# Examination of Frequency Controlled Asynchronous Drives at Variable Load Torque - Laboratory Simulator

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*Abstract* – **Contemporary electrical transport vehicles are designed on the base of power drives controlled by highly efficient devices and microprocessor safety and control systems. A laboratory simulator, based on the newest technologies, enables the examination of both open loop motion control and vector control on a drive in case of inconstant load torque.**

*Keywords* – **asynchronous drives, frequency control, characteristics.**

## I. INTRODUCTION

The development of the energy and transport equipment entered into a new stage during the past years. Regenerative converters (based on IGBT technology) and energy-saving motors are introduced into many modern trams, trolleybuses, underground vehicles and locomotives. The fast technological progress entails higher requirements of education quality. The bachelor and master programmes on Power Engineering and Electrical Equipment in the Todor Kableshkov University of Transport in Sofia prepares highly qualified experts in the respective fields of the transport and industry. These fields are attractive areas for Bulgarian and foreign investment for progress, modernization and expert education. The lecturers realize the necessity of training of skilled workers for electrical transport and power engineering needs. Therefore, a modern laboratory simulator built on contemporary devices was created (Fig.1). It includes an energy-saving induction motor AD (2,2 kW), controlled by a Sinamics G120 frequency converter [1]. A SG synchronous generator (30V, 60A) and resistors simulate the load of the motor. An HTL encoder can be used for closed loop motion control on the drive. A WINDOWS-based computer system is used for configuring and data storage. The necessary configuration software STARTER is installed on this computer. It can be used for setting-up the Sinamics G120 frequency converter.

## II. BASIC PRINCIPLES OF THE FREQUENCY CONTROL ON ASYNCHRONOUS DRIVES

As it is known, in order to regulate the speed of asynchronous motors a change of frequency of the supply voltage (frequency control) is necessary [2]. The stator winding is fed with voltage with adjustable frequency $f_1$, that causes changes of the synchronous speed $\omega_o$ defined by the following equation:

$$\omega_o = \frac{2.\pi.f_1}{p} \qquad (1)$$

where $p$ is the number of the motor pole pairs.

At the same time, however, an amendment of the voltage amplitude is required, determined by flux saturation. Ignoring the relatively small voltage drop in the stator circuit, the following relation exists:

$$U_1 \sim E_1 = 4{,}44.w_1.k_{w_1}.\Phi.f_1 = c_1.\Phi.f_1 \qquad (2)$$

where: $U_1$ – supply voltage; $E_1$ – electromotive voltage of the stator winding; $w_1$ – number of turns of stator winding; $k_{w1}$ – coefficient of the filling of the stator winding; $\Phi$ – flux; $c_1$ – coefficient: $c_1 = 4{,}44.w_1.k_{w1}$.

Eq. (2) shows that the reduction in frequency while maintaining the nominal supply voltage is accompanied by a strong increase in magnetic flux $\Phi$ and saturation of the machine. Therefore, when reducing $f_1$ it's necessary to reduce the amplitude of the voltage to meet the condition $\Phi = const$.

There are several techniques for speed and torque control for inverters with induction motors. These techniques can be roughly classified as follows:

- V/f characteristic control (known as: V/f control);
- Field-orientated closed-loop control technique (known as: Vector Control).

The simplest speed control represents proportional V/f characteristic. In this case the stator voltage of the induction motor is adjusted proportionally to the stator frequency. This technique has proven itself for a wide range of basic applications, where the load is approximately constant.

There are several versions of the V/f characteristic:

- Linear (standard case);
- Square-law characteristic ($f^2$ characteristic), which takes into consideration the torque characteristic $M=f(\omega^2)$ of the motor load (e.g. fan/pump). This is an energy saving characteristic as the lower voltage also results in lower currents and losses;
- Programmable characteristic, which takes into consideration a specific torque characteristic of the driven load;
- Flux current control (FCC), which can give a more efficient and better load response than other V/f modes because the FCC characteristic automatically compensates the voltage losses of the stator resistance for static (steady-state) or dynamic loads. This is used especially for small motors which have a relatively high stator resistance.

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The goal of the V/f control is to keep the flux $\Phi$ constant in the motor. In this case, $\Phi$ is proportional to the magnetizing current $I_\mu$ and the ratio between voltage V and frequency f:

$$\Phi \sim I_\mu \sim U_1 / f_1 \quad (3)$$

The torque M, developed by induction motors, is proportional to the vectorial product of flux and current:

$$M = \overline{\Phi} * \overline{I} \quad (4)$$

In order to generate the maximum possible torque from a given current, the flux must be held constant at its nominal value. Therefore, the value of the magnetizing current must be constant even if the stator frequency changes. This can be achieved approximately if the stator voltage U is changed proportionally to the stator frequency.

