

# THE FEATURES OF 0.4KV MOTOR INTERRUPTION BY A VACUUM CONTACTOR WITH DIFFERENT CONTACT MATERIALS

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**Abstract** – A computer aided model has been used to simulate current chopping behaviour at different current levels. This model is based on the known arc life time of a DC current. The appropriate experimental research has been carried out for a batch of 35 industrial VI with CuCr contacts. The obtained dependencies of the average arc life time DC current shows a certain technological scatter that has been taken into account in further chopping current simulations.

The developed software has been used to analyze features of 0.4kV motor interruptions by low voltage vacuum contactor with CuCr and AgWC contacts (low-surge contact material).

The obtained results have been generalized in «safe operation regions» that allow us to consider the necessity of the surge suppression when a low voltage vacuum contactor is applied for motor control.

## Introduction

In recent years vacuum switching technology became widely applied for low voltage (LV) networks (below 1kV). LV vacuum circuit breakers (VCB) are not very popular in the market because of the difficulty to compete with conventional CB with respect to production cost. LV vacuum contactors (LVVC) are becoming more and more commonly used because of the exclusively high interrupting life and low maintenance. Most of all LVVC are applied for frequent motor switching-area where their excellent interrupting performance brings more advantages. In this application however VC should frequently interrupt motors at rated, nominal load or at start. The latter in some occasions may lead to dangerous overvoltages. These overvoltages are generally determined purely by current chopping (Fig. 1). Multiple reignitions for LV network do not occur because of the low rate of rise of recovery voltage, compared with rate of dielectric strength rise for LVVC. Overvoltages produced by chopping current (CC) are determined by current chopping itself and switching load.

Because of the statistical nature of CC and random moment of contact separations overvoltages result in statistical event.

Experimentally determined distribution of CC is often used to calculate overvoltages in different switching regimes. This is not quite correct because of the dependency of CC on interrupting current. A more accurate approach has been proposed in [1] and

developed in some works [2,3,4]. It is based on the measurement of the average DC arc life time and its further conversion to statistical characteristics of CC. However this approach has not been yet combined with calculation of switching overvoltages for real field objects. Moreover generally CC characteristics have been deduced for a single VI sample and regarded as representative for other VI of the same type. Hence technological deviations have been ignored.

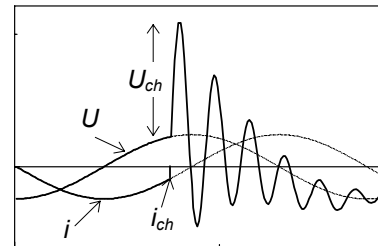


Fig. 1

In the present paper we aim to develop an approach for statistical evaluation of the switching overvoltages produced by LV vacuum contactors coming from the production line.

## 1. COMPUTER SIMULATION OF THE CHOPPING CURRENT

It is well known that current chopping level depends on the contact material and on the interrupted current shape and levels [1,5].

The approach developed in [1] allows us to take into account the shape and level of interrupted current if average arc life time versus interrupted DC current is known.

The following calculations of the statistical parameters of CC are based on the known shape of the interrupted current and the following equation:

$$P(t_A \leq t) = 1 - e^{-\int_{t_0}^{t_0+t} \frac{1}{T(i)} d\tau}, \quad (1)$$

where  $t_0$  - the moment of arc ignition;

$t_A$  - arcing time;

$T(i)$  - average arc life time at DC current

equal to momentary current  $i$ .

Integrating (1) one can deduce necessary statistical characteristics of the CC. An appropriate computer

model has been developed to handle this problem. This model is presented in the authors' earlier paper [4].

### 1.1 Experimental determination of the average arc life time $T(i)$

The test circuit for measurement  $T(i)$  is given in Fig. 2. The tests have been carried out for 35 commercial VI with CuCr contacts. For each VI at each current level (4,6,8,9,10A) 25 interruptions have been executed and average arc life time  $T(i)$  have been calculated.

