SIMULATION OF THE NOVEL SCHEME OF DC DRIVE FOR ELECTRICAL HOIST APPLICATION

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Abstract: This paper represents the simulation and analysis of solid-state speed control of dc series motor in both the direction. The main focus is on the application of dc drive for the crane application. For that different power circuit topologies are discussed and compared with the proposed novel topology. Simulation of the proposed topology is given and benefits of novel topology are concluded.

Key words: dc drive, crane drive, solid-state control

I. INTRODUCTION

DC Drive has a history of application in the crane industry. The following drive configurations are use on cranes.

- Slip-ring motor speed control via variation of the rotor resistor.
- Ward – Leonard converter set.
- DC thyristor drives.
- AC drives.

The first container cranes were equipped with DC motors driven by either. The Ward-Leonard control principle allows precise speed control and is insensitive to the supply voltage variation. The disadvantage though is the Fact that several rotating machines, are to be cascaded to form the drive system. The maintenance effort is correspondingly high and reliability is naturally limited. As consequences, today most of Ward-Leonard drive system is considered obsolete.

DC thyristors converters have been an alternative to Ward- Leonard drive systems from the early 1970s onwards. Solid state DC converters avoid the AC motor and DC generator used in the Ward-Leonard set. DC converters developed to be a compact, almost maintenance free means of power conversion [1].

In the solid-state converters also, there are several possibilities for the controller. They have their individual advantages and disadvantages and applications. Here in this paper those different topologies are discussed.

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. Because in the crane drive it requires consecutive operation in the forward and reverse direction, so converter needs to control the voltage across the motor armature in the both direction with very fast dynamic response.

II. DIFFERENT EXISTING POWER TOPOLOGIES

For the speed control of the dc motor different power topologies are given as bellow. Here in this paper for the crane application dc series motor is used because it has a best suitable characteristic for the hoist application.

1. H-Bridge Chopper

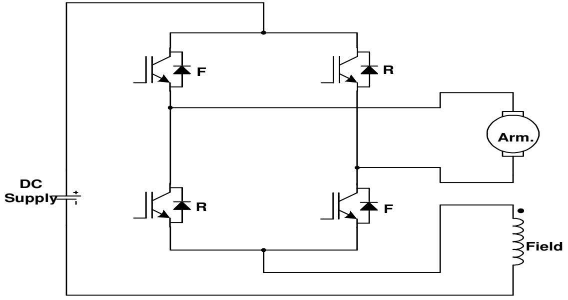


Fig.1 H-Bridge Chopper for the Speed Control of DC Series Motor

Fig.-1 shows the H-bridge chopper configuration for the speed control of the dc series motor. In this scheme for the speed control four IGBTs are used for feeding the supply to the armature. For the speed control in the forward direction two switches (named as F in the fig) are modulated with PWM control technique using close loop PI controller. The major advantage of this scheme is that it does not require any external contactors for the speed reversal, four switches used for the modulation can same uses for the speed reversal. But in this scheme also independent speed and torque control is not possible.

2. *Three Phase Controlled Rectifier*

Fig.- 2 shows the power schematic with control circuit of three-phase full controlled rectifier for the close loop speed control of dc series motor. In this scheme for the speed control the firing angle of the SCR is controlled.

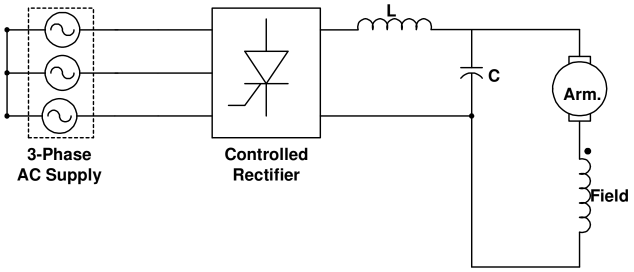


Fig.2 Three-Phase Controlled Rectifier for the Speed Control of DC Series Motor

The major advantage of this scheme is that in this scheme the speed control is achieved directly using control rectifier means it does not require any uncontrolled rectifier and then extra chopper for the speed control, so the system becomes cheaper. But in this scheme also for the speed reversal extra contactors are required, which decreases the reliability of the system.

Other disadvantage of this system is that the time response for the controller is very low in the rectifier circuit as it requires at least one cycle for the stabilization and in the crane drive application the control must be as fast as possible because in such application the consecutive forward and reverse operation at different speed position is required so for this crane application this scheme gives poor performance.

