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Cascaded Interleaved Boost Converter for High Power Applications

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Abstract*: This research paper is about proposing and discussing the concept of an interleaved coupled-inductor boost converter for locomotives. Two switches in the proposed converter can be simultaneously switched ON and OFF by interleaving the inductor in the converter. The main advantage of this type is better efficiency, fewer components, and cost. The voltage across the two inductors is altered at the same time by coupling the inductors. This method reduces volume and cost of the circuit. Interleaving topology reduces the current ripples while the cascading method reduces the voltage ripples. Hence the converter functions and efficiency can be improved. The simulation analysis of the proposed converter with different controllers has been studied and verified in this paper.

***Index Terms*: Interleaved Boost Converter, Coupled Inductor**

I. INTRODUCTION

Electric traction is the better resources of transport as a result of its advantages like fast acceleration and deceleration, environment-friendly, also being very economical. Indian Railways contributes a major part of the country's economic growth. As the population increases and also the movement across the country increases, the demand for high power locos increased. At present, Indian Railways using AC traction vehicles, which has two main power electronic components, four single phase line side converter and the 3 three-phase drive side inverters. Due to increase in demand for high power locos, manufacturers started to develop 9000HP and 12000HP locos. Though it is necessary to increase the power density of the traction, the loco's size should not be huge. So to develop a high power density traction system, traction transformer and traction converter have to be optimized. This paper mainly focuses on the traction converter part. The two main stages of power conversion in the traction converter could be found in the general layout of whole electrical traction system. The first stage of power conversion is converting the AC power from the Over Head Equipments (OHE) lines into DC power by using the rectifiers. The second stage power converter converting the DC supply power into a variable voltage and variable frequency to drive the traction motors. In between the two converters, a DC power stage is present, it has a capacitor and tuned filter (LC filter) to reduce the harmonics in 1Φ rectifier system. It is also responsible for the discharge mechanism and equipment protection.

The main purposes of the DC power stage in the Rectifier-inverter system are [1]

(a) The power from rectifier at the front end converter oscillates 2 times the frequency of supply line. Hence this DC- link will act as a buffer in this condition.
(b) This DC link supplies the inverter current at the frequency equivalent to switching frequency of the semiconductor devices.
(c) And it stops the pulse harmonics from inverter current which get injected and pollutes the OHL.
(d) During transients, power semiconductor device may be subjected to high voltage, hence to protect the inverter DC link is used.
(e) Also to supply the traction in case turnouts which commonly occur when panto spring up and slip for a small interval.

Hence it is understood that foremost component of the system is line capacitor in DC line. This project is done in the view of, when capacitance required is decreased, the size and cost of converter also get decreased. Many researchers were done in developing the power superiority of the traction system. To achieve the high-speed railway with less harmonic suppression, the parameter of the filter design 1Φ LCL type 3 level rectifiers is studied. Higher harmonic LCL filter more appropriate for elevated power and small switching frequency application [2]. A multichannel DC to DC converter with a midway transform link of the elevated frequency scheme will improve the power quality and provides rigid external characteristic [3].

II. WORKING

In the proposed converter, a cascaded filter is used in the DC linkage stage. Within this DC link, the volume of the capacitor is resolute by the bandwidth of on the outside control loop. A latest current reference value is generated in the supply side converter. To meet the latest power demand, the current reference value suddenly gets increased. Now, the capacitor in the DC linkage voltage will compensate the excess power required by motors. To maintain the power balance after the voltage falls across DC linkage, the on the outside voltage loop increases the current reference. Once the rectifier current increases, DC linkage voltage renovate the previous reference value.

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Before this link side converter current gets increased, the motor side converter takes more current, hence capacitor in the DC link has to discharge to supply that current. The duration of power and the capacitor value in the equilibrium between the converters decide the amount of voltage dip. High voltage dip has an adverse effect on loss of regulation. If the power in balance is more, then the converter requires a large capacitor. Before rectifier responds, the power flow path changes and DC linkage capacitor absorbs energy from the driver side. So if the capacitor is not pretty large enough, then DC linkage voltage gets increased to a small number of 100 volts, it can possibly spoil the power semiconductor devices in the circuit. In this paper, interleaving and cascading is done with the filter to improve the converter efficiently. In this type, a C-filter and π-filter is cascaded in the DC-link stage. Interleaving is mainly done to condense the harmonic contents in OHE line [4], with no growing up the switching frequency. Also by cascading the filters, voltage ripples at the end of DC link will get reduced.

