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Full Length Research Paper

Investigation of the starting performance of damper coiled salient pole synchronous generator with different slot design

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Starting performance of synchronous generators and the time in which the machine comes into steady state are important. Hence, there is much research carried out on the starting performance of synchronous generators. The more the power of the synchronous generator is, the more important its starting performance becomes. In the present study, through Ansoft Maxwell program, the design of 2.2 MW and 6600v synchronous generators was made, and then two-dimensional static magnetic analyses and two-dimensional transient analyses were performed. In this way, we were able to investigate starting losses, period of coming to steady state, phase currents and instantaneous torque values of the synchronous generators.

Key words: Salient pole synchronous generator, 2D magnetic analysis, transient analysis, wind generator design.

INTRODUCTION

Starting performance, safe functioning and high heat capacity are the most important characteristics of a salient pole synchronous motor (Silva et al., 2003; Concordia and Poritsky, 1937).

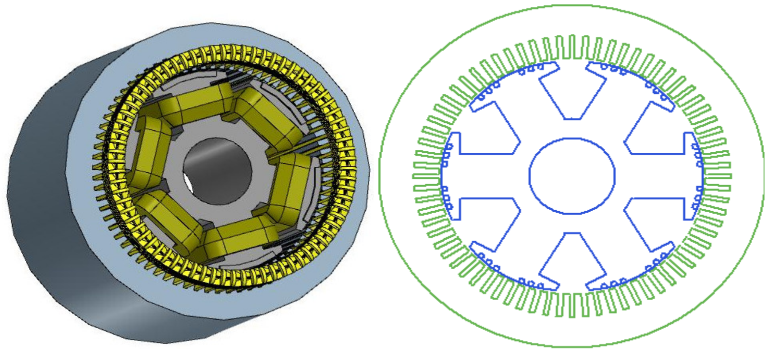
Similar to the working of traditional synchronous motor with salient pole (SPSM), 2D equivalent circuit method is usually related to transient state working performance of SPSM (Wood, 1959; Wood and Concordia,1960; Cundev et al., 1998). For transient performance, due to initial period behavior, skin effect on the surface of pole and serious magnetic non-linearity, the results yielded by traditional motors are not as correct as anticipated (Widger and Adkins, 1968; Karmaker and Mi, 2004). With the advent of powerful computerized computation methods, now it is possible to easily carry out 2D and 3D finite elements analyses. They can be performed not only for the transient mode magnetic analyses, but also for the transient performance analyses of electric motor (Preston et al., 1999; Sturgess and Preston, 1992; Li et al., 2009).

In the present study, through finite elements method (FEM), the design of damper coiled salient pole synchronous generator (SPSGD) to be used in wind tribunes was performed and its 2-dimensional transient analyses were carried out. Through these analyses, all the flux values and parameters of SPSGD were calculated.

Geometric model

In order to carry out such calculations for electric machines, there is a need for the definition of the geometric CAD model of the machine (Tabatabaei et al., 2004). CAD model of the machine lays the basis to carry out FEM calculation within the geometric structure of the motor (Concordia and Poritsky, 1937; Cundev and Petkovska, 2005). Three-dimensional CAD model of the designed SPSGD and its cross section are presented in Figure 1. The measurements of the designed SPSGD are given in Table 1.

Emphasis was first put on the structure of stator slots and the type of materials used to reduce the vertical force induced by the weight in the designed generator. Stator slots should be designed in such a way as to reduce the weight and cost of the materials and yield the desired electrical performance. In the present study, the stator



a b

Figure 1. 3D CAD model of SPSGD (a) six salient poles damper coiled, (b) cross section view of

Table 1. General properties of SPSGD model.

Stator properties		Rotor properties	
External diameter	1100 mm	External diameter	747 mm
Internal diameter	760 mm	Internal diameter	248 mm
Length	750 mm	Length	750 mm
Volume	0.321146 vm^3	Volume	0.194822 m^3
Number of slots	72	Number of slots	24
Width of the slot	14 mm	Number of poles	6
Thickness of the thin plate	0.5 mm	Damper coil	yes

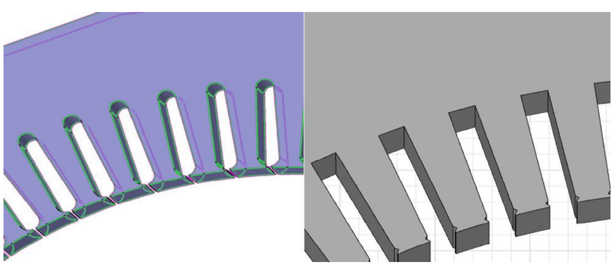


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Figure 2. (a) Classic stator slot (b) stator slot of the model used in the present study.

slots were opened similar to the type seen in the stores of such machines rather than the type commonly used in the asynchronous machines in the market. Here, the aim is to reduce the volume and in this way decrease the weight without causing any electrical and mechanical problems. Two structures are shown in Figure 2. The volume of the stator seen in Figure 2 is 321145823.869 mm^3 while the stator volume in the slot designed in b is 307165730.511 mm^3. The weight difference was nearly reduced by 5%. In this way, the vertical force imposed on the tower by the generator was reduced at the same rate. These volume calculations were performed through Ansoft Maxwell program. Moreover, the FeV 450-50 HE material is lighter than the other material, 0.5 mm 1080 steel, used in the previous studies. In this way, the weight could be reduced more.

Apart from the weight as a vertical force, horizontal forces are also affecting the tower. When the sweeping force of the wind hits the nacelle, it results in horizontal strain. In order to reduce this strain, the nacelle has an aerodynamic design, but decreasing the height of this will lead to decrease in the force of the wind hitting, hence, this is important. Therefore, the generator was designed lower and longer when compared to classic salient pole synchronous generators.

2D transient analysis of SPSGD

Here, two-dimensional transient analysis of SPSGD was carried out. These analyses are complementary to three-dimensional analyses and they could analyze induced voltage, current, torque induced and induced voltages in the air gap when the generator is rotated at constant 1000 rpm. Time-dependent analysis of the system was carried out by taking 1/6 of the three-dimensional model. The starting performance of the designed synchronous generator and its behaviors were investigated. The model through which transient analysis was carried out is seen in Figure 3.

In the present study, it was investigated whether

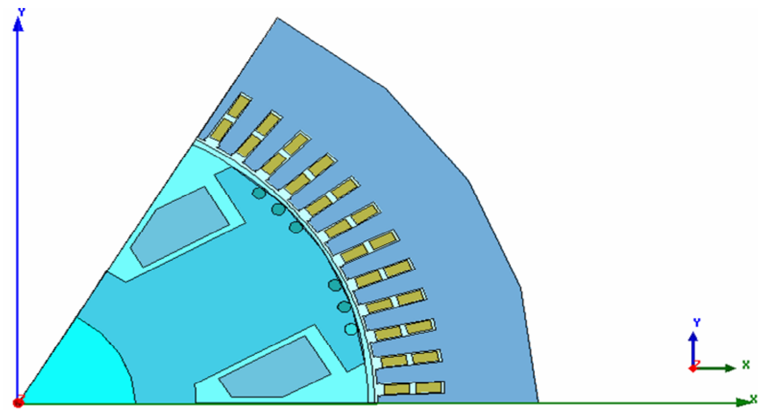


Figure 3. 1/6 of the generator where transient analyses was carried out.

