Strategies for Increasing Energy Efficiency in Electrical Drives

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Abstract: - The common goal of design and optimization of electrical machines is to achieve a minimum cost of production, concomitant with meeting the required operational performance. Currently, several software packages have been developed to design software and / or optimization are available to achieve this desiderate. Using variable speed drives can reduce energy consumption up to 50%. The electric drive systems (EDS) powered variable speed inverters, energy saving is possible if the voltage is adjusted so as to maximize efficiency at part load operation [1]. Savings are possible in systems of fans and pumps operated by EDS using power electronic circuits and variable speed [2]. In this way, adjusting the parameters is done with minimum losses for the entire range of motor speeds. To have a reasonable investment, annual savings from limiting the apparent losses exceed the total annual cost of power electronic equipment used. The design of modern electric motors is moving on to determine the current use of high-density flows. The disadvantage is that these types of motors are an inevitable source of electromagnetic radiations. Noise and vibration associated with electric motors are inherent in normal operating conditions, their complete elimination is impossible. However, in some ways the sources and their effects can be minimized and may be acceptable in accordance with the specifications of different international standards [3].

Key-Words: - electric drive systems (EDS), high-efficiency induction motors, operating costs, energy savings, variable speed drives, noise and vibrations, actuators.

1 Introduction

It is often said that electrical equipment manufactured by a firm are "more reliable" than those made by another firm. In this case, "reliability" of electrical equipment is taken into account if the relative costs are not important. In a strict sense, reliability is the property of an entity to meet one or more functions necessary for fixed terms [4].

The reliability result consists in product successful resulting from material stage to stage rolling operation. Major blocks of principal interest are:

- Specifications
- Design
- Specific material
- Manufacturing,
- Technical competence in manufacturing
- Testing to evaluate the mean life of the motor
- Environmental conditions.

The application of functional analysis techniques can evaluate certain forward-looking performance of the system. For example, the system of induction motor drive is made up of eight subsystems (converters AC / DC rectifier, filters, inverters, induction motor, control unit, power supply, interface and operating system dialog with the operator).

Recent study findings show that:

- The most common accidents are caused by high temperatures [5];
- 25% of accidents could be prevented by preventive maintenance measures;
- Frequency of failure of the modern electric drive systems vary between 6% and 9% in one year.

Increased utilization factor is closely related to reliability because it allows:

- Uncertainty in predicting the real power needs;

- Overload due to changes in the operating system. The aging system, they tend to wear out and thus require increased maintenance process parameters;
- Overload of short duration and higher ambient temperatures of 40 ˚C.

Low power motors are used where there is a big distinction between motors power and standard rated.

At high power, standard regimens are similar. Also, motors shaft power than are currently built to order and requires data on nominal maximum power specification of the motor shaft [6].

2 Manufacturing and operating costs

The common goal of design and optimization of electrical machines is to achieve a minimum cost of manufacturing (or initial cost) and meeting during this time of operation and operating performance [7], [8]. We currently have several software packages for design and optimizations are available to assist this process [9]. In addition, concentrated efforts are made to reduce energy consumption during use of EDS. These costs represent the cost of reliability or cost of use.

Manufacturing costs consist of:

- Costs of the stator and rotor ferromagnetic cores;
- Stator winding copper;
- Alumina rotor bars and rings for collectors;
- Cost of structural materials;
- Insulation and workmanship to achieve the coils.

Reducing manufacturing costs is achieved by reducing the product of its diameter and length of the machine and the stator coil calibration. These actions result in increased current density and temperature rise. For these reasons it is desirable that the current density is limited in order to ensure it does not exceed the limit. With growing concern in terms of reducing costs and achieving energy savings compared with standard drives, emphasis was placed on developing the design and use high-efficiency induction motors. These motors use both the stator and rotor conductors to achieve much lower resistance losses in the winding as well as small. To have the same efficiency, these motors have the same size as standard motors stator but have a greater axial length. Initial cost is increased by 25%.

A major consideration in EDS is represented by motors operation costs. If the overall efficiency can be increased as a result of reduced losses in the drive, this is clearly a positive effect on lowering costs. An example of loss reduction can be achieved by a motor that operates below the nominal load. Taking, for example, a cage induction motor, its design will be done in such a way as to maximize efficiency at full load operating conditions. Rotor losses are divided into two parts, one is the loss of magnetization which are subject to feeding voltage, the other is the electrical losses in copper caused by the electric current (Joule losses). At less than rated load operation, a voltage drop will reduce the motor speed but will decrease the least significant magnetic losses [3], [4].

