UDC [621.313.322/.323+621.316.717] : 621.311.21

RESULTS OF FIELD TEST OF LARGE GENERATOR AND STATIC CONVERTERR STARTING SYSTEM (FOR PALMIET PUMPED STORAGE POWER STATION)

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1. FOREWORD

In the past Fuji Electric manufactured large capacity pumped storage generator equipment with special features for the Korean Power Company (206MW Fracis type pump turbine and generator-motor x 2) and Samrangjin (376MW generator-motor x 2), etc.

We have now delivered two 250MVA generator-motors for 203.5MW Francis type pump turbine for the Palmiet pumpted storage power station. The No. 2 unit began commercial operation on April 11, 1988 and the No. 1 unit began commercial operation on May 30, 1988. The generator-motors for the Palmiet pumped storage power station concentrate new technology with the results of the achievements and experience mentioned above. Their greatest features are the use of the static converter starting system that has gained much attention recently as the starting system and adoption of a DDC (Direct Digital Control) system as its controller.

Ample results were obtained from these devices in field tests. Part of the field tests are introduced here.

Refer to contribution (1) for a description of the deisgn features.

2. OVERVIEW OF GENERATOR-MOTOR AND STATIC CONVERTER STARTING SYSTEM

The Palmiet pumped storage power station is a pure pumped storage underground power station. It was constructed to adjust the peak load, frequency, and voltage for rational operation with a steam power plant. The generator-motor ratings and specifications are shown in *Table 1*. The static converter starting system ratings and specifications are shown in *Table 2*. The assembly section of the generator-motor is shown in *Fig. 1* and exterior views of the static converter starting system and DDC system are shown in *Fig. 2* and *Fig. 3*.

Table 1 Ratings of generator-motor

No. of unit	2	
Type	Vertical shaft totally enclosed internal cooling with air coolers type 3-phase synchronous generator-motor.	
Rating	(Generator)	(Motor)
Capacity	250,000kVA	200,000kW
Rated voltage	16.5kV	16.5kV
Rated frequency	50Hz	50Hz
Rated speed	300rpm	300rpm
Rated power factor	0.8 (lagging)	0.8 (leading)
Flywheel effect	9,700t-m^2	
Bearing arrangement	Semi-umbrella, with magnetic bearing	

Table 2 Ratings of static converter starting system

No. of unit	1	
Ratings	(Rectifier)	(Inverter)
Output capacity	21.8MW	21.8MW
Rated DC voltage	15.7kV	15.7kV
Rated DC current	1,391A	1,391A
Rated frequency	50Hz	50Hz
Input/output voltage	16.5kV	16.5kV
Accelerating/braking time	150(sec.)/150(sec.)	
Operating duty	Continuous (Mode change duty 3.7 times per day)	
Cooling method	Dieonized water cooling	
Arm construction	3-phase full-wave bridge, 16S-1P-6A, 4kV-1,000A, indirect optical firing	
Synchronizing method	Low voltage synchronizing	

3. FIELD TEST RESULTS OF GENERATOR-MOTOR

3.1 Generator-motor design features

A rim ventilation system using the fan action of the rotor rim was adopted as the generator-motor cooling system.

The use of the rim ventilation system makes it possible to omit the motor-operated blower and optimize the cooling air and substantially improves the generator-motor efficiency.

The bearing loss of the thrust bearing, one of the generator-motor. design points, is reduced and bearing reliability is improved considerably by using Fuji Electric's patented magnetic thrust bearing. The bearing oil circulation system was made a self-pumping system for both the top and bottom bearings and the motor-operated pump

