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Influence of Supply Voltage on the Internal Angle and Reactive Power at a Synchronous Motor from an Electric Drive

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Abstract

There are practical cases in which some synchronous motor drives are faced with situations in which the supply voltage can be higher / lower than the nominal supply voltage, but without pronounced fluctuations or relatively slow fluctuations in time. The paper examines the influence of this situation on the internal angle of the machine and on reactive power produced by it. Conclusions obtained are more important having in view that this kind of drives, regularly, have high power and sometimes very high power.

Key words: *voltage, synchronous motor, electric drives*

Introduction

Analysing power systems to various industrial customers [1], [2], [3], [4], we found cases in which electric drives are made with synchronous motors, powered by 6 kV medium voltage, receivers having power range between 500 and 1000 kW. These drive systems with synchronous motors used for compressors and pumps with high flow have direct start in asynchronous mode, being in "hard starts" category. Some of these types of drives have automatic adjustment of the excitation current of synchronous motor, to operate with a power factor value conveniently chosen very close to the unit value or equal with unit value. Other electric drive systems with synchronous motors, to analyzed customers, do not have such control systems, namely the excitation current adjustment is done manually by observing a meter for power factor, which in many cases allowed to obtain average values good enough for this parameter. This last operating variant is possible especially when the supply voltage of the drive system has a small and relatively slow variation in relation to a certain time interval, Δt, which is not too small, so that the operator is not "locked" at the control panel. However, situations have arisen in which the variation in supply voltage by comparison to the voltage standard was quite high even at a voltage by 20 kV, and strongly fluctuating.

Such a real case is shown in figure 1. In this situation, synchronous motor drive systems equipped with automatic adjustment of the excitation current has worked almost perfectly, achieving a power factor with many hourly average equal with unit values.

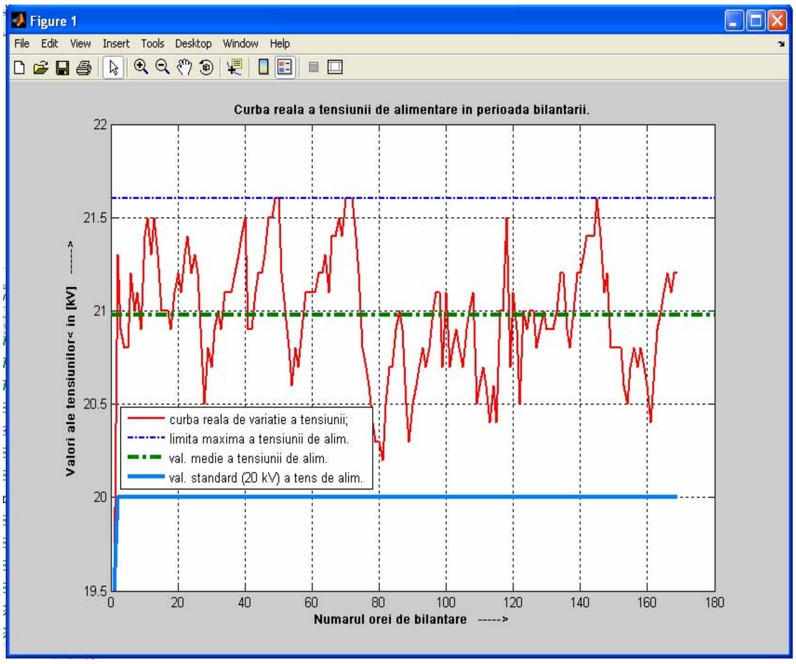

Fig. 1- Real curve of the supply voltage in comparison with the standard one by 20 kV

In the same working conditions, electric drive systems that were not equipped with an automatic adjustment of the excitation current were able to achieve performances that were worse (even much weaker) in terms of power factor.

This issue does not have anything special in itself, because it is well known, what actually led eventually to the conclusion that is necessary an automated system for regulating the excitation current of the synchronous motor. However, we can highlight two aspects that apparently were not sufficiently analyzed in the literature:

--- that supply voltage can be higher / lower than the nominal supply voltage, but without pronounced fluctuations or relatively slow fluctuations in the time;

--- the fact that voltage is strongly fluctuating, even if its average value is the nominal value, respectively in the case when its average value does not correspond to the nominal value, it was over/under nominal value.

And yet some synchronous motor drives is facing such situations, and this is especially important since such drives are generally by high power and even very high power.

Establishment of Initial Issues

For a more detailed analysis of these elements may be taken into account for the synchronous motor are given all the parameters needed to perform calculations and determination of specific sizes and features of that engine (which is not realized in the usual catalogs engines synchronous).

