Grading Capacitor Requirements

For Metal-Enclosed Capacitor Banks Utilizing Vacuum Switches with Two or More Series Connected Vacuum Bottles

Introduction

Metal-Enclosed Capacitor Banks and Harmonic Filter Banks applied at the 34.5kV to 38kV voltage level often utilize vacuum switches (as shown in Figure 1) equipped with two or more series connected vacuum interrupters. These vacuum switches, when applied within a metal enclosure, are more likely to re-strike and result in equipment damage. To reduce this possibility, NEPSI recommends a grading capacitor be connected across each of the series connected vacuum interrupters.

This tech-note provides background information on the above recommendation and is based upon actual analysis and events experienced by NEPSI during the commissioning of two 34.5kV, 18 MVAR, 3 Step 3 Stage Metal-Enclosed Automatic Capacitor Banks purchased by the City of Burbank.

Figure 1 - Typical 34.5 kV Vacuum Switch With Two Series Connected Vacuum Bottles.

Definitions

Transient Recovery Voltage - Also referenced as TRV, is defined as the voltage across the vacuum contacts of a vacuum switch immediately following current interruption. Capacitor de-energization provides a high level of transient recovery voltage to vacuum switches as peak positive or negative voltage is trapped on the capacitor just following current interruption.

Restrike - Is defined as the re-ignition of load current following current interruption within a vacuum switch. It occurs during the switch interruption process when the parting contacts of a vacuum switch do not achieve adequate dielectric recovery and the extinguished arc reignites ("restrikes"). The restrike can result in capacitor and system transient over-voltages of 3, 5, 7, and even 9 per unit system line-to-neutral voltage.

Figure two shows a typical case rupture caused by vacuum switch re-strike. In this particular restrike case, five capacitors cans ruptured as shown.

Description of Problem

Vacuum switches that utilize two or more series connected vacuum bottles work on the premise that each vacuum bottle will share nearly equal percentages of the transient recovery voltage during interruption. The application of this premise allows vacuum switch manufacturers to use lower voltage rated vacuum bottles to achieve load current interruption at higher voltage levels. When the transient recovery voltage is not equally shared, however, restrike free load interruption may not take place. Restrike results in the re-ignition of current flow and is followed by a high voltage and current transient similar to an overshoot experienced during capacitor energization (see NEPSI tech-note on Capacitor Bank Switching Transients at the following web address http://www.nepsi.com/transients.htm). The transient however, is far worse and can result in equipment damage as shown and experienced by our equipment in Figure 2.

Figure 2 - Restrike Caused 5 Capacitors to Rupture Like the Opening of a Sardine Can as Shown Above

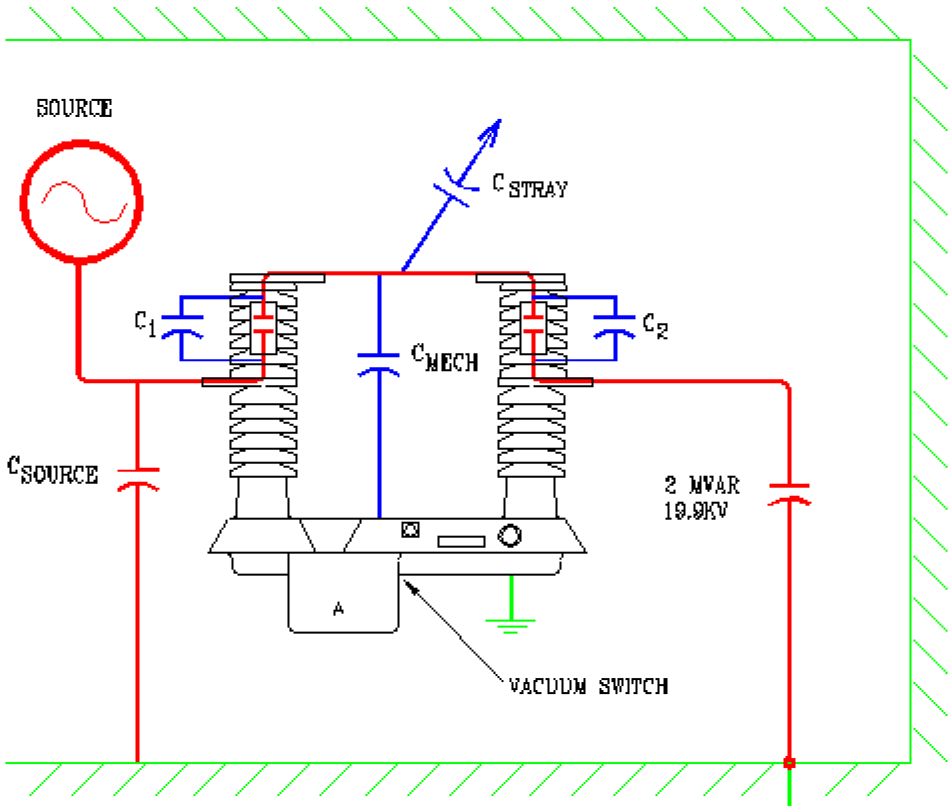

Figure 3 - Capacitor Voltage, Vacuum Bottle Voltage and Line Voltage With Cmech + Cstray =35Pf

