IMPROVED EQUIVALENT CIRCUIT FOR ANALYSIS OF THE DOUBLE-CAGE INDUCTION MOTOR

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Abstract

The most commonly used equivalent circuit of Kron (1951) for steady-state analysis has the disadvantages of (i) giving unexpected transient behaviour of individual cages, though their sum is true behaviour of the motor, and (ii) unability to use design calculations of the single-cage induction motor for design of the double-cage induction motor. This paper suggests a new equivalent circuit for the double-cage induction motor which could remove both obstacles. Determination of parameters for analysis of the double-cage induction motor is included in this paper.

Introduction

Much has been said about the works done by previous authors (Burdi 1980) on the double-cage induction motor but no one has successfully predicted its exact performance, whether steady- state or transient, as far as its design equivalent circuits and individual cages are concerned. Kron (1951) suggested Fig.1 for steady-state equivalent circuit of the induction motor. This circuit is still widely used, although other forms of equivalent circuits for different purposes are also used. But no one has been successful in using design parameters of Fig.1, and whenever parameters of this equivalent circuit, determined from ordinary test (Burdi 1980, Theraja 1984), are used in design or transient analysis, wrong results are obtained. Predicted results (Burdi 1980, 1982, Theraja, 1984 and Burdi, 1989) of individual cages based upon the equivalent circuit of Fig.1 are always wrong when parameters from the circuit are used into equations for transient behaviour based upon Fig.2. The results show that the torque of inner-cage is in direct opposition to the torque of outer-cage.

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Sindh Univ. Res.Jour. (Sci. Sr.)Vol. 20(2): 13 to 18 (1988)

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Also Designers could not use the equivalent circuit of Fig.1 (Burdi 1980 and Padhyay 1970) and they, instead, introduced complicated unrealistic equivalent circuits which could not be used either for steady-state or transient behaviour. As a result the equivalent circuits differ from one another very widely, causing unavailability of any single circuit for all purposes. Equivalent circuit of Fig.1 is better than several others but X_{r12} is located at wrong place. This error is detected when steady-state loop equations of Figs. 1 and 2 are compared. After detection of the error, an alternative equivalent circuit is suggested.

Detection of Error in Existing Equivalent Circuits

Figs.1 and 2 are two widely used steady-state and transient behaviour equivalent circuits. Writing loop equations for Figs. 1 and 2, we get

$$v = [R_s + j(X_s + X_m)]\, I_s + j X_m (I_1 + I_2)$$

$$o = jX_m I_s + [R_{r1} + j(X_{r1} + X_m + X_{r12})]I_1 + j(X_m + X_{r12})I_2$$

$$o = jX_m I_s + j(X_m + X_{r12})\, I_1 + [R_{r2} + jX_{r2} + X_m + X_{r12})]I_2 \qquad \text{..... (1)}$$

$$v = [R_s + j(X_s + X_m)]I_s + j(X_{m1})I_1 + j(X_{m2})I_2$$

$$o = jX_{m1} I_s + [R_{r1} + j(X_{r1} + X_{m1} + X_{r12})]I_1 + jX_{r12} I_2$$

$$o = jX_{m2} I_s + jX_{r12} I_1 + [R_{r2} + j(X_{r2} + X_{m2} + X_{r12})]I_2 \qquad \text{..... (2)}$$

Comparing Eqs. 1 and 2, we get

$$X_{m1} = X_{m2} = X_m = 0 \qquad \text{..... (3)}$$

Equation (3), clearly shows that the equivalent circuits of Figs.1 and 2 are not the same even for steady-state operation and therefore the parameters of the equivalent circuit of Fig.1 in any case cannot be used for transients based upon the equivalent circuit of Fig.2.

