

DC Bus Voltage Clamp Method to Protect Over-Voltage & Insulation Failures in Adjustable Speed Drives

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Abstract - This project investigates the effect of PWM switching and long cable length on the voltage insulation components inside an adjustable speed drive (ASD). This project shows that high potential voltage insulation issue may exist on various components inside the ASD and cause earlier failures under very long cable or multiple drive conditions. A system model to describe this phenomenon is described in the project. A dc bus voltage clamp circuit is proposed to reduce these voltage stresses. The effectiveness of this circuit is verified by both simulation and experimental results.

I. INTRODUCTION

Nowadays, the physical sizes of the ASD drive and its high voltage components have been reduced dramatically to remain competitive. Typical ways of reducing drive size is to replace the bus bars with printed circuit board (PCB), to integrate high voltage component with low voltage circuitry, to shrink the component sizes, and to reduce or remove unnecessary components. All above optimizations may increase voltage stresses of these components and cause unexpected voltage failures.

A simple dc bus voltage clamp circuit is introduced to help reduce the voltage stresses. This circuit has the minimum number of components:-two diodes; one capacitor; and one resistor. It clamps the voltage stresses of the ASD components to slightly higher than dc bus voltages. One advantage of this circuit is that it only operates when the GND is higher than dc+ or is lower than dc-. The wattage losses of the overall system and the voltage ratings of the discharging capacitors can be very low. Simulation results are provided in the paper to verify the effectiveness of the circuit.

A. Adjustable speed drives

Adjustable speed drive (ASD) or variable-speed drive (VSD) describes equipment used to control the speed of machinery. Many industrial processes such as assembly lines must operate at different speeds for different products. Where process conditions demand adjustment of flow from a pump or fan, varying the speed of the drive may save energy compared with other techniques for flow control. The speeds may be selected from several different pre-set ranges, usually the drive is said to be adjustable speed. If the output

speed can be changed without steps over a range, the drive is usually referred to as variable speed.

B. Voltage stresses in adjustable speed drive

High voltage components and their voltage stresses in asd drive one characteristic of ASDs is to use low voltage control signals to control high voltage switching devices. Based on their functionality, there are two types of high voltage components.

The first type of components are the main circuit components that transfer power from line to load side, including inverter IGBT, rectifier diode/SCR, dc link choke, dc bus capacitor, snubber capacitor, and etc. They are all located in the differential mode (DM) circuit and their voltage stresses are generally no higher than the dc bus voltage. Selection of voltage ratings for these components is straightforward.

The second type of components provide protective separation between the control circuit and the main circuit, including opto-coupler, PCB, sensors, voltage/current transducer, switch mode power supply (SMPS) transformer, and etc. The high voltage (HV) sides of these components are either no higher than the positive bus or no lower than the negative bus. The low voltage (LV) sides are the control voltage that is very close to GND voltage. Therefore, the insulation voltage of the protective separation component can be approximated as the voltage between GND and the dc bus terminals. Selection of the voltage ratings for these components may be influenced by the operating condition heavily.

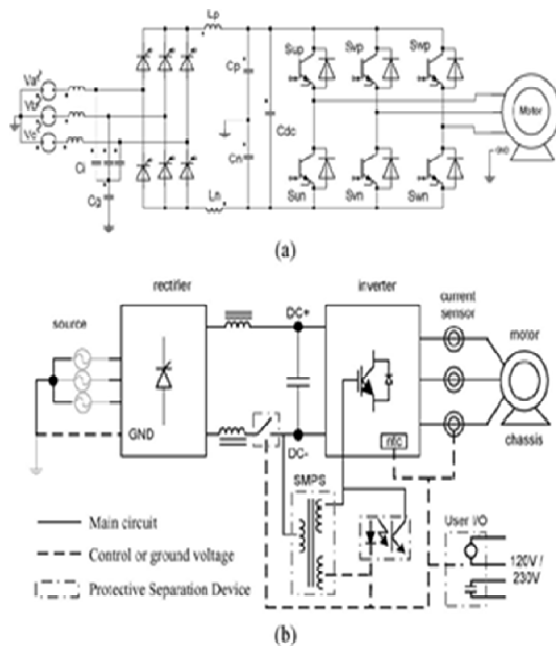


Fig.1 Schematics of a standard ASD with common mode and cable models:
 (a)Diagram of an ASD drive with SCR front end; (b) Components that are exposed to high voltage stresses

C. Differential Mode Voltage between DC Bus Terminals to the GND

The voltage stresses between the ground and the dc bus terminals can be calculated by adding the common mode and differential mode components. For the differential mode circuit, this voltage stresses can be approximated as half the dc bus voltage for a Y grounded system.