Vector Control significantly improves the torque control. The Vector Control is based on the fact that for a specific load situation or required torque, the required motor current is regulated with respect to the motor flux so that the appropriate torque is obtained. If the stator current is emulated in a circulating coordinate system, linked with the rotor flux Φ, then it can be broken down into the flux-generating current component $i_d$ in-line with the rotor flux and into a torque-generating current component $i_q$, vertical to the rotor flux. These components are corrected to track their set points in the current controller using their own dedicated PI controllers and are equal to the set points in steady-state operation. Then the component $i_d$ is proportional to the flux $\Phi$ and the torque is proportional to the product of $i_d$ and $i_q$.

When compared to V/f control, Vector Control has the following advantages: stable during load and set point changes, better control performance, better noise/disturbance characteristics, the motor and braking torque are controlled independently of the speed, accelerating and braking are possible with a maximum adjustable torque.

## III. Methods for testing the characteristics of frequency controlled asynchronous drive at variable torque

Methods for examination of two aspects of frequency controlled asynchronous drives are developed:

- Determination of the static mechanical and electro-mechanical characteristics of asynchronous electric drive with frequency control;

- Determination of the dynamic characteristics at a load torque change.

In all examinations the load torque can be changed by various techniques:

- It can be changed lightly altering the resistance of the load resistors or the generator flux current;

- It can be raised with a jerk switching the circuit closers $K_1$ and $K_2$ by pushing buttons $B_1$ and $B_2$. Then the load torque can be reduced with a jerk by pushing button S.

The laboratory simulator enables examinations of many cases of open loop or closed loop motion control in inconstant load torque. The Sinamics G120 frequency converter offers several versions of the V/f characteristic control without speed feedback: it can be linear (parameter P1300=0), flux current control (parameter P1300=1), square-law characteristic (parameter P1300=2) or programmable characteristic (parameter P1300=3) [3]. The closed-loop vector control with speed encoder can be examined, too (parameter P1300=21). This frequency converter offers also many other methods of control: the user can fix the output voltage of the inverter, independently of the frequency, or there is a typical setup for textile applications. Even a sensorless vector control without feedback may be used (parameter P1300=20) if very high speed accuracy is not required and a defined torque has not to be maintained for low speeds (below approximately 10% of the rated motor frequency) [1].

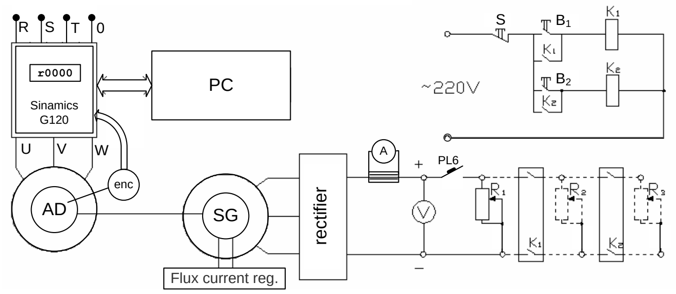


Fig. 1. Laboratory simulator

### A. Determination of the static mechanical and electro-mechanical characteristics of asynchronous electric drives

The static mechanical and electromechanical characteristics of an asynchronous electric drive represent the speed as functions of the torque and the motor current:

$$\omega = f(M),\ \omega = f(I)$$

Interesting are also the characteristics that show the change of energetic parameters (power factor $cos\varphi$ and efficiency $\eta$) of the drive at the load change:

$$cos\varphi = f(M),\ \eta = f(M)$$

The static characteristics are examined at a set frequency by changing the load. The first point of the characteristics is obtained at the minimum load torque (PL6 on Fig. 1 is opened). During the examination, the following variables are measured by the Sinamics G120 frequency converter: actual inverter output frequency $f$ (parameter r0024), rms voltage applied to motor $U_{AD}$ (parameter r0025), rms value of motor current $I_{AD}$ (parameter r0027), electrical torque $M$ (parameter r0031), power $P_{AD}$ (parameter r0032), power factor (parameter r0038) and the actual speed detected by encoder $n$ (parameter r0061). At the same time, also the generator voltage $U_g$ and current $I_g$ are measured respectively by the voltmeter and ammeter mounted in the load circuit. The generator speed $\omega_g$ is measured by a digital tachometer. In order to get the second and further points of the characteristics, PL6 must be closed and the load torque must be changed by the above listed techniques ($M_{rated}$ = 14,8 Nm).