Formation of New Equivalent Circuit

In order to make steady-state and transient behaviour of two equivalent circuits same, either of the circuits be readjusted. Readjusting parameters in Fig.1, a new circuit of Fig.3 is obtained. Writing voltage equations for Fig.3,

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$$v = [R_s + j(X_s + X_m)]I_s + jX_mI_2 + jX_mI_1$$

$$o = jX_mI_s + [R_{r1} + j(X_m + X_{r1} + X_{r12})]I_1 + jX_{r12}I_2$$

$$o = jX_mI_s + jX_{r12}I_1 + [R_{r2} + j(X_{r2} + X_m + X_{r12})]I_2 \quad \text{..... (4)}$$

and comparing these with Eq.2, we get

$$X_{m1} = X_{m2} = X_m \neq 0 \quad \text{..... (5)}$$

it is observed that the two sets of equations are exactly the same provided X_{m1} and X_m are replaced by X_m. Thus the new equivalent circuit of Fig.3 (for steady-state operation) perfectly gives same equations and therefore, the parameters of this circuit can be used into the transient equations formed from Fig.2. For accurate solutions, it is, therefore, established that the circuit of Fig.1, should be replaced by the one in Fig.3. The error of X_{r12} in Fig.1 is removed by relocating it as in Fig.3.

Determination of parameters

The parameters of the equivalent circuit in Fig.3 can be determined either by single-cage design calculations or by ordinary test measurements, when alternately the outer-cage and inner cage is removed away. The value of X_{r12} is determined from either locked-rotor or normal operation test when both cages are present.

Determination of X_{r12}

First $R_s, X_s, X_m, X_{r1}, R_{r1}$ are determined from locked rotor and light-load tests after removing outer-cage from the rotor of the motor. Then inner-cage is removed and outer-cage is inserted back into the rotor to determine X_{r2} and R_{rs} (and to confirm R_s, X_s and X_m) as a single-cage motor. X_{r12} is determined from locked rotor test by following calculations.

$$P_f = \frac{W_{ph}}{V_{ph}\, I_{ph}} = \text{Power factor}$$

$$P_{lf} = \text{Sin}\,(\text{Cos}^{-1}(P_f))$$

V_s = Voltage drop in stator impedance

$$= (R_s + jX_s)[I_{ph}(P_f - jP_{lf})]$$

V_r = Voltage drop in rotor = $(V_{ph}-j_0)-V_s$

Z_m = No-load or magnetizing impedance

$$= R_m (jX_m) / (R_m + jX_m)$$

I_m = No-load or magnetizing current = V_r / Z_m

I_r = Rotor circuit current = $I_{ph}(P_f - jP_{lf}) - I_m$ ..... (6

Z_r = Rotor Impedance = $V_r / I_r = (R_r + jX_r)$

$$= \frac{[R_{r2} + j(X_{r2} + X_{r12})][R_{r1} + j(X_{r1} + X_{r12})]}{R_{r2} + R_{r1} + j(X_{r2} + X_{r1} + 2Xr_{12})} \quad \text{..... (7)}$$

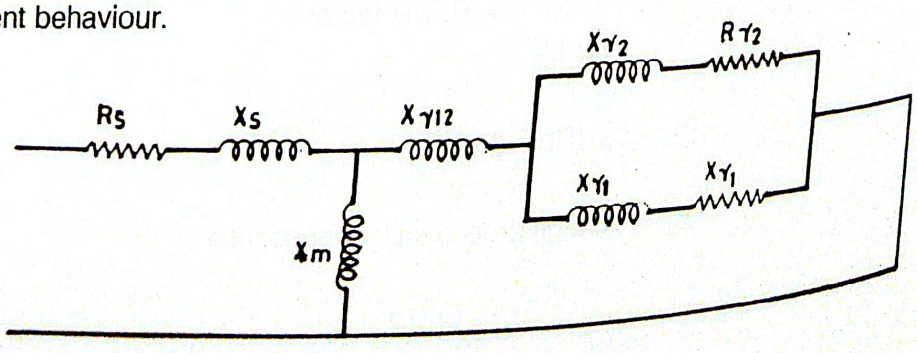
Simplifying Eq.7 and separating real and imaginary terms from resulting e
we get

$$X_{r12} = \frac{R_{r1}X_{r2} + R_{r2}X_{r1} - R_r(X_{r1} + X_{r2}) - X_r(R_{r1} + R_{r2})}{2R_r - R_{r1} - R_{r2}} \quad \text{..... (7)}$$

