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ANADOLU UNIVERSITY
DEPT. OF ELECTRICAL AND ELECTRONICS ENGINEERING

EEM 471 ELECTRICAL MACHINERY LABORATORY

EXPERIMENT VI

3Φ Synchronous Machine

- Mechanical, Iron, Copper and additional losses of a Synchronous Machine
MEASURING THE MECHANICAL, IRON AND ADDITIONAL LOSSES

TEST MOTOR DRIVING METHOD

During the alternators operation, inside the generator itself some power losses occur, due to different reasons. To know the numeric value of these lost powers in the various load conditions is essential to calculate the efficiency curve of the machine. Here, a testing experiment will be described, that allows to measure the value of the following alternator's losses:

a) Mechanical losses

They represent the power loss in the rotating section due to the friction in the bearings and to the ventilation. This power is exclusively associated to the rotating speed and isn't subject to significant changes when the machine passes from no-load to full-load conditions (only with machines of big sizes when passing to load condition a slight variation of the friction losses may occur, due to the different value of the stresses in the bearings and to the unavoidable increase of vibrations).

b) Iron losses

The magnetic circuit of the poles is excited with DC current and, therefore, is crossed, in its fixed section, by a constant flux that doesn't produce losses. On the other hand, due to the rotation, the armature is subjected to a cyclically variable magnetization and, therefore, in the stator power losses rise due to magnetic hysteresis and to Foucault eddy currents.

This power loss, represents the alternator's iron loss; of course, it is related to the value of the resulting flux and to the output frequency (therefore to the rotating speed). Therefore, we are not interested only to the flux generated by the poles, but to the one resulting from the composition on the latter with the armature reaction flux. Anyway, as it would be extremely complicated to evaluate every single case (i.e. every value of current and of output cos Φ), the amount of the real iron losses due to the real structure and magnitude of the resulting field, the CEI RULES (N° 77) have established what follows:

1) Iron losses of the alternators are considered these occurring in no-load operation with rated voltage and frequency.
2) The variations of the resulting flux (and, therefore, of the iron losses) are kept globally into consideration by introducing the concept of additional losses. The latter exclusively depend from the armature current, and they are described in following point c.

C) Additional losses

As said, they have to keep account, in a global way, of the iron losses increase due to the alteration of the inductor magnetic field when passing from no-load to full-load. Moreover, they have to include the following other causes of lost power (always of small entity, difficult determination and exclusively related to the armature current):

1) Eddy current losses generated in the surrounding metallic components (casing, chassis, etc) by the leakage flux of the armature windings.
2) Unequal distribution of the current in the cross section of the armature conductors (skin effect), again due to the armature flux that strikes against the generating conductors.
TEST NO: 1 No-load losses of the test motor

When the test motor is decoupled and it's speed is the rated speed at the alternator, it absorb the power

\[ P_M = V_M I_M \]

This power corresponds to the no-load losses at the test motor excluded the excitation losses.

TEST NO: 2 Mechanical losses of the alternator

Mechanically couple the two machines with the special joint and restart the motor. Control that the speed is the rated speed of the alternator without excitation. The new power absorbed by the motor will be:

\[ P^I_M = V^I_M I^I_M \]

The power will be the mechanical losses of the motor and alternator. In fact, the motor has now to drive the alternator that, being completely unexcitated, only requires its mechanical losses. As the motor operates in the identical conditions of the previous test 1 (same armature voltage, same speed, armature current very slightly greater), it is possible to assume that its losses are still the same and, therefore, to consider the mechanical losses of alternator as:

\[ P_m = P^I_M - P_M \]

TEST NO: 3 Iron losses of the alternator

Couple the two machines. Regulate the excitation so as the output voltage is the rated voltage, in no-load condition and with a speed of exactly the rated speed. Observe again the \( V_M \) and \( I_M \) readings of the instruments connected to the motor. The new absorbed power will be:

\[ P^{II}_M = V^{II}_M I^{II}_M \]

It will be slightly greater than the value measured in previous test 2 as the motor is now loaded also with the alternator's iron losses. Assuming that the motor losses are practically constant, the iron losses of the alternator will be:

\[ P_{iron} = P^{II}_M - P_m - P_M \]
TEST NO: 4 Additional losses in the alternator