$$V_{pgpk_DM} = \frac{V_{dc}}{2}; \quad V_{ngpk_DM} = -\frac{V_{dc}}{2}$$

Where V_{pgpk_DM} is the maximum voltage between positive dc bus and the GND in differential mode circuit, V_{ngpk_DM} is the minimum voltage between negative bus voltage and the GND in differential mode circuit. For a corner grounded system, the maximum voltage stresses between dc bus terminals to the GND can be as high as dc bus voltage between positive bus and the GND and as low as negative dc bus voltage between negative bus to the GND as shown in differential mode circuit

$$V_{pgpk_DM} = V_{dc}; \quad V_{ngpk_DM} = -V_{dc}. \quad (2)$$

D. Common mode voltage in inverter-driven ac machines

In a three-phase AC system, the common-mode voltage can be defined as the voltage difference between the power source ground and the neutral point of a three-phase load. If the load is an AC motor, the neutral point of the load means the stator neutral of the motor

In a three-phase AC system, the phase to ground voltage can be written as the sum of the voltage from phase to the neutral point of the load and the neutral point of the load to system ground. As per the definition, the common mode voltage is the voltage across the neutral point of the load and the system ground. Since in a balanced system, the sum of all three phase-to-neutral voltages is zero, the voltage from neutral to ground (common-mode voltage) can be defined in terms of phase to ground voltage.

In inverter-driven AC machine, there exists a common-mode voltage because the voltage source inverter does not constitute an ideal balanced source. In an inverter-driven system, the common mode voltage (V_{com} or V_{N-G}) can also be defined as the voltage across the stator neutral (N) and the DC bus mid-point (M) because from a high-frequency viewpoint, the DC bus mid-point (M) is same as the electrical ground (G) of the system. The common mode current (i_{com}) is defined as the instantaneous sum-total of all the currents flowing through the motor cable and inside the motor are the paths of this current, and a source of EMI noise problems

E. Proposed method dc bus voltage clamp method

The projects have deals with a protective circuit that may be used to provide over voltage protection for an ASD. The protective circuit provides the benefits of fewer components with lower power ratings than existing protective circuits. This protective circuit may be incorporated directly in the ASD for continuous protection or mounted externally and connected to the ASD under the operating conditions that require the circuits. This flexibility for mounting the protective circuit allows the capacitor of the protective circuit to be sized either in relation to capacitive elements on the DC bus within the ASD or according to external capacitance observed at the output of the ASD. In addition, the circuit is only operative during an overvoltage condition, allowing for power ratings lower than would be required for continuous operation

The power supply having a DC bus providing a DC voltage across a positive and negative bus rail. The DC bus is connected to one or more inverters which provide power to windings of an electric motor. The DC bus has at least one capacitive element connected across the positive and negative bus rails. This circuit for reducing electrical transients on the DC bus including at least one damping element having a resistor and a damping capacitor connected in parallel with the resistor. A first and a second diode are connected in series with a damping element between the common point and the positive and negative bus rails, respectively. The

direction of conductance of the first diode is from the common point to the positive rail, and the direction of conductance of the second diode is from the negative rail to the common point.

The damping circuit is used to reduce electrical transients across the capacitive elements of a DC bus. The diode connected in series with the damping element as a switch to engage the damping circuit only when it is needed, allowing for lower power rating on the damping circuit components.

F. Block diagram

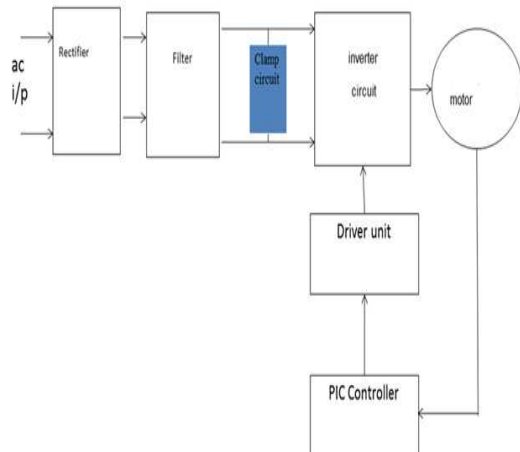


Fig.2 Block diagram of the proposed method

II. PROPOSED VOLTAGE CLAMP METHOD

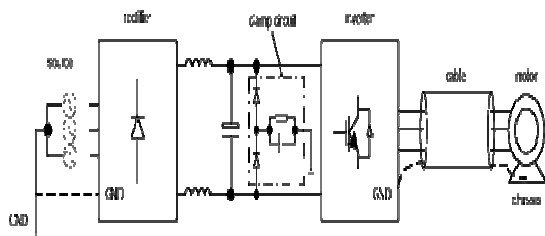


Fig 3. proposed voltage clamp circuit

The Fig 3.shows the proposed voltage clamp circuit for an ASD drive. It consists of three types of components.Two diodes clamped between the positive and negative bus voltage. A clamping capacitor between the neutral of the two diodes and the GND. The snubber capacitance is generally selected to be higher than the common mode capacitance of the cables and motors. The leakage inductance between the capacitor to the dc bus terminal should be designed as low as possible.

