@2013 Journal of PU, Part: B
Vol.2 No.2, July 2013, pp 78-83
PRESIDENCY UNIVERSITY
ISSN: 2224-7610

Steady State Analysis of an Inverter Fed Synchronous Motor

Tapan Kumar Chakraborty*

ABSTRACT

The steady state analytical performance of a line commutated inverter fed three phase synchronous motor under variable speed condition is presented. The firing pulses for six silicon-controlled-rectifiers of the three phase inverter are generated by the control circuit in proper sequence with the help of synchronizing signal derived from the induced electromotive force of the synchronous machine by using voltage sensor. The analytical results indicate that a three-phase synchronous machine supplied by an inverter with the excitation winding connected in series to the input of the inverter provides similar characteristics of dc series motor.

***Keywords*:** Line commutated inverter, firing control circuit, synchronous motor, and steady-state analysis.

INTRODUCTION

Recently, many modern variable speed drives use synchronous motor as well as induction motor for precise and smooth control of speed with long-term stability and good transient performance [1-5]. The silicon-controlled-rectifier (SCR) based inverter is now used to control the speed of these drives. In order to obtain reliable control of the SCR-based power converter, a synchronous firing control scheme is necessary for its SCRs over a wide range of ac supply frequencies [6]. From the very beginning, the conventional dc motors have been used as variable speed drives in many industrial applications. However, for reliable operation of the system, the dc motor drives are not advisable in many cases due the drawbacks, such as, mechanical commutator needs regular maintenance, power/weight ratio reduces due to the additional weight of commutator, brush and commutator wear occurs due to friction and sparking, the commutator construction increases the cost of the dc motor drive, and unsuitable to operate in explosive and dusty environments.

Load commutated inverter fed synchronous motor with its excitation winding connected in series to the input of the inverter can be used most economically as variable speed drives in place of conventional dc motor drives over a wide range of speed [7-10]. The power circuit and firing control circuit configuration of the inverter are very simple [6] in structure.

A few research works have been performed on the line commutated inverter fed synchronous motor [8-10]. Almost all research works were performed using speed sensor for generating triggering pulses for SCRs of the inverter. The hardware for the system based on rotor position sensor is very complicated. In the present work, the steady state analysis of an inverter fed synchronous motor with the help of voltage sensor instead of speed sensor has been performed to realize the characteristics of dc series motor.

---

[*] *Department of Electrical and Computer Engineerin*
Presidency University, Dhaka, Bangladesh, Email: chak@presidency.edu.bd

System Description

The block diagram of the system considered for steady-state analysis is shown in Fig. 1. The system comprises of a three-phase autotransformer, an uncontrolled three-phase bridge rectifier, a dc link inductor and a three-phase line commutated inverter. The function of the dc link inductor is to suppress the harmonics contained in the output of the bridge rectifier. The combination of the uncontrolled rectifier and dc link inductor acts as a current source for the inverter. The excitation winding of the synchronous machine is connected in series to the input of the inverter. The synchronizing signal is obtained by sensing line-to-line voltages with the help of a small step-down transformer from the synchronous machine terminals. This synchronizing signal is inputted to the control circuit for generating firing pulses for six SCRs of the inverter in proper sequence.

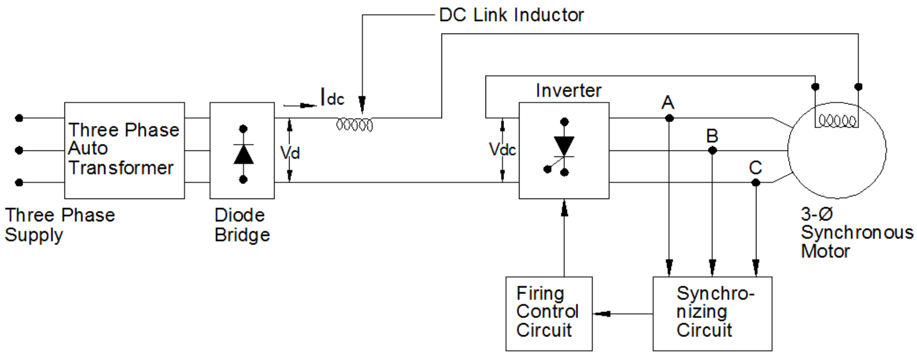

Fig. 1 The block diagram of the inverter fed synchronous motor.

Analytical Model

The steady-state analysis of the system is based on several assumptions to simplify the derivations. These assumptions are as follows: (i) The dc link current I_{dc} is assumed to be rippling free, (ii) The stator windings resistance drop I_{sy} R_{sy} of the synchronous machine is neglected, (iii) A gating signal for the SCR is available at the inverter lead angle β, (iv) The voltage commutated inverter operation is assumed to be loss less and free from harmonics, (v) The effect of magnetic saturation on the performance of synchronous machine is neglected, (vi) Flux-linkage is assumed to be constant during commutation period of SCR, (vii) Mechanical moment of inertia of the machine is assumed to be large so that the machine speed remains constant during commutation period, and (viii) Terminal voltages of the synchronous machine are assumed to be balanced and sinusoidal.