After discussing all above three schemes it is easy to understand that no one scheme can provide all required characteristics for the crane application. So here in this paper one power topology is proposed which satisfies all required characteristic like it gives independent speed and torque control as well as the same topology can use for the speed reversal without any contactors across the field or armature. In other words it gives totally solid-state solution for the all four-quadrant operation, with independent armature and field current control.

This topology has a one more advantage of the future application, that the same topology is also applicable for the induction motor with very less change in the microprocessor software tool.

III. PROPOSED POWER TOPOLOGY

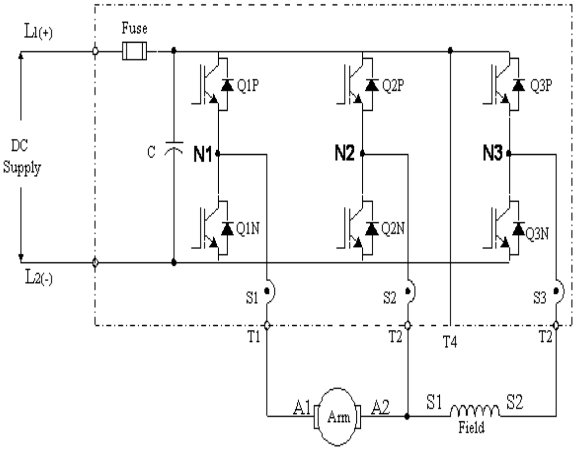


Fig.3 Proposed Topology for the Speed Control of DC Series Motor

Fig.-3 shows the power schematic for the reversible DC series motor drive, which supplies the motor current through terminals T_1, T_2 and T_3 only. This allows some or the entire armature current to pass directly to the field current winding when the torque is in the usual direction for balancing the load on the hoist. This substantially reduces the heating in the semiconductor device that controls T_2. This scheme gives four-quadrant operation. This means that it can produce either positive or negative torque irrespective of whether the motor is running in the forward direction or the reverse. The controller is therefore able to absorb energy from the motor when it is providing torque such a 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 to allow it to recover some energy from the load and return it to the DC supply. For the speed control of motor Pulse Width Modulation (PWM) is used to produce an output voltage on each terminal that is a proportion of the DC supply voltage by controlling the duty cycle of the top and bottom IGBTs of each half bridge. In fig.-6, the voltage that appears across the motor winding is the difference between that of two terminals and may be made positive or negative as desired. The pulse frequency, typically 1 KHz, is high enough for the inductance of the motor windings to act as a very effective smoothing choke. The current that flow have a small amount of high frequency ripple but are substantially the same as if they had been derived from a smooth DC source.

As shown in fig.5, IGBTs Q2P and Q2N are employed to control the voltage at second output terminal by switching it to either the positive or negative side of the DC supply voltage. IGBT Q3N controls the voltage at a third output terminal. A diode across the Q3N provides a free wheel path for current entering terminal when Q3N is not conducting.

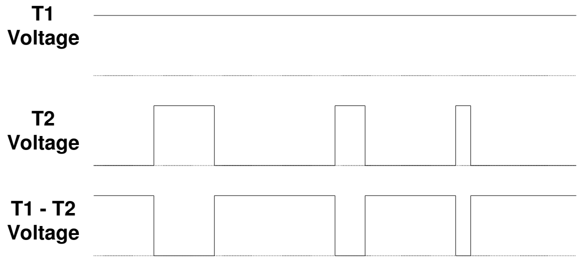


Fig.4 Pulse Width Modulation Waveforms

Referring to the fig3, 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.

To initiate hoisting, the operator moves a master switch of the operator's control panel away from the "OFF" potion to the "RAISE" direction. In response, the DC/DC controller modulates the DC/DC converter to initiate current flow in the direction from node N1, to terminal T1, to point A1, to the armature, and to the point A2 by increasing the voltage at node N1 above 50%V. With node N2 remaining at 50% V and node N3 at less than 50%V, current will then flow in two paths (1) in to terminal T2 to node N2 and (2) into point S1, to field winding, to point S2 and in to terminal T3 to node N3.

The operator than moves a master switch of the operator's control panel to desired speed reference position. In response, the DC/DC converter to cause the DC voltages at all three nodes t vary in order to maintain the appropriate armature and field currents corresponding to "series motor" mode operation during which such armature and field currents are equal or by alternate setup to a customized speed-torque profile. At the maximum hoist speed and load, typical node voltages are 100%V, 5%V, and 0%V at nodes N1, N2, and N3, respectively, corresponding to 95% input voltage across the armature and 5% input voltage across the field winding, with the armature and field currents being equal.

