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# ANALYSIS OF ROTOR AND STATOR CURRENTS IN DOUBLY FED MACHINE SUPPLIED FROM CYCLOCONVERTER

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**Abstract:** A numerical model of an adjustable-speed power unit utilizing a doubly fed machine (DFM) with a 12-pulse cycloconverter in the rotor circuit was developed. The rotor and stator currents of this machine for different operating states were analysed.

**Keywords:** Doubly fed machine, harmonic analysis, cycloconverter.

## 1 Introduction

Speed of doubly-fed machines can be controlled easily by means of changes of rotor current frequency. This fact represents a considerable advantage in comparison with synchronous machines operating only at synchronous speed. Doubly fed machines resembling induction machines with wound rotors as far as their construction is concerned, can be utilized for example at pumped storage plants. A change in speed can result in higher efficiency of the turbine foremost at small loads [1], [2]. In addition, an unfavourable influence of erosion of turbine blades can be reduced by means of a convenient change of speed. Independent changes of speed and rotor voltage provide a possibility of optimal control of both active and reactive powers. A convenient control of the doubly fed machine can bring about improvement of the grid stability at temporary use of the kinetic energy accumulated in rotating inertial masses [3]. At present production and utilization of these machines up to the outputs 500MW are under consideration. For these outputs and for control of

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speed in ranges about 5% above and under synchronous speed it is suitable to feed the rotor winding from a cycloconverter.

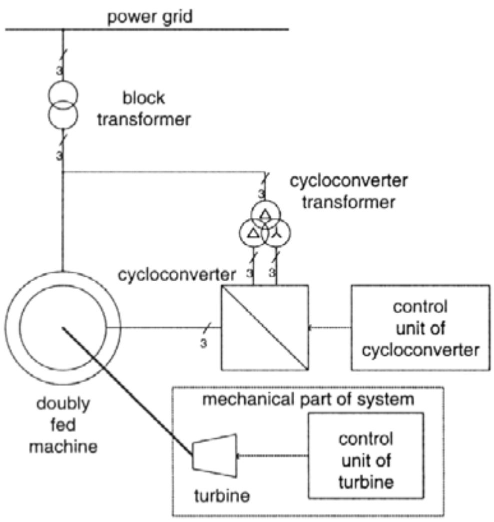

Fig. 1 Adjustable-speed power unit

A simplified scheme of the power unit with variable speed is in Fig.1. The stator winding is connected to the grid through block transformer. The rotor is driven by an adjustable blade turbine and fed from the 12-pulse cycloconverter with the three-winding transformer.

In order to stator and rotor windings can be designed, we need to know the content of higher harmonics in currents that arise as a consequence of non-sinusoidal feeding from the cycloconverter (for different operating states).

# 2 Model of the system

Operation of the unit can be analysed by means of a mathematical model. The model used in this paper of consits of a model of the DFM with the mechanical part of the system, based on the space phasor theory, a model of the 12-pulse cycloconverter with the transformer, which has been developed under the assumption of ideal switches and a model of the control unit [4], [5].

The numerical model of the mechanical part takes into consideration the influence of inertia of the electrical machine, water turbine, and water mass. Furthermore, it is necessary to consider the load or drive torque of the hydro-machine given by the height of the water column and the control of the turbine. Description of dynamic behaviour of such a system is relatively complicated. For simplicity, the properties of the mechanical system are only respected by the moment of inertia of rotating masses and the load torque.

The cycloconverter model is describe in [6] and [7]. A 12-pulse cycloconverter with the topology without circulating currents has been considered. The effect of snubber and other auxiliary circuits has been neglected.

A cycloconverter transformer with two delta and lambda connected secondary windings and one primary delta connected winding is used to obtain two mutually independent three-phase voltage systems.

# 3 Numerical simulation

The following figures hold true for a machine with the output 320 MW operating at the slip $s$ = 5%. In Fig. 2 there are time courses of rotor voltage $u_{Rd}$

and current $i_{Rd}$ in the axis $d$, the current in the stator phase $i_{Sd}$ and the torque in the air gap for the operating point $P_{\max}$ that means for a regime when the machine is operating with maximum active output. Torque course is containing a pulsation of frequency defined as six fold of the basic harmonic of the feeding voltage and pulsations of higher frequencies. Trajectories of stator and rotor current phasors for this case are in Fig. 3.

