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A NEW ENERGY BASED CURRENT CONTROLLED CSI-FED INDUCTION MOTOR DRIVE

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Abstract: *A new induction motor drive control strategy is introduced for current source inverter. The so-called contact energy model is used. The contact energy control diagram is presented that is the base of the strategy. Speed or torque control can be realized without measurement or calculation of mechanical speed. Laboratory experimental results are also presented.*

Key Words: ***Adjustable Speed Drives, Sensorless Control, Energy Based Current Control, Contact Energy Control Diagram, Standardized Control Strategy for Inverter-Fed Drives, Shaft-Frequency Seeking and Tracking Logic, Low Speed control.***

1. INTRODUCTION

High performance, reliable induction motor drives can be realised by controlled current or voltage source inverters. Therefore induction motors are more and more popular nowadays. Inverter-fed squirrel-cage induction motors can be used in dangerous environment also, for example in mining and in chemical and oil industry. The application of sensorless drives is especially advantageous in the above-mentioned risky environment. The control strategy introduced in these paper gives excellent results without calculation or measurement of rotor speed. The applied commutation strategy supports the low speed mode and decreases the voltage peaks.

2. CONTACT ENERGY CONTROL - ENERGY BASED CURRENT CONTROL (EBCC)

The block diagram of the new controller is shown in

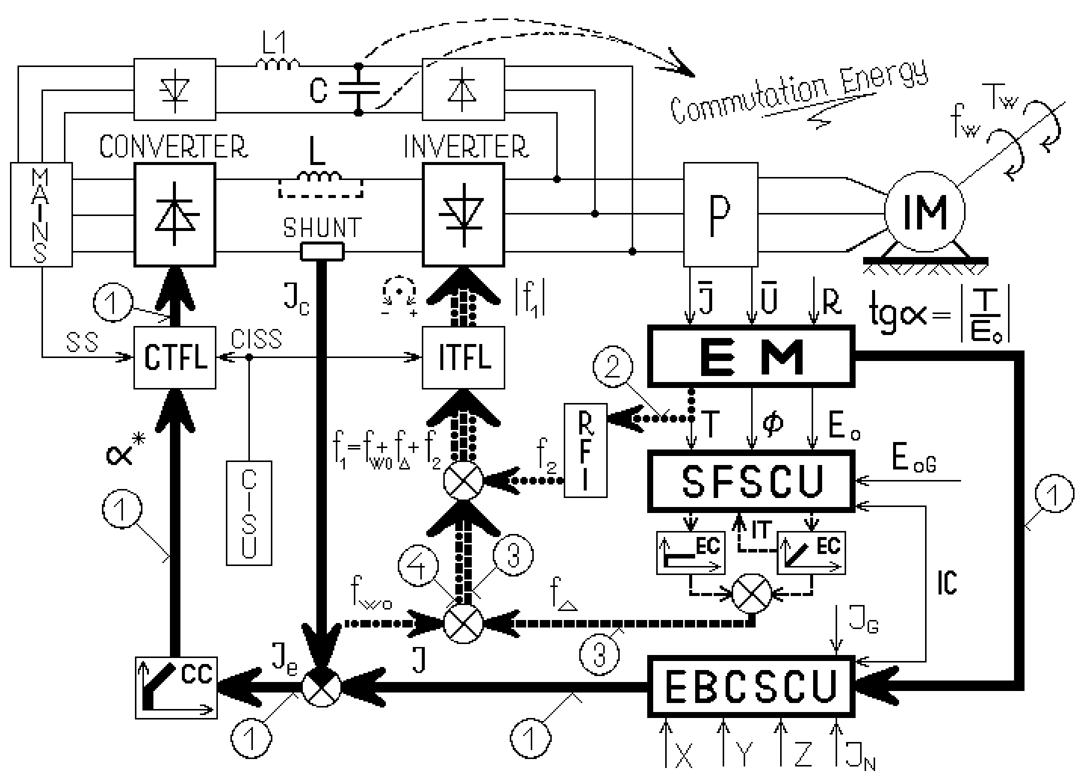

Fig. 1: *Energy Based Current Control (EBCC)*

Fig.1. The scheme results fast and accurate control. After turning on the power supply, the controller immediately sets the mechanical speed. The controller gives good results at and around zero speed also. The control strategy is based on energy quotient: $\mathrm{tg}\, a = |T / E_0|$. The reduction of magnetic energy and also the torque increase result the immidiate increase of current reference signal I, that results good dynamical behaviour.