Figure 3 illustrates the reason restrike is more probable in vacuum switches that utilize two or more series connected vacuum bottles. The figure shows a single-phase representation of a vacuum switch utilizing two series connected vacuum bottles, utility voltage source, 2 MVAR capacitor bank, vacuum bottle capacitance, and capacitance connected to the mid-point of the vacuum bottles. The mid-point capacitance consists of Cstray and Cmech. Cmech exists regardless of whether the bank is mounted in an enclosure or outside on a rack. Cstray consists of capacitance to all other grounded objects (in our case, the metal enclosure).

The mid-point capacitance causes unequal voltage division between the two series vacuum bottles during interruption. Ideally, as stated above, equal voltage division between the vacuum bottles is desired. The unequal voltage division causes the line-side vacuum bottle to carry a disproportionate amount of the Transient Recovery Voltage (TRV) during de-energization of the bank. Based on field measurements, nearly 70% of the TRV can be distributed across the line-side vacuum bottle (in a two vacuum bottle switch), while the load side vacuum bottle experiences near 30%. Figure 4 below illustrates how the voltage division is developed during de-energization. In looking at the figure and the equations, and assuming that C1 equals C2, it is obvious that the sum of Cmech+Cstray causes the unequal voltage division.

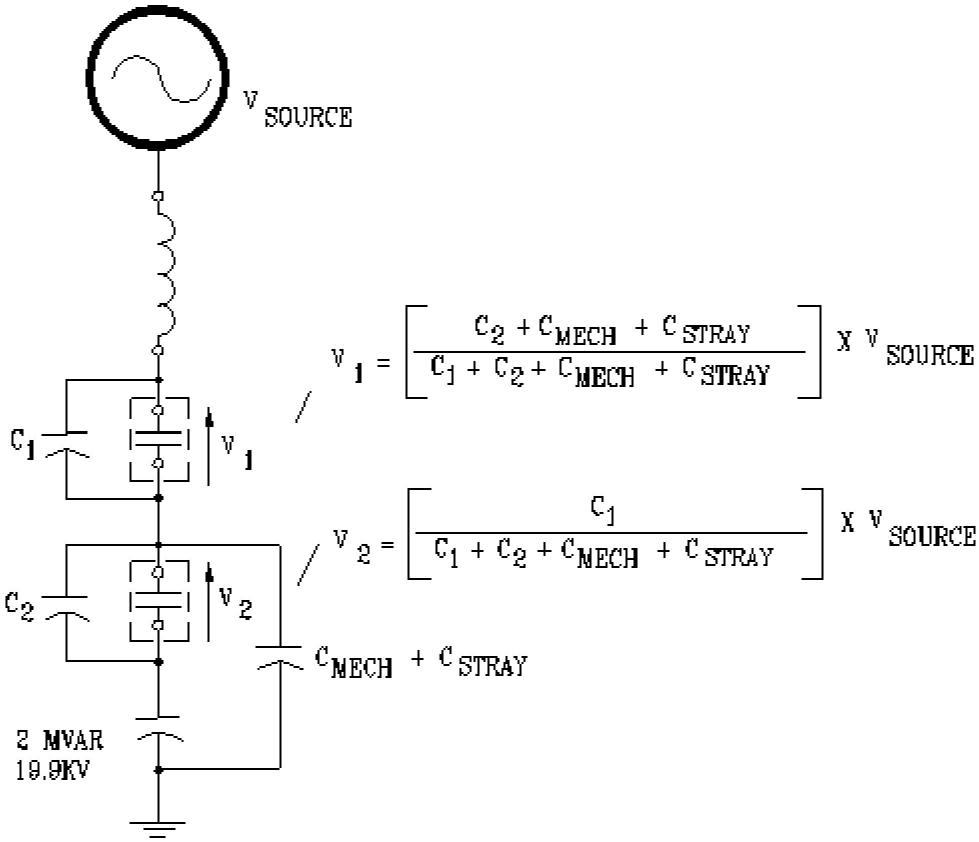

Figure 4 - Capacitor Voltage, Vacuum Bottle Voltage and Line Voltage With Cmech + Cstray =35Pf

EMTP Results

Figure 5 and Figure 6 below show the waveform plots as simulated in EMTP by NEPSI using field test data of the actual system at the City of Burbank. The waveforms show a disproportionate voltage across the line side vacuum bottle. Nearly 70% of the TRV is dropped across the line-side vacuum bottle and only 30% across the load-side vacuum bottle. This unequal sharing resulted in switch restrike.