Using high-efficiency induction motors in place of the standard motors clearly increase the initial cost of EDS. This cost can however be more than offset by the decrease losses and reduce operating costs [10]. For example, a 6% increase in efficiency is obtained in a 10 kW motor if the motor is running close to the rated load for 80% of operating time, the economy will be 420 kW per year representing an amount of 400 - 2100 Euro. This economy can be compared with an addition to the initial cost of about 300 Euro. Thus, the initial investment can be recovered in a few months of operation.

Optimal management process includes the following:

- Specific consumption minimization;
- Minimize operating costs;
- Maximize productivity;
- Maximum safety;
- Quality to a given standard.

Comparing EDS constant speed with EDS variable speed that the latter involves a larger investment. It is essential to consider not only investment costs but also operating costs, particularly energy costs. In an analysis of the profitability of a fan with a nominal power, 315 kW, it is clear that investment for a difference of 30 000 USD (with a cost of energy consumption of 0.12 to 0.5 Euro per kWh and a number of operating hours per year) payback period is surprisingly low (between 0.5 and 2 years). This example was extracted from a light and medium section mill. Another point to be considered is that the result of miniaturization, integration and price per kWh of final control elements will be much reduced.

Intelligent computer software is available to achieve sizing mechanical parts. Particularly for higher rated engine rotors, with a high efficiency is necessary to take into account a large number of parameters and boundary conditions (at maximum torque, maximum speed). For example, the diameter should be decreased (thus minimizing losses due to air friction). However, this reduction leads to increased length of the rotor so that critical velocity decreases (cooling is worse). An optimization calculation is also essential.

In conclusion, the initial cost is a factor, but **IT IS NOT ONLY** to be taken into consideration when choosing a particular EDS for a given application.

3 Energy Savings

Using variable speed can reduce energy consumption by 50%. Energy saving is a very important necessity in industries where high power is used pumps, fans and compressors. With EDS (electrical drive systems) powered variable speed inverters, energy saving is possible if the required output voltage adjust and a given speed so as to maximize operational efficiency at lower load nominal load. Savings are possible drive systems and power electronic circuits used in variable speed fans and pumps where the torque is proportional to the square of the velocity if properly adjusting parameters to obtain minimum losses for the entire range of motor speeds [11]. To be a profitable investment, the annual savings from the reduction of apparent losses exceed the total annual cost of power electronic equipment added.

Flow can be controlled in two ways:

a) Varying the centrifugal machine geometry of heat discharge;

b) Varying the speed of centrifugal machine.

At maximum flow, power consumption is almost the same, assuming that the fixed-speed control device is fully open or inactive. Taking into account a reduction in flow to 70%, the ratio of power absorbed at the amount required for variable speed fixed rate is approximately 0.45, while for a flow rate of approximately 40% of maximum flow, the same ratio may decrease to 0.15%. Knowing the cycle (motor cycle) a process (for example the relationship between flow and Ti), and specific features of the tool, energy ΔE can be saved by adopting variable rate is calculated as follows:

$$\Delta E = \sum (P_{m1i} - P_{m21}) \times T_i \qquad (1)$$

where: P_{m2i} and P_{m1i} are absorbed powers by the machine on fixed-speed machine and to the variable-speed machine, at a given flow.

So, large centrifugal machines (currently existing) are normally operated in fixed speed of medium voltage induction motors, fed from a source of 50 Hz [12]. Retrofitting variable speed can be achieved by one of two ways:

- Variable-frequency motor control with an inverter;
- By interposing a hydraulic coupling between the motor and centrifugal machine.

An example of the most attractive areas for it is retrofit existing auxiliary equipment (thermal generation units) of the FD and ID fans, water circulation pumps and power pumps (water) boiler, all being in order MW. Experience has shown energy savings of 20 to 50% in these cases.