The block diagram of Energy Based Current Controller is shown in Fig. 1.

1. **The following control loops are used in the controller:** 1 Current controller, 2 Rotor-frequency controller, 3 Magnetic energy controller, 4 Shaft-frequency controller.
2. **The main parts of the controller are:** *EM* Energy Model, *SFSCU* Shaft Frequency Seeking and Controlling Unit, *EBCSCU* Energy Based Current Signal Computation Unit, *CTFL* Converter Thyristor Firing Logic, *ITFL* Inverter Thyristor Firing Logic, *CISU* Converter-Inverter Synchronizing Unit, *RFI* Rotor Frequency Interface, *CC* Current Controller, *EC* Energy Controller, *P* Park-vector presentation circuit, *IM* Induction Motor.
3. **The signals of the controller are:** I_C current control signal, I_e current error signal, I current reference or principal signal, I_G current limit value, I_N rated current, X p.u. current value, if $a = 45^0$, Y p.u. current value if $a = 0^0$, Z transfer factor, *IC* communication, *SS* synchronous signal, *CISS* converter-inverter synchronous signal, $\bar{I}$ current space vector, $\bar{U}$ voltage space vector, R stator resistance, a^* firing angle, T effective energy, T_w shaft torque, f flux, E_{0G} magnetic energy limit, *IT* integrator inhibit, f_1 stator frequency, f_2 rotor frequency, f_w shaft frequency, f_{wo} shaft frequency reference value, f_Δ frequency compensation, $L, L1$ inductances, C capacitor.

3. CONTACT ENERGY MODEL OF INDUCTION MACHINE

Field oriented control strategy is the most frequently used and most adequate control method of induction motor drives. The knowledge of rotor flux and the torque current control with high dynamical parameters are the main goals. In order to carry out this strategy, the determination of the motor parameters are necessary. Additionally, coordinate transformations are also necessary. The field orientation is shown in Fig. 2. The transformation from the stationary $x^* - y^*$ reference system to the $a^* - b^*$ rotor flux co-ordinate system is carried out by using angle r. After the transformation the control algorithm is executed, and subsequently the inverse transformation is carried out. If the contact energy control method is used, these procedure is not necessary. The $\bar{f}$ flux space vector and the $\bar{I}$ stator current space vectors are applied for the contact energy control mode.

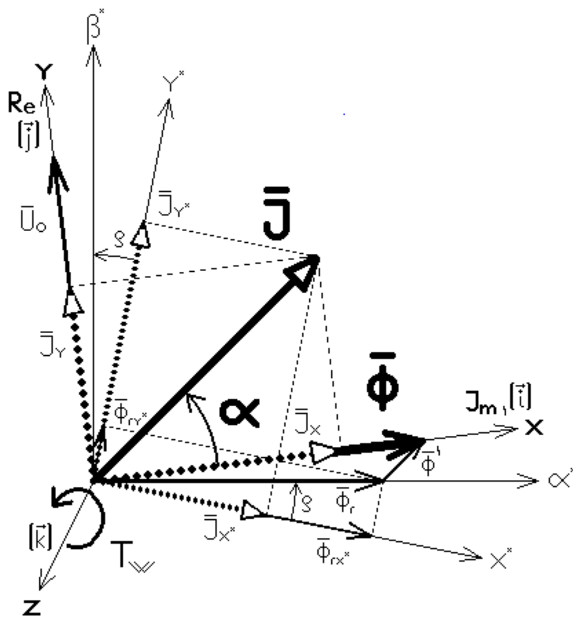

Fig. 2. *Field orientation and contact energy*

3.1 Determination of torque

From the relation of the directed fields $\bar{f}$ and $\bar{I}$ results the torque T_w. It is determined by the following form:

$$\vec{T}_w = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ f_x & f_y & 0 \\ I_x & I_y & 0 \end{vmatrix} = \vec{k} \cdot \left(f_x \cdot I_y - f_y \cdot I_x \right) \qquad (1)$$

$$\vec{T}_w = \vec{k} \cdot T_w \ (\mathrm{VAs}), (\mathrm{Nm}) \qquad (2)$$

The value of variables $\bar{f}$ and $\bar{I}$ can be determined from the induction machine model.