Short-circuit the alternator’s armature. Start the set again. Set constant the speed to its rated value and excitate the alternator with different current values. Note the indications $V_M'''$ and $I_M'''$ of the instruments on the motor. The new absorbed power will be:

$$P_M''' = V_M'''I_M'''$$

Due to their small magnitude the iron losses may be neglected. Therefore:

$$P_M''' - P_M = \text{Mechanical losses} + \text{Copper losses in the alternator}$$

Therefore the copper losses:

$$P_{CU} = P_M''' - P_M - P_m$$

The $P_{CU}$ copper losses are slightly greater than which may be calculated starting from the winding resistance values (Practical test 1) and from the short-circuit current used during the measurement. The additional losses, corresponding to the armature current $I_{SC}$ are therefore

$$P_{add} = P_{CU} - 3R_fI_{SC}^2f$$

NOTE

As the above description clearly shows, all the test is based on the assumption that the driving motor’s own losses don’t significantly change during the passage from no-load condition to the operation with the small axis load represented by mechanical losses and the iron losses of the alternator. This assumption is as true as greater is the rated power of the motor with respect to the alternator’s losses value.

In practice, it is already fully acceptable when the rated power of the motor is equal to the rated power of the alternator. When a driving motor having enough power isn’t available, it is necessary to consider the variability of its efficiency and, for this reason, its $T|f(P_{abs})$ must be known. In the latter case the motor, that is often called "calibrated motor", may also have a power much lower than the generator under test; in fact, it is enough for the motor to balance the losses in the machine to be driven whose value surely doesn’t exceed the 20 - 25% of the rated power.
GRAPH

Drawing the test results related to the test NO 4 in the short-circuit condition in a diagram, it can be emphasized the behaviour of the additional losses for variation of the armature current:

Measuring the mechanical, the iron and the additional losses
SEQUENCE OF OPERATIONS

When the power supply is set perform the following operations:

TEST NO 1 - NO-LOAD LOSSES OF THE TEST MOTOR

Mechanically disconnect the alternator from the motor. Set the connection only to the motor.

1 Set the controls of the modules:

VARIABLE DC OUTPUT : Switch open
( excitation) Knobs fully turned in CCW

VARIABLE DC OUTPUT : Switch open
Output with about 200 V

STARTING RESISTANCE : Max
EXCITATION RESISTANCE : Min. resistance

2 Set the switch on. DC motor must be turn. Verify that the rotation sense of the motor is correct. Set the commutator Ra from "1" position to "6" position.

3 Acting on variac adjust the power supply to the exact value shown on the motor plate and with excitation resistance regulate the speed until the rated speed of the alternator.

4 Read the instruments indications Al e V1

5 Open the switch to stop the motor.

TEST NO 2 - MECHANICAL LOSSES OF THE ALTERNATOR

NOTE : Mechanically connect the alternator to the the motor. Don't excitate the alternator.

1 Start the motor until the rated speed at the alternator, Repeat the point 1-6 of Test NO 1.

TEST NO 3 - IRON LOSSES OF THE ALTERNATOR

1 Mechanically connect the alternator to the motor. Connect only the V2 voltmeter.

2 Repeat the operations 1 and 4 of test NO 1

3 When the rotation speed is exactly the rated speed, excitate the alternator until the output voltage is the rated value. Control it by the voltmeter V2.

4 Read the input voltage and current of the motor.
TEST NO 4 - ADDITIONAL LOSSES OF THE ALTERNATOR

NOTE: Mechanically connect the alternator to the motor. Connect only the ammeter A2 and connect U1 to V1.

1 Start the motor as in the test NO 1

2 When the rotation speed is equal to the rated ones, excite the alternator until the output short-circuit current is about 120% of the rated ones. Control it with the ammeter A2.

3 Read the indications of the input voltage and current at the motor.

4 Repeat the measurement for decreasing value for the output current.

5 Open the switch to stop the motor.

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<th>Alternator Losses</th>
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<td>( V_1 )</td>
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<tr>
<td>Test 1</td>
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<td>Test 2</td>
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<th>Test 4</th>
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<td>Additional losses of Alternator</td>
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