Reduction of Common Mode Voltage in PWM Rectifier Fed Motor Drives

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ABSTRACT

A common-mode (CM) filter based on the LCL filter topology is proposed in this project, which reduces the magnitude of the common mode voltage. The CM filter makes use of the components of a line to line LCL filter, which is modified to address the CM voltage with minimal additional components. This leads to a compact filtering solution. The CM voltage of an adjustable speed drive using a PWM rectifier is analyzed for this purpose. The filter design is based on the CM equivalent circuit of the drive system. The filter addresses the adverse effects of the PWM rectifier in an adjustable speed drive. Guidelines are provided on the selection of the filter components. Different variants of the filter topology are evaluated to establish the effectiveness of the proposed circuit. Experimental results for the CM voltage measurement on the motor side with multi level inverter and PWM rectifier with LCL filter topology are presented. These results validate the effectiveness of the filter.

Keywords – Common mode voltage, LCL filter, Active front end rectifiers, parasitic capacitance, dv/dt filter.

I. INTRODUCTION

Present day IGBT based power adjustable speed drives have fast turn-ON and turn-OFF time results in high dv/dt being applied to the motor terminals. The high dv/dt switching waveforms along with travelling wave effects of long cables stress motor insulation, cause high ground currents and affects the motor bearings. The main cause for the occurrence of a shaft end to end voltage in an inverter-driven motor is the voltage-source PWM inverter employing the latest trench-gate insulated-gate bipolar transistors (IGBTs) which brings high-frequency common-mode and differential-mode voltages to the motor terminals.

These issues are exacerbated in PWM Active Front End (AFE) rectifier based motor drives when compared to one using a diode rectifier. Hence there are problems associated with IGBT technology based ASD with AFE rectifier using long cables. The common mode voltage due to such motor drive with AFE rectifier is a significant issue today. An integrated approach for filter design is discussed herein the adverse effects of both AFE rectifier and the drive inverter are addressed on both common and differential mode basis. The proposed topology addresses the problems of common mode voltage, common mode current and voltage doubling due to ASD. The design procedure for this proposed filter topology is discussed with simulation results that validate the effectiveness of the a technology based Adjustable Speed Drives (ASD) using Active Front End (AFE) converter is widely used today. Advantages of using IGBT based power converter are as following,

- High switching frequency.
- Smaller turn-ON and turn-OFF times, this reduces switching losses.
- Advance PWM techniques can be used for control.

Some of the applications require long cable between the motor and the power converter. In this case it has been observed that the voltage at the motor terminal doubles during switching transients as compared to voltage at inverter end.

Also the high dv/dt at the inverter end due to faster turn-ON and turn-OFF times leads to problems.

- Increased ground currents apart from voltage doubling at motor terminal.
- Bearing damage and insulation failure at load end.
- EMI/EMC concerns.

The DC bus energized using three phase diode bridge rectifiers injects lower order harmonics into grid. When this is not desirable along with the need for regenerative capabilities, AFE converter is a suitable alternative.
II. FILTER DESIGN OBJECTIVES

The design of ASD has to account the electrical noises introduced by modern PWM converters. This demands end to end solutions, wherein the electrical noises are minimized or eliminated with suitable filter topology as an integral part of the ASD system. The filter has to address both common mode and differential mode components. The design procedure needs to be independent of the load, but in most cases the load has to be considered to effectively mitigate the problem.

Further to address deleterious effects of CMV the presence of AFE converter has to be taken into account and retain the electrical noises generated within the system. This adds to the complexity of designing the filter. The filter design here address two aspects,

- Elimination of voltage doubling at motor terminal and minimizing CMC.
- To eliminate the CMV effects of AFE converter on the load and restrict the electrical switching noise within the ASD system.

II.1. Design Objectives for Motor Filter

The key aspects of this design are,

To eliminate the voltage doubling at the motor terminal by varying the $dv/dt$ of applied voltage.

To reduce the size and cost of the filter such that it can be integrated with the power circuit of the converter.

- Minimization of CMC.
- Easily scalable for high power drives without increasing the cost and size of the filter significantly.

To meet the aforementioned constraint a $dv/dt$ filter is used. The filter addresses both common mode and differential mode noise with slight modification of topology.

