

## VOLTAGE LIMITER INTERRUPTERS

Elmer L. Leuhring

We have designed a recovery voltage limiter for high voltage interrupter switches. The principle of operation involves reduction of transient recovery voltage by conversion of electromagnetic energy into heat in a nonlinear resistance during a switching event. Each interrupter module is shunted by a nonlinear resistance.

Vacuum interrupter attachments for high voltage air switches have allowed such switches to be rated for load interruption in many different circuits. The size and cost of an interrupter attachment is determined by the load to be interrupted and its switching recovery voltage. A study of transient recovery voltage in power systems will show that in the simple single phase circuit, the peak switching recovery voltage will be twice the peak system voltage for many situations. The source of this added voltage is the energy stored in reactive elements (such as capacitors and inductors) of the circuit at the instant of switching. Fault switching is characterized by a high frequency transient as the energy trapped in "stray" capacitance flows alternately back and forth to the inductance of the circuit. In shunt capacitor switching, the "transient" is very long and nonoscillatory. The capacitor voltage is a decaying voltage reduced in time by the system resistances. Three phase switching recovery voltages are larger than single phase recovery voltages.

Voltage across an open switch after a switching transient has subsided is normally the same as the line to ground voltage. Interrupter switches are designed to withstand a high peak transient recovery voltage even though the normal voltage at the switch will be much less. Limiting the switching transient recovery voltage can allow the interrupter device to be reduced in size.

Interrupter switches equipped with voltage limiters have fewer modules for a given rated voltage than similar switches without limiters. Application data is based on system switching energy. Switching energy is the energy trapped in inductive or capacitive elements as the circuit is interrupted. For capacitance switching, the trapped charge on the switched capacitor is a major portion of the switching recovery voltage.

A BASIC statement for the charge energy in joules is:

$$\text{CAPENERGY} = 1/2 * \text{CAPACITANCE} * \text{CAPVOLTAGE}^2$$

where CAPACITANCE is in farads and CAPVOLTAGE is the voltage existing on the CAPACITANCE at current zero.

Most of this trapped energy can be removed during the recovery voltage interval with a Voltage Limiter. Additional system energy is converted to heat in the process so that the voltage limiter resistor will receive about twice the energy trapped in the capacitor.

Voltage Limiters are produced in ratings of 4000 Joules, 10,000 and 15,000 Joules. These ratings can be applied to vacuum interrupters of the 20kV class. Most interrupters are made up of 20kV class modules with sufficient number in series to withstand the switching recovery voltage. The recovery voltage rating of a 20kV class module is 60kV peak for currents below 50 amperes. Voltage Limiters are designed to prevent recovery voltage from exceeding 60kV. The minimum life expectancy exceeds 500 operations where the absorbed energy is less than rated.

For a given capacitive current, the switching energy for 50 Hertz systems will be about 15% higher than for 60 Hertz systems because of the longer current pulse. The higher energy will reduce the life expectancy for a given current to 40% of that listed in the table on the next page. Remember that line charging current for a given circuit length is less at 50 Hz than at 60 Hz. On a circuit mile basis the life will be about the same for each frequency.

| Maximum System Voltage (kV) | Line Charging Current (Amps) | Number & Size of Modules | Maximum Module Energy (Joules) | Minimum Expected Life (Operations) |
|-----------------------------|------------------------------|--------------------------|--------------------------------|------------------------------------|
| 38                          | 15                           | 1-A                      | 3,500                          | 1,000                              |
|                             | 25                           | 1-A                      | 5,700                          | 198                                |
|                             | 25                           | 1-B                      | 4,484                          | 635                                |
|                             | 50 Cable                     | 1-B                      | 5,400                          | 341                                |
|                             | 25                           | 1-F                      | 5,800                          | >10,000                            |
|                             | 50 Cable                     | 1-F                      | 2,488                          | >10,000                            |
| 48.3                        | 15                           | 1-A                      | 5,800                          | 189                                |
|                             | 15                           | 1-B                      | 5,007                          | 441                                |
|                             | 25 Cable                     | 1-B                      | 4,110                          | 849                                |
| 72.5                        | 10                           | 1-F                      | 23,267                         | 60                                 |
|                             | 15                           | 1-F                      | 34,662                         | 16                                 |
|                             | 20                           | 2-A                      | 3,900                          | 699                                |
|                             | 25                           | 2-B                      | 6,793                          | 160                                |
|                             | 50                           | 2-C                      | 10,501                         | 844                                |
|                             | 50 Cable                     | 2-C                      | 4,840                          | 11,000                             |
| 121                         | 15                           | 2-F                      | 16,400                         | 628                                |
|                             | 15                           | 3-A                      | 9,000                          | 43                                 |
|                             | 15                           | 3-B                      | 5,370                          | 348                                |
|                             | 30                           | 3-C                      | 9,559                          | 1,154                              |
|                             | 50                           | 3-C                      | 14,420                         | 294                                |
|                             | 50 Cable                     | 2-F                      | 10,154                         | 3,090                              |
| 145                         | 10                           | 2-F                      | 23,267                         | 60                                 |
|                             | 10                           | 3-A                      | 11,217                         | 21                                 |
|                             | 10                           | 3-B                      | 9,245                          | 57                                 |
|                             | 15                           | 3-C                      | 13,578                         | 360                                |
|                             | 20                           | 3-C                      | 17,647                         | 151                                |
|                             | 50 Cable                     | 3-C                      | 8,159                          | 1,953                              |
| 169                         | 15                           | 3-F                      | 12,467                         | 1,562                              |
|                             | 15                           | 4-A                      | 10,900                         | 23                                 |
|                             | 15                           | 4-B                      | 7,337                          | 124                                |
|                             | 25                           | 3-F                      | 19,860                         | 332                                |
|                             | 50 Cable                     | 3-F                      | 9,273                          | 4,177                              |
| 242                         | 15                           | 4-F                      | 16,400                         | 628                                |
|                             | 25                           | 5-F                      | 7,973                          | 6,901                              |
|                             | 50                           | 5-F                      | 15,307                         | 790                                |
|                             | 75                           | 5-F                      | 20,000                         | 350                                |
|                             | 100                          | 5-F                      | 25,000                         | 150                                |
|                             | 50 Cable                     | 5-F                      | 7,180                          | 9,774                              |

NOTES FOR TABLE:

B phase interruption occurs 5.2 cycles after A.

C phase interruption occurs 2.3 cycles after A.

The ratio of positive sequence to zero sequence capacitance is six (6) through 72.5 kV and four (4) for higher voltages except for currents marked "Cable" where the ratio is one (1).

Letters designating module size refer to the voltage limiter construction as follows:

A uses nine (9) Joslyn 1.4kV ZE blocks and limits recovery voltage to 42kV.

B uses ten (10) Joslyn 1.4kV ZE blocks and limits recovery voltage to 46kV.

C uses seven (7) Joslyn ZJ blocks and limits recovery voltage to 48kV.

F uses ten (10) Joslyn ZJ blocks and limits recovery voltage to 60 kV.