

Control systems for high power Induction machines

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Abstract: - Issues orders in a power drives should be viewed in a more complex and different from how do Electronics engineers of control systems. It is best to look at the control system as a set of black boxes cascading with mathematical models defined on a system of alternating current application. Even if it takes a vector control strategy and obtain a similar behavior to that of a DC motor, many problems remain unresolved because of the particular structures of the converter and the motor due to their interaction with load and source. This paper recommends to the experts and to the users of command systems with frequency converters the usage of speed command and position command to the variable frequency drives. There are analyzed also the commands without position transducers, speed transducers or flux transducers based on approximately results. There are included also logic elements and it's proves how the velocity evolution of the technology command of electrical machines in different branches of the world economy finds a specific field in modern electrical applications [10]. Powerful microprocessors and DSP (Digital Signal Processor) are able not only to directly calculate the time of ignition of a power semiconductor circuit such as the bridge phase, operating on frequency of feed, but also perform other important tasks in applications industrial automation as well as startup and shutdown sequencing, self monitoring and diagnosing faults. The most important contribution is that power chips have opened new frontiers in implementing sophisticated control systems for electric drives.

Key-Words: - Electrical commands, scalar control, vector control, mechanical characteristics, transducers control, direct control approach, indirect control approach, harmonic unit, test signal injection method.

1 Introduction

The commands of AC motors has a great impact in many technical applications like transportations, home devices or industrial automations, and recently even in recherche studies. The frequency regulation advantages can't be full exploited without an appropriate control strategy.

Torque pulsations, the frequency harmonic content, optimize efficiency, change parameters, response times etc. are just some of the many issues to be resolved by an application engineer and control strategies that can help solve. Another major factor that helped shareholders AC technology drive to grow rapidly and is closely connected to issues of control represents the development of microprocessors [12].

The evolution of power electronic semiconductor devices to the default static frequency converter is a key point in the evolution of advanced applications [4], [5].

The existence of a system capable of generating energy with a frequency adjustable machine allowed AC to reach a new horizon in the field for research and technical applications, a horizon probably completely unexploited today [3].

The inherent advantages in the operation of adjusting the frequency can not be fully exploited without the adoption of an appropriate control strategy, which is essential in characterizing the overall performance of a system [6], [7].

In Fig.1 are presented specific strategies [9] for control of induction machines.

Command strategies ensure a correct and efficient operation to drives [13]. During normal

operation the nominal values of the motors and inverter must be met by ensuring that motor operation is limited in operation domain.

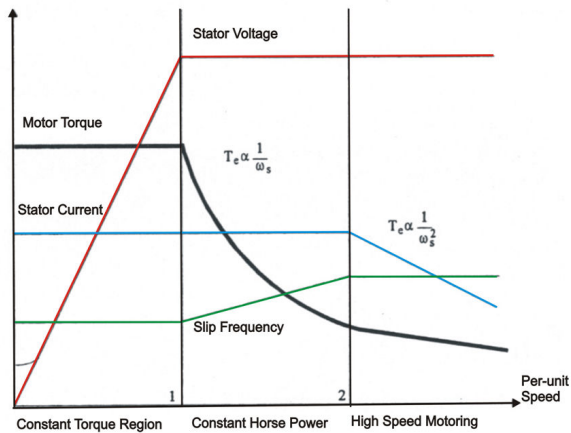


Fig.1 – Command specific strategies for induction machines. The variations of voltage, current, frequency sliding and torque according to induction motor speed.

Control problems to an electric machine should be regarded in a different way to research how to make control systems specialists [9]. Preferably be considered as a set of black boxes cascade having defined mathematical models. The command system in AC is complex and multivariate nonlinear parameters, which can hardly be described on a single analytical model.

Even if it adopts a vector control strategy and it obtains a similar behavior to that of a DC motor, many problems remain unsolved due to structures of private AC machine and converter and interaction with the source and load with different characters and behavior [12]. The torque pulsations, the harmonic frequency, variation of parameters, the response time is only few of the many issues that must solve a specialist and that control strategies can help solve.

Another major factor which contributed to the technological advance commands in alternating current and is closely related to control issues is the evolution microprocessors of computers and specialized software. Powerful microprocessors such as DSP (Digital Signal Processor) are able not only to directly calculate the time of ignition of power semiconductor in a circuit of a three phase bridge operating frequency on power supply frequency, but also to fulfill other important tasks in automation applications industrial as well sequential startup and shutdown, auto tests, deficiencies in monitoring and diagnosis during the operation.

The most important contribution of power microprocessors is that it has opened new frontiers

in the application of sophisticated control strategies in terms of electrical systems commands [4].

In the supply lines and electric drive, electric induction machines of metallurgy start from a few kW up to several hundred kW. This range of power makes induction motor is used primarily. For the reel, and means roller or rolling mill but also for electric drives of the utility of metallurgy, power range can extend even up to 9 MW.

