Simulation of Protective Schemes of High Voltage Utility Motors

Archana soni , Gayatri Agnihotri, Ganga A.

Electrical Engineering Department, Maulana Azad National Institute of Technology, Bhopal-462007 India (e-mail : soni_archana@yahoo.com)

***Abstract* -- Motors are a vital component of the energy conversion process for electric utilities large high voltage motors are used to drive water pumps, fans and other auxiliary items. The failure of a motor may have immediate serious consequences such as necessitating a shut down of generating unit or require that redundant plant be utilized to circumvent the failure of a particular motor. A premature winding failure that seems to be initiated by turn insulation puncture is often ascribed to voltage surges, which impinge on the stator winding. The surges are usually caused by circuit breaker operations or faults on the supply circuit. Although voltage surges and their effect on electrical machinery has been a subject of numerous studies and publications over four decades, however, there is still confusion and disagreement on practices relating to motor surge protection. This is because the knowledge of surge environment in which the motor is to operate is necessary in determining the surge capability requirement of the motor. This paper presents a computer simulation study of switching surges using electromagnetic transients direct-current (EMTDC/PSCAD) software package. A bench-mark model suggested by CIGRE is used as motor-equivalent circuits during starting.**

Index Terms—EMTDC, PSCAD, Motor-Protection, Switching Transients

I. Introduction

Motors are a vital component of the energy conversion process for electric utilities large high voltage motors are used to drive water pumps, fans and other auxiliary items. The failure of a motor may have immediate serious consequences such as necessitating a shut down of generating unit or require that redundant plant be utilized to circumvent the failure of a particular motor. Such events are undesirable since they constitute a decrease in overall system reliability and additional demands on manpower, finance & time in order to rectify the problem.

Most large ac motors rated 3 KV and above and many small generators, have stators with preformed multi-turn coils. The insulation system for such a coil consists of ground-wall insulation and turn insulation. The ground-wall insulation is the major component separating the winding from the grounded core. The turn insulation is usually much thinner and prevents the individual turns from contacting one another. Typically, the voltage between turns is only several tens of volts ac under normal operating conditions.

Failure of the turn insulation results in heavy circulating currents through the faulted coil, causing overheating, which deteriorates the ground-wall insulation. Eventually a ground-wall punctures results, causing a forced outage of the machine. A premature winding failure that seems to be initiated by turn insulation puncture is often ascribed to voltage surges, which impinge on the stator winding. The surges are usually caused by circuit breaker operations or faults on the supply circuit. The availability & use of new and improved materials and devices and the desire to produce cost effective competitive product has resulted in greater exposure of the motor to high amplitude steep fronted surges. Because of their reliability, compact size, low maintenance needs and longer life, vacuum switchgear is almost universally used. However, they produce repetitive, high amplitude steep fronted surges during closing as well as opening operations. Voltage transients are produced by circuit breakers during contact opening as well as contact closing. Air magnetic breakers produce a fast rise time surge during closing only, whereas the vacuum breaker produces steep fronted surges during opening as well as closing. Thus, for a single event of opening or closing the vacuum breaker produces multiple surges and therefore stresses the insulation more than other switching devices. Further, multiple re-ignitions cause each successive surge to be at a level higher than the previous one.

Although voltage surges and their effect on electrical machinery has been a subject of numerous studies and publications over four decades, however, there is still confusion and disagreement on practices relating to motor surge protection. This is because the knowledge of surge environment in which the motor is to operate is necessary in determining the surge capability requirement of the motor. Higher level of surge capability and specified dedicated time installation are not quite free, both the size and efficiency are adversely affected. Dedicated surge protection equipment for the motor should be considered as a factor in the economic analysis for motor selection. In critical applications, irrespective of the level and type of turn insulation specified the use of dedicated surge protection should be considered.

II. Surge Protection

Surge protection devices may be divided into two categories; firstly those that protect against surge voltage magnitude and secondly those that modify transient voltage rate of rise. The first category includes all types of surge arresters from conventional gapped station class arresters with low protective levels, to intermediate and distribution class arresters having high protective levels. The new technology component in this area is the ZnO surge arrester, which has much better V-I characteristics than does the SiC used in a conventional arrester. ZnO arresters may be gapless or they may have either series or parallel gaps. Several manufacturers throughout the world have developed ZnO surge suppressors specifically to be applied with vacuum switchgear. A ZnO surge suppressor is basically similar to a ZnO arrester. It is usually (but not always) gapless and is generally a lighter duty unit having some-what lower energy absorption capability than that of a ZnO arrester.

