Common-Mode Noise Reduction with Two Symmetrical Three-Phase Inverters

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Abstract—In recent times, more than 60 percent of the world’s energy is used to drive electric motors. Because of the growing requirements of speed control, pulse width modulated (PWM) inverters are widely used in adjustable speed drives. Noise generated by PWM inverter fed AC motor drive systems causes severe parasitic current problems, especially at the cases of high frequency. This paper proposes two new methods to reduce common mode noise current generated by Inverter fed AC motor systems. The effect of two proposed methods have been verified by simulation and experiment. The results of simulation are very perfect because the common-mode voltage and the common-mode current are almost be reduced to 0V and 0A.

Keywords—common-mode; conducted-noise; balance; symmetrical circuit; Current-cancellation

I. INTRODUCTION

PWM inverter-fed AC motor drive systems are widely used in many industrial and large household electrical appliances. Increasing power density and decreasing cost and size of system are market requirements. The increase of the carrier frequency of PWM inverters intensifies the problems caused by the non-negligible amount of high-frequency leakage current (i.e., noise current). Hence, noise is the key factor needed to be considered before designing the optimization of a drive system.

In inverter-fed AC motor systems, PWM inverters have been found to be a major cause of motor bearing failures in inverter motor drive systems.

As shown in Fig. 1, all inverters generate common-mode voltages \(V_N\) relative to the ground, because the switching operation in one phase of the inverter causes a one-third-fold step change in the dc link voltage in the \(V_N\). Fig.2 shows the common-mode equivalent circuit which will also be used later when we explain the propose methods.

\(V_N\) produces not only common-mode noise current through parasitic stray capacitor electrostatic coupling between output terminals and the ground but also shaft voltage through electrostatic couplings between a rotor and stator windings and the rotor and a frame, which can cause bearing currents when the shaft voltage exceeds a breakdown voltage level of the bearing grease.

However, few studies have addressed this problem. In this study, we propose two new methods that can completely reduce common-mode noise current generated by inverter-fed AC motor systems. The effect has been verified by simulation and experiment.

II. TRADITIONAL METHODS FOR REDUCING COMMON-MODE NOISE

A. Traditional Method 1—Common-Mode Choke

A common-mode choke has been used to reduce the common-mode noise current, which is connected in series between the terminals of the inverter and motor [2]. The configuration of the PWM inverter-fed AC motor system, including a common-mode choke is shown in Fig.3.

The connection of the common-mode choke is effective in reducing the peak value. This method is the most wildly used method.

\[
V_N = \frac{V_u + V_v + V_w}{3}
\]
B. Traditional Method 2---The Active Common-Mode Canceller (ACC) Method

This method has been employed. Fig. 4 shows the configuration of the PWM inverter-fed AC motor system, including the ACC circuit.

First the Y-connected capacitors (Fig. 4) are used to detect the common-mode voltage produced by the inverter. Then, the same detected voltage is applied to the common-mode transformer. Finally, the three primary windings of the common mode transformer (with polarity indicated by dots in Fig. 4) are connected between the output terminals of the inverter and the feeder wires. Therefore, the polarity of the compensating voltage is opposite to that of the \( V_N \) generated by the inverter. As a result, cancellation of the \( V_N \) is performed perfectly and there is no flow of common-mode current. [3]

C. Disadvantages of the Traditional Methods

- The traditional method 1 can reduce the common-mode noise current but cannot inhibit the generation of common-mode noise. Therefore, a small amount of aperiodic ground current still remains.
- The ACC method completely cancels the common-mode noise current but its disadvantages are equally notable:
  1. Needs to use amplifier circuit and external power supply.
  2. Uses active components. Due to the capacity of resisting pressure of the active components, the applicable voltage range of ACC method is limited.
  3. Uses capacitors to detect the \( V_N \). These capacitors cause surge current which can easily destroy electronic components.

In order to overcome these disadvantages, we propose two new methods for reducing the common-mode noise completely without using active components.

III. METHOD FOR REDUCING NOISE CURRENT GENERATED BY PARASITIC CAPS IN INVERTERS

We propose two new methods to solve the problems resulting from the common mode voltage.

