International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 7, No. 1, March 2016, pp. 1~6
ISSN: 2088-8694

Experimental Investigations of the Self-Controlled Synchronous Motor Connected to a Three-Phase Line Commutated SCR Inverter

Tapan Kumar Chakraborty
Department of Electrical and Computer Engineering, Presidency University, Bangladesh

Article Info

Article history:

Received Aug 12, 2015
Revised Oct 11, 2015
Accepted Nov 2, 2015

Keyword:

Constant delay angle
Firing circuit
Line-commutated inverter
Synchronous motor
Voltage sensor

ABSTRACT

This paper concerns the experimental investigations of the three-phase line commutated SCR inverter fed synchronous motor. The fabricated system consists of a line-commuted inverter, a three-phase synchronous motor with the excitation winding connected in series to the inverter input, a terminal voltage sensor and a gate-pulse generating circuit. The firing pulses for SCRs of the inverter are generated by the microprocessor in proper sequence with the help of synchronizing signal derived from the terminal voltages of the synchronous machine. The steady state performance characteristics are obtained experimentally using the fabricated system. The experimental results show that a three-phase synchronous motor supplied by a line commutated inverter with the excitation winding connected in series to the dc link provide excellent characteristics of the conventional dc series motor.

Corresponding Author:

Tapan Kumar Chakraborty
Departement of Electrical and Computer Engineering,
Presidency University,
10 Kemal Ataturk Avenue, Banani, Dhaka-1213, Bangladesh.
Email: chak@mail.presidency.edu.bd

1. INTRODUCTION

Many modern industrial applications need variable speed motors with a precise and smooth control of speed with long term stability and good transient performance [1]. From the very beginning, the conventional dc motors have been used as variable speed drives in many industrial applications [2]. 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.

The silicon-controlled-rectifier (SCR) based inverter is now used to control the speed of induction and synchronous motors. 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 [2]. 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 [3]-[10]. The power circuit and triggering circuit [11] for SCRs of the inverter are very simple in structure.

Forced commutated inverters have been widely used as variable frequency source for speed control of synchronous machines. However, this scheme needs complicated power and control circuits [3]. As a result of availability of improved voltage and current rating SCR and with their prices coming down, people have shown considerable interest in synchronous type machines instead of conventional dc motor for variable speed drives. Line commutated inverter overcomes all the problems of forced commutated inverters as well as cycloconverters. Almost all research works were performed using rotor-speed sensor for generating triggering pulses for SCRs of the inverter [12]-[16]. The hardware implementation of the rotor-position sensor is very complicated.

In this work, the experimental investigations have been carried out to study the steady state performance characteristics of a SCR inverter fed three-phase synchronous motor with the help of voltage sensor instead of speed sensor.

2. SYSTEM DESCRIPTION AND OPERATION

The block diagram of the system used for experimental investigations is shown in Figure 1. The system basically consists of a three-phase autotransformer, an uncontrolled three-phase bridge rectifier, a dc link smoothing inductor, a three-phase line commutated SCR inverter, a three-phase synchronous motor, synchronizing circuit and a microprocessor-based firing circuit. The three-phase autotransformer provides variable ac input voltage to the uncontrolled bridge rectifier to produce variable dc output voltage. This dc source supplies active power required for the synchronous motor. 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 SCR inverter.

