Current Trends on Command, Control, Modeling and Simulation of the Induction Machines

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Abstract: - AC motor drives have produced and still produce a particularly high impact in many technical applications. Advantages of adjusting the frequency operation can not be fully exploited without adjustment command and control strategies through modeling of the corresponding components. Simulation of drive systems is complicated due to nonlinear high level they bring power electronics and also due to control, adjustment and protection in the transfer of power flux. Moreover, mathematical models of semiconductor and control functions not yet found in many programs and this requires the designer or specialist to introduce its version in the simulation program [1]. Currently known multi-level modeling, which is available to describe static converters and each model can introduce undesirable effects on the behavior of electric machine [2]. This paper presents the current trends of advanced control techniques and control of induction machines used for variable frequency drives, depending on the torque, speed and rotor position. It analyzes the possibilities of command and control without sensors and estimates are made of results obtained by modeling and simulation of the control and adjustable system. Also, present paper recommends how to run a simulated vector controlled induction electric machines.

Key-Words: - **N**on-sensorial control, vector control, parameter estimation, modeling drive system, model of vector controlled electric drive system, block diagram, mathematical models, micro-models, macro-model.

1. Introduction

As known from literature on systems theory adjustment for AC motors drives controlled by conventional vectors, control system requires rotor position transducers for the stator current vector orientation at a given angular displacement depending on the rotor flux. This should be done in correlation with construction and functional characteristics of AC motor.

Where necessary the direct control of torque by the stator current command in amplitude, we want to hear instantaneous angular position of rotor flux with a well-defined system in terms of mathematics [3] and physics.

2. Drive systems using different types of transducers

In general block diagram of Fig. 1 shows a synchronous motor drive system (you can also use an induction motor) ordered by speed control, including vector control field. On the kinematics axis of the system are involved two electromechanical transducers while speed transducer is used to implement closed loop speed control. Transducer position is used only to obtain the total torque and flux control.

Position transducers that can be used, flux sensors / transducers with Hall Effect or optical systems coded transducers. All these transducers increase the cost, size and complexity of induction motors, and often-reduced and system reliability, seriously limiting the practical application. This limitation affects not only induction motors but even those that use non-standard motors, such as variable reluctance synchronous motors (motors which are now recommended as an alternative for induction motors).

Although it may seem as a good solution in many applications (such as shareholders with average performance, but at reduced prices), the presence of transducer position affects the overall cost of operation. An application of this type can be made to order in the rolling mills stands, where even reach 9MW power electric machine, however, rate control do not require a very high precision.

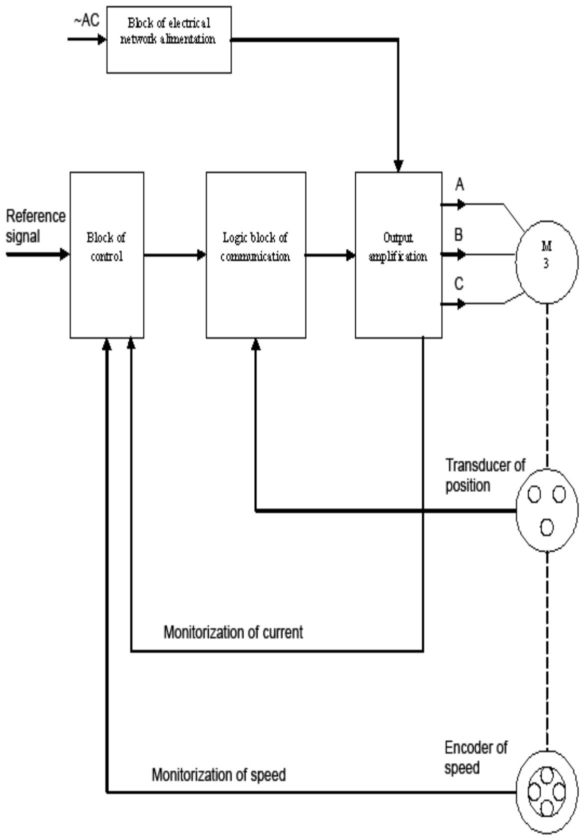

Fig. 1. Block diagram of a system drive synchronous motor vector control

3. Command and control of non-sensors schemes

In general, an effective scheme of non-sensor control speed or an efficient scheme to estimate the position should be involved only standard sensors always included in drive systems. Typical electrical variables can be measured directly and those derived from measurable quantities include voltage, current, time of growth and decrease the switching current, inductance, total flux and response f.e.m.

Figures 2, 3 and 4 are exemplified changes in the system voltage at the terminals of the machine operating at 10Hz (Fig.2 and Fig.3) and in the braking operating at 10 Hz (Fig.4).

Figures 5, 6, 7, 8, 9 and 10 exemplifies the voltage variations at the terminals of the induction machine operating at 20Hz, 30Hz and 50 Hz (fig.5, 6 and 7) and in the braking operation at 20Hz, 30Hz and 50 Hz (Fig.8, 9 and 10). In fig. 9 is observed the transient regime in the passing of the asynchronous machine from operating regime thru the braking operating regime.

