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Transient over Voltage Due to Switching Operation of Industrial Motor by Vacuum Circuit Breaker and Suppression of Surges

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Abstract: ***Large industrial establishments like steel plants, cement plants, Paper and pulp industries, refineries and petrochemical industries use high power motors for various operations. The motors are connected through long cables and controlled through vacuum circuit breaker. It has been the experience that several duties of motors such as switching-in and off, abort start, inching, jogging and hunting give rise to high voltage surges at the breaker and motor terminals. Several motors have failed due to the above duties. The present paper reports the occurrence of overvoltage due to switching duties for a given pole to clear factor. The control of switching surges by R-C surge suppressor and its effectiveness are discussed in the paper.***

Keyword: ***Switching surges; High power industrial motor; R-C surge suppressor.***

1. Introduction

Several heavy industrial installations like cement plants, steel mills, paper & pulp industries, fertilizers and petro chemicals use large size motors for their operations. The voltage and power rating of motors could be as high as 11 kV and 6 MW respectively. The motors cater to heavy duties work of above industries and handle large currents. High currents cannot be handled by the contactors and hence in majority of cases vacuum circuit breakers of appropriate ratings are employed for achieving switching requirements. It has been observed that control of motors of low power rating is occasionally done by vacuum contactors as well. The vacuum devices are robust, safe and occupy less space compared to oil breakers.

Further, current interruption occurs in a shorter time than oil breakers. Some of the industries have been using SF6 circuit breakers or air magnet for current interruption. There are several advantages of vacuum circuit breakers. Typically, they are flame proof and less affected by the seismic vibrations. Further, its control mechanism is simple. However, it suffers from voltage escalation due to switching surges and re-ignitions during opening and closing operation. A method based on R-C surge suppression in reducing the peak surge magnitude is reported by Vollety et al. [1]. It is known that current chopping in vacuum contactors and breakers also lead to generation of higher transient voltages. Electric drives in heavy industries are mostly located at long distances from power source; hence they are connected by long power cables. The total inductance and capacitance associated with long length of cables are proportionally high. This gives rise to high voltage surges during switching activity.

The surges are very fast in nature with magnitude rising to a higher level with every re-ignition in the breaker. Vukelja et al. [2] have reported the investigation of surge generated due to abort start duty of motors by Minimum Oil Circuit Breaker (MOCB), Air Magnetic(AM) and Vacuum Circuit Breaker(VCB). The paper has suggested taking certain measures to mitigate the effect. The actual value of peak magnitude is determined by the length of cable, the number of re-ignitions, damping in the circuit and short circuit impedance of source at breaker terminal. Such surges begin propagating along the cable length and enter the terminal of motor. Since the rate of rise of pulses is of the order of a few nano-seconds, it causes non-linear distribution of voltage in the winding. Jackson et al. [3] published a survey report on the use of surge protective capacitors and arrestors for rotating machines and its effect on degree of protection. Naveed et al. [4] reported the voltage surge generated in a 6.6 kV motor due to operation of Vacuum Circuit Breakers (VCB) using MATLAB.

The analysis reports the effect of various cable lengths on magnitude of surges during switching and its effect on failure of motor. Dick et al. [5] reported the turn to turn stress in a motor subjected to steep fronted surges due to VCB switching. The voltage levels are affected by shield and ground capacitances as well as motor capacitances. The work reported in this paper deals with the calculation of surges due to switching of large motor in a steel plant and its reduction with the use of R-C surge suppressor. At certain instances it is observed that the circuit breaker opens immediately after it closes. Hence a typical system is modeled to obtain voltage surges, if the breaker opens immediately after closing to simulate abort start duty.

2. Modeling of System for EMTP

2.1. Calculation

The circuit consists of motor of a three phase 6.6 kV, 260 kW connected to a power supply system through 132 /6.6 kV transformer. The cable length connecting the transformer and motor is 750 meters. A vacuum circuit breaker is connected at the transformer end and R-C surge suppressor is connected at the motor terminal.

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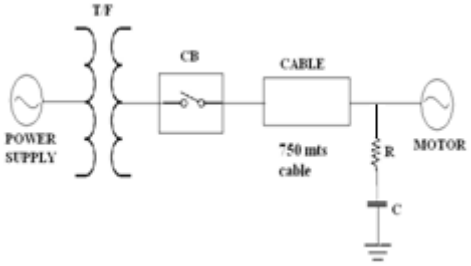


Figure 1: Single line diagram of the motor system.

A single line diagram showing the power supply, transformer, cable and motor is shown in Fig. 1. Although several other motors are also connected to the same supply they are assumed to be permanently on and only one motor is considered for switching in and off duty.

