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APPLICATION OF STAR-DELTA MIXED STATOR WINDING IN SYNCHRONOUS MACHINES WITH PERMANENT MAGNETS ON THE ROTOR SURFACE

Results of application of star-delta mixed stator winding in synchronous machine, with permanent magnets on the rotor surface, were presented. Field-circuit model of permanent magnet synchronous machine based on the KOMEL production PMGg180L-8B type was applied in Maxwell ver. 14 program. Influence of the star-delta mixed stator winding application in the permanent magnet synchronous machine on the higher harmonics limitation and the machine running properties was examined.

1. INTRODUCTION

Permanent Magnet Synchronous Machines in comparison with standard AC machine types have one important drawback-significant current higher harmonics [2, 3]. Besides slot harmonics, low row zone harmonics are significant problem due to rectangular MMF distribution produced by permanent magnets. Content of higher harmonics during no-current state can be partially limited by arrangement of proper angle between permanent magnets (about 2/3 of pole pitch). Moreover, content of higher harmonics strongly depends on the machine load level [4].

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In small machines (in the range of few kW) higher harmonics limitation cannot be reduced by short-chorded winding application because generally this type of electric motors has single layer winding. In [1] single layer star-delta mixed stator winding is demonstrated. Some coils are connected in delta and the other coils – in star. According to the authors star-delta mixed stator winding obtains higher winding factor for the first harmonic and simultaneously much lower winding factors for higher harmonics. The second aspect is more significant for permanent magnet synchronous machines.

In [5] application of star-delta mixed stator winding in line start permanent magnet synchronous motor, with squirrel-cage in the rotor, is analyzed. According to the obtained results, application of star-delta mixed stator winding in line start permanent magnet synchronous motor causes limitation of current higher harmonics, increase of the motor efficiency in the high range of the load power and decrease of the motor efficiency in the low range of the load power.

The goal of this work is to investigate the influence of the star-delta mixed stator winding application in the permanent magnet synchronous generator and motor, with permanent magnets on the rotor surface, on the higher harmonics limitation and on the machine running properties.

2. FEM MODEL

Two dimensional field-circuit model of the permanent magnet synchronous motor, with permanent magnets on the rotor surface, was applied in Maxwell ver. 14 program. The model is based on the KOMEL production permanent magnet synchronous machine PMGg180L-8B type. The machine was investigated as generator and as motor. The generator rated power S_n = 15 kVA and rated voltage U_n = 440 V. The motor rated power P_n = 15 kW and rated voltage U_n = 500 V. For both machines rated speed n_n = 750 rpm. Neodymium magnet N33SH type with B_r = 1.15 T and H_{cb} = 836 kA/m was chosen for the excitation. The first machine model has standard star stator winding (winding factor for phase-to-phase voltage equals to 0.837) and the second one – star-delta mixed stator winding (winding factor for phase-to-phase voltage equals to 0.933). Number of turns for each coil of the standard star stator winding machine is the same and equals to 15. Number of turns for each coil of the star-delta mixed stator winding machine is also the same and equals to 27. Both stator windings are shown in Fig. 1 and field part of the motor model is shown in Fig. 2.

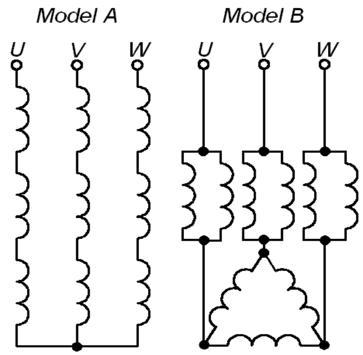


Fig. 1. Standard star stator winding (Model A)
and star-delta mixed stator winding (Model B)

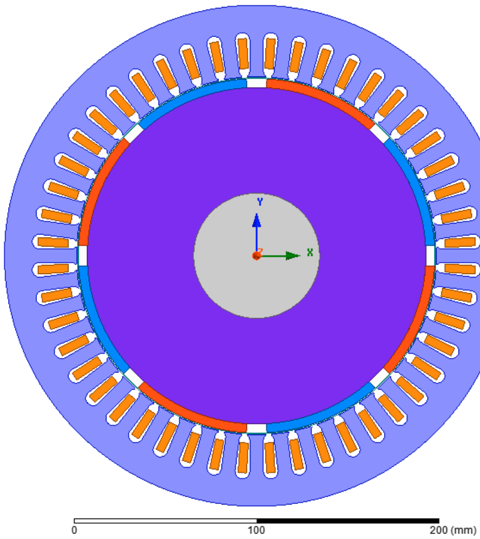


Fig. 2. Cross-section of the PMGg180L-8B
permanent magnet synchronous machine

3. GENERATOR PROPERTIES

As a load, pure resistance was chosen. EMF, voltage drop and the generator efficiency for both stator windings were investigated. Results of EMF in frequency domain for idle-running, half load and full load are presented in Fig. 3.

