

Analysis of Electromagnetic Properties of Doubly-fed Turbine Generator

Ding Shuye¹, Zhang Ning¹

¹College of Electrical and Electronic Engineering, Harbin University of Science and Technology
Harbin 150080, China

Abstract

For the sake of studying the electromagnetic properties of doubly-fed turbine generator. This paper proposed a method which adds an equivalent impedance to simulate the doubly-fed turbine generator's rated state in Maxwell Circuit Editor. Time-stepping finite element was adopted to calculate. Transfer radial air-gap flux density as FFT, getting harmonic content and the influence of harmonic wave on loss.

Keywords: Turbine generator, Finite element, Core loss, Harmonic analysis

Copyright © 2013 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

Doubly-fed generator is a new type of power generation system. The stator winding is connected with power frequency grid. The rotor winding is connected with three-phase alternating currents which frequency can be adjusted. Its speed can follow the change of water velocity make corresponding adjustment. Make the turbine is always running near the unit speed, and the efficiency of the generator is improved, the damage caused by the turbine due to cavitation phenomenon is reduced, at the same time, by controlling the current parameters of the feed rotor winding, not only keep the same frequency, but also the grid power factor can be adjusted to improve the stability of the system.

In view of doubly-fed generator possesses incomparable superiority and broad application prospects, compared with traditional generator. Nowadays, some domestic scholars have done a lot of research about operating principles and power process of doubly-fed turbine generator, which provide a strong basic theory for the person who would engage in this area in the future. Then some scholars have done a lot of researches in doubly-fed turbine generation's controlling system.

These researches didn't consider the internal structure influences to the performance of the generator. This article used a method called time-stepping finite element to analyze the circumstance of the rated loading electromagnetic performance. According to the motor parameter using circuit knowledge to calculate the load resistor, load inductance, and then build the external circuit to simulate load conditions. After the calculation of the finite element, analyze the saturation of the rotor teeth and yoke flux density, extract radial air-gap flux density of air gap to transfer as FFT. Make harmonic amplitude histograms to find the main harmonic content and analyze the reasons. Then extract the doubly-fed hydroelectric generator's iron loss and phase current waveforms to analyze the results and calculate copper loss [3].

2. Mathematical Model

To simplify the analysis of doubly-fed turbine generator to make the following assumptions [7,8]:

- (1) Magnetic induction only considers the radial component.
- (2) Ignore the magnetic field outside the motor; the stator cylindrical magnetic vector is zero.
- (3) Do not take the skin effect into account.
- (4) The end effects of stator and rotor is included in the constant inductance.
- (5) Ignore the temperature effect of the electrical conductivity and magnetic permeability.

Base on above assumptions, the Maxwell equation can be composed of the following nonlinear poisson equation:

$$\frac{\partial}{\partial x} \left(\frac{1}{\mu} \frac{\partial A_z}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{1}{\mu} \frac{\partial A_z}{\partial y} \right) = -J_z + \sigma \frac{\partial A_z}{\partial t} \quad (1)$$

3. Establish Physical Model and External Circuit

In this paper, the 6.5 MW doubly-fed turbine generator electromagnetic properties were studied. The stator and rotor winding adopt star connection. Generator's rated voltage, rate frequency, power factor and other main parameters were shown in Table 1.

Table 1. The Main Parameters of The 6.5MW Doubly-Fed Turbine Generator

Power	Frequency	Voltage	Power factor	Efficiency
6.5 MW	50 Hz	6300 V	0.85	95%

According to the above assumptions, the stator and rotor's end effects are included in constant inductance. Therefore, two-dimensional model can be used. The simplified physical model was shown in Figure 1.

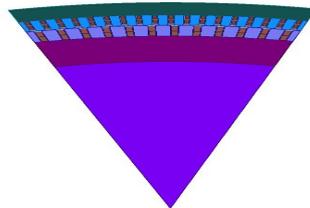


Figure 1. Finite Element Model of Doubly-Fed Turbine Generator

To calculate the rated load of the working conditions, it requires external circuit to simulate load conditions. Table 1 provides the main parameters of the generator. Put these parameters into the formula (2) to (4).