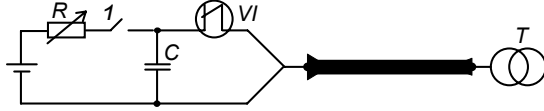


Fig. 2

where  $l$  - switch;  
 $VI$  - tested vacuum interrupter;  
 $C$  - capacitance to inhibition of the voltage pulses at the source side;  
 $T$  - unloaded transformer;  
 $R$  - resistor for current adjustment

Fig. 3 for 8 VI presents the dependencies  $T(i)$  in logarithmic scale.

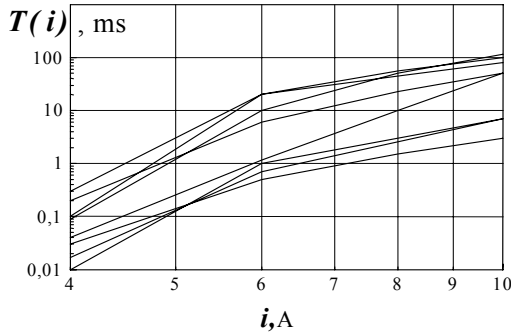


Fig. 3

Fig. 3 clearly states that dependencies are different from VI to VI and can be approximated by two broken lines in logarithmic axis. The knee point for  $T(i)$  dependency fits well with 6A for all VI.

So for each interval:

$$T(i) = A|i|^B \quad (2)$$

where  $A$  and  $B$  are particular parameters for a certain VI.

As it is seen from Fig. 4 and Fig. 5 for each interval dependency between  $\lg A$  and  $B$  can be approximated by a straight line. The appropriate approximations are presented below:

for  $i < 6A$

$$B = -0.92 * \lg A + 0.92 \quad (3)$$

for  $i \geq 6A$

$$B = -1.01 * \lg A - 1.81$$

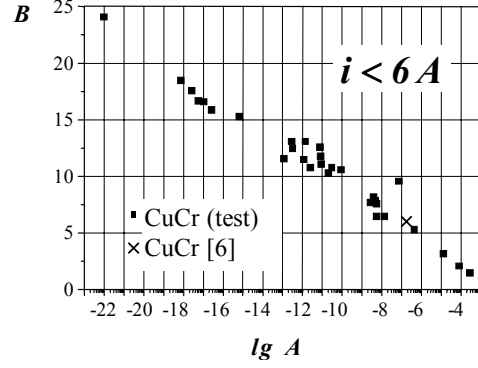


Fig. 4

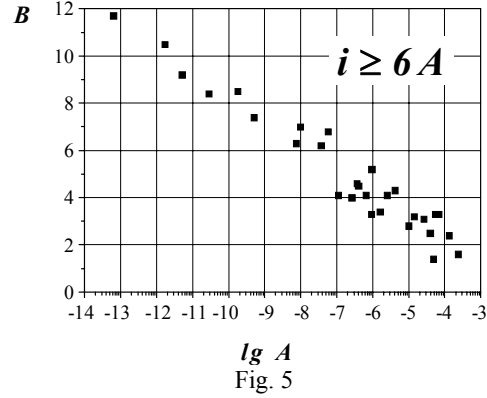


Fig. 5

Distribution of  $B$  fits well the Weibull function

$$F(B) = 1 - \exp(-((B - \delta) / (\Theta - \delta))^m) \quad (4)$$

where

for  $i < 6A$ :

$$\Theta = 12.4, \bar{B} = 11.0, \sigma = 1.5, m = 2.0 \quad (5)$$

for  $i \geq 6A$ :

$$\Theta = 6.0, \bar{B} = 5.1, \sigma = 1.4, m = 2.2 \quad (6)$$

Equations (2)-(7) allow the calculation of the necessary statistical characteristics of CC at any shape and level of interrupting current for the chosen type of VI (with the aid of software described in [4]). A similar approach can be proposed to evaluate CC behavior for other types of VI. For example we can use experimental data observed in [6] for CuCr 75/25 and AgWC 25/75 to determine a couple of A and B parameters for each material:

$$B_{CuCr} = 5.9, A_{CuCr} = 1.6 \cdot 10^{-7} \quad (7)$$

$$B_{AgWC} = 8.5, A_{AgWC} = 5.6 \cdot 10^{-4} \quad (8)$$

As seen from Fig. 4  $A$  and  $B$  parameters derived from the tests [6] correlate well with A and B dependency derived from the authors test.