For applications in metallurgy, motor characteristics must be such so that they can avoid the large rated current values require larger the inverter and increased costs of investment. Figure 2 shows an example of application type reel (envelopes) with characteristic of load figure with red line. Basic speed of this application is 300 rpm. For these types of loads it is compared two motor options, considering the impact of overload requirement to maximum motor speed. The mechanical characteristics of the motor represented in blue are the standard motor.

Both options are for a motor with eight (8) pole, with a torque represented on the same axis. Special Option Blue is the most recommended combining better torque load required. As torque decreases very rapidly, this could be maintained only if the maximum speed of the mechanism involved does not exceed 900 rpm, taking into account the limit appropriate overload.

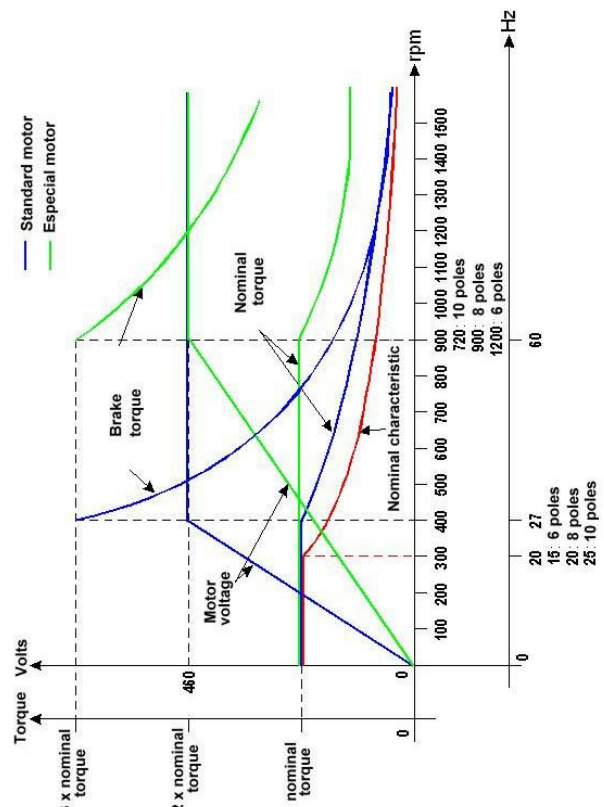


Fig. 2 Output characteristics of the actuator of a envelopes

Great advantage for this choice is the classification of motor rated current that occurs due to load and achieves nominal voltage of 480 V at a slower speed than synchronous. This standard option should be selected if maximum motor speed or pump required more than 1500 rpm. Very important to protect the motor and unit sizing of inverters is the choice and sizing of the reactance [8].

Inverters supplying units feed a voltage with voltage amplitude of the intermediate circuit. Considering that it is used high frequency and type IGBT semiconductor devices, when voltage will increase to values of approximately 10 kV high, causing the insulation and compatibility motor conversion.

This request is more obvious when the distance between the inverter units and electrical machines is significant and the power cables default length is large and small sections.

Great length cables are high capacitive loads and lead to worsening of commutation and therefore it is necessary to increase the inverter. Cables also increase the energy stored in Corona effect which is very harmful to the motor installation and prompted us to take measures to introduce filter du / dt according to Figure 3.

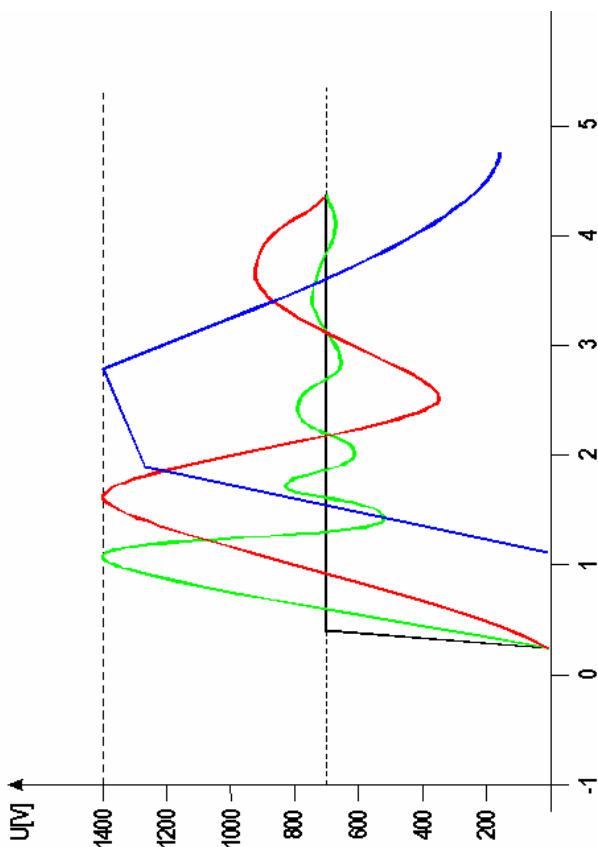


Fig.3 Voltage at motor terminals, depending on cable length

Cable length 20 m can generate a significant voltage peak for motor terminals, leading to a phenomenon reflecting the blood by about 65% higher than the voltage of intermediate circuit. The lengths of over 50 m, maximum voltage increases slowly according to cable length and easy to approach the theoretical maximum, twice the voltage of intermediate circuit ($2U_d$).

