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Performance Simulation of 300MW Turbine Generator by Ansoft Maxwell

Cai Chen [1#], Shuquan Zhang [2], Huijuan Liu [1]

1. School of Electrical Engineering, Beijing Jiaotong University, Beijing, 100044, China

2. Beijing Jingqiao Thermal Power Co., Ltd., Beijing, 100067, China

[#]Email: 13121387@bjtu.edu.cn

Abstract

The finite element model of a 300MW turbine generator is established by means of the finite element analysis software-Maxwell in this paper. Through the simulation analysis, the operating characteristics and various electromagnetic parameters including no-load characteristic, short-circuit characteristic, air-gap flux density, stator induced voltage, electromagnetic torque and reactance parameters of the generator as well as the core-loss are obtained. Compared with the design values, the simulation model established is verified by the simulation results.

Keywords: 300MW Turbine Generator; Electromagnetic Performance; Finite Element Analysis (FEA)

1 INTRODUCTION

The turbine generator is one of important devices in the power systems. Generally, the power of the turbo- generator can reach hundreds of megawatts and even larger, so the performance of the generator plays a great role in determining the efficiency and stability of the entire power system. Therefore, it is necessary to analyze the electromagnetic performance carefully so as to achieve its maximum efficiency. There are about three traditional methods to calculate electromagnetic properties of generators, they are the analytical method using continuous field model, the method using discrete field model and the tooth loop method based on the field respectively. But to some extent, there are some shortcomings of these methods, such as longer time or more assumptions are needed. Additionally, the special rotor structures, the short slots and the partial slots in the rotor, make it much more complex to analyze the generator. However, these problems can be solved effectively by the finite element analysis. Furthermore, the FEA can make the simulation models closer to the actual situation and can get more accurate transient process [1]. This paper mainly simulated the electromagnetic performances and calculated related parameters of the 300MW turbine generator using Maxwell and the simulation results are compared with the design values.

2 SIMULATION CONTENTS AND RESULTS

The finite element method applied in the electromagnetic field of the electric machinery mainly includes several crucial steps like modeling, adding material, setting the boundary conditions, adding excitation source, meshing, solving and post-processing.

2.1 Simulation Model of the Turbine Generator

The two-dimensional finite element model of the generator is presented in the FIG.1. The rotor is designed as such structure showed in the FIG.1 so as to expand the area of the the magnetic circuit in the magnetic poles [2]. There are short slots and the partial slots in the places close to the large teeth not the evenly distributed slots in the rotor and this is what the turbine generator distinguishes most from the common non-salient pole machines. Concretely, there are 32 rotor slots, 8 slots of them close to the large teeth are short slots or the partial slots. The rotor core is forged as a whole one and made of 26Cr2Ni4MoV alloy steel. The stator winding is three-phase symmetrical double-layer

short pitch winding, and there are 54 stator slots which are evenly distributed in the stator. The stator core is made of DW310-35 silicon steel sheets.

TABLE 1 BASIC PARAMETERS OF THE GENERATOR

stator outer diameter (mm)	2500	stator inner diameter (mm)	1250
rotor outer diameter (mm)	1100	air-gap length(mm)	75
pole number	2	frequency(Hz)	50
stack length(mm)	5130	rotor slots	32
stator slots	54	rated voltage (kV)	20
rated current (A)	10189	power factor	0.85

