2011 4th International Conference on Power Electronics Systems and Applications

Design and simulation of a novel planar Switched reluctance generator

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Abstract–A novel two-dimensional (2D) direct-drive generator based on switched reluctance principle is proposed in this paper. Due to its unique structure, the device is considered as a 2D power generator for sustainable energy utilization such as wind and wave energy with multi-dimensional motion forms. The generator has the advantages of simple structure and elimination of mechanical gears and rotary-to-linear motion converters. In this paper, a three dimensional (3D) mechanical model of this generator is designed and finite element analysis (FEA) is applied to simulate the model. From the simulation results, the coupling effect between each direction of power generation is negligible and each phase can be controlled independently. It is expected that the planar switched reluctance generator (PSRG) finds its potential applications in energy utilization area.

Keywords–direct-drive, sustainable energy, FEM, PSRG

I. INTRODUCTION

Two dimensional, high-precision actuator, especially the X-Y table now finds its applications in many areas, such as electric component insertion, integrated circuit packaging, and precision watch assembly [1]. However, due to its rotary-to-linear motion converters, it has the disadvantages of reduced accuracy, complex mechanical structure and frequent adjustments and alignments. The motion control system with direct-drive actuators is a better option to achieve linear and planar movement since the mechanical structure is greatly simplified and the whole system is easier to assemble, reduced in cost, and increased in performance [2]. At present, a typical two-dimensional direct-drive machine is the planar switched reluctance machine (PSRM) and it is mainly used as a motor converting electrical energy into mechanical energy for high-precision control [3]. According to the principle of switched reluctance machines, by simply changing the exciting scheme, a PSRM can be used as a generator as well. At present, researches are mainly focused on one dimensional rotary and linear switched reluctance power generators, such as wind power generators. In this paper, a novel double-sided PSRG is designed. Compared with a single-sided PSRM, since the magnetic paths are doubled, it is expected that the PSRG has higher efficiency. Based on the mechanical model, the finite element analysis is applied to obtain the relationship for inductance vs. position and propulsion force outputs, which validates the performance of a PSRG for further study and manufacture. It is expected that the PSRG can be applied in some power generation areas for direct absorption of two-dimensional energy forms, for instance, wave energy.

II. DESIGN AND CONFIGURATION OF THE PSRG

A single-sided PSRM consists of two sets of three phase stators (with windings), a moving platform, position detecting device and supporter components [4]. For a double-sided PSRG, as shown in Fig.1, the moving and stationary part are reversed, and each side is symmetric to the other about the moving platform, making the whole model a spacing-saving structure with an improved ratio of force vs. volume.

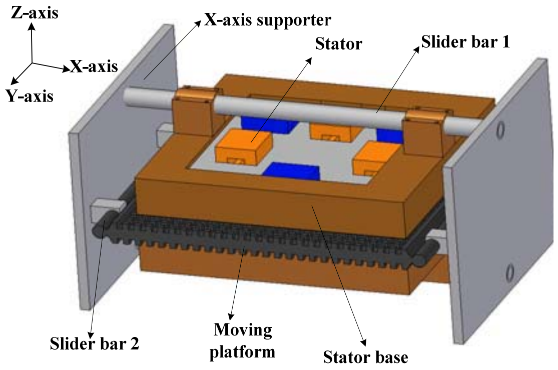

Fig. 1: Modeling of the PSRG

For one side, six identical stators are fixed vertically on the stator base. One set is responsible for the movement of X-direction and the other for Y-direction. The moving platform is capable for the movement in both X and Y directions. For X direction, the moving platform moves together with the X-axis supporter along the slider bar 1 and for Y direction, it moves along the slider bar 2.

The design of a PSRG is mainly focused on the following parameters: width of stator pole (W_{tp}), width of stator slot (W_{ts}), width of moving platform pole (W_{sp}), width of moving platform slot (W_{ss}), distance between each two adjacent phase stators in X-direction (L_x) and Y-direction(L_y), air gap between the stator and the moving platform(λ_a), length of pole-pitch (τ), and number of turns per phase winding(n).

Fig.2 shows the parameters from the inner structure. For one side of the three-phase stators, to make sure the excited stator is aligned to the corresponding poles and slots of the moving platform, the other two stators should be unaligned to the moving platform and it can move in opposite directions when excited respectively. The relations of parameters are given as:

$$W_{tp} = W_{ts} = W_{sp} = W_{ss} \tag{1}$$

$$\tau = W_{tp} + W_{ts} \tag{2}$$

For parameter L_x and L_y, they are obtained as,

$$L_x = L_y = \frac{3n+1}{3}\tau - W_{tp} \tag{3}$$

The air gap is selected as λ_a=0.3*mm*.

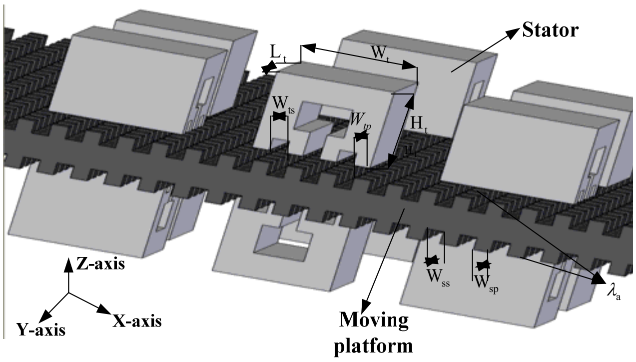

Fig. 2: Parameter definition of the inner structure

III. MODEL SIMULATION

In this section, FEA simulation is carried out based on Ansoft Maxwell/3D. As shown in Fig.3, the model is derived from the Fig.1 with only the moving platform and four stators remained, while the other parts—the slider bars, the supporter and the stator platform which are usually non magnetic-conducting material can be ignored when the FEA is applied. The moving platform of the PSRG moves a distance of 6 mm along the X-axis from the aligned position (*x=0mm*) to the unaligned position (*x=6mm*) with phase excitation of 8A added to the coil1. For every step of 1 mm, coupling effect between any two stators are observed and values of the phase inductance (*L*), propulsion force (*F*x) are calculated for each simulation step.

