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Reduction of Switching Surges in Large Industrial Motors Connected by Cables

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ABSTRACT

Switching of high power motors in the Megawatt range leads to transient over voltage at motor terminals. Steepness of transient voltage depends on type of circuit breaker used for switching the motors. If magnitude of transient exceeds the basic insulation level of winding, a scheme is required to protect the motor from insulation failure. This paper deals with the multiple reignitions and voltage escalation due to switching operation of circuit breaker and installation of suitable surge suppressor between line and ground. The circuit parameters like cable, motor, circuit breaker and surge suppressors are properly simulated in the equivalent network. Over voltages of motor circuits are calculated using Electro Magnetic Transient Program (EMTP™). It is found that switching and reignition voltages can be suitably controlled by appropriate surge suppressor parameters

Keywords: Switching surges, high power industrial motors, EMTP™, multiple re-ignition, circuit breaker.

1. INTRODUCTION

Industrial establishments like pulp and paper industries cement plants, steel mills, and petro chemicals complexes use large size motors for their operations. Depending upon the requirement there are frequent switching on and off operations. Since the current required is high, medium voltage vacuum or SF6 breakers are used for switching duties. Transient over voltages are generated due to switching of high power motors by vacuum or SF6 circuit breakers. These transient over voltages propagate along the cable and reach the motor terminal. Several authors reported the behavior of multiple reignitions of vacuum circuit breaker. The origin of multiple reignitions is due to separation of switch contacts. During movement of contact, the circuit is interrupted and the gap contains high density of ionized particles. If the rise of voltage between the contacts is higher than the dielectric strength of the gap then the gap breaks down predominantly and voltage at motor end attains higher voltage than power frequency voltage. The phenomena of arc quenching and flashover between the gap continues several times until the ionization in the gap has significantly reduced. This phenomenon gives rise to voltage across motor terminal which is several times higher than system voltage. Such phenomena may cause failure of motor winding. Medium voltage circuit breakers with inductive loads connected through short cables are very risky [1] in terms of multiple restrikes at the breaker terminal. By using double breaker we can improve the behavior of circuit breaker, but this may lead to stress on the electrical equipments especially in high voltage applications [2]. In case of small gap length, during the time of natural current zero crossing, vacuum gap cannot withstand the generated transient recovery voltage. This leads to a train of reignitions travelling along the cable length. Impact of the phenomenon has been subject of many investigations [3]-[4]. Authors observed that amplitude of generated over voltages reach more than 8 p.u. Borghetti et. al. [5] reported that, the reignitions at vacuum circuit breaker are due to opening and closing operations of breaker. The authors suggested that by increasing the

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TRV capability of the vacuum circuit breaker and connecting the snubber circuit, one can protect the motor winding insulation.

In this paper typical system is modeled to simulate the reignition voltages of circuit breaker with and without surge arrester. The model parameters like L, C etc. are taken from a motor of a typical cement plant. The main objective of this paper is to evaluate transient over voltages as a function of cable length and provide suitable RC surge suppressor arrester to protect the motor stator winding insulation.

2. SWİTCHİNG OVER VOLTAGES

2.1. Over voltages during opening operation

The fundamental reason of generation of over voltages is related to the interruption of inductive current before natural zero crossing due to instability of arc. Steepness of voltage depends on the type of circuit breaker used for switching. H G Templaar et. al. [6] reported that smaller the current to be switched the higher the over voltage. In other words highest voltage would be expected at no load switching. In case of short length cable, time derivative of high frequency current is large, therefore the switching gap is unable to interrupt them. Conversely, very long length cables increased losses of the cable making it impossible to have very large over voltage amplitude.

2.2. Over voltages during closing operation

In the same manner as described in section 2.1, same breaker chops the high frequency current during the closing operations. Current chopping be followed by a reignitions of the arc. This leads to voltage escalation. Decreasing [7] contact distances leads to decrease in transient over voltage amplitude. Tarik Abdulahovic et. al. [8] reported that the vacuum circuit breaker model is tested using a laboratory test setup and simulation results show a good agreement with the obtained measurements.