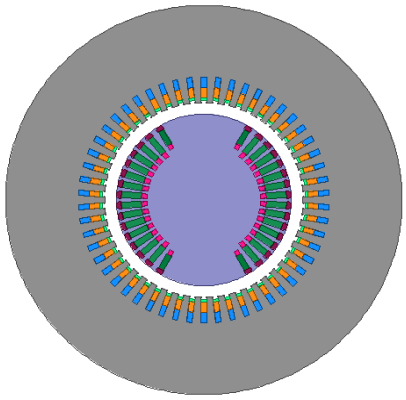


FIG.1 FINITE ELEMENT MODEL OF THE TURBINE GENERATOR

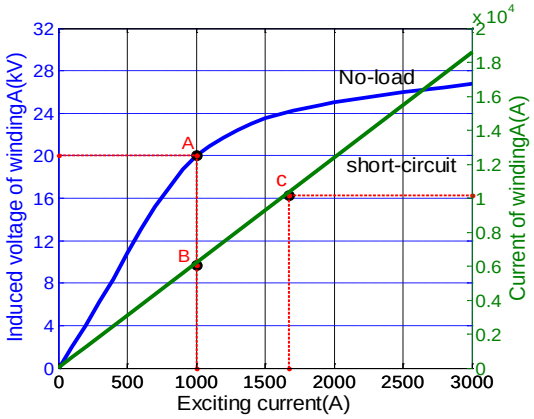


FIG.2 NO-LOAD AND SHORT-CIRCUIT CHARACTERISTIC

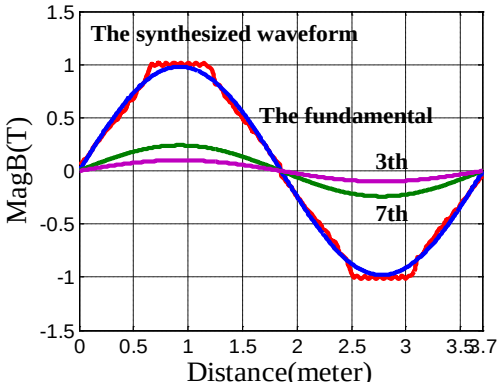


FIG.3 NO-LOAD FLUX DENSITY AND ITS HARMONIC CONTENT

2.2 The Open-Circuit Characteristics and Short-Circuit Characteristics

We can get the no-load characteristic curve of the generator shown as the blue line in FIG.2 when the generator is open-circuited, likewise, we can get short-circuit characteristic curve of the generator shown as the green line in FIG.2 when the stator windings was short circuit.

Generally, the armature resistance is much less than the synchronous reactance, consequently, the resistance effect can be neglected, the armature circuit is close to pure inductance circuit, the short-circuit current lags the induced voltage by 90 electrical angle, and so the armature reaction at this time manifested as the demagnetization armature reaction, the magnetic flux within the motor case is weak and the magnetic circuit is unsaturated which is why the short-circuit characteristic curve is approximately a straight line[3].

When the electricity and mechanical energy was converted mutually in the generator, energy will be passed through the magnetic field of air-gap between stator and rotor, the flux density in the air-gap is an important parameter in the analysis of the electromagnetic field, the impact of flux density on the generator is mainly reflected by the motor torque ripple, vibration noise, iron loss and efficiency and so on [4]. Therefore, it is necessary to analyze the flux density in the air gap. When the rotor speed is 3000rpm, the stator winding is open-circuit, 987A direct current is

added to the rotor field winding, and we can get the flux density waveform of the air-gap in this case which is shown in FIG.3. Due to the double layer and short-pitch windings, in the turbine generator, the pitch is 22, therefore the 5th harmonic was weakened, we can get the fundamental, 3rd and 7th harmonic and their harmonic contents are 0.98T, 0.048T and 0.03T respectively.

2.3 The Reactance

Reactance is the parameter what reflects the degree of magnetic saturation in the motor, a different degree of saturation corresponding to a different value of the reactance. For the turbine generator, we need to calculate the values at these two cases respectively in order to compare saturated and unsaturated reactance values.

1) The Saturated Synchronous Reactance

Due to the no-load and short-circuit characteristics have been calculated, so the saturation value of its synchronous reactance can be achieved by the no-load and short-circuit characteristic.

The saturation extent of main magnetic circuit depends on the actual synthesis magnetic motive forces (MMFs) in the magnetic field. If the voltage drop of the leakage impedance is not counted, we can approximately considered that depend on the terminal voltage of the armature, Therefore, the direct-axis reactance corresponding to the rated voltage is usually taken as the saturation[5-6]. We can find out the excitation current If corresponding to the rated phase voltage U_N from the no-load curve is 987A and the short-circuit current I_S corresponding to the excitation current If from the short circuit characteristics is about 6300A, as shown in FIG.2. Since the turbine generator stator windings are connected in Y, so the U_N is 11.547kV, so we can achieve the approximate value of the saturated reactance.

$$X_{d(saturation)} \approx \frac{U_N}{I_S} \tag{1}$$

Therefore, the Xd(saturation) is $1.85\,\Omega$. According to the rated parameters of the turbine generator, we can get the base value of the impedance

$$Z_b = \frac{20000}{\sqrt{3}\cdot 10189} = 1.13\ \Omega \tag{2}$$

Therefore, the per-unit value of X_d is 165%, for non-salient pole synchronous generator, direct axis reactance that is saturated synchronous reactance.

