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PRELIMINARY STUDY OF THE REQUIREMENTS FOR VARIABLE SPEED ELECTRIC DRIVES

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Abstract- The preliminary study of a variable speed electric drive requires knowledge of a number of basic data, such as required power, supply voltage, the type of operation (number of quadrants), speed range, and the accuracy over speed. We also show some effects on motors of the supply through a converter: the voltage peaks, the effects of voltage gradients, and the losses caused by harmonics. Nowadays, this know-how is very important for the design of a circuit where electric engine is being used. And the number of applications of electric drives seems that it does not have end: industrial processes such as pumps and compressors, machinery like presses and grinders, industrial cold and heat conditioning, steel and paper industry, etc.

Keywords: Drive, Variable Speed, Rectifier, Inverter, Motor, Converter.

I. INTRODUCTION

The main objective of the electric drives is to obtain a determined answer from a mechanical system. That answer may be:
- to a reference speed
- a reference torque
- a reference position

But we can divide this main objective in some more specific objectives, such as:
- Fix, vary or maintain the speed
- Start and stop gradually
- Adjust parameters of the mechanical process (caudal, pressure, etc.)
- Synchronize the speed of the motors
- Synchronize the position of the motors
- Control accelerations

In order to obtain these objectives, we will normally design our drive like a system that is composed by four subsystems:
- Regulation system
- Supply source and electronic converter
- Electric motor
- Transmission system

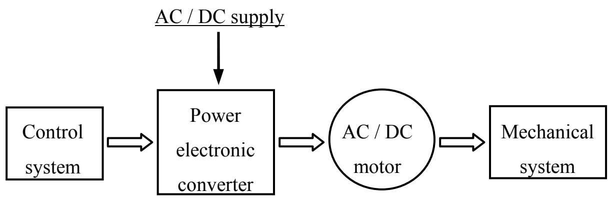

Figure 1. Parts of the drives

Leaving aside the assemblies that allow only the speed variation within a limited range (DC motor fed with constant voltage) or by a strong performance degradation (action to the sliding of the asynchronous motor), variable speed drives are those shown in the Figure 1 when they are fed by the network. These are:
- Drive with DC motor (Figure 2a) fed variable voltage;
- Drive with cycloconverter (Figure 2b) and alternating current motor, asynchronous or synchronous;
- Drive with inverter (Figure 2c) and AC motor, asynchronous or synchronous.

In this case, the inverter that feeds the engine can be:
- A power inverter (CSI: current source inverter),
- A voltage source inverter (VSI).

The "self-controlled" synchronous motor ensures the auto-switching of the inverter that feeds it (LCI: line commuted inverter). The control circuit is the "brain" of the speed drive. This circuit develops the control signals of the power semiconductors based on data from
- The process (flow, pressure...)
- Motor (voltage, current, speed, torque, acceleration, vibrations, ...)
- Network (voltage, current, power factor, harmonics)
- Operators (start, stop)
- Supervisors,

For the drive to provide optimum service without any of its elements has to bear excessive constraints.

Note that sometimes a transformer between the network and the entrance drive is get. The function of this device is:
- electrically isolate the converter from the network,
- reducing, when necessary, the voltage of the power source,
- limiting the short circuit flows, when failure.

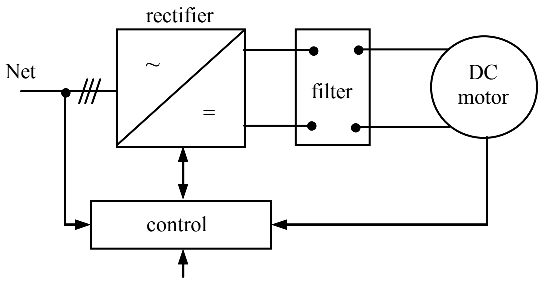

Figure 2a. DC motor and rectifier

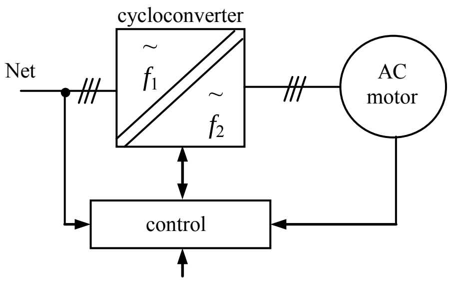

Figure 2b. AC motor and cycloconverter

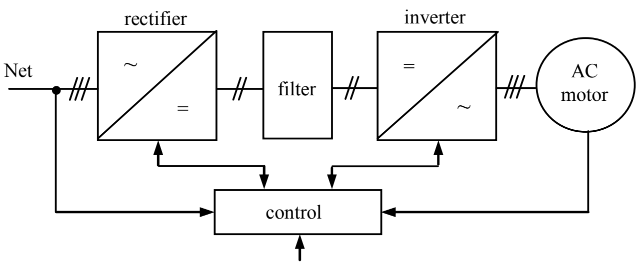

Figure 2c. AC motor and inverter

II. CRITERIA TO DEFINE A SPEED DRIVE

The preliminary study of a variable speed electric drive requires knowledge of a number of basic data like

- Required power,
- Supply voltage,
- The type of operation (number of quadrants)
- Speed range,
- Accuracy over speed.

