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Research paper

Analysis of Generation Characteristics of Large-Scale Synchronous Generators for Hydroelectric Power

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Abstract

Background/Objectives: Hydroelectric power generators are used in various capacities from small capacity to large capacity, but research on large capacity generators is lacking.
Methods/Statistical analysis: The electromagnetic characteristics of 1MW class wound type synchronous generators are analyzed. No load analysis, load analysis, and operation characteristics analysis are performed.A commercial finite element method tool is used for the electromagnetic characteristics analysis. The reliability of the analysis is secured through the experiments.
Findings:Electromagnetic characteristics of a 1MW class wounded type synchronous generators are analyzed by using finite element method. First, the power generation characteristics under rated conditions are analyzed. Next, open circuit analysis and short circuit analysis are performed to consider the saturation characteristics of the generator. In addition, the reliability of the analysis is secured through the experiments. Finally, the V-curve according to the capacity and power factor of the SG is extracted and the operation interval was secured accordingly. This can be interpreted the field currents in lagging power factor operation and leading power factor operation, and can check the thermal limiting period of the field windings generated during the leading power factor operation.
Improvements/Applications:This paper can be used for analysis and design of large capacity wound type synchronous generator.

Keywords: *Wound-type synchronous generator, Hydroelectric power, Short-circuit ratio, V-curve, Electromagnetic analysis.*

1. Introduction

Recently, as the unit capacity of large hydroelectric generator increases, the research of the large capacity synchronous generator (SG) is needed [1-3]. The SG can be divided into a permanent magnet type SG and wounded typed SG [4-5]. The permanent magnet type uses a permanent magnet as a stimulus to simplify and lighten the structure because it does not need an exciter, and it is possible to operate in a wide operating range and high efficiency, but it is not suitable for a large capacity power generation system due to problems such as permanent magnet scattering[6-7].However, since most of the wound type SGs can easily control the magnitude of the field current, they can be operated at various capacities and are suitable for large capacity generators[8-10].
Therefore, in this paper, the electromagnetic characteristics of a 1MW class wounded type SGs are analyzed by using finite element method (FEM).First, the power generation characteristics under rated conditions are analyzed.Next, open circuit analysis and short circuit analysis are performed to consider the saturation characteristics of the generator. In addition, the reliability of the analysis is secured through the experiments.Finally, the V-curve according to the capacity and power factor of the SG is extracted and the operation interval was secured accordingly. This can be interpreted the field currents in lagging power factor operation and leading power factor operation, and can check the thermal limiting period of the field windings generated during the leading power factor operation.

2. Analysis of Synchronous Generator

2.1. Analysis Model

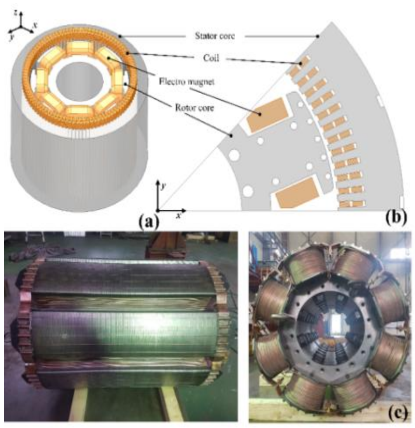

Figure 1: (a) 3-D analysis model of wound type synchronous generator, (b) 2-D analysis model of Wound type synchronous generator, (c) manufactured wound type rotor core

Table 1: Specifications of synchronous generator

Parameter	Value	Parameter	Value
Rated Power	1 MVA	Rated Voltage	3300 V
Rated Speed	900 rpm	Pole / Slot	8 / 96
Stator Diameter	1043 mm	Rotor Diameter	751 mm
Air gap	7 mm	Axial length	800 mm

Figure 1 shows the analysis model of a 1MVA class wound-type SGs for hydroelectric power. The wound-type SG consists of an electromagnet and a rotor core in the rotor, and a coil and a stator core in the stator. Figure 1. (c) shows the manufactured rotor. Table 1 shows the specifications of the wound-type SGs. The rated power is 1MVA, the rated voltage is 3300V, and the combination of pole slots is 8 poles and 96 slots. The analysis of the SGs has carried out through a commercial finite element program and its validity has verified through the experiments.

2.2. Analysis Results

Figure 2 shows the analysis model of the wound-type SG and the results of the FEM. Figure 2. a shows the distribution of magnetic lines by electromagnets, and Figure 2. b shows the distribution of magnetic flux densities by electromagnets. It can be confirmed that the rotor core is partially saturated by an electromagnetic magnet. Figure 3 shows the analysis results of the SGs under rated conditions. Figure 3.a shows the rated output power. The detailed analysis results are shown in Table 2. At this time, it is confirmed that the efficiency is over the 96%.

