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Control of Active Front-End Rectifier in Electric Drive under Unbalanced Voltage Supply in Transient States

***Abstract**. The situation when voltage-source inverter is supplied with unbalanced system of voltages is investigated. This can cause problems in operation of an electric drive as voltage pulsations can arise in the DC-bus. Suitable control methods may be applied to eliminate this effect in the active front-end rectifier. The paper particularly focuses on transient processes that accompany operation of the drive. They can be caused by changes in control of the drive, changes in load, or changes in the supply voltages.*

***Streszczenie.** Zbada no przypadek podłączenia przekształtnika do niezrównoważonego system napięciowego. Może powodować to problemy takie jak pojawienie się pulsacji napięcia w szynie DC. W artykule analizowano procesy przejściowe w sterownikach. (**Sterowanie aktywnym prostownikiem przy zasilaniu niezrównoważonym w stanach przejściowych**)*

Keywords: Unbalanced Voltage Supply, DC-Link Voltage Pulsations, Pulse-Width Modulation.
Słowa kluczowe: przekształtnik, prostownik, systemy niezrównoiważone.

Introduction

An electric drive only seldom operates under ideal operating conditions and certain non-standard operating conditions in the power grid such as voltage-unbalance conditions that can arise in the power network may affect operation of electric drives in a negative way. The cause of the unbalance may be a failure in the network or presence of an unbalanced load in the vicinity of the affected drive. Unsymmetrical system of voltages at the input of a voltage source inverter gives rise to the pulsations in the DC-link voltage when no suitable countermeasures are taken. This may result in significantly reduced power capabilities and, therefore, limited controllability of the drive as well as negative influence on the lifetime of the electric motor in the drive. In the literature, numerous methods dealing with such a situation in electric drives have been described [1-5]. The main attention in this paper is paid to the restrictions for the control part of the drive arising from the voltage unbalance.

Control Method

Figure 1 presents a simplified scheme of the drive under investigation. Suitable control of the front-end AC/DC converter can be employed in order to draw constant input power from the power network even at unbalanced voltage supply [6]. The switching functions for the front-end AC/DC converter are generated so that a constant voltage across the DC bus can be maintained. Series combinations of inductance and resistance are considered at the input terminals of the inverter. The proper choice of the switching functions may optimize the power quality effect of the inverter on the power grid [7-9].

Operation under Unbalanced Voltage Supply

If the voltage unbalance is to be eliminated by means of modifications to the switching functions, the control range may be significantly changed compared to operation under symmetrical voltage supply. The necessity to generate the negative sequence component of the switching functions in order to eliminate the effect of the supply-voltage unbalance on the DC-link voltage pulsations reduces the control range for the positive sequence component of the switching functions [7]. This is due to the fact that in individual phases the maximum of the switching function can only be one at any time. Another constraint results from the current rating of the converter. The resulting constraints are dependent on the value and type of the unbalance [10].

The reference parameters of the input impedance were chosen to be R = 0.1 Ω and L = 10 mH. The DC-link capacitor had capacitance of 1000 µF. The input phase voltages had nominal voltage amplitudes of 230 V_{RMS}, nominal frequency of 50 Hz, and mutual phase shifts of 120° to form a three phase voltage system in the case of the symmetrical system. The DC-link voltage was set to 400 V. As an example, the unbalance caused by setting the magnitude of the voltage in phase *A* to 200 V_{RMS} was investigated. Figures 2 and 3 show the corresponding quantities at the input of the rectifier and in the DC bus when no measures are taken to eliminate the pulsations by suitable modification of switching in the active front-end rectifier. The DC-link current and voltage contain significant pulsations that would make control of the drive more complicated.