As we can see from FIG.2, the stator winding rated current is 10189A, the short-circuit current corresponding to the stator winding rated current is about 1670A, while the excitation current corresponding to the stator winding rated voltage is 987A, so the short circuit ratio of the turbine generator is about 0.58, and the design value is 0.6, so we can draw the conclusion that the simulation model is close to the actual values.

2) The Unsaturated Synchronous Reactance

The slip method is adopted to calculate unsaturated value of X_d and X_q. Slip method, as the name implies, there exists slip between the rotor speed and synchronous speed, namely, the rotor speed is not the synchronous speed but close to the synchronous speed. In the calculation, the rotor speed was set 2970 rpm, that is close to but not the synchronous speed 3000 rpm, slip rate is 0.01, the field winding is open-circuit, symmetrical three-phase AC current is added to the stator windings, the frequency of the current is 50Hz and the amplitude is 100A, when the stator rotating magnetic field coincides with straight shaft, the stator current reaches its minimum, the reactance reaches its maximum, in this case, the reactance of stator is the direct-axis reactance X_d. Likewise, when the rotating magnetic field coincides with the quadrature-axis, the stator current reaches its maximum and the reactance reaches its minimum, the reactance attained is the quadrature-axis reactance X_q. Taking winding A as an example, in order to calculate the X_d and X_q, we just need to obtain the flux linkage waveform, since the direct-axis continuously alternates with quadrature-axis, therefore the flux linkage waveform looks like an envelope shape [7]. The finite element simulation results of A-phase flux linkage waveform are shown in FIG.4. The maximum value of the flux linkage reflects the X_d and the minimum reflects the X_q. Since the turbine generator is a non-salient pole synchronous generator, the X_d is almost equal to X_q, additionally, the current is just 1% of the stator rated current I_N,

so the envelope shape is not quite pronounced. From the FIG.4, we can get the ψ_d =0.56Web, ψ_q=0.54Web. According to the formula (3) and (4), we can obtain L_d = 0.0056H, L_q = 0.0054H, thus, X_d = 1.758Ω, X_q = 1.696Ω, from the equation (2), Hence, X^*_d and X^*_q is 155% and 150% respectively.

$$\psi = Li \tag{3}$$

$$X = \omega L \tag{4}$$

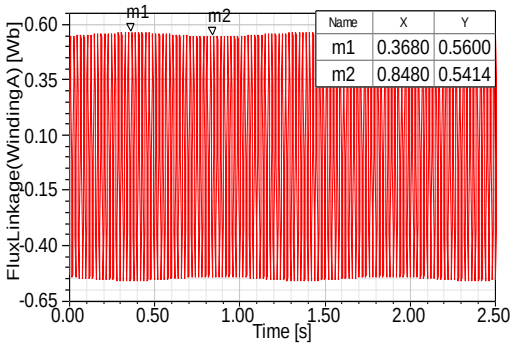


FIG.4 FLUX LINKAGE WAVEFORM OF WINDING A

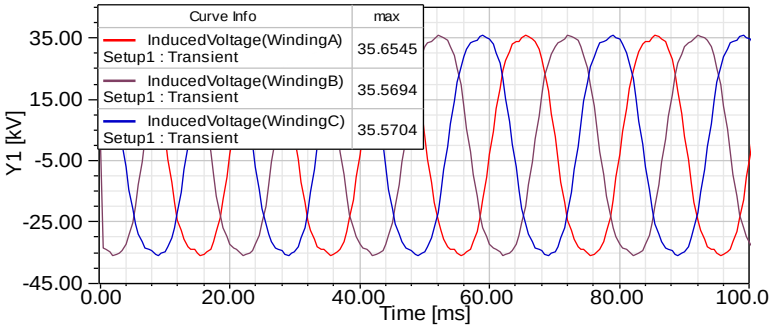


FIG.5 THE RATED INDUCED VOLTAGE

2.4 Full-load Operation

Before simulating the rated performance of the generator, the initial position of the generator rotor is needed to be determined first. The initial position of the rotor needs to satisfy that the magnetic field direction of winding A is opposite to the rotor magnetic field direction [8-9]. In this simulation, the conditions above is meted when the rotor direct axis coincides with the A-phase winding centerline. Therefore, the initial position angle of the rotor is determined as 103.33 electrical angles. When the generator operates at the rated condition, the induced voltage of winding A at the rated state is presented in the FIG.5. According to the rated data of the turbine generator and the phasor diagram of the non-salient synchronous machine [10], the induced voltage of winding A can be calculated in theory; we can get the RMS value of the rated induced voltage of winding A is 24.57kV based on formula (5) and the amplitude 34.74kV. The rating armature current is presented in the FIG.6.