Fig.5 shows one of the mode of operation for DC/DC converter of fig. 5. This mode allows speed under light load to be limited. In this mode the field current I_F is controlled independently and may be maintain at a higher value or a lower value than the armature current I_A when the need arises. When forward motion is requests IGBT Q1P is ON. IGBT devices Q2P and Q2N are driven by Q2P and Q2N signals respectively of fig.7. IGBT device Q3N is modulated with a suitable duty cycle on Q3N signal of fig.7. Node N1 is set to 100%V during this operating mode, thereby, in effect, connecting output terminal T1 to positive DC supply voltage. IGBTs Q2P and Q2N are electronically interlocked through the microprocessor in order that when Q2p s ON Q2N is OFF and vice versa.

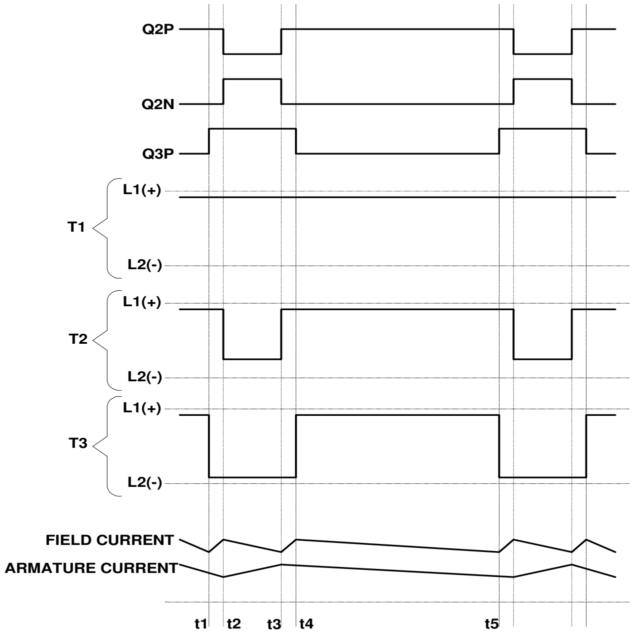


Fig.5. Mode of operation for the hoisting motion

This sequence of states permits the mean voltage across the armature to be controlled independently of the mean voltage across the field with the restriction that the sum of the two voltages cannot exceed the positive DC supply voltage. The voltage across the field is not more than a few percent of the positive DC supply voltage. Using this mode of operation, it is possible to achieve hoisting speeds that are less dependent on the load being lifted.

Continuing to refer to fig.5, the field current may also be held constant if necessary. This is most advantageous for light load where the difficulty of controlling the speed of a simple series field motor is most pronounced. By maintaining the minimum level of field current, a natural speed limit is reached when the armature voltage V_A approaches to positive DC supply voltage. In other words, the motor cannot over-speed since there always exists a finite and significant field flux even when armature current is very low [4]. When maximum hoisting effort is required, the field current is increased in line with the armature current, but may still be independent controlled so as to modify the torque/speed characteristic of the motor if desire.

Referring to fig.6, when a request for the movement in the lowering direction, IGBT Q1N is ON. Terminal T1 is set to 0%V, thereby effectively connecting point A1 to the negative terminal. During power lowering, current flows from output terminalT2 and divides to become partly field current into point S1 and partly armature current in to point A2. IGBT Q2P and diode of that IGBT supply the sum of these two currents. The overall torque capability in this mode is, hence limited by the rating of these two devises, but fortunately, the torque requirement for power lowering is merely that necessary to overcome friction losses which are relatively small. It is, therefore, readily possible to provide sufficient torque for this mode without excessive current in to two devises.

