Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 2, rok 2006, ročník LII, řada strojní
článek č. 1553

Csaba SZABÓ [*], Maria IMECS [**], Ioan Iov INCZE [***]

SIMPLE VOLTAGE-HERTZ CONTROL WITH CURRENT-FEEDBACK OF A CONSTANT FIELD-EXCITATED SYNCHRONOUS MOTOR

JEDNODUCHÉ NAPĚŤOVĚ-FREKVENČNÍ ŘÍZENÍ S PROUDOVOU ZPĚTNOU VAZBOU PŘI KONSTANTNÍM BUZENÍ SYNCHRONNÍHO MOTORU

Abstract

In order to achieve the highest torque per ampere ratio for the AC machines, the flux-linkage amplitude has to be maintained at his rated value. This can be achieved by adjusting in a proper way the amplitude of the stator-voltage and its frequency. Based on this fact the first control method, which assures the so-called “loss-less” operation for the motor was developed, that is the well known constant Voltage-per-frequency operation. The only control variable is the frequency, while the stator voltage is computed based on the simplified steady-state equivalent circuit of the motor. The main back-draw of this method consists in the presence of the stator-voltage drop, which may cause stability problems at low speed, if they are neglected. Different methods were developed in order to compensate the voltage s. This paper concentrates on the compensation realized by means of current-feedback. Computer-based simulation was performed for validation.

Abstrakt

Pro dosažení nejvyššího poměru točivý moment/proud v AC strojích, musí být udržován sdružený magnetický tok na odpovídající úrovni. Toho je možné dosáhnout vhodným nastavením hodnoty napětí statoru a jeho frekvence. Na základě této skutečnosti byla vyvinuta metoda řízení, která zaručuje tzv. „méně ztrátovou“ funkci, známou také jako metoda konstantního poměru napětí/frekvence. Jedinou řídicí proměnou je frekvence, zatímco napětí statoru je určeno výpočtem na základě zjednodušeného ustáleného stavu ekvivalentního obvodu motoru. Hlavní nevýhoda této metody spočívá v přítomnosti poklesu napětí statoru, které pokud je zanedbáno, může způsobit problémy se stabilitou při nízké rychlosti. Pro kompenzaci poklesu napětí byly vyvinuty různé metody. Příspěvek se zabývá realizací kompenzace pomocí proudové zpětné vazby. Ověření bylo provedeno počítačovou simulací.

1 INTRODUCTION

In AC drives historically the first control method, which assures loss-less operation for the motor, was the so-called constant Voltage-per-frequency (or simple V/Hz) procedure. The constant stator-flux operation is obtained indirectly i.e. empirically, (no flux identification is required) by an

---

[*] Lecturer, eng, Department of Electrical Drives and Robots, Faculty of Electrical Engineering, Technical University of Cluj-Napoca, Daicoviciu Street 15, Cluj-Napoca, Romania, tel. (+40) 264 401 242, e-mail csaba.szabo@edr.utcluj.ro

[**] Professor, Dr.-eng. Department of Electrical Drives and Robots, Faculty of Electrical Engineering, Technical University of Cluj-Napoca, Daicoviciu Street 15, Cluj-Napoca, Romania, tel. (+40) 264 401 242, e-mail imecs@edr.utcluj.ro

[***] Lecturer, Dr.-eng, Department of Electrical Drives and Robots, Faculty of Electrical Engineering, Technical University of Cluj-Napoca, Daicoviciu Street 15, Cluj-Napoca, Romania, tel. (+40) 264 401 242, e-mail ioan.incze@edr.utcluj.ro

open-loop feed-forward scalar control procedure, without mechanical sensors. The only reference variable is the supply frequency, while the stator-voltage is computed based on the simplified stator equation resulting from the steady-state equivalent circuit.

In spite of the development considering the vector control procedures for the AC machines, the scalar control method still finds his place in various industrial applications. Most of the electrical drives present on the market include beside the vector control structures, also scalar control based strategies. Usually, the scalar control is preferable in reduced speed-range applications ($\omega_{\min}/\omega_{\max} \approx$ 1:10), where is no need for high dynamic behaviour, like pumps, ventilators, etc.

