A High Efficiency Conditioning Method of Vacuum Interrupters by High Frequency Voltage Impulses

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***Abstract*- It is well-known that the high-voltage withstand ability of vacuum interrupters (VIs) can be increased by conditioning processes. Several conventional conditioning methods, such as spark conditioning and current conditioning, are used by most vacuum interrupter manufacturers. However, the conditioning efficiency of these methods is low and the conditioning energy is high which would lead to an accompanying 'de-conditioning' process. The objective of this paper is to propose a conditioning technique for vacuum interrupters by using a series of sub-microsecond voltage impulses that have a high conditioning efficiency and low conditioning energy. Two 7.2kV VIs are used to investigate the improvement of the basic impulse level (BIL) by this proposed technique, compared with the other two VIs which are conditioned by the conventional method. During the conditioning process, VI suffers several hundreds of batches of sub-microsecond high voltage impulses (1000Hz, 0.1s). The peak value of each impulse reaches 100kV. If a breakdown occurs, a high frequency conditioning current of several kA (peak value) would flow through the vacuum interrupter. The experimental results show that this conditioning technology has a higher efficiency compared with the conventional method by decreasing the conditioning process duration from several minutes to tens of seconds. The average value of the BIL voltages by using the new conditioning is 27% higher than that of the conventional conditioning. And the scattering of the breakdown voltage could be reduced by 31%. The conditioned area occupies to the whole contact surface after the high frequency voltage impulses conditioning, which is superior to that of the conventional conditioning.**

I. INTRODUCTION

The insulation strength of a vacuum gap can be increased to a saturation level with a number of breakdowns or arcing phenomena. This procedure is defined as 'conditioning' to increase the breakdown voltage of vacuum interrupters (VIs). VI is developed to transmission voltage level and or more compact. Thus, conditioning is a key technique for VIs' approaching to high insulation level [1-3].

Conditioning technique is developed for tens of years. So far spark conditioning (using high-voltage ac power or 1.2/50 μs lighting impulse) and current conditioning are two kinds of major conventional conditioning methods commonly used worldwide. However, low conditioning efficiency of these conditioning methods is a disadvantage for VI manufacturers. Moreover, uncontrolled conditioning energy may cause a 'de-conditioning' process. So the improvements on the conditioning techniques are necessary.

Experimental results of Ballt et al [2] show that a better conditioning effect can be achieved by adjusting the circuit parameters in spark conditioning process using high voltage ac power which can produce high frequency breakdown current. Fink et al [3] describe a high-frequency (HF) current conditioning method. An improvement of dielectric performance of VIs has been achieved.

The objective of this paper is to propose a new conditioning technique by using a series of high frequency sub-microsecond voltage impulses. The basic impulse level of VI can be improved by this new technique as the conditioned areas occupy to the whole contact surface. And the proposed new conditioning technique can also reduce the conditioning energy and improve conditioning efficiency compared with the conventional conditioning technique.

II. EXPERMENTAL SETUP

A circuit of sub-microsecond voltage impulses conditioning for VIs is shown in Fig. 1. C1 is a main capacitor for storing energy supplied by a high voltage transformer. The voltage of C1 determines the peak value of each impulse which can reach 100 kV. C2 is charged by C1 through a reactor L1 and a resistance Rs. C2 discharges after a hydrogen thyratron S1 is triggered. Thereafter a high voltage impulse is applied to a VI through a pulse transformer T. If a breakdown in the VI occurs, a high frequency conditioning current of several kA peak values flows between the contact surfaces. The conditioning energy injected into the contact gap can be controlled form 0J ~ 3.5J by the charged voltage and the capacitance value of C2. The frequency and duration of a series of high voltage impulses depend on an operation frequency of S1 (1~2000Hz, 0.1~10.0s). The size outside of this

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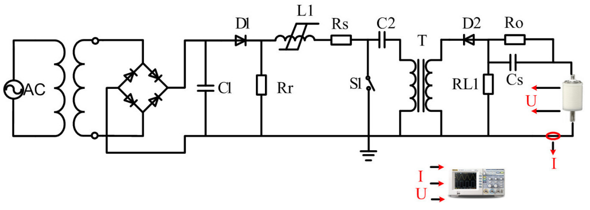


Fig. 1. Electrical test circuit for sub-microsecond continuous impulse voltage conditioning

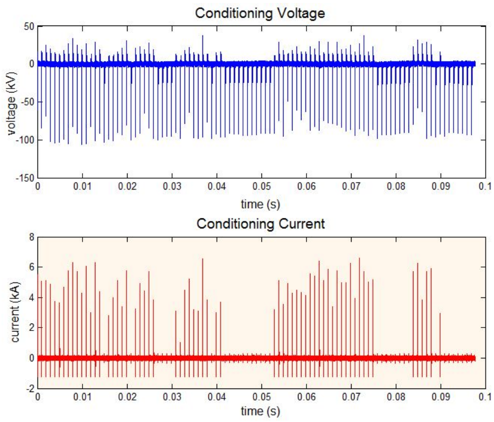


Fig. 2. A typical oscillogram of conditioning voltage and current for a batch of high voltage impulses

conditioning apparatus is 100cm*80cm*106cm.

