REVOLVING MAGNETIC FIELD IN D-C CHOPPER AIDED CSI-FED INDUCTION MOTOR

Dr G Fekete　　Dr L Szentirmai

Department of Electrical Engineering　Technical University H-3515 Miskolc Hungary

Abstract

There has been a new current-source inverter (CSI)-fed induction motor drive developed, designed and put into practice by a project headed by the authors. Under discontinuous current conduction the revolving magnetic field can be maintained in a continuous way by the new electronic control. The pattern of the revolving magnetic field plays a great role in the favourable performances of the drive, thus computer-aided design of the new drive is based on equivalent circuits, space-phasor presentations and it incorporates the current-phasor dancing plus significant characteristics as well. New equation has been developed particularly for CSI-fed, reactor-less induction motor drive in order to present the behaviour of magnetic flux.

Introduction

There is the advent of variable-speed induction motor drives in industry taking the excellent performances of CSI-fed induction motor drives into account. The first product of the new and patented drive was exhibited at Budapest International Fair in May 1988. There are 4 closed-loop electronic controls working simultaneously such as speed control with subordinate current control, slip-frequency and torque-angle control as well.

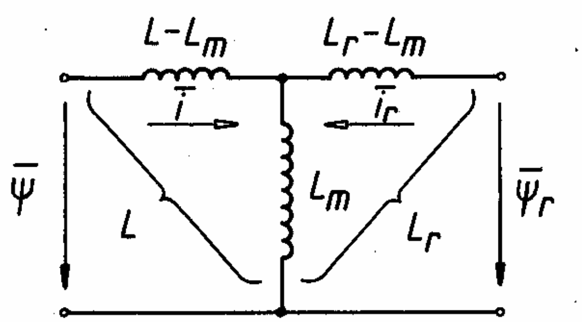


Fig. 1. Equivalent circuit for magnetic flux of induction motor

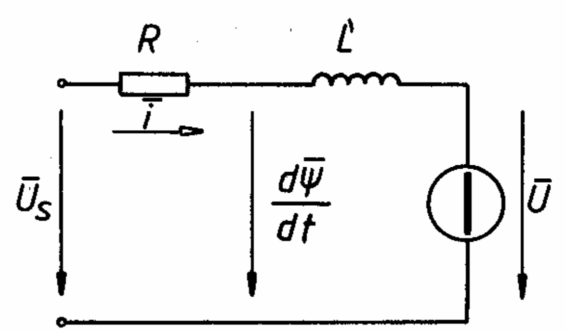


Fig. 2. Equivalent circuit of induction motor both for fundamental and harmonics (transformed circuit)

Due to the advanced control electronics, reactor is not needed in the d-c link, revolving magnetic field can exist continuously, 4-quadrant operation, energy-saving character, minimised current-input are also provided.

The revolving magnetic field contributes to the significant performance of the drive, thus it is being kept in the focus of scientific interest.

Equivalent circuit for magnetic flux of induction motor

The operation of induction motor can be described by the following equations keeping in mind that voltage, current and flux are presented in space-phasor form:

$$\bar{u}_s = \bar{i}\,R + \frac{d\bar{\Psi}}{dt} + j\,\omega_o\bar{\Psi}$$

$$\bar{u}_r = \bar{i}_r R_r + \frac{d\bar{\Psi}}{dt} + j(\omega_o - \omega)\;\bar{\Psi}_r$$

$$\bar{\Psi} = \bar{i}\,L + \bar{i}_r L_m$$

$$\bar{\Psi}_r = \bar{i}\,L_m + \bar{i}_r L_r$$

where

$\bar{u}_s$ - stator voltage space phasor
$\bar{u}_r$ - rotor voltage space phasor
$\bar{i}$ - stator current space phasor
$\bar{i}_r$ - rotor current space phasor
R - stator resistance
R_r - rotor resistance
$\bar{\Psi}$ - stator flux linkage space phasor
$\bar{\Psi}_r$ - rotor flux linkage space phasor
ω_o - angular frequency of frequency converter
ω_r - rotor angular speed in electric degrees
L - stator inductance
L_m - magnetizing shunt branch inductance
L_r - rotor inductance

