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EXPERIMENTAL BEHAVIOUR OF A CRYOALTERNATOR CONNECTED TO THE 50 Hz ELECTRICAL NETWORK

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Résumé - Après plusieurs essais à des vitesses inférieures à 3000 tr/min, un cryoalternateur de 500 kW a été relié au réseau général EdF (50 Hz). Les essais (régimes permanents et régimes de défaut) ont été réalisés au laboratoire EdF de St-Denis. Plusieurs couplages et courts circuits ont été réalisés révélant la fiabilité de cette technique. Ces essais sont présentés. Le dipôle supraconducteur a travaillé avec son courant nominal, et, en cas de transition, le temps de récupération de l'état supraconducteur est inférieur à 20 mn. L'ensemble des résultats correspond aux objectifs qui étaient fixés à cette étude, commencée il y a quatre ans.

Abstract - After a set of experiments made at speeds lower than 3000 rpm, a 500 kW cryoalternator has been connected to the 50 Hz electrical network in the EdF laboratory in St-Denis. Permanent and transient performances have been explored during several hours ; the machine working as an alternator or a condenser. Short circuits and coupling were performed without any problems showing the reliability of this technique. These experimental results are presented. The superconducting dipole worked up to its maximum current. In case of transition in the normal state of the S.C dipole under fault conditions, the recovery time is less than 20 mn.

With these results, the goals of this experimental study, begun four years ago in the CNRS-CRTBT laboratory, have been achieved.

I - INTRODUCTION

A 500 kW hypersynchronous driven cryoalternator has been designed and built in the CNRS-CRTBT Laboratory-Grenoble. This machine, described before /1/, is able to work in the classical configuration when a simple modification (adjunction of 6 screws) is made.

The first tests, both in the hypersynchronous and classical configuration, have been performed in Grenoble, from 1977 to 1979 /2/. Then, the machine moved to St Denis-EdF Laboratory to complete further tests. At the end of 1982, the experimental study was achieved.

The consumption of liquid helium is about 25 l/h (under nominal conditions) and a 500 l helium vessel is sufficient to cool down and supply the experiment.

II - PREVIOUS TESTS AND 50 Hz OPERATION

Steady state and transient tests (no load, short circuit, resistive load) have been made in Grenoble showing that there is no significant advantage in the hypersynchronous configuration /2/. Connected to an artificial network (500 kW Ward Leonard Group) the cryomachine has been extensively studied at speeds around 2000 rpm to avoid me-
chanical problems. The results of synchronization and load variation tests are reported in ref. 3. In order to run at 3000 rpm, the seals allowing the recovery of helium vapors are removed. Temperature and vibration levels reveal a good comportment at 3000 rpm: the temperature of the bearings remains less than 50°C and the vibration level is less than 15 µm (with a maximum of 40 µm at 2500 rpm, showing a critical frequency at this speed). The machine is now driven with an asynchronous motor fed by the W.L. group. The output is connected to the EdF network through a transformer allowing different voltages (Fig. 1).

III - STEADY STATE OPERATION

Condenser tests have been performed with two output voltages (Fig. 2). The maximum absorbed reactive power is given for very small values of the field current, because the reactances ratio \( \frac{L_d}{M_{sd}} \) is smaller than for normal synchronous machines. For the same reasons, the curves \( Q(I_F) \) are nearly straight and show a significant slope, increasing the stability of the cyromachine under lagging conditions (Fig. 3). Despite the bad stability of the W-L group it was possible to realize some steady state tests, the machine working as a motor or a generator (Table I).

Table I: Steady-state operation (the transformer is 5 127 V/ Y 380 V and 5 220 V/ A 380 V)

<table>
<thead>
<tr>
<th>E_V</th>
<th>I_F</th>
<th>I_A</th>
<th>Q_kVA</th>
<th>P_kW</th>
<th>Cryomachine state</th>
</tr>
</thead>
<tbody>
<tr>
<td>66,4</td>
<td>63,2</td>
<td>187,5</td>
<td>0</td>
<td>37,5</td>
<td>Motor</td>
</tr>
<tr>
<td>51,5</td>
<td>49</td>
<td>750</td>
<td>-110</td>
<td>86,2</td>
<td>Generator</td>
</tr>
<tr>
<td>67,8</td>
<td>64,5</td>
<td>750</td>
<td>-108</td>
<td>112,5</td>
<td>&quot;</td>
</tr>
<tr>
<td>105</td>
<td>100</td>
<td>412,5</td>
<td>50</td>
<td>71,3</td>
<td>&quot;</td>
</tr>
<tr>
<td>97,5</td>
<td>92,5</td>
<td>500</td>
<td>-112,6</td>
<td>127,5</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

IV - TRANSIENTS

The major parts of the transient tests have been reported elsewhere /3/. Under severe conditions - such as coupling with a phase difference near \( \pi \) - the superconducting dipole quenches. The recovery time is less than 20 ms. The machine is able to operate with \( \frac{d\Phi}{dt} \approx 2T/s \); after a short circuit, the evolution of the currents are the same as those reported by some other authors /4/ (Fig. 4).

Some coupling and sudden short circuits have been made at 50 Hz. Attempts of coupling between the grid and the cryomachine have been made with different values of the output voltage. Even with a difference of 15 % between the output voltage and the main voltage, the coupling succeeded giving us the preceding results. The cryomachine has suffered two sudden short circuits (point A in Fig. 1). The protection circuits of the grid worked as the current reached 620 A but no transition of the superconducting dipole, energetized with 65 A (1/3 of its nominal value), occurred.

V - CONCLUSION

The set of experiences made on this cryoalternator, at 50 Hz or at speeds lower than 3000 rpm, gives a proof of the good comportment of such a machine on an industrial grid. The efficiency of the shields, especially during transients and resynchronization operations is fairly good.

With these results, the goals of the prototype have been achieved.
REFERENCES

/1/: PINET C., BRUNET Y., "A 500 kW, 3000 rpm alternator of a new type", Electrical Machines and Electromechanics", vol. 3 (1979) 171.
/3/: BRUNET Y., PAQUIEN L., SABRIE J.C., "Experimental study of cryoalternators", Proceedings of ICEC 9, 416.

Fig. 1: Schematic diagram of the electric installation in ÉDF St Denis laboratory

Fig. 2: The cryoalternator in the synchronous condensor state, with 2 different transformer ratios.
Fig. 3: STEADY STATE POWER DIAGRAM FOR A CLASSICAL TURBOGENERATOR ($\chi_d = 2$ pu) AND A SUPERCONDUCTING MACHINE ($\chi_d = 0.5$ pu) WITH THE SAME CHARACTERISTICS $V_n$ $I_n$.
1. FIELD CURRENT LIMITATION
2. TURBINE OUTPUT LIMITATION
3. STATOR CURRENT LIMITATION
4. STATIC STABILITY LIMITATION

Reactive power absorption is limited by the natural stability for the classical configuration, while it is the stator current which governs this limit for the cryogenic case. Likewise, field current limitation is governed by external thermal consideration (cooling system) in the classical machine and by the maximum critical value of the superconductor (intrinsic physical limit).

Fig. 4: Variation of stator and field current during a 0.5 s short circuit at the mains of the cryomachine.