Vibrations in Electric Machine with Permanent Magnets during Unsymmetrical Operation Point

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***Abstract*—The article presents the concept of an electromagnetic circuit of generator with permanent magnets designed for single phase work. The paper presents comparative analysis of simulation results of three generator operation points. First point was calculated as single phase work with serial connection of each phase winding. Second operation point was calculated as three phase asymmetrical load and the last one was calculated as three phase symmetrical load. The time course of electromagnetic torque in the air gap of machine for each operation point for rated power were displayed and discussed. The comparison of three waveforms of electromagnetic torque for each operation point was presented.**

Keywords-permanent magnet generator; permanent magnets; vibration; pulsations of torque; course of torque; single phase work; asymmetrical three phase work

I INTRODUCTION

The development of production of rare earth magnets (NdFeB) inspires their use. One of the examples of application is area of electric machines with permanent magnets. Depending on the application, these machines are designed and manufactured as motors or generators. Three phase synchronous machines with permanent magnet, compared to the other, characterized by the highest efficiency and highest power density per unit volume [1]. For that reason they are widely used in the renewable energy sector as a source of electrical energy. Synchronous generators described in this paper are manufactured as three-phase symmetrical machines [2,3,4]. However, sometimes the needs of consumers of electricity are different, one such example is the synchronous generator used as a source of voltage in the testing station for voltage and current transformers testing. In such kind testing station a three-phase generator work as one-phase machine. Synchronous generators with electromagnetic excitation are very sensitive to asymmetry load. The asymmetry of load currents does not exceed 10%, the question is how will work permanent magnet generator with asymmetry of the load current? The paper presents simulations of electromagnetic torque waveform in the air gap of the machine with three conditions of load: symmetrical three-phase load, three-phase asymmetrical load and single phase work.

II TECHNICAL REQUIREMENTS

Computational model was worked out based on following requirements. The power load of generator was 30 kW, line to line voltage was 400 V, numbers of poles 6, rotational speed 1250 rpm. Synchronous generator is powered by induction motor which is controlled by electronic inverter. Electronic inverter provide soft start and rotational speed (frequency of voltage generator) regulations in range from 0 to 3000 rpm (150 Hz). Computational model was worked out in Maxwell 2D program which used finite element methods to calculations parameter of generator. To calculate the model in different point operations of generator external circuit in Maxwell program was used. The modeled external circuit for one-phase point operation was presented in Figure1. Calculations was made only for pure resistive load. In the rest of point operations the external circuit was change by adding three phase load resistor.

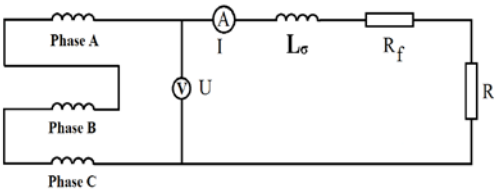

FIGURE I. ELECTRIC CIRCUIT USED IN CALCULATIONS FOR ONE-PHASE POINT OPERATION.

Results simulations were used to analyzed electromagnetic torque waveforms for three described operation points. First analyzed operation point was three phase, symmetrical load. Second one was unsymmetrical load (two phases load only). Third analyzed operation point was one-phase load of generator using appropriate winding configurations (Figure 4b).

III THREE PHASE SYMMETRICAL POINT OPERATION

The waveform of electromagnetic torque in the air gap machine was presented in Figure 2. The most important fact in this figure is torque pulses which are relatively small according to others torque waveform described in this work.

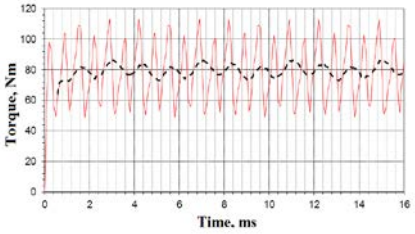

FIGURE II. THE TORQUE WAVEFORM IN THE AIR GAP OF GENERATOR FOR SYMMETRICAL OPERATION POINT.

As we can see in Figure 2 mean value of this waveform is 80 N•m. In this waveform we can see two variable component:

First with 1500 Hz frequency and amplitude about 25% of mean torque;

Second one with 300 Hz and amplitude about 5% of mean torque.

Source of variable component in the waveform of torque is cogging torque which is always presence in the machine with permanent magnets. It is created from reaction between rotor poles with magnetic core of stator. Additional source of variable component in waveform of torque in the air gap of generator is presence the slots in stator.

IV THREE PHASE UNSYMMETRICAL POINT OPERATION

In the second stage of simulations unsymmetrical point operation was calculated and described. In this stage every phase of generator was loaded by different value of resistance RA = 25 Ω, RB = 40 Ω, RC = 60 Ω. These calculations gives results about torque waveform in this operation point.

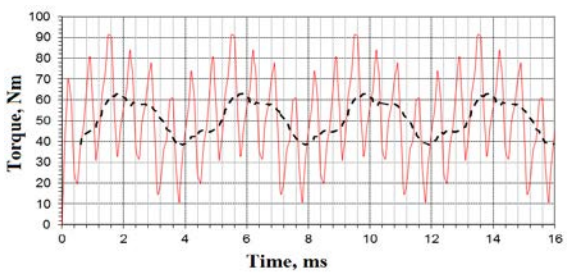

FIGURE III. THE TORQUE WAVEFORM IN THE AIR GAP OF GENERATOR FOR UNSYMMETRICAL OPERATION POINT.

As we can see in Figure2 mean value of this waveform is 50 N•m. In this waveform variable components risen according to previously waveform (Figure2):

First component 1500 Hz has amplitude about 50% of mean torque;

Second one with 300 Hz has amplitude about 19% of mean torque.