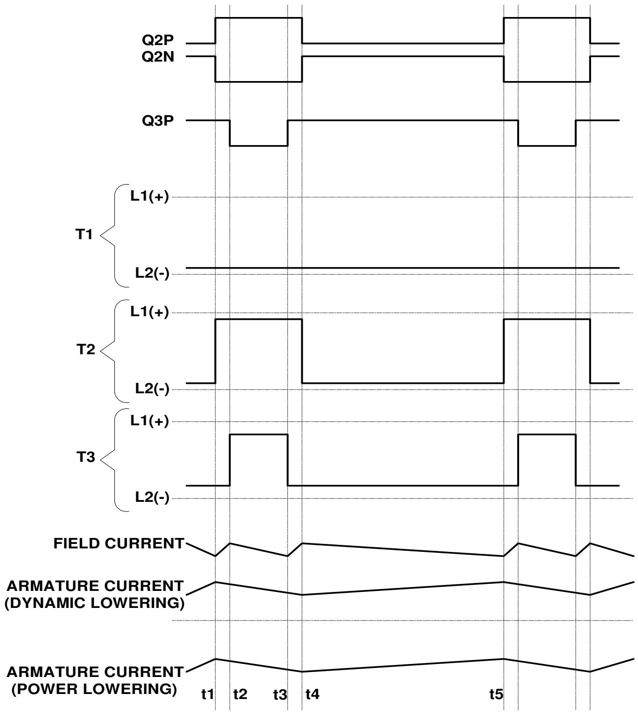


Fig.6. Mode of operation for the lowering motion

III. SIMULATION OF PROPOSED TOPOLOGY

To verify the proposed topology, it is simulated with the Psim software tool with close loop PI controller as shown in fig. 7. 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 = 0.5Ω, Rf = 1Ω, La = 2mH, and 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. 10 shows the control circuit for the power topology, this includes the speed loop PI controller, armature current control PI controller and field current PI controller to regulate the speed at the reference speed.

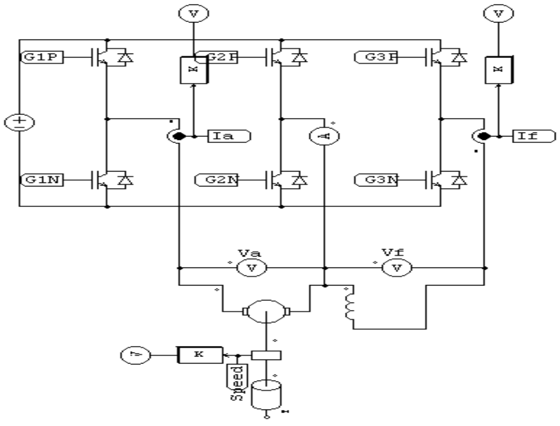


Fig. 7 Power Circuit of the Proposed Topology

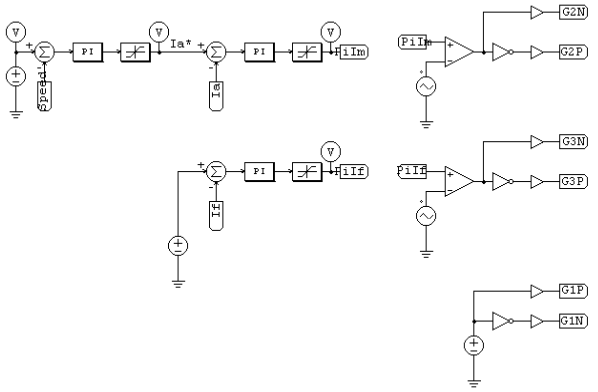


Fig. 8 Control Circuit of the Proposed Topology

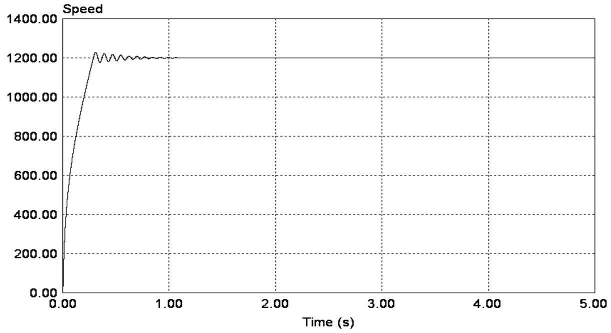
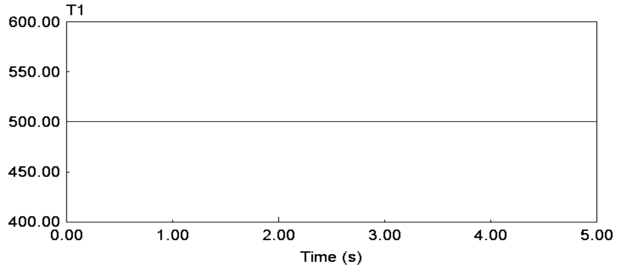
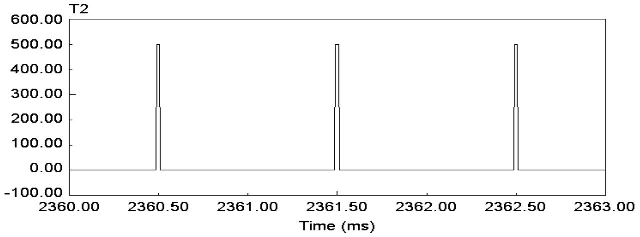


