FOREIGN PATENTS OR APPLICATIONS
275,966 3/1928 Great Britain..........................307/93

OTHER PUBLICATIONS
Rovnyak, R. M.; Arc, Surge, and Noise Suppression; Electronic's World; May, 1967.

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ABSTRACT
A vacuum switch apparatus comprising a vacuum switch having a pair of electrodes, and a series circuit consisting of a resistor and capacitor disposed between one of said electrodes and ground to suppress the oscillation of abnormal voltage generated at the opening of said switch. The resistor preferably has a value of 100 ohms and the capacitor preferably has a value of 0.1μF.

7 Claims, 11 Drawing Figures
VACUUM SWITCH APPARATUS

The present invention relates to a vacuum switch apparatus. Vacuum switches and vacuum breakers have broad applications due to their excellent dielectric recovery and extinction characteristics and easy maintenance. However, switches of such type cause an abnormal voltage to be generated by current chopping or reignition at the opening of the switch, with the result that a load is subject to damage due to the abnormal voltage.

Appearance of abnormal voltages due to current chopping may be eliminated using electrode materials in which there takes place a low degree of current chopping. With respect to generation of abnormal voltage due to reignition, however, the cause is not clearly defined and there have not yet been proposed fully satisfactory countermeasures, with the result that the load is still subject to damage due to generation of abnormal voltage at the opening of the switch, particularly that resulting from reignition.

There have been conducted in connection with the present invention a large number of experiments and analyses of phenomena to search for the cause of the aforementioned reignition. As a result, it has been found that the reignition originates with oscillations in an L-C circuit consisting of line inductance and stray capacity on the source and load sides. There will now be described this fact by reference to the equivalent circuit of FIG. 1 representing the case where there was used a conventional vacuum switch in the circuit of an induction motor. Referring to FIG. 1, numeral 11 denotes a power source, 12 a vacuum switch, 13 an induction motor, 14 source inductance, 15 source stray capacity, 16 line stray inductance and 17 load side stray capacity. When the switch 12 is opened in said circuit, current is cut off at the following zero point, and there appears a recovery voltage across the terminals of said switch 12. The wave form of a load side voltage impressed in this case is illustrated in FIG. 2 and the wave form of an interelectrode voltage of the switch 12 in FIG. 3. Normally when current is cut off by the switch 12 at point 20 in FIGS. 2 and 3, the load side voltage is progressively reduced to zero potential as indicated by a dotted line 21, while oscillating with a certain frequency expressed by the following formula:

$$ f = 1/2\pi \sqrt{L/\text{LeCe}} $$

where:
- \( L \) = reactance of load 13
- \( \text{Ce} \) = stray capacity of the same

However, when the opening of the switch 12 happens to cause current to be cut off not exactly at the zero point but in its neighborhood, the switch contact has just been disconnected, only leaving a very slight gap and full insulation is not yet regained. Accordingly, even if insulation is realized at the zero point, there will immediately occur reignition at point 22 in FIG. 2 with the resulting conducted state, causing the voltage to be brought back to the level prevailing on the source side. Since this conduction appears in the L-C circuit, the load side voltage overshoots up to point 23 in FIG. 2 from the source voltage. Assuming that there is no circuit loss, said overshooting portion of the voltage is substantially equal to the interelectrode voltage at the time of reignition. Current passing through the contact of the switch 12 upon reignition travels through a circuit including line inductance 16 and stray capacities 15 and 17 with a frequency expressed by the following formula:

$$ f = 1/2\pi \sqrt{\text{Cs} + \text{Ce}/\text{LoCeCs}} $$

where:
- \( \text{Cs} \) = stray capacity 15 on source side
- \( \text{Ce} \) = stray capacity 17 on load side
- \( \text{Lo} \) = line inductance 16

With a vacuum switch, however, insulation is restored very quickly with respect to vacuum arcs, so that high frequency current is cut off at the zero point, the so-called high frequency extinction. Immediately upon current cut off, there appears recovery voltage or reignition across the electrodes for which there is not yet restored full insulation. This phenomenon of reignition continues until the switch contact is fully opened, permitting the resulting insulation to overcome the occurrence of any recovered voltage.

The present invention has been accomplished by taking countermeasures for the fact that said phenomenon of reignition originates, as described above, with the L-C circuit included in the switch circuit. It is accordingly the object of the invention to provide a vacuum switch wherein there is provided a high frequency oscillation control circuit on the switch so as to prevent the generation of abnormal voltage at its opening.

According to Summary of the Invention an aspect of the present invention, there is provided a vacuum switch apparatus including a series connection of a capacitor and resistor which is connected between one of the electrodes of vacuum switch and ground or between the electrodes, to suppress the oscillation of abnormal voltages generated at the opening of the switch.