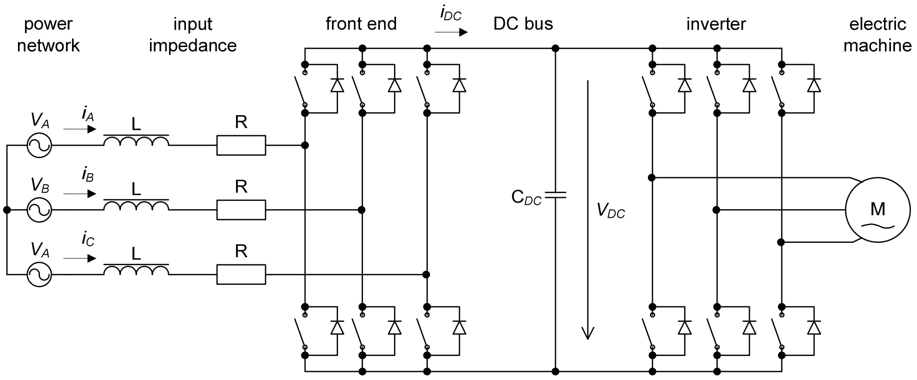

Fig. 1. Scheme of system under investigation

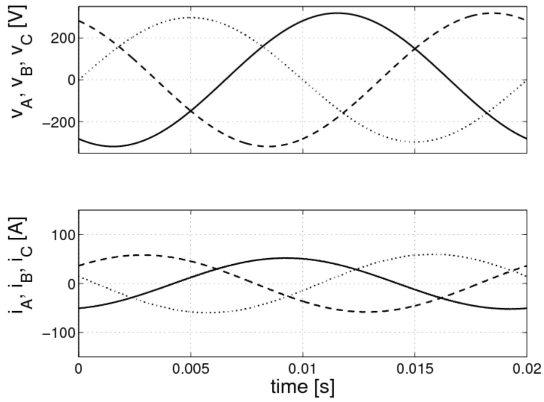

Fig. 2. Phase voltages and currents under unbalanced voltage supply without compensation

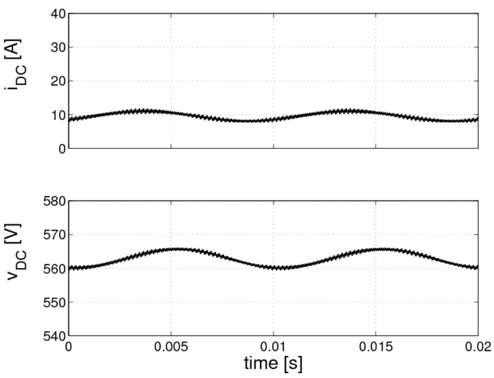

Fig. 3. DC-link voltage and current under unbalanced voltage supply without compensation

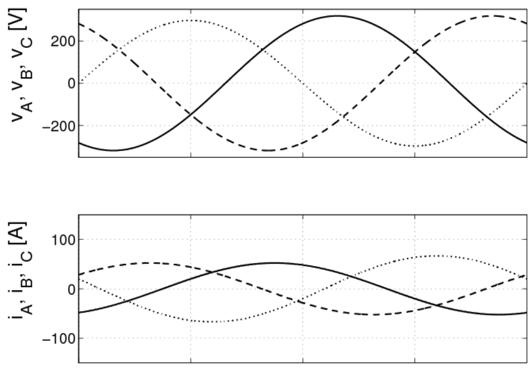

Fig. 4. Phase voltages and currents under unbalanced voltage supply with compensation

When the switching functions are modified in order to eliminate the effect of the supply voltage unbalance, the pulsations are nearly entirely eliminated, Figs. 4 and 5. This has also an effect on the input phase currents compared to the previous case.

The situation when the DC-link current magnitude is increased by approximately 75% by means of increasing the angle of the phasor of positive-sequence component of the switching functions has been simulated and analyzed. The supply voltage unbalance was formed by reducing the voltage magnitude in phase *A* to 220 V_{RMS} and by increasing the voltage magnitude in phase *B* to 260 V_{RMS}.

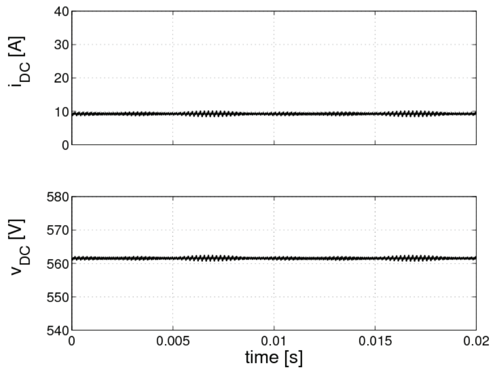

Fig. 5. DC-link voltage and current under unbalanced voltage supply with compensation

