LOAD COMMUTATED CURRENT SOURCE INVERTER FED AC MOTOR DRIVES WITH OPEN-END STATOR WINDINGS

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Abstract

Silicon Controlled Rectifier (SCR) is one of the most rugged power semiconductor devices, available in high current and voltage ratings. However, being a semi-controlled device an SCR can only be turned ON by applying gate pulse but turning OFF (commutation) requires its anode current to be brought down below the holding current. Hence complex forced commutation circuits are required for SCRs, in many applications. In AC circuits, natural commutation of the SCR can be achieved if the current through the device is leading ahead of the voltage. A synchronous motor can be operated at leading power factor by resorting to over-excitation thereby making the motor current leading ahead of the voltage. This feature makes the SCR an ideal switching device in the CSI fed load commutated synchronous motor drive since the SCRs will be naturally commutated by the back-EMF of the motor (load commutation) during the inverter operation. In load commutated synchronous motor drive since the CSI is fed from a well regulated current source with a large inductor it has inherent short circuit protection. It is also free from problems like DC bus shoot through fault, encountered in VSI. These features enhance the reliability and ruggedness of load commutated synchronous motor drive. The main drawback of drive is that since large inductors are used for realizing the current source, they have slower dynamic response compared to that of VSI fed drives. However most of the medium and high power drives are used for loads like pumps, fans, conveyors and compressors where high dynamic performance is not a requirement. So, SCR based load commutated CSI fed synchronous motors are extensively used in high power drive applications.

When compared to the synchronous motors, the induction motors are more rugged, reliable, cheaper, and efficient and hence always preferred in industrial applications. However, since the induction motor operates at lagging power factor it was not possible to achieve load commutation of SCRs in load commutated induction motor drives unlike synchronous motor drives. If the load commutation can be achieved in SCR based CSI

fed induction motor drive, it would be a very good choice in many high power drive applications. In this thesis a new topology of a load-commutated silicon controlled rectifier (SCR)-based current source inverter (CSI)-fed induction motor drive with open-end stator winding is presented. The proposed topology has a SCR based CSI connected at one end of the stator windings for feeding active power to the motor and a capacitor fed IGBT based VSI is connected at the other end of the stator windings for supplying reactive power. Load commutation of the SCRs of the CSI is achieved by controlling the VSI in such a way that it over-compensates the reactive power required by the motor so that at the CSI terminals the current leads ahead of the voltage. Since the CSI current leads ahead of the CSI terminal voltage under all conditions of operation of the motor, the SCRs of the CSI are naturally commutated. The CSI supplies the entire active power required by the motor. Since the VSI supplies only the reactive power required to maintain slightly leading power factor at the CSI terminals, the power handled by the VSI is only 20-25$\%$ of that of the CSI, for high power motors. This topology is also free from problems like commutation failure at low speeds normally encountered in CSI fed high power synchronous motor drives due to insufficient back-EMF. The experimental verification of the proposed scheme is carried out on a laboratory prototype with 1.5HP induction motor having open-end stator windings. A digital signal processor (TMS320F28335) is used for implementation of the control algorithm. The proposed scheme was also experimentally verified on a 10 HP induction motor with open-end stator windings, subsequently.

However, in the proposed scheme the motor current is quasi square wave due to the 120 degree conduction mode of CSI operation, which is rich in low order harmonics. Harmonic analysis of this motor current waveform reveals that 5^{th} and 7^{th} harmonic contents are 20$\%$ and 14.35$\%$ (of fundamental) respectively, that can result in considerable 6^{th} harmonic torque pulsations. To mitigate this, a load commutated SCR based multilevel current source inverter (CSI) configuration for open-end winding induction motor is proposed to establish multilevel motor current instead of the quasi square wave current. The multilevel current waveform is realized using two isolated load commutated SCR based current source inverters connected in parallel configuration, but operated with a phase shift of 30 degrees thereby attaining significant reduction in harmonic distortion of the motor current. Harmonic analysis of this motor current waveform reveals that 5^{th}

and 7^{th} harmonic contents are reduced to 5.36% and 3.83% respectively, that results in significant reduction in torque pulsations and the losses due to harmonics. Even in the multilevel CSI configuration the VSI connected at the other end of the stator winding of open-end winding IM is used for reactive power compensation. Even when the two CSIs are operating with a phase shift of 30 degrees, load commutation of SCRs in both CSIs are achieved using the VSI. A new closed loop control scheme was developed and implemented to achieve this task. The proposed multilevel CSI fed IM drive scheme is experimentally verified on an induction motor with open-end stator winding.

A major problem faced in the conventional load commutated current source inverter fed synchronous motor drive is the commutation failure during low speed operation due to insufficient back-EMF. The scheme adopted by the industry as a solution for this problem is to employ pulsed mode of operation during starting and at low speed. However, the pulsed mode of operation results in undesirable high torque pulsation. A new scheme to facilitate hassle-free load commutation of CSI fed synchronous motor drives during starting as well as at low speed without resorting to pulsed mode operation is proposed in this thesis. The proposed scheme consists of an open-end winding synchronous motor with SCR based current source inverter connected to one side of the stator windings and an IGBT based voltage source inverter connected to the other side to aid commutation of SCRs when the back-EMF is insufficient. The CSI provides the real power requirement of the system, while the VSI is controlled to generate sufficient voltage which gets added to the motor back-EMF to facilitate load commutation during start-up and low speed operation. When the drive speed exceeds the change-over speed the VSI operation can be stopped and the CSI alone will be in operation. Alternatively, the VSI operation can be continued in the entire speed range if frequent operations at low speed or reversal of the speed is required.

The proposed schemes for realization of load commutated SCR based CSI fed AC motor drives have been experimentally validated under transient as well as steady state operations including speed reversal and regenerative braking.