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R&D project on superconductor power application technologies ☆

Yoshimichi Aiyama *,[1], Takasuke Ageta [2]

F310, 2-1, Nishi, Toride, Ibaraki 302-0025, Japan

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Abstract

The R&D project on superconductor power application technologies (FY1988–1999), one of the projects in the Ministry of International Trade and Industry (MITI)/Agency of Industrial Science and Technology (AIST) New Sunshine (NSS) Program, is reviewed. The purposes of the project are to develop the technologies necessary for the superconductor applications in electric power systems and, especially for superconducting generators (SCGs) which have distinguished merits, to provide all technologies necessary for their commercialization. With the steady R&D efforts of Engineering Research Association for Superconductive Generation Equipment and Materials (Super-GM), the technologies to design and construct the Pilot SCG of 200 MW class had been established, finally through the verification tests of the model machines of 70 MW class. © 2001 Published by Elsevier Science Ltd.

Keywords: Superconductor power applications; Superconducting generator; National R&D project

1. Introduction

From FY1988 to FY1999, New Energy and Industrial Technology Development Organization (NEDO) had executed and managed the R&D project on superconductor power application technologies as a part of the Ministry of International Trade and Industry (MITI)/ Agency of Industrial Science and Technology (AIST) New Sunshine (NSS) Program which aimed at developing new energy, energy conservation and global environment technologies (MITI; AIST). In this project, Engineering Research Association for Superconductive Generation Equipment and Materials (Super-GM), composed of 16 members of industrial circles, had played the dominant role (cf. Table 1).

The purposes of the project were to develop the technologies necessary for the superconductor applications in power systems and, especially for superconducting generators (SCGs), to provide all technologies necessary for their commercialization. In the R&D activities in this project, the refrigerator technologies and superconductor technologies for superconducting power apparatuses were included. Manufacturing processes of oxide superconductors in wire or tape forms and AC characteristics of metallic superconductors (NbTi, Nb_3Sn) had been the important research items in the latter subject.

Within the project period (~March 2000), the technologies to design and construct the Pilot SCG of 200 MW class had been established, finally through the verification tests of the model machines of 70 MW class, including power generation tests, long-duration tests up to 1500 h, severe tests, the rotary-condenser-type operation tests in the 77 kV power grid and so on. These are the fruits of the R&Ds on component technologies, basic engineering problems and partial model experiments for SCG.

In this paper, the outline of the project [1–4] is reported and special attention is paid to SCG and its outstanding characteristics in power systems.

2. SCGs in power systems [5]

Typical examples of internal impedances of conventional apparatuses in electric power systems are shown in Table 2. Among the various system apparatuses, conventional generators have extraordinarily high

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* Corresponding author.
E-mail address: aiyama@mva.biglobe.ne.jp (Y. Aiyama).
[1] Free; the former chairman of NEDO Tech. Committee for the Project.
[2] Super-GM, Umeda UN Bldg., Nishi-tenma, 530–0047 Osaka, Japan.

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Table 1
Organization structure of the project

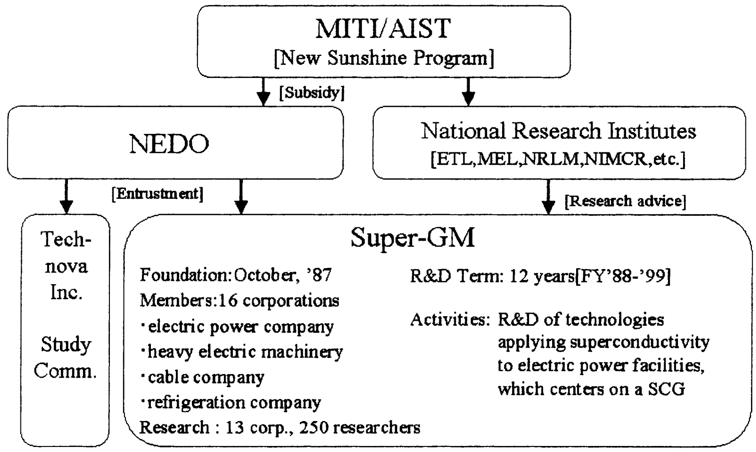

Table 2
Internal impedances of power system apparatuses

Apparatus (rating)	Resistance r (p.u.)	Reactance x (p.u.)	x/r
Generator (1 GVA)	4.5×10^{-3}	1.7	37.8
Over-head transmission line (500 kV, 100 km)	4.2×10^{-3}	0.126	29.9
Cable (cross-linked polyethylene) (2500 mm^2, 275 kV, 20 km)	0.011	0.237	21.5
Transformer (500/275 kV, 1 GVA)	3.1×10^{-3}	0.14	45.2
Superconducting field winding generator (1 GVA)	1.6×10^{-3}	0.3	188
Cable (superconducting) (275 kV, 20 km)	7×10^{-6}	0.0115	1600
(1 GVA-base)			

internal impedances. This has been the result of the requirement of large capacity turbine generators to have reasonable compactness under the restriction of finite magnetization (saturation magnetization) of their iron cores, for these 50 years. The generator with its internal impedance of more than 1 p.u. cannot work as a constant-voltage power source and, to keep its output voltage at the fixed value, it is always necessary to control the field current widely depending on its output power.

The effective power supply P_R at the receiving terminal of the power system in its steady state is given by the Eq. (1) (cf. Fig. 1),

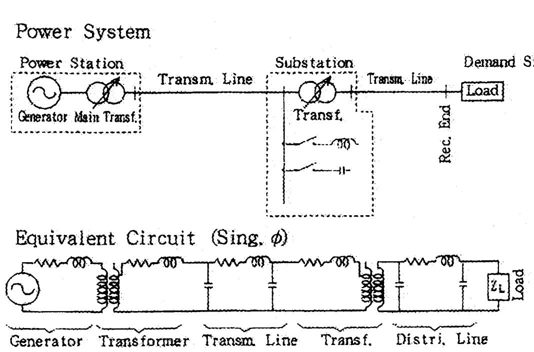

Fig. 1. Electric power system.

$$P_R = \frac{V_0 V_R}{|Z_{tot}|} \sin \theta_0, \qquad (1)$$

where V_0 is the induced internal voltage in the generator, V_R is the voltage at the receiving terminal, Z_{tot} is the total impedance of the system, and θ_0 is the phase angle difference between V_0 and V_R.

The power transmission limit $P_{R,lim}$ (steady), the maximum value of P_R, is inversely proportional to Z_{tot} and the necessity of apparatuses with lower internal impedances is clear. Practically the output voltage V_S of the generator is kept constant by controlling its field current and, in the expression for P_R (Eq. (1)), $V_0 V_R$, θ_0 and Z_{tot} can be simultaneously substituted by $V_S V_R$, θ_S and $Z_{tot} - Z_{gen}$, safely in the steady state, where V_S is the voltage at the transmitting terminal, θ_S is the phase angle difference between transmitting and receiving terminals and Z_{gen} is the internal impedance of the generator. It seems apparent that high value of Z_{gen} has no demerit on power supply. The time constant of its field current control, however, cannot be short enough compared with the one cycle of AC power and then, for discussing the system dynamic or transient stability, synchronizing force, etc., it is necessary to take account of an internal impedance of the generator Z_{gen}.