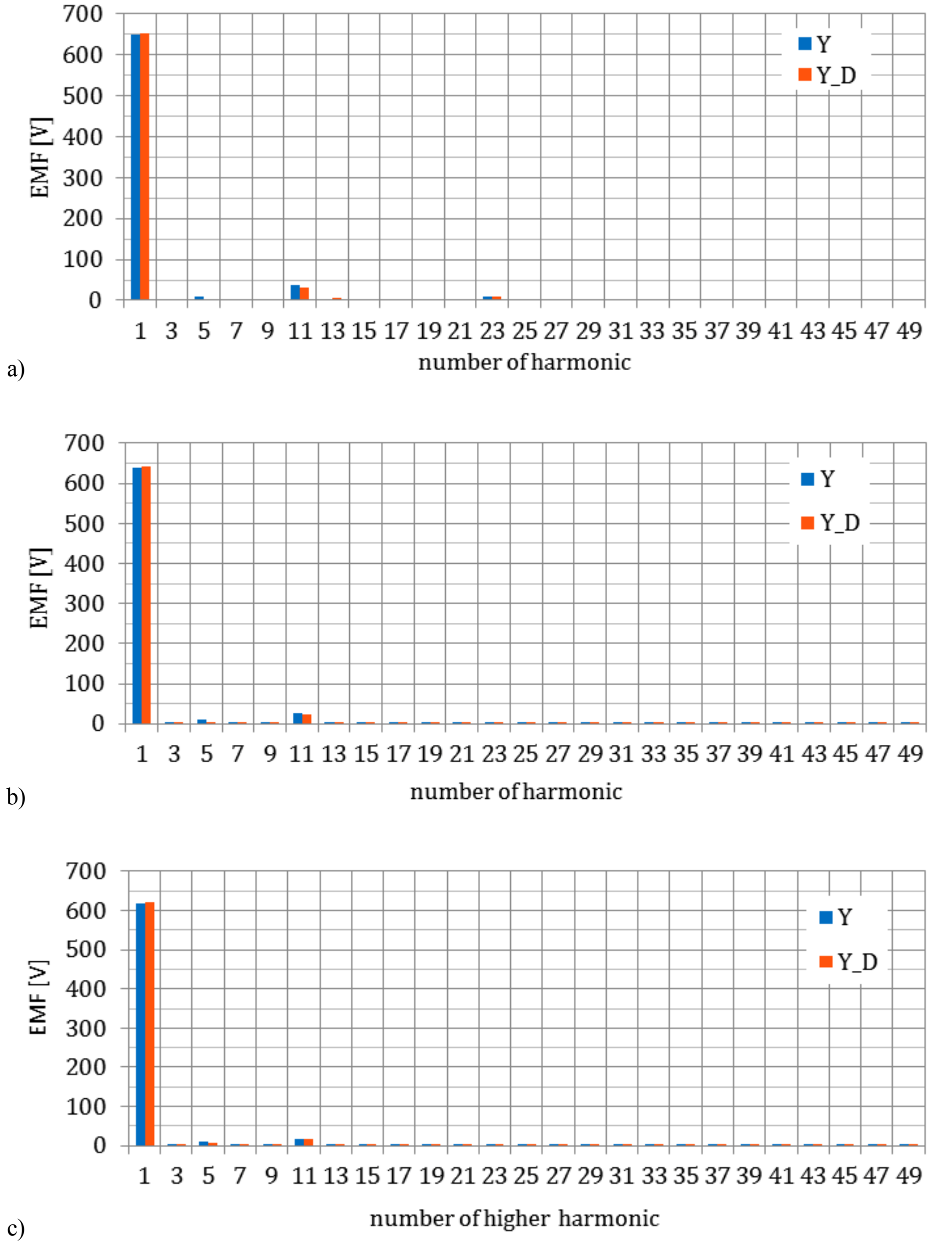


Fig. 3. Generator EMF harmonics analyses for a) idle-running,
b) half load, c) full load

The generator voltage and efficiency in load domain are presented in Fig. 4 and Fig. 5.