3.2 Contact energy model

The generally used Induction machine model consists of resistance and inductance. A modified "Energy Model" is used during the research work, where only the stator resistance is taken into consideration with its original value. The motor remainder part is represented by the $L*$ and $R*$ equivalent elements, as it is shown in Fig. 3. The vectors of stator voltage space vector $\bar{U}$, the stator current space vector $\bar{I}$, and the stator resistance R are derived continuously from the motor. Therefore the flux $\bar{f}$ and stator current $\bar{I}$ space vectors are equal to the actual motor values, that means that the used main field and leakage values are errorless, and the equivalent $L*$ and $R*$ values are not calculated. The electromagnetic energy E_0 inside the motor represents the energy of the magnetic wave field produced by voltage or current compulsion and is considered as a potential energy.

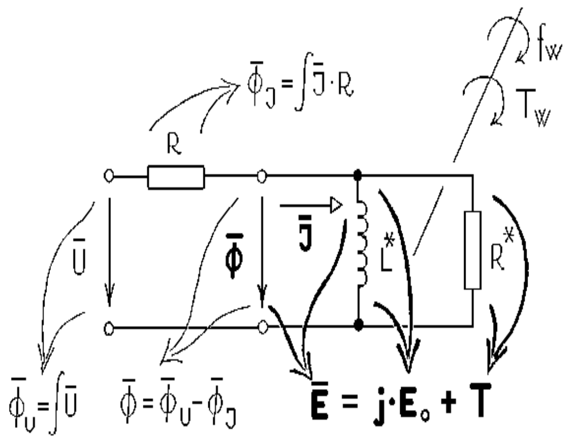

Fig. 3. *Induction motor contact energy model*

3.3 Contact energy space vector

The following form can determine the Contact energy space vector:

$$
\begin{aligned}
&\bar{E} = \left(\bar{f} \cdot \bar{I}^*\right)^* \cdot j = \\
&= \left(\left(f_y + j \cdot f_x\right) \cdot \left(I_y - j \cdot I_x\right)\right)^* \cdot j = \\
&= \left(f_x \cdot I_y - f_y \cdot I_x\right) + j \cdot \left(f_y \cdot I_y + f_x \cdot I_x\right) = \\
&= \mathrm{T} + j \cdot E_0 \qquad (\text{VAs}).
\end{aligned}
\tag{3}
$$

In this approach the potential effective energy (T) is equal to the motor torque measured on the shaft of the machine (T_w), i.e. $T = T_w$. The (E_0) potential magnetic energy is equal to the energy represented by I_x (see Fig.2.). It's value is constant (if I_x constant), but the spatial position of the directed field is changing.

3.4 Choosing Contact Energy and Current value

If the load angle $a = 45^0$, choosing adequate gain, $\bar{E} * K$ "$= \bar{I}$", and $\left|\bar{I}\right|$"$= I$". In order to determine the contact energy diagram for current I, the load angle a have to be changed between -90^0 and. $+90^0$. In the followings the sign " is neglected.

4. CONTACT ENERGY CONTROL DIAGRAM OF INDUCTION MACHINE

The contact energy control diagram of induction machine is shown in Fig.4. The flux space vector is fixed to the real axes. The Contact energy diagram in the case of $\bar{I}_G$ current limit is represented by broken line. The set points for this current value is determined by the $\bar{I}$ and $\bar{E}$ space vectors driven by thick line. If we determine the set points for every current value, the series of set points gives the Contact-Energy control diagram (continuos thick curved line).

