PRODUCTION OF PULSED HIGH MAGNETIC FIELDS WITH ROTATING MACHINE

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Abstract

We describe the power source delivering a mean power of 100 MW over a pulse duration of 1.5 sec energizing the main toroidal magnet of the TFR experiment for fusion research. The power source includes an asynchronous motor of 1.2 MW running up to 1500 rpm and driving through a gear box a flywheel storing 400 MJ at 6000 rpm. The energy is delivered to the load through a 150 MVA diode rectifier.

I. Introduction

A rotating machine coupled to a flywheel generally gives a good solution to the problem of energizing large pulsed magnets. The advantages of this solution increase with the energy delivered.

An optimization of the parameters according to the working conditions (peak power, pulse length and repetition rate) allows a significant reduction of the power generator cost.

The main characteristics of our "100 MW, 1 sec" generator have been calculated on the basis of the results obtained on our test "Pulsatrice"* which is a single phase bipolar alternator delivering a unidirectional pulse of 70 000 A to an inductive load.

To energize our TFR magnet we need a 35 000 A current pulse having a plateau duration of 0.5 sec; the peak power necessary must be about 120 MW, the energy input 150 MJ and the repetition rate one impulse every four minutes. The power generator is mainly composed of a bipolar alternator revolving at 6000 rpm, a flywheel storing 400 MJ, a diode rectifier and a 1.2 MW motor. The excitation is controlled to give the right current shape.

II. Determination of the Main Characteristics of the Power Generator

Our goal was to find a low price power generator able to energize the main toroidal magnet of the TFR device.

This generator must satisfy the following conditions:

- The current in the load must have the shape shown in Fig. 1: the amplitude of the voltage during the plateau must be about 2500 V.

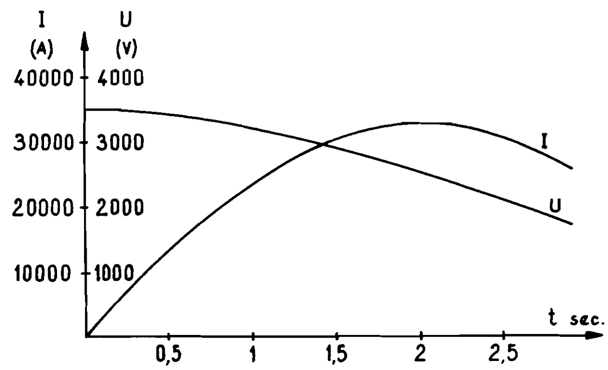

Fig. 1. Time evolution of the load voltage and current.

- The energy must be delivered to a load having an inductance of 0.063 H and a resistance of 0.07 Ω.

- The repetition rate at full power must be one pulse every four minutes.

Taking into account these conditions and the specific power of the pulsatrice (100 MVA/ton) we have, as first step, determined the general characteristics of this new machine, then we have checked if the thermal and mechanical stresses were admissible with the foreseen working conditions.

For this new alternator the specific power obtained with the pulsatrice must be reduced: the pulse duration being longer, the power dissipated in the machine increases and consequently it is necessary to increase the size of the machine, its copper ratio and cooling. In these conditions the expected weight was about 10 tons without taking into account the solid structures and the bearings.

In order to have a high specific power, it was necessary to increase the magnetic flux in the rotor and to maintain the internal inductance of the alternator as low as possible. To satisfy these conditions:

* Four pulsatrices able to deliver 15 MJ each have been designed to energize the superstator project. The rise time foreseen for the current was 15 msec.

- The length of the rotor (2.2 m) must be large compared to its diameter (0.5 m) in order to reduce the inductance of the rotor coil heads and to increase the active part of the rotor.

- The thickness of the air gap between rotor and stator must be as small as possible in order to reduce the leakage inductance and the magnetizing current.

The machine must be conceived in such a way that the stator current has its image in the rotor as close to it as possible.

After several optimizations we have obtained the main parameters of the power generator listed on Fig. 2. Some general views of the generator are shown on Figs. 3, 5 and 6.

-Rotor diameter	50	cm
-Rotor length	220	cm
-External stator diameter	110	cm
-Rotor weight	3800	kg
-Sator weight	11400	kg
-Weight of the fly wheel	13500	kg
-Number of turns of the rotor winding	132	
-Rotor current	4000	A
-Rotor in put voltage	900	V
-Rotor speed	6000	rpm
-Number of turns per phase	6	
-Number of phases	6	
-Peak voltage per phase	3500	V
-Peak current delivered by the rectifiers connected in parallel	35000	A
-Peak power injected to the rotor	3,5	MW
-Peak power delivered by the stator	120	MW
-Energy stored in the fly wheel	400	MJ
-Energy delivered to the load in normal operation	150	MJ
-Repetition rate at full power	1 impulsion every 4 minutes	

Fig. 2. Main parameters of the power generator.