Figure 2: Three phase equivalent circuit diagram of a 6.6 kV motor system with RC surge suppressor

Motor Parameter

L_s= 1.4 mH,
R_m= 1.22 Ω,
C_p = 0.013μF,
R_P = 15 KΩ

Table 1: Sequence parameters per KM of cable length

Sequence	R(Ohms)	L(mH)	C(μF)
Zero sequence	2.81	0.33	0.18
Positive sequence	0.31	0.28	0.34
Negative sequence	0.31	0.28	0.34

The electrical circuit representation of the above system is shown in Fig. 2. The transformer is represented by three phase short circuit impedances with source voltage of 6.6 kV. Only inductance is represented in the circuit. Resistance is ignored in comparison to inductive impedance since its value is very low compared to inductive impedance. Breaker is represented by a simple switch for closing and opening operation. Cable is assigned values equivalent to its zero sequence, positive and negative sequence parameters as given in Table 1. Motor is represented by Rm and Lm in series along with parallel resistance (Rp) and capacitance (Cp). The Rp and Cp represent the resistance and capacitance between winding and core. A three phase surge suppressor comprising appropriate resistance and capacitance in series is connected between the line and neutral through a switch. A typical value used is 100 Ω and 0.5 μF with minimum inductance associated with the elements. The equivalent electric circuit is solved by Electro Magnetic Transient Program (EMTP).

3. EMTP Simulation

All parameters of three phase system given in Fig. 2 are entered in EMTP data system. The short circuit impedance of transformer, sequence parameter of cable, inductance, capacitance and resistance of motor is entered in different cells using proper node definition. Connecting circuit breaker is represented by switch with time to close and open. The surge suppressors are connected through a three phase switch so that study can be made with and without surge suppressor in the circuit. Since the high voltage motors in the system operate without neutral grounding, the neutral end of the motor is kept open. During simulation it is assumed that motor is off and that switching is done at a given phase angle. The surge generated due to switching-in operation is calculated. The closing time of the switch is then changed such that motor closes at different phase angle. To simulate pole to clear factor the closing time of R, Y and B phases are kept different. In order to study the R-C surge suppressor effect, it is connected in the circuit before performing switching-in duty of the breaker. The effect on voltage escalation is determined with different R-C combination. An additional three phase switch is connected in series with the circuit breaker to simulate opening of the circuit after breaker closing to represent abort operation of the circuit breaker.

4. Result and Discussions

In EMTP simulation the breaker contacts are closed at pre specified time. In first case, the R pole contact is closed at 0.5 msec. from the peak of voltage. Y and B phase contacts are also closed simultaneously. Fig.3 shows the transient voltage at motor terminal after closing of the breaker. In Fig. 3 the highest voltage at R phase terminal is observed to be 11.30 kV

Immediately after switching. The other two phases Y and B attain a lower voltage of (-) 10.37 kV and 10.09 kV respectively due to natural damping in the circuit. The voltage surge is a function of pole to clear factor and phase to phase clearing time. Since, in the present case all the poles are closed together the surge magnitude and rise time are decided by the frequency of oscillation of the three phase circuit and the magnitude of voltage at the instant of closing.

To examine the effect of RC surge suppressor a combination of R=100 Ω and C=0.5 μF is connected in all the three phases. The contacts are closed as above and output is recorded as shown in Fig.4. It can be seen that highest phase voltage at motor terminal reduced to 1.37 pu. It shows a significant reduction in oscillation due to damping. However reduction of C from 0.5 μF to 0.1 μF in RC surge suppression yielded only marginal reduction in surge magnitude as shown in figure 5

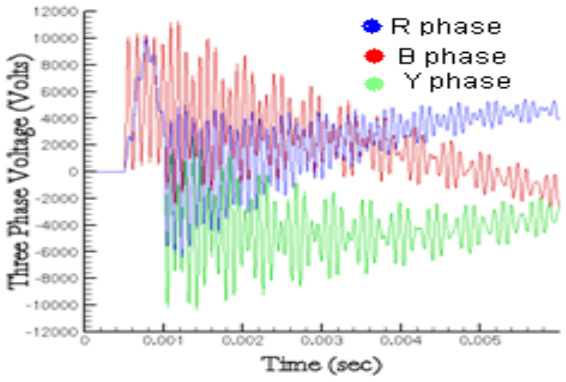


Figure 3: Transient surge at the motor terminal without surge suppressor

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The effect of different combinations of R & C is examined with regard to peak voltage during switching-in operation. The comparative values of surges and rise time are shown in Table 2 Voltage surge during different switching on operation is shown in Table 3. Table 4 shows voltage surges during different switching on and off operation due to abort duty.