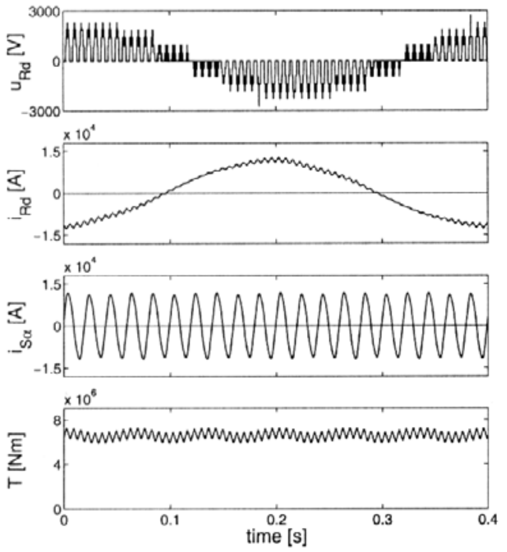


Fig. 2 Rotor voltage and current, stator current, and electromagnetic torque for $s$ = 5%, and $P_{\max}$

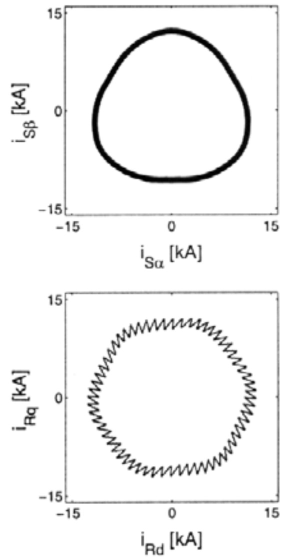


Fig. 3 Loci of stator and rotor current phasors for $s$ = 5%, and $P_{\max}$

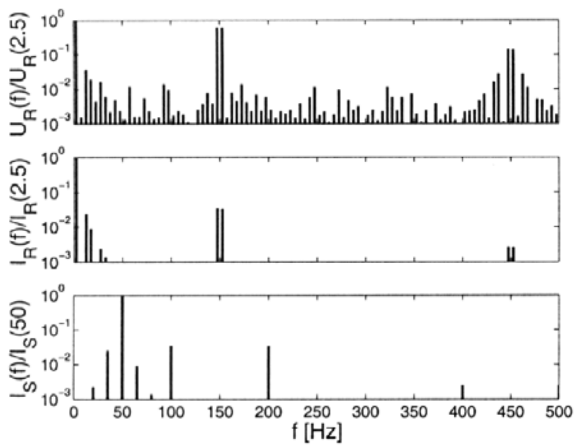


Fig. 4 Frequency analysis of rotor voltage and current, and stator current for $s$ =5% and $P_{\max}$

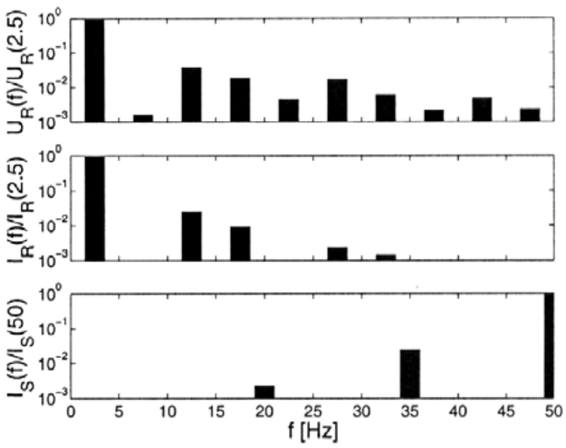


Fig. 5 Frequency analysis of rotor voltage and current, and stator current for $s$ =5% and $P_{\max}$

Harmonic analyses of one phase of the rotor voltage as well as stator and rotor phase currents were carried out. The results are depicted in Fig. 4. The amplitudes $U_R$ of rotor harmonic voltages related to the amplitude of fundamental harmonic which is 2.5 Hz in this case. All the waves up to the frequency 500 Hz were observed. In a similar way proportional values of amplitudes of individual harmonics in stator currents $I_R$ related to its fundamental harmonic amplitude are depicted. Amplitudes of the stator currents $I_S$ are related to the amplitude of the basic harmonic of frequency 50 Hz. Similar proportional values as in the Fig. 4 but only for waves of frequencies up to 50 Hz are in Fig. 5. It is evident that the rotor voltage contains a wide range of harmonics. Besides the fundamental one, other very strong waves are those of orders 5 and 7. The strongest orders, however, are 59 and 61 or rather 179 and 181. In effect the harmonics 5 and 7 are only observable in rotor currents. Due to the growing reactance with the frequency, the influence of higher wave orders is lesser in currents than in voltage. Due to the rotor influence, orders both lesser and higher than the basic harmonic order arise in the stator current. Besides the basic wave of 50 Hz, the waves of frequencies 35, 65, 100 and 200 Hz are most considerable. As it follows from the operating state at the point $P_{min}$ when the machine works with minimum active output, almost the same ranges of harmonics as at the operating point $P_{max}$ are in focus. Courses of the same quantities as in Figs. 2 to 5 but for the operating point $Q_{max}$, when the machine exerts the maximal reactive power, are in Figs. 6 to 9.