A. Proposed Method 1

Fig.5 shows the system configuration of proposed method 1. This method is based on the theory that by using two inverters and two motors, a vertically symmetrical circuit will be formed. In additional, the control signal of the two inverters will differ from each other by 180°. The noise generated from the upper inverter will be absorbed by the lower inverter, which will result in the cancellation of noise inside the circuit instead of leaking it to the ground.

Thus, by this theory, the reduction of common-mode noise can be achieved. The equivalent circuit of the common-mode current is shown in Fig.6. The common-mode current of the motor side \( i_{all} \) will be 0A, but the common-mode current flowing through each motor \( i_{mo1} \) has no changes.

If we can combine the two motors into one, the \( V_N \) should be 0V, i.e., can inhibits the generation of common-mode noise. The following relationships operate in this method:

\[
\begin{align*}
V_{v1} &= V_{v2} \\
V_{w1} &= -V_{w2} \\
V_N &= V_{v1} + V_{v2} + V_{w1} + V_{w2} + V_{s1} + V_{s2} + V_{s3} = 0
\end{align*}
\]

B. Proposed Method 2

If we cannot combine the two motors into one, in order to reduce \( i_{mo1} \) base on method 1, we propose method 2, as shown in Fig. 7. Method 2 is to add a common-mode noise suppression transformer between the output terminals of the two inverters. The equivalent circuit of the common-mode current is shown in Fig.8. As a result, both the common-mode current of the motor side \( i_{all} \) and the common-mode noise currents of each motor will be reduced.

C. Features of the Proposed Methods

- Without amplifier circuit, external power supply, and capacitor.
- Using two inverters and two motors. As we all know, machines such as trains use two sets of inverter fed AC motors. The proposed method can be easily applied to such situations.
We propose two new methods to solve the problems resulting from the common mode voltage.

A. Verification by Simulation

In order to verify the efficacy of the proposed method, taking into consideration the parasitic capacity, inductance and resister, we conducted a simulation confirmation.

We compared the proposed methods with the case of using one inverter without countermeasure. The carrier frequency is 20 kHz. The magnetizing inductor of transformer is 15mH. The leakage inductor of transformer is 100uH. The Rated capacity of motor is 2.2 kW. The Rated voltage of motor is 200 V. The Rated current of motor is 9.5 A. The observation points of the proposed method 1 are shown in Fig. 5. The observation points of the proposed method 2 are shown in Fig. 6. Fig. 9 shows the simulation results. Fig. 9 (a) shows the results of the case of one inverter without countermeasure. Fig. 9 (b) shows the simulation results of the proposed method 1. Fig. 9 (c) shows the simulation results of the proposed method 2.

\[ i_{all} \] can be reduced from 6 A to almost 0 A.

The results of the proposed method 2 show that this method can reduces not only \( i_{all} \) from 6 A to almost 0 A, but also \( i_{m1} \) and \( i_{m2} \), the common-mode noise current of each motor.

The results show that the proposed two methods are effective.

B. Confirmation by Simulation

Fig. 10 shows the experimental results. Fig. 10 (a) shows the results of the case of one inverter without countermeasure. Fig. 10 (b) shows the experiment results of the proposed method 1. Fig. 10 (c) shows the experimental results of the proposed method 2.

The experimental results of the proposed methods are not very ideal. The results show that in the proposed methods, \( i_{all} \), \( i_{m1} \) and \( i_{m2} \) can be reduced only by half. The reason is supposed to be the difference in the control-signal time of both inverters, which is 100 ns as shown in Fig.11.

V. CONCLUSION

In this paper, two new methods for reducing the common mode noise current have been proposed and confirmed by simulation and experiment. The results of the simulation shows that they can completely reduce common-mode noise current generated by inverter-fed AC motor systems. If we
Fig. 9. Simulation results

Fig. 10. Experimental results

Fig. 11. Time delay between $V_{N1}$ and $V_{N2}$ of the two drivers can combine the two motors into one, the $V_N$ should be 0V, i.e., inhibits the generation of common-mode noise. However, because of the time-delay-difference, the results of the experiment are not as favorable as expected. Our future studies will, therefore, focus on solving this time-delay-difference.

REFERENCES