III. BLOCK DIAGRAM

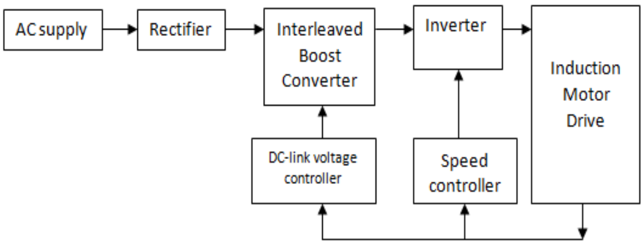

Fig. 1 Block Diagram

In the given block diagram simple Interleaved Boost Converter is introduced between the rectifier and inverter circuit. This boost converter is mainly to boost the level of DC voltage from the rectifier output. By adding the DC link, two controllers are used in the given system. Hence the control over the power circuit can be improved.

IV. CIRCUIT DIAGRAM

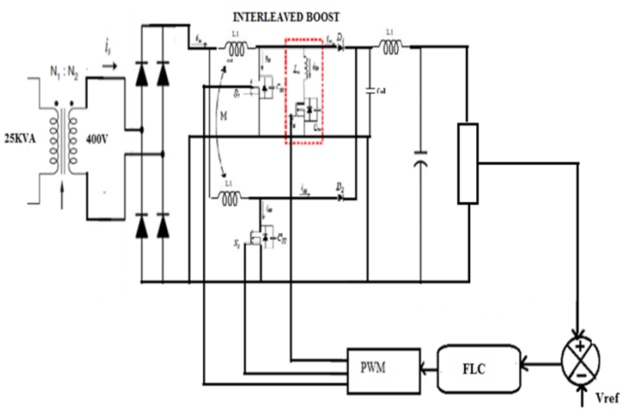

Fig.2: Circuit diagram of the closed loop with controller.

Fig.2 displays the circuit diagram of the cascaded interleaved boost converter with the controller block. The cascaded block contains a C-filter and a π-filter in parallel. This set up mainly reduces the voltage ripples in the output.

V. SIMULATION ANALYSIS

The High step up converter with a 3Φ inverter is simulated in both open and closed loop, without disturbance and the results are taken using MATLAB simulink. The output parameters are displayed by the Scope. The experimental circuits and their results of high step up converter with a 3Φ inverter in closed loop and open loop systems are given below.

A. Open loop circuit of high step up converter with a three-phase inverter using C-Filter without disturbance:

The simulated diagram of open loop circuit of high step up converter with 3Φ inverter using C- Filter with Motor load is shown in figure 3. And its output parameters are measured.

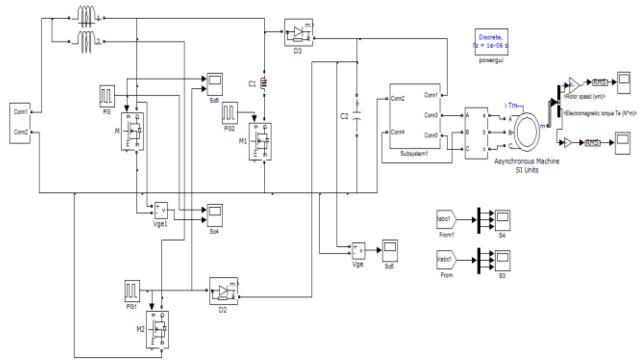

Fig.3: High step up converter with a 3Φ inverter using C-Filter

The figure 4 shows the input voltage of high boost converter with a 3Φ inverter using C-Filter with motor load. The rectifier output voltage is displays in figure 5, the high step up converter's output voltage is displays in figure 6 and the output ripple voltage is displays in figure 7.

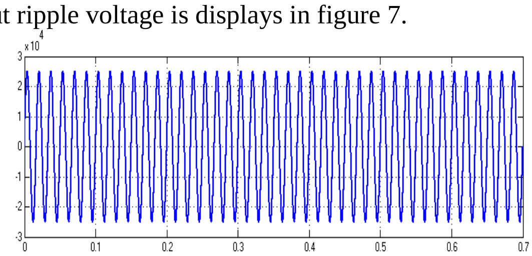

Fig 4: Input voltage

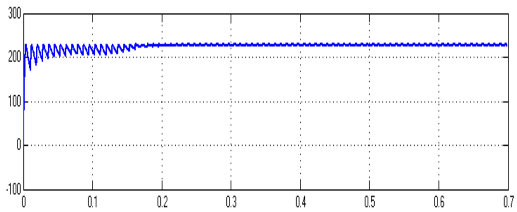

Fig.5: Rectifier Output voltage

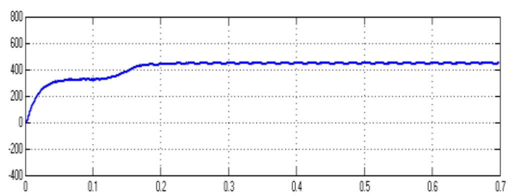

Fig.6: High step-up converter's Output voltage

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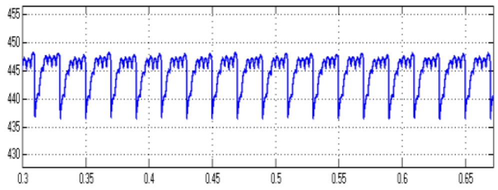