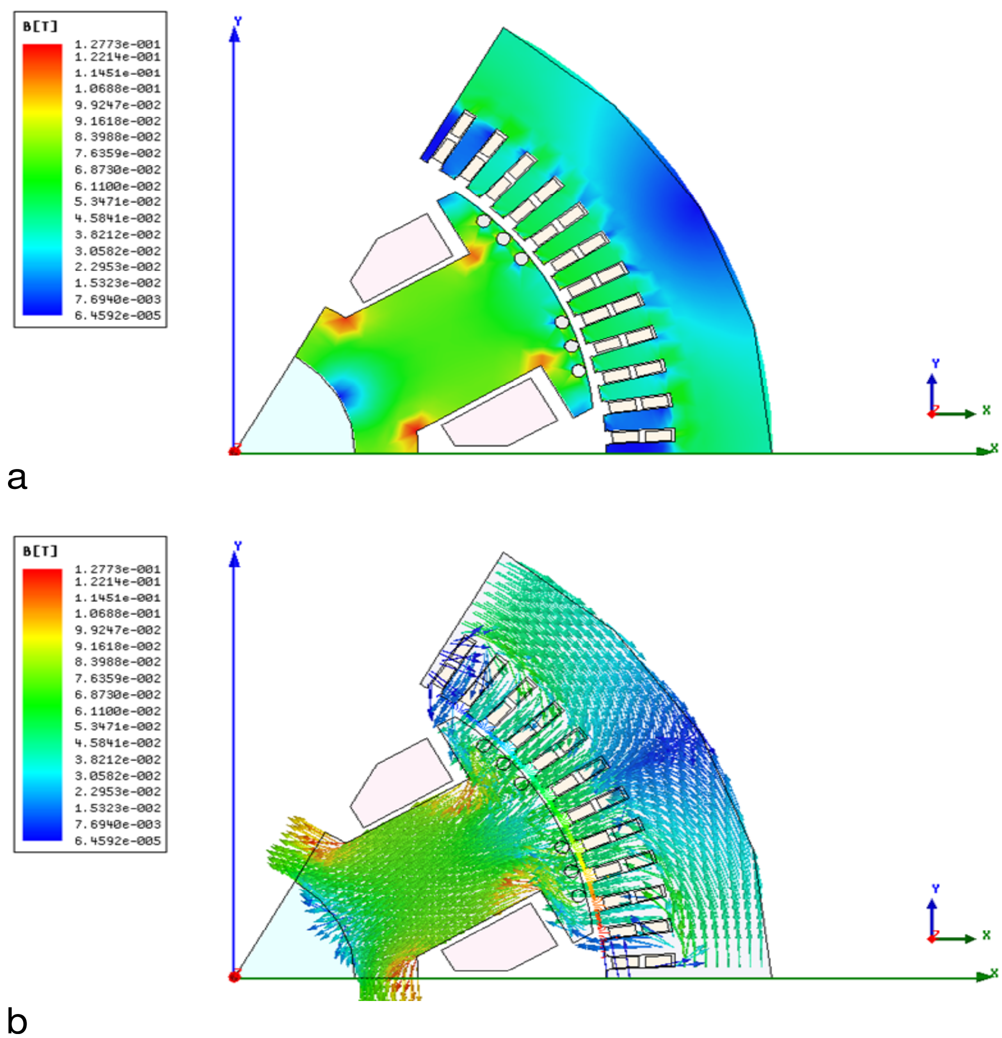


Figure 4. (a) Magnetic flux density distribution (b) Vectorial magnetic flux distribution.

saturation occurs or not depending on the structure of the machine. The stator and B values in the stator and rotor values can be seen in Figure 4. As can be seen in the figure, under these excitation conditions, stator never reaches the saturation. It works nearly between 1.6 and 1.7 T. Under these conditions, it exhibits the expected

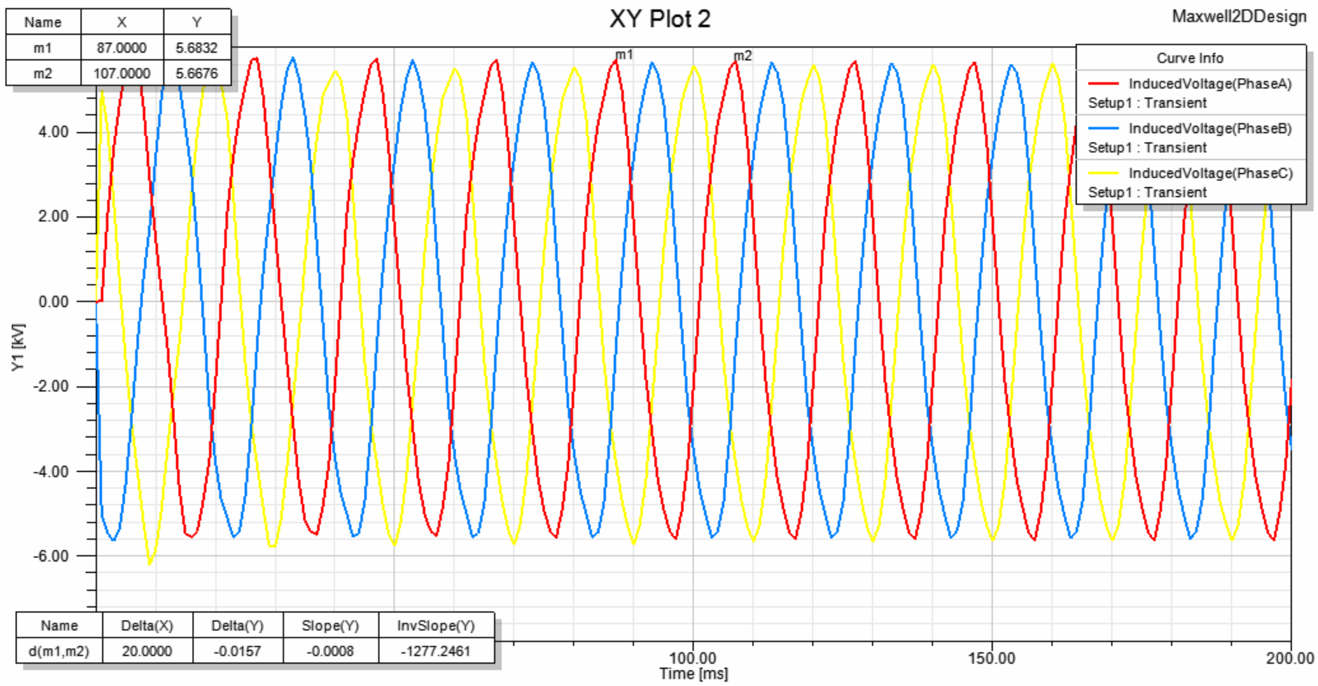


Figure 5. Determination of three-phased voltage and frequency induced from the stator.

voltage and power performance.

Magnetic flux distribution seen in Figure 4 was obtained through transient analysis carried out on the 1/6 of the model.

In Figure 5, 3-phased voltage wave patterns obtained from the stator coils of synchronous generator through time-dependent transient analysis are shown. It is shown in the figure that the shape is in the form of sinus and there is 120° phase difference between the phases. Again, the peak value of the output voltage reaches 6100 V.

Before starting with the design, the expected voltage value was 6600 V, hence, we can say that we have reached the target. As the generator was designed as six-pole generator, when it is rotated at 1000 rpm, 50 Hz voltage can be obtained. It is shown in the figure that if the two different points of the peak value of a phase are detected, and the time period between these two points is calculated during the simulation, it is found to be 20 min and this time proves that the frequency is 50 Hz.