As cable lengths increase, the reflection wave power generated (between motor and control unit) results in a longer transition period until the motor terminals will reach a voltage equal to that of the intermediate DC circuit. All motors manufacturers have taken steps to prevent effects due to transition Corona which is an exponential increase and the length power cord with significant consequences dielectric insulation breakthrough production engine (Figure 4).

AC motors fed by inverters were analyzed taking into account that the insulation should be able to withstand shocks caused by IGBT controls and cable lengths up to 300m without filters du / dt .

If output reactances are designed in accordance with the lengths of wire, inverters can function properly without further guidance. Output reactance offset capacitive load existing supply network and the existing capacitive output current limiting, reducing voltages and thus indirectly helping the motor. Switching frequency IGBT orders out advantages and disadvantages they offer presents.

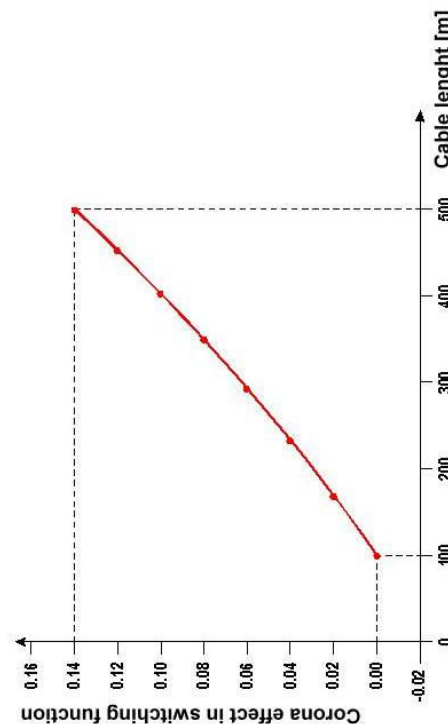


Fig.4 Corona effect transition by cable energy

Output voltage pulse shaped blocks and generates a high frequency current is in the form of pulses. In situations where there is high capacity it will leak at the table between the cable, motor and belt ground.

As a result circuit interruption and voltage drop can interfere with control signals from blocks of small signals. The most effective way to avoid this interference can be achieved by separating the control signals and signals produced by the additional capacity of cable. This requires that in order cabinets to meet a minimum distance of 20 cm between the control and power blocks and 60 cm between power blocs.

2 Basic techniques for control of AC machines

Positive response that the market gave shareholders the application of variable frequency in many areas is due mainly guarantee that electric drive is the best solution in at least two classes of application. The first class is required with a fair and efficient management of electricity and that can achieve high converting applications for energy, normally at constant speed in variable speed systems driven by electric motors controlled by AC frequency (rolling mills or large machine tools) [16], [17].

Increased efficiency can be 20-30% higher compared with the constant speed systems, meaning a major economic power over a short period, which take into account additional costs due to electric power equipment. The energy savings were so convincing that the drives for variable speed pumps and fans are now the most popular electric drives and there are easily purchased.

A second class of applications includes industrial automation. Here, the need for easy integration and reliable performance of the execution element (power command) in the automatically process find an appropriate response to shareholders very dynamic performance of variable frequency [20]. The result is that an increasing number of hydraulic and pneumatic automatic systems are replaced today by the drive which provides speed and higher precision control and a better power / weight ratio, robustness and ease in maintenance.

The two classes of electrical drives have control diagrams very different. Variable speed drives for energy saving energy consuming are equipped with a constant voltage / frequency control of open loop, while drives of high dynamic performance are made with a more complex control, usually involving a vector control for independent regulation of torque

and flux, including field weakening mode for high speed commands [4], [5].

The simple and cheap method of controlling the speed of induction motor, obtained by keeping constant the ratio U / f , has been extensively studied and applied [18].

There are introduced several improvements in the control scheme to overcome some of its significant disadvantages. Offsetting the fall in voltage stator resistance can be achieved by implementing a characteristic voltage / frequency in which the tension is increased above its nominal value out of the proportionality of the frequency at lower values. Voltage regulation may be proportional to the magnitude of stator current or (in alternative) to the phase component of stator current [19].

Current control in closed loop during the transfer operation has been introduced to solve the problem overcurrent value trigger, while slip adjusting is usually added to compensate for the fall speed due to load. Although drive performance is improved by the previous operations, the value of the constant voltage / frequency ratio remains still a difficult problem because it can not be held the air-gap flux to a constant value corresponding to a fixed point of operation.