The second category of surge protectors includes surge capacitors, C-R suppressors and series reactors. In accordance with industry practices and standards surge capacitors should be located at the load and as close to the load terminals as possible. This minimizes series inductance effects, which reduce the effective surge impedance of the load circuit. All of these factors are important in reducing the probability of degradation of solid insulation, which could result from the non-uniform distribution of fast transient voltages in machine windings.

It is important to locate the surge capacitors at the load and not at the breaker. If the capacitor is located at the load, the high frequency current resulting from re-ignition is limited in amplitude by the surge impedance of the cable located between the capacitor and the breaker. This limitation of the amplitude of high frequency current reduces the probability of virtual current chopping. In addition, location of capacitors at the load minimizes series inductance effects. If, on the other hand, the capacitor is located at the breaker, re-ignition can cause the capacitor to discharge bulk through the breaker. In that case, the high frequency current could have a higher frequency and amplitude than if the capacitor were located on the load side of the cable at the load.

III. Computer Simulation

Electromagnetic transient simulation is a field of study, which allows one to analyze and examine a complicated or nonlinear model or process. A quantitative evaluation of switching surges in high-voltage motor systems has been carried out under different operating conditions using the EMTDC program.

A. EMTDC/PSCAD

EMTDC/PSCAD is software developed by Manitoba HVDC Research Centre Inc., Canada. It is the professional's simulation tool for analyzing power system. PSCAD is the graphical user interface and EMTDC is the simulation engine. EMTDC/PSCAD is most suitable for simulating the time domain instantaneous responses, also popularly known as electromagnetic transients of electrical systems.

The PSCAD Graphical Interface greatly enhances the power of EMTDC. It allows the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated graphical environment.

B. Test Circuit Simulation

A standard circuit as suggested by CIGRE Working Group No. 13-02 simulates the rotor-locked motor. The parameters of the circuit have been chosen to represent a relatively severe case with respect to over voltages and will cover the majority of service applications. Figure 1 represents the CIGRE circuit.

The circuit represents three-phase induction motor under standstill rotor condition. The power-frequency impedance is represented by the linear inductance L and resistance R for each phase. The natural frequency and damping of the circuit are adjusted by means of capacitances Cp to earth and parallel resistance Rp.

C. Characteristics of Supply Circuit

In our circuit, we have used a simple R-L series three phase voltage source. There are three types of source control modes Fixed, External and Auto. We have used fixed control for our system.

D. Modeling of Cable

The cable capacitance is a predominant constant for the cable. The inductance of the cable contributes substantially in surge impedance calculation. However, the value of resistance being small, its effect in reduction of over voltages through dissipation of energy in surge is neglected in the simulation study. The cable is represented as a π-network of impedance and capacitance. The cable constants are entered in the DATA file as branch data.

E. Modeling of Circuit Breaker

The interaction between the circuit breaker and the motor circuit is represented by simulating the breaker. During interruption of starting current the circuit breaker duty is characterized by a high current and a low power factor. Also, since the interrupted current is high, the chopping current can attain high values. The circuit breaker is modeled in EMTDC by a resistor, which has either a very-low resistance value or a very-high resistance value depending on whether closing or opening is to be simulated.

F. Induction Motor Modeling

The equivalent circuits of high-voltage motor as shown in Figure 1 suggested by CIGRE, represent the three-phase induction motor under block-rotor condition. Damping at higher frequencies due to increased losses in copper and iron is accounted for by adding the parallel resistor Rp. Distributed turn-to-turn capacitance and turn-to-ground capacitance contribute to wave-like propagation of transients through the machine. The capacitance of the winding is assumed to be lumped at machine terminals

(Cp). Cp assumes two discrete values for two different starting current values. The load circuit represents a three phase load. The motor –substitute circuit is connected to the circuit breaker.