Fig.7: Voltage ripple

B. Open loop circuit of high step up converter with a three-phase inverter using cascade Filter without disturbance:

The simulated diagram of open loop circuit of high step up converter through a three-phase inverter using Cascade-Filter with Motor load is shown in figure 8. And its output parameters are measured.

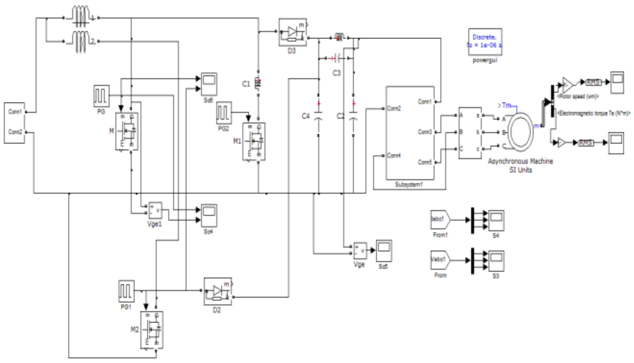

Fig.8: High step up converter with a 3Φ inverter using Cascade Filter

The figure 9 shows the input voltage of High step up converter with 3Φ inverter using cascade filter with motor load. The figure 10 displays the output voltage of the rectifier and figure 11 and figure 12 displays output voltage of the elevated step up converter and voltage ripple of the output respectively.

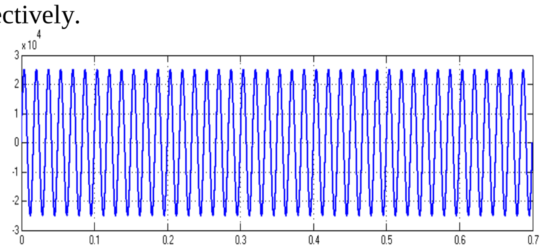

Fig.9: Input voltage

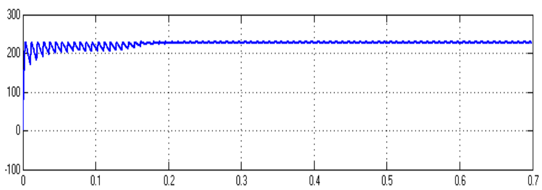

Fig.10: Rectifier Output voltage

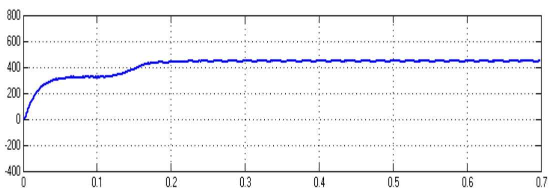

Fig.11: Output voltage of the converter

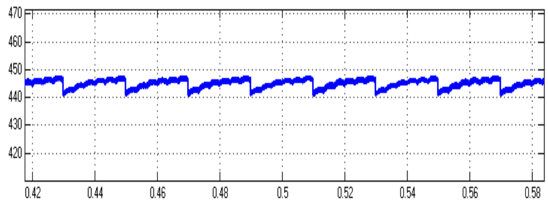

Fig.12: Voltage ripple

Table -I

Comparison of time domain parameters

High step-up converter	Voltage ripple
C-Filter	10V
Cascade-Filter	5V

From the above results, the output voltage ripple is very less in cascade-filter. And also choosing the cascade filter is used for the closed loop circuit for different controllers.

C. Closed loop circuit of high step up converter with a three-phase inverter using PID Controller:

The simulated diagram of closed loop circuit of a elevated step up converter with a three-phase inverter using PID controller with Motor load is shown in figure 13. And its output parameters are measured.

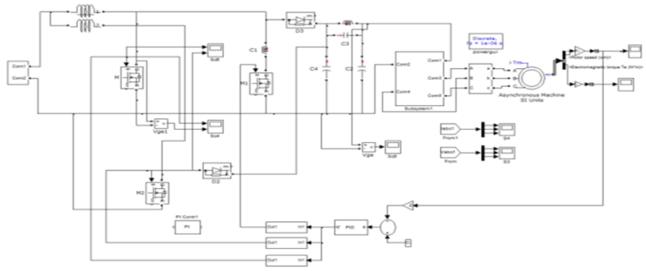

Fig.13: High step-up converter with a three-phase inverter using Cascade Filter

The output voltage and output current of the inverter of high step up converter with a three-phase inverter using cascade filter with motor load are displays in figure 14 & figure 15. The figure 16 displays the speed of the motor and figure 17 displays the torque of the motor.