A discharging resistor in parallel with the clamping capacitor.

III. MODES OF OPERATION

There are three operation modes of the clamp circuit.

- 1) Standby mode
- 2) Clamping mode
- 3) Discharging mode

A. Standby mode

During normal condition, the voltage of the GND is always lower than the dc+ and higher than dc-, both diodes are anti-biased. The voltage across the RC snubber circuit is zero as shown in Fig.4.The voltage difference between GND and bus terminal is less than $V_{dc} = V_{dc+} - V_{dc-}$.

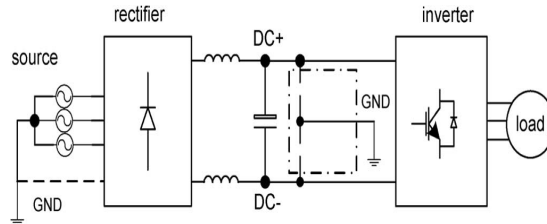


Fig 4. Standby mode

B. Clamping mode

If the GND is either higher than dc+ or lower than the dc-, one of the diode starts to conduct. The common mode energy will be transferred to the RC snubber circuit, since the capacitance of this snubber circuit is selected to be much higher than the overall cable and motor common mode capacitance. The potential of the GND will be clamped to one of the two dc bus voltages (dc+ or dc-). Fig.5.shows a circuit diagram at this mode when V_{gnd} is higher than V_{dc+} . The voltage difference between GND and bus terminal is slightly higher than $V_{dc} = V_{dc+} - V_{dc-}$.

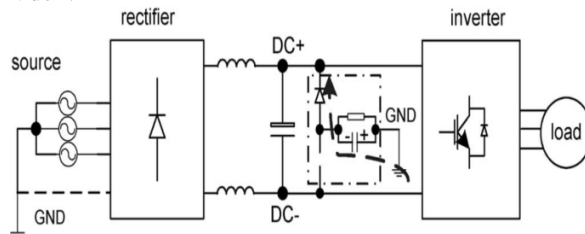


Fig.5. Clamping mode

C. Discharging mode:

After the PWM switching transient is over, the GND potential is low than dc+ and higher than the dc-. Both diodes return to off condition. The energy of the snubber capacitor is now discharged by the snubber resistor. After all energies are discharged, the system goes back to standby mode. The voltage difference between GND and bus terminal is still less than $V_{dc} = V_{dc+} - V_{dc-}$.

IV. SELECTION OF CLAMPER ELEMENTS:

Follow these tips when fine tuning the clamping snubber:

The diode selection is critical, make sure that the diode can handle a voltage greater than any of the spikes in the circuit, and that it can handle the peak current. It's better to over-specify this one component from the start.

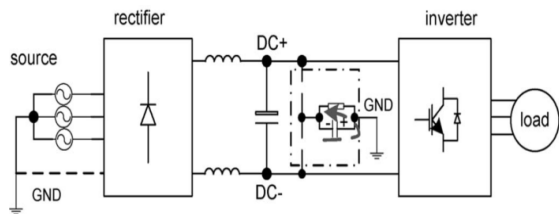


Fig.6. Discharging mode

Monitor the voltage between the diode and the resistor. This should be a nearly DC value. If it is chopped then either the capacitor is too small, or the diode has too low of a voltage rating.

There is a tradeoff between the clamp voltage and the power that the circuit dissipates. The lower the snubber voltage, the hotter all of the components will get. Make sure the capacitor has a high voltage rating. The rating must be greater than the expected clamping voltage. Adjust the clamping voltage by raising or lowering the resistance, with all other components fixed.

A. Advantages

The proposed method has the following advantages.

It has the minimum number of components, only two diodes and a RC snubber circuit is needed.

The voltage across the capacitor is zero majority of time, the voltage stresses on the clamped capacitor is much lower than other topologies.

The circuit only starts to operate when the GND potential is higher than dc+ or lower dc-. The wattage losses of the discharging resistor can be much lower than any other circuit that operates all the time.