G. Modeling of Protective Devices

The protective devices used during simulation studies are surge capacitors, R-C suppressors and ZnO varistors. These devices are helpful in limiting the peak/ slope of the waveform of switching surges and thus provide protection for turn to turn and ground insulation of the motor. We have dealt with various cases as listed below. The analysis has been done by studying the results obtained by using the protective devices on both the motor and source side. The various cases under study are (both for 3.3 KV and 6.6 KV system) :

a. Without Protection
b. With Capacitor of capacity 0.1 μF at motor end
c. With Capacitor of capacity 0.5 μF at breaker end
d. With RC at motor end(R=100Ω & C= 0.05μF)
e. With RC at breaker end(R=100Ω & C= 0.05μF)
f. With Surge Arrester at motor end
g. With Surge Arrester at breaker end
h. With Surge Arrester and Capacitor (0.5 μF) in parallel at motor end
i. With Surge Arrester and Capacitor (0.5 μF) in series at motor end

H. Metal Oxide Surge Arrestor Model

The arrester is modeled as a non-linear resistor which is represented with positive node numbers in the DATA file, in series with a variable voltage source. The resistance of the branch is changed piece-wise linearly over the complete operating region.

IV. Simulation Results

The over voltages are measured at motor as well as breaker terminals. Comparative study of various circuits using different schemes of protection has been shown in tabular form. It can be clearly inferred from the fig. 2 and the table that:

- The digital simulation results of over voltage at load terminals with surge capacitors at motor terminals show that there is a substantial increase in the rise time of the surges. This leads to a more uniform distribution of surges in the windings, thus reducing the stresses imposed on the motor turn insulation.
- Similarly, the effect of R-C suppressor placed at motor terminals offer an additional advantage, i.e. oscillations are substantially damped.
- The highly non-linear characteristic of surge arrestor leads to a reduced magnitude of switching surges generated with surge arrestor placed at motor terminals. Damping in the oscillations is also introduced to a large extent.
- The combination of surge arrestor and capacitor in parallel proves to be the best to reduce the magnitude of the surge.

Acknowledgments

We are thankful to AME division , BHEL, Bhopal , for providing us the data required for the simulation work. We are also thankful to Electrical Engineering Department, M.A.N.I.T, Bhopal, for providing the facility for the simulation work.

References

[1] Archana Soni, Gayatri Agnihotri, Arvind Mittal, " Surge monitoring and analysis of large a.c. rotating machines ", International conference on electrical rotating machines, ELROMA-99 , pp III-21 to III-26, Jan.99, Mumbai
[2] Archana Soni, Gayatri Agnihotri, Arvind Mittal, "Protection of motors against high voltage switching sources" , Journal of MACT vol.31,1998 pp. 163-171
[3] Paul G Slade, " Vaccum Interrupters : The new technology for switching and protecting distribution circuits", IEEE transaction on Industrial Application Vol. 33 No. 6 Nov./Dec. 1997
[4] Nirmal K. Ghai, "Design & Application consideration for Motor in Steep Fronted surge Environments", IEEE IA/Vol.33, No.1, Jan. 1997.
[5] Grardado, cornick, venegas, Naredo, Melogza, " A threee phase model for surge Distribution studies in Electrical LM/C", IEEE, EC-Vol. 12, No.1, pp 24-31 March 1997.
[6] Richard L Doughty, " Cost effective motor surge capability", IEEE Transaction on Industrial Application Vol. 33 No. 1 Jan./Feb. 1997
[7] Peter A Zotos, " Motor failures due to steep fronted switching surges : The need for surge protection-User's experience,", IEEE Transaction on Industrial Application Vol. 30 No. 6 Nov./Dec. 1994
[8] B.K. Gupta, Nilsson, D.K. Sharma, "Protection of motors against high voltage switching surges", IEEE trans. On EC, Vol.7, No.1, March 1992
[9] E.P. Dick, B.K. Gupta, J.W. Porter, A. Greenwood, " Practical design of generator surge protection", IEEE Transaction on Power Delivery, Vol. 6, No. 2, April 1991
[10]P. Walker, J.W. Champion, " Experience with Turn Insulation Failures in Large 132 KV Synchronous Motors", IEEE , EC, Vol. 6 No. 1, pp. 670-677, Dec.1991
[11]B.K. Gupta, D.K. Sharma, "Degradation of Turn Insulation in Motor Coils Under Repetitive Surges", IEEE, Vol. EC_5, No.2, pp. 320-325 June 1990.
[12]J.D. Gibbs, D.Koch, Dr. P. Malkin, K.J. Cornick, "Comparision of performance of switching technologies on cigre motor simulation circuit", IEEE, PD-Vol. 4, No.3, pp. 745-1750, July 1989.
[13]Narang, B.K. Gupta, E.P. Dick, D.K. Sharma, "Measurement and analysis of surge distribution in motor stator windings", IEEE, EC-Vol.4, No.I, PP 126-134, March 1989.
[14] MANITOBA HVDC RESEARCH CENTRE, "EMTDC USER'S MANUAL", CANADA