After the measuring is finished, the frequency can be changed and all examinations may be repeated.

Thus a family of characteristics may be obtained (Figs 2 and 3).

The drive efficiency and the load torque may be calculated:

$$\eta = \frac{P_g}{P_{AD}} = \frac{U_g.I_g}{P_{AD}} \quad (5)$$

$$M_c = \frac{P_g}{\omega_g} = \frac{U_g.I_g}{\omega_g} \quad (6)$$

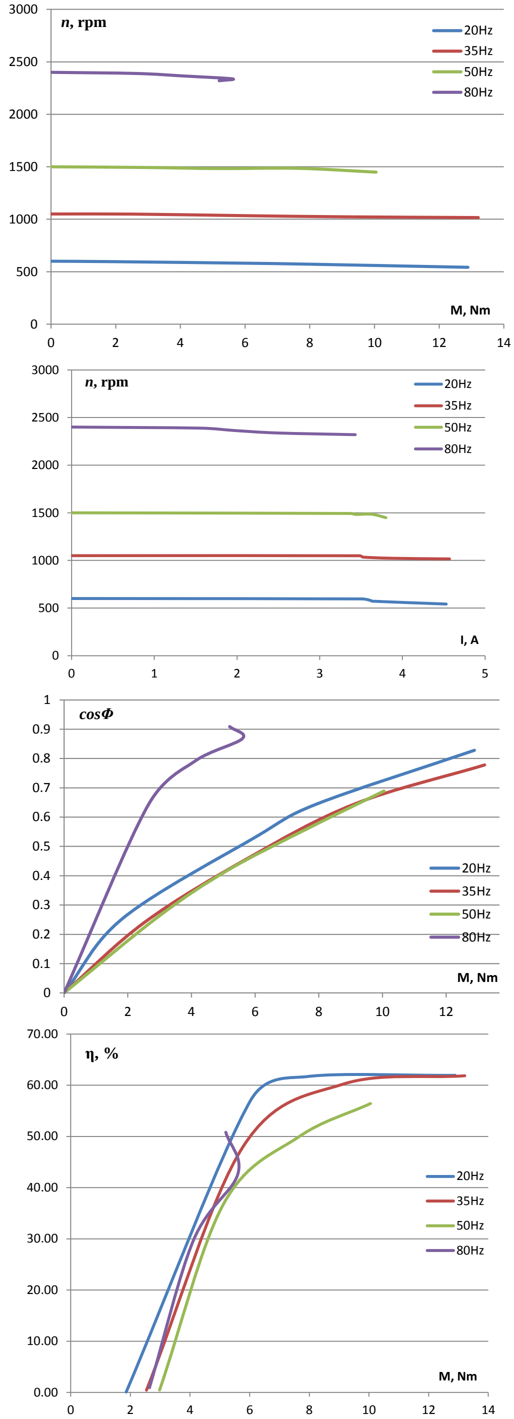


Fig. 2. Static characteristics at linear V/f control

*B. Determination of the dynamic characteristics of asynchronous electric drives*

The software STARTER provides additional options for control on the drive. A program which can trace the parameters of the frequency converter in the real time and write them into the computer memory is added. It can trace up to 30 parameters simultaneously, and then export the obtained data into an Excel sheet and create graphs. Many characteristics at motor starting and subsequent load changing are obtained at various control modes (Fig. 4a-f).