Fig. 9 speed of the motor with 1200-rpm reference

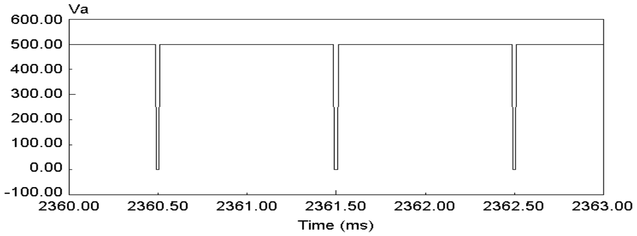
Fig. 9 shows the speed of the motor at the no load when the reference speed is set to 1200rpm, as shown in fig. 9 motor speed is matched with the reference speed very fast.



(a). T1 Terminal Voltage



(b). T2 Terminal Voltage

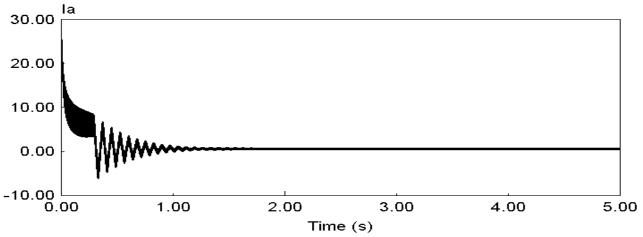


(c). Voltage across Armature

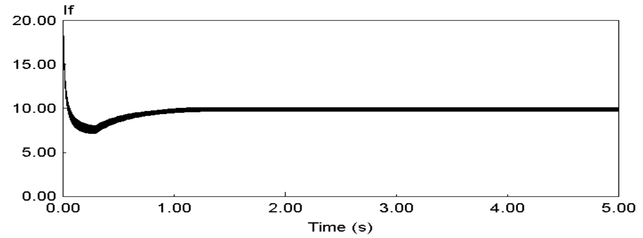
Fig. 10. Armature voltage waveform for 1200rpm

Fig. 10 shows the voltage pattern for the maximum 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, voltage is available at the armature.

Fig.11. shows the armature (a) and field (b) current 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.



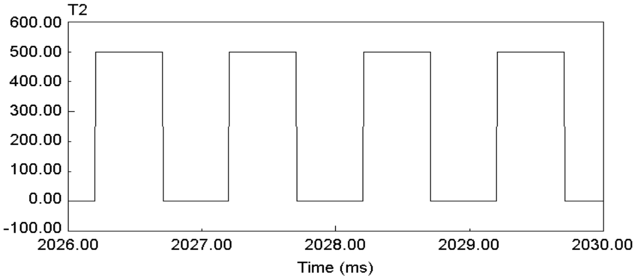
(a). Armature Current



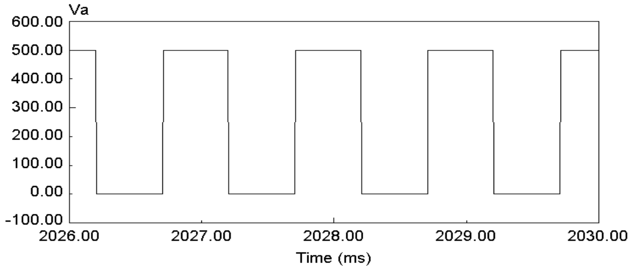
(a). Field Current

Fig. 11 Armature and Field Current Waveforms

Fig. 12 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. 4. At this speed also the field current is same as the maximum range and armature current is reduced.

