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SIMPLE VOLTAGE – HERTZ CONTROL WITH CURRENT FEEDBACK OF THE INDUCTION MACHINE

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Abstract **—The main back draw of the classical ”constant Volt/Hertz” (or U/f=constant) procedure, is the effects at low speed of the neglected stator voltage drops, which can be eliminated using different techniques, like programmed voltage-frequency characteristics, formula based voltage drop compensation and current-feedback based voltage drop compensation. The paper investigates the computation of the voltage angle- and amplitude-reference by the current-feedback-based method. Different approaches are presented, among others the current dependent slope characteristics are especially discussed in detail. MATLAB-Simulink simulation of a current-feedback based system was performed, followed by experimental investigation. The description of the test rig is also given, which is based on a dSPACE DS1104 controller board. Conclusions and references are presented.**

Keywords **— Scalar control procedure, U/f control, Volt-Hertz principle, Voltage drop compensation, Simulation**

1. INTRODUCTION

In spite of the technological advances in the field of vector controlled induction motors, the scalar control procedures did not loose their actuality. In order to deliver the highest possible torque per amper of stator current (i.e. optimal use of the drive capabilities) the flux-level has to be maintained constant at the rated value. This requirement can be performed by adjusting the output quantities of power supply, as the stator-voltage U_s and its frequency f_s . Usually the supply frequency is imposed by the working condition of the load-machine, therefore the only way to ensure the constant flux is the proper control of voltage applied to the stator.

Historically, the first economical (loss-less) control method for induction motors was the well-known “constant Volt/Hertz” (known also as U/f = constant) one. This is an empirical feed forward scalar control procedure, used in open loop, without rotational sensors, in order to maintain the rated flux level. Only the stator-frequency is imposed and the voltage is computed in direct proportion to the frequency accordingly to a simplified steady-state equivalent circuit of the stator. Ignoring the stator resistance and stator-leakage inductance the flux may be regarded as dependent only from ratio U/f and independent from the load, i.e. the stator current.

The structure of an induction motor drive system using scalar control according to constant Volt/Hertz principle is shown in Fig.1. The imposed frequency signal f_s^{Ref} is transformed by the “Voltage Reference Computation” block into the angle γ_s and amplitude U_s^{Ref} of the stator voltage reference vector, which serve as a basis for generating (by the block “3~ Sine Wave Generator”) the tree-phase sine-wave stator-voltage reference signals. The inverter “amplifies” them and drives the induction motor. The basic arrangement is without feedback. In the same case it is the most simple procedure, where the stator- voltage reference is computed approximately according to expression:

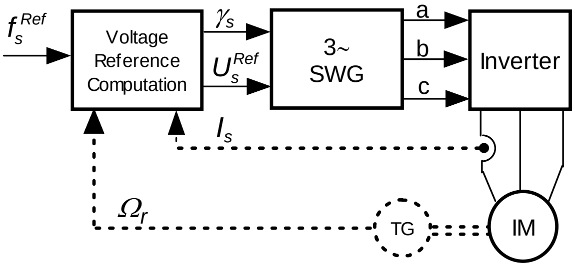


Fig. 1. Basic configuration of a scalar induction motor drive system, based on the Volt/Hertz principle.

$$U_s^{Ref} = U_{sN} * (f_s / f_{sN}) \tag{1}$$

For enhanced performances, the structure is supplemented with feedback signals (represented in dashed lines). In the above described simple approach of the “constant Volt/Hertz” procedure the supposition that the flux depends only on ratio U/f works rather well near and above the rated frequency. At low speed region, where the ignored stator-voltage drop becomes comparable with the applied one, a decreasing of the flux level and therefore also of the torque capability of the motor is evident. The effect of this neglected voltage-drop is as more important as the ratio $a_s = X_s/R_s$ is reduced [6]. Above $X_s = \Omega_s L_s$ where $\Omega_s = 2\pi f_s$ the synchronous angular frequency, R_s – the stator resistance, and $L_s = (L_m + L_{\sigma s})$ the resultant three-phase inductance, incuding also the leakage component.