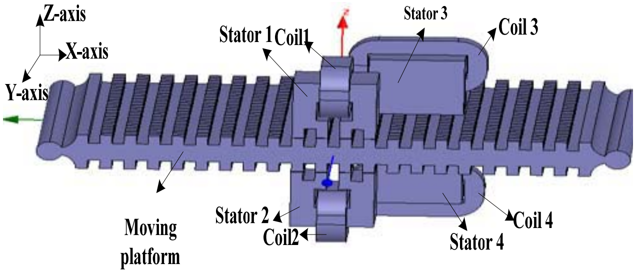

Fig. 3: The mechanical model for FEA

3.1 Test of coupling effect of any of two stators

It is crucial to know the condition of coupling effect between any of the two stators, for it has a significant effect on future control strategy. Fig.4 shows the magnetic flux distribution at the position of $x = 0mm$ (the aligned position). Since Stator 2 is closest to Stator 1, it can be observed that magnetic flux merely distributes around Stator 1 and it hardly affects the flux path of Stator 2 and other adjacent stators. We can draw the conclusion that the coupling effects are negligible between any two phases, and one stator is independent to the other when any of the coil gets excited, making the control strategy simple for the PSRG.

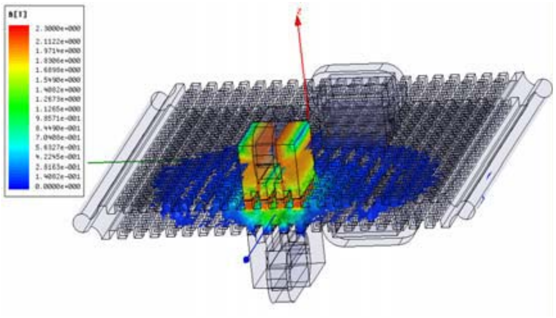

Fig. 4: The flux path of the model

Another factor that reflects coupling effect is mutual inductance between any two stators. For an ideal condition, the mutual inductance between any of the two stators should be zero. As shown in Fig.5, the X-axis label represents the relative position of the stator against the X-axis, and Y-axis label represents the value of inductance. It can be seen that the mutual inductance between any two coils is close to zero and it can be concluded that mutual inductance is negligible.

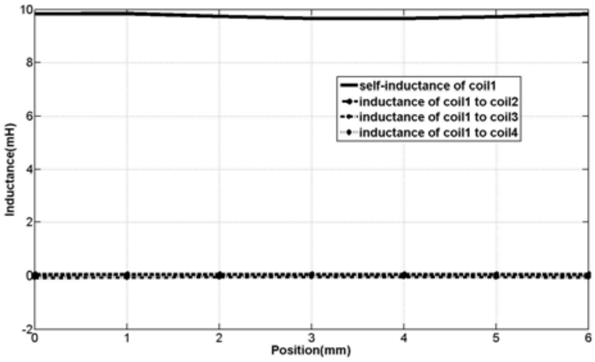

Fig. 5: The inductance vs. the x-axis

3.2 Test of propulsion force in X-axis and Y-axis

As long as one of the three stators for X direction is excited, the moving platform will obtain forces in three directions. The force are assigned as X-force (propulsion force), Y-force (disparity force), and Z-force (normal force), respectively. Due to its symmetric structure, the force on the moving platform along Z-axis can be considered negligible, and the simulation results for X-force and Y-force are shown in Fig.6. Regardless of saturation, propulsion force in X-direction and disparity force from Y-direction can also be theoretically derived from the following equations, respectively [5],

$$f_x(x,i) = \frac{\pi \cdot i^2 \cdot L_\Delta}{p} \sin(\frac{2\pi x}{p}) \tag{4}$$

$$f_y(x,i) = -\frac{\mu_0 l N^2 i^2 (d-x)}{2z^2} \tag{5}$$

where x is the moving distance in X-axis, i is the phase current, p is pole-pitch, N is number of turns, l is stack length, z is air gap, d is pole-width and L_Δ is change of phase inductance.

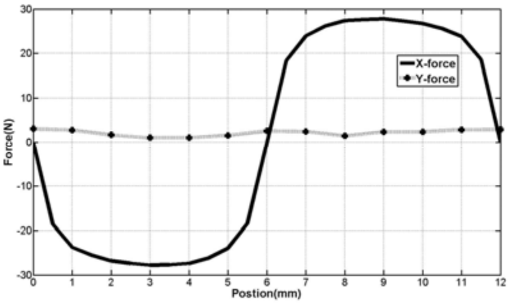

Fig. 6: The result for propulsion force

It can be seen that Y-force is only less than 10% of the maximum propulsion force of X-force therefore no extra decoupling mechanism is needed.

IV. CONCLUSION

A mechanical model of a novel planar switched reluctance generator is designed. In this paper, coupling effects and mutual inductance are examined and output forces are also calculated based on the analysis of FEA. From the simulation results, it is expected that the novel double-sided PSRG has better efficiency compared with a single-sided PSRM and it can be applied for two-dimensional power conversion areas in the future.

ACKNOWLEDGMENT

The authors would like to thank the National Natural Science Foundation of China and Hong Kong University Grants Council for sponsoring of this research project under the project code 51007059 and B-Q06X; the authors would also like to thank Shenzhen government fund under the project code JC201005280390A for the support.

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BIOGRAPHY

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