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Important aspects of Inter turn Insulation in High Voltage Motors

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Abstract

High voltage induction motors play a vital role in reliable operation and performance of process industries and utilities of power plants. H.V. motors are used to drive boiler feed pumps, primary air fan, cooling water pumps, induced and forced draught fan drive motors, mill motors and other utility operation in thermal power plant. Induction motors have been the most popular electric motors in the family of motors. The failure data on large induction motors indicate that the stator related failure account for about 37% of the total failure. Stator insulation failure results from either the failure of turn to ground insulation or turn to turn insulation which ultimately leads to main insulation failure. The inter turn insulation in a motor is a weak spot, soundness of inter turn insulation is crucial for reliability of motor. The present paper is aimed to identify the occurrence of inter turn faults within the coils and turns of the stator winding, requirement of inter turn insulation details of inter turn insulation systems and impulse voltage withstand capacity of inter turn insulation., precautions to be taken during manufacture and assembly of winding.

Keywords: High voltage induction motor, stator coils, inter turn insulation, steep front transient voltages, insulation failure.

Introduction

Induction motors have been widely used in many industrial applications[1], because of simplicity of control. Direct current motors were used earlier for adjustable speed, however recent advances in both digital technology and power electronics[2], ac drives have become more economical and popular. The role of high voltage motors is vital in reliable operation and performance of power plants and process industries. High voltage induction motors are widely used for utilities of thermal power plants e.g. boiler feed pumps, primary air fan, cooling water pumps, induced and forced draught fan, coal handling and ash handling plant etc. Motor failure cause expensive outage of power plants[3] and production stoppages in process industries. The inter turn insulation in a motor is a weak spot. The major cause of inter turn failure is considered to be the Steep front transient voltages generated during switching operation of circuit breakers and IGBT resulting in unequal voltage distribution in the winding and over stressing the inter turn insulation. The stress level of the inter turn insulation depends upon the steepness of wave shape. It is estimated that stator turn-to-turn failure correspond to large percentage of failures in inductions motors. Soundness of inter turn insulation system of high voltage motors is required for uninterrupted operation[4] and reliability of the system. Inter turn insulation failure results in excessive heating due to flow of heavy current, this excessive heating deteriorates the ground wall insulation. Turn insulation failures are seen in the stator coils as melted copper conductors and hole in the main insulation[4] due to earth fault.

Use of new and improved materials and devices and special precautions at the time of production of coils and winding in the core, have addressed the problem of inter turn failure up to a certain extent.

Figure-1
Image of 13.7 Mw High voltage Induction motor

Causes of Inter turn Failure: The inter-turn insulation failure, can be due to workmanship or process variation caused during manufacturing[4]. This could have led to a flaw in the thin insulation between the conductors of the coil (inter-turn insulation). Another cause of inter-turn insulation failure is a voltage that is higher than the nominal turn voltage which is applied across a turn. Steep front transient voltages[5] generated during switching operation resulting in unequal voltage distribution in the winding is considered as the major cause of inter turn failure. If the turn insulation is of an insufficient

thickness or has aged in service, the insulation will puncture when a short rise-time voltage surge occurs. Failure of turn insulation allows for a very high circulating current to flow into the shorted turn, melting the copper conductors, which, in turn, result in a consequent burning/ of the slot liner insulation, thus leading to a stator winding ground fault[6]. The coil insulation will experience practically the whole surge amplitude, which results in degradation of insulation due to switching surges. The combination of deteriorated weak insulation and the steep front surges accelerate the deterioration process[7] leading to motor's electrical failure.

Case Study of Inter turn failure investigation of stator coils of BFP Motor: Investigation has been done to find the root cause of inter turn failure of stator coils of a 10 Mw[8] motor coil. The coils were assembled in the stator core, wedging done so that coils were fitted tight in the core. Surge comparison test was done to test the soundness of inter turn insulation. During surge comparison test one coil was found inter turn short.

Root cause analysis[8] was done to identify the cause of failure and also for corrective and preventive action so that this does not repeat.

The rating of the motor is as follows:
10Mw, 11Kv, 4 Pole 72 slots Squirrel cage induction motor for Boiler Feed Pump of 500 Mw thermal power plant.
Coil details: copper size: 3.7x6.5
Conductor arrangement: 2 in width and 11 in depth
Core length: 765 mm,
Number of turns: 11

Method of analysis

Main insulation of the coil was removed on connection end side over hang portion. On opening the insulation the failure point was observed between top coil side connection lead and adjacent turn. As per drawing an additional reinforcement[8] is provided to protect the turn below lead to sustain mechanical pressure exerted on lead during winding and connection of series joint. It was observed that the protection piece of resin poor mica paper tape[8] having glass baking on both sides, was found damaged. Due to damage of this protection piece the pressure created during winding has damaged the turn insulation resulting in turn to turn short.

Corrective/Preventive actions: i. Adequate care at the time of insertion of protection piece between lead and conductor below lead. ii. Operator training to be provided for proper insertion of protection piece. iii. Care during winding, lead bending and making series joints. iv. Adequate care during handling of coils.