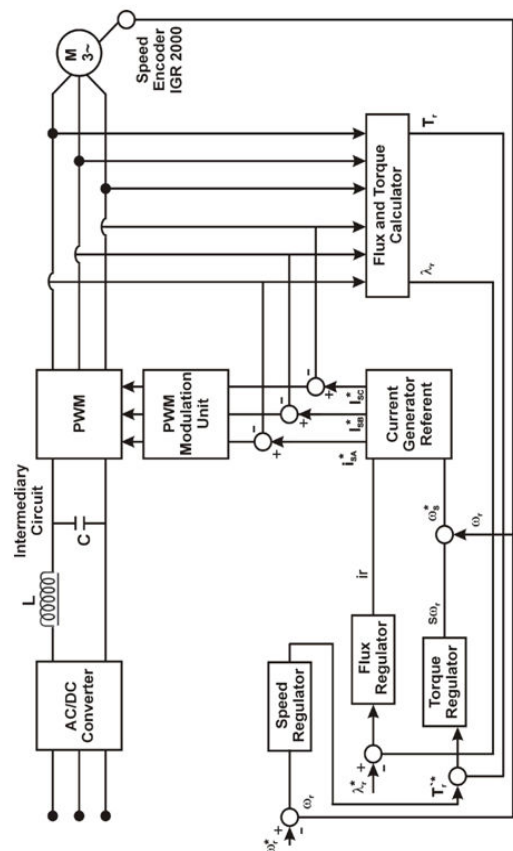


Fig.5 – Torque control of induction motor using decoupled scalar flux method

In the presence of variations of this report (due to temperature and / or saturation) the response can disrupts in a different operation point. Scalar decoupled control was introduced to enable a control scheme to provide an acceptable performance when good dynamic performances of the application are demanded.

Such a scheme (such as in Fig.5) is based on a separate flux and torque control of the motor, but the tensions and currents must be previous measured to calculate the flux and torque sizes.

Vector control system is the structure of any drive system operating in AC high performance. For now, it suffices to recall that the vector control may allow the motor torque and flux are controlled independently, in accordance with the real variations, designing in two stator current reactive components in a field of reference that rotates with the synchronous rotors flux. In this way, motor torque is directly controlled by the „q” current component and flux through the „d” component. To implement the vector control is necessary to measure and to calculate both the magnitude and position of the rotor’s flux [15].

These problems are specific to both induction machines and synchronous machines [19]. However, while the synchronous machines flow angle rotors can be detected as a size mechanical precision, because the rotor’s flux is in synchronism with the motor axis, it becomes impossible for an induction motor (asynchronous), since the frequency of different rotors frequency of air-gap (slipping occurs) [1], [14].

We adopt two strategies that will define two different types of vector control:

1. In the „direct control” approach, the vector of rotor’s flux is produced directly using detectors such as flux coils or Hall sensors located in the stator slots for the measurement of air-gap flux. There are also measured stator voltages and stator currents to obtain the voltage change over time due to stator flux. To the direct methods we have known dispersion inductances to calculate rotor’s flux. The main shortcomings of this method occurs at low frequency, where both need to assess the fall voltage stator resistance and difficulties related to the tension - to get the flux signal – conducts to a very difficult definition of flux vector. As a recommendation, direct method does not apply to low speeds;

2. Indirect method. It determines the position of rotor’s flux by adding to the rotor position the position corresponding to the slip, calculated as an integral function of frequency sliding. In turn, this value is reconstituted from the values that belong to

the order of the two components of current using a mathematical model of the electric machine. Although most high performance drives is based on indirect vector control are recorded and some drawbacks.

The reconstitution of reference values of currents and sliding frequency is not a complex action. These values are determinate from the characteristics of the motors.

The accuracy is much affected by the parameters of the motor used in the calculations, and if the rotor time constant is different to the value used in the calculation of the reference slip frequency, the correct orientation of the field can not be obtained because the dynamic response of the drive is corrupt. The calculations are influenced by variation of rotor resistance with temperature [2] and magnetic saturation influence.