B. Design of snubber circuit

The voltage equation is given by

$$V_s = (R_s + R_L)i + L(di/dt)$$

$$L = V_s / (di/dt)_{max}$$

Snubber resistance

$$R = (L/V_s) \cdot (dv/dt)_{max}$$

Snubber capacitance

$$C = (2D/R_s)^2 L$$

Where D is the damping ratio or damping factor

C. Simulation block diagram and result for without clamp system

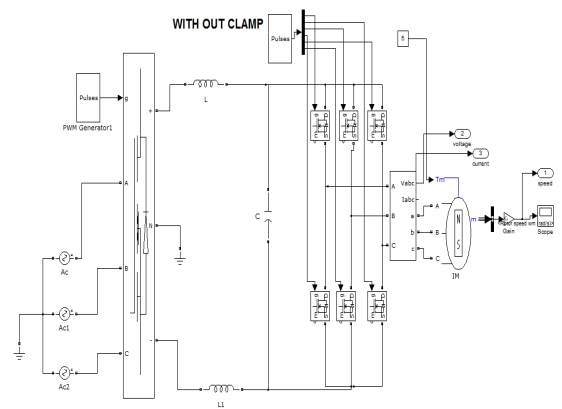


Fig.7. Simulink model for without clamp system

D. Simulation block diagram and result for proposed system

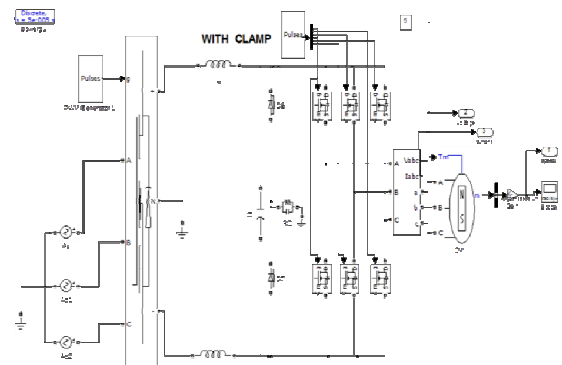


Fig 8 Simulink model for with clamp system

V. CONCLUSION

It should be noted that the main focus of this circuit is to protect the drive component from voltage failure due to PWM switching of the inverter. For all above cases, the voltage stresses between dc bus terminals to the GND are much higher than the dc bus voltage without the clamp circuit. After the clamp circuit is added, the voltages are slightly higher than dc bus voltage. The effectiveness of the circuit is clearly verified through the simulation result.

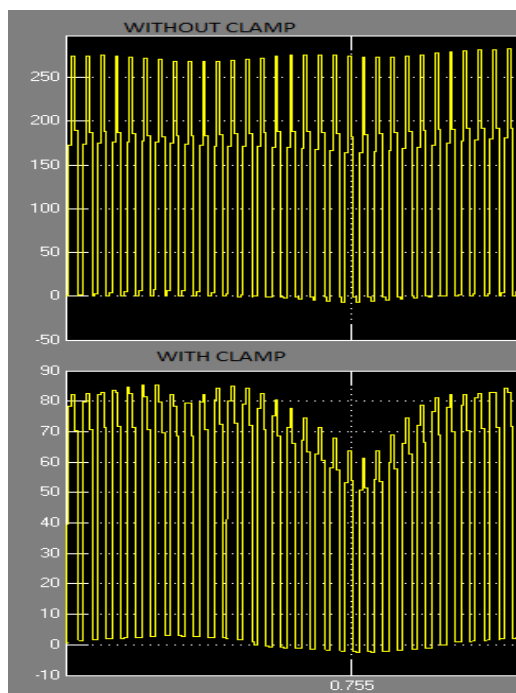


Fig 9. voltage stresses of dc+ to GND comparison

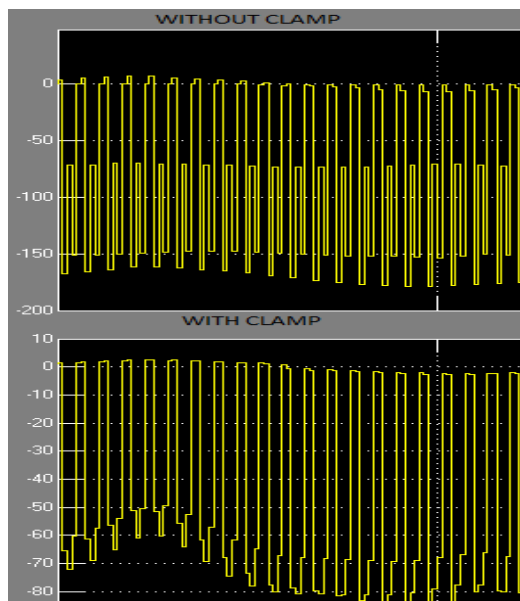


Fig 10 voltage stresses of dc- to GND comparison

VI. REFERENCES

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