NON LINEAR VOLTAGE DISTRIBUTION IN MOTOR WINDING DUE TO FAST SURGES

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ABSTRACT
In large industries such as cement plant, paper mills, petrochemicals etc high power motors are required for auxiliary operations to meet the demands of industry. For turning on and off the machines circuit breakers are utilized. On and off operations of circuit breaker causes surges at the motor terminal due to multiple re-ignitions of the breaker. Rise time of the surge and steepness depends on type of circuit breaker used. Fast surges cause the non-uniform voltage distribution among the machine stator winding coils. Present paper discusses the voltage distribution and stress across the turns of the coil. In the present analysis the line-end coil of machine winding subjected to steep fronted surges is examined. For this multi-conductor transmission line model of 11 kV is developed to represent the entrance coil of the winding under surge conditions. The parameters of above coil are calculated from the coil geometry. The voltage distribution at any point in the line-end coil is calculated from EMTP. Paper presents the technique that can be used to design winding insulation capable of withstanding high stresses caused by fastsurges.

INTRODUCTION

Large industrial motors are commonly used to drive process equipments, which are critical to sustaining plant production in large industrial establishment. Failure of motor causes the serious economic consequences, far beyond the repairing cost of motor. Surveys conducted to assess the reliability of motors in utilities and industrial applications have found that stator insulation accounted for nearly one third of all motors failures. Further, in most of the cases the failures are reported to have occurred as a result of inter turn fault often located in end coil of the winding. W Z Gandhare [1] reported that switching surges can stress the turn-turn and turn to ground insulation beyond its withstand capability. Authors reported that impulse voltage at breaker terminal is higher than motor terminal. Sayeed Ul Haq et. al. [2] reported that group of coils are selected to apply voltage endurance test. Report suggested that coils having thinnest insulation are failed at 20 kV. It is observed [3] that stator winding faults account for a large percentage of the failure of machine. About 37 % of faults are due to inter turn insulation failure. The complete analysis of black out in Libya [4] is due to failure of surge arresters and protective equipments. It is reported that other preventive counter measures are to be considered. E Safaan [5] reported that multi break vacuum switch has high dielectric strength restoration during switching operations. For waves with rise time 0.1 µs, the withstand voltages [6] are of the order of 5 p.u. and more. It is therefore a matter of growing concern to motor designer to know the magnitude of over voltage and its steepness likely to appear at the motor terminals. Voltage distribution [7, 8] becomes distinctly non-linear across turns within a coil for surge fronts below 1 µs, whereas non-uniformity across coils begins for surge fronts shorter than about 3 µs. As per Carlo Petrarca et al. [9] voltage stress is not distributed uniformly among the coil and distribution depends upon the rise time of the impinging surge and parameters of the coil. This requires further investigations for computing the influence of fast surges on the motor winding insulation.

The present paper discusses the non-linear voltage distribution in the 11 kV industrial motor winding and voltage drop across turns for different rise times. In this paper turn to ground and inter turn voltages of 11 kV motor coil are calculated using Electromagnetic Transient Program (EMTP™). The parameters of equivalent electrical network, like series and shunt capacitance, self-inductance of each turn and mutual inductances between individual turns are calculated. Using Electromagnetic Transient Program (EMTP™) the voltage distribution along the coil is calculated for fast surge voltage applied at line end.

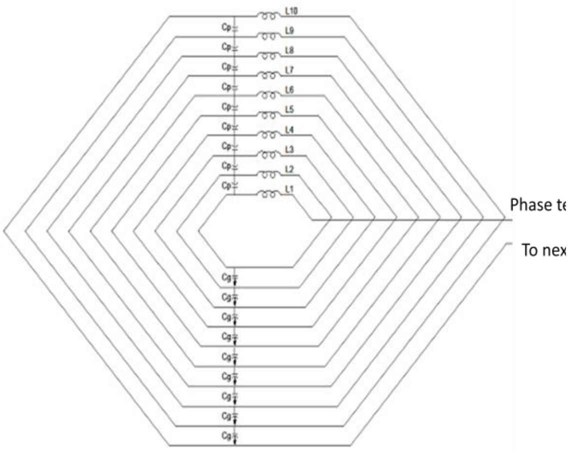

Fig. 1. Coil subjected to surge voltage

2 CALCULATION OF MODEL PARAMETERS

The single coil of 11 kV motor is shown in Fig. 1. Coil consisting 9 turns. In the present analysis only a single coil of the motor is considered with the assumption that a major portion of the surge voltage appears across the first coil. Surge voltage impinges on the nose of coil as shown in Fig. 1. As voltage applied at nose of the coil it starts propagating along the coil until it reaches the slot entry. Portion of voltage drops across the winding depends on L and C parameters. Self and mutual inductances are calculated using standard formulae given by Grover [10]. Inductance matrix is derived and implemented in EMTP to calculate turn to turn and turn to ground voltages. Fig.2 shows the coil on which analysis is done. The slot configuration is shown in Fig. 3. An 11 kV motor coil having nine turns is wrapped with the aluminum foil on the slot portion of the coil.