So, one could expect A and B parameters to have technological scatter if tests in [6] were carried out for a batch of VI.

## 1.2 The results of current chopping simulation

Fig. 6 presents the dependencies of the average CC level on interrupting AC current for CuCr and AgWC.

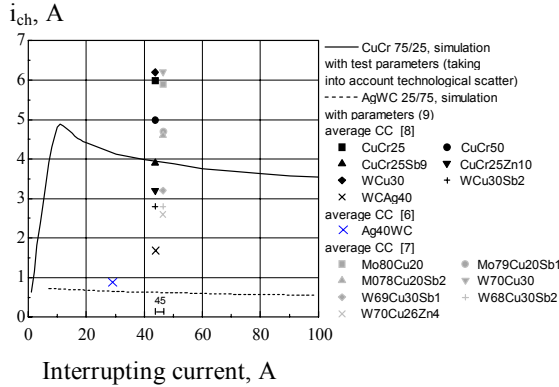


Fig. 6

These results are compared with CC measurements obtained for different contact materials [6,7,8] at 45 RMS current.

Fig. 6 shows that CC is greatly influenced by the level of interrupted current and thus should be taken into account in switching surge analysis.

## 2. THE CALCULATION OF OVERVOLTAGES AT LOW VOLTAGE MOTORS INTERRUPTION

### 2.1 The equivalent circuit of LVM winding

Most of the 0.4kV circuits historically have grounded neutral and this fact allows to consider each pole of LVM independently. The equivalent circuit of LVM pole is presented in Fig.7.

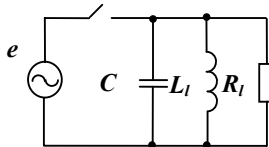


Fig. 7

The circuit parameters were calculated with the aid of a method described in [9], but winding capacitance was determined experimentally.

### 2.2 Calculation results

The calculation of overvoltages has been executed with the aid of the above described model for typical commercial LVM 30-315kW.

Fig. 8 - Fig. 10 show maximum overvoltages (with 1% probability) at LVM interruption by VC with CuCr 75/25 contact as function of LVM power for all motor regimes.

Rated rotor speed  $n$  has been varied from 1000 to 3000 turns a minute, cable capacitance were not considered.

(This regime is most dangerous from the overvoltages point of view).