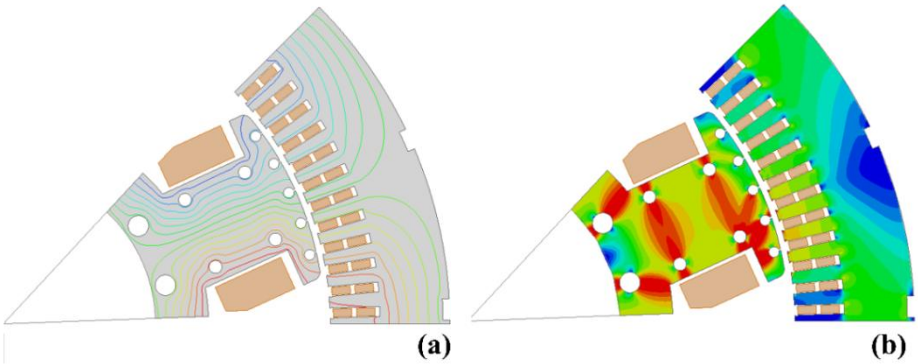

Figure 2: Analysis results of wound-type SG. (a)flux line magnetic flux density due to electromagnet, (b) magnetic flux density due to electromagnet

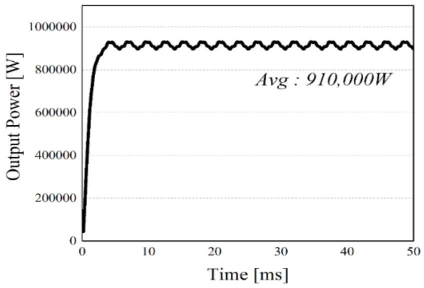

Figure 3: Output power of wound-type SG.

Table 2: Analysis results of synchronous generator

Parameter	Value	Parameter	Value
Output Power	910 kW	Voltage	3360 V
Current	157A	Field Current	270 Adc
Power Factor	0.9	Copper Loss	9.3 kW
Core Loss	21.2 kW	Efficiency	96.7 %

3. Experimental Results and Discussion

Figure 4 shows a set of tests for performance tests of the wound-type SGs. Experiments will confirm the basic characteristics of the generator, such as no-load saturation characteristics, reactance, Impedance, etc.

Figure 4: Test set for experimental of SGs

3.1. Open Circuit Test

Figure 5 is an equivalent circuit diagram for an open circuit test of a synchronous generator. In the open circuit test, the 3-phase winding is opened, and the field current is increased and then, the back EMF is measured. This gives a graph of the back EMF versus field current. This graph is the so-called open circuit characteristics(OCC) of the wound type SG. With this characteristic, it is possible to find the internal generated voltage of the generator for any given field current. The OCC has nonlinear characteristics due to the permeability of the electrical steel sheet and can be confirmed to be saturation point after a certain field current. It is also called air-gap field curve because of the EMF generated in the air gap.

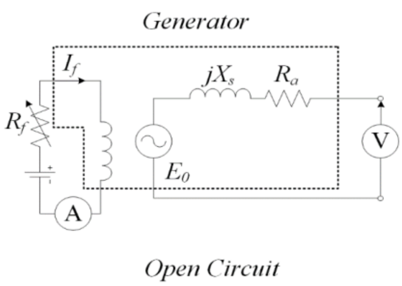

Figure 5: Equivalent circuit diagram for open circuit test

3.2. Short Circuit Test

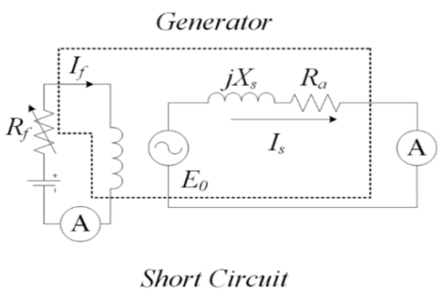

Figure 6: Equivalent circuit diagram for short circuit test.

Figure 6 shows the equivalent circuit for a short-circuit test. The short-circuit test is a test for short-circuiting the load side and measuring the short-circuit current according to the change of the field current. As the field current increases, the no-load induced electromotive force becomes larger, so that the short-circuit current also increases. The armature reaction magnetic flux acts as a demagnetization, so even if the field current is increased, the iron core is not saturated, so that the short circuit current exhibits a linear characteristic. This is called a short circuit curve (SCC).

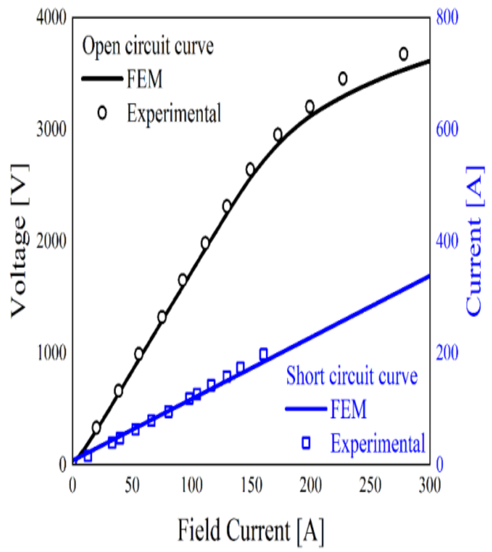

Figure 7: Open circuit curve and short circuit curve of synchronous generator.