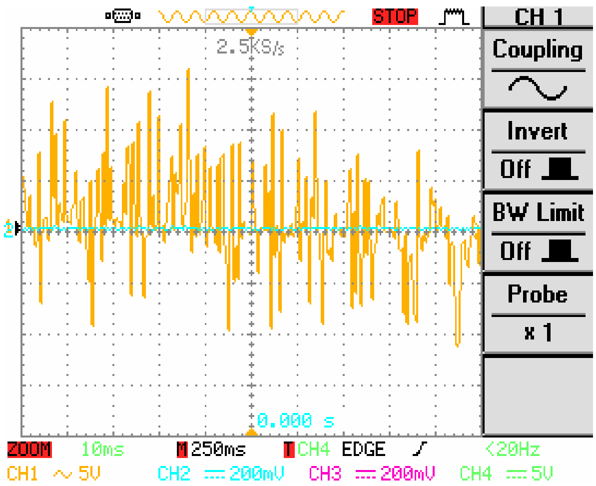

Fig. 2. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the operating mode to 10 Hz.

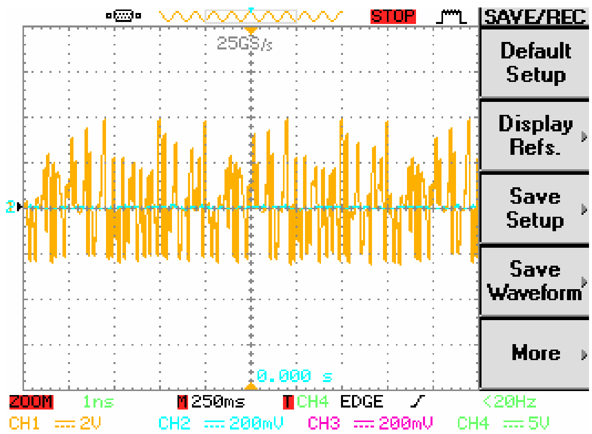

Fig 3. Voltage drop on a semiconductor device of a variable frequency converter operating to 10 Hz.

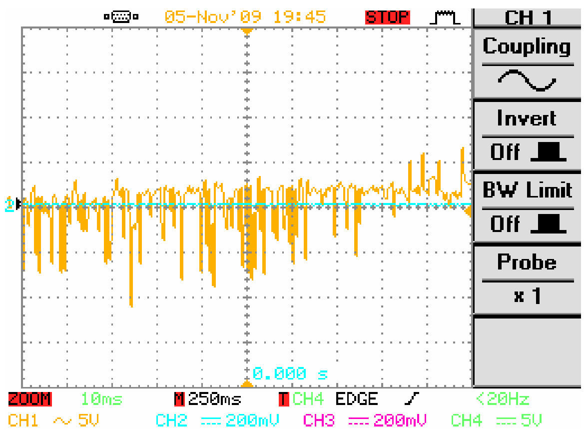

Fig 4. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the braking operation to 10 Hz.

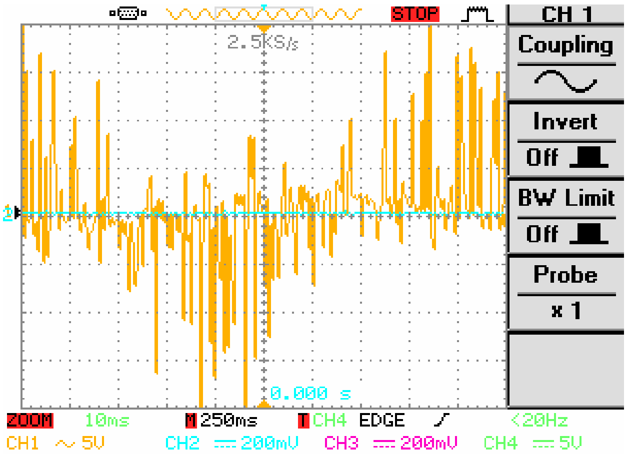

Fig. 5. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the operating mode to 20 Hz.

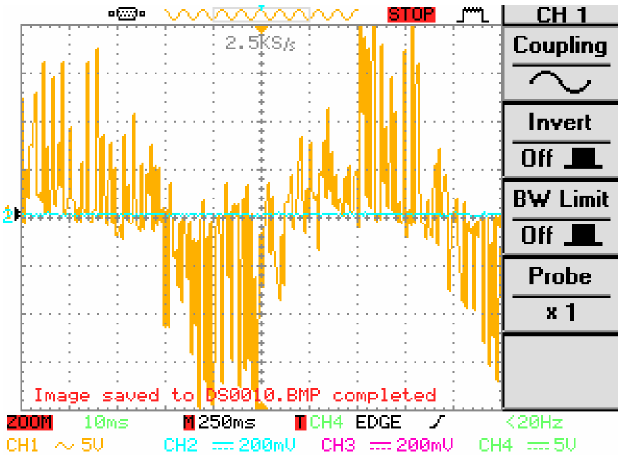

Fig. 6. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the operating mode to 30 Hz.