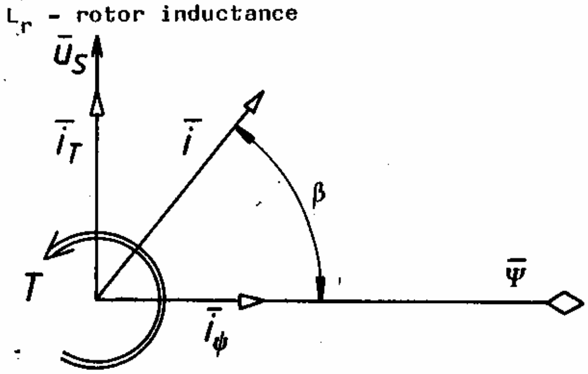


Fig. 3. The contribution of magnetic flux to torque development

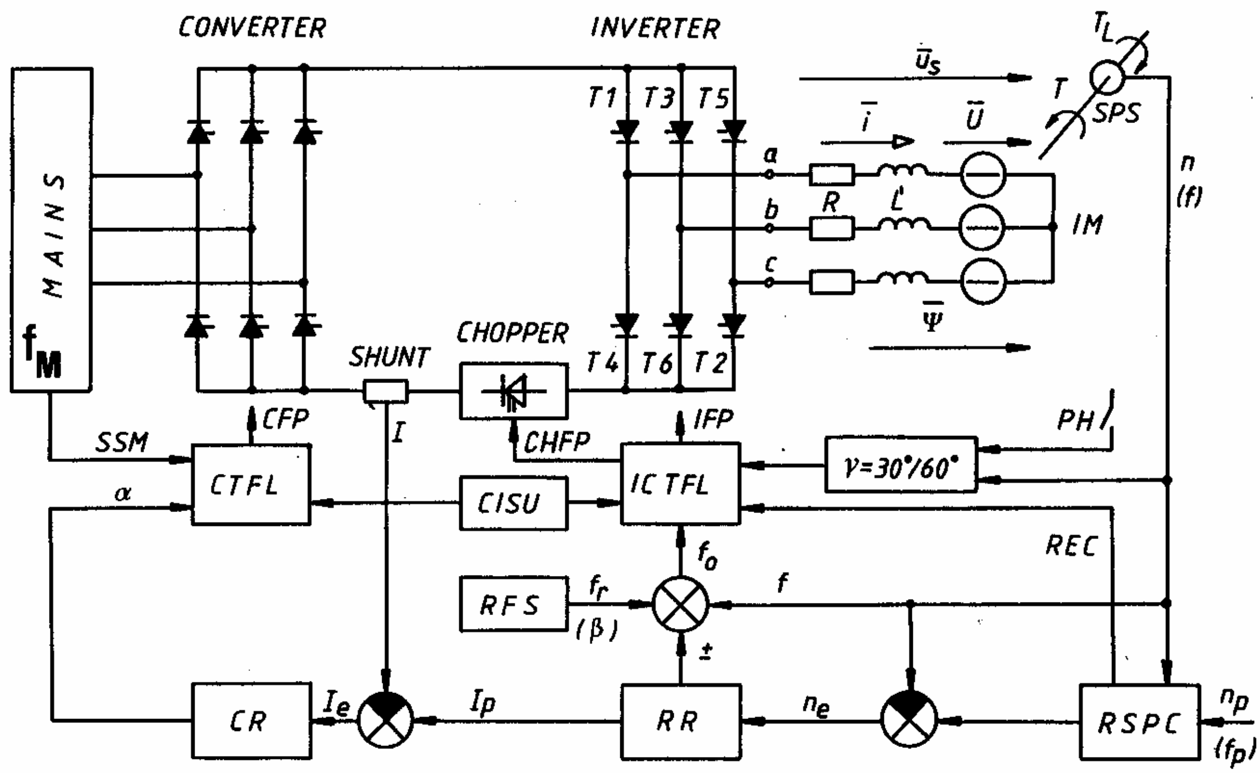


Fig.4. Block-diagram of current-source inverter-fed induction motor with chopper in the d-c link, provided with electronic logic for field stepping of 30/60 degrees

CFP - Converter Firing Pulse, CISU - Converter-Inverter Synchronizing Unit, CR - Current Regulator/Control Unit, CTFL - Converter Thyristors Firing Logic, CHFP - Chopper Firing Pulse, I - current control signal, I_e - current error signal, I_p - current reference or principal signal, ICTFL - Inverter-Chopper Thyristors Firing Logic, IFP - Inverter Firing Pulse, IM - Induction Motor, PH - Phase Angle Switch for Field Stepping of 30/60 degrees, REC - Reversal Code, RFS - Rotor Frequency Signal Generator Unit, RR - r.p.m. control/regulator, RSPC - Reference Signal Producing Circuit, SSM - Synchronous Signal from Mains, T - motor torque, T_L - load torque, SPS - Speed Sensor. --- α - firing angle adjusting signal, β - torque angle, γ = 30/60 degrees, field stepping electronic logic, f - digital signal proportional to speed, f_o - digital signal proportional to synchronous speed, f_r - digital signal proportional to rotor frequency, f_p - digital signal proportional to reference signal, n - actual speed in r.p.m., n_e - r.p.m. error signal, n_p - r.p.m. reference signal.