So, the authors have taken from [5] a synchronous motor having a nominal power close to those of the industrial consumers: 400 kW and supply voltage by 6 kV. Nominal parameters are: In=45.6 A; Ien=13A; Uen=49.5 V; E1n=3954 V; ns=1000 rot/min; cosφn=0.9 – capacitiv; r1=0.0246 u.r. xs1=0.087 u.r.; xd=1.37 u.r.; xq=0.78 u.r.; re=0.035 u.r.; xσe=0.253 u.r.; rd=0.31 u.r.; xσd=0.105 u.r.; rq=0.119 u.r.; xσq=0.05 u.r.; ksd=0.978, saturated value of coefficient kd; ksq=0.9, saturated value of coefficient kq; all notations are the usual for parameters of a synchronous motor.

The expression of electromagnetic torque is known [2]:

$$M=\frac{mU}{\Omega}\left[\frac{E_0}{X_d}\sin\theta+\frac{U}{2}\left(\frac{1}{X_q}-\frac{1}{X_d}\right)\sin 2\theta\right], \qquad (1)$$

Taking the nominal values for M, U, E0, then through an iterative algorithm in some programming environments (eg MATLAB version 7.4) can be obtained the nominal internal angle for given engine: θn = 43.127 degrees, in conditions in which the value of internal angle at which the torque has maximum value is θmax = 64.90 degrees, with Mmax = 4374.04 Nm; Mn = 3824 Nm, respectively km = Mmax/Mn = 1.144.

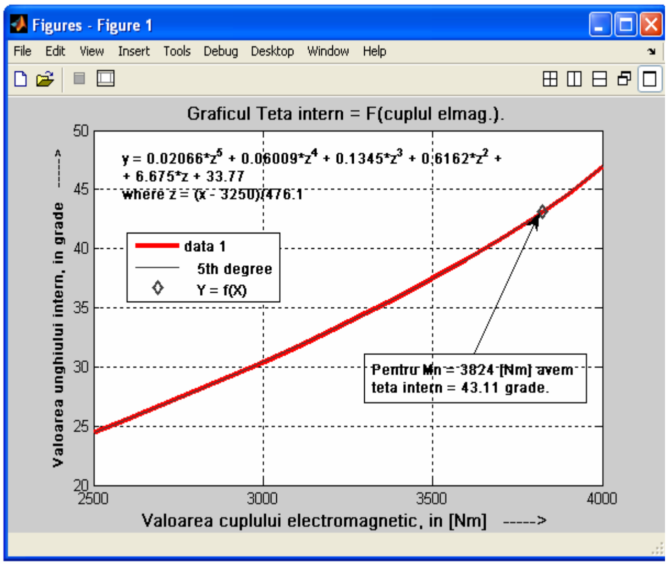

Fig. 2- θ_{intern} = F(electromagnetic torque).

It is known that the internal angle of the synchronous motor depends on the electromagnetic torque, which in steady state is equal with the torque resistant of its shaft. Thus, keeping the nominal voltages U and E_0 we can get the variation curve of the internal angle of the synchronous motor according to torque resistant of his shaft.

This curve appears as in Figure 2, for the given engine. Within this figure is also given the polynomial representation (grade 5, waste under 0.05), which can reflect the nominal value of the internal angle (θn = 43.11 degrees, compared to that previously determined by the iterative method of 43.127 degrees). Polynomial representation may allow relatively rapid determination of the internal angle of the synchronous motor, in the considered variation range of couples (in this case between: 2500 ... 4000 Nm), the detailed expression of the polynomial representation is shown in Figure 2.

Influence of Supply Voltage on the Internal Angle of Synchronous Motor

It can be analyzed the case in which the electromagnetic torque M (M = Mr = const) and the electromagnetic voltage, E_0, remain at nominal values, but the supply voltage is changed in a certain area under / over-nominal; usually a variation of ± 5% have already considered abnormal, especially if it is about the national system of medium voltage (6,20 kV)._Suppose that this gap from the initial voltage to the nominal one, is not complemented by a pronounced fluctuation of voltage, then this voltage deviation can be defined using a coefficient ku = 0.9 ... 1.1, which will increase the nominal voltage (ie, is allowed a deviation of ± 10%). Figure 3 shows how to change the internal angle of the synchronous motor given in this case._It is noted that the internal angle of the motor decreases with increased voltage.

If decreasing of voltage becomes too pronounced, it is possible that this angle (see Figure 3 for the case ku = 0.9) exceed the θmax, i.e to reach the unstable zone of operation of synchronous motor (area θmax <θ ≤ 180 degrees) when the synchronous motor is out of synchronism and stops.