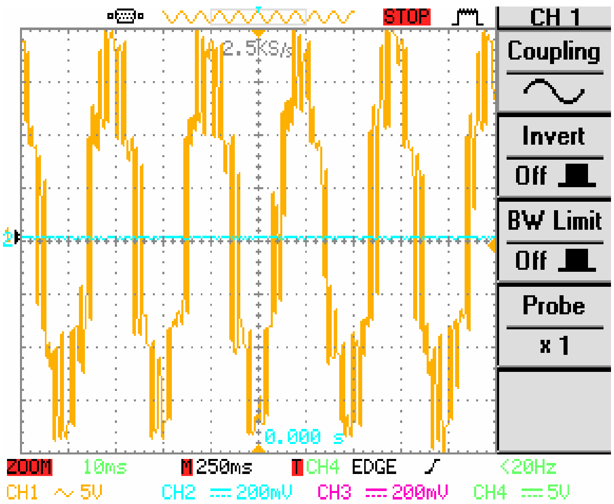

Fig. 7. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the operating mode to 50 Hz.

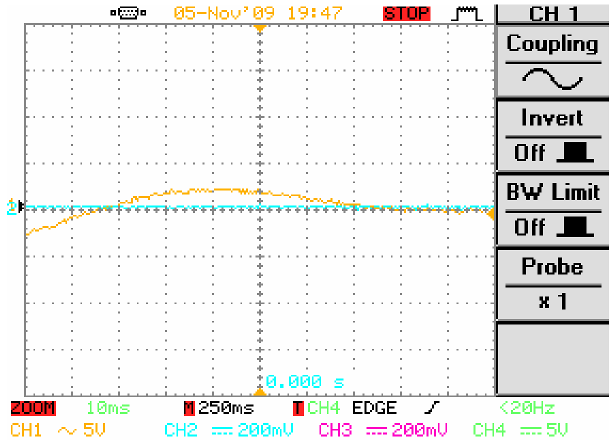

Fig 8. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the braking operation to 20 Hz.

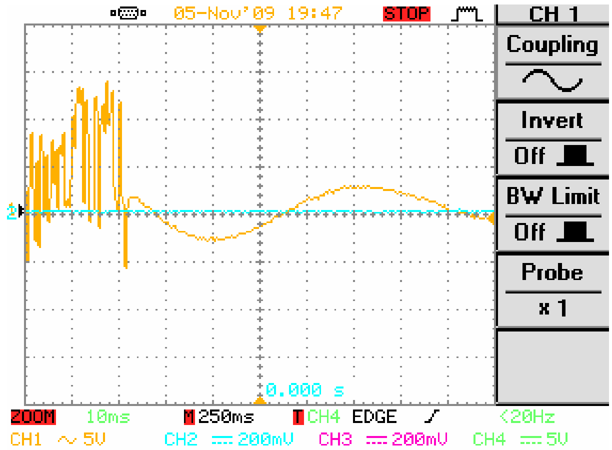

Fig 9. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the braking operation to 30 Hz.

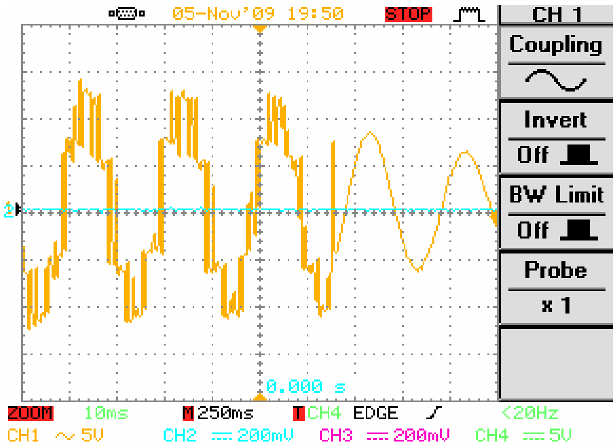

Fig 10. Voltage forms at the terminals of an induction motor ordered with a variable frequency converter in the braking operation to 50 Hz.

It requires that non-sensor scheme have easy and flexible implementation and can be applicable to most drive the same kind, without modifications in the structure of machines or additional installation systems.

Accuracy must be less than 0.5 revolutions per minute for the detection of speed, while for field orientation control schemes usually requires a resolution of 8 bits (10 24 ') and 16 bits for servo control of motion. This type of control can be achieved with a frequency converter like Fig.11.

Basic speed range of 1:100 to 1:150 should be provided for minimum stator frequency, 1 Hz level, low torque and reliable control for zero speed. Such performance is currently offered by existing schemes non-sensor (fig.11), while improving accuracy and effective active operation zero stator frequency are goals that are still growing.

Modeling and simulation non-sensor estimate schemes of speed in low - medium performance drives rotor frequency estimation allows a calculation about the f.e.m., which is defined as a change in time of rotor flux. The f.e.m. answer is calculated from current and voltage signals.

Rotor frequency estimator can be used in a drive system controlled by a low frequency filter. This filter is inserted to avoid stability problems, but, unfortunately, reduces the system dynamic performance.

In high performance drives, field oriented control can be obtained by calculating the rotor flux. It can be expected, in turn, the current and terminal voltage. In a speed non-sensor scheme, signal speed can be obtained also through technical estimates. According to the model approach the stator voltage, stator flux is estimated by integrating the stator voltage, after withdrawal of fall of tension on the stator resistance:

$$\lambda_{qds} = \int \left(v_{qds} - R_s i_{qds} \right) dt \qquad (1)$$

It is calculated rotor flux by highlighting the stator and rotor leakage reactance. With all that is good behavior on almost the entire range of speed, flux estimates obtained with the above expression is affected, especially at low frequencies: digital approximation errors, disturbances, measurement of voltage, current deviation, mistuning of parameters, etc.

