CONTRIBUTION TO OVERALL SIMULATION OF CONTROLLED-SLIP-INVERTER-INDUCTION MOTOR DRIVE SYSTEMS

M.A. Shimy MANSOUR, M.A. ALHAIDER & I. FATOH
Electrical Engineering Department
College of Engineering
Riyad University
Riyad, Saudi Arabia

Recent developments in high-performance variable-speed induction motor drive systems offer the possibility of wide applications. Operation at controlled-slip frequency gives the induction motor desirable characteristics for traction and industrial applications. A method for simulation of controlled-slip variable-speed converter-inverter-induction motor drive system is described. The simulation method is developed considering source and filter time constants, converter switching effects, motor and load dynamic effects on the source as well as harmonic effects. A previous paper [1] shows how the fixed-slip frequency drive can be correlated with an overall system simulation. The method can be used for optimization and predicting the dynamic behavior of drives and control systems using induction motors.

I. SIMULATION OF AN INDUCTION MOTOR OPERATING AT CONTROLLED-SLIP FREQUENCY

A high performance variable-speed electric drive scheme is obtainable today with new drives using a rugged squirrel-cage induction motor and solid state inverter as the generalized schematic diagram of the controlled-slip drive system shown in Fig. (1). The power source and inverter shown in Fig. (1) provide a three-phase supply, to the induction motor, of variable amplitude and frequency, matching the requirements of the motor at all speeds of operation. The amplitude of the signal is determined by the operator's command, while the frequency is controlled automatically by receiving a signal from a tachometer on the motor shaft indicating the mechanical frequency of the motor [2].

The motor simulation is derived from a previous analysis which may be arranged as follows:

The absolute value of motor impedance may be expressed as:

$$Z = \left\{ \left(R^s + \frac{f}{f_s} \frac{R^r (2\pi M)^2}{(\frac{R^r}{f_s})^2 + (2\pi)^2 (L_\ell^r + M)^2}\right)^2 + f^2 \left(2L_\ell^s + \frac{(\frac{R^r}{f_s})^2 + (2\pi)^2 L_\ell^r (L_\ell^r + M)}{(\frac{R^r}{f_s})^2 + (2\pi)^2 (L_\ell^r + M)^2} 2M\right)^2 \right\}^{1/2} \qquad (1)$$

From the above equation it may be concluded that for a given motor, the motor impedance is a function of the slip frequency and the synchronous frequency. For a motor operating at a fixed-slip frequency, the motor impedance nearly varies linearly with the motor synchronous frequency [2].

Hence, the motor current and torque are given by:

$$I = \frac{V}{|Z|} \qquad (2)$$

$$T = 0.2388\ 2P \frac{R^r}{f_s} (I^r)^2 \qquad (3)$$

Equation (3) indicates that the torque produced is a function of motor current and slip frequency, the torque and current equations are similar to the corresponding equations for a series D.C. motor. This shows clearly the adaptability of the controlled-slip induction motor for tractive applications.

Using the above relationships, the characteristics of an induction motor are simulated by the block diagram of Fig. (2), with three input terminals to which the applied voltage, the synchronous frequency and the slip frequency are applied and an output terminal producing the torque.

The simulation of Fig. (2) can be used to optimize the performance of the electric drive, where it may be desirable in certain applications to program the slip frequency of the motor to achieve optimization of selected system performance [2].

The presented simulation considers ideal inverter performance and neglects filter and source time constants, converter switching effects and load dynamic effects. This may lead to considerable errors in cases where the stability of the system, system design and system optimization, become a problem.

A modified simulation is presented in section II hereunder as an extension to the new digital model that is presented in reference [1].

II. MODIFIED OVERALL SIMULATION OF CONVERTER-INVERTER-INDUCTION MOTOR DRIVE.

It is known that the inverter output voltages and currents contain many harmonics, so the previous simulation is improved by using the developed new digital model in reference [1].

Fig. (3) shows the overall simulation of a converter-inverter induction motor drive using the drive scheme of Fig. (1). As indicated, the frequency signal (f_m) produced by the tachometer on the motor shaft is fed to the logic and control circuitry, producing an output frequency (f) which represents the synchronous frequency of the motor. The voltage amplitude is controlled by converter firing angle signal (α). This signal is produced by the logic and control circuitry according to the synchronous frequency.

The block diagram representation shown in Fig. (3) is derived from the detailed analysis of reference [1]; - Blocks '1', '2', '3', '4' and '5' in Fig. (3) are represented by the system of equations 4, 5 and 6.

$$[Pi]_n = -[L]_1^{-1} [G_{(w^r)}][i]_n + [L]_1^{-1} [V]_n \qquad (4)$$

$$P\ \dot{\theta}_n = [i_{(n)}]^T [G_{(n)}] - [R][i_{(n)}] \frac{P}{Jw^r} - \frac{T_L}{J} \qquad (5)$$

$$p\begin{pmatrix} x_1 \\ x_2 \\ [i]_n \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 \\ -\frac{1}{C_f}[C]_n[L]^{-1}[C_v]_n & -\frac{R}{L} & -\frac{R}{LC_f}[C]_n \\ +\frac{1}{C_f}[C]_n[L]^{-1}[G_{(w^r)}] & & \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ [i]_n \end{pmatrix} + \begin{pmatrix} 0 \\ \\ \frac{1}{LC_f} \end{pmatrix} \bar{V}_{s(n)} \qquad (6)$$

- Block '6', represents the load dynamics, where the speed of the motor depends on it and the magnitude and duration of torque developed by the motor.

- Block '7', represents a transducer for converting motor speed into frequency.

- Block '8', represents a programmed trajectory that is adjusted with respect to motor speed to give the desired slip-frequency operation.