Study of inter turn insulation System of High Voltage motors: There has been a significant improvement in the inter turn insulation of H.V. motors. Insulation system with combination of different materials[9] having high dielectric strength, high mechanical strength, environmental protection, better thermal conductivityand performance at higher temperature. Stranded conductors are used to improve the efficiency of the motor by reducing eddy current and skin effect losses. Turn insulation to isolate the copper turns from each other. In modern motors the turn insulation is provided using either Dacron and glass composite[9] or mica paper/Polyamide and polyimde taping on copper conductor.

Figure-2
Damage of lead turn insulation resulted in inter turn insulation

The turn insulation in rotating machines has to fulfill mainly two tasks: i. To provide insulation between turns. ii. To provide good adhesion to the copper conductor and the main wall insulation and the impregnating resin.

The turn/conductor insulation is positioned in a critical place of the coil. It is subject to a high electric field, especially on the edges of rectangular wires[10] used for high voltage machines. Because of different thermal coefficient of expansion of copper and insulation material the conductor insulation[10] is exposed to severe shear forces. The turn insulation has to sustain severe mechanical and flexural stress during coil manufacturing (loop winding and coil forming, winding, lead bending etc)

Copper conductors taped with corona resistant polyimide film in combination with mica paper are being experimented[10] for High Voltage motors up to 13.3 kV this new system has resulted increased thermal conductivity and thinner insulation consequently increasing power output with same frame size.

Precautions to be taken during manufacture of taped conductors / stator coils: Mica taped copper conductors are produced on high speed conductor taping machines. Before application of tape, the copper conductor should be dust free and should have desired corner radius[11], sharp edges if any shall damage the insulation tape.

During manufacture of coils at loop winding stage and pulling stage special precaution to be taken for protection of inter turn insulation. During pulling over-riding of conductors to avoided, special protection piece of insulation material[11] to be provided to protect the lead, bend portion and nose portion.

Stator core slots to be checked thoroughly for burrs, dust and presence of any foreign particles, before coil housing in the stator core.

Since reliability is vital for insulation system, it is important to verify that the materials, components and workmanship used are of acceptable quality. A detailed Inspection and Test Plan (IandT Plan) which covers the following has to be prepared. i. Coil manufacture and QA testing, ii. Stator core preparation and testing prior to winding, iii. Stator coil insertion and testing during winding, iv. Checks on slot wedge insertion and tightness after coil insertion, v. Adequacy of end winding radial bracing, inter coil blocking and inter-coil spacing, vi. Final testing of completed winding and core insulation, vii. Commissioning tests after motor is placed in service

Surge comparison Test of Inter turn Insulation: This test detects turn-to-turn, coil-to-coil, and phase to-phase insulation defects that cannot be discovered by other methods.

Surge comparison testing[12,13] is based on the principle that coils of same motor with no winding defects, are identical having same value of R, L and C. Surge comparison test is used to detect turn to turn fault[3], coil to coil, phase to phase short circuit, wrong connection and wrong turn counts. Inter turn insulation strength is tested by impressing identical high voltage on the winding, if the insulation is sound the CRO will show single wave.

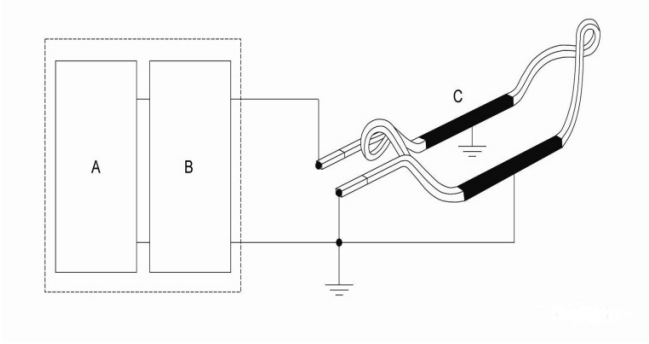

Figure-3
Circuit details of Impulse test on sample coil A: Impulse Generator, B: Measurement Unit, C: Sample Coil

Impulse test is conducted on stator coils of motors with rated voltage from 3 kV to 15 kV as per IEC60034-15/2009. The test is performed by applying an impulse of 0.2 ± 0.1 micro second. The voltage peak between the terminals shall be 0.65 of (4Un+5kV)[14]

Results and Discussion

Root cause analysis of inter turn failure on a coil of 10 Mw BFP motor stator was carried out. It is found that small negligence during manufacture can result in serious inter turn faults in the motor winding. Stator coils are quite delicate and requires careful handling and storage. Insulation reinforcement wherever called in drawing has to be provided which takes care of the mechanical stress during coil manufacture and assembly in the stator core. Surge comparison test is one of the important and most reliable test by which inter turn faults can be identified.

Conclusion

The inter-turn insulation failure, a common problem in inverter fed motors, could be a result of defects introduced during manufacturing. This could have led to a flaw in the thin insulation between the conductors of the coil (inter-turn insulation). Another source of inter-turn insulation failure is in exploitation when a voltage that is higher than the nominal turn voltage is applied across a turn.

The problem associated with inter-turn voltage failure has received increase attention in recent years. This is due to the availability and use of new and improved materials and devices.

A reliable insulation system must be designed and precautions taken during manufacture of coils and also assembly of winding.

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