In order to eliminate the effect of the neglected voltage drop, different techniques were developed:

- Programmed voltage-frequency characteristics [1];
- Formula-based voltage drop compensation [6], [10];
- Current-feedback-based voltage drop compensation [1], [3], [5].

Basically, at low frequencies all of above mentioned methods provide more voltage to the motor than the described simple approach. In the first case this is obtained by a constant voltage “boost” at low frequencies. The second method computes the corresponding voltage reference based on imposed frequency, slip and motor parameters. The computation formula is derived from the steady-state equivalent circuit of the motor. In the both cases the voltage dependence on the load is ignored. In the third case the voltage value is computed taking into account the motor current, making thus the voltage reference load-dependent. This method is developed in the followings.

2. CURRENT-FEEDBACK-BASED VOLTAGE DROP COMPENSATION

Evolved Volt/Hertz techniques apply load-dependent compensation of stator-voltage drop. There are some approaches, which are based on adding to the stator-voltage a component proportional to the measured stator-current. The derived characteristics are parallel shifted as is shown in Fig. 2.a), [1].

In a simple approach the current-dependent “boost” component is computed as $R_s i_s$, where i_s represents the rms value of the actual stator current [1], [2]. This simple method provides the torque even if the speed is low. At no-load running, the machine is still over-exited, because the magnetizing current is treated as load current. The compensation is also inadequate in regenerative operation [1].

In order to ameliorate the above described drawbacks other approach is based on the phase-sensitive rectifying of the stator-current, using as phase reference the stator-voltage. The component of the current in phase with the voltage will be used for stator-voltage boost computing [1].

Due to the parallel up-shifting of voltage-frequency characteristics from Fig. 2.a the voltage-limiting (at the rated voltage U_{sN}) is achieved at frequencies lower than the rated frequency f_{sN}, leading to an inadequate compensation in this upper speed region. This inaccuracy may be avoided by current-dependent modification of the characteristics slope as is shown in Fig. 3.a. That is performed by computing the voltage reference according to the following relation [3]:

$$U_s^{Ref} = \sqrt{2}\left(R_s I_s^{rms} + \frac{U_{sN}^{rms} - R_s I_s^{rms}}{f_{sN}} f_s^{Ref} \right), \text{ where } \sqrt{2}\left(\frac{U_{sN}^{rms} - R_s I_s^{rms}}{f_{sN}} \right) \text{ is the slope.} \quad (2)$$

Fig. 3.b) presents the computing structure of the angle- and amplitude-reference for stator-voltage generation based on equation (2). The mathematical calculi involved in voltage computation are simple; it may be performed even by means of low-end microcontrollers, supporting low cost applications.

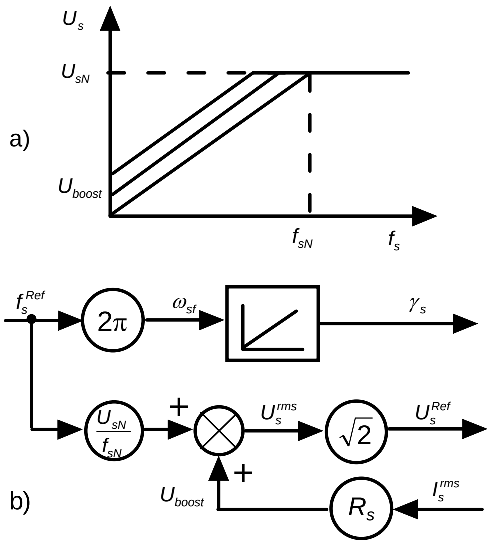


Fig. 2. Current-compensated U/f method
with parallel characteristics:
a) U-f characteristics b) structure.