It is possible to estimate the torque required when the generator is connected to wind tribune and accordingly wing diameter, tower height etc. can be calculated. When the patterns in Figure 6 are examined, it is seen that torque, phase flux and losses become stable after 200 min fluctuation and the generator becomes stable. When the figure was examined, there are extreme losses during the starting performance of the generator up to 200 min, after which they become stable. Throughout this analysis, the speed of the generator was kept constant at 1000 rpm.

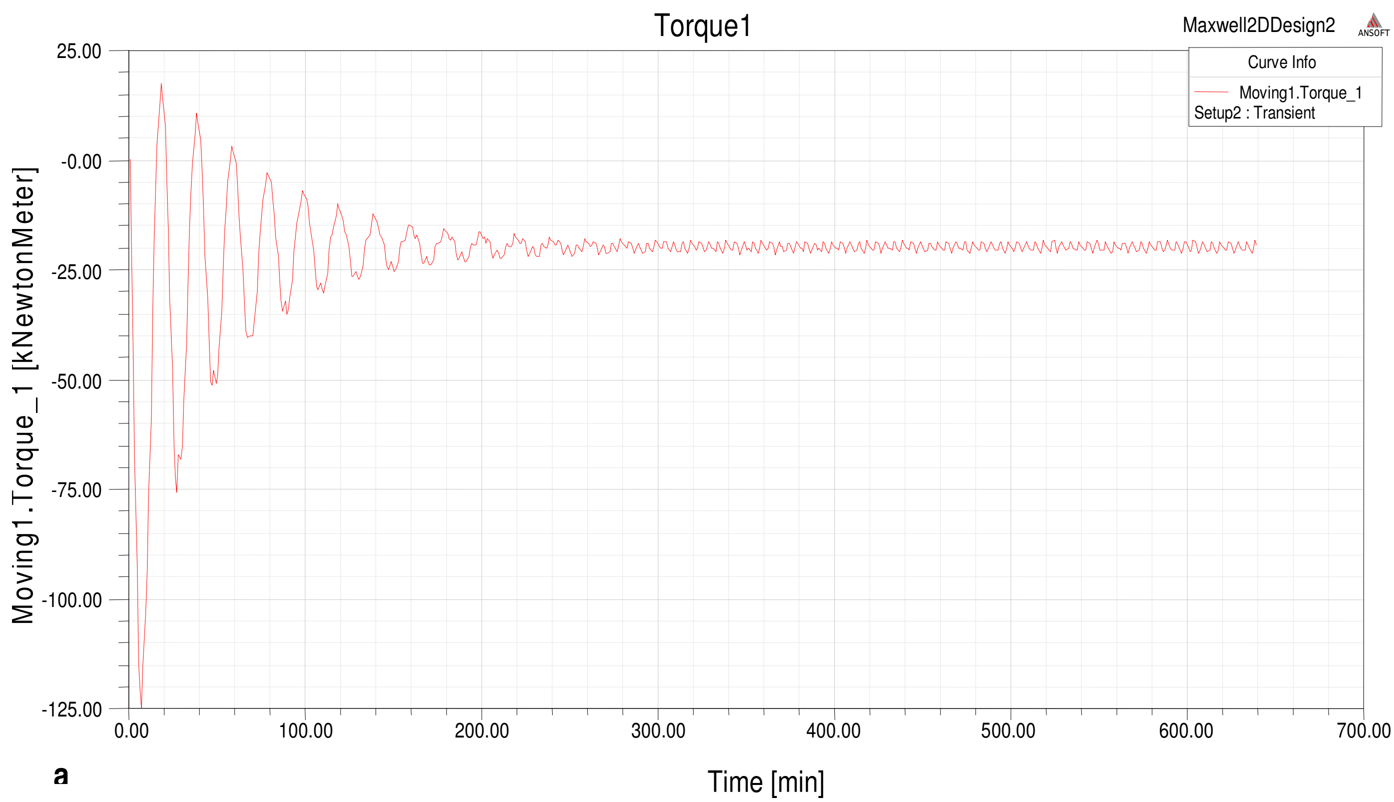
It seems to be appropriate to carry out two- and three-dimensional analyses besides transient analysis to examine the behaviors of the generator. For the exact determination of the system parameters, two-dimensional static magnetic analysis was also carried out. In Figure 7, two -dimensional magnetic flux distributions of SPSGD are presented. As can be seen in Figure 7, the designed synchronous generator could work without reaching to saturation and in a stable manner. This can be seen easily from flux distribution.

The results of the transient analysis revealed that the designed synchronous generator can provide the expected voltage and current values. Moreover, through the adjustment of starting current, reactive power yielding change was also observed in a type of generator connected to the ring system. The machine could produce about 6000 V with 50 Hz frequency.

Patterns of air gap flux which is closely connected with the voltage produced in the generator are seen in Figures 8e and f. What is shown in Figure 8e is the air gap magnetic flux. What is shown in Figure 8f is the air gap pattern when the machine is fully loaded with 2.4 MW. It is seen here how much skewing is induced by the load on air gap flux density.