In position 1 ($E_0 = T = 0$) the frequency has an infinite value.

In position 2, $E_0 = T$, that is the breakdown torque value, and the rotor frequency is the breakdown frequency.

In position 3 the total energy input is equal to the E_0 component, and $f_{rot} = 0$.

The no-load point is signed by A. The current controller works on the interval $A - B$. E_0 decreases on the interval $B - C$. The contact energy is controlled around C, that results frequency seeking and tracking. Other special positions on the diagram are: ($I.$) motor mode forward, ($II.$) generator mode forward, (Δa) load angle difference, (E_{0G}) magnetic energy limit, (T_G) torque limit.

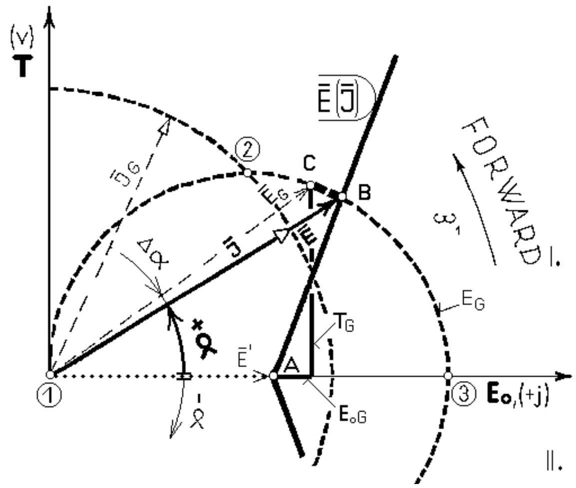

Fig. 4. *Induction machine combined Contact Energy and Contact Energy Control diagram*

During the development work of the energy-based current controller three versions of I current reference signal (b, g, d) was tested (b, g do not used here). In the case of d version (Fig.5.) the forms are:

$$
I = I_N \cdot X \cdot \left(1 + K1 \cdot K2\right) \tag{4}
$$

where

$$
K1 = 1 - \frac{Y}{X}, \quad K2 = \left(\left|\frac{T}{E_0}\right|\right)^Z - 1 \tag{5}
$$

by rated value (I_N):- E_U Energy in case of voltage force
- E_I Energy in case of current force.

The $\bar{I}$ current space vector trajectory moves on the energy based current control diagram (thick continous line). In the same time, the $\bar{E}$ space vector that is in phase with $\bar{I}$ current space vector, moves on the thick broken line if the control parameters are: $I(x)/I_N = 1.25$, $Z = 2$, $I(y)/I_N = 0.5$. In order to be fitted to the technology process, the control parameters $I = f(x, y, z, \mathrm{tg}\, a, I_N)$ are chosen.

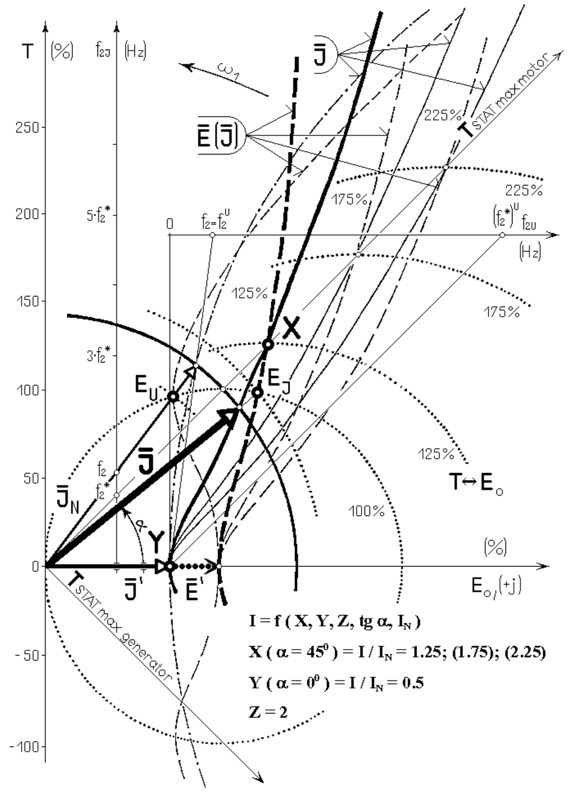

Fig. 5. *Energy Based Current Control diagram of induction machine*

5. EXPERIMENTAL RESULTS

The variation of current reference signal is shown in Fig. 6. During dynamical brake mode. On the oscilloscope picture 1 cm = 0.5 sec. The dynamical brake mode is shown. In Fig. 7. The induction machine is loaded by dc machine, in order to realize four quadrant operation mode.