Another method for flux estimating is to use a separate flux estimate, derived from rotor current model:

$$\lambda_{qdr} = \frac{L_m}{\tau_r \left(p + \frac{1}{\tau_r} - j\omega_r \right)} i_{qds} \qquad (2)$$

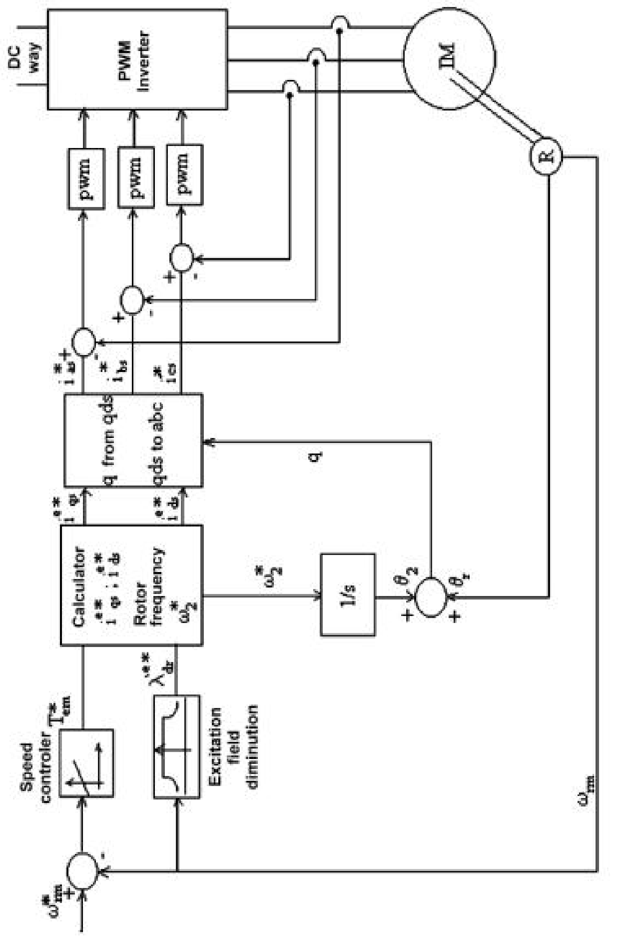

Fig.11. Command and indirect control of induction machine with a PWM frequency converter by field orientation with position and speed transducer incorporated

The two methods are used together to estimate the rotor speed. The calculation of errors in estimates of stator and rotor flux models, followed by minimizing the error rate evaluation may be forced to converge to its true value.

The stator serves as a reference, while the rotor model has adjustable parameters that can be forced to produce the same vector as that of runner flow reference model.

Thus, we perform an adaptive control system where the adjustment mechanism may be a simple PI controller or a more complicated algorithm based on Lyapunov criterion or even the logic of diffuse. But such sophisticated techniques can prevent errors introduced by these non-sensor schemes.

The two models above are, in fact, two "surface-flow" based on schemes which seek to identify flux and speed simultaneously.

Variants of this scheme are practical multiple, since it is one of the most interesting research topics in recent years in the field. The rotor can be used to estimate the speed or, as proposed, for estimating torque. Later, the obtained torque can be used to determine speed estimates required by the rotor model; a non-linear nature observer complete the observers of sliding, non-linear observers of reduced order etc. Extended Kallman filters are able to provide additional techniques more acceptable performance as the mechanical speed reduces.

Estimated speed can be obtained, also thru determinations of the effects of the magnetic machine.

The slots of the rotor magnetic core produce harmonics (depending on speed) that can be found in the stator current waveform. Distortions are due to rotor slots or its eccentricity or imbalance caused by the driver, leaving the field or power asymmetries of the rotor.

The determined characteristics provide a set of information allowing the derivation of rotor speed of the fundamental harmonic frequency of stator voltage. Speed detection algorithms are based on digital filtering and sampling, followed by spectral estimation to reduce the time of sampling as the accuracy required, followed by reporting the rotor speed.

Higher rotor harmonics modulate stator flux drops with a frequency proportional to the rotor speed. The parameters read heads placed particular stator windings, higher harmonic signals can be separated by a fundamental f.e.m., because they distinguish the change in frequency, while the third order voltage components are deleted.

The suppression of harmonic components - other than the fundamental harmonic - an adaptive filter bandwidth, the speed signal is obtained proportional to their frequencies.

Accuracy of detected speed is bad because of the limited information on the winding rotor, which is leading to a moderate speed dynamic control but maintaining a considerable accuracy even at a high speed.

Methods based on test signal injection on a machine phase are recommended for applications with low speeds. The signal contains information of rotor position and it may be directly or inversely proportional to the rotor position.

Modulation techniques of machine parameters (phase, frequency or amplitude modulated position) are in this class and all are based on injecting a voltage-carrying high-frequency sinusoidal form.

Each of the carrier signal parameters change with changing the instantaneous value of information obtained after applying a strategy for determining which allows deduction of the initial signal modulated signal.