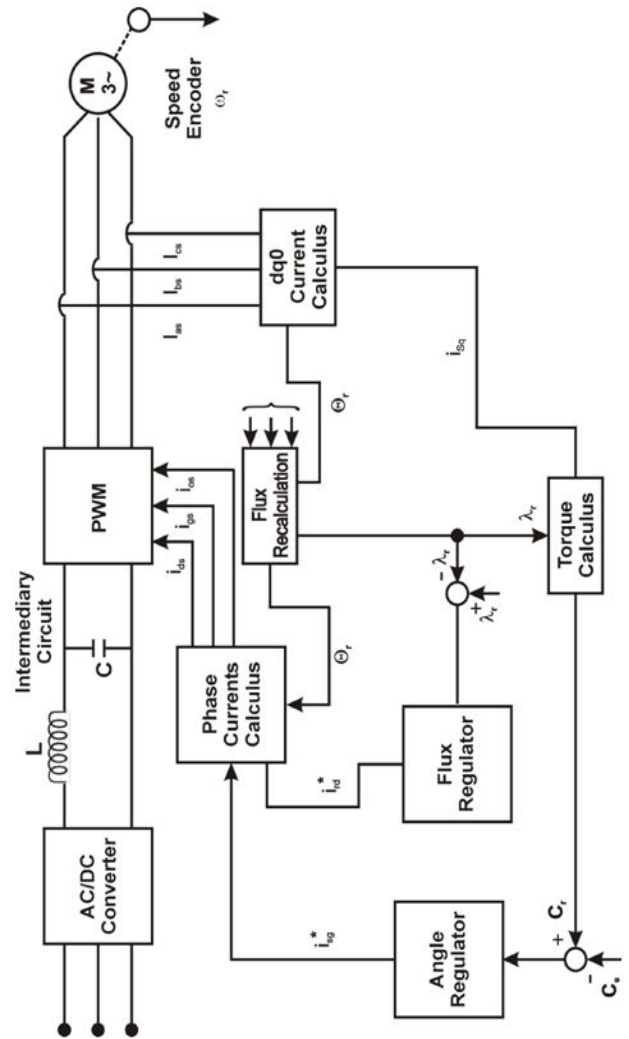


Fig.6 – The scheme of oriented directly control of the field

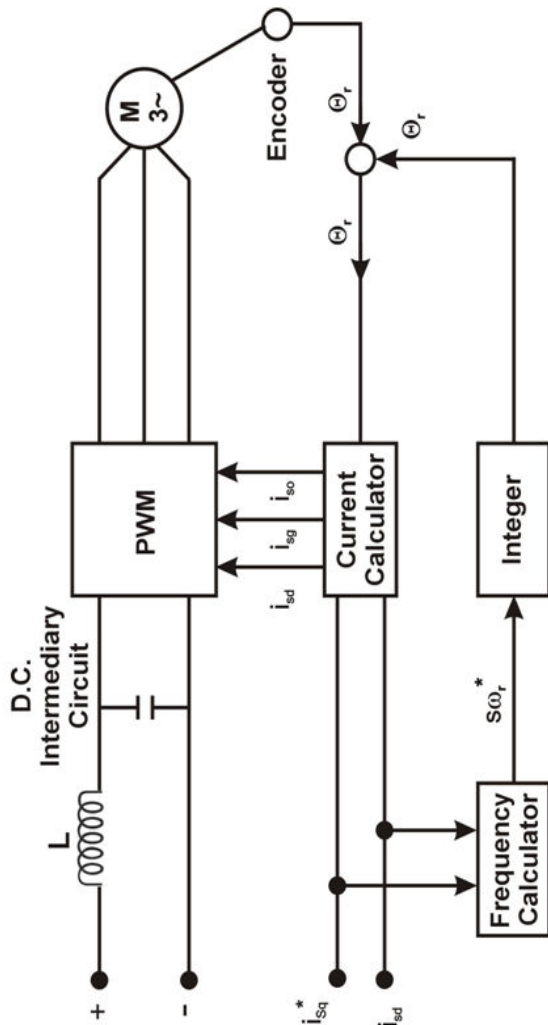


Fig.7 – The scheme of oriented indirectly control of the field.

Vector control accentuates the fact that will be resolved at least two problems, especially for indirect variant, for induction motor drives [8], (whichever has been applied successfully in high performance drive):

1. Simplifying or even eliminating any mechanical device used to detect speed tangential or angular.
2. Identifying electrical and mechanical parameters of the drive to set the controller parameters (for the initial drive for an arbitrary machine, and the granting of the control system for sophisticated applications).

3 Adjust AC vector controlled drives parameters

Study on induction machine control simulation shows that the indirect vector controls applications, is an

essential requirement and determination of rotor resistance machine (or rotor time constant) [11].

Although so far have been conducted many studies, the question of continue according has not been resolved satisfactorily because of shortcomings in control systems due to their complexity.

Once the indirect vector control has been a wide use only high performance and the servo drives for special purposes, but also in a number of low-cost applications, linear estimation of parameters for the grant is still a crucial issue, having several important features to satisfy. A proper award should be inexpensive and non time consumption, and not require additional sensors compared to those required under the original scheme of indirect vector control, avoiding thus, complexity and costs increased. Also, the functions should be self-granted that they ensure automatic and accurate determination of amplification and sliding both during normal operation - including a low speed, - and before the start operation.

To achieve full automation, award system would require a motor or controller there restrictive external mechanical means such as locking the motor. Finally, normal motor operating functions should be disturbed by the procedure of testing and adjusting the amplification and sliding (when injected into the motor test signals to identify time constant rotor).