$$\dot{E} = \dot{U} + jX_s\dot{I} \tag{5}$$

The full load air-gap flux density waveform is also investigated and showed in the FIG.7. Compared to the no-load flux density waveform, the waveform at the rated state is approximately a sine wave; however, there is a slight deviation from the straight shaft due to armature reaction. The harmonic content is also researched, we can see that the fundamental amplitude is 1.45T; the amplitude of 3rd and 5th harmonic was 0.13T and 0.06T, the harmonics more than 5th carry less content.

The rated torque is about 938 kNm which is less than the design value 955kNm and the torque curve is showed in the FIG.8. The core-loss is about 645.65kW as we can see from the FIG.9 and the design value of it is 724kW.

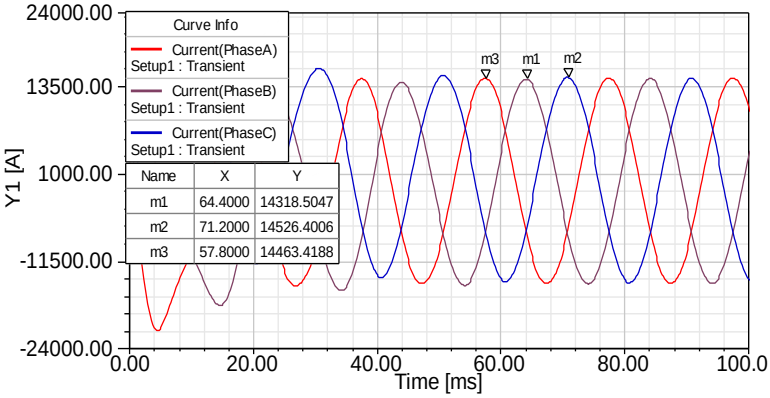


FIG.6 THE ARMATURE CURRENT IN WINDING A

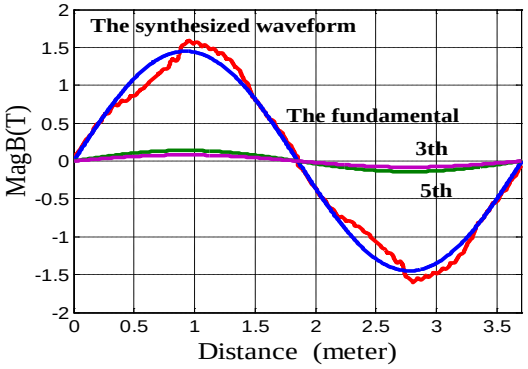


FIG. 7 THE AIR-GAP FLUX DENSITY AND ITS HARMONIC CONTENTS

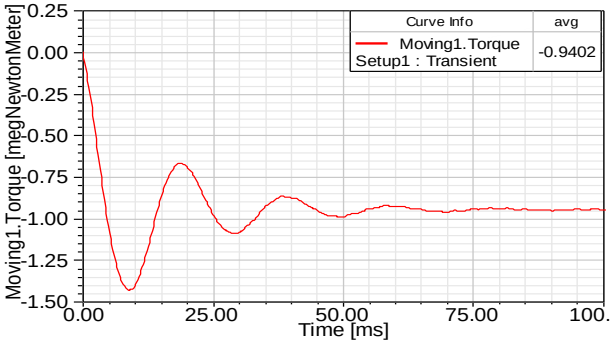


FIG.8 THE RATED TORQUE CURVE

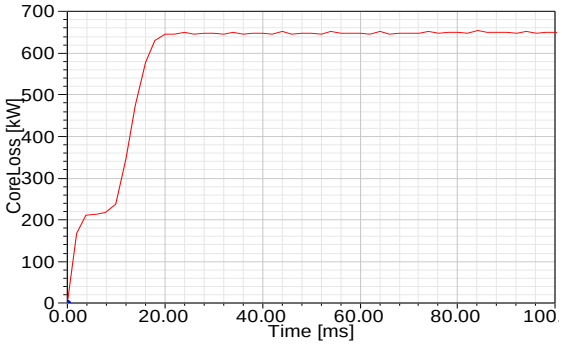


FIG.9 THE CORE-LOSS CURVE

3 CONCLUSION

The operating characteristics and electromagnetic parameters of a 300MW 2-pole turbine generator are simulated and calculated by the finite element software. According to the simulation results, we can get that:

(1) Though the generator is a non-salient pole synchronous machine, the special rotor structure resulted in the inequality between the X_d and X_q.

(2)There is a slight deviation of the full load air-gap flux density waveform from the direct axis due to armature reaction.

The simulation results are validated by design values of generator. The model and method in this paper can be used for the further analysis of turbine generator.

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REFERENCES

[1] Wang Yi-Xuan;Wang Ying;Liu Xin;Qiu Hai-Fei.“Electromagnetic design and dynamic analysis of large turbo-generator”, Journal of Enerhy and Power Engineering, pp.19-28, Dec. 2009.

[2] Wladyslaw Paszek, Jan Staszak. “Electromagnetic Parameters of a Turbine generator Determined by the Finite Element Calculation”, Electromagnetic Fields in Electrical Engineering, pp. 171-176, 1988.

[3] Michael G. Pantelyat, Oszkár Bíró, Andrej Stermecki, “Transient electromagnetic field, losses and forces in a synchronous turbine generator rotor”, The international journal for computation and mathematics in electrical and electronic engineering, Vol. 32,no. 3, pp.794-808, 2013.

[4] M. A. Arjona L. “Discussion of Parameter calculation of a turbinegenerator during an open-circuit transient excitation”, IEEE Transactions on Energy Conversion .vol.19, no.1, p.46-52, Mar.2004.

[5] Yang Zhao,Bo Yan, Changlin Chen, Jianan Deng, Qingwu Zhou, “Parametric Study on Dynamic Characteristics of Turbine generator Stator End Winding”, IEEE Transactions on Energy Conversion, Vol. 29, no. 1, pp. 129-137, Mar. 2014.

[6] Shima K, Ide K, Takahashi M, “Finite-element calculation of leakage inductances of a saturated salient-pole synchronous machine with damper circuits”, IEEE Transactions on Energy Conversion, vol. 17, no. 4, pp. 463-470, Aug.2002.

[7] D. Ban, D. Zarko, Z. Maljkovic. “The application of finite element method for more accurate calculation and analysis of turbinegenerator parameters”, Electric Machines and Power Systems, Vol. 26, no. 10, pp.1081-1093, Dec. 1998.

[8] Jinyao Hu, “Electromagnetic Parameter Calculation and Transient Performance Analysis for Large Turbo-generator”, Harbin University of Science and Technology, pp.16-47, Mar.2012.

[9] R. Mizokami, M. Kimura and M. Muraoka, “Electromagnetic field analysis for the new series of air-cooled, two-pole turbine-generator”, Fuji Electric journal, Vol. 72, pp. 271-274. 1999.

[10] Huijuan Liu, Yu Fan. Electrical Machinery. China Machine Press, Beijing, pp.200-230, Apr.2014.

AUTHORS

[1]***Cai Chen*** (1989-), he is a master in Electrical Engineering of Beijing Jiaotong University. His research interest is analysis of ferromagnetic resonance mechanism for gas turbine generator dragging by SFC.

[2]***Shuquan Zhang*** (1974-), he received B.S. degree in Electrical Engineering and Automation in 2008 and M.S. degree in Control Engineering in 2013 from North China Electric Power University, his research interest mainly focus on large-scale thermal power units control and electrical work.

[3]***Huijuan Liu*** (1967-), she received Ph. D. in Electrical Engineering from Beijing Jiaotong University (China) in 2009, and received the B.S. degree and M.S. degree from Tianjin University (China) in 1989 and 1994 respectively. Since December 2005, she has been an Associate Professor with Beijing Jiaotong University. Her current research interests mainly focus on numerical methods of electromagnetic field computation, optimal design and control of induction machine, doubly fed brushless machine, and permanent magnetic machine for wind power and other new power source development.