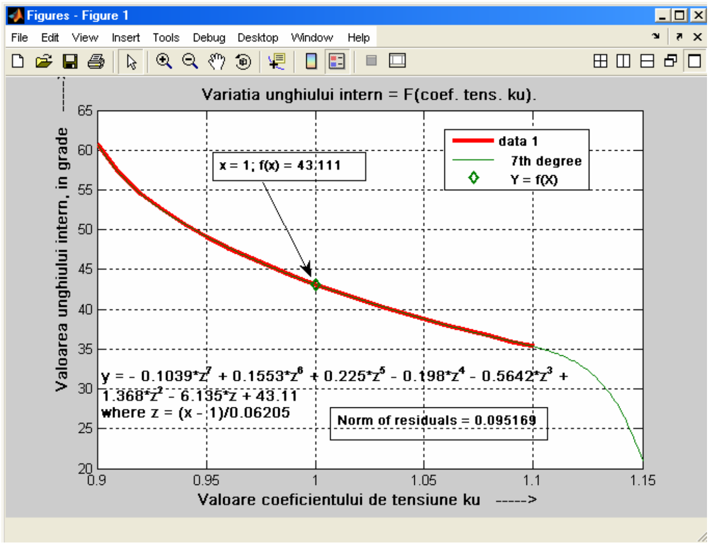

Fig. 3- The curve θ_{intern} = F(voltage coefficient k_u).

It is true that in the dynamic regime with drive having synchronous motor, in the case of out of synchronism should be considered the theorem of equal areas, but if it keeps the voltage drop given for a greater period of time Δt, then the motor is out of synchronism and off to is safe.

In Figure 3 is also given, the polynomial representation (grade 7 in this case) which can establish the internal angle, for a change of the supply voltage of the given motor (for ku = 1, is found the value of θn with an accuracy good enough).

Such a polynomial representation could be used in an automatic protection against voltage decreases, which may lead to shut down a major receiver of a drive system.

To avoid operating system shutdown in such a situation can be taken, according to a certain order of priorities, two kinds of measures: growth of parameter E_0 (respectively increasing the excitation current Ie, i.e overdraft within the allowable limits for the excitation circuit of the engine) or a corresponding reduction of electromagnetic torque, respectively the torque that is resistant to the motor shaft.

The safety margin, for the case when the internal angle, θ, is close to θmax must be well correlated (in the case of automation) with time constants of the execution systems running on "overdraft" or with the reduction in resistance torque of the motor shaft (that, usually, includes some mechanical elements: valves, etc.) to avoid stopping the drive.

Influence of Supply Voltage to Reactive Power

A special importance can have the manner in which is changed the reactive power which is circulated in a drive systems having a given synchronous motor, once the changing of the engine supply voltage. So, it is considered again the parameters M, E0 at the nominal values, respectively the voltage coefficient, ku, having variation range previously established.

The term of synchronous motor reactive power (apparent pole) is also known [6]:

$$Q = mU\left[\frac{E_0}{X_d}\cos\theta + \frac{U}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\cos 2\theta - \frac{U}{2}\left(\frac{1}{X_q} + \frac{1}{X_d}\right)\right], \qquad (2)$$

The notations are known and specific for a synchronous motor.

It have to make a notice: to see how to change depending on U, the reactive power Q, the voltage U will be multiplied with the coefficient ku, only that with changing supply voltage, at constant values of M, respectively E_0, it will change the internal angle θ of the engine, according to a polynomial representation as in Figure 3, set for the given engine.

So, the calculation algorithm should also take account of this aspect: internal angle depends on the electromagnetic torque, respectively by the resistant torque on the motor shaft (in a steady state), but for a constant torque, it also depends on the motor supply voltage.

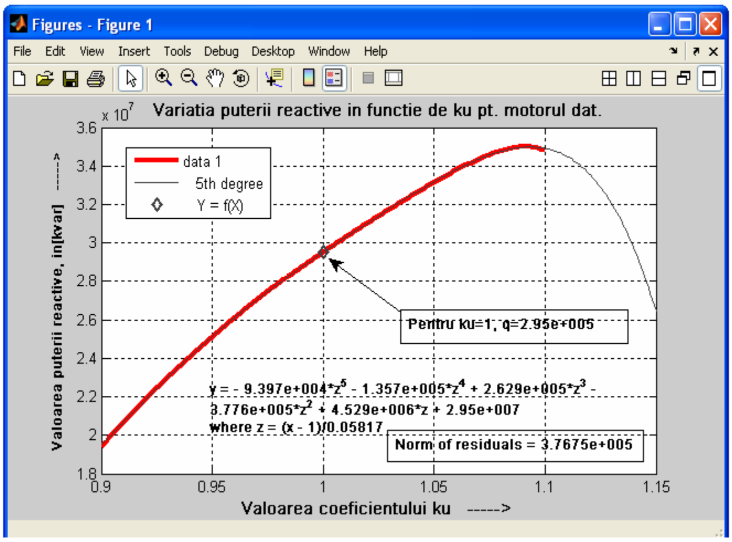

Fig. 4- Variation curve Q = F(ku) for a given synchronous motor .