Conveyor belt motors fed by low speed with speed control cycle-converters may decrease, also the energy consumption as follows:

a) Substituting the early start or hydraulic clutch carrier wound rotor motors / collector ring with a starter (because this drive system has a small loss in speed control);

b) Using the command continues (because the drive does not suffer any additional loss by sharing the burden of loading multiple operating systems);

c) When the conveyor speed is adjusted depending on the flow of material - because speed control reduces friction and hysteretic losses.

The top energy savings lays in the synchronous drive systems they have an inherent capacity creep speed belt without using additional equipment. This reduces maintenance requirements by eliminating the bearings, gearbox (gear), hydraulic couplings and wound rotor motors / with rings, standard technology associated with the conveyor belts and thereby protecting the entire system for smoother starts and stops.

The variable speed drives can reduce energy consumption by:

- Start-up without sliding;
- Removal characteristics of continuous sliding load balancing;
- The ability to adjust vehicle speed in relation to the work required.

Efficiency "η" of a drive system powered by inverter is defined as:

$$\eta = \frac{\omega T}{\omega T + \Delta P_M + \Delta P_{MV} + \Delta P_{inv}} \qquad (2)$$

where:

T - electromagnetic torque developed by motor;
ω - angular speed;
ΔP_M - core losses of motor;
ΔP_{MV} - motor losses due to harmonics;
ΔP_{inV} - inverter and converter losses amount.

Internal frictions of the motor are included in the friction torque. Thus, efficiency is improved to a certain degree (1%) and has little effect on the loss minimum (minimum loss point).

Both theoretical calculations and measurements show that the operating system that works best with a shift to a low load task, 2-3% of the nominal apparent power can be saved by reference to our operating system operating in nominal flow. About the same amount of energy can be saved at low speeds and rated load capacity, but in this case the motor flow must increase more than nominal value. Two-speed motors, with two pairs of poles, eg 2 / 4 and 4 / 6 can be used profitably in place with single-speed motors for energy saving applicable operating system of pumps and fans.

In practice, proper energy saving drive system - in case of inverter supply - can be achieved by a motor control voltage, while the speed control loop produces fundamental frequency drive system [4], [10].

The simplest method of voltage controll is to keep the optimal value of the slide in memory (as a function of fundamental frequency).

4 The noise and the vibrations

Noise generated by any device (fan, compressor, etc.) decreases exponentially with decreasing speed. In reality, the intensity noise from a fan perceived decreases faster than prescribed. This is because the human ear's sensitivity decreases with frequency from peak sensitivity at about 2500 Hz. American National Standards Institute (ANSI) introduced A-weight function, based on empirical data to describe this effect. The equation below was used to assess the noise impact on human communities:

$$L_{dn} = (10\log_{10} 1/24)[15x10^{(Ld/10)} + 9x10^{(Ln+10)/10}] \quad (3)$$

where:

L_d - noise level between photoperiod (7 am to 10 pm);

L_n - noise level in the time interval between the night (10 pm and 7 am).

Note that in this equation, 10 dB is added to the normal night time L_n to take into account the increased sensitivity at night.

At less than 150 kW motors, the main design criterion was the minimum cost per unit of power. The designs of modern electric motors are moving on the use of high density currents and flows [13]. To keep the machine size to a minimum and maximum efficiency with high efficiency motors are used. Such motors are, however, an inevitable source of mechanical noise.

The world imposed strict noise control to protect people from environmental hazard noisy. Thus, it became mandatory for motors manufacturers to specify the noise from electrical machine products, concomitant with their attempt to realize them as less noisy. Vibrations, therefore, noise from machine can be reduced with a high degree if the forces arising during use does not interact with the machine resonant parts of the machine. Generally, for medium and large size machines, the noise spectrum is usually dominated by the electromagnetic noise and by the ventilation noise. Ventilation noise is generally associated with air turbulence and broadband in general. Electromagnetic noise is due to Maxwell stress acting on the iron surface in the presence of magnetic field. These forces induce vibrations in the structure of the stator, which generates noise. Nature is linked to the existence of electromagnetic noise in the air gap magnetic field, the mechanical response of the stator and stator thermal radiation coefficient. Air-gap of an induction motor squirrel cage has a large variety of magnetic field harmonics. These harmonics are the causes of magnetic noise, disturbance torque and additional losses [14].

Noise and vibration associated with electric machine are inherent. In normal operating conditions, is impossible to completely remove the noise. However, noise sources and effects can be minimized and may be acceptable in accordance with the specifications of different international standards.