III. Description of the Generator

The generator is a bipolar alternator similar to a turbo alternator with a small air gap (1 cm) coupled to a flywheel through a short torsible shaft.

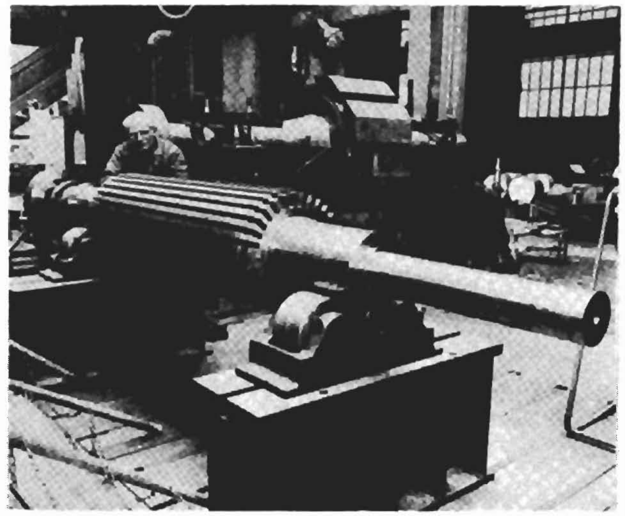

Fig. 3. View of the rotor.

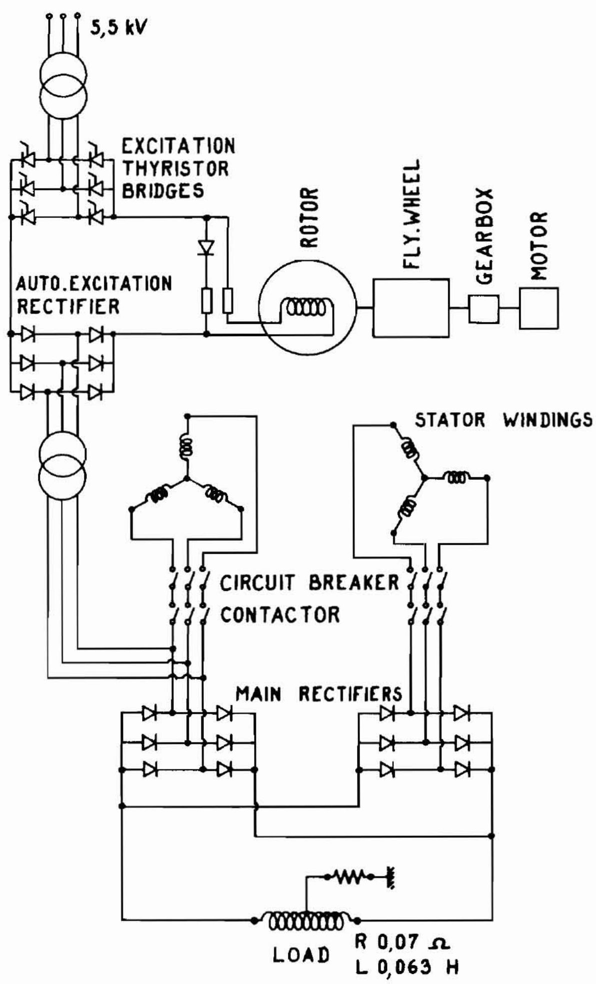

Fig. 4. Electrical diagram of the power generator system.

- The rotor revolves at 6000 rpm and it is very similar to a turbo alternator rotor except that the mechanical part is reinforced to withstand the electrical forces.

The volume and position of the rotor coil are adjusted to allow a very large current in it. This current mainly compensates the current of the stator and produces a very high magnetic flux of about 1 T.

The induction in the rotor reaches 30 kG and the mean permeability is about 10. The rotor is energized by two power supplies connected in series, Fig. 4.

- A 500 kW rectifier using thyristor bridges connected to the main electrical network controls the current delivered by the alternator.

- A 3 MW diode rectifier connected to the stator of the alternator through a transformer with several coupling ratios compensates the opposing ampere-turns produced by the current flowing in the stator.

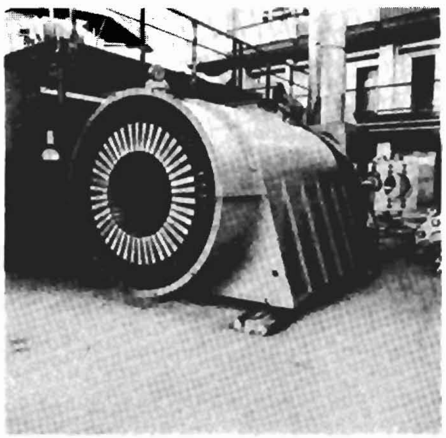

Fig. 5. External view of the stator.