- Block '9', represents a programmed trajectory that is adjusted with respect to the inverter frequency to give the desired converter firing angle (α).

III. CONCLUSION

This developed simulation technique considers the source and filter time constants, converter switching effects, motor and load dynamic effects on the source, and harmonic effects. Also, the digital computer would provide a suitable approach for the design and optimization of selected system performance of the electric drive.

Operation at controlled-slip frequency gives the induction motor desirable characteristics for traction and industrial applications. To predict the response of systems using such drives, it is essential to represent the induction motor and associated solid-state control circuitry in block diagrams to be incorporated in the overall system simulation.

Block diagram representation of an inverter-induction motor is derived from analysis shown in reference [1].

LIST OF SYMBOLS

$[C]$	Connection matrix
C_f	Filter capacitance
$[C_v]_n$	Defined matrix
f	Frequency, Function
f_s	Slip frequency of the fundamental frequency f
$[G_{(w^r)}]$	Speed dependent impedance matrix
$[G_{(n)}]$	Speed dependent impedance matrix at interval n or time nΔt
$[i]$	General current vector
$[i_{(n)}]$	Current vector at time interval (nΔt)
$[i]^T$	Transpose of matrix [i]
I^r	Rotor current referred to stator
J	Angular moment of inertia
$[L]$	Speed independent inductance matrix
L_ℓ^r	Rotor leakage inductance referred to stator
L_ℓ^s	Stator leakage inductance
M	Magnetizing inductance
n	Interval number
P	Number of pair poles
p	$\frac{d}{dt}$
R^r	Rotor reistance per phase referred to stator
R^s	Stator resistance per phase
T	Electromagnetic torque
T_L	Load torque
$[V]$	General voltage vector
$\bar{V}_s$	Forcing function
w^r	Electrical angular frequency of the rotor
x_1, x_2	State variables
Z	Impedance
α	Thyristor firing angle
θ	Rotor angular displacement
$\dot{\theta}$	Rotor angular speed
Δt	Time interval

REFERENCES

[1] Mansour, Alhaider, Fatoh, A wide range static inverter suitable for induction motor drives, digital model and test results, EUROCON 80, 1980.

[2] L.J. Jacovides, Analysis of induction motor drives with a nonsinusoidal supply voltage using Fourier Analysis, 1973, IEEE Trans. Industry and Applications, Vol. IA-9, No. 6, p. 741-747.

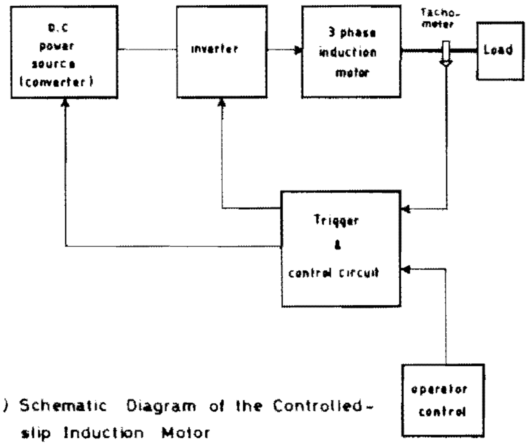

Fig (1) Schematic Diagram of the Controlled-slip Induction Motor

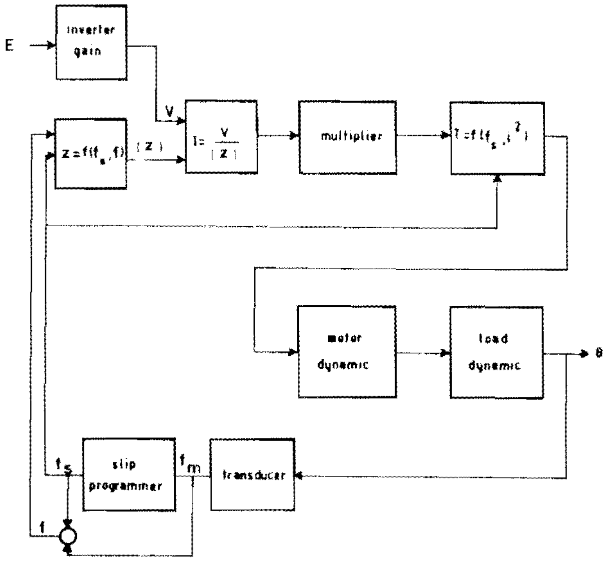

Fig (2) Simulation of Controlled Slip Induction Motor Drive Systems Powered Through 3 Phase Inverter System.

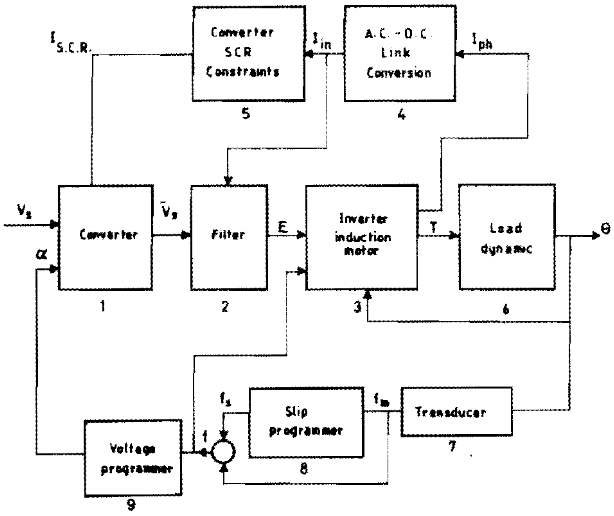

Fig.(3) Overall Simulation of Converter - Inverter Induction Motor Drive with Control Slip Frequency.