Fig. 1 Generator-motor assembly sectional view

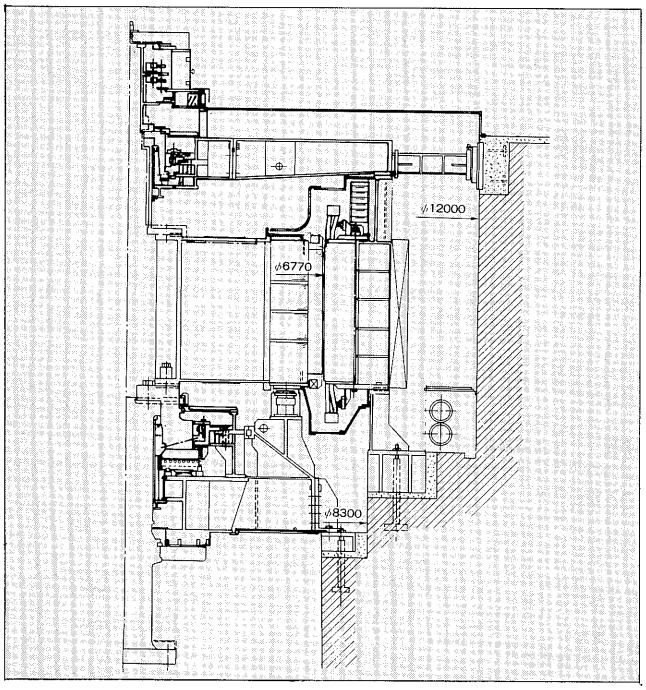


Fig. 2 Exterior view of static converter starting system

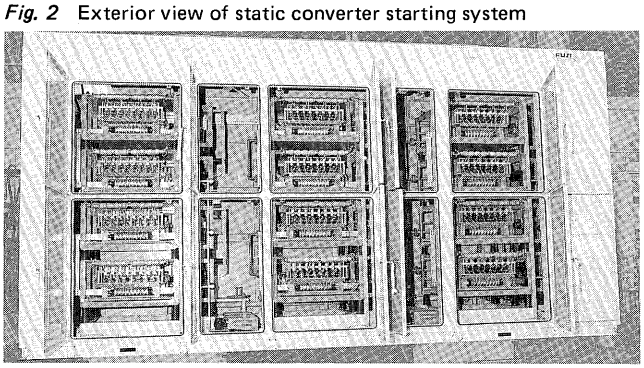
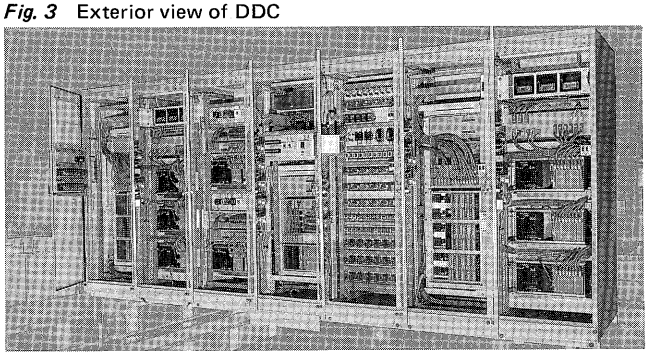


Fig. 3 Exterior view of DDC



was omitted.

Besides, a high pressure oil accumulator system for the demand for black-out starting when the power station's internal power fails, regenerating brake with static converter starting system, and other new technology are also used in this machine.

3.2 Field test results

Since this machine was field assembled. Factory assembled tests were omitted. Various tests were conducted in the field to confirm product performance and reliability. The test results, including an efficiency exceeding the 98.34% guaranteed efficiency, were very satisfactory. Some of the test results are shown below.

(1) Electrical characteristics

Short circuit ratio	: 1.01
Negative-phase sequence reactance	: 19.7%
Zero phase sequence reactance	: 13.7%
Voltage wave distortion factor	: 0.52%
Stator winding temperature rise	: 51°C
Field winding temperature rise	: 76°C

(2) Bearing temperature rise (cooling water temperature 15°C)