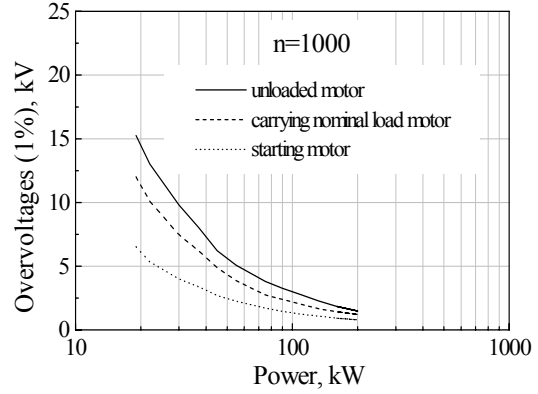


Fig. 8

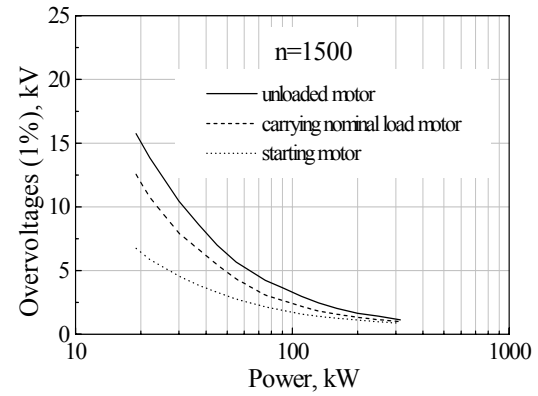


Fig. 9

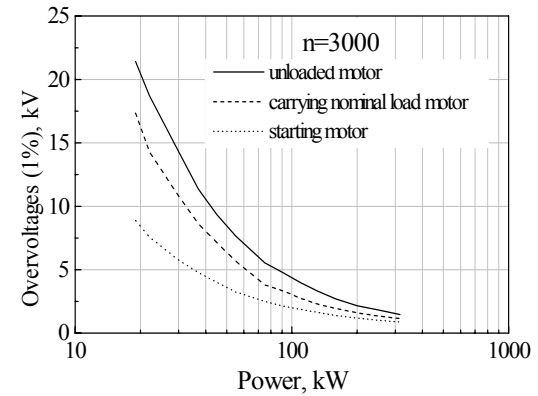


Fig. 10

It is clear from Fig. 8 - Fig. 10, the most dangerous regime for LVM is interruption of unloaded motor.

Fig. 11 - Fig. 13 show the «safe operation regions» deducted for different motors at interruption by VC with CuCr 75/25 contact material (1.5kV safe level has been considered). For VC with AgWC contacts switching overvoltages are unhazardous for all investigated area.

Feeder capacitance presented in these figures is the sum of motor winding and cable capacitance. If the stray capacitance of the used cable (pF/m) and cable length are known one can easily use the presented diagrams to

evaluate the necessity to apply protection means against switching surges.

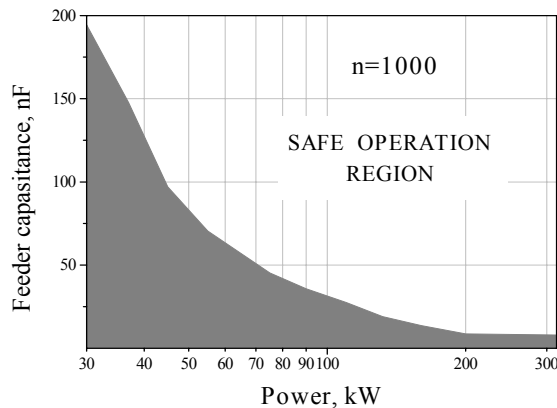


Fig. 11

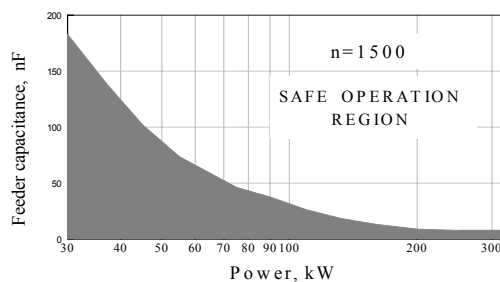


Fig. 12

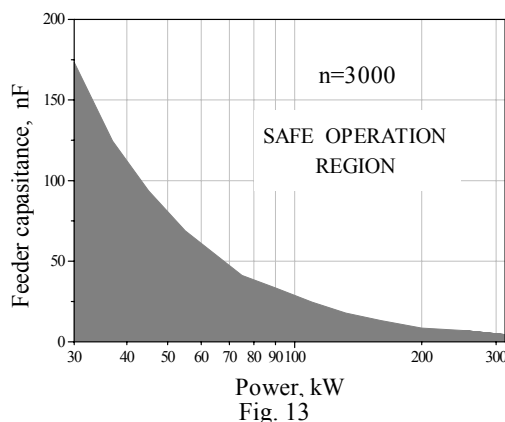


Fig. 13

## CONCLUSIONS

Special software allows us to convert DC arc life time vs current characteristics to necessary CC statistical values at any interrupting current.

The basic parameters that describe the DC arc life time vs current dependency show the tendency to technological scatter when a real batch of industrial VI is considered.

The developed software allows us to handle this scatter and to take it into account for simulation of CC characteristics.

Interruption of low voltage motors by vacuum contactor may cause dangerous overvoltages. These overvoltages are greatly influenced by contact material. Application

of low surge contact material (AgWC) allows us to suppress overvoltages below un Hazardous level in all practical cases. However even conventional contact material (CuCr) can very often be used for LV motor interruption without special protection means. «Safe operation regions» diagrams are a suitable means for evaluating the necessity of surge suppression.

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