Fig. 2. 11 kV motor coil

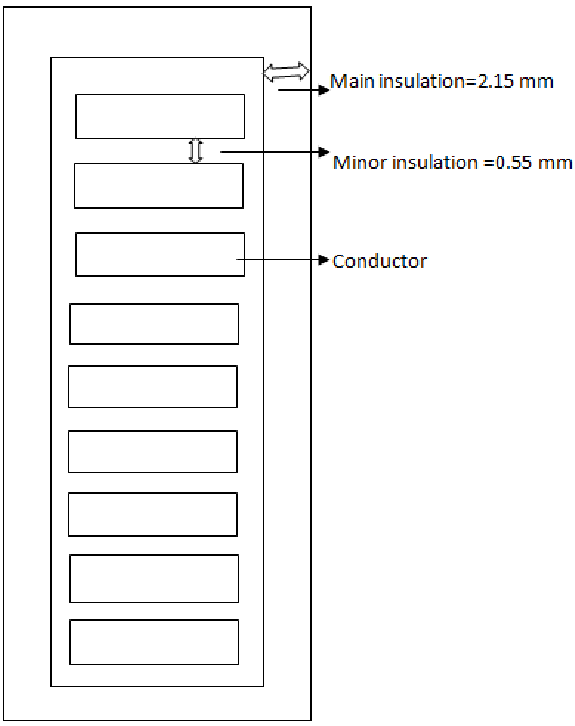

Fig. 3. Configuration of coil slots

To calculate series and shunt capacitances as well as self and mutual inductances, well established formulae [11] have been used. Calculated self and mutual inductances are formed in matrix form and implemented in EMTP.

3. COMPUTATION OF SURGE VOLTAGE DISTRIBUTION IN THE COIL USING EMTP

3.1 NODE TO GROUND VOLTAGES

For computing surge voltage distribution in the line end coil, an electrical network described in earlier section is used. Results of EMTP calculations are tabulated in table 2. The rise time of the surge wave is set at 0.2/2 µs and unit step voltage. Table 3 shows the turn to ground voltage distribution across the coil.

Table 1.
Turn to ground voltage distribution

Turn No.	Peak node to ground voltage for fast surge 0.2/2 µs (kV)	Peak node to ground voltage for Unit step(kV)
1-G	29.36	49
2-G	28.45	59
3-G	30.14	60
4-G	30.84	66.7
5-G	30.81	65.4
6-G	28.6	49.99
7-G	25.58	48.9
8-G	21.1	42.8
9-G	11.86	28.9

From Table 1 it is observed that voltage distribution is non-linear across the coil. Related wave shapes for 0.2/2 µs and unit step are shown in Fig. 4 and Fig. 5.

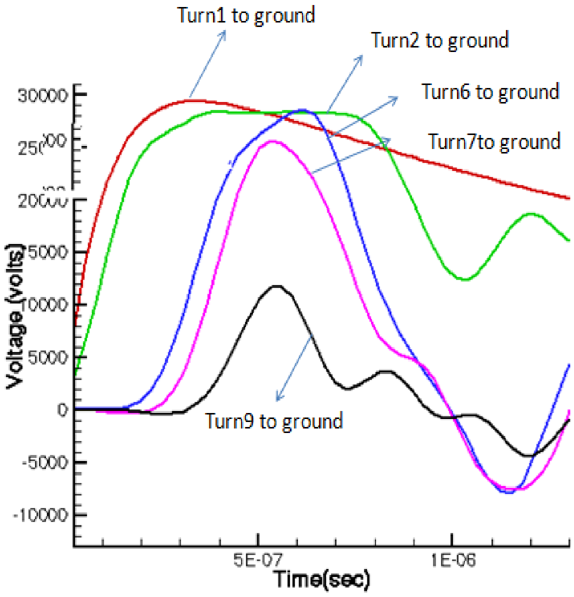

Fig. 4. Node to ground voltages for 0.2/2 µs

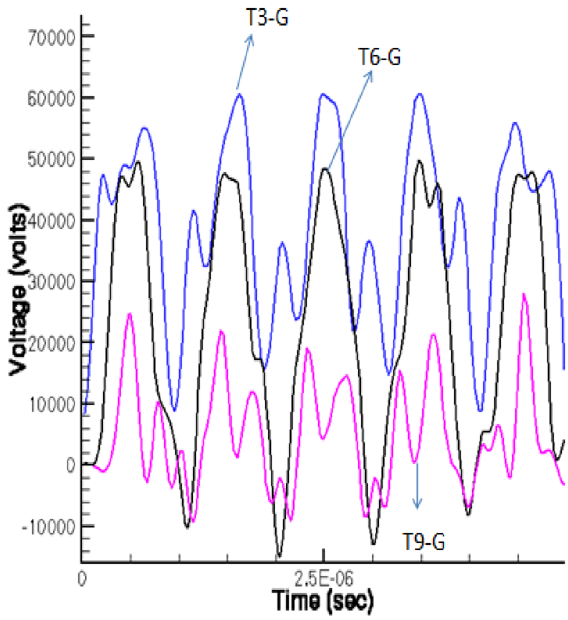

Fig. 5 Turn to ground voltages for unit step voltage

It is seen that turn to ground voltages are decreasing towards earth node in both the cases.