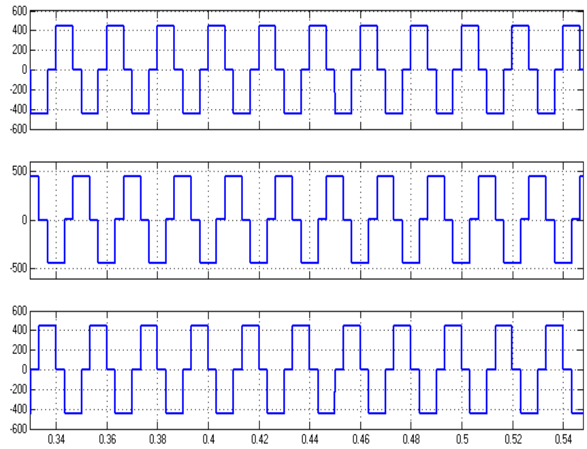

Fig.14: Inverter's Output voltage

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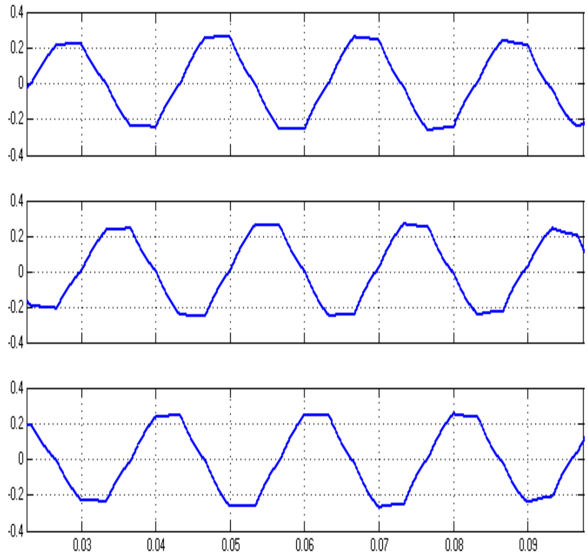

Fig.15: Inverter's Output current

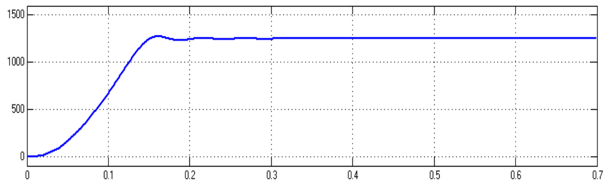

Fig.16: Motor speed

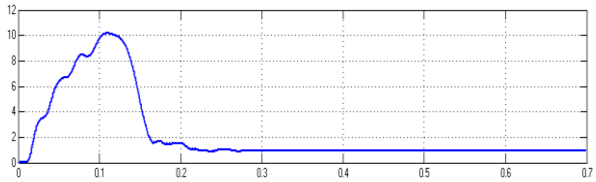

Fig.17: Torque

D. The closed loop circuit of high step up converter with a three-phase inverter using FOPID Controller:

The simulated diagram of closed loop circuit of high step up converter with a three-phase inverter using FOPID controller with RLE load is displays in figure 18. And its output parameters are measured.

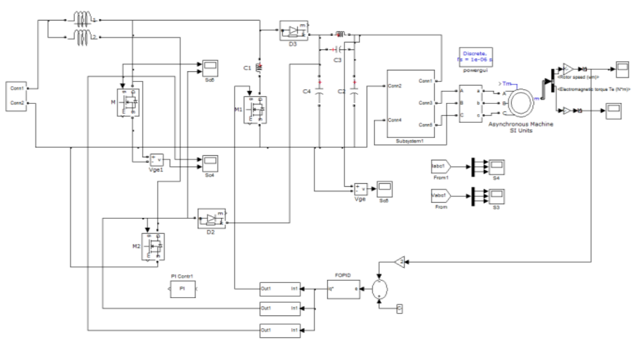

Fig.18: Closed loop with FOPID controller

The figure 19 and figure 20 displays the output voltage and output current of the DC-AC converter of high step up converter with a three-phase inverter using cascade filter with motor load. The figure 21 displays the speed of the motor and figure 22 displays the torque of the motor.