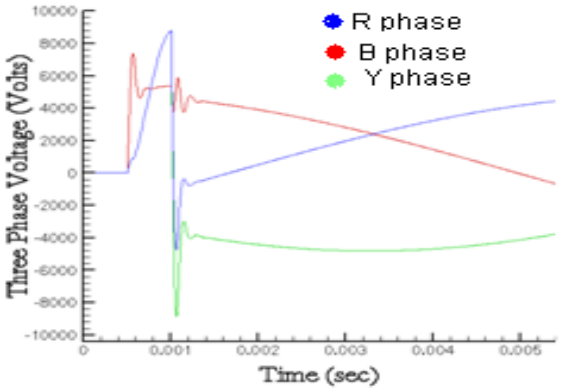


Figure 4: Transient over voltage at breaker terminal with surge suppression of R=100 ohm and C=0.5µF.

To examine the abort start duty the R phase switch is opened within a pre-specified time after switching off. It is observed that voltage rise is 14.16 kV in R-phase and (-) 16.4kV in Y-phase during abort start. If the RC surge suppressor (100Ω, 0.5µF) remains connected during abort start the surge voltage declines to (-)7.38 kV in R phase and of (-)8.8 kV in Y -phase.

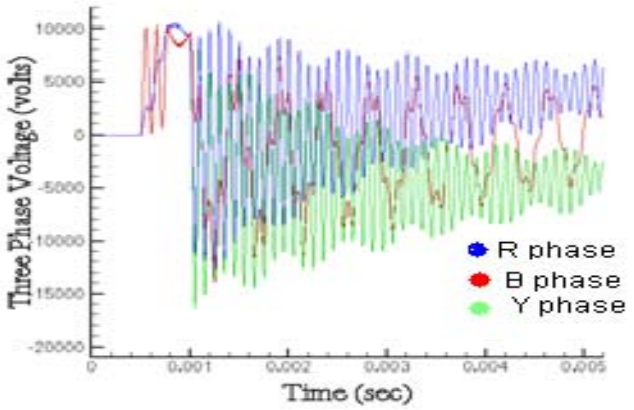


Figure 5: Transient over voltage at breaker terminal with surge suppression of R=100 ohm and C=0.1µF.

Table 2: The peak value and rise time of pulse at motor terminal

S. No	*R (Ohms)*	*C (µF)*	*Magnitude of Peak Over Voltage (kV)*	*Time to rise (µs)*
1	No RC	No RC	11.30	46.1
2	100	0.1	09.31	55.6
3	100	0.2	08.50	58.0
4	100	0.3	07.98	59.3
5	100	0.4	07.60	62.7
6	100	0.5	07.38	59.4
7	50	0.1	09.60	58.3

Table 3: Voltage surges during different instant of switching-on of the breaker.

R (msec)	*Y & B (msec)*	*R (kV)*	*Y (kV)*	*B (kV)*
0.5	0.5	11.3	-8.11	9.0043
0.5	1.0	10.3	-8.34	6.24
0.5	2.0	10.34	-9.03	10.09
0.5	3.0	10.35	-10.45	10.09

Table 4: Switching surge due to abort operation

Case	*Phase*	*Breaker Closing time (m sec)*	*Switch opening time (msec)*	*Peak voltage (KV)*		
				R phase	*Y phase*	*B phase*
1	R	0.5	0.75	-14.16 (2.6 pu)	-16.4 (3.04 pu)	-12.2 (2.26 pu)
	Y	1.0	-			
	B	1.0	-			
2	R	0.5	1.0	10.3 (1.9 pu)	-10.5 (1.94 pu)	10.09 (1.87 pu)
	Y	1.0	-			
	B	1.0	-			
3	R	0.5	1.5	11.4 (2.1 pu)	-10.34 (1.9 pu)	10.09 (1.87 pu)
	Y	1.0	-			
	B	1.0	-			

5. Conclusion

The paper, Transient Over Voltage Due to Switching Operation of Industrial Motor by Vacuum Circuit Breaker and Suppression of Surges describes the result of voltage surge generated during three phase switching operation of a vacuum circuit breaker in 6.6 kV high power motor connected through HV cable. The effect of abort start is examined. Reduction in surge magnitude by RC surge suppressor is significant as per study using EMTP simulation. It is observed that surge generated at motor terminal is far in excess (2.1 pu) of the normal power frequency peak voltage when surge suppressor is not in the circuit. Abort start of a motor gives rise to further high voltage surges. It can be concluded that the voltage surges can be controlled by RC surge suppressor, for longer cable lengths between the transformer and industrial motors.

6. Acknowledgements

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