3.2. INTER TURN VOLTAGES AND STRESS

Table 2 show the calculated peak inter turn voltages for rise time of 0.2/2 µs as well as for unit step. The table also includes the voltage stress across the turns. The related wave shapes are shown in Fig. 6 and Fig. 7.

Table 2.
Inter turn voltages for different wave fronts

Between turns	Peak Inter turn voltage for 0.2/2 µs (kV)	Stress kV/mm for 0.2/2 µs (kV)	Peak Inter turn Voltage for Unit step (kV)	Stress kV/mm for Unit step (kV)
1-2	10.4	18.9	24	43.6
2-3	8.37	15.2	19.9	36.2
3-4	7.98	14.5	19.6	35.6
4-5	7.69	14.0	22.38	40.7
5-6	7.35	13.4	17.85	32.5
6-7	7.47	13.6	22.29	40.5
7-8	8.89	16.2	20	36.4
8-9	9.39	17.1	18.57	33.8
9-10	11.8	21.6	28.9	50.9

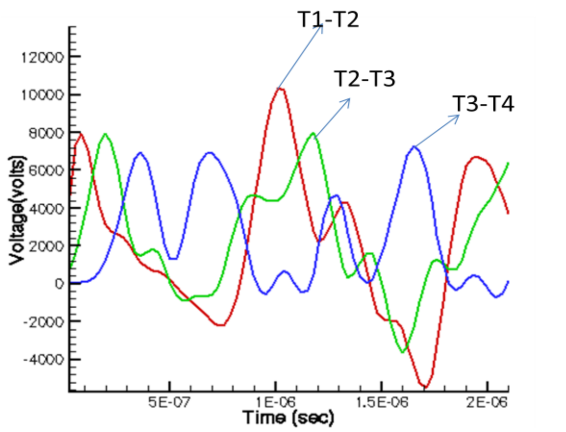

Fig. 6. Inter turn voltage distribution across starting turns for 0.2/2 µs.

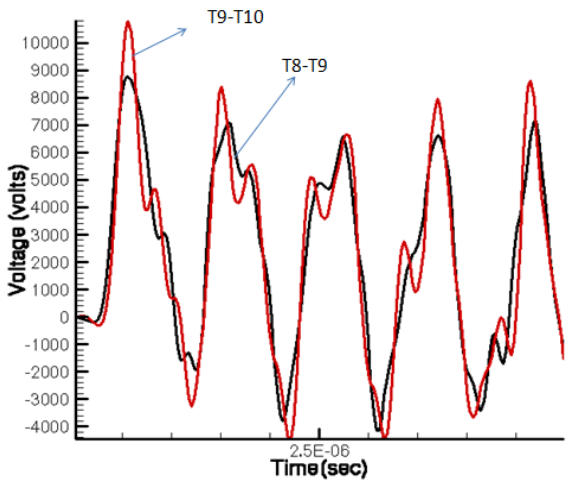

Fig. 7 Inter turn voltage distribution across last two turns for 0.2/2 µs.

4 RESULTS AND DISCUSSION

It is found from Table 2 that the stress is more at last turn of the coil in both the cases. The severity is more for unit step in comparison with 0.2/2 µs. From Table 2 it is seen that voltage distribution is not uniform for 0.2/2 µs and unit step. Fig. 6 and 7 depicts that steepness of the surge increases as the front time of the wave decreases. For unit step voltage oscillations are more pronounced than that of 0.2/2 µs. Table 3 shows that for unit step voltage stress is always higher than that of 0.2/2 µs. The results are in accepted manner since the rise of voltage is higher than that of 0.2/2 µs. The coils with higher voltage drop produce higher stress and may lead to failure subsequently.

5 CONCLUSIONS

Present paper objective is to calculate the voltage distribution across the turns of 11 kV motor coil and voltage stress which leads to failure of insulation. For this the coil parameters have been calculated and modeled in Electromagnetic Transient Program. Results show that for unit step voltage oscillations are more pronounced than 0.2/2 µs rise time pulse. From the results it is also found that voltage stress is higher at last turn of the coil. The work presents the voltage distribution across turns of 11 kV motor coil. From results it is concluded that voltage distribution is non-linear. The coils with higher voltage drop produce higher stress. The work examines the effect due to fast surge.

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Mr. Dr. Mohammed Sajid obtained his B.Tech., M.Tech. and Ph. D. from JNTU, Hyderabad. His research area is Power systems and Drives. He has more than 18 research publications. Presently he is working as Assistant Professor in Electrical Engineering department, Muffkham Jah College of Engineering and Technology, Banjara Hills, Hyderabad, Telangana, India.

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Key words—EMTP, 11 kV motor, Voltage stress, unit step, non linear voltage.