control. And the dynamic response of such technique is also very fast for hoist as well as for bridge and trolley configuration that is shown in simulation results. And it is also concluded as in table II. with the variation in the load also actual speed match the reference speed.

If one wants to replace the dc motor with 3-phase, the other major advantage of the proposed technique is that the future application induction motor same power topology can be used for speed control of 3-AC motor, only need to change in the program in the processor for the controller.

References

1. Gerhard L. Fischer “Comparison of DC and AC Container Crane Drive Systems” IEEE Conference on power electronics and drive system, PEDS’99, July-1999, Hong-Kong, p.p.297-302
2. F. Busschots “application of field-oriented control in crane drives” on Industry Applications Society Annual Meeting, 1991, Conference Record of the 1991 IEEE Publication Date: 28 Sep-4 Oct 1991
   On page(s): 347-353
3. Kazimierz Gierlotka, Boguslaw Crzesik, Andrzej Nowak and Jozef' Wojnarowski, Tejas patel “Control of Overhead Crane Drive with Centered Motion and Elimination of the Bevel” on Industrial Electronics, 1996. ISIE '96., Proceedings of the IEEE International Symposium on Publication Date: 17-20 Jun 1996 Volume: 2, On page(s): 1061-1065
4. Ronald Wayne Hughes, Michael Owen Lucas “Method and System for Solid State DC Crane Control” publication at United State Patent Application Patent on Dec. 4. 2003 No. US20030223738A1, p.p. 1-8.
5. Omnipulse DDC, DC to DC Crane Control Instruction Manual, MAGNETEK Material Handling Pvt. Ltd. US
6. Gopal K. Dubey, “Power Semiconductor Controlled Drives”, 2nd edition, Prentice Hall, Englewood Cliffs, New Jersey.