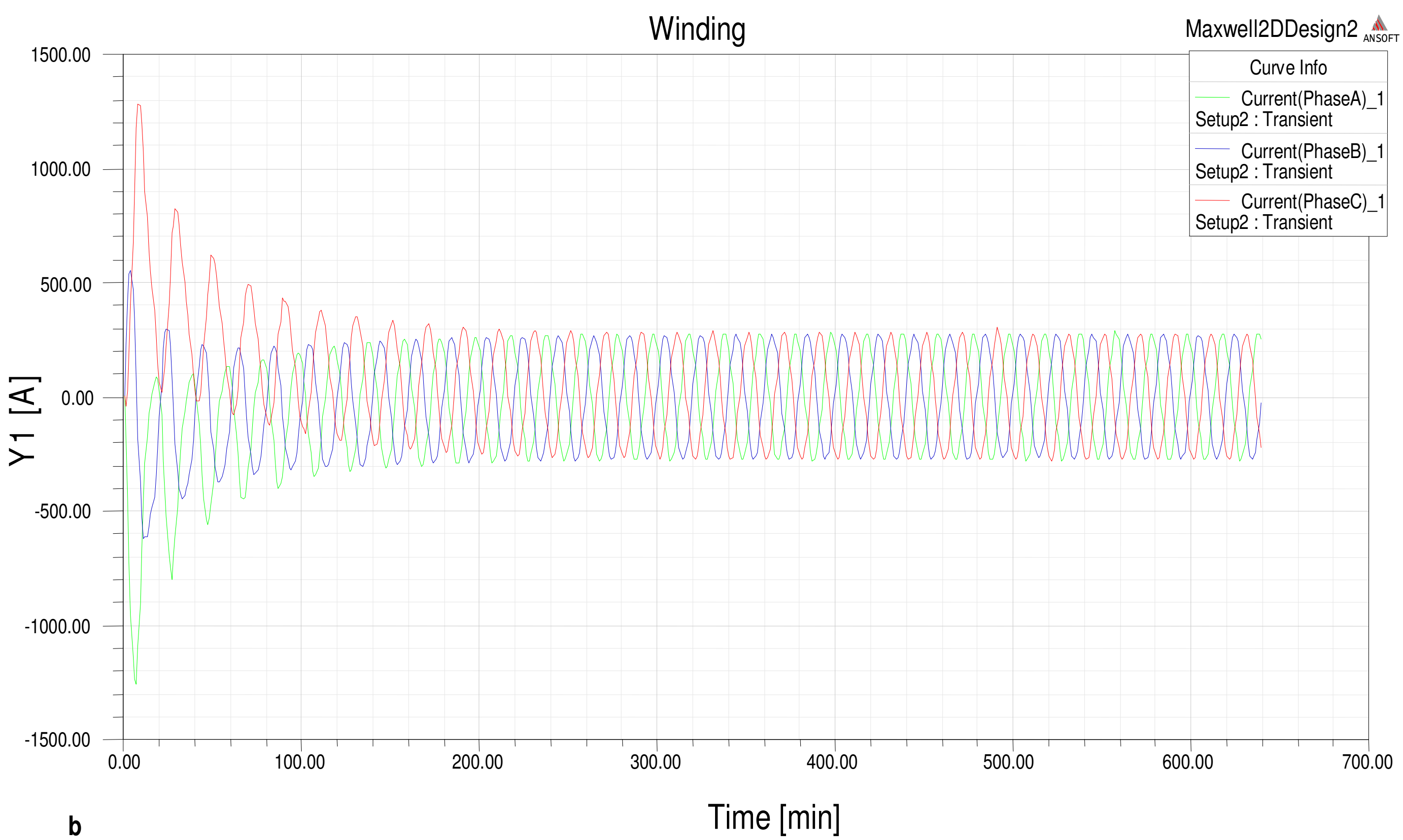
Conclusion

Wind tribune compatible generator designed in the present study has a nominal power of 2.2 MW and gives 6000 V nominal voltage to the external circuit. As it is a



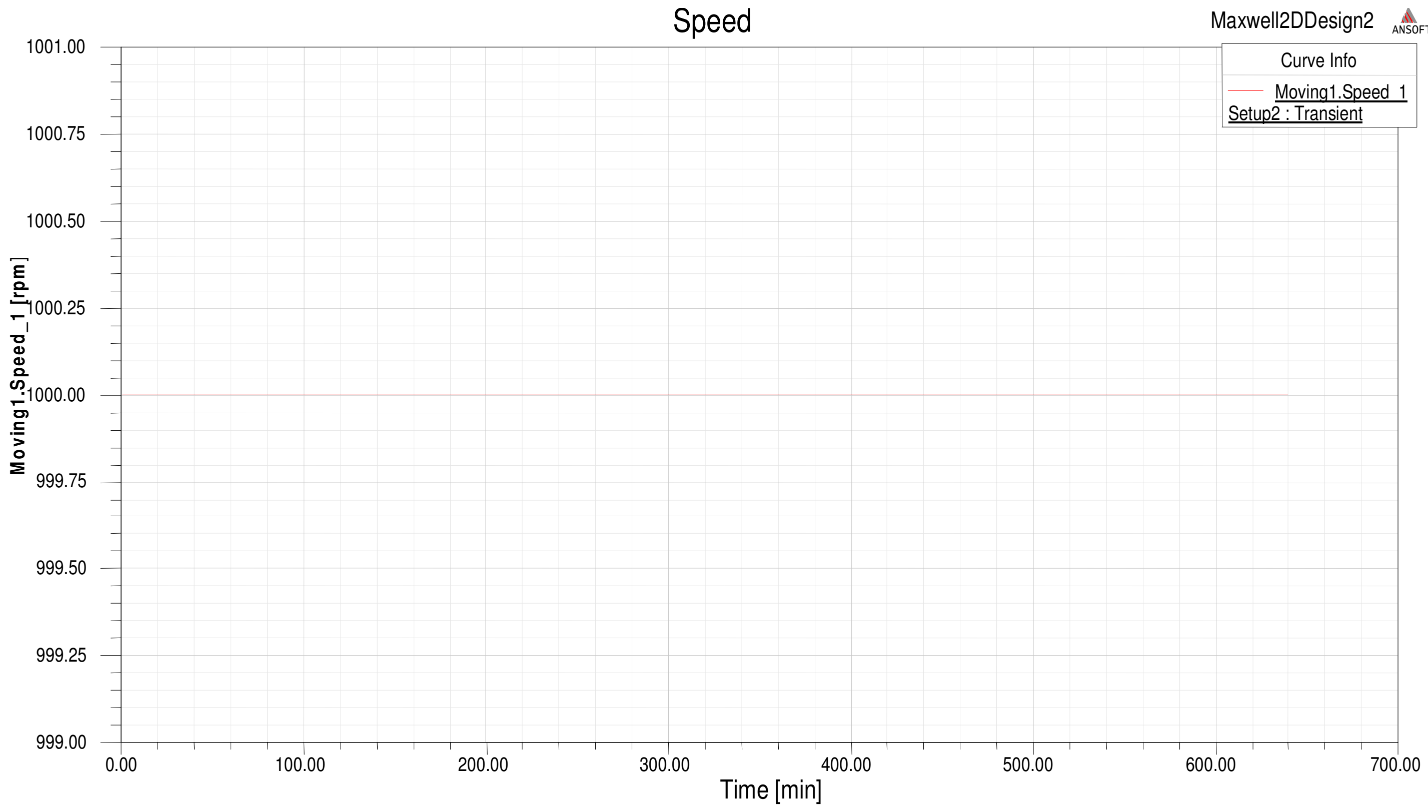
Torque1
Maxwell2DDesign2
ANSOFT
Curve Info
Moving1.Torque_1
Setup2 : Transient
Moving1.Torque_1 [kNewtonMeter]
25.00
-0.00
-25.00
-50.00
-75.00
-100.00
-125.00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
Time [min]