Based on the equations presented on the previous page the equivalent circuit for the magnetic flux of an induction motor can be constructed (Fig.1.). The equivalent circuit of an induction motor which is suitable both for the fundamental and the harmonic components (Fig.2.) will be available by the transformation of the flux equivalent circuit assuming that $(L_r - L_m) = L_2^*$ must be zero. Substituting the fundamental quantities by a source-voltage of a voltage generator $\bar{U}$ and taking the transient inductance of an induction motor into account, we obtain the magnetic flux from Fig.2. as

$$\bar{\Psi} = \int(\bar{u}_s - \bar{I}\,R)dt = \int(\bar{U} + L'\frac{d\bar{I}}{dt})\,dt$$

Current-source inverters can be considered

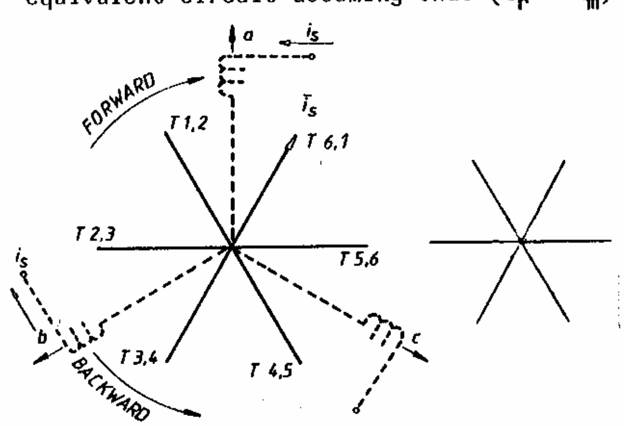


Fig.5. Current space phasor by field stepping of 60 degress. (a) ideal diagram, (b) oscilloscope record at 50 r.p.m., 50% load

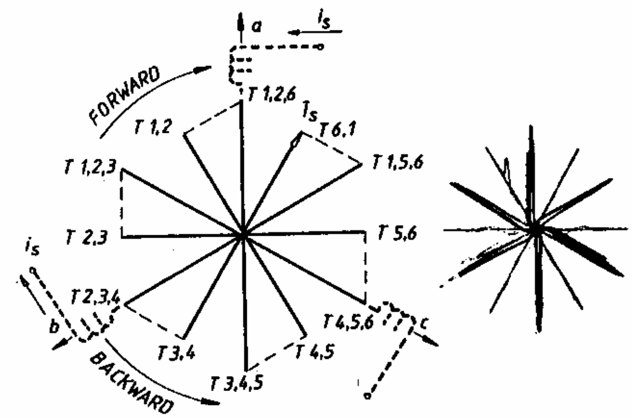


Fig.6. Current space phasor by field stepping of 30 degrees. (a) ideal diagram, (b) oscilloscope record at 50 r.p.m., 50% load

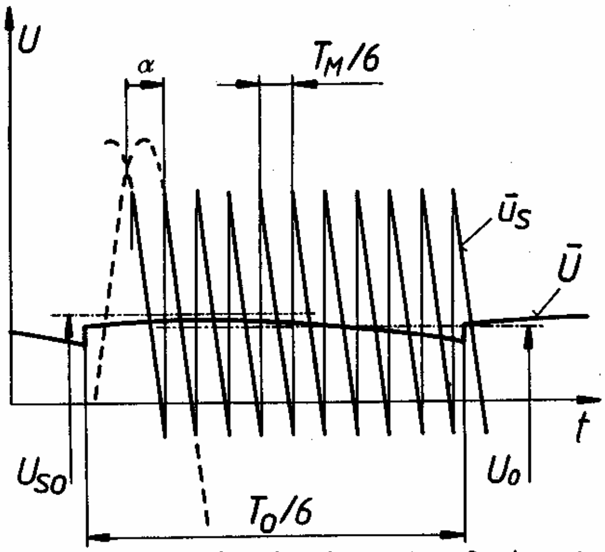


Fig.7. Mains and induction motor fundamental voltages vs. time functions and their relation