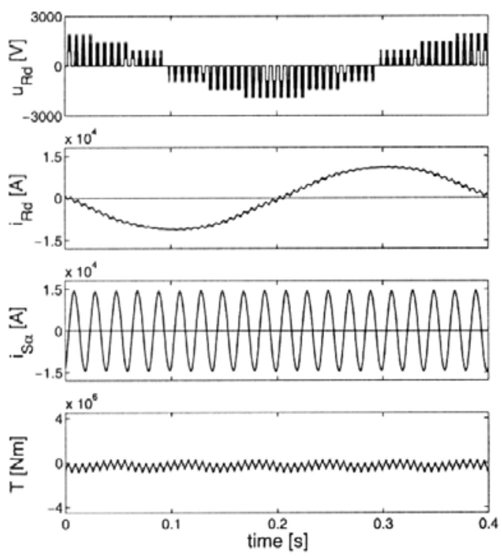


Fig. 6 Rotor voltage and current, stator current, and electromagnetic torque for $s = 5$ % and $Q_{max}$

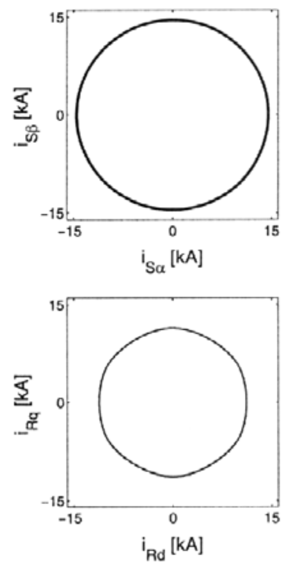


Fig. 7 Loci of stator and rotor current phasors for $s = 5\%$, and $Q_{max}$

The contents of harmonics in individual quantities for the operating point $Q_{min}$ do not differ from the state in the point $Q_{max}$ significantly. Courses of the focused quantities for unloaded machine are in Figs. 10-13. Due to the fact that the first harmonic of the stator current almost equals zero, the course of stator current trajectory in Fig. 11 is distorted considerably by higher harmonics. The distortion is also significant in rotor current trajectories. That is illustrated in Fig. 13 which shows that the amplitudes of some harmonics especially in stator current are near the fundamental wave amplitude.

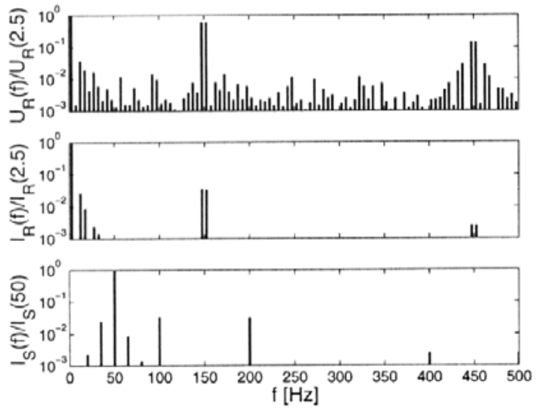


Fig. 8 Frequency analysis of rotor voltage and current, and stator current for $s$ =5% and $Q_{max}$

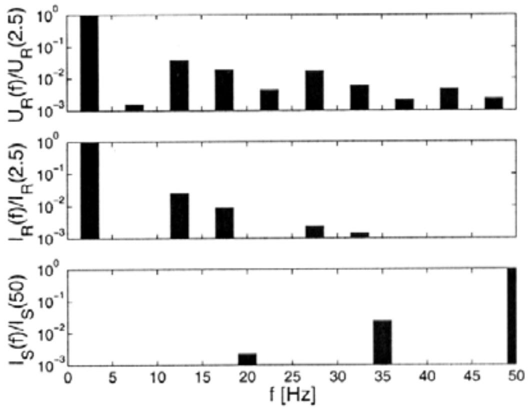


Fig. 9 Frequency analysis of rotor voltage and current, and stator current for $s$ =5% and $Q_{max}$