With all that is insensitive to interference by switching intervals, these methods are not recommended in schemes with a large number of electronic circuits and microprocessors in control circuits. This leads to limiting the flexibility of their control. All additional methods of reading the position, based on inductance variation in terms of the rotor position, involving a modified switching inverter.

Current regulator may extend the period of transition through zero of phase current by decupling both switches on the same stage. During such an extended period zero crossing, the other two phase currents are controlled as a constant reference current. The induced voltage in no leading phase contains information about that phase inductance and can be used effectively to estimate rotor position.

It is very important to mention – among other techniques – that the method based on measuring the current in the hysteresis controller is used to obtain information on the inductance that is contained in current relationship:

- Method based on reconstruction of rotor position of stator currents and voltages;
- Method based on indirect detection by measuring flow in the line of reactants.

Techniques based on observation, on measurement of third order harmonic voltage phase, on the methods of control slipping induction machine are made with good accuracy, but involves a calculation difficult requiring faster microprocessors.

It should be noted and that most non-sensor schemes currently adopted is based on simplistic considerations (such as saturation neglecting and neglecting the effects of time and temperature variation on inductance, the inductance unbalance perfect in connection with the rotor position and geometry of the tooth-shaped poles, stator and rotor).

Finally, should be taken into consideration also the influence in the iron losses on algorithms instituting the position.

4. Methods and levels of modeling

The multiple levels of modeling (which are available to describe static converters) will further detail some.

The first method for the mathematical model is linked to the process of switching semiconductor inside the static converter, with the introduction of the control algorithm may be achieved practical.

These types of models should be simulated depending on time with small steps to be able to see how the converter can generate wave forms of current and voltage at the terminals of electric machine regardless of its operational arrangements.

It should also be considered as the input signal to the device training pulse u_c command for changes to the switch. To this end, there are several models of semiconductor that can be developed, namely the idealized assumption of ideal semiconductor switch to a real representation of physical behavior, described by equations of the internal converter [4].

The second method introduces the mathematical model simplifications on static converter using a description of waveform output with analytical functions between discontinuities introduced by the converter and electrical machines.

This technique allows the study of harmonic effects on transient and mechanical processes of the machine during operation.

It required precise knowledge of component and operation of static power converters to be able to describe the functions of time out, taking into account the signal form detached u_c.

In the third method is compared with the simplest model of the converter power using a description with one variable gain K and a time constant T, which can also be variable.

This last method does not introduce any harmonic, but show the entire command and control of mechanical and electrical drive system.

The first two methods are known as “micro-models” of electric drive systems while the last method is called “macro-model” [5], [6], [7].

5. Basic Electrical Diagrams Vector Control of an Induction Machine

Induction machine is loaded with a working machine with a full load inertia J and the coefficient of friction f.

Stator of electric machine is connected to a three phase VSI inverter associated with a three phase rectifier. In Fig.12 is presented the method that can run simulating a vector controlled induction electric machines.

Electric drive system is powered by an electric network with a highly inductive and the current progress in the circuit of rectifier and inverter, we consider capacitive filter element.

Compared to the above analysis is to determine the frequency converter circuit model intermediate DC voltage constant [8].

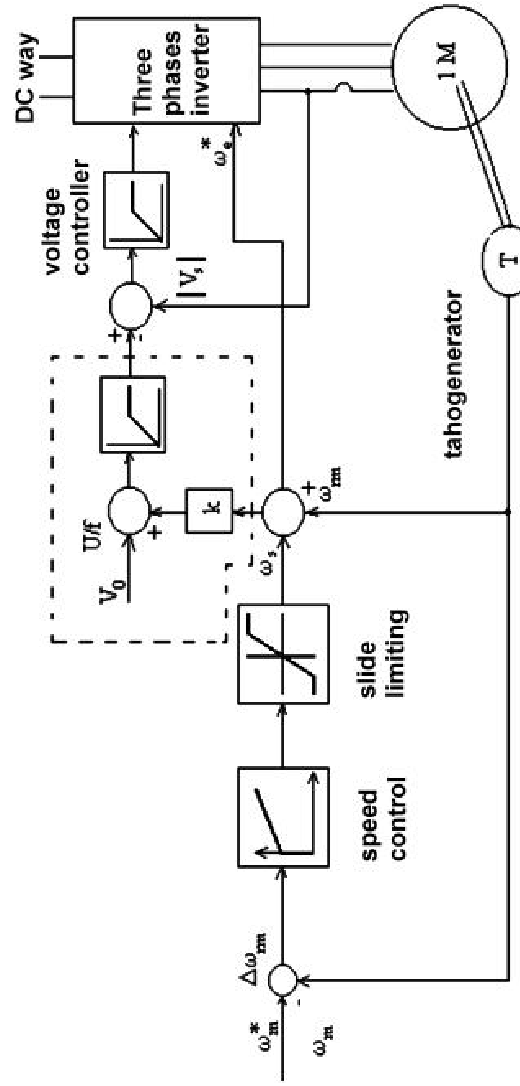

Fig. 12. Basic electrical diagram and block diagram for a drive of an induction machine ordered by a frequency converter

Command and control circuits have been reduced from continuous time functions to complex linear functions. The controller torque (current) type is full - in proportion to the current prescribing limited to a loop with a positive reaction for flow control in electric machine.