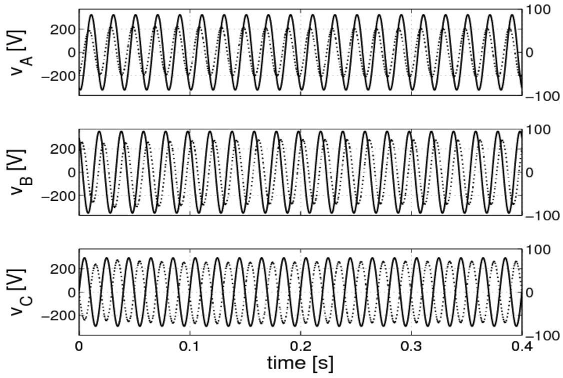

Fig. 6. Phase voltages and currents under change of switching functions without compensation

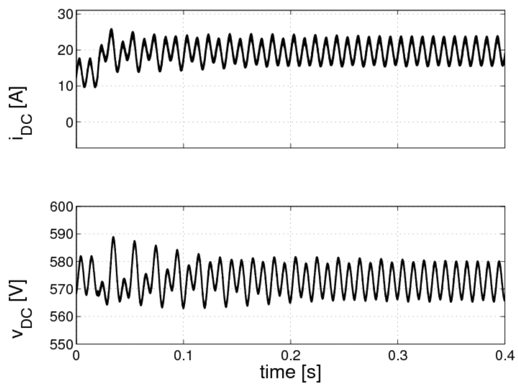

Fig. 7. DC-link voltage and current under change of switching functions without compensation

The DC-link voltage was set at about 570 V. Figures 6 and 7 show the waveforms of the phase voltages and currents and the DC-link current and voltage when the unbalance is not being compensated by modified switching functions. The command to increase the DC-link current was applied in time 0.02 s. In the phase currents, an increase can be seen to cover the increase in the active power supplied to the load. The pulsations in the DC-link current are easily noticeable before as well as after the command. The amplitude of the pulsations in the DC-link current increased a little and this caused an increase in the DC-link voltage as well.

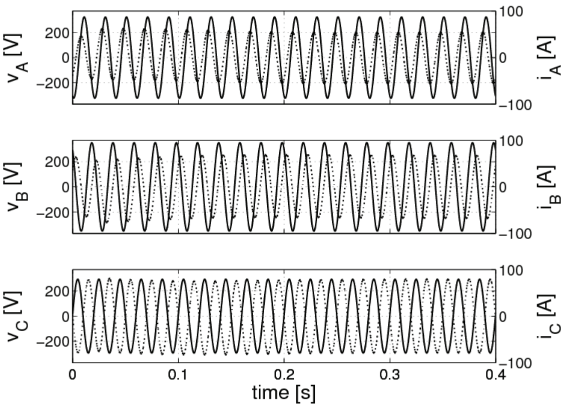

Fig. 8. Phase voltages and currents under change of switching functions with compensation

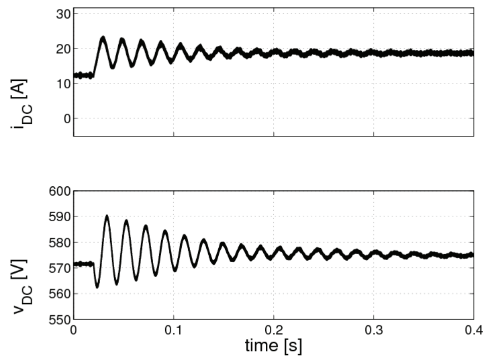

Fig. 9. DC-link voltage and current under change of switching functions with compensation

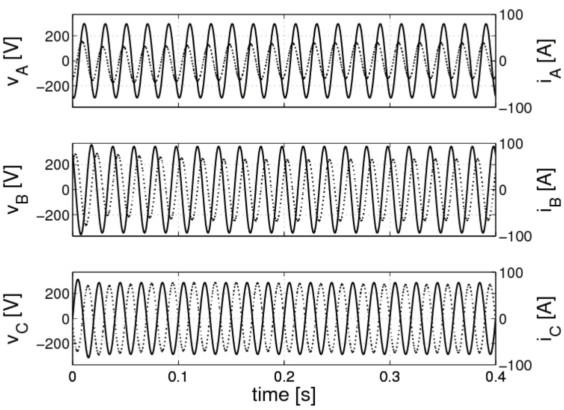

Fig. 10. Phase voltages and currents with unbalanced voltage supply applied with compensation

When the switching functions are modified in order to eliminate the effect of the unbalanced supply voltages in the same case, the pulsations in the DC-link current and voltage are both eliminated, Figs. 8 and 9. However, the transient process triggered by the commanded change in the DC-link current gives rise to transient components in the DC-link current, which decays in about half a second. This transient process is not, however, associated directly with the unbalance and would appear in case of symmetrical voltage supply as well. The frequency of these pulsations, therefore, does not equal to twice the supply frequency. The modified switching functions are able to eliminate the effect of the unbalanced voltage supply and eliminate, thus, the voltage pulsations in the DC bus even in case of this transient process.

