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Proposed Digital Simulation for Controlled Slip Drive

Nomenclature

$[C]$	connection matrix
C_f	filter capacitance
$[C_v]_n$	defined matrix
f	synchronous 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 $n\Delta t$
$[i]$	general current vector
$[i_{(n)}]$	current vector at time interval $[(n\Delta t)]$
$[i]$	transport 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 pole pairs
P	the derivative d/dt
R^r	rotor resistance per phase referred to stator
R^s	stator resistance per phase
T	electromagnetic torque
T_L	load torque
$[V]$	voltage vector
$\bar{V}_s$	forced function
w^r	rotor electric angular frequency
X_1, X_2	state variables
Z	impedance
α	thyristor firing angle
θ	rotor angular displacement
$\dot{\theta}$	rotor angular speed
Δt	time interval

1. Introduction

The developments achieved for the variable-speed induction motor drive systems incorporating solid-state power electronics made it possible to be utilized in many applications [1]. One of these developments is the operation at controlled-slip rotor frequency. This yields suitable drive characteristics for traction and high starting torque demand applications. Therefore, a simulation of such type of drive becomes a necessity to predict its performance beforehand.

A simulation model for a fixed-slip drive has been presented earlier [2]. This model can be extended to cover the controlled-slip frequency type of drives. This letter presents a method for simulating the controlled-slip variable speed converter-inverter induction motor drive system. The proposed simulation takes into consideration the effects of the source and filter time constants, converter switching, motor and load dynamics as well as harmonics. This developed simulation could be adopted, successfully, for optimizing the drive system performance.

2. Simulation Model Basics

A controlled-slip drive system can be schematically represented by the block diagram shown in Fig. 1. The DC power source in connection with the inverter provides a controllable frequency three-phase supply to the induction motor. The supply frequency is varied to match the motor requirements for the operation speed

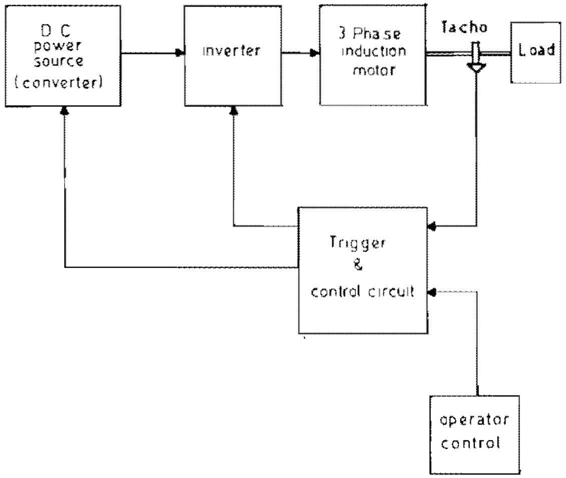

Fig. 1: Schematic Diagram of the Controlled-Slip Induction Motor.

ranges. It is controlled automatically by receiving a signal from the tachometer on the motor shaft which indicates the motor mechanical frequency [3]. The amplitude of the output voltage can be varied (in the case of using AC/DC converter) by the operator command. Therefore, the motor simulation derived from the previous analysis [2] may be arranged as follows.

The motor impedance, at a slip frequency f_s in the rotor, has the following form:

$$Z = R^s + \frac{f}{f_s}\left[\frac{R^r(2\pi M)^2}{\left(\frac{R^r}{f_s}\right)^2 + (2\pi)^2(L_l^r + M)^2}\right] + J2\pi f\left[L_l^s + M\left[\frac{\left(\frac{R^r}{f_s}\right)^2 + (2\pi)^2 L_l^r(L_l^r + M)}{\left(\frac{R^r}{f_s}\right)^2 + (2\pi)^2(L_l^r + M)^2}\right]\right] \quad (1)$$

Equation (1) indicates that, for a given motor, its impedance is a function of both slip and synchronous frequencies. If the motor is operating at a fixed-slip frequency, its impedance approximately varies with its synchronous frequency [3].

Consequently, motor current and torque are:

$$I = V/|Z| \quad (2)$$

and

$$T = 0.2388(2P) \cdot R^r \cdot (I^r)^2/f_s \quad (3)$$

It is clear, from equation (3), that the produced torque, in such a case, is a function of the rotor current and slip frequency. It can also be observed that the torque and current equations are similar to those corresponding to a DC series motor. This demonstrates, clearly, that the controlled-slip frequency drive has a wide range of DC series motor characteristics. Hence, it can be employed successfully for traction purposes.

The above-mentioned relationships can be utilized to simulate the drive systems by the block diagram shown in Fig. 2. There are three inputs corresponding to the applied voltage, synchronous and slip frequencies. The output terminal yields the torque. This simulation was used, properly, to achieve optimality for a selected system performance [3]. One of the drawbacks of this simulation is that it considers an ideal inverter performance and ignores filter and source time constants, converter switching and load dynamics. These effects may lead to considerable errors in cases when the system stability, design and optimization become marginal.