Table I Comparative study of various circuits using different schemes of protection

SURGES IN KV DUE SWITCHING OPERATION OF CIRCUIT BREAKER (System voltage 3.3 KV)					
Mode	**Phase**	**Surge at breaker end**		**Surge at motor end**	
		Magnitude KV	**Rise Time µs**	**Magnitude KV**	**Rise Time µs**
Without Protection	A	96.48	36	96.48	36
	B	8	60	8	60
	C	-186	36	-186	36
With Capacitor of capacity 0.1 µF at motor end	A	41.7	84	41.7	84
	B	1.42	144	1.42	144
	C	-79.6	72	-79.6	72
With Capacitor of capacity 0.5 µF at breaker end	A	20	168	20	180
	B	1.45	312	1.45	288
	C	-38	192	-38	158
With RC at motor end(R=100Ω & C= 0.05µF)	A	51	84	51	84
	B	1.2	120	1.2	120
	C	-97	60	-97	60
With RC at breaker end(R=100Ω & C= 0.05µF)	A	51	84	51	84
	B	1.2	108	1.2	108
	C	-97	60	-97	60
With Surge Arrester at motor end	A	5.5	36	5.5	24
	B	0.77	60	0.77	60
	C	-5.7	60	-5.7	120
With Surge Arrester at breaker end	A	5.89	24	5.89	24
	B	0.67	24	0.77	24
	C	-5.7	120	-6.55	120
With Surge Arrester and Capacitor (0.5 µF) in parallel at motor end	A	4.6	48	5.54	4.6
	B	1.2	228	1.2	228
	C	-5.6	24	-5.6	24
With Surge Arrester and Capacitor (0.5 µF) in series at motor end	A	19.7	132	20.6	132
	B	0.7	48	0.7	60
	C	-37.5	156	-37.5	180