Upper guide bearing	: 58°C
Lower guide bearing	: 38°C
Thrust bearing	: 42.5°C

(3) Bearing vibration

Lower bearing (radial direction)	
Generator operation	: 7.3μm (0-P)
Motor operation	: 11.0μm (0-P)
Lower bearing (axial direction)	
Generator operation	: 13.0μm (0-P)
Motor operation	: 8.0μm (0-P)
Upper bearing (radial direction)	
Generator operation	: 7.0μm (0-P)
Motor operation	: 7.0μm (0-P)
Upper bearing (axial direction)	
Generator operation	: 3.0μm (0-P)
Motor operation	: 3.0μm (0-P)

(4) Synchronous starting

This machine demands synchronous stating using a starting bus as a countermeasure against static converter starting system trouble. Test results that can satisfy this as shown in *Fig. 4* were obtained by selecting the optimum

Fig. 4 Synchronous starting test results (generator-motor starting process)

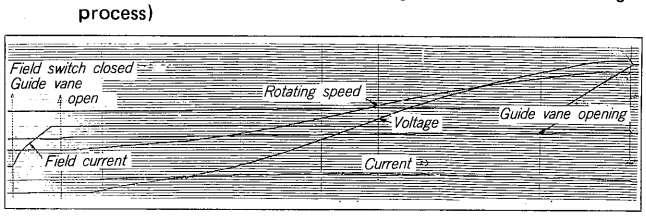
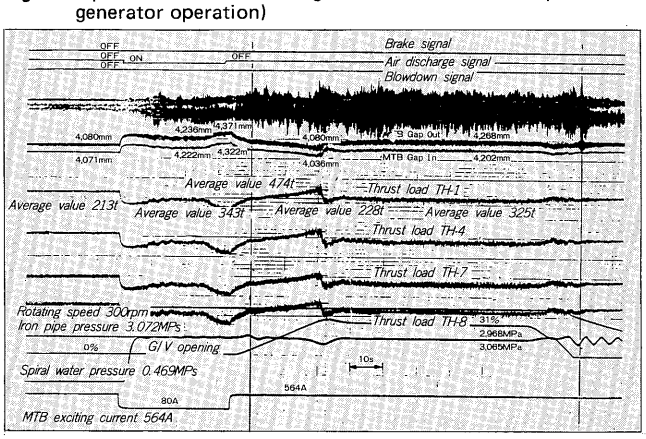


Fig. 5 Operation mode switching test result (condenser operation-generator operation)



turbine guide vane operating speed and generator-motor exciting current.

(5) Characteristics of magnetic thrust bearing

For a pumping up machine, the transient water thrust load changes each time the operation mode is switched. Therefore, to use the magnetic thrust bearing effectively, the water thrust behavior of each operation mode must be amply grasped and switching of the magnetic thrust bearing exciting mode controlled according to water thrust load changes. *Figure 5* is an example of the thrust load measured data taken to decide the magnetic thrust bearing exciting mode.

4. STATIC CONVERTER STARTING SYSTEM FIELD TEST RESULTS

4.1 Starting method

The main circuit configuration is shown in *Fig. 6*. This configuration uses one starting system for two generator-motor by switching. Cross feed that starts one of the generator-motors by another system power source when power source side PT, CB, or AC reactor trouble occurs is also possible. When starting system trouble occurs, synchronous starting can also be performed by using the generator-motor side bus.

4.2 Field test results

The field test results are shown in *Fig. 7* and *Fig. 8*. *Figure 7* is the chart at starting. *Figure 8* is the chart at regenerative braking. Referring to *Fig. 7*, starting is started at point (1) and is raised by 0-100% current intermittent current control. At point (2) at which the speed reaches approximately 13%, operation is switched to motor natural commutation and is the machine is accelerated up to the rated speed (period (3)) by rated current operation at 100% current setting. The measured acceleration time from the start of starting to reaching of the rated speed is 141 seconds and satisfies the guaranteed value 150 seconds. It can be seen that after the rated speed is reached, operation switches to rated speed operation and synchronizing control is implemented (period (4)) and the machine is synchronously closed at point (5).