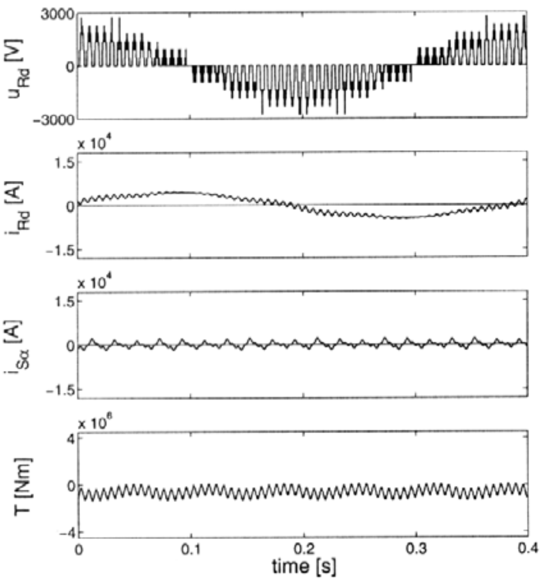


Fig.10 Rotor voltage and current, stator current, and electromagnetic torque for $s$ = 5%, and $P = 0$, $Q = 0$

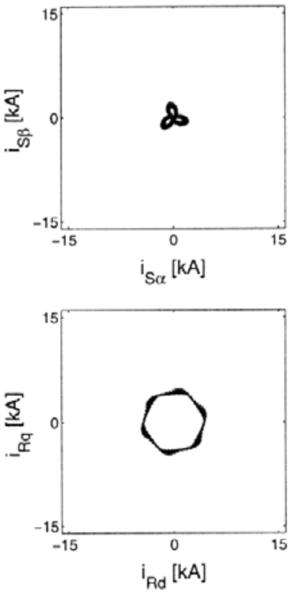


Fig.11 Loci of stator and rotor current phasors for $s$ = 5%, and $P = 0$, $Q = 0$

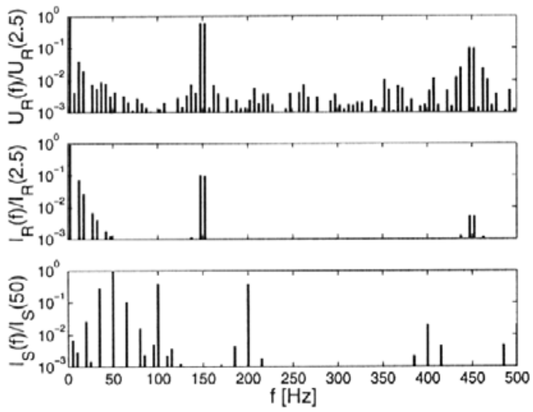


Fig. 12 Frequency analysis of rotor voltage and current, and stator current for $s$ = 5%, and $P = 0$, $Q = 0$

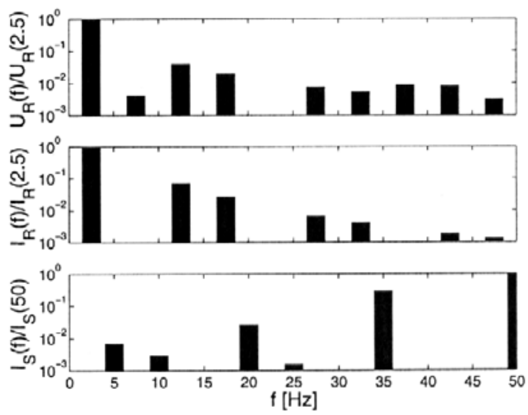


Fig. 13. Frequency analysis of rotor voltage and current, and stator current for $s$ = 5%, and $P = 0$, $Q = 0$

For example the waves of 100 Hz and 200 Hz are quite close to the wave of 50 Hz as far as their magnitude is concerned.

Further working states of the doubly fed machine were analysed similarly, even those where the basic time harmonic of the stator voltage is not an integer number multiple of the rotor frequency. In this case in courses of the focused quantities quite a different scale of higher harmonics appears compared with cases when the frequency of the basic harmonic of the stator voltage was a multiple of the basic harmonic frequency of the rotor voltage.

# 4 Conclusions

In the design of the winding of a doubly fed machines with a cycloconverter in the rotor winding, it is necessary to take into consideration the fact that both stator and rotor currents contain higher harmonics which may enlarge losses in copper. By the introduced mathematical modelling method, orders of harmonics both in rotor voltage and rotor and stator currents can be specified for a given range of speed and for demanded loads.

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