Current loops are carried out by using hysteresis controllers that can execute commands most current independent electric drive systems encountered in practice.

This last feature may be different from other industrial applications such as a simple hysteresis controller leads to tensions within the switchable variable frequency inverter and applied in the winding machine.

In most modern electric drive system control is implemented using digital microprocessors that can be simulated by the same wording as analog controllers, but with different equations and the selectors (switches sampling) and supports instead of Laplace functions comprehensive s [9].

In the proposed scheme, the regulator comes ω_{sref} speed transmission, a convenience factor and voltage depends on the function V_s Indus reducing field (field-weakening function) both constant torque and constant power schemes on.

Speed regulator is equipped with a dynamic limiter is included to provide anti-windup for reference output torque, while the reference current is also limited as to correspond with the conversion of power.

Park transformation is related to switching currents of phase currents using as input the torque (torque currents) and currents flow and also ω_{ref} reference position. In all schemes, it is assumed that the machine parameters are constant and hence will not depend on temperature or level of saturation [10].

Current regulators use current reference and the processed actual values are taken as input two phase currents (current actual). The output of pulses is the trainer of command sequences (primer and extinction) of the semiconductor.

In the charts below (Fig.13.) are represented variation of voltage and current variation from connecting to the network through a drive [11], [12].

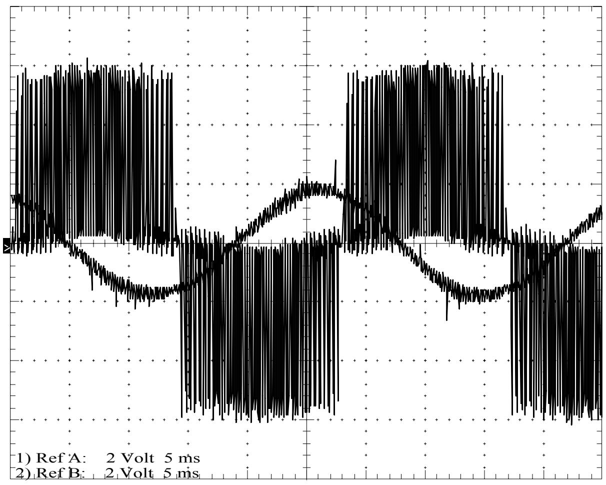

Fig. 13. Waveforms of voltage and current time according to the output terminals of the frequency converter

6. Macro-Model Drives System for Electric Induction Machine

To define a macro-model for driving a vector controlled induction machines, it is necessary to remove all sequences released in the process of switching power converters and suppose that perform the functions without any error.

If the proposed VSI is controlled by DC, which means that we have the stator currents, equivalent to the reference currents give the control block diagram.

To perform this task is of interest to remove the stator transient processes and to relate measurements to measurements of induction machine rotor and the mechanical transient processes taking into account the electromagnetic torque equations of the machine.

Electric machine is described by the following equation [13]:

$$v'_{dr} = r'_r \cdot i'^e_{dr} + p \cdot \lambda'^e_{dr} - (\omega_e - \omega_r) \cdot \lambda'^e_{qr} \quad (1)$$

where:

$$v'^e_{dr} = 0, \quad p \cdot \lambda'^e_{dr} = 0, \quad \lambda'^e_{qr} = 0 \quad (2)$$

and

$$i'^e_{dr} = 0, \; X'^e_{dr} = L_m i^e_{ds} \quad (3)$$

$$T_{em} = K_a \Phi(I_f) I_a \quad (4)$$

$$J \frac{d\omega_{rm}}{dt} = T_{em} + T_{mem} - T_{damp} \quad (5)$$

(1),(2),(3) = rotor equations;
(2) = torque equation;
(3) = mechanical equation.

In the proposed scheme, power regulators, voltage, speed and torque although different in role and structure were represented in the same way as the basic circuit model. The only difference is that electric machine model represented in Fig. 14, reflects primarily the simplifications presented over Fig 12.

It is obvious that such a block diagram can be simulated by a control method such as dedicated software (MATLAB, MATRIX-X).

However, it can be adapted to other control systems, allowing integration of equations (1), (2), (3),(4),(5) equivalent nonlinear differential algebraic functions and linear equations (in our case in the complex simplified).

It emphasized that the mathematical functions of the control system are very close to the basic scheme and only the machine models and power converter electronics are changed into blocks of nonlinear equations including rotor torque expressions and of course, mechanical model played a set of differential equations linear or nonlinear.