In this research, four VIs with a rated voltage of 7.2kV are used to investigate the improvement of the basic impulse level. The contact diameter is 30mm and the contact material is CuCr25.

Two VIs are conditioned by the high frequency voltage impulses conditioning technique. VI is placed vertically on a horizontal insulated platform and the moving terminal is placed upward. Conditioning is executed under a contact gap of 0.8mm. Firstly, the high frequency voltage impulses are applied to the moving contact. Secondly, the high frequency voltage impulses are applied to the fixed contact. A criterion for conditioning completion is set as following. If the VI withstands a whole of 100 impulses for each contact (moving contact and fixed contact), the whole conditioning is completed.

During the conditioning process, the frequency and the duration of each batch of high voltage impulses are set to 1000Hz and 0.1s, respectively. Therefore, there are 100 voltage impulses in each batch. Fig. 2 shows a typical oscillogram of a batch of high voltage impulses. Here nearly half of the impulses cause breakdowns. Fig. 3 gives a typical oscillogram of a high voltage impulse, which has a rising time t_{rise} of 135 ns (form 10%U_{peak} to 90%U_{peak}). Fig. 4 shows a high frequency conditioning current (several kA) flows through the VI when the vacuum gap cannot withstand the impulse.

Then the two 7.2kV VIs are tested for their basic impulse level (BIL) by an up-and-down method at a contact gap of 2.0mm after high frequency voltage impulses conditioning. Firstly, the positive lightning

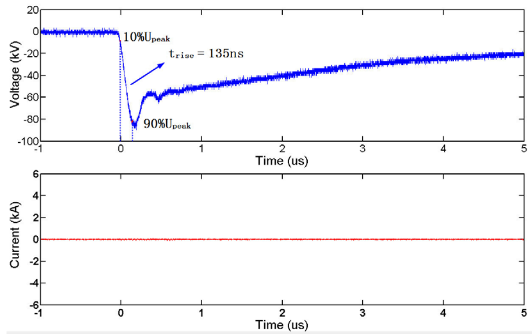


Fig. 3. A high voltage impulse without breakdown

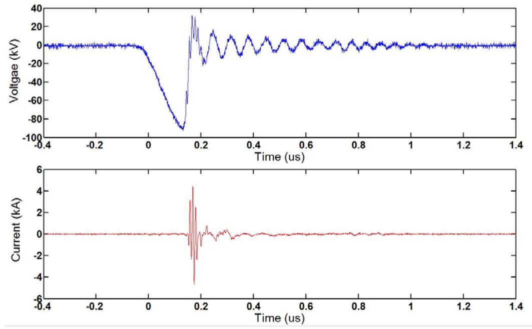


Fig. 4. a high voltage impulse with breakdown

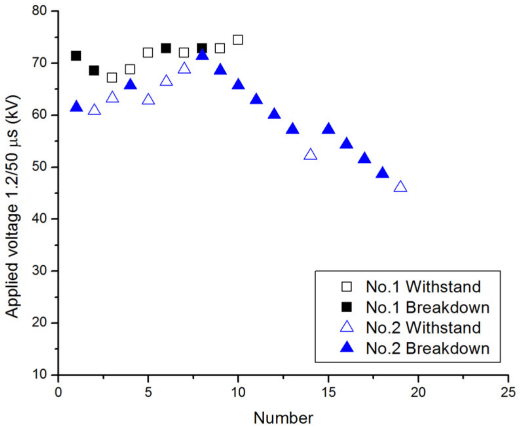
impulses are applied to the moving contact. Secondly, the positive lightning impulses are applied to the fixed contact. To avoid a conditioning effect caused by the BIL voltage, the number of the lightning impulses applied is limited to about 20.

For a comparison, the other two VIs of 7.2kV after conventional conditioning which contains current conditioning (DC 60A $\pm$3times) and ac high-voltage conditioning (45-48kV) are also tested to be a benchmark to the effects of the proposed high frequency voltage impulses conditioning method.