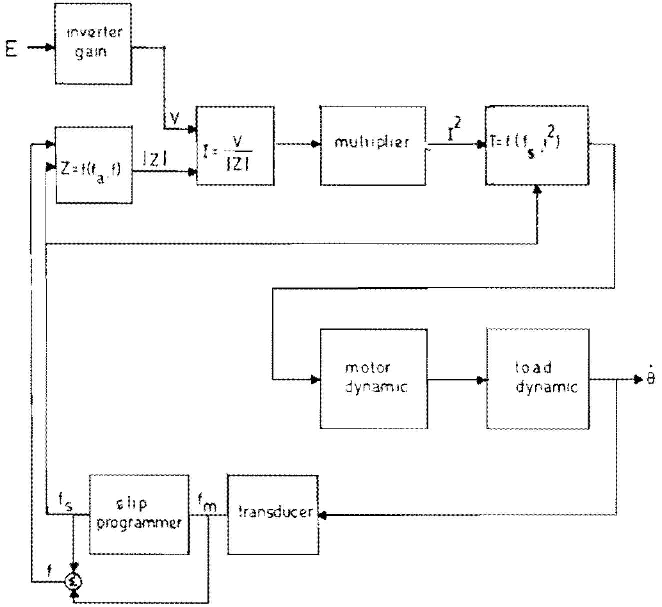

Fig. 2: Block diagram Representation of Controlled-Slip Induction Motor Drive Systems Powered Through 3 Phases.

A digital simulation [2] was developed, taking into consideration the previously mentioned factors. This simulation will be extended and modified, in this letter, to represent the operation of the controlled-slip frequency type of drive.

3. Modified Overall Simulation

The structure features of the modified simulation for the converter-inverter induction motor drive are represented by the block diagram shown in Fig. 3. The model is based on the drive scheme shown in Fig. 1. The block diagram representation of Fig. 3 is derived from the detailed analysis introduced in [2]. The frequency signal f_m, produced by the tachometer on the motor shaft, is fed to the logic and control circuitry. This produces an output frequency f which represents the motor synchronous frequency. The voltage amplitude is controlled by varying the converter firing angle signal α. This signal is produced by the logic and control circuitry according to the synchronous frequency.

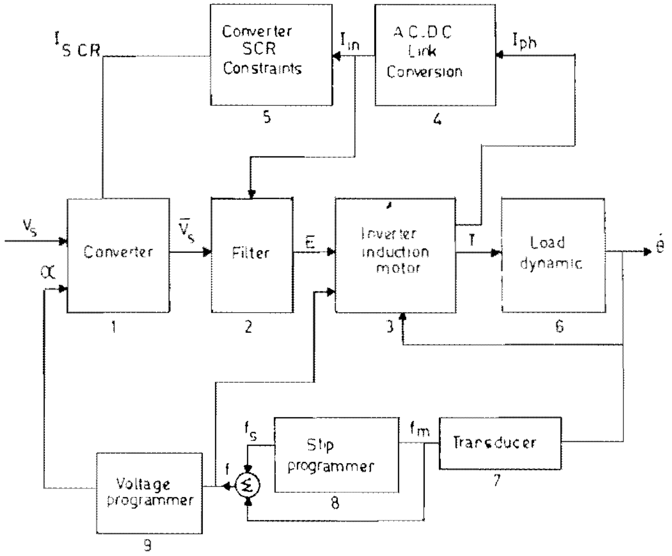

Fig. 3: Overall Simulation of Converter-Inverter Induction Motor Drive with Controlled-Slip Frequency.

The relevant equations governing the operation of blocks 1, 2, 3, 4 and 5 are as follows:

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

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

and

$$P\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ -[C]_n[L]^{-1}[C_v]_n/C_f & -R/L & -R[C]_n/LC_f + [C]_n[L]^{-1}[G_{(w^r)}]/C_f \end{bmatrix}$$

$$\times \begin{bmatrix} X_1 \\ X_2 \\ [i]_{(n)} \end{bmatrix} + \begin{bmatrix} 0 \\ 1/LC_f \end{bmatrix} \bar{V}_{s(n)} \tag{6}$$

The equations of the remaining blocks depend on the used type of drive as well as the nature of the load. The function of each one of these blocks is known as follows:

Block 6: represents the load dynamics on which depend the motor speed as well as the magnitude and duration of the motor electromagnetic torque.

Block 7: represents a transducer to convert motor speed into frequency.

Block 8: represents a programmed trajectory which is adjusted with respect to the 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).

Once these functions are known, then writing their equations become more feasible.

4. Conclusion

A developed simulation model for the operation of a controlled-slip frequency drive system is presented. The simulation considers source and filter time constant, motor and load dynamics and harmonics effects. It gives the drive system desirable operational characteristics for traction and industrial applications. The implementation of such a simulation model, using a digital computer, provides a suitable approach for practical design and optimization performance of the selected electric drive system.

References

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