

THE EFFECT OF THE STRAY CABLE PARAMETERS ON THE HF INTERRUPTING CAPACITY OF VCB

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Abstract - HF interruption behaviour of VCB is very important for analysis of switching surges induced at interruption of inductive load by VCB.

In an actual network, HF current is produced when power cable is discharged through VCB separating contacts.

Many researchers dealt with this problem by simulating actual cable by LC circuit with lumped elements.

We have conducted experimental research concerning HF interruption behaviour of VCB with CuCr contacts at interruption of the «artificial» cable and equivalent single-frequency LC circuit.

The experimental results revealed a strong effect of cable stray parameters on the VCB HF interruption behaviour.

Introduction

When inductive load is interrupted by VCB, dangerous overvoltages may be generated due to the process of voltage escalation and virtual current chopping [1-3]. The development of these processes depends on the ability of the vacuum interrupter (VI) to interrupt high frequency (HF) current.

HF interrupting capacity of VI has been investigated by many researchers [4-8]. This problem turned out to be quite complicated and a general view on the criteria that determines HF interrupting capacity of VI does not exist

so far. A lot of experimental research has been undertaken which proposes different criteria to evaluate this capacity: breakdown voltage, interrupting current or/and voltage rate, interrupting current rate and breakdown voltage at the instant when HF current is quenched [1-8].

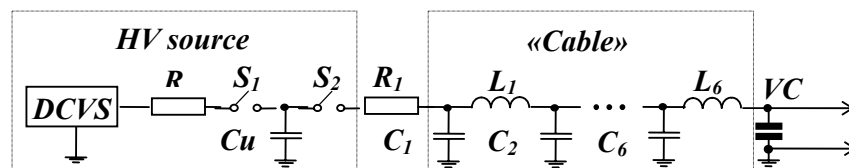
All of this research has been conducted in LC experimental set up with lumped elements. Consequently sinusoidal current waveforms have been analyzed.

In a real case we are faced with the discharge of power cable that is more accurately described as a line with stray inductance and capacitance. The latter determines HF current waveform to be far from sinusoidal. One could expect that this change in current waveform may lead to different HF current quenching behaviour.

The present paper is aimed at investigating the effect of the stray cable parameters on the HF interrupting capacity of VCB. Based on this research one can approve or disapprove simulation of an actual cable with single frequency LC circuit.

1. TEST TECHNIQUE AND PROCEDURE

Block diagram of the experimental set up is presented in Fig. 1.



Where *DCVS* - DC voltage source Spellman 40 kV, 5 mA;

Cu=1μF - source capacitor;

R= 2 MΩ - current limiting resistor;

S₁ - *Cu* charging switch;

S₂ - «artificial» cable to *Cu* connecting switch;

R₁=30kΩ - «cable» charge current limiting resistor (also it disconnect the «cable» and HV source during HF process);

L₁=...=*L₆*=22μH - lumped inductors;

C₁=...=*C₆*=0.022μF - lumped capacitors;

VC - vacuum chamber with CuCr 75/25 contacts;

Fig.1

It consists of the DC high voltage power source that charges source capacitor C_u (1 μ F), two switches S_1 , S_2 (to provide charge and discharge of C_u respectively) and «artificial» cable.

Actual cable has been simulated by an equivalent single frequency circuit and 6 «chains» «artificial» line.

In both case L and C lumped parameters have been chosen in order to provide the same frequency of the discharge and the same surge resistance.

$$Z = \sqrt{\frac{L}{C}}; \quad f = \frac{1}{2\pi} \sqrt{\frac{1}{LC}}$$

This approach is generally used when it is necessary to substitute the real electrical line with a single frequency LC circuit.

Table 1 presents parameters of the «artificial» line and equivalent circuit. Both present substitution for the real cable with surge resistance 29.3 Ω and length equal to 420m.

Table 1 - Parameters of cable model

Count of LC-«chains»	L_i μH	C_i nF
1 LC-circuit	79	91,8
6 LC circuit	22	22

A vacuum interrupter was connected to the «artificial» cable (see Fig.1). It incorporated two 20mm diameter contacts made from sintered CuCr 75/25 fixed at a distance of 0.25mm.

