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SUPERCONDUCTING MAGNETIC ENERGY STORAGE FOR BPA TRANSMISSION LINE STABILIZATION*

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Abstract

The Bonneville Power Administration (BPA) operates the electrical transmission system that joins the Pacific Northwest with southern California. A 30 MJ (8.4 kWh) Superconducting Magnetic Energy Storage (SMES) unit with a 10 MW converter is being installed at the Tacoma Substation to provide system damping for low frequency oscillations of 0.35 Hz. The integrated system status is described and reviewed. Components included in the system are the superconducting coil, seismically mounted in an epoxy fiberglass nonconducting dewar; a helium refrigerator; a heat rejection subsystem; a high pressure gas recovery subsystem; a liquid nitrogen trailer; the converter with power transformers and switchgear; and a computer system for remote microwave link operation of the SMES unit.

Introduction

Electric power systems that have major load and generation centers separated by large distances may experience low frequency power oscillations. Such instabilities have occurred on the 2800 MW Pacific AC Intertie that connects the southern California load to the hydroelectric power source of the Pacific Northwest, 900 miles apart. A separate, parallel dc transmission line also connects these areas. The BPA, which operates this system, has overcome the instability by a system of controls and circuitry for transferring power between the HVDC and HVAC lines. The maximum possible power modulation on the HVDC Intertie is ± 40 MW, which can stabilize the HVAC Intertie from about 2100 MW to 2500 MW whenever the HVDC is operating. However, because the HVDC does not operate continuously, there is interest in exploring other methods of line stabilization. A 30 MJ (8.4 kWh) SMES system with a 10 MW converter can provide similar damping for the 0.35 Hz instability. Figure 1 shows a line sketch of the SMES facility as it is presently being installed at the Tacoma Substation.

During operation the coil will be charged to the average current of 4470 A. When required by the power line, the coil will discharge 5 MJ into the line or take 5 MJ additional charging energy. The coupling of the energy storage coil to the power line is through a 10 MW, ± 2.5 kV converter. The coil will normally be operated unattended with only daily inspections. The system will be computer controlled and an alarm system will alert remote personnel in the event of a malfunction. The power demand signal will be transmitted to the SMES system by microwave link from BPA.

Details of the 5 kA superconducting cable, the 30 MJ coil, computer control, and the SMES system have been presented elsewhere.¹⁻¹⁰ This paper discusses more recent developments and the status of the installation at the BPA substation. Table I gives the SMES system parameters, and Table II gives the specifications for the superconducting cable.

30 MJ Coil with Seismic Mounting

At Tacoma, WA, the SMES system is installed in a Zone C seismic region, with design accelerations of 0.24 g horizontal and 0.16 g vertical. A stiff support system is required to suspend the coil freely within an open mouth helium vessel. The coil with two of the four trapezoidal shear panels and vertical axial load strut sets readily visible is shown in Fig. 2. The horizontal discs are thermal radiation shields. The slightly angled micarta blocks to the right of center on the coil are supports for the joints between conductor of the pancake coil pairs. Nineteen such support block with subcable joints are located around the coil. The 30 MJ coil and the nonconducting dewar were shipped to the Covington Substation for assembly together in an enclosed building and then moved 17 miles to the Tacoma Substation.

Vapor Cooled Leads

Each of the ten subcables of the 5 kA superconducting cable must carry equal currents of 500 A. The series resistance of the subcables varies because of the interpancake coil joints and superconducting strand cold welds. The leads were designed with ten separate vapor cooled sections. These connect individually to the subcables to provide series resistances to balance the currents. The leads were successfully tested at 5.5 kA with 80% of rated helium gas flow without overheating and at 13 kV withstand voltage, substantially above the expected maximum of 5 kV. The leads were installed onto the 30 MJ coil at Covington, WA.

Nonconducting Dewar

The nonconducting dewar contract was placed in November 1981. Unusual delays occurred because California rains washed mud into the dewar fabrication building. The dewar shells, epoxy fiberglass inner and polyester fiberglass outer, were made by wet layup techniques. One hundred layers of striped aluminized Mylar superinsulation, interleaved with Nexus cloth, were placed in the vacuum space for radiation shielding. A special aluminum lid was obtained for a flange bolt hole locating drill pattern and to test the dewar. The cryogenic test of the dewar was performed near the manufacturer's plant at the Lawrence Berkeley National Laboratory (LBNL). Figures 3 and 4 show, respectively, the inner dewar shell with superinsulation in place and the dewar being prepared for testing at the LBNL. Because of the limitation on time and funds a nonequilibrium heat leak test was run with only about 500 liters of He in the dewar after over two days of having the dewar at ~ 4 to 5 K. The heat leak was measured to be equivalent to 45 l/h helium vaporization. To reduce this, superinsulation batts were added to the radiation shields on the lid.