a

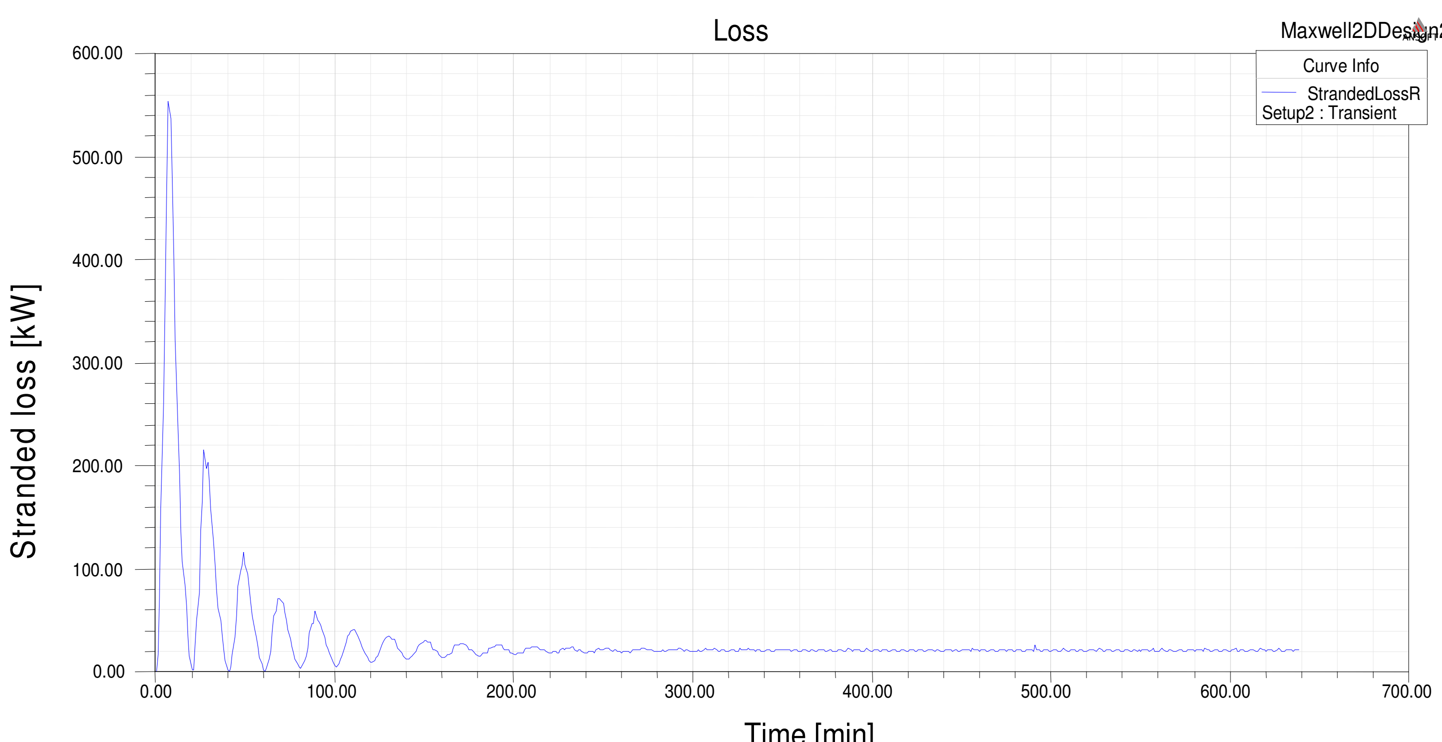


Winding
Maxwell2DDesign2
ANSOFT
Curve Info
Current(PhaseA)_1
Setup2 : Transient
Current(PhaseB)_1
Setup2 : Transient
Current(PhaseC)_1
Setup2 : Transient
Y1 [A]
1500.00
1000.00
500.00
0.00
-500.00
-1000.00
-1500.00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
Time [min]