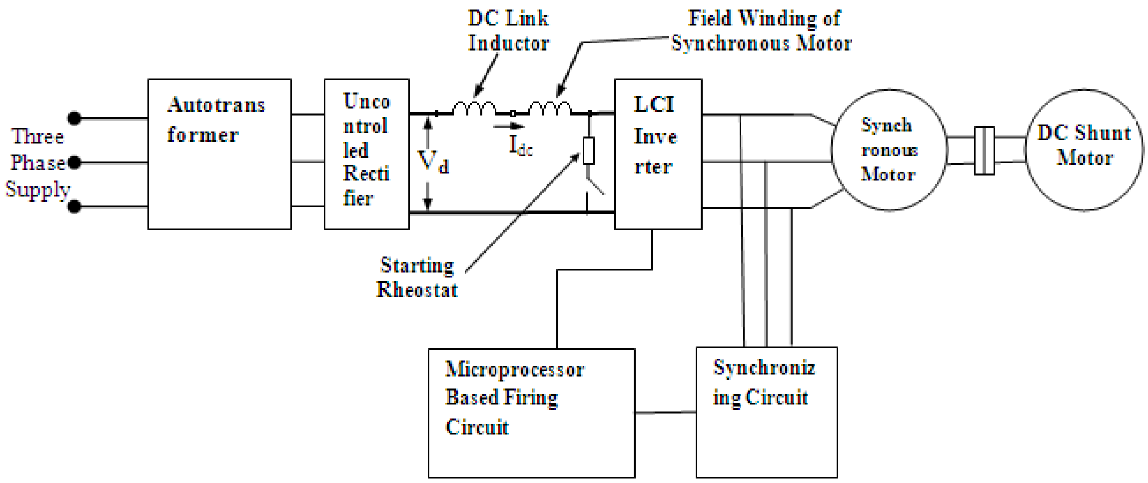

Figure 1. Block diagram of the SCR inverter fed three-phase synchronous motor

The excitation winding of the synchronous machine is connected in series to the input of the inverter and therefore the excitation current is directly proportional to the load current like a conventional dc series motor. A synchronizing squire-wave signal of 60 degree pulse width 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 microprocessor-based control circuit [11] for generating firing pulses for six SCRs of the inverter in proper sequence. The firing angle of the line commutated inverter is always kept between 90 degree to 180 degree. The commutation of the SCRs of inverter is performed by the voltage induced in the stator winding of the synchronous motor which is seen by the inverter as a three-phase ac source.

Under standstill condition, synchronous motor terminal voltage is zero and therefore firing pulse generation is not possible. The synchronous motor is unable to start from standstill condition. Therefore extra starting methods are necessary to start the synchronous machine from standstill condition. In the present work, a dc shunt motor is used to drive the synchronous motor as a generator as shown in Figure 1 for producing sufficient induced voltage in the stator winding for generating firing pulses. A variable resistor as shown in Figure 1 is connected across the inverter to allow current flowing through the field winding of the synchronous motor during stating. Firing pulses for SCRs of the inverter are now produced from the no load induced emf of the generator. When the speed of the motor becomes about 500 rpm, power supply to the dc motor is switched off and the resistance of the starting rehostat is gradually increased. Now the synchronous motor receives electrical power from the dc source and always runs at synchronous speed corresponding to the frequency of the motor terminal voltage. Under steady state condition, the speed of the motor can be varied in the following ways:

i) Varying the input dc voltage to the inverter like a conventional dc series motor.

ii) Changing the firing angle of the inverter just like the speed change of a conventional dc series motor by shifting the brush position.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental performance of the system under load has been obtained with the help of coupled dc machine running as separately excited dc generator. The synchronous motor used in the present work has the following ratings: 3 ph, 440 V, 10.8 A, 7.5 KVA, 1500 rpm, 50 H_Z, and excitation: 40 V, 8 A. Load tests are carried out on the system by varying the load on the synchronous motor with dc link voltage, V_d and firing angle, α constant. The experimental characteristics of the system under loaded condition are shown in Figures 1 to 4. It can be observed from Figure 1 that the system exhibits almost similar torque versus speed characteristic like a conventional dc series motor. The characteristic curve is shifted upward with increase in firing angle. It is obvious that at lower motor speed, torque is very high and becomes low at higher speed. The variation of torque with dc link current for different combination of dc link current and firing angle is shown in Figure 2.

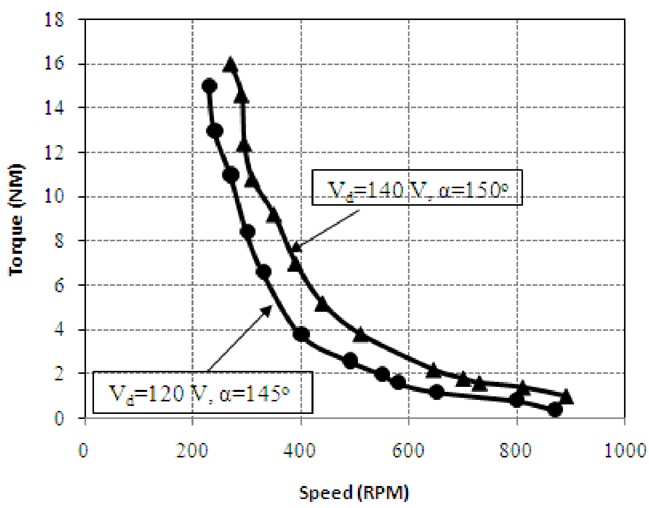

Figure 1. Variation of torque with machine speed for different values of dc link voltage and firing angle