Grant by injecting the test signal. Unfortunately, all methods considered for the award of vector controlled drives can meet only some of the above performance requirements, because they rely on the use of appropriate test signals. However, further improvements were possible by adjusting the properties of PWM inverter step by step and on-line. Next we present in detail one of these possibilities. Under this method the direct and indirect granting of a vector controlled drives can be obtained by using error rate effects due to a test signal injected on the baseline rotor flux value.

$$i_{qs}^* = \frac{T_e^*}{\frac{3}{2} \bar{p} \frac{L_m}{L_r} \lambda_{dr}^*} \tag{1}$$

$$\omega_s^* = \frac{L_r}{\tau_r^*} \frac{T_e^*}{\frac{3}{2} \bar{p} \lambda_{dr}^{*2}} \tag{2}$$

From the above equations can be deduced that if a superimpose pulsation (ripple) on low frequency sinusoidal reference rotor flux shaft torque produced will not change, which shows that the time constant rotor slip frequency controller is chosen

correctly. Otherwise, if is not correct, the couple will be different and will show oscillations. A simple and effective way to detect any conditions for granting poor observation error is speed or - even better - its integral, given respectively:

$$e_{\omega} = \omega_r^* - \omega_r \tag{3}$$

$$I_{e\omega} = \int e_{\omega} dt \tag{4}$$

Because the system works with a PI speed regulator, the above sizes are available and hence the two signals T_{ep}^* , T_{el}^* can be detected and is proportional to e_{ω} and respectively $I_{e\omega}$.

If the rotor time constant τ_r^* used in the amplification of slipping, torque pulsation will occur at the same frequency as the pulse flow will lead to impaired runner speed error and its integral (or signals corresponding entry regulators).

Pulse amplitude is the integral of speed error T_{el}^* by τ_r^* being loaded sinusoidal test signal as error signal from: $\tau_r^* : e_r = \tau_r - \tau_r^*$.

If this error is negative, the pulsation T_{el}^* of the signal is delayed to the test and if error is positive, the pulsation T_{el}^* is advanced to the test signal.

In conclusion, by calculating the amplitude and phase shift pulse T_{el}^* becomes possible to deduct an appropriate correction within the rotor time constant.

The granting automatic time constant adjustment is shown in Fig. 8.

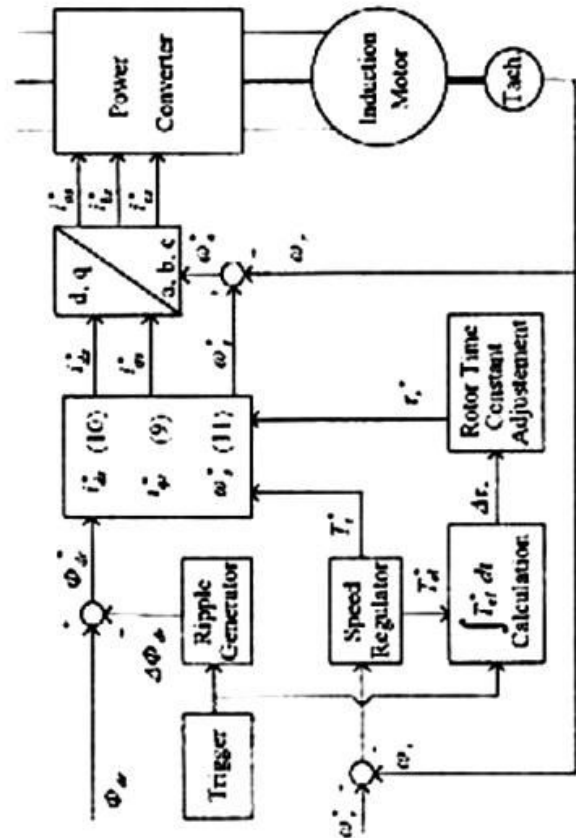


Figure 8. Adjusting the rotor time constant by injecting the test signal.

This system only requires the speed transducer (Tahogenerator) usually included in shareholders for indirect vector controlled induction motors, speed control and field orientation. Granting process may be made independently of the value of speed, including zero speed, and not affect the normal order of operation.

Grant by injecting a voltage of third harmonic.

It can be made a harmonic analysis of alternatives study, based on injecting third harmonic voltages. Both machines and as induction, synchronous, for reasons of efficiency are designed to work in the area of saturation characteristics B - H. Therefore, as the flux of air-gap is distorted and flattened. In this case, the flux waveforms can be viewed as the sum of a fundamental harmonic and a number of harmonics with a predominant triple that of fundamental network. A precise technical flow detection and flow assessment air-gap position can be obtained taking into account (instead fundamental harmonic) third harmonic stator voltage. In a star connected three phase motor third harmonic stator currents can not exist, and the third harmonic voltage is not affected by load or stator resistance variations. Furthermore, the third

harmonic is a frequency, which is three times the fundamental harmonic frequency and to obtain a better signal low-speed work.