In industrial applications the Volt-per-Hertz control is frequently used, due to his simplicity. The stator construction of the induction motors and the synchronous machines are the same, consequently this control method theoretically may be applied without any changes for both machine types. Because the synchronous motor operates at synchronous speed, there are no slip-related problems to be solved in comparison with other motor types. The mechanical characteristics speed versus torque are constant, only the load angle will be variable depending on the load torque modification, which has no importance on this scalar control procedure.

Figure 1 presents the block diagram of the salient-pole synchronous motor drive system-using the constant Volt-per-Hertz scalar control procedure. Considering the f_s^{Ref} reference frequency, the U_s^{Ref} amplitude and Ω_s synchronous angular speed of the stator-voltage vector is computed by means of the “Voltage Reference Computation” block, which provides the input signals serving as parameters for the block “3~ Sine Wave Generator”, which generates the modulation signals of the three-phase sine-wave stator-voltage. The DC-link inverter “amplifies” them and drives the synchronous motor. The basic arrangement usually is without feed-back, because the original control method is a feed-forward one, consequently it does not require any feedback for the computation of the control variables.

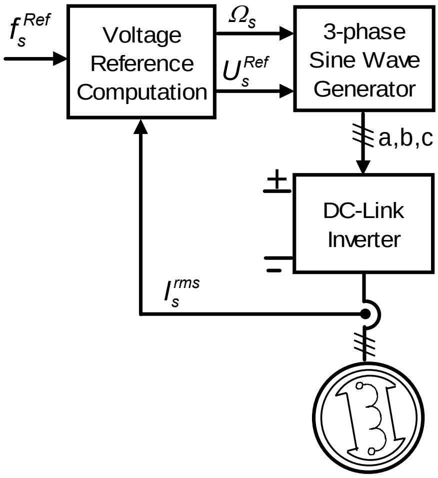


Fig. 1. Basic configuration of a salient-pole synchronous motor drive system based on the Volt-per-Hertz scalar control procedure using current feed-back.

In this case the stator-voltage reference may be computed approximately according the following expression:

$$U_s^{Ref} = U_{sN} \frac{f_s}{f_{sN}} \tag{1}$$

where U_{sN} is the rated stator voltage, f_{sN} the rated and f_s the actual value of the stator frequency.

Nevertheless, the main drawback of the constant Volt-per-Hertz procedure consists in the effects of the stator-voltage drop, which cause difficulties especially at low speed operation. The voltage drop at low frequencies has the same order of magnitude with the computed voltage and it makes the method inadequate for low speed region. This problem can be eliminated by adopting different improving techniques, like:

- programmed voltage versus frequency characteristics [1];
- voltage-drop compensation using current-feedback [2], [3];
- formula based voltage-drop compensation [4].

All these procedures are based on providing more voltage on the motor phases, than in case of the basic control method. In the first case a constant "boost" voltage is added to the initially computed value. The second method computes the corresponding voltage reference based on the imposed frequency and motor parameters. Neither of the two methods takes into account the load. In the third case the motor load is also taken into account in the reference voltage computation by means of the actual stator current. This procedure will be presented in the followings.

2 CURRENT-FEEDBACK BASED VOLTAGE-DROP COMPUTATION

The former evolved constant Volt/Hertz procedure applies load-dependent compensation of stator-voltage drop. In a simple approach, an actual stator-current dependent "boost" component is added to the computed reference voltage. It provides torque even at low frequencies, but the voltage-frequency characteristics will be parallel shifted, and the voltage limit (set at the U_{sN} rated stator voltage value) will be achieved at frequencies lower than f_{sN} the rated one, 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 Figure 2. That is performed by computing the voltage reference according to the following relation [2]:

$$U_s^{Ref} = \sqrt{2}\left(R_s I_s^{rms} + \frac{U_{sN}^{rms} - R_s I_s^{rms}}{f_{sN}} f_s^{Ref}\right), \tag{2}$$

where R_s is the stator resistance.

In equation (2) the term

$$\sqrt{2}\left(\frac{U_{sN}^{rms} - R_s I_s^{rms}}{f_{sN}}\right) \tag{3}$$

represents the variable slope of the characteristics from Fig. 2, depending on the stator current.

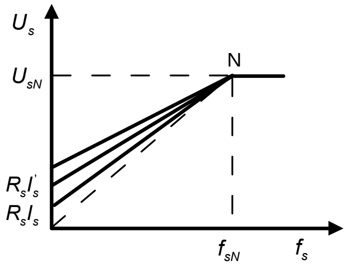


Fig. 2. Voltage-frequency diagram for the current-compensated Volt/Hertz method with variable slope of the characteristics.

