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The time derivative of flux-linkage dependence on flux-linkage with partitioned-stator doubly-salient permanent-magnet generator structure

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Abstract

The time derivative of flux-linkage, d*Ψ*/d*t* dependence on flux-linkage of partitioned-stator doubly-salient permanent-magnet generator (PS-DSPG) structure with varying the number of poles is proposed. The analysis is based on finite element method using COMSOL software. The result shows that the flux-linkage is reduced with an increasing of the number of poles. Nevertheless, the d*Ψ*/d*t* is enhanced when the number of poles is increased. This is because the d*Ψ*/d*t* and the flux-linkage do not only depend on the number of poles but it also depends on the flux-linkage circulation.

Keywords: Time derivative, Flux-linkage, Partitioned-stator, Number of pole, Circulation

1. Introduction

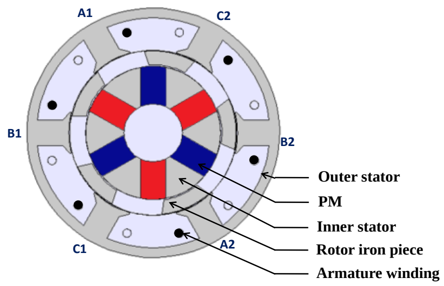
Recently, wind turbine machines are required to be operated at a low velocity. Thus, the machines should have high electromotive force, high torque density and high power density [1-2]. These requirements can be covered by using the partitioned-stator doubly-salient permanent-magnet machine (PS-DSPM) structure, which is the doubly-salient permanent magnet (PM) machine with adding partitioned-stator. The PS-DSPM structure, which utilizes an armature winding as outer stator and PM (Nd-B-Fe) as inner stator, was proposed by Z. Wu and Y. Fan [3-4]. For wind turbine, the d*Ψ*/d*t* is an important variable which could indicate an efficiency of the machine. This factor can be varied by modification of the number of poles or the number of winding turn [5].

In this paper, the comparison between the time derivative of flux-linkage and the flux-linkage with varying the number of poles of the partitioned-stator doubly-salient permanent-magnet generator (PS-DSPG) structure is carried out. For other factors, such as electromotive force and output frequency of the structures of PS-DSPG, are studied as proposed in [6]. The simulation based on finite element analysis in COMSOL software is performed.

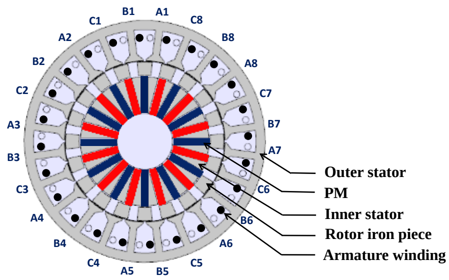
2. Machine designed

2.1 Topology selection

The 6*n*/5*n*-pole PS-DSPG structures with varying the number of poles from $n = 1$ to $n = 6$ were proposed by Z. Zhang [5] et al. Examples of PS-DSPG structures with 6/5-pole ($n = 1$) and 24/20-pole ($n = 4$) are shown in Figure 1. The number of permanent magnet is equal to the number of outer stator teeth. As can be seen from Figure 1 that there is no winding, permanent magnet and brush at the rotor of PS-DSPG structure, so the inertia and weight of the machine can be very low.



(a)



(b)

Figure 1 The 3-phase cross-section of (a) 6/5-pole and (b) 24/20-pole PS-DSPG structures

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2.2 Concerned methodology

The two-dimensional finite element method (2D-FEM) for COMSOL software is used for an analysis of flux-linkage. The rated speed is 400 rpm. The magnetic vector potential in z-axis, $\boldsymbol{A}_z$ can be calculated by Eq. 1 which is solved from Ampere's law of Maxwell's equation:

$$\sigma \cdot \frac{\partial \boldsymbol{A}_z}{\partial t} + \nabla \times (\frac{1}{\mu_0}(\nabla \times \boldsymbol{A}_z - \boldsymbol{B}_r)) = \boldsymbol{J}_e \quad (1)$$

where

$\boldsymbol{B}_r$ is the remanent flux density of permanent magnet (Nd-Fe-B) which is 1.08 T
$\boldsymbol{J}_e$ is an externally generated current density which is 0 A
μ_0 is the vacuum permeability of air
σ is the electrical conductivity of air