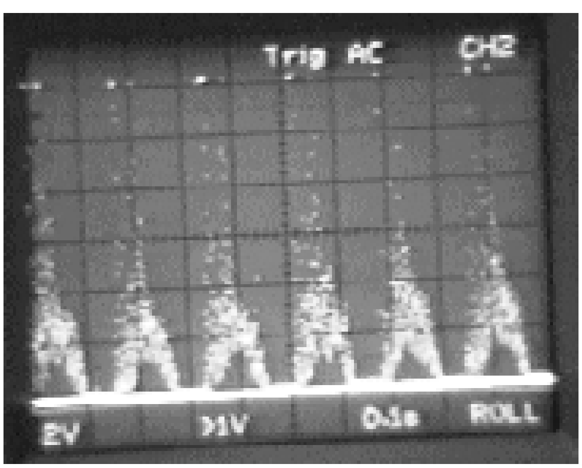

Fig. 6. *Current reference signal during dynamical brake*

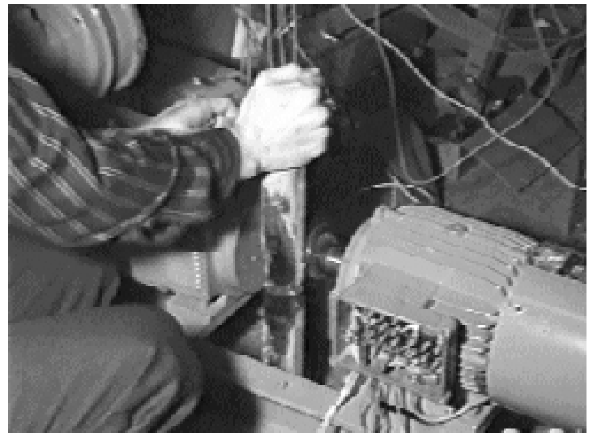

Fig. 7. *Dynamical brake mode of induction motor.*

As a result of the energy base control mode, the drive shows better dynamical behaviour, than the dc motor. Therefore it can not be loaded dynamically by the dc machine. Therefore the shaft of the induction motor is mechanically braked as it is shown in the picture. The flux and current time function is shown in Fig.8, when the dynamically change of the load forces rotational direction of the induction machine to change. (On the picture, 1 cm = 0.1 sec). The behaviour of the drive and the control electronic is shown at near zero speed. The torque demand is satisfied by swinging magnetic field.

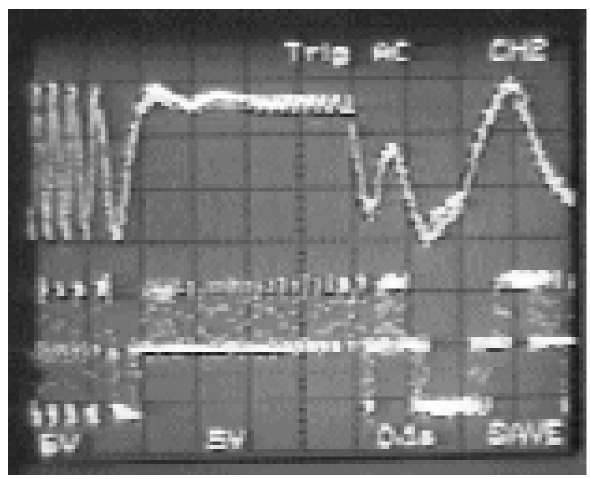

Fig. 8. *Flux and current waveforms*

The shaft speed is changing according to a triangle time function in Fig.9. The zero speed (zero speed reference signal) is on the zero line of the oscilloscope scale (On the picture, 1 cm = 0.2 sec). The sign of the values are positive or negative, according to the forward and reverse rotation. The square wave shape of the torque can also be observed on the picture. The transition between the generator and motor mode can also be observed according to the reference signal positive and negative ramps. The commutation voltage integrals, flux variations during the inverter current commutation process are shown in Fig. 10, according to the modified configuration shown previously in Fig. 1 (commutation energy). The voltage space vector trajectory is shown in