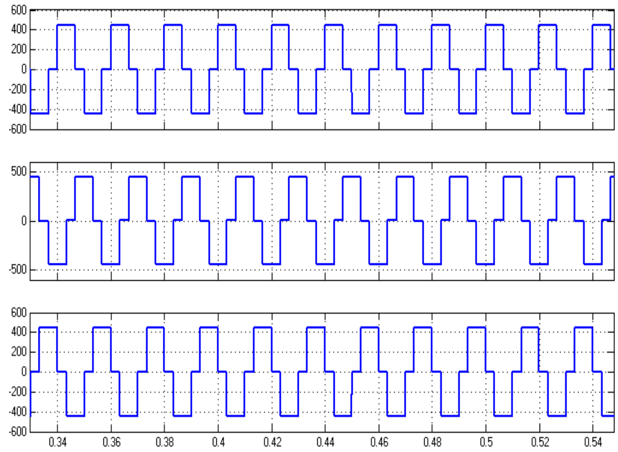

Fig.19: Inverter's Output voltage

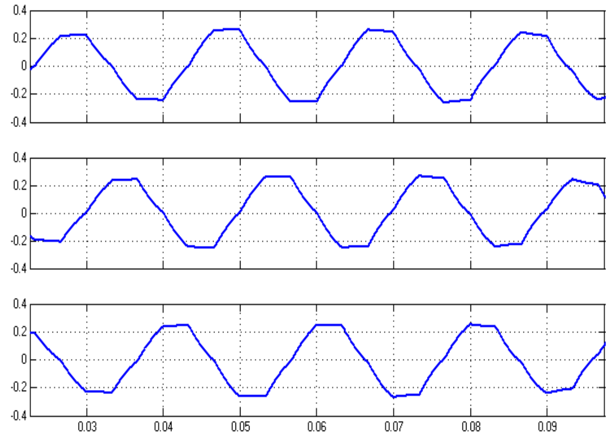

Fig.20: Inverter's Output current

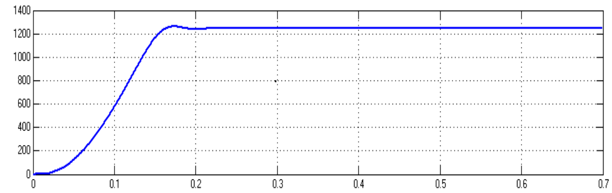

Fig.21: Motor speed

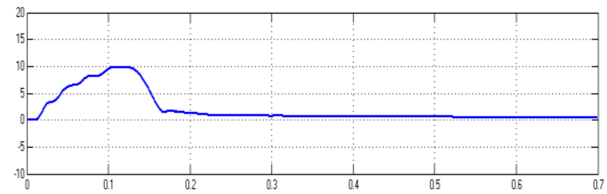

Fig.22: Torque

Table - II

Comparison of time domain parameters

Types of Controller	Tr	Tp	Ts	Ess
PID	0.16	0.19	0.26	1.8
FOPID	0.14	0.16	0.18	0.8

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From the above results, the FOPID controller is best controller. Because in this controller the rise, settling time and peak overshoot is very less. So FOPID controller is very best controller for zeta converter.

VI. EXPERIMENTAL SETUP

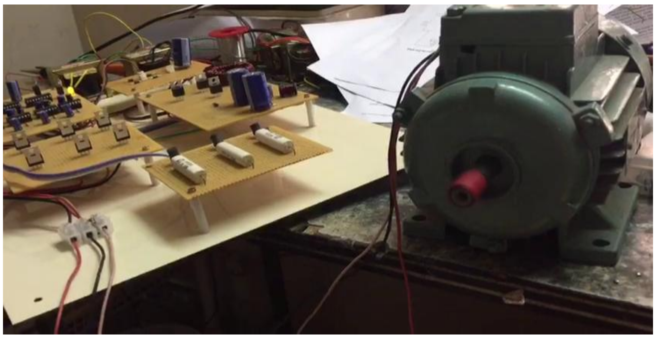

Fig.23: Experimental setup of High step-up converter with a three-phase inverter.

VII. SUMMARY AND CONCLUSION

In this expose, the interleaving on supply side converters and its effects on the system have been studied in view of reducing the voltage and current ripples in turn to get better the speed and torque of an induction motor used. Simulation analysis of FOPID and PID controller is presented. By comparing these two controllers, we can conclude that FOPID provides the motor to achieve the settling time to be earlier than the PID controller. This minimizes the error in the time domain parameter calculation. Also in open loop simulation by using ILBC we reduced the voltage ripple (compare with C-filter or π-filter). The proposed control proposal shows its competence in improving the power quality of the traction system.

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