A. Required Power

The power of a drive is determined by the needs of the load drawn. This power should be defined under both steady state and transient. The determination of power begins with that of the engine, which is the system element closest to the load. The power for sizing the motor and converter are not, on the other hand, the same due to the significant difference between the thermal time constants (a few minutes for the engine and only a few seconds for semiconductors).

The rated power of the motor is the product of its nominal useful torque by its rated speed. To calculate the rated value of the useful torque C_u it is necessary to know the curve showing the variation of resistance torque C_r of the load drawn according to the speed (N or Ω), and the total moment of inertia J of the system in rotation, the duration and rate (cadence) of acceleration and braking.

$$C_u = C_r + J\frac{d\Omega}{dt}$$

In practice, the maximum power is used for sizing the converter. This power corresponds to the maximum torque, which is usually the starting torque that the motor can develop.

B. Supply Voltage

The AC input voltage of the converter is an important variable when doing the sizing, since it can change the architecture of the equipment (whether or not a transformer, type of semiconductor components used, difficulties arise over the voltage peaks than current peaks,...) and it price. Thus, for equipments whose power is less than or equal to 250 kW, which are fed by medium voltage network and using an asynchronous motor, an economical solution would be to use a transformer, to increase the voltage, between the drive output and motor. In this case, it is normally used a medium voltage motor to 3000, 5000 or 6600 volts and a standard drive. The power limit in order to be this solution cheaper may vary depending on the technological and market developments, and it depends on the manufacturer.

C. Type of Operation

Depending on whether the drive is operated in one rotation direction or in directions, if there is recovery braking, rheostat braking or electric braking does not occur, the structure of the converter will be different.

D. Speed Range

The speed range of a drive is the relationship between the maximum speed and the minimum speed of the engine that ensures the accuracy shown.

If the rated speed is 3000 r.p.m. and the range is from 1 to 1000, the drive can supply the motor that rotates between 3000 rpm and 3 r.p.m. with the desired accuracy. The drive can also rotate it with less than 3 r.p.m. but accuracy is no longer guaranteed.

It is necessary that the speed range of the drive is higher than the range required by the application. When the drive is inserted into a loop position, the minimum speed is obtained for the minimum speed signal that allows obtains the displacement. In this case, the accuracy is determined by the position loop.

The speed ranges are usually:

- The range from 1 to 100

For standard equipments with mediocre performance,
These drives can use:
DC motor without speed sensor; voltage U applied to the induced is corrected to take into account the ohmic drop RI; the *emf* $U - RI$ is the image of the speed, standard asynchronous motor without sensor; the flow is controlled by the ratio U/f to keep it constant;

- The range from 1 to 1000

For medium performance equipments,
These drives can use:

Usual DC motor with analogical sensor, standard asynchronous motor with sensor and traditional vectorial control;
- The range from 1 to 10000
For high-end equipments used in robotics or for certain machine-tools (some position adjustments require the range from 1 to 30000).

These drives can use:
- A synchronous motor with permanent magnets,
- A special DC motor with numerical sensor,
- A special asynchronous motor with known characteristics, with vectorial control that takes into account the parameters of the engine and its variations, with sensor.

E. Accuracy on Speed

The accuracy on the velocity is determined by the application and is linked logically with the speed range. This accuracy can influence the choice of drive and the choice of regulator. Depending on the type of regulator, the accuracy is more or less affected by
- The temperature,
- Type of torque applied by the motor,
- Voltage of the power network.

We can distinguish
- Static accuracy (or error) is the difference ε_1, (Figure 3) between actual speed and the speed in steady state;
- Dynamic accuracy (or error) is the difference ε_2 between the actual speeds and speed in steady state caused by a sudden variation of load torque (torque step). The dynamic error is higher than the static error and depends on the speed control.

According to the specifications, accuracy is expressed as a percentage of rated speed or as a percentage of the speed indicated. The manufacturer shows (or he understands) in many cases the first percentage.