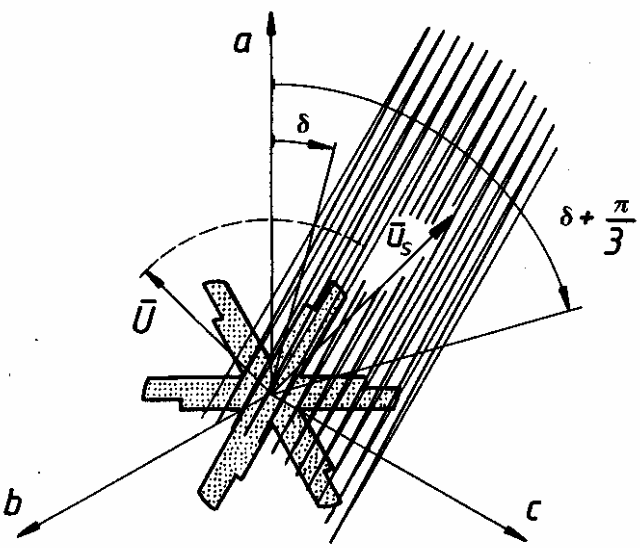


Fig.8. Development of resultant flux derivative taking equivalent circuit into account

harmonic sources viewed from the induction motor. Torque load must be balanced by the vectorial product of flux and current vectors (Fig.3.) $\bar{T} = \bar{\Psi} \times \bar{i}$

Electronic control can transmit the same torque by various torque angle β and it can be influenced by f_r, hence

$$\tan \beta = k_o f_r$$

Electronic control equipment rotates the motor at the required speed and the load must be taken up by the motor.

D-C link (Fig.4.) has neither reactor nor capacitor, the currents carrying in the stator windings are oriented by chopper and electronic control ensures continuous current conduction. Current compulsions are implemented by field stepping of 30 or 60 degrees due to the fact that the motor terminals are connected to the mains through the converter and the inverter.

The magnetic flux created in induction motor can be treated by space phasors which are derived from current space phasors (Fig. 5. and 6.).