By measuring the air-gap flux using third harmonic stator voltage, it is possible to overcome a major shortcoming of conventional flow measuring techniques based on integration fundamental voltage is dependent resistive voltage drop. Moreover, it is possible to measure flow and very low speeds.

Analysis of the third harmonic was used directly to measure the current position of air-gap flux, or to induction motors controlled by field orientation for granting indirect rotor time constant.

In the first case, strictly requires continuous measurement of rotor flux position correctly align the stator current vector. An accurate assessment air-gap flux position can be obtained by observing the zero crossings of the flow for third harmonic, which is not affected by machine parameters or place of functioning. With such an approach is not possible to obtain continuous information flux position because each spin can be detected only 6 positions.

Continuous information flux about the rotor position can be derived from assessing the flux of third harmonic amplitude, which in an induction machine is depending on the magnitude of fundamental harmonic. Direct measurement of the third harmonic voltage can be easily obtained summing the three stator voltages obtained in the common point of connection between the star or by measuring center of the star and the midpoint of the filter capacitance of the power converter.

Using the method of the third harmonic is possible also the calculation flux position runner as a function of the flux of air-gap and stator current components. Moreover, there must be a surveillance system to close loop speed control speed. It turned out that by this method can drive the car even up to 0.1 Hz and reverse direction of rotation without problems. So, as stated earlier, in induction motors with field orientation indirect rotor time constant compensation can continuously and easily on each pass through zero for the third harmonic flux.

Grant through the filters. To overcome the shortcomings associated with the injection method of test signals in the machine, estimate rotor time constant and other parameters of the machine can be used conventional identification methods such as Kalman filter. Although the story first appeared 15 years ago and today is done attention to this matter. Kalman filter method is based on the consideration that the supply voltage from inverter motor have a broadband harmonic spectrum can be considered as a noise (disturbance) of the amount required inverter motor itself. Such a motive drive system can be seen

as an ideal set for the application of extended Kalman filter that is naturally available to identify random input parameters and all elements are present for direct estimation of rotor time constant.

Recent studies on the characteristics of convergence, parameter sensitivity and accuracy of measurements of speed (when adopting schemes extended Kalman filter) showed that the practical implementation of an extended Kalman filter identifier may be inefficient at low speeds and sensitivity to changes in other parameters that may be noticeable. Clearly further research is needed on this method before to obtaining a final decision on its practical efficiency.

4 Conclusions

The very fast developing of the drives with asynchronous motors and variable speed and of systems for the conversion of electrical energy made also technical innovation to be an unprecedented level [5], [20].

Share increasingly large asynchronous motors in industrial processes, in drives with variable speed, in processes of high fidelity and precision electronics boosted the development of power electronics and regulation and control electronics (at a rate comparable I would say with the computer and consumer goods), so that the news in this market began to appear in very short periods of time [13]. Thus, the electrical adjustable drives with asynchronous motors led to significant energy savings, increasing product quality, increase system reliability, etc.

Major factor which has helped the technology of alternating current drives to increase rapidly the market is the evolution of several closely related fields like this: power semiconductor devices, frequency converters, microprocessors, techniques of control and simulation through mathematical models.

The impact of advanced and unconventional control strategies in electrical drives development was examined in this article with a great attention directed on non-sensory strategies and issues forecasts in order to identify the size of electrical machines and parameters of mechanical transmission.

Techniques based on observation shows a better precision, but suffer from machine load (loading) and the sophisticated methods of calculation, needed, obviously, the fastest microprocessors. It should be noted that, currently, most adopted non-sensors scheme are

based on approximate data (such as saturation neglect and the effects of time and temperature variation on inductance, inductance perfect symmetry about the position shaped tooth of poles, stator and rotor), which in practice, obviously, are not true, and that affects the accuracy of the algorithm for calculation and analysis. Finally, it should be taken into account the influence of iron losses in position detection algorithms etc.

Compared with uniform harmonic current shareholders, AC drives generate additional non-unitary harmonic band called marginal (edge band).

Compared with other commonly used AC drives, frequency converters generate significant levels of higher order harmonics.

To assess whether a converter disrupt their command or other tasks must be fulfilled before a trial installation of a system such converter. The greater the power, the study is the importance.