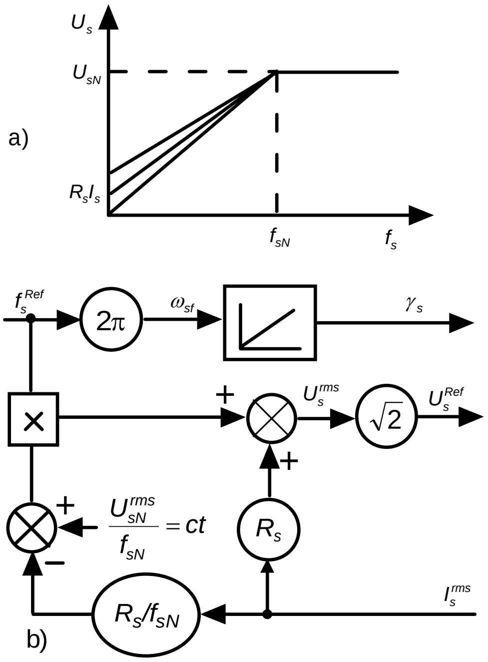


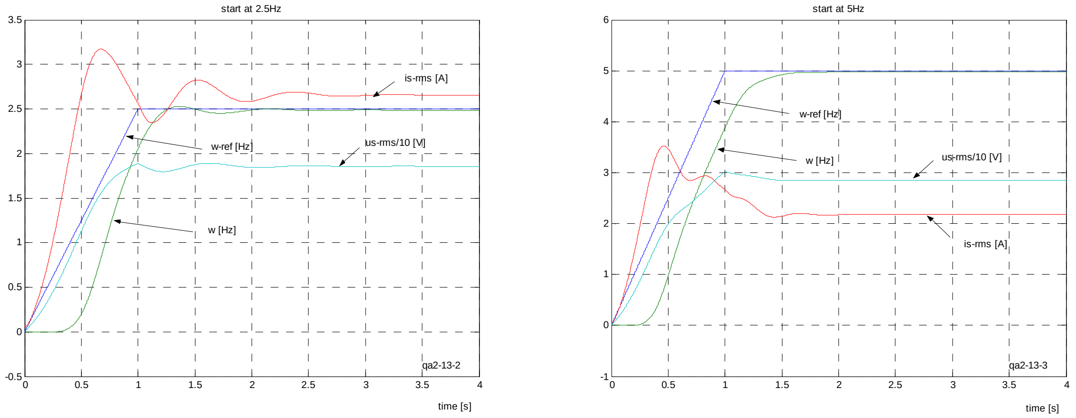
Fig. 3. Current-compensated U/f method
with variable slope of characteristics:
a) U-f characteristics b) structure.

By 100% compensation of the current-dependent voltage drop often stability problems are observed [1], [7], [9]. Therefore in order to stabilize the drive it would be necessary to make low-pass filtering of the current-dependent voltage component [9].

Vectorial compensation of stator-voltage drop offers more accurate performance [7], but the computational effort is considerable increased.

3. SIMULATION RESULTS

Simulation of current compensated constant Volt/Hertz operation according to equation (2) was performed. The nameplate data of the motor are P_N=2.2 kW, f_{sN}=50 Hz, U_{sN}=230/400 V, I_{sN}=8.2/4.7 A, cosφ= 0.82, n_N=1420 rpm.



a) 0…2.5 Hz b) 0…5 Hz

Fig. 4. Simulation results of no-load starting in the low speed region.

The simulation structure neglects the PWM effects of the inverter. Fig. 4.a) and fig. 4.b) presents the rotor shaft frequency (for the z_p=1 pole-pair) equivalent motor, stator voltage and stator current versus time, for no load starting. The ramping of the reference frequency is from 0 Hz to 2.5 Hz and 5 Hz, respectively.