If X_{r12} is determined by normal operation test (Burdi 1980), R_{r1} and R_{r2} in Eq
replaced by R_{r2} / S and R_{r1} / S where S is the slip of the motor under measurement.

Generalized Machine Equations for the Induction

All generalised machine equations (Burdi 1980, 1982, 1989, and Padhyay 1970)
the double-cage induction motor can be tried for the determination of steady-state
transient behaviour.



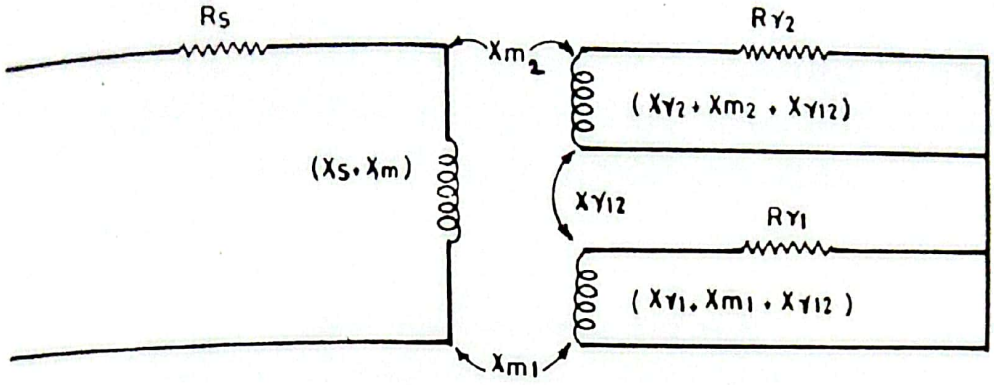


Fig: 2

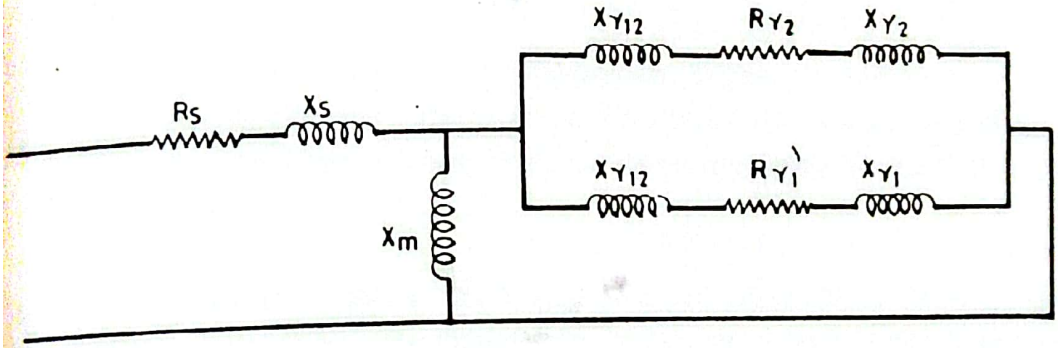


Fig: 3

Conclusion

A new equivalent circuit is suggested, the parameters of which can be determined from design, ordinary locked-rotor and light- load tests. The parameters so found could be used in prediction of behaviour of the double-cage induction motor. With this suggested circuit, design calculations of the single-cage induction motor are equally valid. This single equivalent circuit can be used for all purposes to represent a double-cage induction motor. This new equivalent circuit can also easily accommodate each new cage of a multi-cage machines just by adding corresponding rotor parameters.

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