Line commutation of the SCRs of inverter is made possible by the fact that it's ac terminals are connected to the synchronous machine which is seen by the inverter as a three-phase ac source of terminal voltage V_{sy} (line-to-neutral) and per phase commutating reactance X_c. The steady state analytical model of the drive is described by a set of equations [7].

The no-load line-to-neutral voltage of the synchronous machine is given by,

$$E_{sy} = K_1 I_{dc} N \tag{1}$$

Where K1 is a constant, *Idc* is the dc link current flowing through the excitation winding of the synchronous motor, and N is the speed of the motor.

The fundamental component Isy (rms value) of the rectangular wave ac line current of amplitude I_{dc} is,

$$I_{sy} = \frac{\sqrt{6}}{\pi} I_{dc} \tag{2}$$

The supplementary displacement angle γ between E_{sy} and I_{sy} is found from the following equation,

$$cos\gamma = \frac{\sqrt{cos\beta[1-2K_d sin\gamma + K_d{}^2(sin^2\gamma + q^2cos^2\gamma)]} \quad + 0.0104X_c/K_1}{1-K_d(1-q)sin\gamma} \tag{3}$$

Where, K_1, K_d and q are constants. The inverter lead angle, $\beta = 180^o - \alpha$. The angle α is the triggering angle of SCR of the inverter. For a particular value of triggering angle, γ can be found by trial and error method using equation (3).

The electromagnetic torque developed by the synchronous machine is given by,

$$T = K_T I_{dc}{}^2 \tag{4}$$

Where, K_T is constant if the triggering angle of SCR remains at a fixed value. Thus the torque of the motor is directly proportional to the square of the dc link current like a conventional dc series motor.

The speed of the motor in rpm is given by,

$$N = \frac{V_d - I_{dc}R_{dc}}{K_N I_{dc} cos\beta} \tag{5}$$

Where, K_N is a constant, V_d is the dc link voltage, and R_{dc} is the total resistance of the dc link inductor and the excitation winding of the motor.

SIMULATION RESULTS AND DISCUSSIONS

The synchronous motor used in the present work has ratings: 3 ph, Y, 440 V, 10.8 A, 7.5 KVA, cosφ = 0.8, 1500 rpm, $50H_Z$, Excitation: 40 V, 8 A. The parameters of the motor are: X_d = 21.51 ohms/phase, X_q = 13.87 ohms/phase, Rf = 3.67 ohms, R_{sy} = 1.88 ohms/phase. The steady-state performance of the inverter fed synchronous motor is computed by using the mathematical equations (1-5) on a digital computer. Figure 2 shows that the variation of machine torque with dc link current for specific values of firing angle and dc link voltage. The firing angle must be within the safe region to avoid commutation failure. The variation of machine torque with the machine speed for specific values of firing angle and dc link voltage is shown in Fig. 3. It is observed that at low motor speed, torque is very high and becomes low at higher speed. It is very interesting to note that the characteristics of the Inverter fed synchronous motor are similar to those of conventional dc series motor.

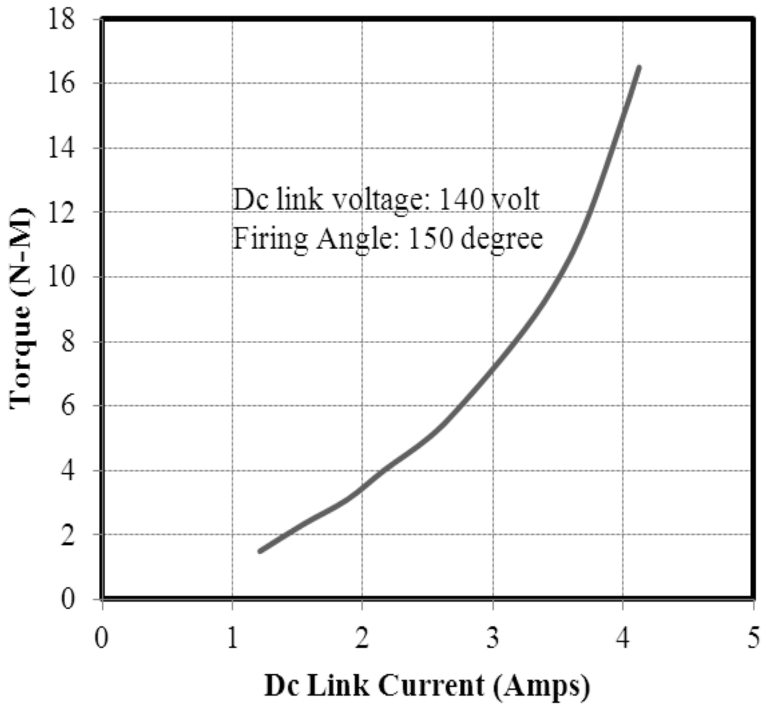

Fig. 2 Machine torque versus dc link current.