U_N : Rated voltage; P_N : Rated power; $\cos \varphi$: Rated power factor:

$$3 \left(\frac{U_N}{\sqrt{3}} \right) * I_N * \cos \varphi = P_N \quad (2)$$

$$\left(\frac{U_N / \sqrt{3}}{\sqrt{R^2 + (wL)^2}} \right) = I_N \quad (3)$$

$$\frac{R}{\sqrt{R^2 + L^2}} = \cos \varphi \quad (4)$$

$$R = 4.41 \Omega \quad L = 8.7 mH$$

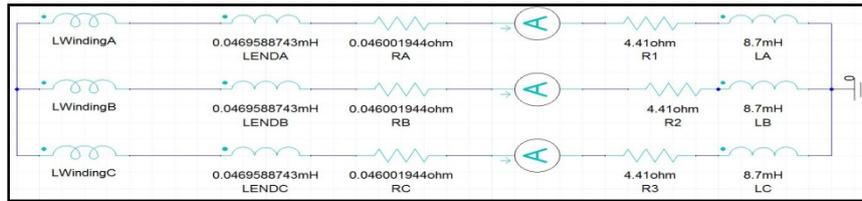


Figure 2. External Circuit of Doubly-Fed Turbine Generator

Take a phase for instance, LWindingA is A- phase winding; LENDA is A-phase end leakage; RA is A-phase resistance value. R1 and LA are external circuit resistance and inductance value.

4. Model Split and Finite Element Calculation Results

4.1. Model Split

For considering harmonic magnetic field, the generator's teeth and air gap should be encrypted to split.

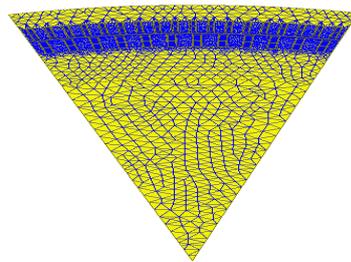


Figure 3. The Mesh of Physical Model

4.2. Results and Analysis

The flux density is the main parameter of the generator, it being too high will lead to core loss increase. Thus extract the flux density's contours to analyze.

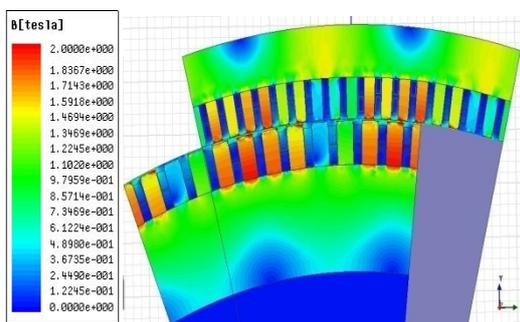


Figure 4. Rated Load Flux Density Contour

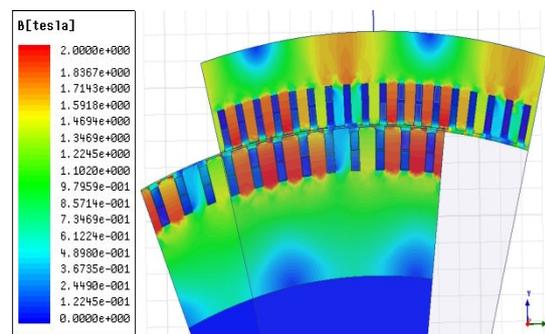


Figure 5. Under No Load Flux Density Contour

Figure 4 and 5 are flux density contours of doubly-fed turbine generator in rated load and no load condition. Compare two Figures. The flux density of motor is conspicuously larger than rated load. Because of the load is inductive. So it played the role of demagnetization, that's

why the saturation level in no load is lower than under the load. The stator and the rotor slots are chosen for the parallel groove, so tooth are trapezoid. Therefore, in the 1/3 place of flux density is the average flux density. Rated load with the largest of the stator flux density of teeth is about 1.86T so it is the same with rotor, whose flux density of the tooth is 1.837T.

The theory and experiment proved that, harmonic will cause a lot of adverse effects, such as produce a larger loss make the generator temperature increase, reduce the efficiency of the generator, so harmonic content can not be ignored [3]. Therefore, in order to analyze the harmonic content, transfer radial air-gap flux density as FFT.

