Application of common-mode-free control topology to a two-level inverter

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Abstract. The use of asynchronous motors in electric drive systems has become widespread and convenient. Also, since the frequency converters became wide-spread and popular devices, induction motors became the most popular machine type in both constant- and variable-speed applications. However, the conventional two-level frequency converter’s output three-phase waveform is not fully repeating ideal sine waves provided from the grid. The so-called common-mode voltage appears because of specifics of the converter operation and works as the source of harmful parasitic phenomena of bearing currents. Flowing through the motor bearings, these currents providing a list of undesirable effects, finally causing the bearing properties degradation and early system failure. Current paper deals with the novel control method described earlier and show the method implementation by the means of the two-level frequency converter.

1. Introduction

The need to use variable speed electric drive systems in various areas and industries is well understood and indisputable. Since frequency converters have now become widespread and popular devices, the asynchronous motor has become the most popular type of electric machine in installations where it is necessary to provide speed control, as well as in mechanisms with a constant speed. However, the output three-phase voltage of a conventional frequency converter does not completely repeat the form of the mains voltage. The so-called common-mode voltage arises due to the nature of the converter. This common-mode voltage is a form of electromagnetic interference and, in the study of electric machines, mainly acts as a source of harmful parasitic phenomena in the form of bearing currents. The phenomena of current passing through the bearings in electric machines have been a known problem and have been the subject of research for the past decades. This phenomenon as a whole is not a new problem for a modern electric drive. However, supplying non-sinusoidal voltage to electric motors has opened up new ways for the generation of bearing currents. The effect of voltage on the motor shaft and the currents flowing through the bearings were investigated, for example in [1-6].

When passing through the motor bearings, these currents create a number of undesirable effects, which ultimately lead to deterioration of the properties of the bearings and premature system failure. Research and development of various methods for reducing currents in bearings remain an area for further research, while the final solution to this problem has not yet been presented.

Thus, the danger of bearing currents is one of the main drawbacks of modern electric drive systems posed by the need to use an induction motor as an adjustable machine without significantly reducing the reliability of the system. Currently, there are several basic approaches in the fight against bearing currents. Firstly, technical solutions can suppress higher harmonics and the common-mode voltage at
the stage of their origin, that is, in a frequency converter. This can be achieved by changing the design and control algorithms of the frequency converter [7-9]. Secondly, on the way from the inverter to the motor, it is possible to install filters and chokes, which also contributes to the suppression of the common-mode voltage and higher harmonics [10–12]. Thirdly, it is possible to significantly increase the resistance of the paths of leakage currents by minimizing the parasitic capacitances or modifying the bearings themselves [13, 14]. Fourthly, the provision of alternative paths of parasitic current flow, for example, the introduction of shaft grounding devices [15].

This paper addresses the problem of bearing currents using the first approach. In this work, the unconventional topology of the inverter control is considered, which allows excluding the common-mode voltage at the motor terminals. The considered control method has been proposed for implementation on a two-level inverter and allows obtaining an output voltage having three levels instead of two.

2. Common-mode voltage and common-mode-free inverter

According to the basic principles of operation of three-phase networks, in the case of a uniform three-phase load (which is an asynchronous motor), the sum of the phase voltages and currents at each time point is zero. However, in the case of a three-phase power supply via a frequency converter, due to the peculiarities of the two-level inverter operation, the instantaneous sum of voltages, and, accordingly, currents, will not be equal to zero. Common-mode voltage is usually defined as (1) [16]:

\[
U_{\text{com}} = \frac{U_1 + U_2 + \cdots + U_n}{n}
\]  

(1)

A schematic diagram of a two-level inverter is shown in Figure 1. The semiconductor switches S1-S6 operate with interconnected pairs (S1-S2; S3-S4, S5-S6) in such a way that, regardless of the specified vector of magnetic induction in the electric motor, one key is always connected to any DC bus bar while the second key supplying the same phase of the load will be disabled. It turns out that when considering all three phase conductors at the output of the converter, one conductor will always be connected to any DC bus, and the other two will be connected to the opposite bus. Usually, in two-level inverters, a control signal is applied, which has two states that determine to which DC bus the phase conductor of the converter output should be connected. Table 1 shows the switching table of the semiconductor switches S1-S6, depending on the control signal.