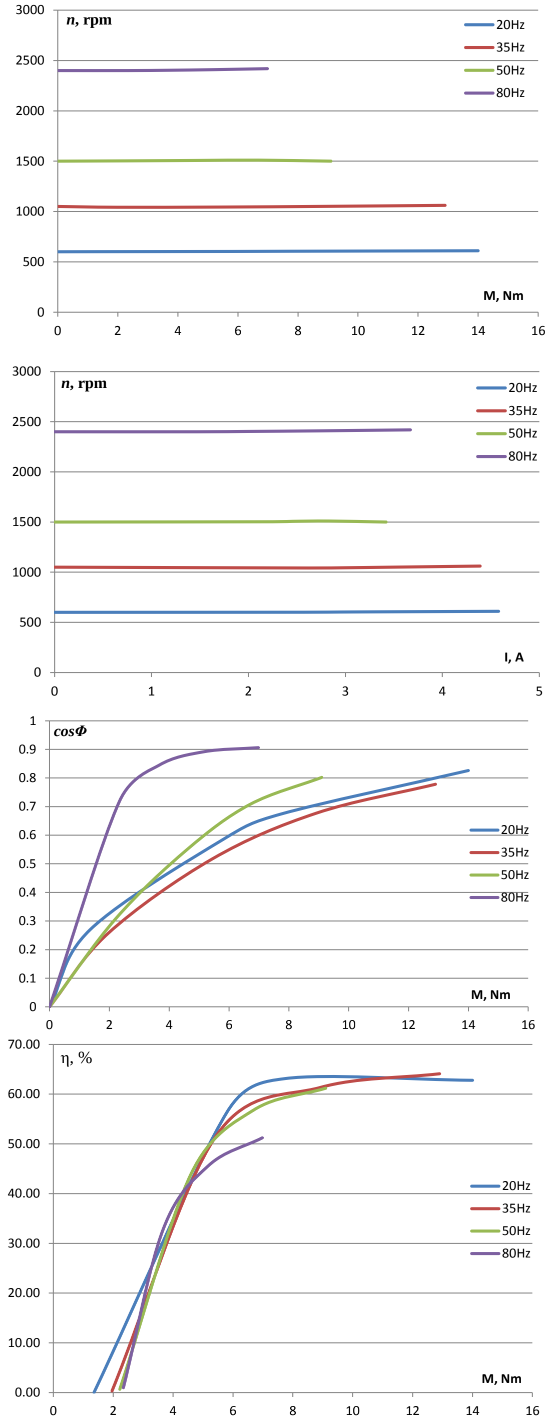


Fig. 3. Static characteristics at Vector control

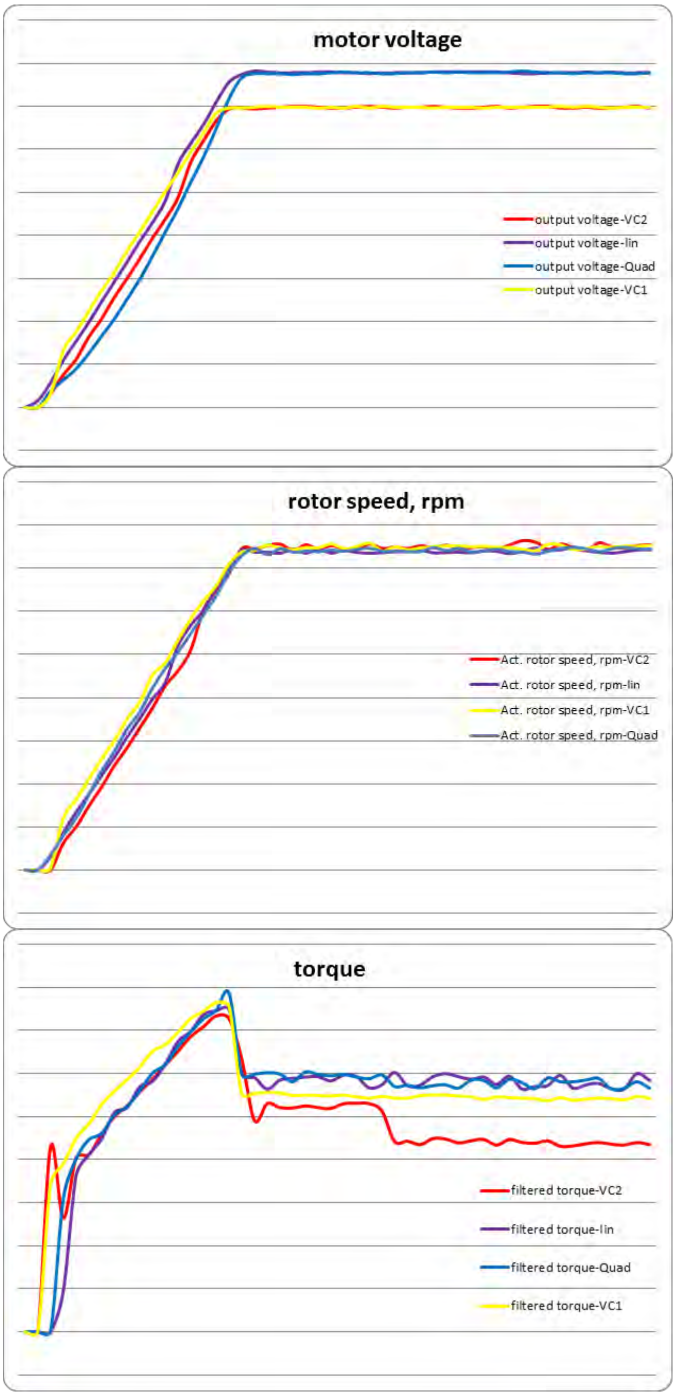


Fig. 4a, b, c. Dynamic characteristics

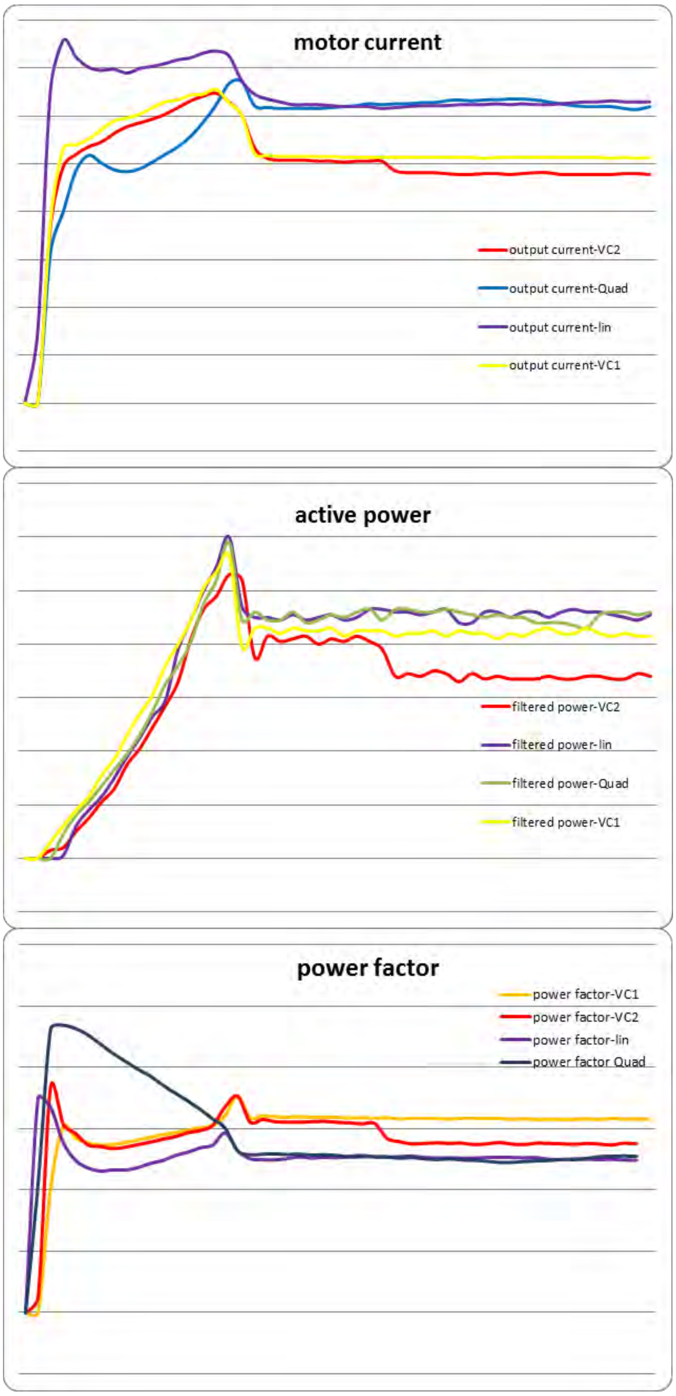


Fig. 4d, e, f. Dynamic characteristics

## IV. CONCLUSION

In this paper an experimental verification of the principles of the frequency control on the asynchronous drives is done. The Vector Control provides a stable speed irrespective of any changes of the load. It achieves almost the same moment, but at much lower current and voltage compared to the V/f characteristic control. This leads to higher values of the power factor and the efficiency. Therefore, the vector control must be used in all applications where the load varies widely, as in electric vehicles. If the load torque is approximately constant or varies in a narrow range the V/f control gives good results.

The square-law characteristic offers higher values of the power factor at low frequencies due to less flux generating current. It should be used to drive fans, pumps and other centrifugal mechanisms.

## REFERENCES

[1] SINAMICS G120 - Function Manual, Siemens, 2007.
[2] Boldea I, S.Nasar, Electrical Drives, CRC/Taylor&Francis,2006
[3] SINAMICS G120 - Control Units CU240E, CU240S, Parameter Manual, Siemens, 2008.