b

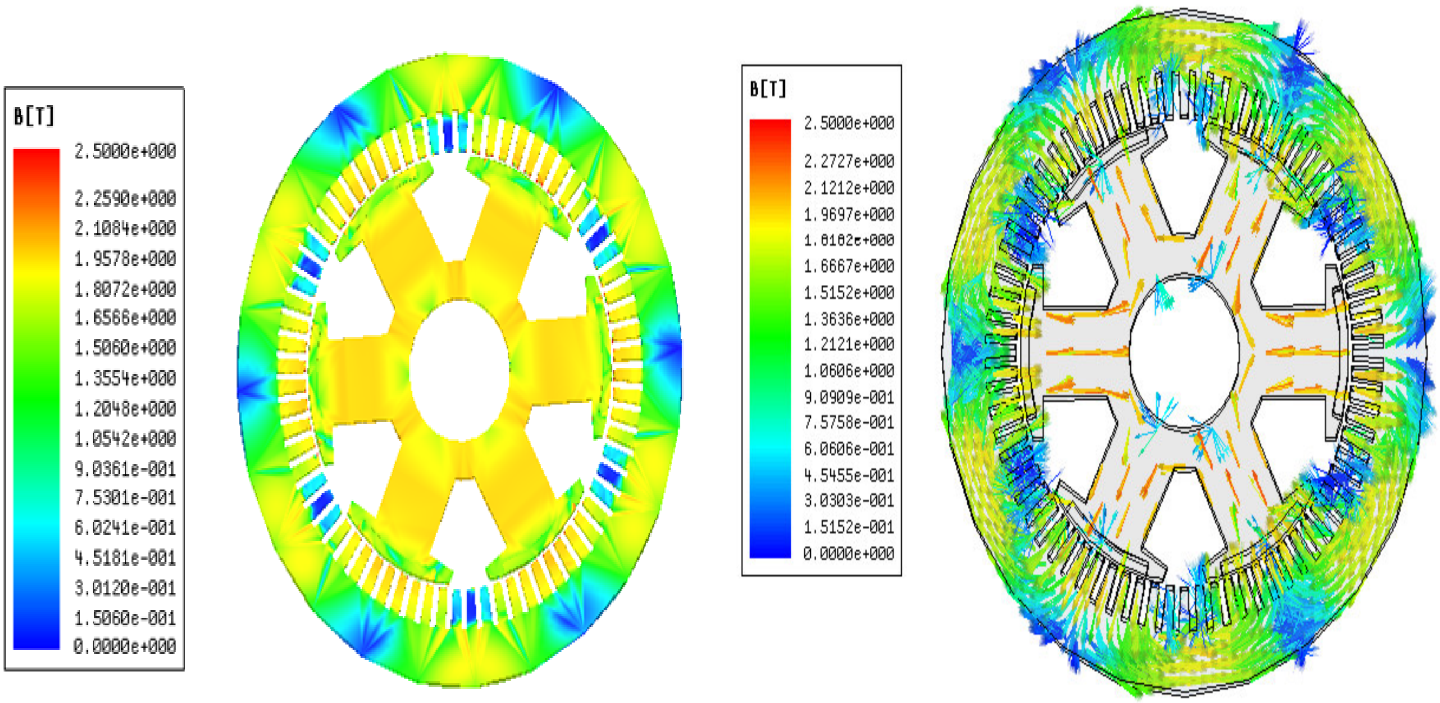


c



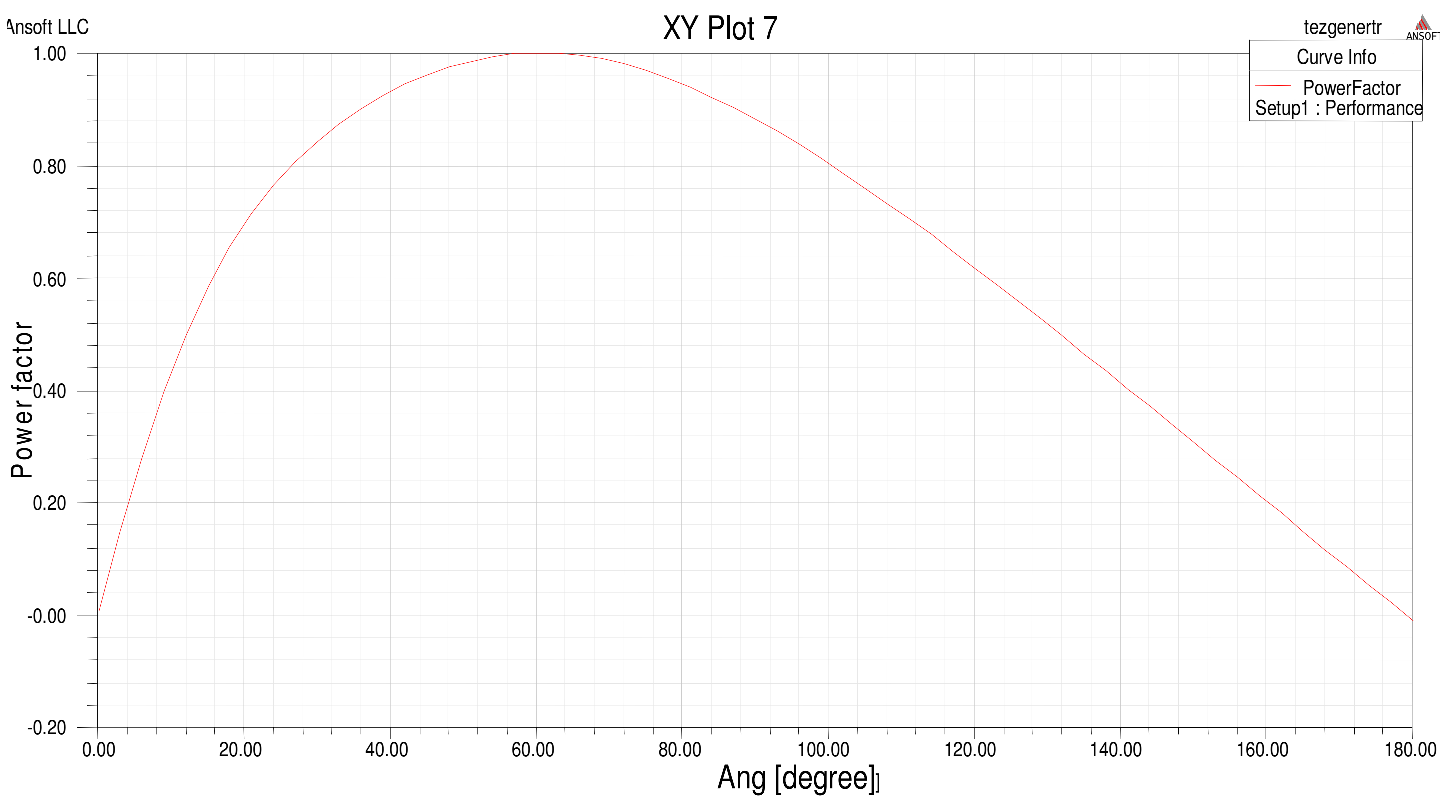
d

Figure 6. Characteristic curves of SPSGD obtained as a result of the simulation (a)Torque-time, (b) three phase fluxes, (c) revolutions per minute, (d) first starting losses.