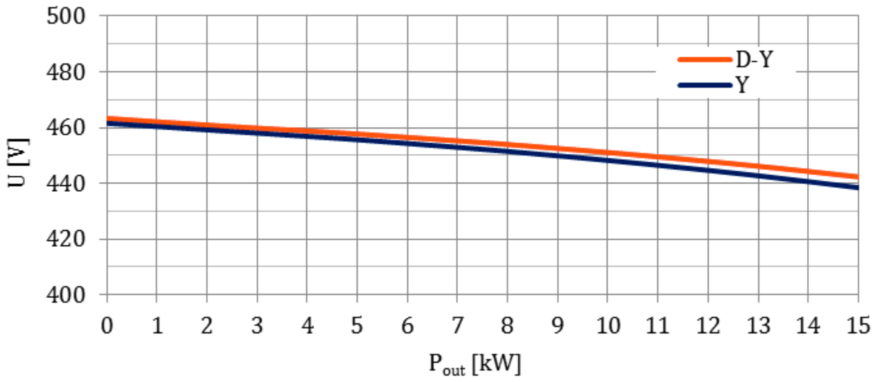


Fig. 4. Generator voltage curves in load domain

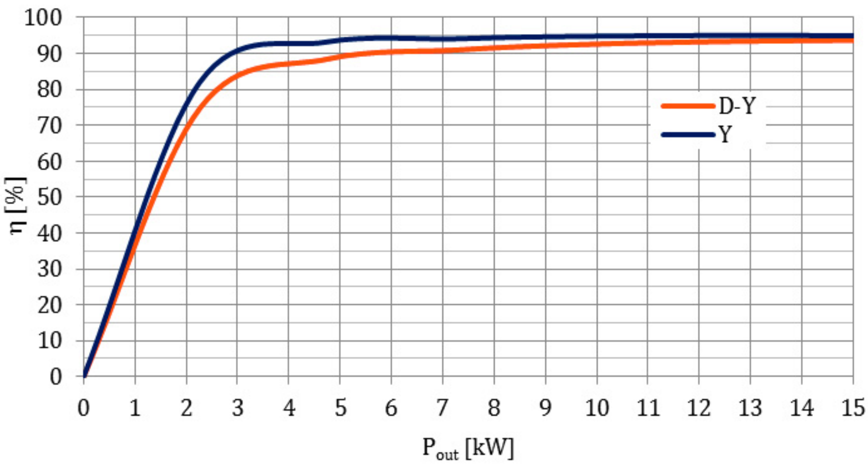


Fig. 5. Generator efficiency curves in load domain

The generator voltage total harmonic distortion THD_U for idle-running, half load and full load was calculated according to the equation (1):

$$THD_U = \frac{\sqrt{\sum_2^{40} (U_h)^2}}{U_1} \tag{1}$$

and presented in Tab. 1.

Table 1. Voltage total harmonic distortion
for both generators

Load state	THD_U [%]	
	Y winding	Y-D winding
idle-running	6.48	5.21
half load	4.71	3.87
full load	3.40	2.95

Application of star-delta mixed stator winding in permanent magnet synchronous generator, with permanent magnets on the rotor surface, causes indeed limitation of the EMF higher harmonics but simultaneously the generator efficiency is lower in the whole range of the load power due to the third and its multiple current harmonics flowing through the delta connection. Voltage drop is a little bit lower.

3. MOTOR PROPERTIES

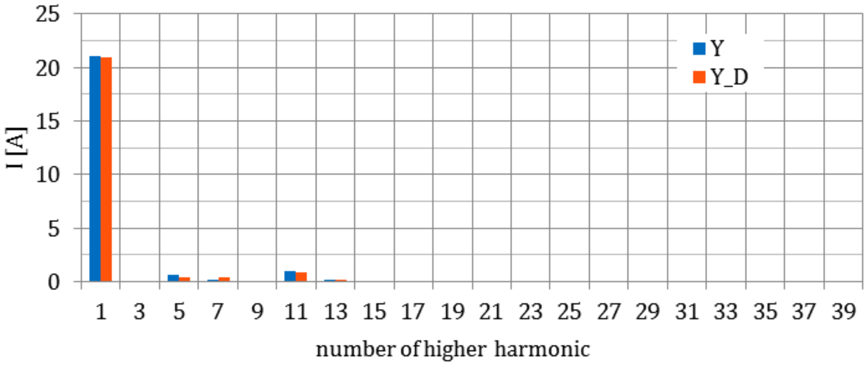
Rated voltage of the synchronous motor, with permanent magnets on the rotor surface, U_n = 500 V. The motor efficiency, current and current harmonics analyses for both stator windings were investigated.

Results of current in frequency domain for half load and full load are presented in Fig. 6.