Amplitudes of variable components risen according to variable components in waveform of torque in three phase symmetrical operation because of unsymmetrical load. As we can see in Figure3 unsymmetrical load of generator has influence on resultant waveform torque in the air gap of generator. Bigger pulses of torque can be source of vibration during unsymmetrical load of three phase synchronous generator with permanent magnets.

V ONE PHASE POINT OPERATION

One phase operation point of permanent magnets synchronous generator can be arranged by three ways:

by load only one phase of generator RA = 25Ω, RB=RC = 25Ω;

by load only two phases RAB = 25 Ω, RBC=RCA=100 MΩ;

by special winding configurations shows in Figure 4. It is possible when the generator has brought out all ends of phases.

In Paper only the last variant was described.

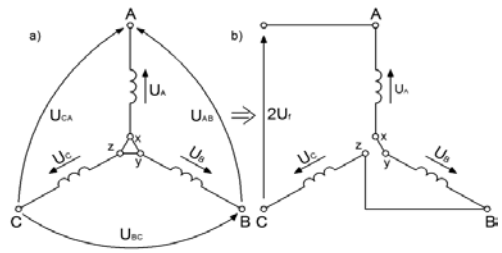

FIGURE IV: THE CONNECTION CHART OF PHASES IN SPECIAL WINDING CONFIGURATION INTENDED TO ONE PHASE OPERATION POINT OF GENERATOR WITH PERMANENT MAGNETS.

The phase vector chart of voltages in one phase point operation was shown in Figure 5.

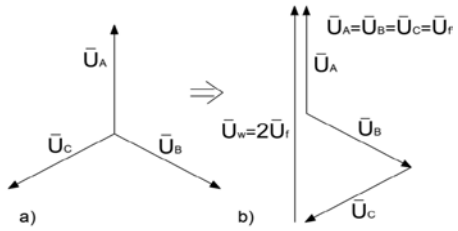

FIGURE V. THE PHASE VECTOR CHART PF VOLTAGES OF GENERATOR IN SPECIAL CONFIGURATIONS: A – THREE PHASE, B – ONE PHASE BY USING SERIAL CONNECTION OF THREE PHASES OF WINDING.

If the winding of generator will be configured according to Figure4b then it will operate as one phase generator. In this kind of point operation the main, resultant induced voltage UABC in generator is equal to twice value of phase voltage in the normal, three phase point operation. This dependence was shown in relation (1).

$$U_{ABC} = 2U_f \quad (1)$$

Where:

$$Uf = UA = UB = UC \quad (2)$$

Results of calculations in this point operation were shown in Figure6 as waveform torque in the air gap of generator.

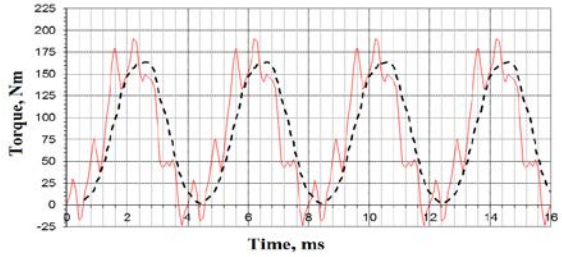

FIGURE VI. THE TORQUE WAVEFORM IN THE AIR GAP OF GENERATOR FOR UNSYMMETRICAL OPERATION POINT.

As we can see in Figure6 mean value of this waveform is 60 N•m. In this waveform variable components raise according to previously waveforms (Figure2, Figure3). In Figure6 mean value of waveform torque was drawn with a dashed line. Basic harmonic of mean torque in this waveform has frequency about 250 Hz and its amplitude is about 80 N•m. Those big pulses of torque can be produce vibrations in the machine. Vibrations during unsymmetrical operation point in machines with permanent magnets cause axial movement of the rotor relative to the stator. That movement is the cause of inducting additional voltage in the winding of stator [5, 6]. After Fourier frequency analyzing of voltages and currents waveforms of generator, it can be concluded that in the machine are presence excessive vibration [7]. The phenomenon detecting vibration in permanent magnets machines is very effective and cheap way to diagnostics of these machines during exploitation.

VI SUMMARY

The purpose of this work was present the generator with permanent magnets intended do single phase work using special configuration of stator winding (Figure4, Figure5). Three operations points of generator were calculated as the results the waveforms of torque in the air gap of generator (Figure2, Figure3, and Figure 6). The comparison of three waveforms of this torques was presented in Figure7.

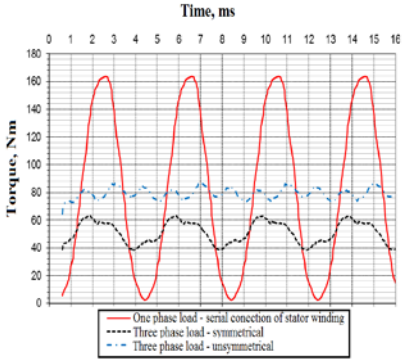

FIGURE VII. THE COMPARISON OF TORQUE WAVEFORMS IN THREE DIFFERENT OPERATION POINTS OF GENERATOR WITH PERMANENT MAGNETS.

The smallest pulses of electromagnetic torque are in generator working as three phase symmetrical load. In unsymmetrical load operation of three phase generator pulses of torque are higher due to the higher share of variable-frequency components of approx. 250 Hz and 1500 Hz. The biggest pulses of torque are during single phase work with special configurations of stator winding. In this operation point the frequency of pulses is 250 Hz. Three phase permanent magnets synchronous generator can be good source of electrical energy in hybrid vehicle, for example buses with buffer drive system.

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