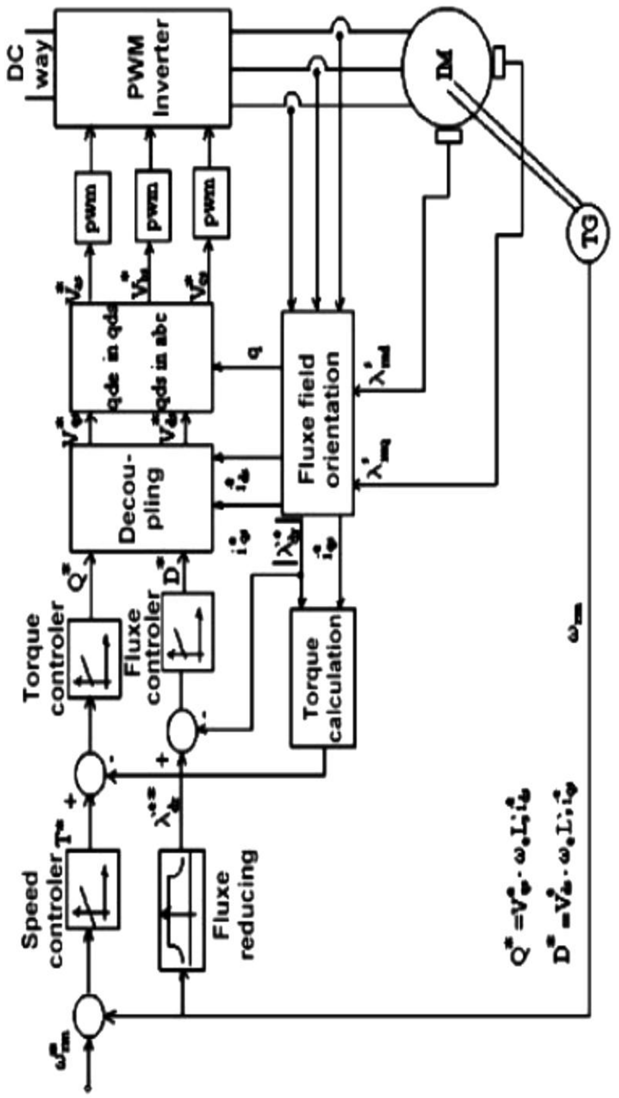

Fig. 14. Block diagram representation of the macro-model of vector controlled induction machines

The nonlinear block can be modified and turned into a subsystem, with representation by block diagrams.
This option is recommended to use control-oriented programs with libraries of predefined blocks [14].

7. Micro-Model of Electric Systems Drive Machine Induction

When it is necessary to simulate the complete control of the converter algorithms for power, the previous model is not suitable and should be extended. In this case, it be defined micro-model power converter topology and include the semiconductor switch.

The low level of power converter model involving the replacement of each semiconductor with linear elements is shown below (Fig.15).

The induction machine is introduced in topology power converters using voltage-controlled sources and possibly a equivalent electrical circuit for the mechanical load. Thus, control functions are based on block diagram defined in the macro-model, which is complemented by control schemes related to the power converter and induction machine model. These features are not represented in micro-model scheme because they have developed special features included in the simulation.

This approach requires a mixed representation of the power grid and is also on complicated control functions and is not a feature included in many programs.

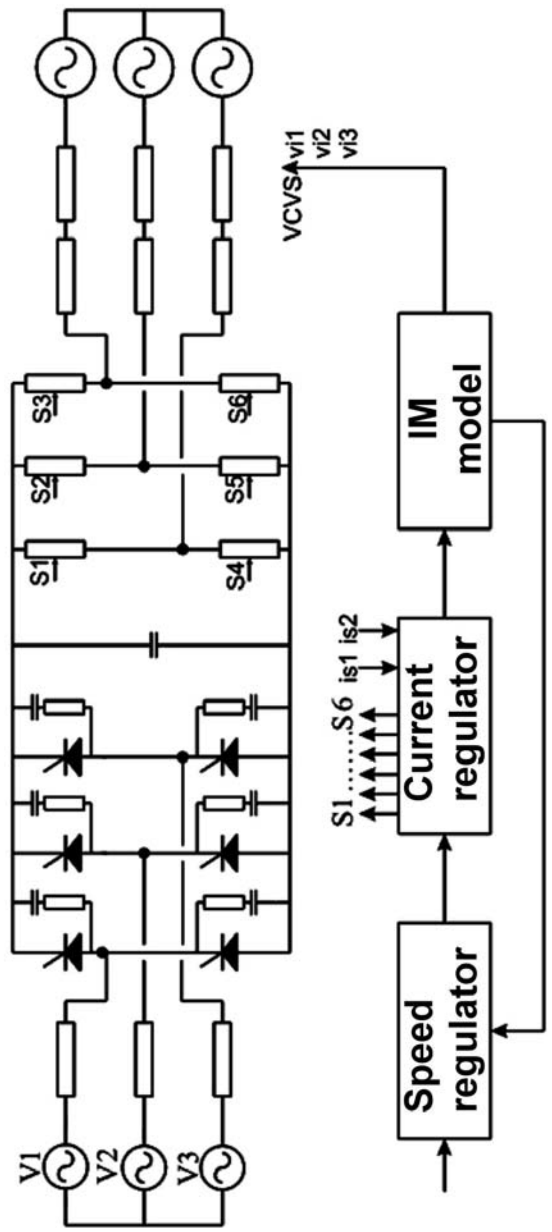

Fig. 15. Simplified electric scheme for the micro-model of vector controlled induction machine

The electricity grid, all diodes are associated with groups of RC surge protection to remove numerical oscillations.

Proposed power converter has two stages (phases) and to remove simulation processes extended, is necessary to initialize variables input power and rotor currents and capacitive voltages of the intermediate circuit [15].

Currents control algorithms defined in the current regulator can be achieved by analog or digital functions (in fact are made by two-phase currents as input and output signals and control the power semiconductor gate).

The induction machine can develop and using internal tension control voltage sources as Fig.16.