An example of noise reduction may result from use of the ASD, holding a fan whose blades have a frequency of 150 Hz produce a noise level of 60dB.

At a constant speed drive L_{dn} value will be 66 dB. It is assumed that the fan was not turned off during periods of lower demand from power.

If the fan running at half speed at night is typically the case, reducing the noise power is 15 dB. On the logarithmic decibel scale, 15 dB represents a reduction greater than 10 to 1.

A common technique to reduce noise and vibration is to use high frequency switching noise so the result may be ultrasonic. To do this, however, it is required high-speed switching devices which are very expensive.

Any periodic function can be represented by a Fourier series as follows:

$$f(\omega t) = \sum_{n=1}^{\infty}[a_n \sin(n\omega t) + b_n \cos(n\omega t)] \quad (4)$$

If they are maintained semi-wave and quarter-wave symmetries in this function, then the Fourier series coefficients of order hair can be considered $b_n = 0$ and:

$$a_n = \frac{4}{n\pi}[1 + 2\sum_{k=1}^{M}(-1)^k \cos(n\alpha_k)] \quad (5)$$

where:

$k = 1, 2, 3, 4, \dots,$

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \dots \alpha_m$ - angles of the fourth cycle saturation;

a_1 - fundamental frequency coefficient;

$a_3, a_5, a_7, a_9, \dots,$ - harmonic frequency coefficients.

To minimize vibration and noise, fundamental frequency coefficient a1 must be maximized with the removal of unwanted harmonic frequencies. Such saturation angles α_k (k = 1, 2, 3, ...) should be chosen so that α_1 maximized, while a subset of year (n = 5, 7, 11, 17, ...) is set to 0.

As shown in Equation 5, M degrees of freedom exist in the fourth period. If one degree of freedom than the initial is used to control the amplitude of the fundamental frequency (a_1), then (M-1) degrees of freedom can be used to eliminate unwanted harmonics (M-1) (a1). Thus, M-harmonic frequencies that need to be removed are those that interact with the machine's natural frequencies gives rise to unwanted vibrations and noise.

Suppressed frequency components that appear in the spectrum of motor vibrations are resulted from differences in amounts and frequencies of fundamental and harmonic currents in high-frequency drive system. Thus, PMV schemes can be used to suppress higher harmonic components that cause undesirable harmonic components in vibration spectrum. Saturation angle can be determined from the spectrum of engine vibration.

5 Conclusions

The next 20 years will be interesting as adjustable speed drive motors will fully enter the market and in all applications. Since large electrical machines and small penetrate all aspects of electricity, almost all these applications can benefit from adjustable speed, this entry will be really important. Although a variety of engines c.c. and AC are already available today as off-the-shelf products, technologies and dominant products of the future will be those that will be simple, robust and cheap.

Since most applications in electric motors are smaller and products at low prices, put severe restrictions on operating systems that may be acceptable. Thus, the full spread of technology applications that use motors with adjustable speed will require simplifications prevalent and "strengthen" actuator systems. Although the technology is quite advanced from shareholders sophisticated equipment is still too expensive and complex for most applications that could benefit from these actuators.

One reason for variable frequency systems applications compared to other power electronic systems is the variety of implications that the controls they produce an electric drive.

Control techniques to ensure a fair and efficient operation of the drive during normal operation. Nominal data of the motor and inverter must be met and ensuring that optimum motor performance is in areas of maximum torque (current and speed).

The main advantages of induction motors are their simple construction, moderate maintenance, lack of switches and collector rings, low price, reliability and capability to control moderate speed, as for DC motors (using the concept of vector control). The main drawbacks are their small air gap, rotor bars can break due to the heat concentration points in counter-current brake and change direction of rotation. This efficiency is lower, power-mass ratio and power factor are lower than the synchronous motors. Currently, energy saving is very important and high efficiency is crucial for engines used in high numbers.

From the viewpoint of energy economy, performance and reliability synchronous motor seems to be better It is anticipated that in the XXI century will be more common than induction motors. Using permanent magnets from rare elements in electrical machines not only improves efficiency and dynamic performance, but also the balance of power - mass, stability and efficiency of the motor [15]. Another option is to use seemingly pole rotor excitation, such as variable reluctance motor.

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