4. EXPERIMENTAL RESULTS

Fig. 5. shows the structure of the experimental set-up, which is consisting of the tested induction motor drive (IM), the mechanical load (a permanent magnet synchronous servomotor PMSM) and the control equipment. The drive under test is composed by the above mentioned IM (Type 1LA7-4AA10, SIEMENS), powered by a modified industrial DANFOSS inverter (type VLT5004) controlled by PC, via a dSPACE DS1104 controller card. The mechanical load machine is a SIEMENS PMSM driven in 4 quadrants by a SIMOVERT equipment configured in torque-control mode. It provides also the measured actual speed and actual torque value. The control signals and the acquisitioned data are conditioned and isolated galvanic by a Signal Conditioning Unit (SCU). The real-time software is running on RISC/DSP processors of the DS1104 card, and it is generated automaticaly based on MATLAB-Simulink files. The controlling and monitoring tasks of real-time experiments are provided by ControlDesk experiment software. Fig. 6. a), b), c) and d) show the stator currents, stator voltage, reference-frequency and rotor speed for a no-load start with frequency ramping from 0 up to 5Hz (i.e. 150 rpm). In fig. 7. a), b), c) and d) there are presented the same quantities for ramping from 0 up to 2.5 Hz stator frequency (i.e. 75 rpm).

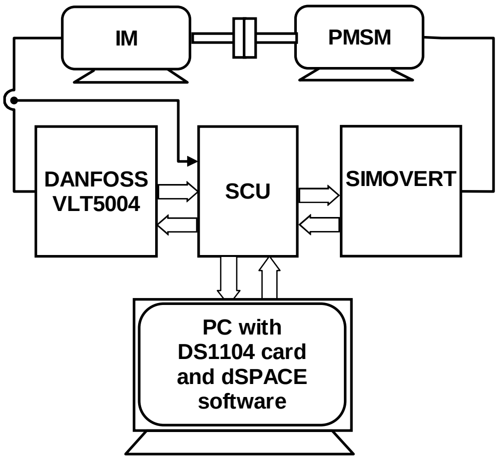


Fig. 5. Experimental set-up.

A. Frequency ramping from 0 Hz up to 5 Hz:

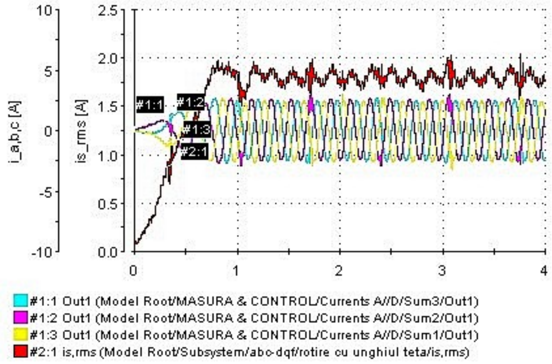


Fig. 6. a) Stator currents versus time:
r.m.s. and instantaneous values.

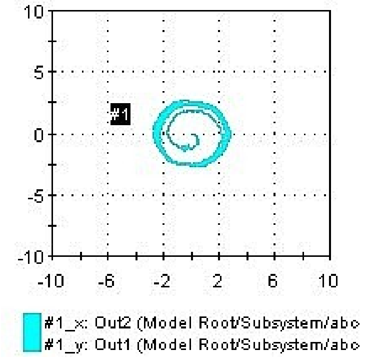


Fig. 6. b) Stator-current space-phasor
diagram.

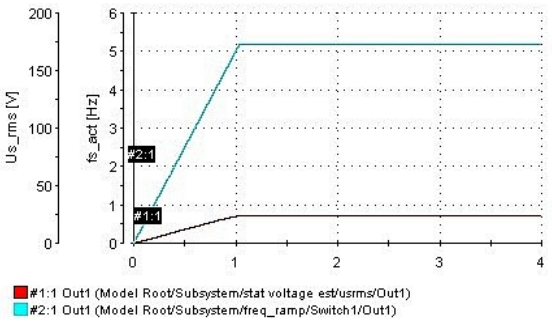


Fig. 6. c) Stator voltage and reference
frequency versus time.