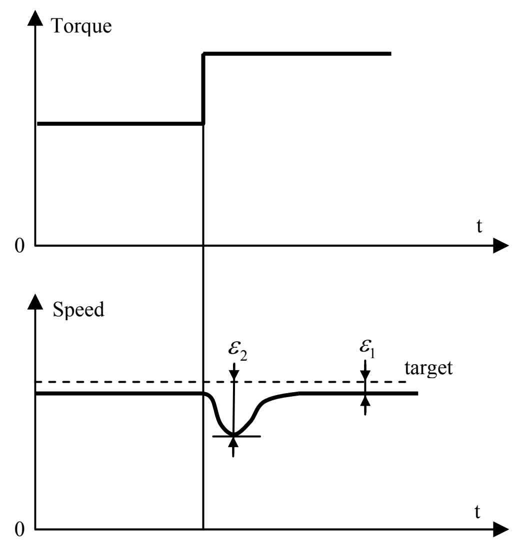

Figure 3. Accuracy on speed

III. EFFECTS ON MOTOR OF THE SUPPLY THROUGH A CONVERTER

Among the effects on the motor of the supply through a converter, we will centre our study in the effects of non-sinusoidal supply. The rectifier supplying a DC motor supplies a voltage composed by sinusoidal arcs that have abrupt steps from one arc to another one.

The motor is equivalent to an electromotive force in series with a resistor and an inductor. This force, usually augmented by a series inductance with the armature, reduces the ripples of the absorbed current.

However, the engine must be declassified with regard to its supply at a voltage without ripples. AC motors, synchronous or asynchronous, are also equivalent to an electromotive force in series with a resistor and a reactance. The reactance occurring during the abrupt changes and the calculation of the effects of harmonics, is the leakage reactance.

The engine is not powered by a sinusoidal wave:

If it is fed by voltage, that is, by a voltage inverter, it receives a voltage formed by alternating or rectangular pulses consisting of constant height.

If current is fed by current, that is, through a current inverter, it receives a current formed by pulses or pulse sequences.

This non-sinusoidal form of the signals applied to the motor has three types of consequences which we can say briefly. These are:
- Voltage peaks,
- The effects of the voltage gradient on the winding,
- Losses caused by harmonics.

A. The Voltage Peaks

- In the current supplies, the abrupt changes in current cause overvoltages in the machine ($u = \ell \frac{di}{dt}$). These overvoltages are higher when those abrupt changes are higher and the inductance of the motor is higher. It is necessary either to reduce the current steps from one value to another, either to limit the overvoltages.

- In voltage supplies, however, the inductance of the motor tends to mitigate the effects on the current of the abrupt changes in voltage ($\frac{di}{dt} = \frac{u}{\ell}$) and to make the waveform of the current is as close as possible to the sinusoidal form.

For these inverters, parasitic inductances in the converter input cause overvoltages. To mitigate them, it is necessary to put in the motor terminals semiconductors as help circuits for switching, that is, some snubbers.

B. The Effects of Voltage Gradient

In a sinusoidal supply, the *dv/dt* of the voltage is weak: the voltage is distributed evenly among the various turns in the stator winding of each phase.

In a voltage supply, the *dv/dt* can exceed the 1500 V/μs. These waves are hard edge waves against which the winding behaves as a distributed constant circuit in which parasitic capacitances play an important role. This translates into a significant overvoltage in the first turn or in all of the first turns.

The phenomenon can be greater if the cable between the inverter and the motor is too long. Due to the voltage peaks or voltage gradients, isolation of the motors to be powered by a drive should be taken into account.

C. The Losses Caused by Harmonics

The harmonics of the voltage applied by the voltage inverter to the motor generate in that motor current harmonics weaker the higher the frequency of the harmonics and the higher the reactance of the motor.

The harmonic currents supplied by a current inverter to the phases of a motor generate in that motor harmonic voltages. The ratio voltage / current of each harmonic increases with the reactance and frequency.

Harmonics increase Joule losses and iron losses of the engine and reduce its performance causing the need to declassify a little bit.

VI. CONCLUSIONS

Required power, supply voltage, the type of operation (number of quadrants), speed range, and the accuracy over speed are normally basic data that we have to know when we are designing a circuit including a variable speed electric drive. Among the effects of non-sinusoidal supply, for example in by the rectifier supplying a DC motor, we have studied the voltage peaks, the effects of the voltage gradient on the winding, and the losses caused by harmonics.

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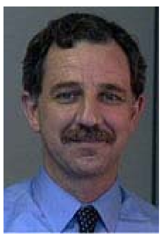

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