3. NETWORK DESCRIPTION

In this work a three phase induction motor is supplied from a transformer via circuit breaker connected by a cable. Figure 2 shows the equivalent test circuit which have been used for the Electromagnetic Transient Program (EMTP™) simulations. 3-phase 6.6 kV motor is connected through circuit breaker and a cable length of 750 m long. An RC surge suppressor is connected at motor terminal side. The equivalent parameters of various components are as follows

Motor parameters

Motor inductance (Lm) =1.4 mH

Motor resistance (Rm) =1.22 Ω

Motor phase to ground capacitance (Cp) = 0.013 µF

Motor insulation resistance (Rp)=15 kΩ

Table 1
Sequence parameters of cable /km

Sequence parameter	*R(ohm)*	*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

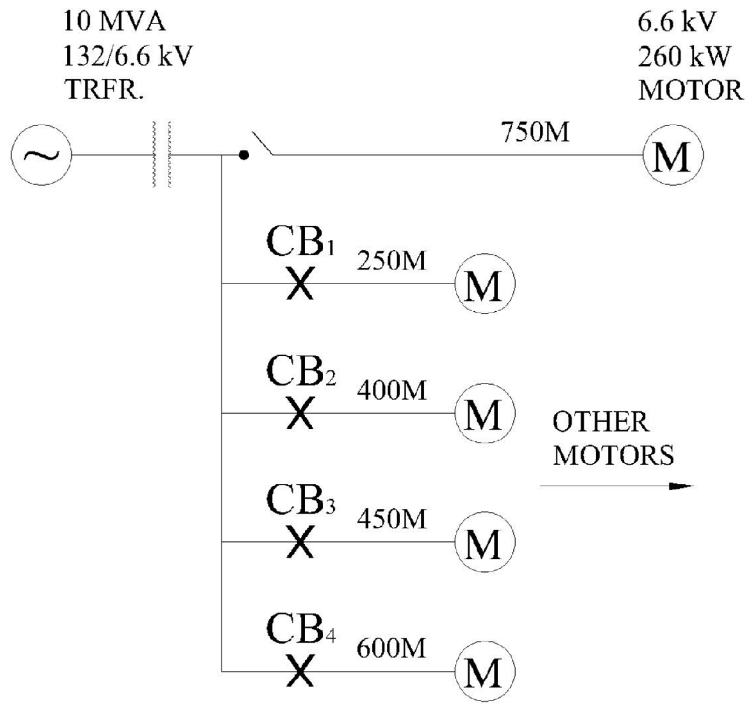

Figure 1: Line diagram of motor system

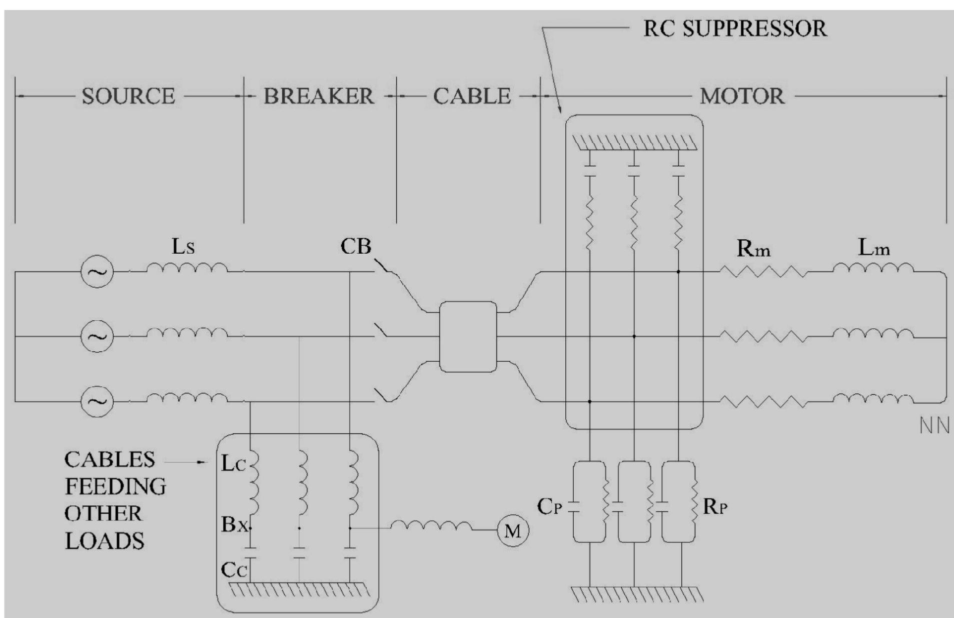

Figure 2: Equivalent circuit of three phase motor system with surge suppressor

The equivalent electrical circuit of three phase induction motor with surge suppressor is given in Figure 2. In this system transformer is represented by three phase short circuit impedances with source voltage of 6.6 kV. Source inductance Ls is calculated from the short circuit MVA of the source. The three phase breaker is represented as a three simple switches. In this study only one three phase switch is considered. The other motors are assumed to be on permanently. It is so, to record the different pre-strike conditions in motor circuit with 750 m long cable. Cable is modeled with its calculated values of zero, positive and negative sequence parameters as given in Table 1. The equivalent parameters of the motor are Rm, Lm, Rp and Cp.