The situation when supply voltage unbalance suddenly arises in time 0.02 s is presented in Figs. 10 and 11. The modified switching functions are able to eliminate the effect of the unbalance immediately and no pulsations with twice the frequency of the supply voltages appear. The change in the supply voltage, however, triggers a similar transient as was apparent in the previous cases. Moreover, the average value of the DC-link current decreases in this case. In order to maintain its value constant a change to the switching functions would need to be applied.

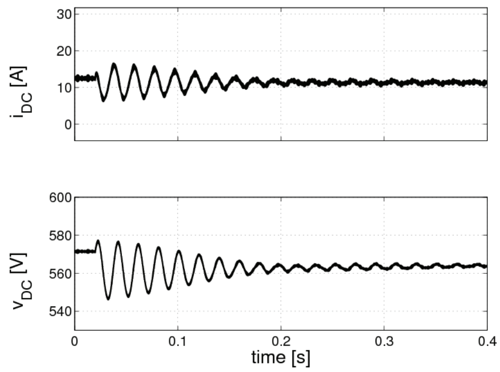

Fig. 11. DC-link voltage and current with unbalanced voltage supply applied with compensation

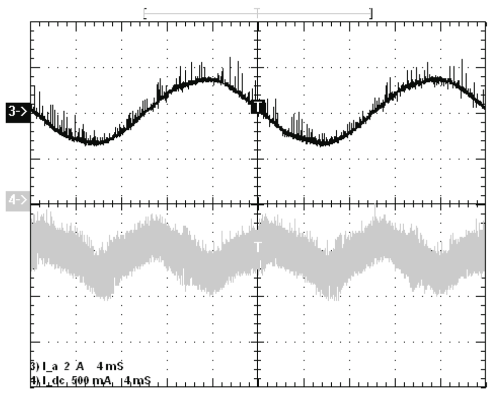

Fig. 12. Phase *A* current and DC-link current under unbalanced voltage supply without elimination of pulsating component

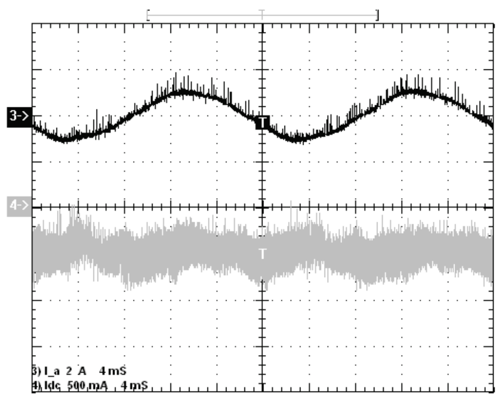

Fig. 13. Phase *A* current and DC-link current under unbalanced voltage supply with elimination of pulsating component

Measurements on an experimental system identical to the simulated one have been carried out in order to verify the investigated method. The scope traces in Fig. 12 show the measured current in phase *A* and the DC-link current when the negative sequence in the supply voltage is not compensated for by the control method and the DC-link current, therefore, contains significant component pulsating with a frequency of 100 Hz, twice the fundamental network frequency. The case when unbalanced voltage system is compensated by the investigated control method is illustrated in Fig. 13. It can be seen that the pulsating component of the DC-link current has been effectively eliminated by the investigated method.

It should be noted, that the proposed control method is suitable to compensate for unbalanced voltage supply without higher harmonics present only. Modifications would be possible to extend its functionality to deal with the problem of higher harmonics as well.

Conclusion

The need to compensate for the negative sequence component in the supply voltages at the input of active bridge rectifier brings along significant restriction in the available operating region for the switching functions. This restriction can be analytically evaluated and particular constraints may be identified for different types and levels of the unbalance. Changes in control, active power supplied to the load, or supply voltages give rise to transient processes, which affect operation of the system and should be considered in development of control algorithms. It has been shown that the proposed control method is suitable for eliminating the negative effects of unbalanced voltage supply even in transient processes.

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