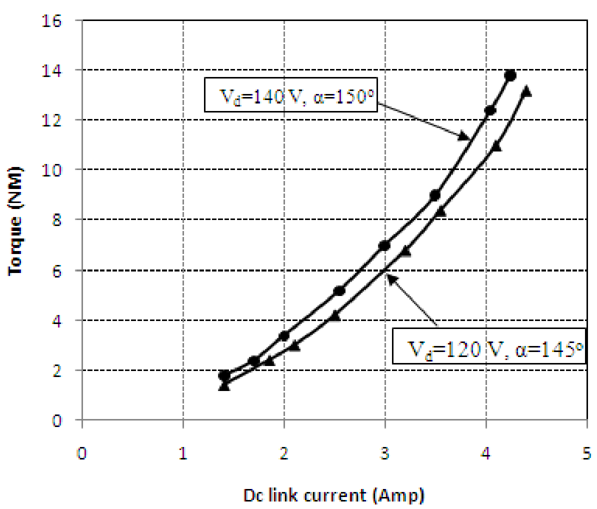

Figure 2. Variation of torque with dc link current for different values of dc link voltage and firing angle

It is observed from Figure 3 that synchronous motor speed changes with dc link current like a dc series motor. Figure 4 shows the variation of motor speed with firing angle at constant dc link voltage. The firing angle must be within the safe region to avoid commutation failure. So large range of speed variation is not possible by firing angle change as may be observed from Figure 4.

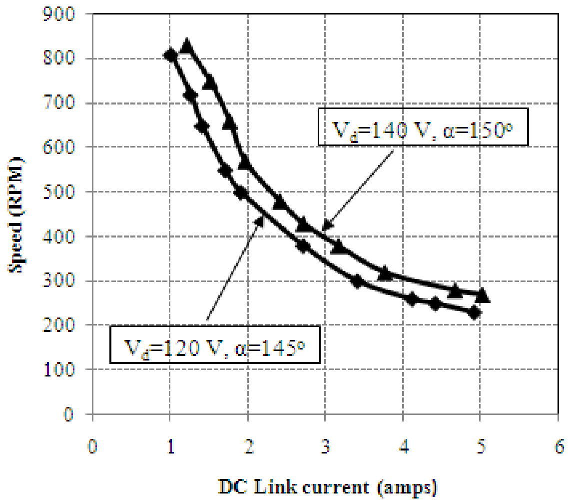

Figure 3. Variation of machine speed with input dc current to the inverter

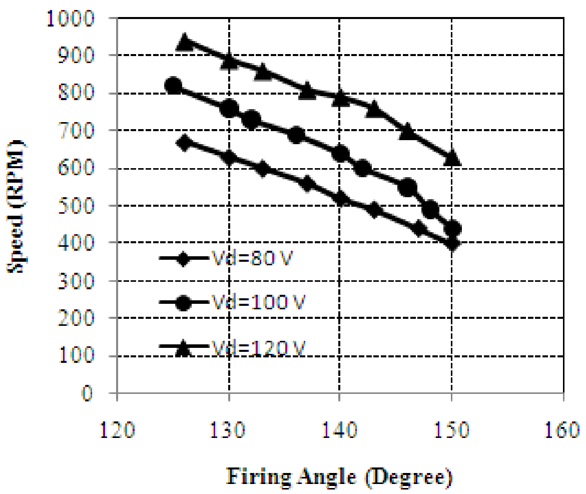

Figure 4. Variation of machine speed with firing angle for different values of dc link voltage

The waveforms for machine terminal voltages are given in Figure 5 in which the commutation spikes are clearly visible at 60 degree interval. The oscillograms of dc link voltage and inverter input dc current at loaded conditions of the drive are given in Figure 6. It is observed that the ripple content in dc link current is small due to high inductance in the dc link.