References:

- [1] CARDOLERTI, L., Commande et réglage de moteurs synchrotes auto-commutés par des capteurs indirects de position, *Thesis No 1118*, EPFL, Lausanne, 1993.
- [2] ENESCU, D., COANDA H.G., VIRJOGHE E.,O. and CACIULA, I., Numerical investigation by means of polynomial regression method for determining the temperature fields in a medium with phase transition, *The 8th WSEAS International Conference Systems Theory and Scientific Computation (ISTASC 08)*, Rhodos, Grecia, August 20-22, 2008, pg.88-93, ISSN: 1790-2769, ISBN: 978-960-6766-96-1
- [3] IONEL, M., STAN, M.F., DOGARU, V., IONEL, M.O. Possibilities of Diminishing the Distortions Introduced by Superior Harmonics of Electric Current, *Proceedings of 6th WSEAS International Conference on Simulation, Modelling and Optimization*, Lisbon, Portugal, September 22-24, 2006, pp. 689-692, ISSN 1790-5117;
- [4] IONEL, M., STAN, M.F., *Electrical Engineering Treaty*, vol. II, Bibliotheca Publishing House, Târgoviște, 2006, ISBN 978-973-712-191-2.
- [5] IONEL, M., STAN, M.F., *Electrical machines and electrical drive system. Electronic converters commands*, Bibliotheca Publishing House, Târgoviște, 2005, ISBN 973-8413-648.
- [6] IONEL, M., STAN, M.F., IVANOVICI, T., The integration of the a.c. machines command system, *Scientific Bulletin of the Electrical Engineering Faculty*, no. 1 / 2009, Bibliotheca Publishing House, Târgoviște, June 2009, pp. 23-27, ISSN 1843-6188.
- [7] IONEL, M., STAN, M.F., The complete drive system, *Proceedings of International Symposium on Electrical Engineering, ISEE 2005*, 17-19 oct. 2005, Târgoviște, Dâmbovița, pp. 93-96, ISBN 973-712-101-5.
- [8] IONEL, M., STAN, M.F., The inverters noise caused by electromagnetic induction of the asynchronous cages motors, *The Scientific Bulletin of the Electrical Engineering Faculty*, no.1, november, 2006, pp.13-16, ISSN 1843-6188;
- [9] IONEL, M., STAN, M.F., VÎRJOGHE, E.O., New methods for the command of the electrical induction machines, *The Scientific Bulletin of the Electrical Engineering Faculty*, no.2, october, 2007, pp.45-47, ISSN 1843-6188;
- [10] IONEL, M., STAN, M.F., SĂLIȘTEANU I.C., IONEL, M.O. Advanced command techniques of electrical induction machines, *Proceedings of the 9th WSEAS International Conference on Power Systems (PS '09)*, Budapest, Hungary, September 3-5, 2009, pp.176-180, ISSN 1790-5117;
- [11] IONEL, M., *Adjustable electric drives with induction motors for iron and steel industry*, Bibliotheca Publishing House, Targoviste, 2004, ISBN: 973-8413-81-8
- [12] JUFER, M., Electrical drives. Classification, structures and applications. *Symposium on Electrical Drives*, Cagliari, 1987, pp. 255-266.
- [13] JUFER, M., Entrainements électriques pour transfert de position. Evolution et comparaison, *Compte-rendu des 4^{es} journées d'études sur les moteurs pas a pas*, Lausanne, Ecole Polytechnique Fédérale, pp. 1-10, 1986.
- [14] OSSENI, R., Modélisation et auto-commutation de moteurs synchrotes, *Thesis No 767*. EPFL, Lausanne, 1988,
- [15] STAN, M.F., IONEL, M., Double-fed induction machines, *Proceedings of International Symposium on Electrical Engineering, ISEE 2005*, 17-19 oct. 2005, Târgoviște, Dâmbovița, pp. 89-92, ISBN 973-712-101-5.
- [16] STAN, M.F., IONEL, M., IONEL, O.M., Contribution to the Optimization of the Electrical Drives of the Pronounced Dynamic Regime Working Machines, *WSEAS Transactions on Power System, Issue 9*, volume 1, September 2006, pp.1654-1658, ISSN 1790-5060;
- [17] STAN, M.F., IONEL, M., IONEL, O.M., Modern automatic system for the optimization of the electrical drives for working machines with mechanical branches, *Proceedings of 8th WSEAS*

International Conference on Mathematical Methods and Computational Techniques in Electrical Engineering, Bucharest, Romania, October 16-17, 2006, pp. 5-8, ISSN 1790-5117;

- [18] STAN, M.F., IONEL, M., VRĂBIEȘCU, L.,
New structures of synchronous motors with two stators and single rotor, radial flux, *The Scientific Bulletin of the Electrical Engineering Faculty*, no.1, november, 2006, pp.7-11, ISSN 1843-6188.
- [19] STAN, M.F., VÎRJOGHE, E.L., IONEL, M.,
Electrical Engineering Treaty, vol. I, Bibliotheca Publishing House, Târgoviște, 2005, ISBN 973-712-099-X.
- [20] VLĂDESCU, C., STAN, M.F., IONEL, M.,
Supple electrical drives optimization for metallurgical industry, Bibliotheca Publishing House, Târgoviște, 2007, ISBN 978-973-712-300-8.