A three phase surge suppressor is connected as shown in Figure 2 between line and neutral through a switch, which comprises the suitable resistance and capacitance. In this work typical values of the R and C are 50 ohms and 0.1 μF respectively. The Electromagnetic Transient Program (EMTP™) is used to simulate the above equivalent electrical circuit.

4. EMTP™ SIMULATIONS

All the parameters of the system are entered in EMTP™ data system. The vacuum circuit breaker is represented by a switch [9] with opening and closing time. The RC surge suppressor is connected through a switch so that study can be made with and without surge suppressor. Initially, motor is assumed to be off and switching duty is done at a given phase angle. The generated surge due to switching-in operation is calculated. The closing time of the switch is changed in such a way that motor closes at different phase angle. It is so, to calculate voltage escalation due to circuit breaker closing operations with different pole to clear factor. The time interval between two adjacent reignitions depends on the L and C parameters of the circuit.

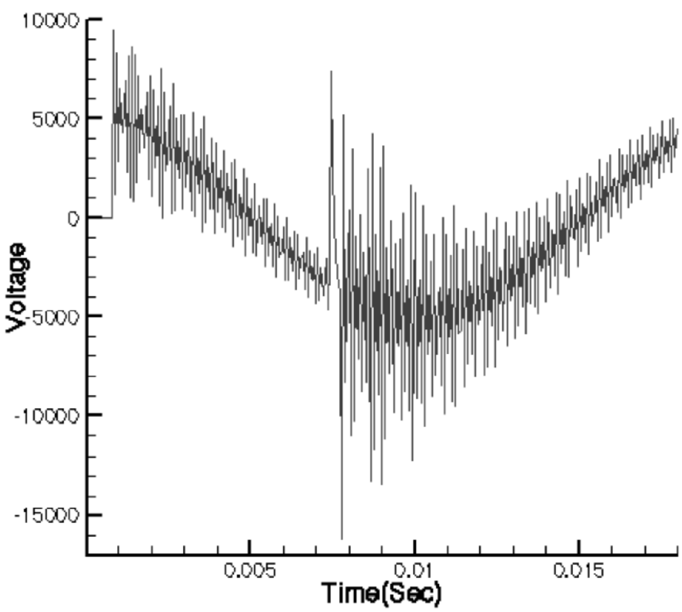

Figure 3: Voltage escalation due to first reignition

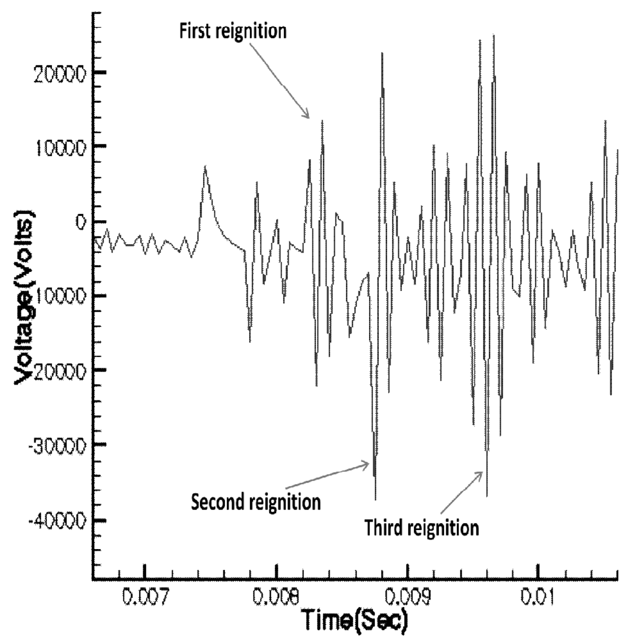

Figure 4: Voltage escalation due to switching operation of motor through circuit breaker