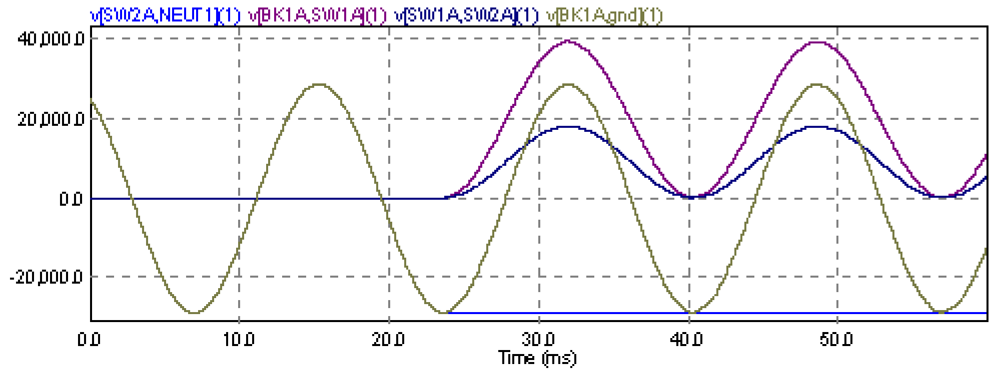

Figure 5 - Capacitor Voltage, Vacuum Bottle Voltage and Line Voltage With Cmech + Cstray =35Pf

Key to Figure 5

V[SW2A,NEUT1](1) = Capacitor Voltage to Ground
V[BK1A,SW1A](1) = Voltage Across Line-Side Vacuum Bottle during interruption
V[SW1A,SW2A](1) = Voltage Across Load-Side Vacuum Bottle during interruption
V[BK1A,gnd](1) = System Line-Ground Voltage at Capacitor Bank Terminals

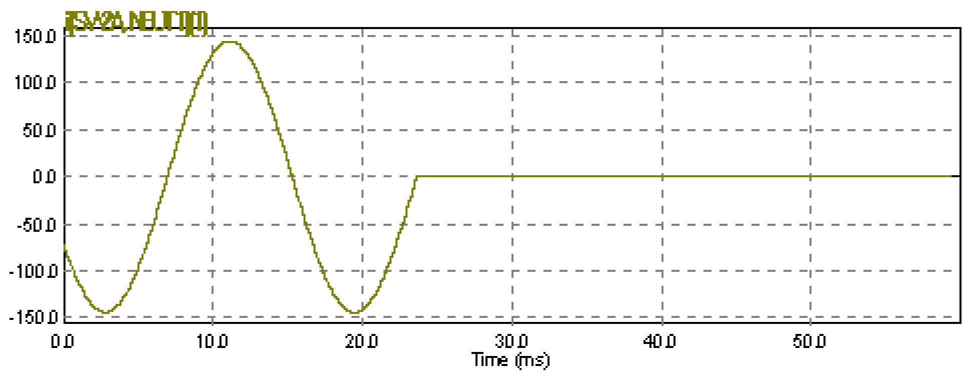

Figure 6 - Capacitor Current With Cmech + Cstray =35Pf

Key to Figure 6

i[SW2A,NEUT1](1) = Switch current or capacitor bank current

Physical Characteristics Experienced During Restrike

- Unusually large noise (pop) during de-energization of the bank. This sound occurred for all instances where restrike occurred.
- Single or multiple fuse operations with or without capacitor case rupture.
- Single or multiple capacitor case ruptures with or without fuse blowing.

Corrective Measures

To ensure equal voltage division across the series connected vacuum bottles, NEPSI recommends the following measures:

- After Installation of the vacuum switch within the enclosure, measure the capacitance across each vacuum bottle when the switch is in the open position. A high end, low capacitance meter such as the one shown in figure 7 is required to perform this test. If nearly equal values of capacitance are not measured, install sufficiently sized grading capacitors to equalize the voltage.

- After installation of the grading capacitors, re-check the capacitance across each vacuum bottle to ensure nearly equal values. If values are not nearly equal, adjust the size of the grading capacitor.

Figure 7 - A High Precision LCR Meter With an Accuracy On The Order of 0.05% in the Picofarad Range is Required to Ensure Equal Capacitance Accross the Vacuum Bottles

Figure 8 - Picture to left shows the 18 MVAR 3 Step 3 stage automatic capacitor bank being loaded for shipment to the City of Burbank. The bank was of all stainless steel construction and painted per the customer's requested color.

After the installation of grading capacitors, the vacuum switches operated free from restrikes during de-energization.

Northeast Power Systems, Inc.
66 Carey Road
Queensbury, New York 12804
Phone: 518-792-4776
Fax: 518-792-5767
E-mail: sales@nepsi.com
Website : www.nepsi.com