Fault Tolerant Control Strategies of Induction Motor Drive fed from Voltage Source Converters

Abstract

Adjustable speed drives (ASDs) uses induction motor extensively to control pumps, fans and other loads in the process industries. In order to control the speed of the induction motor dynamically, rotor field oriented control (RFOC) is a common technique employed in these drives. In the ASDs, different kinds of voltage source converters (VSCs) are employed to obtain a pulse width modulated voltage of varying magnitude and varying frequency to the motor depending on the reference speed requirements. Sometimes, the output voltage available from the VSCs reduce due to the conditions like a sag in the supply grid voltage or a fault in the components of the VSC. For example, in an adjustable speed drive employing a three-phase diode bridge rectifier and a two-level voltage source converter (2L-VSC), the DC-link voltage reduces from the nominal value due to a sag in the grid's supply voltage. In this condition, if a proper control mechanism is not activated, the reference speed and load torque of the rotor field oriented induction motor (RFO-IM) connected to the 2L-VSC could not be maintained due to the reduced output voltage from the converter. Similarly, in an adjustable speed drive employing a cascaded H-bridge multi-level (CHB-ML) converter based VSC, the available voltage from the converter reduces when some of the faulty H-bridges are bypassed. In this scenario, a RFO-IM connected to such a CHB-ML converter results in a reduced speed and torque in the post-fault operation. The primary objective of the research work in the thesis is to maintain the speed and torque of the RFO-IM in the event of a dip in the voltage available from the 2L-VSC and the CHB-ML voltage source converters.

In a 2L-VSC based RFO-IM drive, a modified vector control is proposed to maintain the speed and torque of the motor during the input supply voltage sag. In this control technique, the reference d-axis and q-axis stator current commands are obtained by solving the voltage, current and torque constraints in the current dq plane. The analysis includes the traversal of motor's operating point in the current dq plane (during the supply voltage sag), voltage sag limit for the particular loading and the settling speed of the RFO-IM when the voltage sags beyond the limit. In the event of a voltage sag beyond a limit, the control is made such that the motor delivers the load torque with reduced speed. Mathematical equations explaining the current trajectory to be followed during voltage sag, voltage sag limit and the settling speed for voltage sag beyond the limit are derived. The proposed control is simulated in MATLAB/Simulink and experimental validation is conducted on a 3-hp induction motor (IM) in the laboratory.

Next part of the research is the extension to CHB-ML converter based RFO-IM drive. In this multi-level VSC, the available voltage reduces when the faulty H-bridges or power cells are bypassed in the post-fault operation. In this scenario, a post-fault control technique is proposed to maintain the speed

and torque of the RFO-IM and to balance the line voltages of the CHB-ML converter in the post-fault operating conditions. The control strategy is to vary the magnitude and phase shift of the injected fundamental common mode voltage (FCMV) according to the motor's loading condition and the converter's fault configuration. The addition of the proposed FCMV with the reference phase voltages, not only ensures maximum line voltage in the post-fault operating condition but also shares equal power among the remaining healthy cells of the converter. Moreover, in the post-fault operation, a detailed analysis is performed on both motor and converter, and the integrated control is presented to maintain the command speed and load torque of the RFO-IM. This includes the mathematical equation explaining the new operating point of the motor for different fault configurations, traversal of operating point, and the variation in power factor of each leg of the converter in post-fault conditions. The dynamic generation of FCMV is calculated from the new operating point of the stator current components in the current dq-plane and the fault configuration of the CHB-ML converter. Computer simulation and experimental results are shown to validate the proposed control.

In addition to the above two control techniques, CHB-ML converter fed RFO-IM with redundant power cell topology is also studied. The objective of the control strategy is to maintain the torque and speed of the RFO-IM in post-fault operation and to maximize the converter's power capability by adding maximum number of power cells during postfault operation. Furthermore, maximum line voltage is utilized from the redundant cells without increasing the DC-link voltage of power cells, and the motor's operating point in voltage plane is analyzed and determined for various loading conditions during pre-fault and post-fault operation. In the post-fault operation, a common mode voltage of fundamental frequency is also added depending on the motor's loading condition and post-fault configuration to distribute power evenly among the remaining healthy cells. Theoretical and graphical analyses include the equation of the operating point in the voltage plane, traversal of the operating point from pre-fault to post-fault operation, and selection of common mode voltage of fundamental frequency based on the fault configuration and the motor's loading. The simulation and experimental data are used to validate the proposed fault tolerant control approach.