To study the effect of RC surge suppressor, it is connected in the circuit as shown in Figure 3. In this work, to study the effect of surge suppressor, different combinations of RC values have been considered.

5. RESULTS AND DISCUSSION

As stated above, to examine the effect of surge suppressor, simulation has been done with and without surge suppressor. Figure 3 shows the voltage escalation due to switching operation without surge suppressor. From Figure 4 it has been observed that due to circuit breaker reignition voltage levels have reached 48 kV, which may propagate through the cable and reach the motor terminal, which could damage the motor stator winding insulation. Figure 5 shows the typical voltage wave shapes at the motor terminal with surge suppressor.

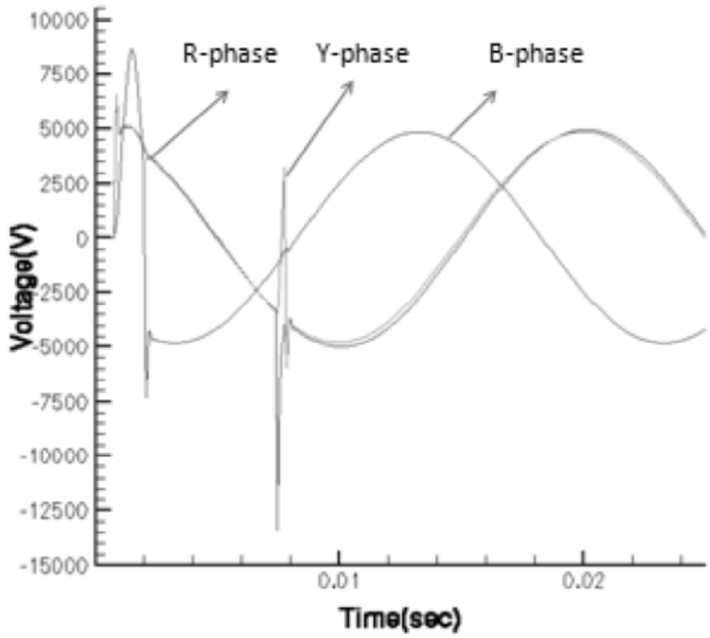

Figure 5: Transient voltages at breaker terminal with surge arrester

From Figure 5 it is observed that voltage rise is reduced to 6.6 kV in R phase, (-) 7.3kV in Y phase and 8.6 kV in B phase for a given values of RC, i.e. R=50 Ω and C= 0.1 μF. Table 2 gives the transient over voltages for different combinations of RC surge suppressor.

Table 2
Transient over voltages for different RC surge suppressor during third re ignition

S.No.	*Resistance (Ω)*	*Capacitance(μF)*	*Peak over voltage(kV)*
1	Without RC	-	48 kV in R phase
2	R=50	C=0.5	7.6 in R phase
3	R=130	C=1	7.1 in R phase
4	R=250	C=0.5	8.16 in R phase
5	R=50	C=0.1	6.6 kV in R phase

The results of figure 5 and Table 2 allow to infer that reduced transients is achieved using the parameters of suppressor are, R= 50 Ω and C= 0.1μF.

5. CONCLUSION

In this paper multiple reignitions of vacuum circuit breaker during switching in and off operation of large industrial motor through circuit breaker have been investigated and required protection is proposed. The network considered in this work consists of vacuum switch, 3 phase induction motor supplied by transformer via circuit breaker. A vacuum switch is used for switching duties. It is observed that in the absence of RC surge suppressor, three reignition voltage is high. Such voltage may damage the insulation of the motor. A suitable combination of R and C surge suppressor is connected between line and ground which reduces the maximum transient over voltage. Hence it is recommended that for a given cable length and motor parameters appropriate value of RC should be connected.

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