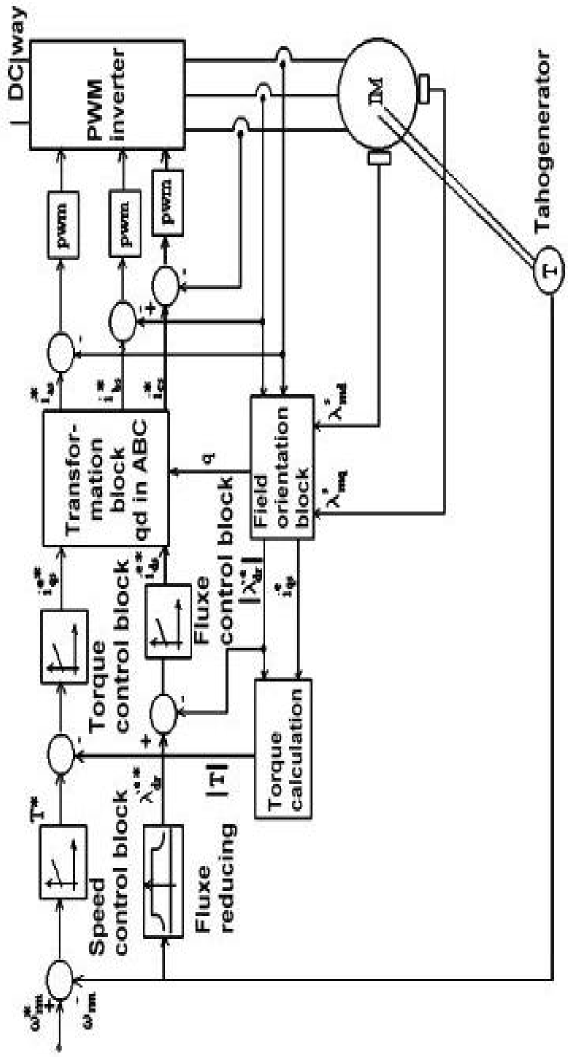

Fig.16. Order 132 KW Induction machine by controlling the voltage sources

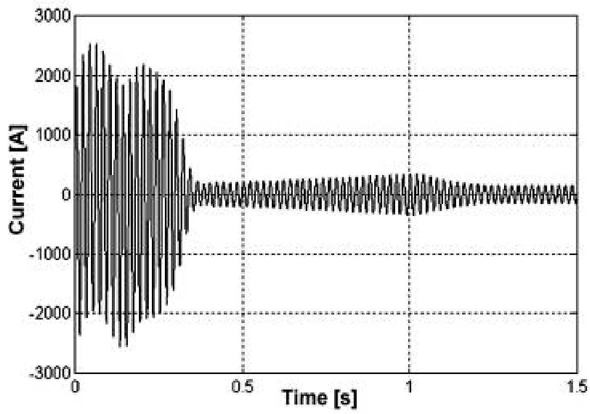

Fig.17. Current variation from 132 kW asynchronous machine by the power source control variable torque

8. Conclusions

The article provides a uniform treatment of issues relating to implementation, analysis, simulation and control systems for electric drives of high power induction machines emphasizing the practical application in heavy industry particularly in metallurgy where prevailing adjustable drives of all types.

Very rapid development of asynchronous motors with variable speed drives and electric power conversion systems has made the technical development in the field to achieve unprecedented.

Nowadays, the share of asynchronous machines is becoming more and more, this increased acting in detriment of DC current machines using in industrial processes and in variable speed drives even in terms of saving electricity.

Technological processes of high precision and accuracy, have spurred the development of power electronics devices, regulating and control systems at rates comparable, we could say, that of computers and consumer goods, so what's new in this field have began to occur within very short time.

Adjustable electric drives induction motors are driven, in addition to energy savings, increased quality and reliability of finished products and savings schemes to pay for industrial operators.

Most important factor which allowed the shareholders AC technology to increase quickly the market is the evolution of several closely interrelated areas such as semiconductor devices of power electronics, various types of frequency converters, microprocessors, advanced command and control techniques etc.

The impact of advanced strategies and unconventional command and control in electric drives development was examined in this work by giving more attention to non-sensor strategies and issues estimate in order to identify functional parameters of electric machines by elaborate systems modeling and simulation systems.

Simulation of systems vector controlled electric drive remains a very complex problem because we have not found any specific program able to consider all aspects and the constructive and functional features of such a system. The best way to achieve simulation is to use general programs that have the opportunity to shape each set of control system components and the electric machine using only the specific features of the program.

In this article, as recommended by the project to develop and apply models for most drive systems using the equivalent electrical network or using the representation scheme of control and regulation through schemes and block diagrams can highlight the complex variables and finally the variation of time functions describing the machine and its operation.

However, the solution is often complicated because we have always carried schemes traversing parts or electric drive systems are available simulation programs dedicated to them. It is generally considered that in future programming languages will be possible with a high-level simulation systems operated as if there analog integrated circuits with AHDL (Analog High-level Definition Language).

Proposed methods are very good because many subsystems (electronic blocks) and are described as mathematical functions are needed in different ways, each corresponding to a particular characteristic. For example we can consider characteristic functions to simulate an adjustment block, a block protection, surveillance, control or some blocks of training and command pulse amplification.

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