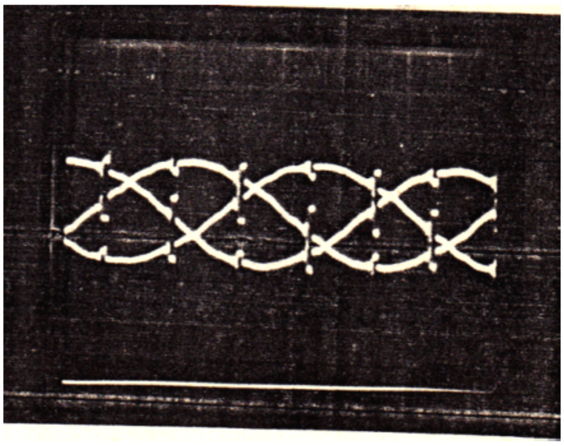

Figure 5. Waveforms of machine Terminal voltages V_{ab}, V_{bc} and V_{ca}

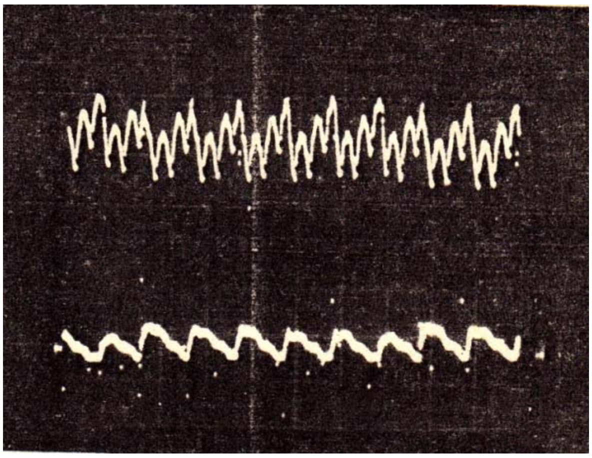

Figure 6. Waveforms of dc link voltage and input dc current at loaded condition

4. CONCLUSION

The steady state performance characteristics of the line-commutated SCR inverter fed synchronous motor have been investigated experimentally at loaded conditions. From the results of the experimental study, it is observed that the developed system exhibits almost similar characteristics like a conventional dc series motor. It is expected that the system will find good applications like traction, drilling, lifting and hoisting, etc in place of conventional dc series motor.

REFERENCES

[1] M.H. Rashid, Power Electronics-Circuits, Devices and Applications, Prentice Hall of India Publishers Ltd., 2009.

[2] P.C. Sen, Modern Power Electronics, Wheeler Publishing, 1998.

[3] 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.

[4] B. Singh, S. Singh, S.P. Hemanth Chender, "Harmonics Mitigation in LCI-Fed Synchronous Motor Drives", *IEEE Transactions on Energy Conversion,* pp. 369 – 380, Vol. 25, Issue: 2, June 2010.

[5] A.B. Chattopadhyay, S. Thomas and R. Chatterjee, "Analysis of Steady State Analysis of a Current Source.

[6] C. Namuduri and P.C. Sen, "Digital Simulation of an Inverter-Fed Self-Controlled Synchronous Motor", *IEEE Transactions on Industrial Electronics,* Vol. 34, No. 2, pp. 205-215, 1987.

[7] K.A. Mary, A. Patra, N.K. De and S. Sengupta, "Design and implementation of the control system for an inverter-fed synchronous motor drive", *IEEE Transactions on Control System Technology*, Vol. 10, No. 6, pp. 853-859, 2002.

[8] 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.
[9] 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.
[10] 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.
[11] 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.
[12] S.D. Sudhoff, “Start up performance of load-commutated inverter fed synchronous machine drives”, *IEEE Transactions on Energy Conversions*, Vol. 10, No. 2, 1995.
[13] T.K. Chakraborty, “Microprocessor controlled commutatorless DC series motor drive”, M.Sc. Engg Thesis, Department of Electrical Engineering, University of Roorkee, 1988.
[14] 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.
[15] 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.
[16] 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.

BIOGRAPHY OF AUTHOR

Tapan Kumar Chakraborty received his Bachelor of Science in Electrical and Electronic Engineering degree from Bangladesh University of Engineering and Technology, Dhaka in 1984. He completed the M. Engg degree in Electrical Engineering at the University of Roorkee, India in 1988. He obtained his Ph.D degree in Electrical and computer Engineering from Kanazawa University, Japan in 1998. He served as lecturer, assistant professor, associate professor and professor in the department of Electrical and Electronic Engineering at Dhaka University of Engineering and Technology from 1988 to 2005. In 2005, he joined the department of Electrical and Computer Engineering as a professor at the Presidency University, Dhaka. He has over fifteen research papers to his credit in various journals and conferences of national and international repute. His fields of interests are electronic materials and devices, phase change memory, electronic circuits and power electronics. He is a member of the Institution of Engineers, Bangladesh and a member of the IEEE.