The structure of the stator-voltage computation block, based on equation (2), is shown in the Fig. 3.

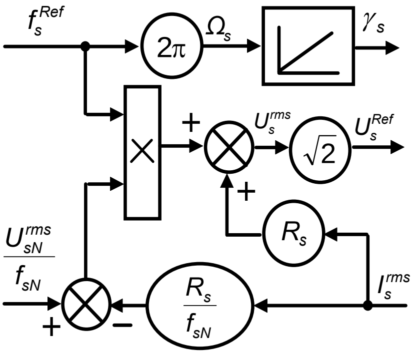


Fig. 3. Structure of the voltage computation block of the current-compensated Volt/Hertz method with variable slope of the characteristics.

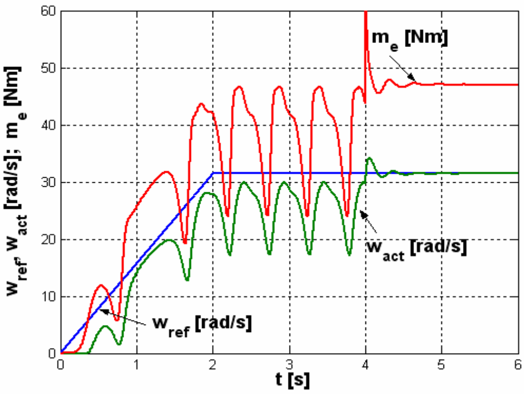
By 100% compensation of the current-dependent voltage drop often stability problems are observed [1], [5]. Therefore in order to stabilize the drive it would be necessary to make low-pass filtering of the current-dependent voltage component [5].

3 SIMULATION RESULTS

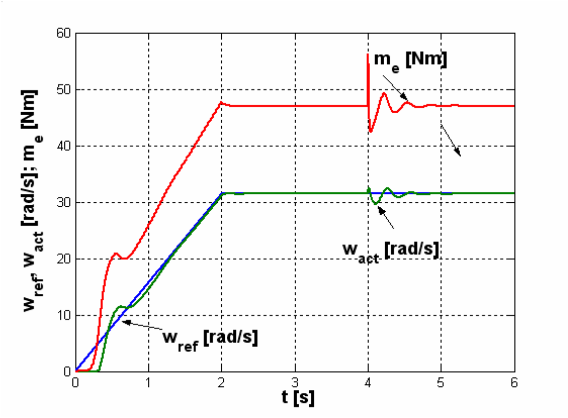
For validation of the proposed voltage-drop compensation technique, computer simulation was performed, using the MATLAB/Simulink dynamic simulation environment.

The initial conditions were the followings: the salient-pole synchronous motor with damper windings is started in asynchronous operation mode (the excitation winding is not fed). A speed-dependent linear load-torque profile is applied, i.e. its value increases from the motor no-load torque (at zero speed) to the rated electromagnetic torque (at the reference speed) corresponding to the steady-state operation. Because the presented technique is developed to enhance operation at low speed region, the imposed reference frequency was chosen 5 Hz.

Figure 4 shows the evolutions of the electrical angular speed and the electromagnetic torque versus time. A slow starting was simulated, with a slope of 2.5 Hz/s. At 4s from the starting the excitation is connected to the DC-supply, consequently the motor operates in synchronous mode. Simulations were performed for both, the basic Volt/Hertz operation and the procedure with current-feedback compensation.



a)



b)

Fig. 4. Electrical angular speed (ω_{ref} – reference value, ω_{act} – actual value) and electromagnetic torque (m_e) versus time for:
a) basic Volt/Hertz procedure,
b) current-feedback based voltage-drop compensation procedure.

By analyzing the simulated results, it can be observed, that the motor speed presents oscillations during the starting process, and the so-called hunting characteristic phenomenon appears, because of the torque perturbations. After synchronization the torque and speed are stabilizing. In comparison with current-feedback compensation of the stator-voltage drop a smooth starting is ensured and the additional current-dependent voltage component also eliminates the hunting phenomenon. In this case the motor transient operation is significantly improved. In figure 5 are presented the evolution of the computed stator-voltage amplitude for the two cases mentioned before.