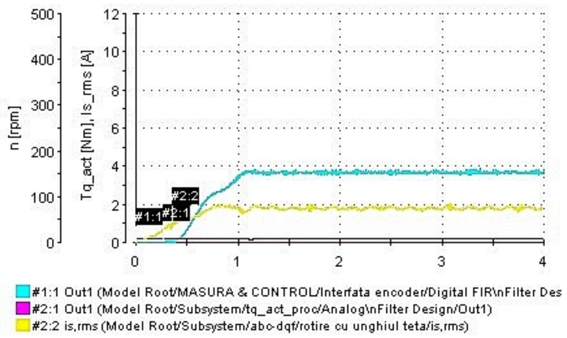


Fig. 6. d) Rotor speed and stator voltage
versus time.

B. Frequency ramping from 0 Hz up to 2.5 Hz:

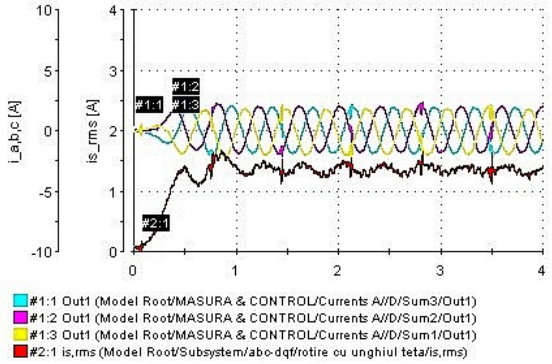


Fig. 7. a) Stator currents versus time:
r.m.s. and instantaneous values.

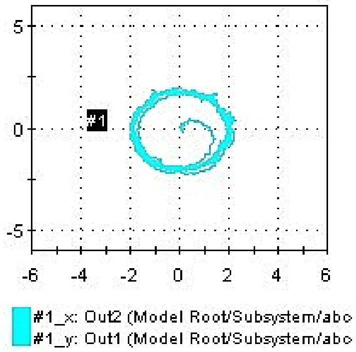


Fig. 7. b) Stator-current space-phasor
diagram.

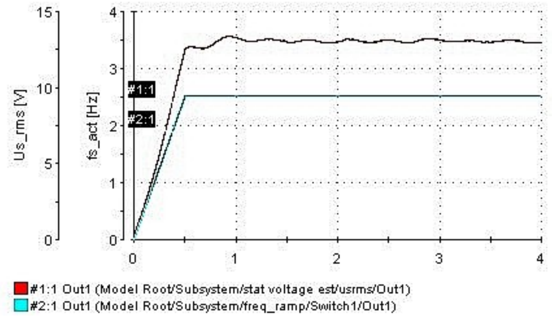


Fig. 7. c) Stator voltage and reference
frequency versus time.

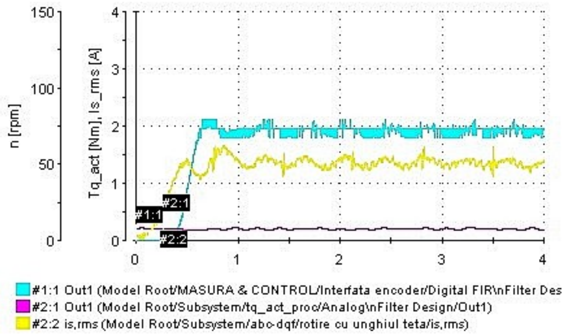


Fig. 7. d) Rotor speed and stator voltage
versus time.

5. CONCLUSIONS

The simulation and experimental results show that the Volt/Hertz principle with current dependent slope of the characteristics is a viable procedure, offering adequate compensation of the resistive voltage drop at low and also at high speed. The simulated currents are higher in comparison with the measured ones due to the neglected inverter losses. At low speed some instability appears, therefore it was necessary to introduce a first order leg in order to filter the current dependent component of the stator-voltage computation.

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