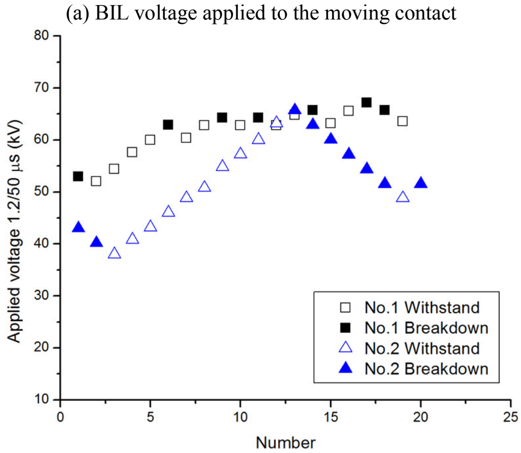
III. EXPERMENTAL RESULTS

Firstly, VIs (No.1 and No.2) are conditioned by the proposed high frequency voltage impulses at the contact gap of 0.8mm. Then the basic impulse levels of these two VIs are investigated at the contact gap of 2.0mm. Fig. 5 gives the result of the BIL voltage distributions of VIs (No.1 and No.2). Fig. 5 (a) shows the positive lightning voltages are applied to the moving contact and Fig. 5 (b) shows the positive lightning voltages are applied to the fixed contact. By a limit of external flashover of VI (No.1), the test data of the BIL voltage cannot exceed 75kV when the positive lightning voltages are applied to the moving contact. It shows that the BIL voltages of No.1 VI are higher and more stable than that of No.2 VI in both Fig. 5 (a) and Fig. 5 (b).

The basic impulse levels of the other two VIs (No.3 and No.4) after conventional conditioning are investigated for a comparison. Fig. 6 gives the result of the BIL voltage distribution of VIs (No.3 and No.4). Fig. 6 (a) shows that the BIL voltages of No.3 VI are

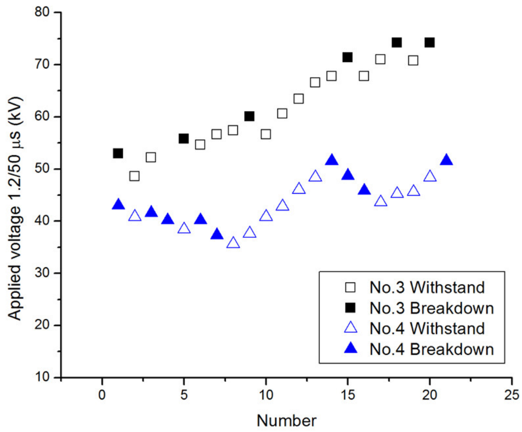


(a) BIL voltage applied to the moving contact

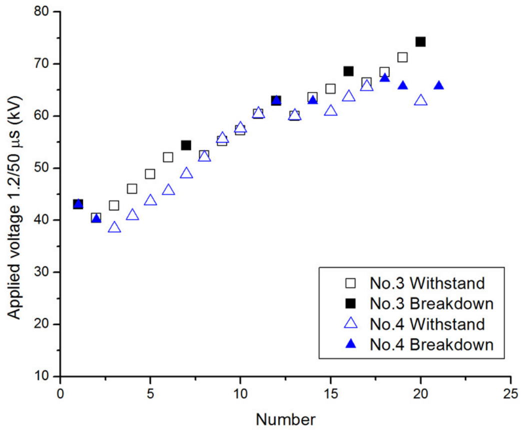


(b) BIL voltage applied to the fixed contact

Fig. 5. The distribution of BIL voltage after the proposed high frequency conditioning



(a) BIL voltage applied to the moving contact



(b) BIL voltage applied to the fixed contact

Fig. 6. The distribution of BIL voltage after the proposed conventional conditioning

higher than that of No.4 VI when the positive lightning voltages are applied to the moving contact. Fig. 6 (b) shows that the distributions of BIL voltage are close to each other for No.3 and No.4 VIs when the positive lightning voltages are applied to the fixed contact.

A statistics analysis to the test data shown in Fig. 5 and Fig. 6 is given in Table 1 and Table 2. In both two tables, U_{ave} represents the average value of the BIL voltages and ΔU (U_{max}-U_{min}) is the scattering of breakdown voltages. When the positive lightning voltages are applied to the moving contact, the U_{new} can be improved by the proposed new conditioning technique, reaching on average 66kV which is 27% higher than that of the conventional technique $U_{convention}$ (52kV). And the ΔU is 14kV on average which is 22% lower than that after conventional conditioning (18kV).