The present invention can be more fully understood from the following detailed description when taken in connection with the accompanying drawings, in which:

FIG. 1 is an equivalent circuit diagram representing the case where there is used a prior art vacuum switch;

FIG. 2 shows the wave form of load side voltage appearing at the time of reignition in the circuit of FIG. 1;

FIG. 3 indicates the wave form of voltage occurring across the switch electrodes at the time of reignition in the circuit of FIG. 1;

FIG. 4 illustrates a vacuum switch circuit according to an embodiment of the present invention;

FIGS. 5 and 6 are equivalent circuit diagrams of FIG. 4;

FIG. 7 is a co-ordinate representation showing the values of the capacitor and resistor constituting high frequency oscillation control means used in the vacuum switch of the present invention;

FIG. 8 presents the wave form of load side voltage in the circuit of FIG. 4 when it is opened;

FIG. 9 shows the wave form of voltage across the switch electrodes in the circuit of FIG. 4 when it is opened;

FIGS. 10 and 11 are circuit diagrams using vacuum switches according to other embodiments of the invention.

Referring to FIG. 4, numeral 30 represents a vacuum switch which is connected to a power source 33 and load 34 through cables 31 and 32 respectively. The load side electrode of the vacuum switch 30 is grounded through a series circuit consisting of a resistor 35 and capacitor 36. This series circuit constitutes
high frequency oscillation control means 37 which effectively controls the oscillation of abnormal voltage which would progressively increase with repetition of reignition occurring at the opening of the vacuum switch 30. Referring to FIG. 5 which illustrates an equivalent circuit of FIG. 4, numeral 38 denotes load side stray capacity, 39 source side stray capacity, 40 line stray inductance and 41 source inductance. FIG. 6 taken out of FIG. 5 shows a circuit through which a high frequency current flows when the reignition occurs. The non-oscillatory conditions are expressed by the following formulas

\[ R_1 = R = R_2 \]  
(1)

\[ m > 8 \]  
(2)

\[ n = \frac{8(m+1)}{m-8} \]  
(3)

where  
\[ n = \frac{C}{Ce}, m = \frac{Cs}{Ce}, q = 1 + m + \frac{n}{2} \]

The non-oscillatory conditions are expressed by the following formulas:

\[ R_1 = R = R_2 \]  
(4)

\[ m > 8 \]  
(5)

\[ n = \frac{8(m+1)}{m-8} \]  
(6)

where  
\[ n = \frac{C}{Ce}, m = \frac{Cs}{Cs}, q = 1 + m + \frac{n}{2} \]

As mentioned above, connection according to the present invention of a series circuit including a capacitor and a resistor between one of the electrodes of a vacuum switch and ground, or between the electrodes of the switch itself effectively suppresses the oscillation of transient recovery voltage and in consequence the occurrence of abnormal voltage, thereby ensuring the safety of the load side.

What we claim is:

1. A vacuum switch apparatus comprising at least one vacuum switch having a pair of electrodes and an RC surge suppressor circuit coupled between one of said electrodes and ground, said surge suppressor circuit being comprised of a series connection of a resistor \( R \) and a capacitor \( C \), the values of said resistor \( R \) and capacitor \( C \) satisfying the following:

\[ n = \frac{8(m+1)}{m-8} \]  
(7)

\[ m > 8 \]  
(8)

\[ R_1 = R = R_2 \]  
(9)

where  
\[ n = \frac{C}{Ce}, m = \frac{Cs}{Cs}, q = 1 + m + \frac{n}{2} \]

2. A vacuum switch apparatus according to claim 1 comprising three RC surge suppressor circuits, and wherein said vacuum switch is of the three phase type having three pairs of electrodes, one electrode of each pair being connected to ground through a respective RC surge suppressor circuit.

3. A vacuum switch apparatus according to claim 1 comprising test means connected to said surge suppressor circuit for a short circuit test thereof.

4. A vacuum switch apparatus according to claim 1 wherein said resistor is chosen to have a resistance of 100 ohms and said capacitor to have a capacity of 0.1µF.

5. A vacuum switch apparatus comprising at least one vacuum switch having a pair of electrodes and an RC surge suppressor circuit coupled between said electrodes, said surge suppressor circuit being comprised of a series connection of a resistor \( R \) and a capacitor \( C \), the values of said resistor \( R \) and capacitor \( C \) satisfying the following:

\[ n = \frac{8(m+1)}{m-8} \]  
(10)

\[ m > 8 \]  
(11)

\[ R_1 = R = R_2 \]  
(12)

where  
\[ n = \frac{C}{Ce}, m = \frac{Cs}{Cs}, q = 1 + m + \frac{n}{2} \]
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Ce: load side stray capacity
Cs: source side stray capacity
Lo: line stray inductance.

6. A vacuum switch apparatus according to claim 5 comprising three RC surge suppressor circuits, and wherein said vacuum switch is of the three phase type having three pairs of electrodes, each surge suppressor circuit being connected between respective pairs of said switch electrodes.

7. A vacuum switch apparatus according to claim 5 wherein said resistor is chosen to have a resistance of 100 ohms and said capacitor to have a capacity of 0.1\(\mu\)F.