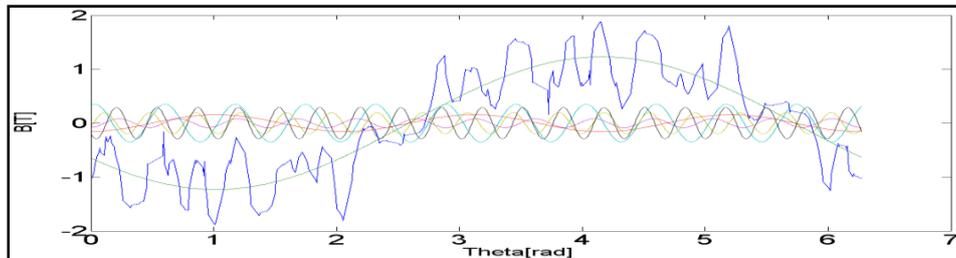


Figure 6. Fourier Decomposition of Air Gap Flux

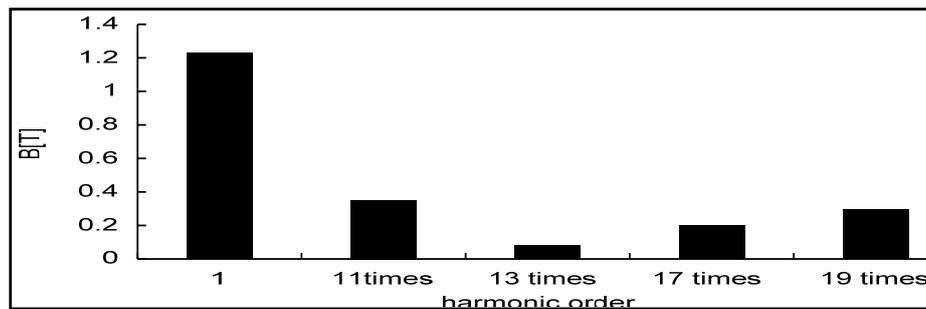


Figure 7. The Various Harmonics Amplitude

It can be seen from Figure 7 that the tooth harmonic content is higher. Because of the generator does not wake the tooth harmonic.

5. Copper loss and iron loss

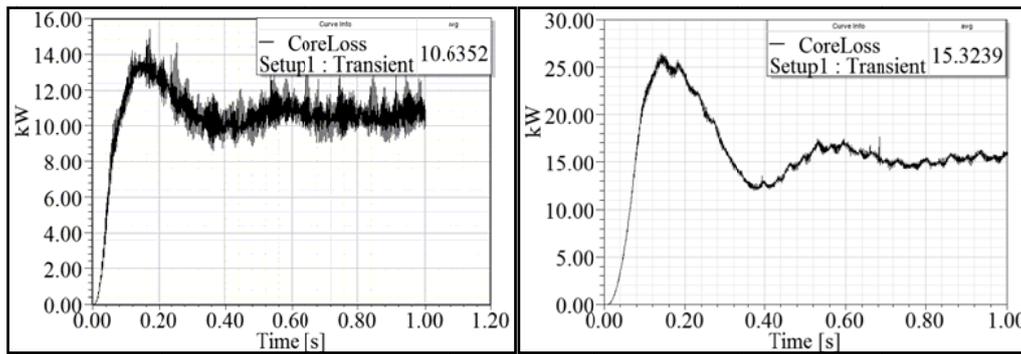
5.1 Iron loss

In fact, there are many methods to calculate the iron loss. This paper use the time step finite element method to calculate the iron loss. Adopt a relatively wide range of iron loss calculation method called "three-phase constant coefficient" which improved by Bertotti. The formula is as follows [11].

$$P_{fe} = k_a f B^2 + k_e f^2 B^2 + k_a f^{1.5} B^{1.5} \quad (5)$$

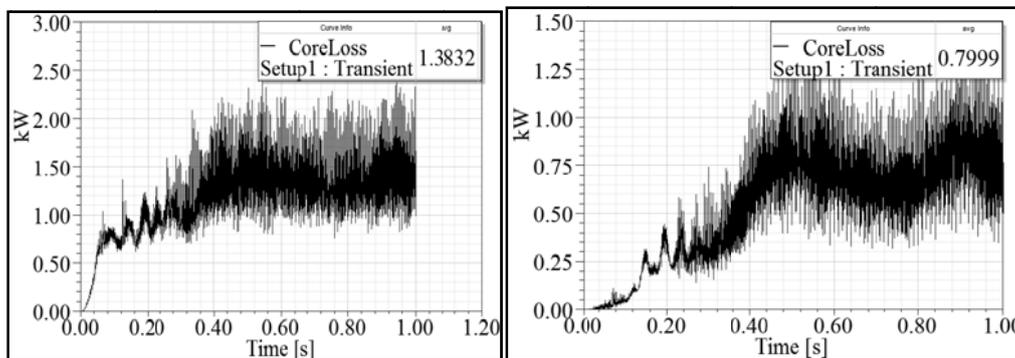
$$k_e = \frac{\pi^2 \gamma d^2}{6\rho} \quad (6)$$

Where γ is the conductivity; d is the thickness of the silicon steel sheet; ρ is the density of ferromagnetic material; k_h 、 k_a can be got through the measured loss of silicon steel. The calculation results show in Figure 8.



a) Core loss of stator tooth

b) Core loss of stator yoke



c) Core loss of rotor tooth

d) Core loss of rotor yoke

Figure 8. Core Loss Waveform

It can be seen from Figure 8, the rotor iron loss is slightly larger. In addition, due to the use two-dimensional physical model does not consider the end of the structure, so the value is low [11-13]

5.2. Copper Loss

After the waveform reaching stability, between 0.8 and 1 second take the average of the peak, then the effective value of phase currents can be got. The effective value of the stator phase current is 693A. The effective value of the rotor phase current is 784A.

