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Analysis of the Isolated Induction Generator

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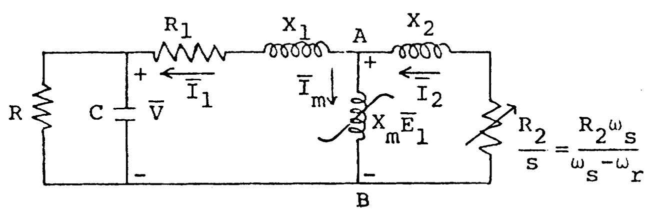
The basic problem in the analysis of an isolated induction generator is to predict its output voltage and frequency at a given shaft speed, when the load and exciting capacitance are known. The problem is complicated by the fact that the machine reactances are functions of frequency, and frequency depends on both shaft speed and slip, and slip depends on the output power. The output power depends on terminal voltage, which depends on both frequency and the excitation provided by capacitors, also a function of frequency.

The solution presented here applies directly to a three-phase machine, and relies on the Steinmetz circuit model with core loss neglected. The assumed model is shown in the following figure.



The no-load saturation curve of the machine may be obtained by applying a variable, three-phase, ac voltage of rated frequency to its terminals while it is being driven at synchronous speed corresponding to that frequency. Under these conditions, the input phase current (I_{n1}) equals the magnetizing current, and E_1 is given by

$$E_1 = \left[\left(\frac{V_{n1}{}^2}{3I_{n1}{}^2} - R_1{}^2\right)^{1/2} - X_1\right] I_{n1}. \tag{1}$$

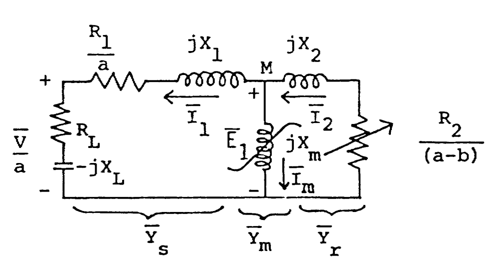
A plot of E_1 as a function of I_{n1} is the magnetization curve of the machine.

One key to the solution of this problem was suggested by M. G. Say in his book, *Alternating Current Machines*, (New York: Wiley, 1976); that is, let the system be normalized in terms of two new variables as follows:

$$a = \frac{\text{actual frequency}}{\text{rated frequency}}$$

$$b = \frac{\text{actual speed}}{\text{synchronous speed at rated frequency}}.$$

In terms of these variables, with the parallel RC load replaced by its series equivalent, the circuit model of the system becomes



If $\overline{Y}_s$ is the complex admittance of the stator portion of the circuits $\overline{Y}_m = -j/X_m$, and $\overline{Y}_r$, the admittance of the referred rotor circuit, then conservation of both power and vars is expressed by

$$E_1{}^2\overline{Y}_s + E_1{}^2\overline{Y}_m + E_1{}^2\overline{Y}_r = 0 \tag{2}$$

or simply

$$\overline{Y}_s + \overline{Y}_m + \overline{Y}_r = 0. \tag{3}$$

Power conservation is obtained when the sum of the real parts of the admittances is set equal to zero as in the following:

$$\frac{(R_L + R_1/a)}{(X_1 - X_L)^2 + (R_L + R_1/a)^2} + \frac{R_2/(a-b)}{X_2{}^2 + (R_2/(a-b))^2} = 0. \tag{4}$$

Given the shaft speed, b is known, and this equation may be solved for a. The equation is a fifth-order polynomial in a, having only one real root. The output frequency for the given load, capacitor, and shaft speed is thus determined. The slip is also determined.

The solution of (3) for X_m yields

$$X_m = \frac{(R_L + R_1/a)[X_2{}^2 + (R_2/(a-b))^2]}{(R_2/(a-b))(X_1 - X_L) - X_2(R_L + R_1/a)}. \tag{5}$$

With both a and b known, the value of X_m is established. A line of this slope, passing through the origin of the magnetization curve will intersect that curve at E_1, corresponding to rate frequency. The actual induced voltage will be a times this value.

Since E_1 and the frequency are known, either of the above circuits may be solved to determine terminal voltage and output power.

This procedure was evaluated by a laboratory test using a 10 hp, 2-pole motor for which the 60 Hz reactances were known from design data. Output voltage and frequency, over ranges of shaft speed, load resistance, and exciting capacitance, were predictable within a few percent. It was interesting to note that the slip is always quite small for normal loads resulting in an output frequency that depends almost entirely on shaft speed, and is not related to resonance between the magnetizing capacitors and X_m.

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An Approach to DC Motor Modeling and Parameter Calculation Using Finite Element Analysis and Tensor Mathematics

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This paper presents a general approach to dc motor modeling, using the finite element technique for magnetic analysis, and tensor manipulation of network parameters to simulate the machine to the desired degree of complexity. Winding types and saturation of magnetic materials are taken into account. By including electrical and mechanical dynamic behavior in the equations of state, this approach compactly manipulates the generalized mathematical machine model to calculate transient response.