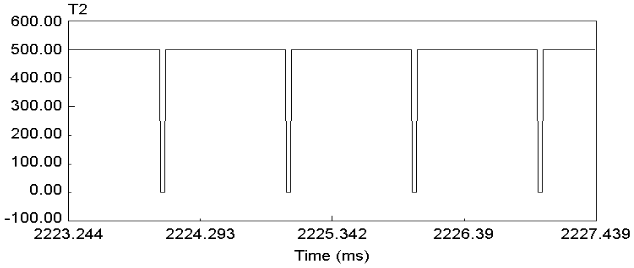


(a). T2 Terminal Voltage

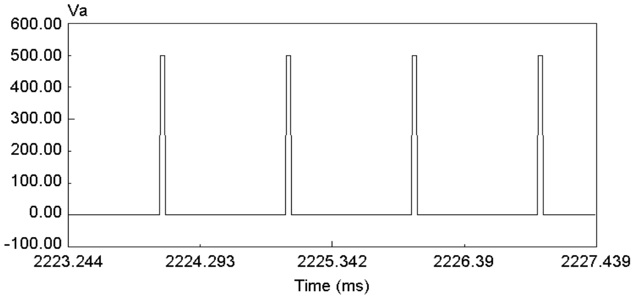


(b). Voltage across Armature

Fig. 12. Armature voltage waveform for 600rpm



(a). T2 Terminal Voltage

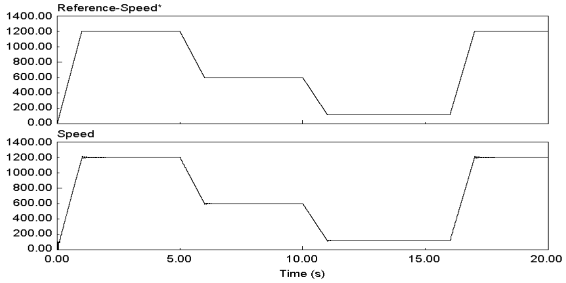


(b). Voltage across Armature

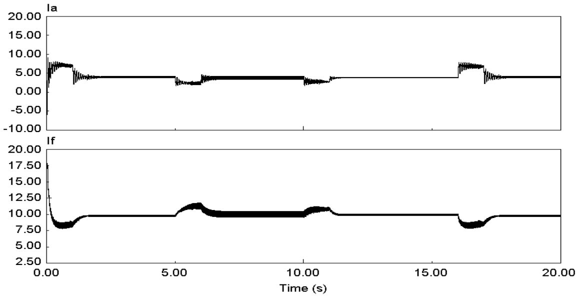
Fig. 13 Armature voltage waveform for 50rpm

Fig.13 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).

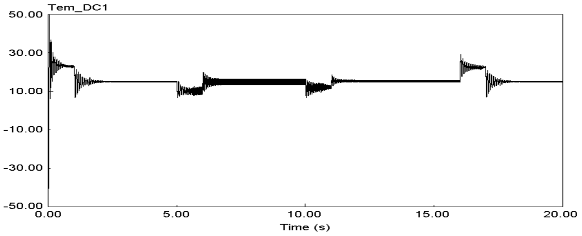
Fig. 14 shows the motor response for the different reference speed condition with the constant 15 N-m load torque and it shows in fig.15 (c) that motor can generate the same motor torque at any speed position and is also shows that motor armature current increases as the load torque increases and field current remains constant for the entire speed range. Fig. 15 (a) shows the actual speed of the motor which follows the reference speed signal as in fig. 15 (b), it shows the dynamic response of the motor which is very fast for the minimum to the maximum speed.



(a). Actual Motor Speed at different Reference Speed



(b). Armature and Field current at different Ref. Speed



(c). Generated Motor Torque at 15N-m Load Torque

Fig. 14 Motor Response at 15N-m load with different Reference Speed

IV. COMPARISION OF DIFFERENT SCHEMES

Table – 1 Comparison of all schemes

Sr. No.		**Scheme-1**	**Scheme-2**	**Proposed Scheme**
1.	Switching Loss	Medium	Low	Medium
2.	Response	Fast	Low	Very Fast
3.	4-Q Operation	Not - Possible	Not - Possible	Possible
4.	Maintenance	Low	High	Very Low
5.	Independent Current Control	Not - Possible	Not - Possible	Possible

V. CONCLUSION

There are various power topologies have been discussed, which can give speed control in both direction but the major problem with the topologies 1 and 3 is the speed reversal of the motor these both schemes required contactors for the speed reversal either across armature or across field winding and those contactors decreases the reliability as well as the efficiency of the drive. Now scheme-2 is suitable for the speed control as well as speed reversal because is uses same semiconductor switches for the control as well as speed reversal but as discussed in the crane drive motor should generate higher starting torque at low speed and for that one have to use scheme which gives independent armature and field current control so at starting with the rated field current one can achieve higher starting torque at low speed, for that requirement the proposed topology is suitable and it also proves the simulation of the proposed topology can work for the independent armature current and field current control.

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