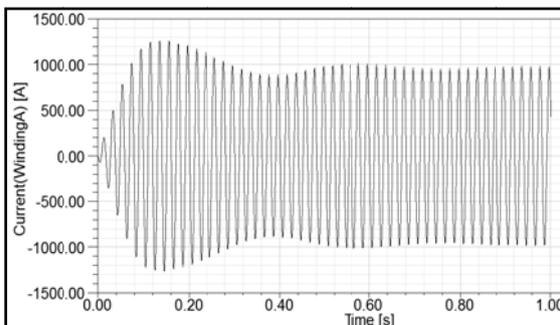


Figure 9. Current Waveform of The Stator

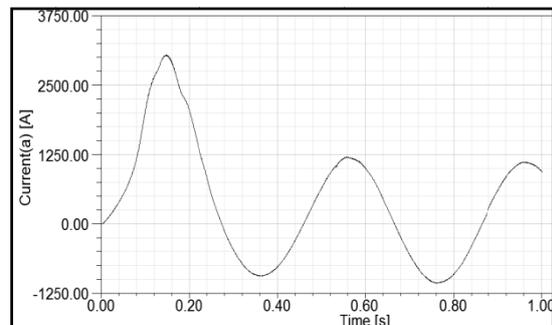


Figure 10. Current Waveform of The Rotor

$$\text{Stator copper loss: } P_{cu1} = 3I_1^2 R_1 = 3 \times 693^2 \times 0.046 = 66.25 \text{ kW}$$

$$\text{Rotor copper loss: } P_{cu2} = 3I_2^2 R_2 = 3 \times 784^2 \times 0.094 = 173.33 \text{ kW}$$

6. Conclusion

This paper take 6.5MW doubly-fed hydraulic generator as an example, the model of finite element was created and the electromagnetic properties were analyzed. The main conclusions are as follows. Without use the structure, which can weaken tooth harmonic will lead to the generator's loss increase. The generator's magnetic flux density which under on-load is greater than the case of the rated load. The iron loss which under on load will be slightly larger accordingly. The result of this paper for improving the structure of the generator to reduce the loss has reference value.

Reference

- [1] Li hui, Yang shunchang. Study of control startegies for hydrogenerator system with doubly-fed generators based on CMAC neural net work. *Journal of Hydroelectric Engineering*. 2007 (03).
- [2] Li hui, Yang shunchang. *Simulation of doubly fed hydrogenerator system based on fuzzy neural network decoupling Technology*. 2005; (09).
- [3] Chen shikun. *Motor design*. Beijing: China Machines Press. 2008.
- [4] Tang yunqiu. *Electromagnetic field in motors*. Science and Technology Press. 1998.
- [5] Chen shiyuan. *Finite element analysis of AC magnetic field*. Harbin: Harbin Engineering University Press. 1998: 153-188.
- [6] Hu minqiang, Huang xueliang. *Numerical computation method of electric machine performance and its application*. Nanjing: Northeast University Publisher. 2003: 171.
- [7] Wang changcun, LI weili, Cheng peng, Sun qiuxia. *Load Performance Analysis and Calculation of Double-fed Induction Winding Generator Based on Field and Circuit Coupling*. Micrometers Servo Technique. 40(6).
- [8] Liang yanping. *The theory and numerical calculation of Synchronous motor parameters*. Harbin Engineering University Press. 1999: 43-137.
- [9] Zhao wenchun, Weiming, Hu an. *FFT algorithm with high accuracy for harmonic analysis in the electric machine*. Proceedings of the CSEE. 2001; 21(12): 83-87.
- [10] Bertotti G. General properties of power losses in soft ferromagnetic material. *IEEE Transactions on Magnetic*. 1988; 24(1): 621-630.
- [11] Zhao Haisen, Luo Yingli, Liu Xiaofang, RH Wang, Chen Weihua. *Analysis on No-load Iron Losses Distribution of Asynchronous Motors With Time-stepping Finite Element Method*. Proceedings of the CSEE. 2010; (30).
- [12] Jianzhao Huang, Jian Xie, et al. Self-adaptive Decomposition Level De-noising Method Based on Wavelet Transform, *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(5).
- [13] Arko Djajadi, Fiona Laoda, Rusman Rusyadi, Tutuko Prajogo, MaraloSinaga. A Model Vision of Sorting System Application Using Robotic Manipulator. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2010; 8(2):137-147.