The flux-linkage, $\Psi_{linkage}$, is required to consider time derivative flux-linkage and so, it can be calculated by Eq. 2:

$$\Psi_{linkage} = N \times \frac{L}{A} \int \boldsymbol{A}_z dA \quad (2)$$

where

N is the number of turn of winding-coil which is 1 turn
L is the stack length in z-axis and
A is the cross-section area of the winding

3. Results and discussion

The comparisons of open-circuit flux-linkage of 6 structures in phase A are shown in Figure 2. The maximum flux-linkage of 595.67 µWb was observed for 12/10-pole (n = 2) structure [4] where the minimum flux-linkage of 231.20 µWb is found for 36/30-pole (n = 6) structure. It is also indicated that the number of poles of these structures is increased by decreasing flux-linkage. However, for 6/5-pole (n = 1) structure, it is exceptional case because this structure has low number of permanent magnet which generates low flux-linkage.

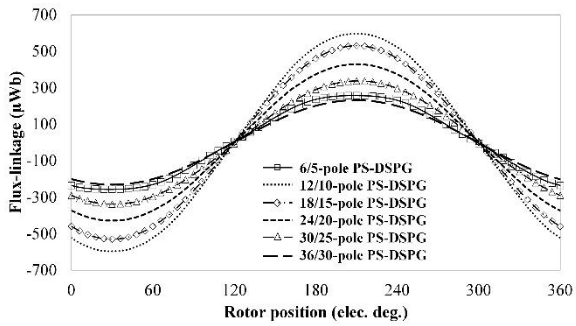

Figure 2 Open-circuit flux-linkage in phase A of 6 structures

The dΨ/dt with varying rotor positions of 6 types PS-DSPG structure are shown in Figure 3. The smallest and highest dΨ/dt of 53.84 and 359.60 V are found in 6/5-pole (n = 1) and 24/20-pole (n = 4) structures, respectively. It is interesting that an increase of the number of poles results in the increasing of dΨ/dt for n =1 - 4, meanwhile it is gradually reduced for $n \geq 5$.

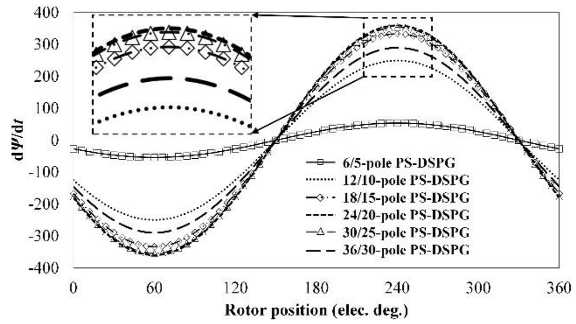

Figure 3 The dΨ/dt in phase A of 6 structures

The comparison between the maximum flux-linkage and the maximum dΨ/dt with the different number of poles is shown in Figure 4. It is seen that the flux-linkage is decreased when the number of poles is increased for $n \geq 2$. However, the dΨ/dt is enhanced with an increasing of the number of poles for $n \leq 4$. This is because the magnitude of the dΨ/dt and the flux-linkage depend on the number of flux-linkage circulated between the outer- and inner- stator. Also, the number of circulated flux-linkage is equal to the number of poles.

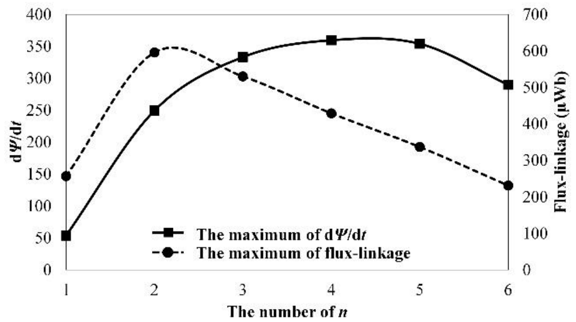

Figure 4 The maximum of flux-linkage and dΨ/dt in phase A of 6 structures

4. Conclusions

The comparison between the dΨ/dt and the flux-linkage of partitioned-stator doubly-salient permanent magnet generator (PS-DSPG) structure by varying the number of poles is investigated. It is found that the flux-linkage has minimum and maximum values for n = 6 (36/30-pole) and 2 (12/10-pole), respectively. However, for dΨ/dt, the smallest and highest values of dΨ/dt are observed for n = 1 (6/5-pole) and 4 (24/20-pole), respectively. This reason is because a reduction of flux-linkage causes the dΨ/dt to increase when the number of poles is increased. Hence, the scale of dΨ/dt and flux-linkage essentially depends on the magnitude of flux-linkage circulation.

5. Acknowledgements

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