II.2 Design Objectives for Common Mode Dc Bus Filter

To address the CMV due to AFE converter capacitors are introduced between DC bus positive rail to ground and negative rail to ground which eliminates common mode voltage. The key design aspects for the proposed common mode filter is,

- To eliminate the CMV propagation to load side due to AFE operation, thereby eliminating the increase in CMC current.

To circulate the switching and lower order harmonic current within the system allowing advance PWM techniques to be adopted for AFE operation.

III. BLOCK DIAGRAM DESCRIPTION

III.1 LCL Filter

LCL Filter has been widely used for harmonic suppression in power system converters, especially at high power conditions. For instance in the 27.5kv locomotive co-phase traction power, the railway power quality conditions is a back to back converter and LCL filter is preferred to suppress the harmonics injected.

III.2 PWM Inverter

Pulse width modulation or PWM technology is used in inverter to give a steady output voltage of 400 or 220 or 110v AC irrespective of the load. The inverter based on the PWM technology is more superior to the conventional inverter. The use of MOSFETs is the output stage and the pwm technology makes these inverter ideal for all types of load . In addition to the pulse width modulate the pwm inverters have additional circuits for production and voltage control. The quality of the inverter output waveform is expressed using Fourier analysis data calculate the total harmonic distortion (THD).

Based on the output waveform, there are three types of inverter. There are

1. Sine wave
2. Modified sine wave or quasi sine wave and
3. Square wave inverter.

III.3 $dv/dt$ filter

$dv/dt$ filter provide a slower voltage rise rate on the motor terminal phase to phase voltage which is particularly important when using shorter motor cable. The higher the level of inductance, the higher the voltage peaks, which can cause flashover, a condition that results in premature...
breakdown of the winding insulation of the connected motor. Following some of the applications are

- Greater motor longevity through lower dv/dt stress
- Reduced transmission of EMI to surrounding cables and equipment
- Trouble-free operation

IV. SIMULATION RESULTS AND DISCUSSION

Fig. IV.1 Schematics of an active front end motor drive with integrated LCL and DC bus common mode filter for grid and dv/dt filter at inverters terminal for motor.

Fig. IV.2 Reduction in Common mode voltage using an LCL filter topology

Fig. IV.3 Measurement of common mode voltage in two level inverter configurations

Fig. IV.4 Measurement of common mode voltage in multi level inverter configuration
Table IV.1 CM voltage in various methods employed.

<table>
<thead>
<tr>
<th>Method</th>
<th>CM voltage</th>
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<tbody>
<tr>
<td>Three phase inverter fed induction motor drive</td>
<td>100 volts</td>
</tr>
<tr>
<td>Multi level inverter fed induction motor drive</td>
<td>81 volts</td>
</tr>
<tr>
<td>Three phase inverter fed induction motor drive with LCL filter topology</td>
<td>36 volts</td>
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</table>

While simulating a multi level inverter to measure the common mode voltage, it is found that the common mode voltage is reduced to 81 volts. This accounts for 54% of the output voltage. With further increase in the number of levels the common mode voltage goes on decreasing. But in this method the increase in number of devices for each level is high when compared to the reduction in common mode voltage. Hence usage of LCL filter topology is found to be more effective in reducing the common mode voltage.

V. CONCLUSION

The overall filter design procedure to address the CM voltages is outlined for a PWM rectifier-based ASD. Analysis of the filter with capacitors $C_y_1$ and $C_y_2$ is discussed based on the CM equivalent circuit. The CM dc-bus filter restrains the high-frequency CM voltage, due to the PWM rectifier, from affecting the load. Variants of the filter topology are evaluated to check the effectiveness of the proposed solution. The proposed filter topology keeps the switching current components along with third-harmonic current components that occur due to advanced PWM techniques, within the power converter. The switching frequency components are effectively filtered on the voltage between the dc bus and the ground. Additionally, there is no need of large over sizing the LCL filter inductors because the third-harmonic circulating current is reduced.

This work can be extended to the selection of appropriate PWM methods in drives that have low CMV requirements. Development of a more embedded design procedure taking into account the conducted EMI disturbances is also under research. However, this will be strongly dependent on the ongoing standards in the field and on the limits they will impose on the switching ripple injection in the grid, and is left for future investigations.

REFERENCES