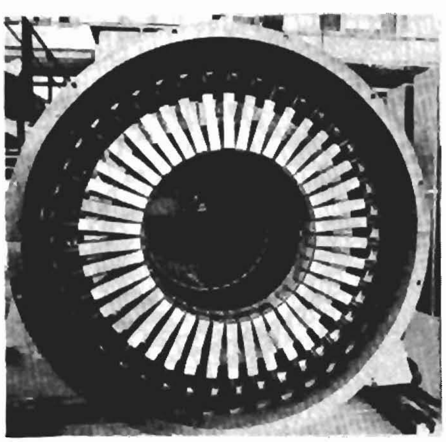

Fig. 6. Internal view of the stator.

The stator has two independent star-connected, three-phase windings, 30^o phase shifted from each other. For each branch of the stars a very high degree of symmetry has been required in radial distribution as well as in axial position of the coil heads, in order to avoid any lack of equilibrium and bias forces. The stator winding is made of 6 elementary solid conductors and 2 hollow conductors connected in parallel. In the middle of the iron these conductors are transposed to obtain the same inductance on every conductor in parallel. Thus the compensation is quite good except along the short twisting region. The coil heads are developed around a cylinder, thus allowing a rugged construction and minimum inductance.

The stator is impregnated with epoxy resin under "vacuum and pressure" to obtain a strong mechanical chocking and a good electrical insulation.

Each star of the stator is connected to a 75 MVA peak power rectifier through a circuit breaker and a contactor, but in our case, the outputs of the rectifiers are connected in parallel (Fig. 4).

The expected ripple level of the current delivered by the rectifiers will be low due to the high value of the load inductance.

The cooling of the alternator is provided by deionized water flowing in the hollow conductors of the stator windings and by fresh air blown between the stator and rotor. During the current pulse the temperature of the alternator increases adiabatically by about 50^oC at full power, then the temperature decreases to its initial value in 4 minutes.

To produce a full power pulse the motor drives the rotor from its initial speed, about 4700 rpm, up to 6000 rpm. We excite the rotor windings by the thyristor rectifier until the stator voltage reaches its maximum value. Then the main contactors connect the stator winding to the load and the current increases with the shape shown on Fig. 1.

At the same time the auto-excitation system which is connected just after the main contactors is energized and compensates the opposing ampere-turns of the stator.

During the current pulse the speed of the rotor decreases to 4700 rpm; in this case the energy recovered from the flywheel reaches 150 MJ.

Due to the high peripheric speed of the flywheel it has been necessary to reduce the air friction losses and the temperature rise by encasing the flywheel in a metallic container and pumping down to a pressure of 1/3 atmosphere, Fig. 7.

The lubrication system which must be very secure consists of two absolutely independent pumping systems powered by two 230 V batteries connected in parallel with the electrical network. Each battery can supply one pump during 4 hours; this time corresponds to the normal slowing down of the rotating group without any braking.

The two pumping groups are working simultaneously in normal operation.

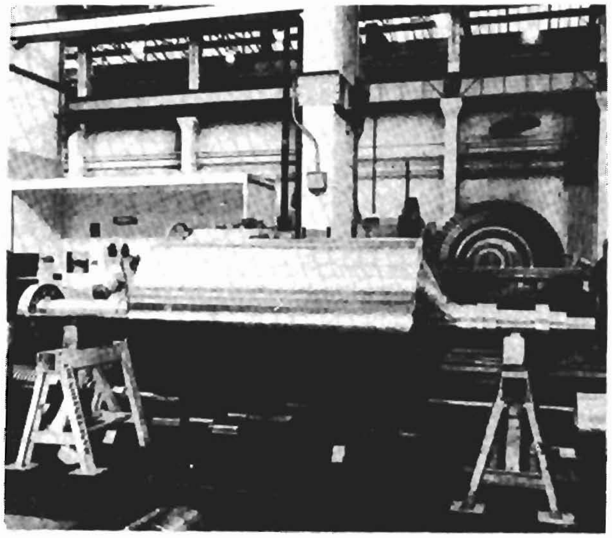

Fig. 7. View of the flywheel.

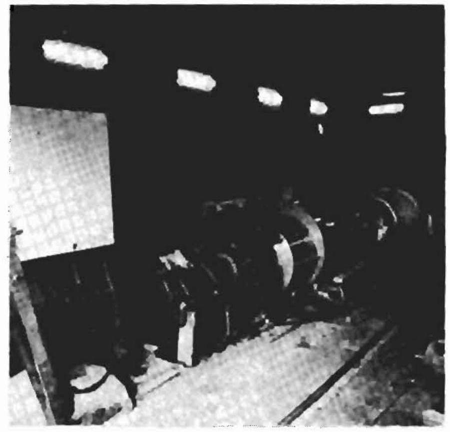

Fig. 8. General view of the power generator.