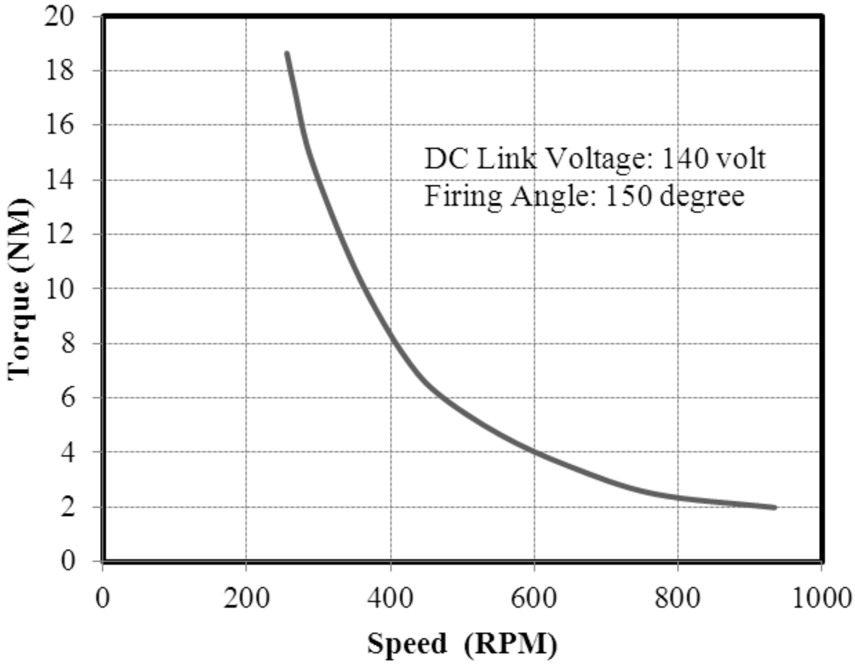

Fig. 3 The torque versus machine speed.

CONCLUSION

The steady state performance of a line commutated inverter fed synchronous motor under variable frequencies has been determined. The triggering pulses for six SCRs of the three phase inverter are generated by the control circuit in proper sequence by sensing terminal voltages of the synchronous motor. The simulated results exhibit almost similar characteristics of a dc series motor. Experimental investigations of the system may be performed in future and the simulated results can be compared with the experimental results.

REFERENCES

[1] S. Sengupta, S. N. Bhadra and A. K. Chattopadhyay, " An Inverter Fed Self-Controlled Commutatatorless Series Motor with the Field Winding in the DC Link", IEEE Transactions on Industry Applications, Vol.33, No.4, August 1997.

[2] R. Arulmozhiyal, and K. Baskaran, "Space vector pulse width modulation based speed control of induction motor using fuzzy PI controller, " International Journal of Computer and Electrical Engineering, vol. 1, no. 1, pp. 98-103, April 2009.

[3] A. Maamoun, A. Soliman, and A. M. Kheirelden, "Space-vector PWM inverter feeding a small induction motor," in Proc. IEEE International Conference on Mechatronics, Komamoto, Japan, pp. 1-4, May 2007.

[4] A. B. Chattopadhyay, S. Thomas and R. Chatterjee, " Analysis of Steady State Analysis of a Current Source Inverter Fed Synchronous Motor Drive System with Damper Windings Included", Trends in Applied Sciences Research, Vol.9, No.6, pp.992-1005, 2011.

[5] M. N. Uddin, and R. S. Rebeiro, "Online Efficiency Optimization of a Fuzzy-Logic Controller-based IPM Synchronous Motor", IEEE Transaction on Industry Applications, Vol.47, No.2, April 2011.
[6] T. K. Chakraborty, B. Singh, and S. P. Gupta, " A Microprocessor-based Firing Control Scheme for Three-Phase Thyristor Power Converter", Journal of Microcomputer Applications, Vol.13, pp.361-369, 1990.
[7] T. K. Chakraborty, "Microprocessor controlled commutatorless DC series motor drive", M. Sc. Engg Thesis, Department of Electrical Engineering, University of Roorkee, 1988.
[8] F.C. Brockhurst, "Performance Equations for D.C Commutatorless Motors using Salient Pole Synchronous Type Machines", IEEE Transaction on Industry Applications, Vol. IA - 16, No. 3, pp. 362 - 371, May / June 1980.
[9] H. Naitoh and F. Harashima, "Effects of magnetic saturation on the performance of thyristor commutatorless motor", IEEE Transaction on Industry Applications, Vol. IA- 18, No. 1, pp. 213-218, May/June, 1982.
[10] H. Natio, K. Iwamoto and F. Harashima, "Dynamic Characteristics and Instability problems of Triggering Lead Angle Controlled Commutatiorless Motors", Electrical Engineering in Japan Vol.102, No.4, pp. 81 - 90, July/August, 1982.