Figure 7 shows the OCC and SCC of a 1 MW generator. OCC and SCC can be used to calculate the impedance and short-circuit ratio of the synchronous generator. Impedance (Z_{SG}) is calculated as follows.

$$Z_{SG} = \frac{E_0}{I_S} \quad (1)$$

Where E_0 is the no-load induced electromotive force and Isis the short-circuit current. The short-circuit ratio can also be calculated. The short-circuit ratio is inversely proportional to the d-axis reactance. The short-circuit ratio of most hydro electric generators has a short-circuit ratio between 0.9 and 1.2. This is because the volume of the generator can be relatively large.

4. Operation Characteristics of Generator

For SGs, the same output voltage should be maintained at the same speed regardless of the load change. This can be confirmed via the V-curve.Load capacities such as resistances, inductances, and capacitances must be calculated to obtain rated conditions. Figure 8 shows the R-load circuit, L-load circuit, and C-load circuit for the rated condition, lagging power factor, and leading power factor analysis. The load capacity can be calculated as follows

$$R_{Load} = \mathrm{Z} \times PF = 20.57 \times 0.85 = 17.48\Omega \quad (2)$$

$$X_{Load} = \sqrt{(Z)^2 - (R)^2} = 10.83\Omega \quad (3)$$

$$L_{Load} = \frac{X_{Load}}{\left(2\pi \times \frac{rpm}{60} \times \frac{P}{2}\right)} = 28.7\, mH \quad (4)$$

$$C_{Load} = \frac{1}{\left(X_{Load} \times 2\pi \times \frac{rpm}{60} \times \frac{P}{2}\right)} = 0.245\, mF \quad (5)$$

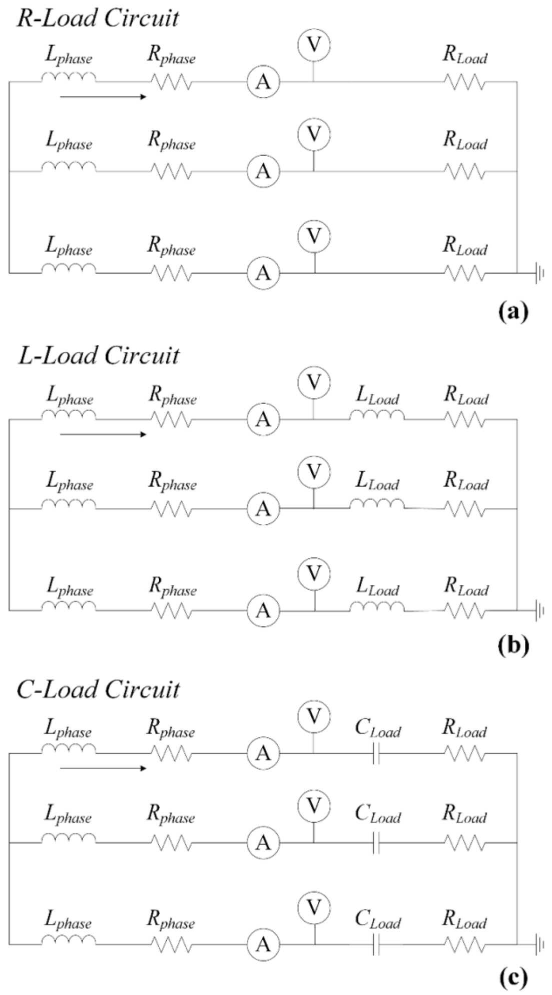

Figure 8: Diagram for load analysis; (a) R-load circuit, (b) R-L load circuit, (c) R-C load circuit

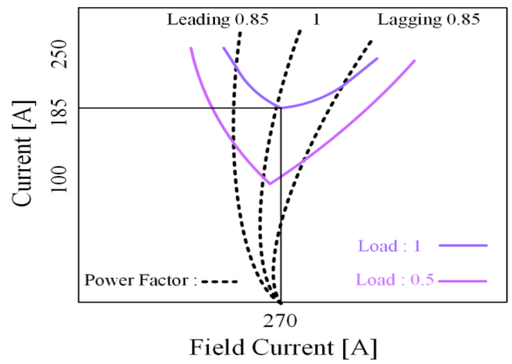

Figure 9: V-curve of synchronous generator

Lagging power factor operation requires a relatively large field current as compared with the leading power factor operation.The lower the power factor during lagging power factor operation, the larger field current is required.It is possible to calculate the necessary field current for each load through the V-curve and to analyze the irreversible operation region by analyzing the field current at the low power factor of the lagging power factor operation.

5. Conclusion

In this paper, the power generation characteristics of 1MW-class SGs for hydroelectric power generation are analyzed by the FEM. No-load analysis and load analysis confirm that the rated specifications are satisfied. And the reliability of analysis resultsare secured through open circuit and short circuit experimental. Finally, the operation performance of the synchronous generator was predicted through the V-curve.

Acknowledgment

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