![Figure 1. Schematic diagram of a two-level frequency converter](image-url)
Table 1. Interpretation of control signals in a classic 2-level converter.

| Switching signals cases | The semiconductor switch names (according to Figure 1) and their states |
|-------------------------|--------------------------------------------------------------------|
|                        | 1 | 2 | 3 | 4 | 5 | 6 |
| 000                    | off | off | off | on | on | on |
| 100                    | on | off | off | on | on | on |
| 110                    | on | on | off | off | on | on |
| 010                    | off | on | off | on | off | on |
| 011                    | off | on | on | on | off | off |
| 001                    | off | off | on | on | on | off |
| 101                    | on | off | on | off | on | off |
| 111                    | on | on | on | off | off | off |

With this method of regeneration of a three-phase voltage system, expression (1) will obviously take on non-zero values.

3. Application of a phase-free control topology to a two-level inverter

The control algorithm, which eliminates voltage imbalances relative to the neutral point of the output network, can counteract bearing currents at an early stage. Such a control algorithm is described in [17] and involves the use of their difference instead of control signals. The proposed algorithm can be used to control a two-level inverter.

This signal processing algorithm allows us to control the inverter so that at any time only one leg of the converter is connected to the “+” and “-” buses, while the remaining leg remains disconnected from the power supply. Thus, the converter operating in accordance with the specified algorithm will remain free from unbalanced three-phase voltage. As a result of this algorithm, the converter starts working as a three-level converter.

The application of this algorithm to a two-level converter will require changes only in the control part of the converter and the adjustment of the switching table. In contrast to the classical control scheme, to implement the proposed scheme, one should use a control signal of three levels. Let’s call them -1; 0; 1 instead of 0 and 1 - states in the classical control [16]. Such signals should be interpreted as follows. When the “1” signal is sent to the semiconductor key, the key responsible for connecting to the “+” bus is open; The “0” signal does not switch on any of the keys; “-1” signal should be interpreted as a gate opening signal for the key responsible for connecting this phase conductor to the “-” bus (Fig. 1). Table 2 shows the state of the semiconductor switches S1-S6, depending on the control signal when working on the proposed algorithm.

Table 2. Interpretation of control signals in a 2-level converter using the proposed control circuit.

| Switching signals cases | The semiconductor switch names (according to Figure 1) and their states |
|-------------------------|--------------------------------------------------------------------|
|                        | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 0 -1                  | on | off | off | off | off | on |
| 0 -1 1                  | off | off | on | off | on | off |
| -1 1 0                  | off | on | off | on | off | off |
| -1 0 1                  | off | off | on | on | off | off |
| 0 1 -1                  | off | on | off | off | on | on |
| 1 -1 0                  | on | off | off | off | on | on |
| 000                     | off | off | off | off | off | off |
| 111                     | on | on | on | off | off | off |
| -1 -1 -1                | off | off | off | on | on | on |
The important point is the fact that the presented approach requires only modification of the control algorithm without modification of the hardware and power electronics. Along with the fact that three- and multi-level converters remain more expensive [18], the possibility of operating a two-level converter in a three-level mode also provides economic advantages.

4. Conclusion
In this paper, it was considered the problem of currents in the bearings of electric drives, caused by the peculiarities of the operation of the frequency converter. The main cause, called common mode voltage, was identified. After the options for suppressing a negative phenomenon were considered, a solution was proposed at an early stage, based on a modification of the inverter control circuit. The proposed improvement transforms a conventional 2-level inverter operating in a 3-level mode, in which the instantaneous sum of the phase voltages always remains equal to 0. When used as a power source, the presented topology eliminates the problem of currents in motor bearings, which increases the reliability and service life of the corresponding electric drive systems. However, the further investigation of resulting voltage waveforms harmonical composition and its influence on the motor should be carried out.

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