The interrupter was pumped out by a turbo molecular pump providing residual pressure to be below 10⁻⁶ Pa.

During experiments voltage across the open gap and arc current were measured with the aid of HF voltage divider and coaxial shunt respectively. Test results have been recorded by Tektronix 7623 A oscilloscope and conducted into the computer memory for statistical analysis.

At experimental shot source capacitor was preliminarily charged up to 20kV. Then at closing S_2 switch «artificial» cable has been charged up to 11kV until breakdown across test gap occurred.

The breakdown has been followed up by HF vacuum arc. Arc current has decayed in time because of the natural damping of the circuit until it has been finally interrupted by VI.

Typical waveforms of discharge current and recovery voltage for single frequency and 6 «chains» circuits are presented in Fig.2 and Fig. 3 respectively.

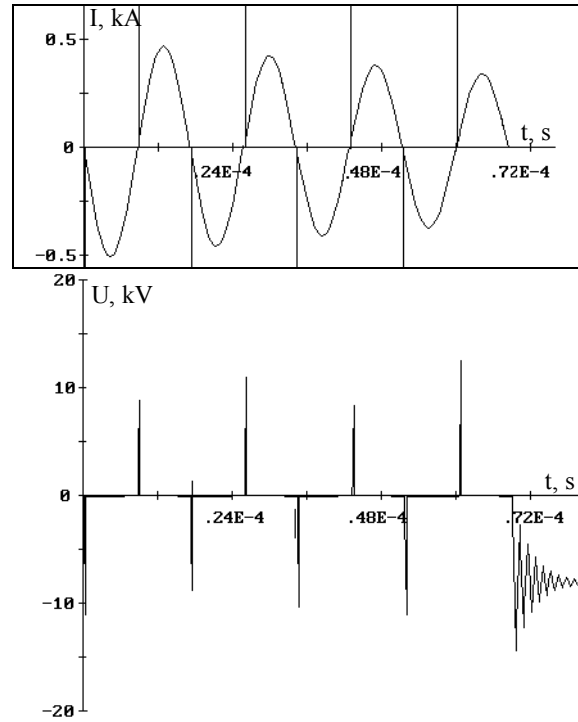


Fig. 2

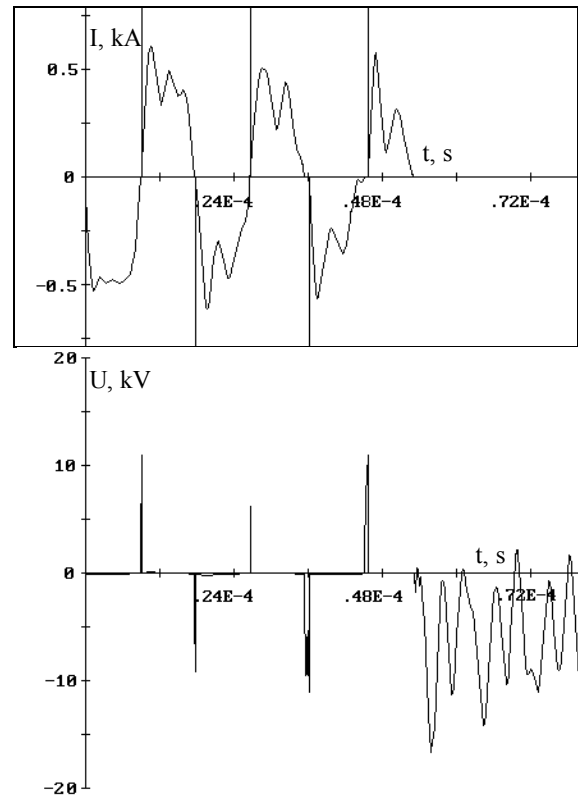


Fig.3

2. EXPERIMENTAL RESULTS AND DISCUSSION

As it follows from Fig.2 and Fig. 3 current waveforms for two investigated circuits are so different that comparison of the switching behaviour using some momentary values (current, voltage) is barely possible. The number of half cycles before final interruption cannot also be used as a criteria for comparison because of a different initial energy trapped in two circuits. We consider energy left in the line at the moment of final interruption to be the most suitable value for comparison in the experiment.