In figure 4 is shown the evolution of reactive power according to the voltage coefficient, ku.

From this figure we see that there is a pronounced variation of reactive power depending on supply voltage: in the range of ku = 0.9 ... 1.1 the variation of reactive power, for the given engine, is realized almost from simple to double, with a greater variation for under-rated voltages. But it is interesting to note that this curve has a tendency to "reduce", that reached a maximum q_{max} = 3.4999e+007 [var], for a k_{umax} = 1.091 (values valid for the given engine). This trend apparent of "reducing" does not remain permanent, because a more pronounced increase in voltage lead to strong oscillations in the values of reactive power with a variable frequency, respectively a certain change of the amplitude variations. So, to some extent, the synchronous motor behaves in this case, as compared with reactive power, as an oscillating circuit.

Representing these aspects of behavior of synchronous motor is shown in figure 5. From this figure it is observed that were admitted over-voltages by 45% higher than the nominal (it is noted also a part of the characteristic that corresponding to Figure 4), which in the practice of drives exploitation neither does not occur and nor is allowed.

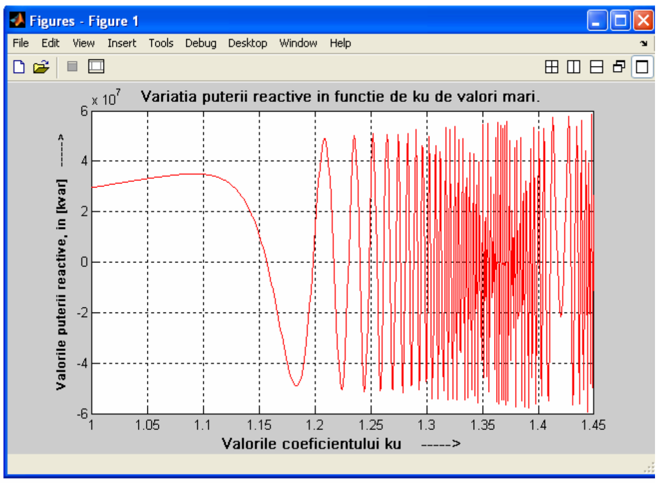

Fig. 5- Reactive power variation at coefficients ku of large amounts for given engine.

The test was carried out only as a study of behavior, considering that there was no precedent in current practice; such a voltage variation on a bar of medium voltage normally would be totally inadmissible, but may be taken into account in case of over-voltage like lightning on the air less protected networks, or in the case of incorrect handling (accidental) in a power system.

In principle, protection of power systems are solidly made, but some "accidents" might occur and when these issues should be considered, although such over-voltage can produce an insulation piercing of engine that produce other effects.

Conclusions

High power electrical drives equipped with synchronous motors can realize some benefits known to the system in which power works.

But sometimes the supply voltage does not comply with the corresponding nominal value, being produced important deviations, which can lead to abnormal functioning of some regimes of that drives, even if the load remains constant for a long time.

The literature also presents some issues, which were not sufficient highlighted, and this study reveals some of the elements that can occur in such situations and what can be done in such cases to limit negative effects.

It is noted that the internal angle of the motor decreases with increasing voltage. If decreasing of voltage becomes too pronounced, it is possible that this angle exceed the θmax, i.e to reach the unstable zone of operation of synchronous motor (area $\theta max < \theta \leq 180$ degrees) when the synchronous motor is out of synchronism and it stops.

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Influența tensiunii de alimentare asupra unghiului intern şi a puterii reactive la un motor sincron dintr-o acționare electrică

Rezumat

Sunt cazuri practice în care unele acționări cu motoare sincrone se confruntă cu situații în care tensiunea de alimentare poate fi mai mare/mai mică decât tensiunea de alimentare nominală, dar fără fluctuații pronunțate sau cu fluctuații relativ lente în timp. Lucrarea analizează influența acestei situații asupra unghiului intern al maşinii si puterii reactive debitate de aceasta. Concluziile obținute sunt cu atât mai importante cu cât asemenea sisteme de acționare electrică sunt, în general, de puteri mari, iar uneori chiar de puteri foarte mari.