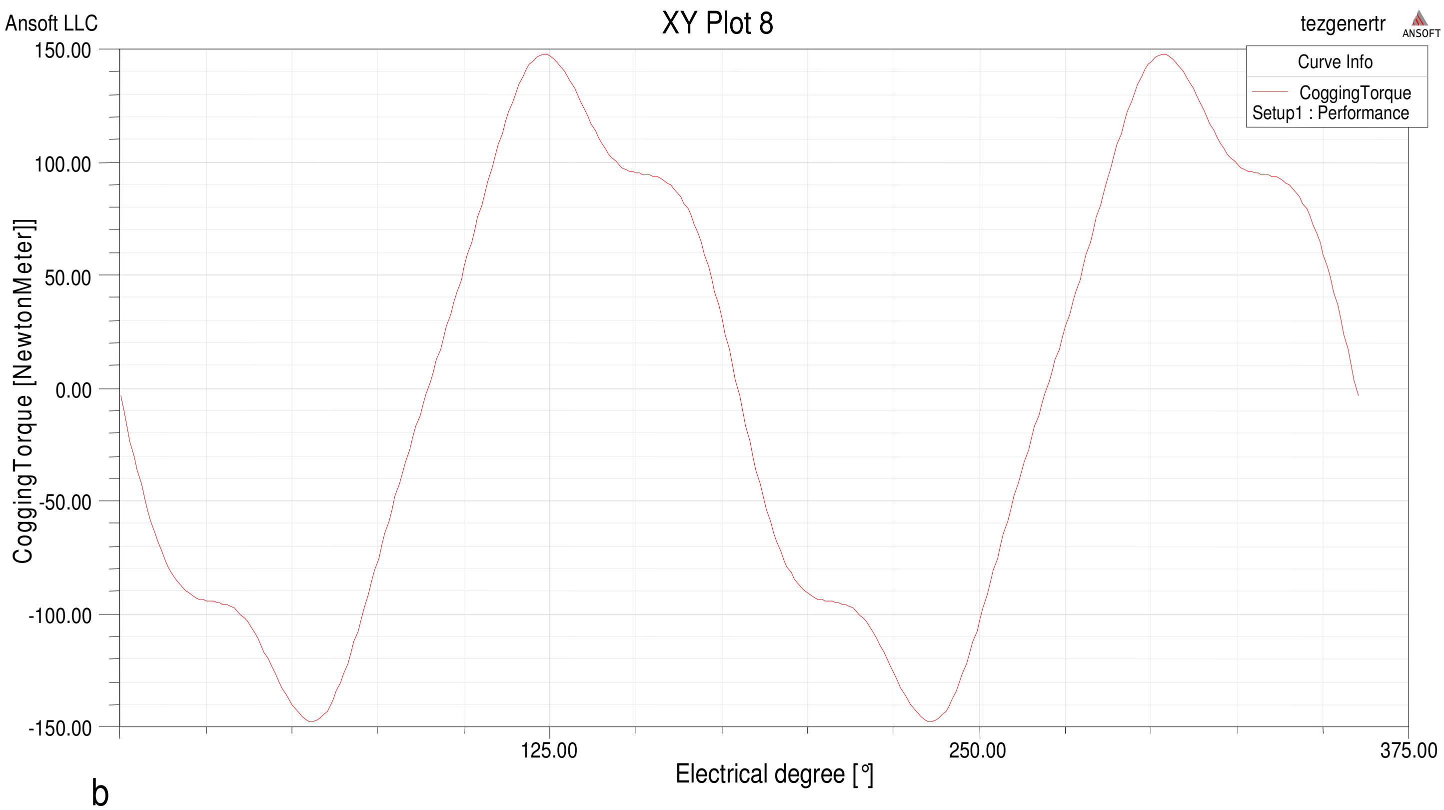


a b

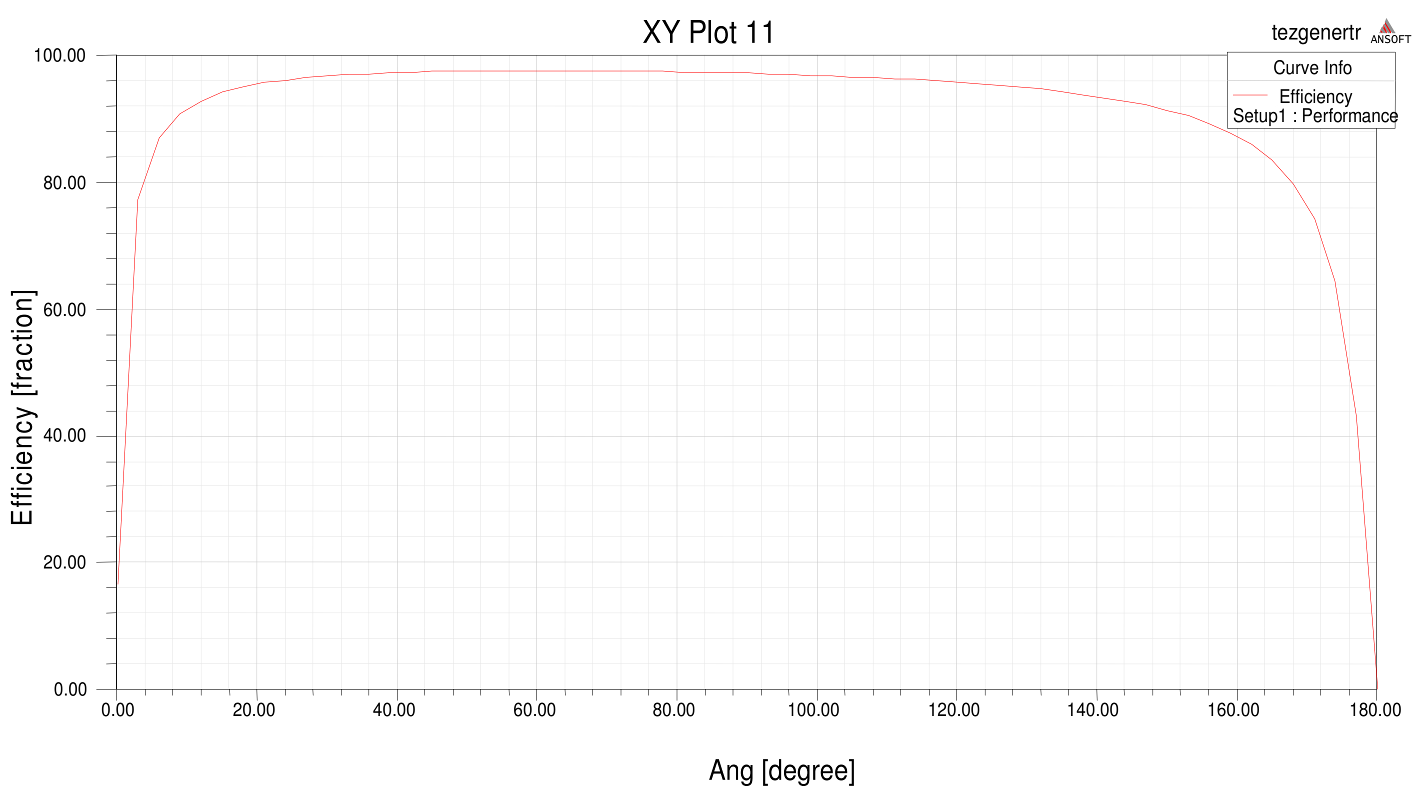
Figure 7. (a) Two-dimensional magnetic flux intensity distribution of SPSGD (b) Two-dimensional vectorial magnetic flux distribution.



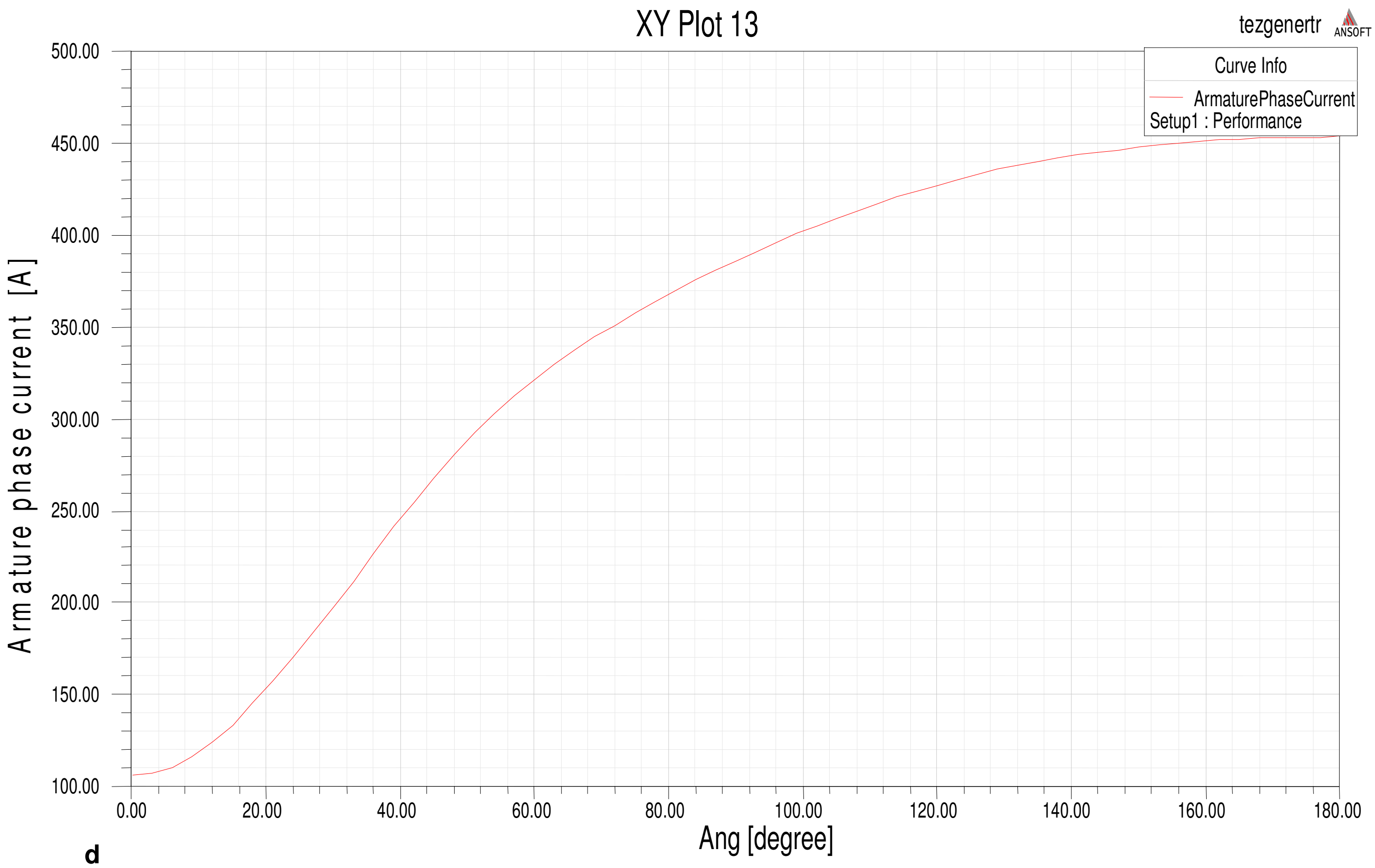
a


Ansoft LLC
XY Plot 8
tezgenertr
ANSOFT
Curve Info
CoggingTorque
Setup1 : Performance
150.00
100.00
50.00
0.00
-50.00
-100.00
-150.00
CoggingTorque [NewtonMeter]]
125.00
250.00
375.00
Electrical degree [°]