Fig.11. The voltage peeks are limited, as it can be seen in the picture. The main advantage of the control and commutation strategy is evident at low speed.

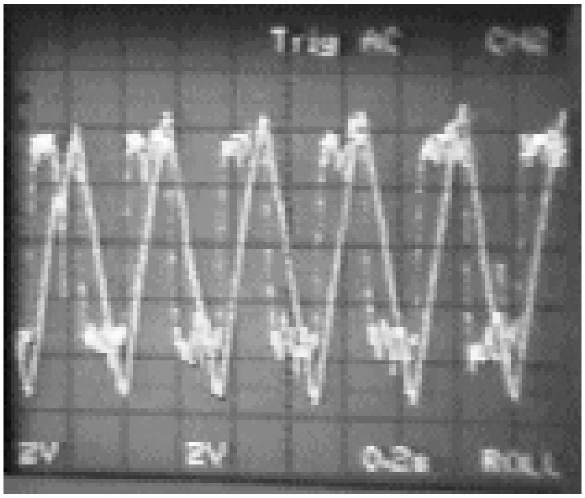

Fig. 9. *Shaft speed and torque waveforms.*

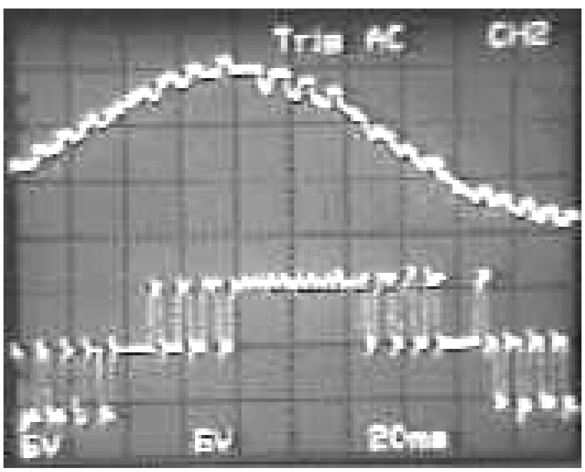

Fig. 10. *Flux and current waveforms*

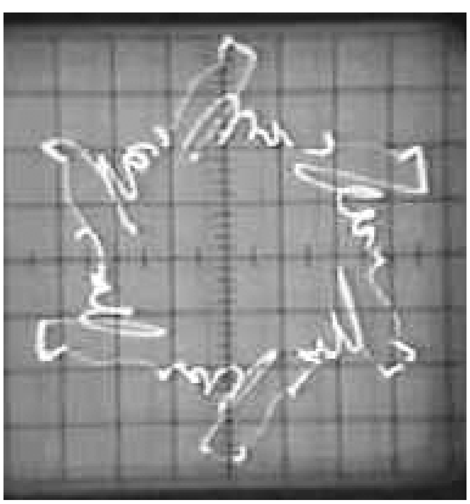

Fig. 11. *Voltage space vector trajectory*

6. CONCLUSIONS

The experimental tests show that the new sensor-less drive gives good results. The measurement or calculation of rotational speed can be neglected. The knowledge of the machine parameters is not necessary. The control strategy gives high precision and excellent dynamical behaviour. The machine is able to work on any set points with high stability. The self-control of the contact energy is realised (Direct self-control, DSC). The contact energy control can also be considered as current-based energy control strategy (CBEC). with the new strategy. The contact energy control control method is a new control strategy that can be used as general control strategy of converter-fed ac machine.

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