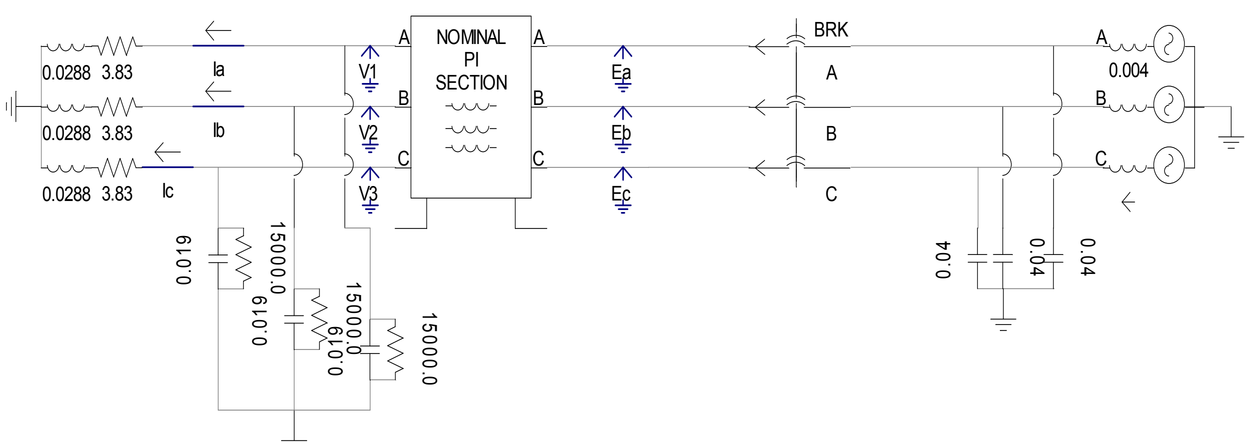

Figure 1. Circuit used for simulation without protection

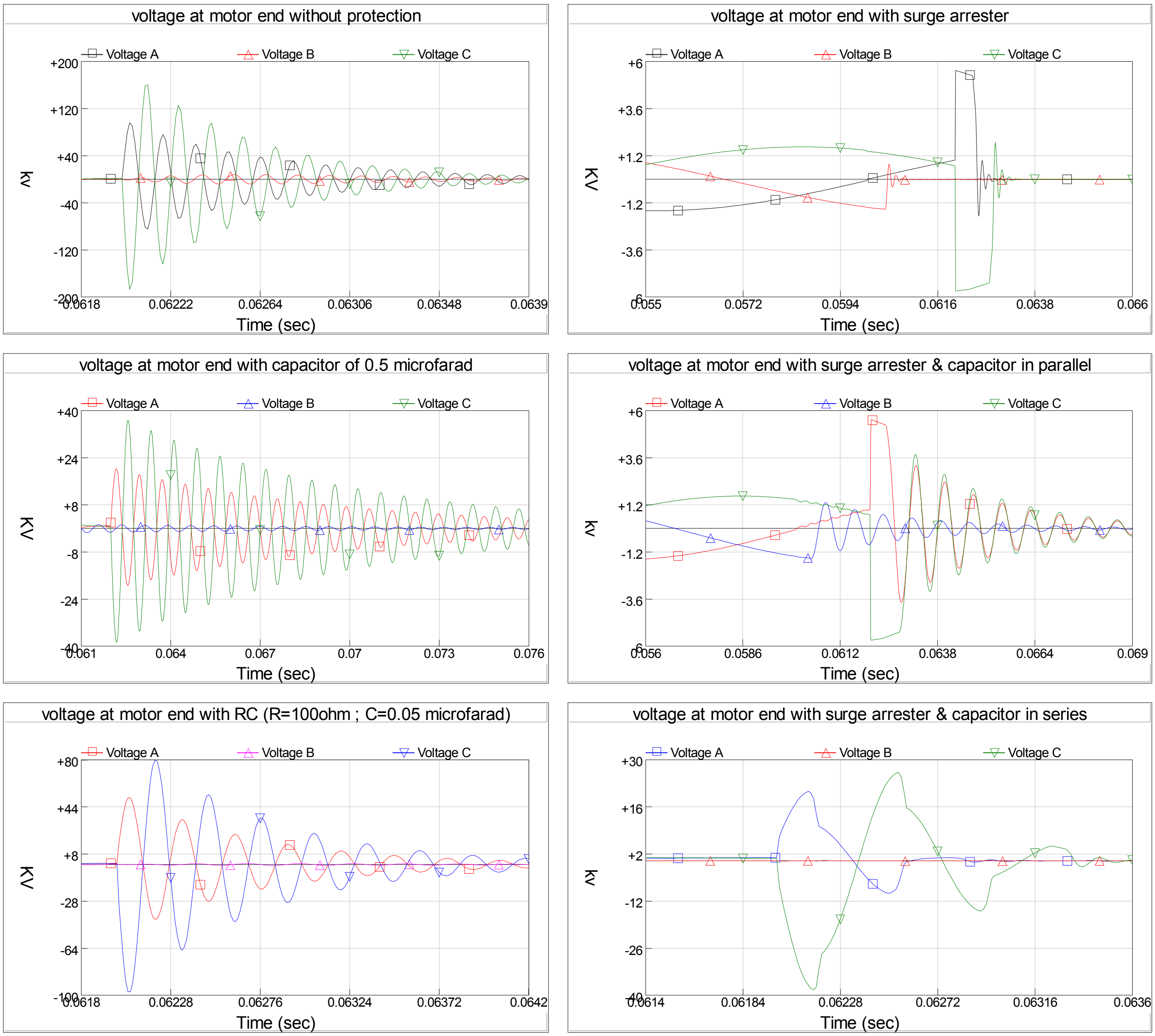

Figure 2 Simulation Results