Operation is switched to intermittent current control at point (3) at which the speed was decelerated to about 13%, similar to acceleration, and regenerative braking is stopped at the point (4) at which the speed was decelerated to 5% speed. Thereafter, the machine is stopped completely by a mechanical brake. The measured stop time is 93 seconds and amply satisfies the guaranteed value of 150 seond.

As shown in the example of the test results above, it was confirmed that the starting system has characteristics almost equal to the design values.

Fig. 6 Starting system main circuit single line wiring diagram

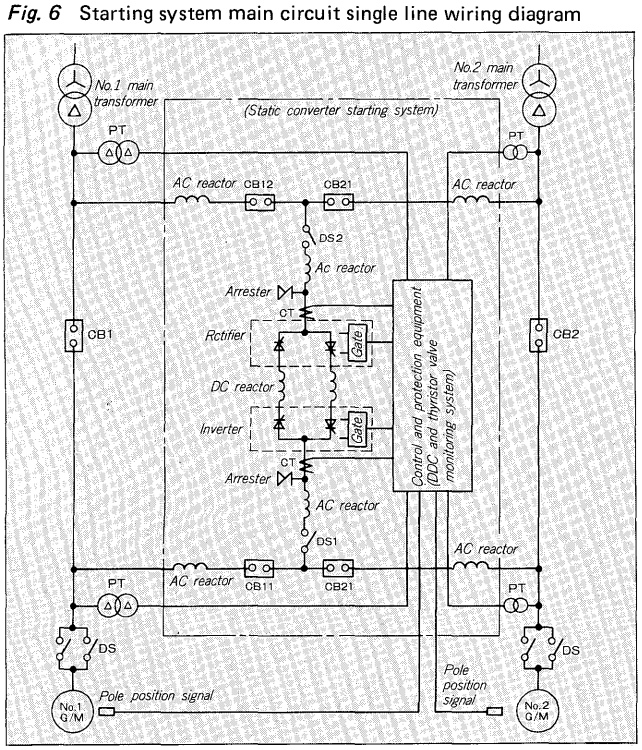


Fig. 7 Starting test oscillogram

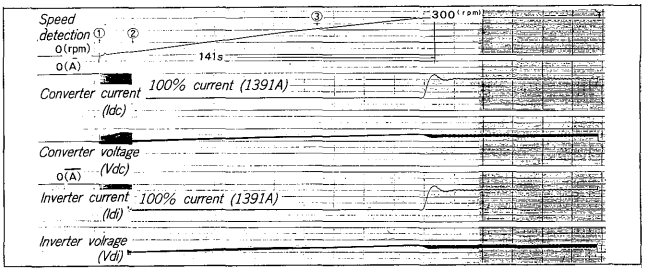
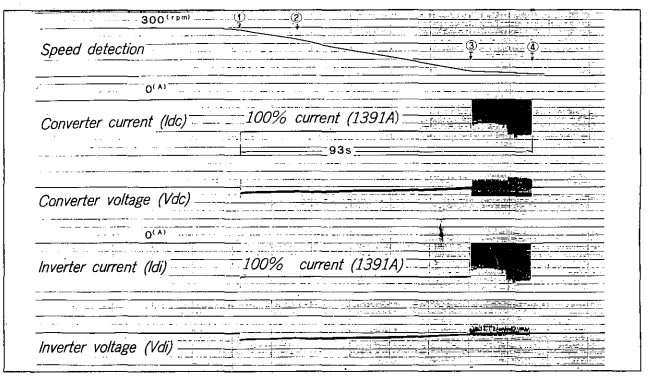


Fig. 8 Regenerative braking test oscillogram



5. CONCLUSION

As a result of conscientious testing in the design, manufacture, and installation stages, field tests ended on a favorable background and the Palmiet pumped storage power station entered commercial operation safely and is currently operating satisfactorily.

The data obtained by completion of the generator-motor and static converter starting system this time is expected to provide a large foundation for the design and manufacture of the next large capacity machine. Finally, we wish to thank all those who gave us there cooperation and guidance regarding the installation and testing of the generator-motor and static converter starting system.