The reason for that is the gradual monotonous decay of this value in time.

For 6 «chain» circuit this energy can be determined with the aid of the following equation:

$$W_6 = \sum_{j=1}^6 \left[\frac{L_j \cdot i_j^2}{2} + \frac{C_j \cdot U_j^2}{2} \right] \quad (1)$$

where i_j , U_j - current and voltage associated with j^{th} chain ($i_6 = 0$ at the moment of HF current interruption).

For single frequency circuit stored energy W_1 at the moment of current interruption can be determined as follows:

$$W_1 = \frac{CU^2}{2} \quad (2)$$

W_1 value has been derived from the number of half cycles before final interruption with the aid of the following formula:

$$W_1 = W_{01} \cdot e^{-\frac{T \cdot n}{\tau}} \quad (3)$$

where T - cycle of the natural circuit oscillations;

n - number of current half cycle before final interruption;

τ - inherent circuit decay time;

W_{01} - initial energy stored in the circuit.

To derive W_6 - from the number of current half cycles before arc extinguishing we developed a computer simulating model using the same circuit as presented in Fig.1 and an «artificial» resistor to adjust inherent circuit decay time.

As it follows from comparison of Fig.3 and Fig.4 the model provides adequacy to the experimental data. The model allowed us to derive W_6 from the number of half cycles before arc extinguishing. The latter has been found out from experimental data.

Fig. 5 provides comparison of the distribution function for W_1 and W_6 calculated from experimental data

using the aforementioned approach. As seen 50% W_6 value is approximately twice lower than W_1 . This means that substitution of the actual cable with a lumped LC circuit leads to the overestimate of the HF interrupting capacity of vacuum interruption and consequently switching overvoltages [8]. The error depends on the chosen criteria for HF current interruption.

For example $\frac{di}{dt}$ at the moment of current interruption depends on the W_1 as follows:

$$\frac{di}{dt} = \frac{1}{L} \sqrt{\frac{2 \cdot W_1}{C}} \quad (4)$$

So in conditions of the present experiment criteria $\frac{di}{dt}$ should be decreased to ~ 1.4 times compared with that measurement in the single frequency circuit.

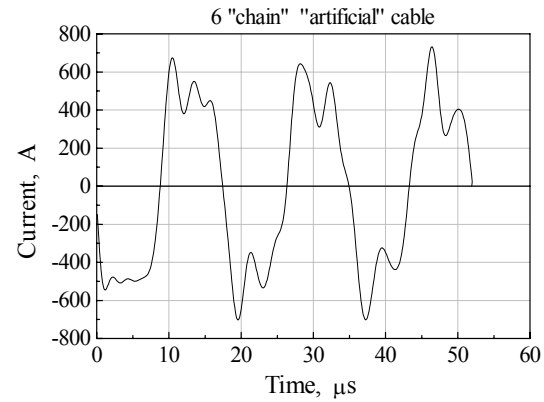


Fig.4

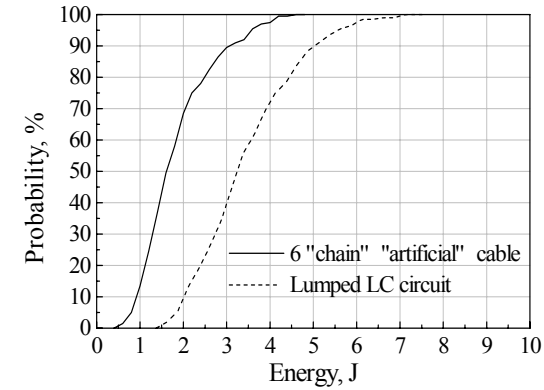


Fig.5

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