§26. Upgrading of 250 MVA Motor-Generator System

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The motor-generator (MG) system was constructed seven years ago mainly for supplying high electric power pulse with considerably short duration to plasma heating devices. Since then continuous endeavor has been made to improve its performance.

In this year, most of the MG power has been utilized for the NBI 's, as conditioning or plasma heating experiments in the LHD. The MG has been also used to excite plasma-confining field in the CHS. The total number of the MG operation has reached 49,222 shots, which is slightly more than that in last year [1] : 45,022 shots for the NBI 's (91.5 %) and 15,437 shots for the CHS (32.4%), where the excess of 100% in total indicates that simultaneous power feed for both the NBI 's and the CHS has been successfully done. Besides the power of 636 shots has been supplied for the Research and Development of the NBI in the plasma heating laboratory. The other 361 shots have been applied for the sequence check of the MG itself, the ECH and the ICRF. The entire operating time was attained about 2,073 hours, in which operations performed for all night long have been included.

For more progress of the performance in the whole scheme, the following modifications have been carried out.

1) Improvement for long generating time operation

The mission for the MG has been shifted to supply moderate power (typically 10 MW) for longer duration time (2 min), on the contrary to the principle at the initial design [2]. The motivation of this requirement has mainly originated from the fact that the prolonged heating powers, especially for the NBI 's, have become essential for long pulse experiments in the LHD.

The exciter, converting the kinetic energy to the electric power, has been slightly modified to meet this requirement.

The hardware for the exciting winding and its DC high power supply has been forecasted to endure the doubled time operation, as long as the repetition time is longer than 30 min, even in summer when the cooling of the generator is poor.

The timer, which limits exciting time, has been altered its setting limit as twice (60 to 120 sec). The other timer, which eliminates over-time excitation, has been also set doubly (65 to 130 sec). The MG computer has been modified to control longer time operation, and to display waveforms of the output voltage and the total output current over 120 sec on its screen.

The critical path in long time operation is attributed to the temperature rise in the exciting windings. Even if the temperature of the winding partially exceeds the allowable limit, the insulator will be gradually deteriorated, which might induce fatal damage in the generator. A protective device is prepared, which emits warning alarm whenever the averaged temperature in the winding exceeds 77 % of the allowable limit and compulsorily interrupts power generation if it goes beyond 79 %. This percentage is decided assuming the ratio of locally highest temperature to the averaged temperature. Using the voltage E_f and the current I_f in the winding, the averaged temperature T_{AV} is calculated as

$$T_{AV} = 253\{(R_f/R_{f0}) - 1\} + 20 \quad (1)$$

$$R_f = E_f/I_f \quad (2)$$

where $R_{f0} = 0.0568\,\Omega$ (value of winding resistance at 20°C).

2) Protection for instantaneous interruption in 6.6 kV line

Some protective schemes were so far applied for coping with instantaneous voltage drop or short time interruption (less than 0.5 sec) in the commercial 6.6 kV line. Nevertheless remarkable effect could not emerge. This is considered that the detecting time of DC power supply for the batteries is so rapid that it sends interlocking signal earlier than the remaining interlocks does not actuated. This interlock has been then eliminated and changed only for indicating the alarm.

3) Availability of various types of multi-load operation

The control system has been modified to operate various kinds of loads in any combination simultaneously: for example, the NBI 's, the ICRF and the CHS. Moreover the timing control system has been replaced to that using the programmable logic controller (PLC). The PLC transmits permission signals to the loads to be operated at the next shot. Therefore the loads can be alternately fed the power when a favorable operating mode is selected: a group of loads can operate at every shot, while the other group can do desultorily.

4) Addition of human-machine interface and safety device

Recorded items in every shot have been enormously increased to obtain sufficient information of the operation. They contain the operating mode, loads operated, power generating time, repetition rate, total energy requested *etc.*

The time during power generation and the ensuing 5 sec has been excluded from changing surgical procedures of the operational condition. It is because the MG computer is so busy that this procedure might cause malfunction of the operational control.

The MG computer measures the rotating speed of the MG by 0.1 sec and predicts that after the ensuing 0.1 sec. A noticing signal has been prepared to distribute for control system of all the loads, if the predicted speed will go under the lower limit speed.

References

1) Kitagawa, S. *et al.,* Annual Report of National Institute for Fusion Science (April 1999-March 2000) 147.
2) Kitagawa, S. *et al., ibid.* 148.