Electrical System

Load testing of the converter with ohmic and inductive loads was completed. Over 5 kA inductive currents were interrupted with the protective dump circuit and discharged into a resistive load. The converter SCR bridges were monitored and corrected for proper current sharing. The converter has been operated under computer control.

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Fig. 1. 30 MJ SMES stabilizing system Tacoma Substation installation with superconducting coil in foreground, converter and transformers to the left, and refrigerator to the right.

TABLE I

30 MJ COIL PARAMETERS

Stored energy peak, MJ	30
Peak current, A	4900
Peak magnetic field, T	2.85
Pulse frequency, Hz	0.35
Pulse amplitude, A	4000 to 4900
Design cycles	10^8
Nominal power, MW	8.5
Peak power, MW	10
Peak emergency discharge voltage, kV	5
Ampere turns	4.51×10^6
Conductor:	
Material	NbTi/copper
Configuration	Rutherford cable
Coil Configuration	20 double pancake modules
Number of layers	40
Number of turns per layer	23
Winding i.d., in.	107.4
Winding o.d., in.	133.1
Coil height, in.	47.7
Total weight, lb	37,800

Cryogenic System

The cryogenic system is composed of the heat rejection trailer, which has operated satisfactorily with computer interfacing; the high pressure gas recovery trailer, which has operated with computer interfacing; a liquid nitrogen supply tank trailer; a helium gas supply, a railway tank car on a siding at the Tacoma Substation; and the CTI Model 2800 helium refrigerator.

The refrigerator has been run several times. It will run with computer control of only its ancillary systems. The main gas bearing turbine control is an internal closed loop subsystem. The refrigerator, as supplied, was in poor condition. The compressor aftercoolers were plugged, one was cleaned and another replaced; the computer instrumentation and control circuits were totally inadequate, now replaced; and the refrigeration capacity has not entirely met performance expectations. Remote computer control of the refrigerator will depend on field calibration and integration of the entire SMES system with operating analog systems.

TABLE II

CABLE SPECIFICATIONS FOR 30 MJ COIL

A. Superconductor Composite Core	
Area of NbTi, mm	4.85×10^{-2}
Filament diameter, μ m	6.5
Number of filaments	1464
Strand diameter, mm	0.511
Cu to NbTi ratio	2.94
Twist pitch, mm, direction	5.0, R.H.
B. First Subcable: Six copper wires	
cabled about one core	
Uncompacted diameter, mm	1.52
Compacted diameter, mm	1.37
Overall Cu to NbTi ratio	26.7
Twist pitch, mm, direction	13.5, L.H.
C. Second Subcable: Six first subcables around	
a stranded, insulated copper core	
Diameter, mm	4.11
Twist pitch, mm, direction	34.9, R.H.
Insulation type	Mylar,* adhesive
Insulation size, mm	0.15×6.4
Insulation pitch, mm, and direction	8.64, L.H.
D. Finished Cable: Ten second subcables	
around a Mylar strip	
Strip dimension, mm	15×0.25
Conductor dimension, mm	23.6×7.6
Twist pitch, mm, direction	200, L.H.

*duPont trademark.

Installation and Operation at Tacoma Substation

The 30 MJ SMES system installation at the Tacoma Substation is very near complete. The system, except the dewar, coil, transfer lines from the refrigerator to the dewar, and the dewar vacuum system, was preassembled and operated at Los Alamos. All subsystems were successfully shipped to Tacoma without damage. Operation of the system is imminent. Early operation will be with manual and local computer control. Fully remote computer control is scheduled to start on 4-1-83 when the BPA microwave link interface is made operational.

Fig. 2. 30 MJ coil with seismic mounting to dewar lid.

Fig. 3. Epoxy fiberglass inner dewar shell with 100 layers superinsulation.

Fig. 4. Nonconducting dewar being prepared for cryogenic test.

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