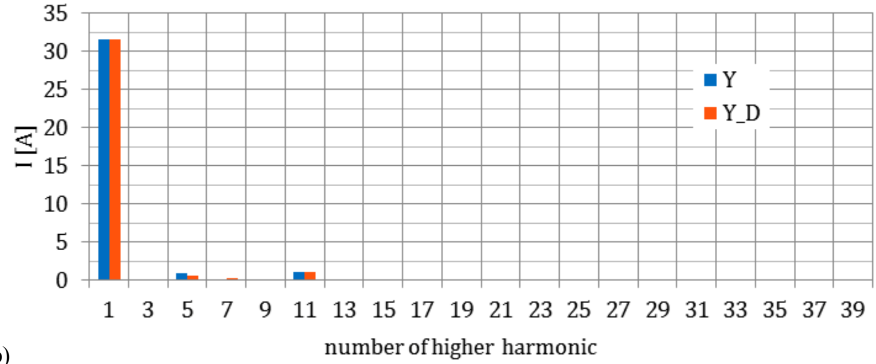
The motor current and efficiency in load domain are presented in Fig. 7 and Fig. 8.

The motor current total harmonic distortion THD_I for half load and full load is presented in Tab. 2.

Application of star-delta mixed stator winding in synchronous motor, with permanent magnets on the rotor surface, causes indeed limitation of the current higher harmonics but simultaneously the motor efficiency is lower in the whole range of the load power due to the third and its multiple current harmonics flowing through the delta connection. Currents for both connections in high range of the load power are almost the same but in the low range of the load power the motor with standard star stator winding draws lower current than the motor with star-delta mixed stator winding.



a)



b)

Fig. 6. Motor current harmonics analyses in load domain for a) half load, b) full load

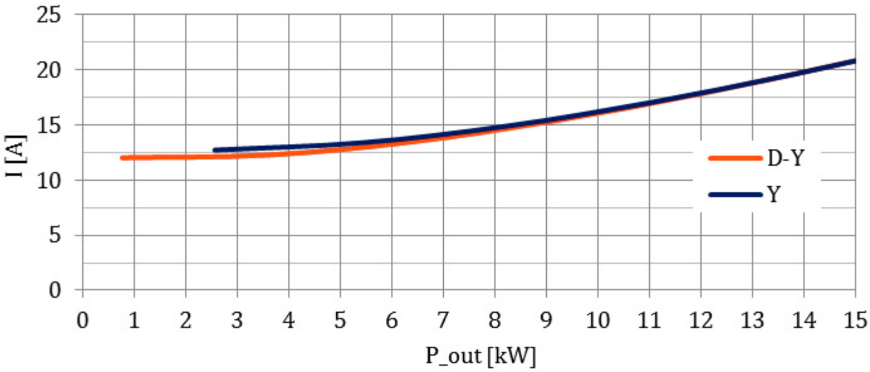


Fig. 7. Motor current curves in load domain

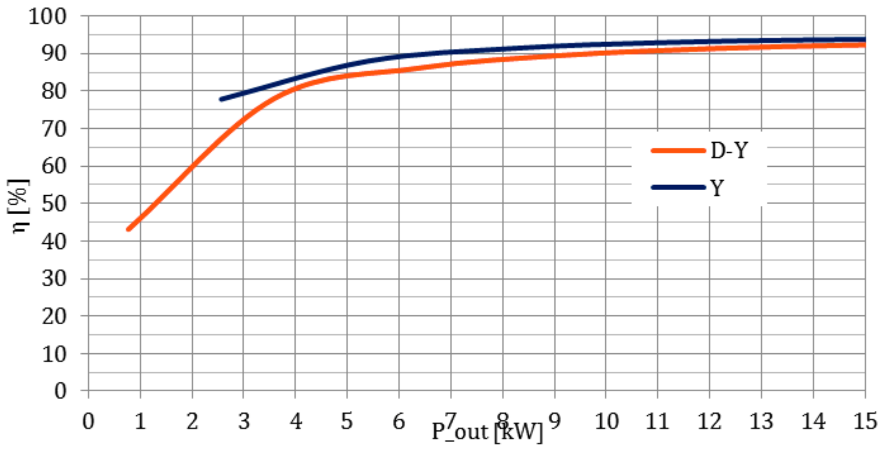


Fig. 8. Motor efficiency curves in load domain

Table 2. Current total harmonic distortion for both generators

load state	THD_I [%]	
	Y winding	Y-D winding
half load	5,82	5,21
full load	4,52	3,99

4. CONCLUSIONS

Application of star-delta mixed stator winding in synchronous machine, with permanent magnets on the rotor surface, cause limitation of higher harmonics and simultaneously decrease of the machine efficiency in the whole range of the load power. This solution is not so effective like in case of line start permanent magnet synchronous motor, with squirrel-cage in the rotor, where application of star-delta mixed stator winding except limitation of the higher harmonics causes also increase of the motor efficiency in the high range of the load power [5].

Synchronous machines, with permanent magnets on the rotor surface, with applied star-delta mixed stator winding can be recommended in applications where requirements for higher harmonics limitation are strict.

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