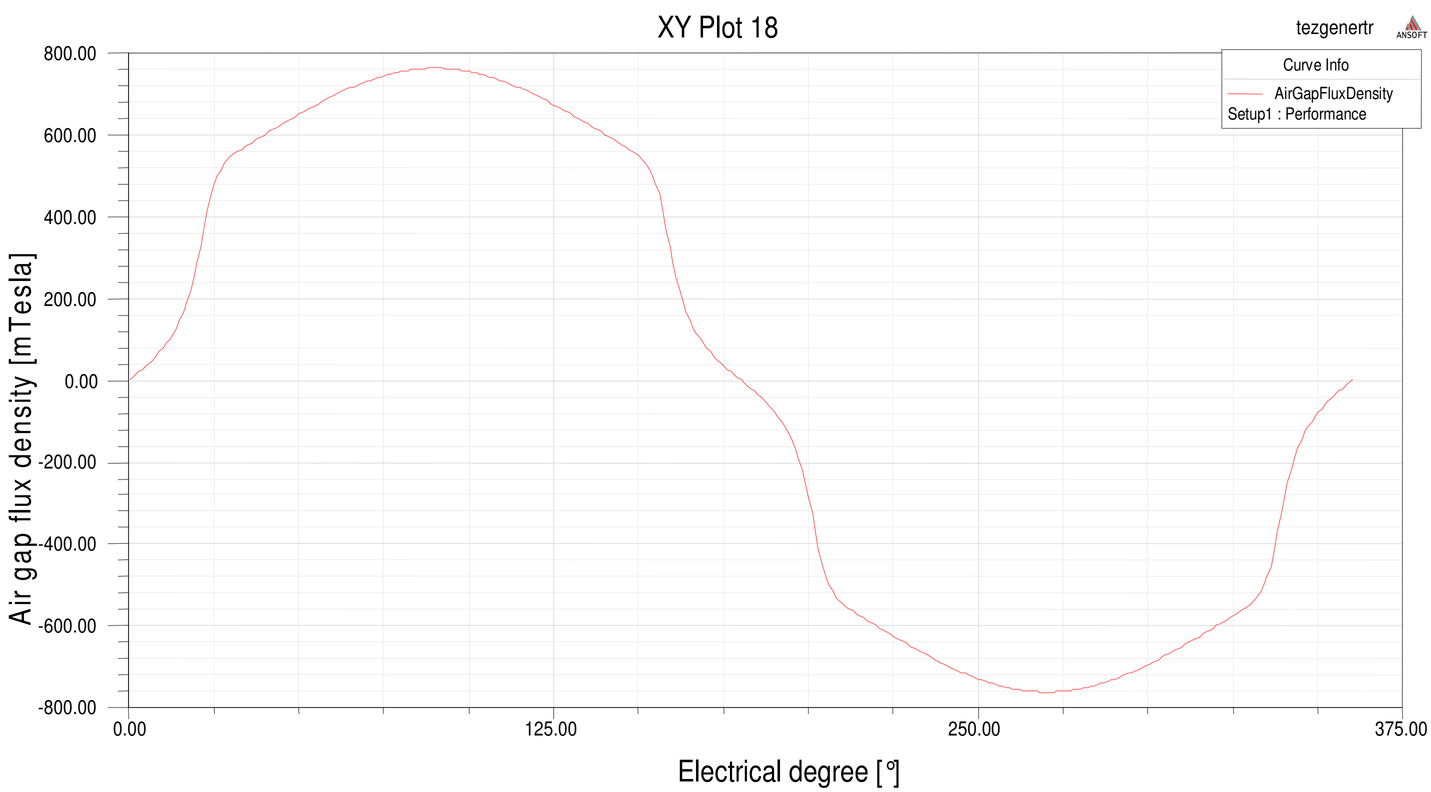
b


XY Plot 11
tezgenertr
ANSOFT
Curve Info
Efficiency
Setup1 : Performance
100.00
80.00
60.00
40.00
20.00
0.00
Efficiency [fraction]
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
Ang [degree]

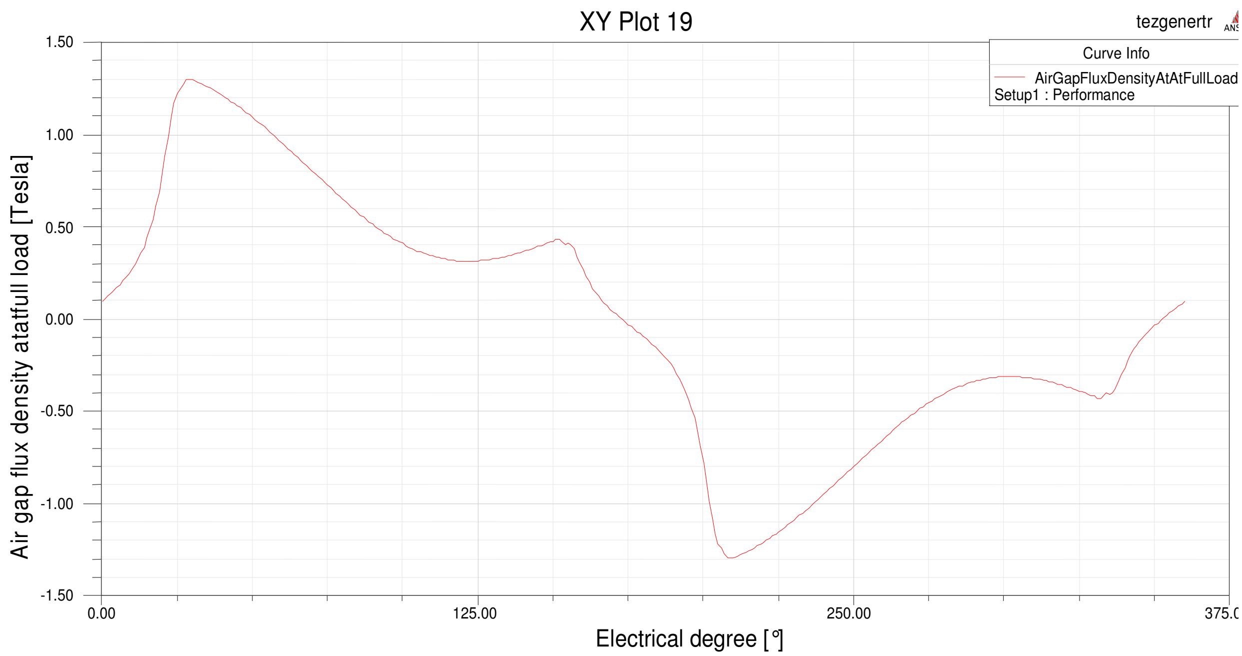
c


XY Plot 13
tezgenertr
ANSOFT
Curve Info
ArmaturePhaseCurrent
Setup1 : Performance
Armature phase current [A]
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
Ang [degree]

d


XY Plot 18
tezgenertr
ANSOFT
Curve Info
AirGapFluxDensity
Setup1 : Performance
Air gap flux density [mTesla]
800.00
600.00
400.00
200.00
0.00
-200.00
-400.00
-600.00
-800.00
0.00
125.00
250.00
375.00
Electrical degree [°]

e



f

Figure 8. Characteristics corves of SPSGD obtained as a result of simulation (a) power factor, (b) cogging Torque, (c) Efficiency, (d) armature phase flux, (e) unloaded air gap magnetic flux density, (f) fully loaded air gap flux density.

synchronous machine, it can directly supply the network on condition that the required controls are performed. The results of the two-dimensional analysis show that the machine cannot reach magnetic saturation under the conditions where the analysis was carried out. Two-dimensional transient analysis revealed that the machine can meet the expected voltage values by becoming stable within 200. The voltage yielded close to the form of sinus can be turned into exact sinusoidal form by means of various phase control circuits.

Through, the material used in the design of the generator, the machine became lighter when compared to its traditional counterparts. This led to decrease in the weight imposed on the wind tribune tower. Moreover, the losses per meter cube induced by the material is less than those caused by core produced from 0.5 mm iron plate.

The sizes of the generator were specially designed. As known, stator width of salient pole synchronous machines is larger than their height. The width of the generator designed in the present study was reduced and its height relatively became larger. This is expected to reduce the impact of horizontal power of wind, which results in a decrease in the force horizontally affecting the tower.

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