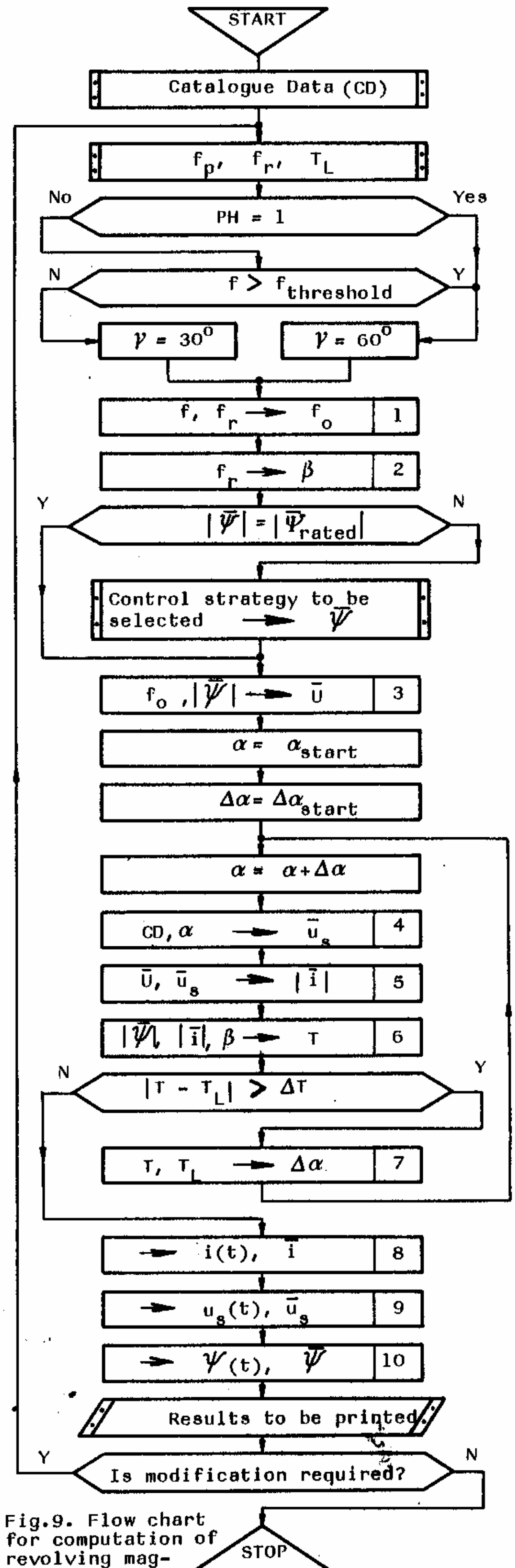


Fig.9. Flow chart for computation of revolving magnetic field

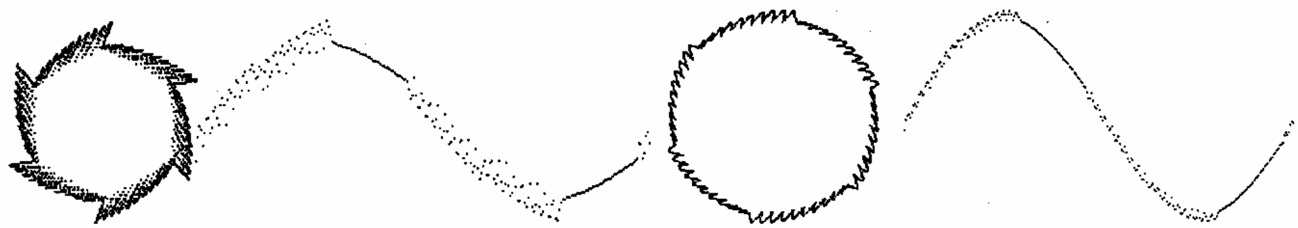
The flux in phase "a" can be computed by the equation developed for this project as

$$\Psi_a(t) = \sum_{m=-\frac{f_M\delta}{f_o\Delta\xi}}^{\frac{f_M(360^0-\delta)}{f_o\Delta\xi}} \mathrm{Re}\left\{U_o e^{-j(\delta+\frac{f_o m\Delta\xi}{f_M})} + \left[U_{Mm}\sin(60^0+\alpha+n\Delta\xi)\Big|_{n=0}^{\frac{60^0}{\Delta\xi}} - U_{so}+aU_{CH}\right]e^{-j(30^0+k60^0)}\right\}$$

where k denotes the values belonging to the values of the actual "m" such as -1, 0, 1, 2, 3, 4, 5, then a is a constant taking the chopper into account, U_{CH} is the chopper voltage and $\Delta\xi$ means the sampling angle of the mains. To solve the equation flow chart is presented in Fig.9.

Space phasors and time functions of magnetic flux plotted by computer

$\delta = 46^0$, f_M = 50 Hz, f_o = 5 Hz



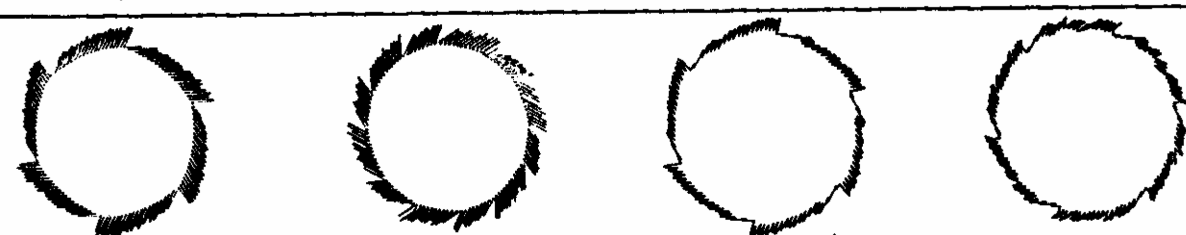
Space phasor Time function
20% load

Space phasor Time function
Rated load

Oscilloscope records

Field Stepping of 60 / 30

Field Stepping of 60 / 30 degrees



Flux space phasors
Small load
50 r.p.m.

Flux space phasors
50% load
50 r.p.m.

Flux versus time functions
Small load
50 r.p.m.

Flux versus time functions
50% load
50 r.p.m.

Conclusions

Revolving magnetic field plays great role in inverter-fed induction motor drives. To treat magnetic flux accordingly, there has been a new equation developed. Computer-aided design of induction motors and also the performance of the drives need thorough investigation on the magnetic flux. Inverter-fed induction motors' working condition requires the study of space phasors; they have been constructed in a scientific way, computed and plotted by computer and finally verified by oscilloscope records.

References

1/ FEKETE, G. - SZENTIRMAI, L.: New performances of CSI-fed induction motor by field stepping of 30 degrees. International Conference on Electrical Machines, ICEM'88, Pisa, Italy, 1988. Proceedings, Vol. II. pp:475-480.

2/ TANG YUN-QIU: Electromagnetic field in electric machine. Science Publishing House, China, 1981.

3/ IEE Publications and Standards.