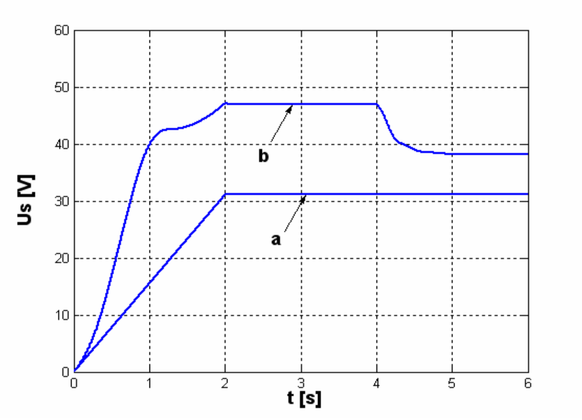


Fig. 5. Stator-voltage amplitude versus time:
a) basic Volt/Hertz procedure,
b) current-feedback compensation procedure.

It can be observed that the difference between the two voltages is significant and it has the same order of magnitude with the initially computed reference value. The sudden voltage-drop, which may be observed on the current-feedback compensated characteristic, occurs when the excitation is connected.

4 CONCLUSIONS

The results obtained by simulations confirm that a compensation of the stator-voltage drop has to be compensated in order to ensure the motor torque and steady-state operation in low speed region. In order to avoid the hunting phenomenon, the motor load should be taken into account, using the current-feedback information for the reference stator-voltage compensation. In addition, based on the simulation results, it is obvious that the compensation voltage component helps the motor to achieve the synchronous operation corresponding to the reference frequency, even if the excitation winding is not connected, and also in the moment, when the excitation is fed.

Further improvements to this method may be achieved by a vectorial compensation of the voltage drop component.

REFERENCES

[1] ABBONDANTI A. Method of flux control in induction motors driven by variable frequency, variable voltage supplies. Reprinted from *Proceedings of IEEE IAS Annual Meeting*. 1977, pp 177-184. Rajashekara K., Kawamura A., Matsuse K. (Editors): *Sensorless Control of AC Drives, A selected reprint volume*. IEEE Press, New York, 1996, pp. 40-47. ISBN 0 7803 1046 2.

[2] IMECS, M. & SZABO, Cs. Control structures of induction motor drives – state-of-the-art. *Proceedings of 4th Workshop on European Scientific and Industrial Collaboration WESIC 2003 - Advanced Technologies in Manufacturing*. Miskolc-Lillafüred, Hungary, 2003, ISBN 963 661 570 5, pp. 495-511.

[3] INCZE I. I. & IMECS, M. & SZABO, Cs. Simple voltage-hertz control with current feedback of the induction machine. In *Proceedings of 2004 IEEE-TTTC AQTR 2004 – THETA 14.* Cluj-Napoca, Romania, 2004, Tome I, ISBN 973-713-046-4, pp. 389-394.

[4] KELEMEN, A. & IMECS, MARIA. *Vector Control of AC Drives. Volume 2: Vector Control of Synchronous Machine Drives*. Budapest, Ecriture, 1993. ISBN 963 593 140 9.

[5] MUNOZ-GARCIA A. & LIPO T. A. & NOVOTNY D. W. A new induction motor V/f control method capable of high-performance regulation at low speeds. *IEEE Transactions on Industry Applications*. 1998, Vol.34, No.4, July/August, pp. 813-821.

[6] IMECS, M., INCZE I. I., SZABO, CS., ADAM, T. Scalar and vector-control structures of AC motors. *Conference of Energetics and Electrical Engineering, ENELKO 2003.* 2003, Cluj-Napoca, Romania, pp. 82-98.

[7] DAS J. C. Effects of momentary voltage dips on the operation of induction and synchronous motors. *IEEE Transactions on Industry Applications.* 1990, Vol. 26, No. 4. July/August, pp. 711-718.

[8] UEDA, R., SONODA, T., KOGA, K., ICHIKAWA, M. Stability analysis in induction motor driven by V/f controlled general-purpose inverter. *IEEE Transactions on Industry Applications*. 1992, Vol. 28, No. 2, March/April, pp. 472-481.

Reviewer: prof. Antonín Víteček, CSc., Dr.h.c., VŠB-Technical University of Ostrava