When the positive lightning voltages are applied to the fixed contact, the average values U_{new} are 57kV, which is same with the $U_{convention}$ of conventional conditioning techniques. Compared with the average value of ΔU (29kV) after the conventional conditioning, the average value of ΔU is 20kV after the new conditioning which is reduced by 31% for the scattering of the data.

Fig. 7 shows a comparison of contact surfaces between the proposed high frequency voltage impulses

TABLE 1. THE STATISTICS ANALYSIS TO BIL VOLTAGES OF VIS ATTER HIGH FREQUENCY CONDITIONING

VIs	Conditioning technique	U_{ave} (kV)		$\Delta U = U_{max}-U_{min}$(kV)	
		[1]Moving contact	[2]Fixed contact	[1]Moving contact	[2]Fixed contact
No.1	[3]New	71	62	4	14
No.2	[3]New	60	52	23	26
U_{new}		66	57	14	20

[1]Moved contact: BIL voltages are applied to the moving contact
[2]Fixed contact: BIL voltages are applied to the fixed contact
[3]New: high frequency voltage impulses conditioning technique

TABLE 2. THE STATISTICS ANALYSIS TO BIL VOLTAGES OF VIS ATTER CONVENTIONAL CONDITIONING

VIs	Conditioning technique	U_{ave} (kV)		$\Delta U = U_{max}-U_{min}$(kV)	
		[1]Moving contact	[2]Fixed contact	[1]Moving contact	[2]Fixed contact
No.3	[3]Convention	60	58	21	31
No.4	[3]Convention	43	55	14	27
$U_{convention}$		52	57	18	29
[4]Comparison		27%	0%	-22%	-31%

[1]Moving contact: BIL voltages are applied to the moving contact
[2]Fixed contact: BIL voltages are applied to the fixed contact
[3]Convention: current and ac high-voltage conditioning technique
[4]Comparison: $(U_{new} - U_{convention}) / U_{convention}$

Fig. 7. The comparison of contact surfaces between new conditioning and conventional conditioning

conditioning technique and the conventional conditioning technique. The condition region can spread to nearly the whole contact surface by using high frequency conditioning. However, the conditioning area cannot cover the edge area of the contact surface by the conventional method.

In addition, the conditioning process is finished after several hundreds of batches of high voltage impulses according the criterion set for conditioning completion. Each batch of high voltage impulses lasts 0.1s. So it takes about several tens of seconds by using the new conditioning method, which is much less than conventional conditioning method (several minutes).

IV. DISCUSSION

The dielectric strength of VIs can be increased by using the new conditioning technique compared with the conventional one. During the new conditioning process, breakdowns not only remove the weak points on the contact surface but also result in high frequency conditioning current of several kA, which has strong conditioning effects to the contact surface. So high-β emission sites and micro-particles can be removed by a combination of spark conditioning and kA current conditioning. During a whole conditioning process, several thousand breakdowns occur in the vacuum gap. Thus, it is possible that sufficient conditioning effects have been achieved to improve the high-voltage withstand ability for VI with a high efficiency.

The discharge energy applied plays an important role during conditioning process [2]. And the inject energy of conditioning into the contacts not only improve but also damage the contact surface [4]. Yingyao Zhang et al [5] show that the breakdown voltage has a large scattering by using the impulse voltage whose energy is about several kJ. While using the sub-microsecond voltage impulse, the conditioning energy is quite small (several J) and can be easily controlled to reduce this 'de-conditioning' phenomenon.

Usually both field emission and contaminations (adsorbed gas and micro-particle) may cause breakdown when testing VIs' basic impulse level [4]. Conditioning region starts at an area with high electric field and movable to wider region of the contact with a lower field as the number of the conditioning voltage application increased [6]. And the contact surfaces which are covered with melted layer resulting from the conditioning have the effects on the field electron emission and thus hold-off the high test voltage [7]. The conditioning region can spread to nearly the whole contact surface by using the new conditioning technique, while the conditioning area cannot cover the edge of the contact surface by using the conventional method. So the region which is not conditioned may cause breakdowns during the BIL tests.

V. CONCLUSION

This paper proposes a new conditioning technique by using sub-microsecond voltage impulses. Four 7.2kV VIs are used to investigate the improvement of the BIL. Two VIs are conditioned by the new technique and the other two are conditioned by the conventional technique. As a result, when the positive lightning voltages are applied to the moving contact, the average value U_{new} can reach to 66kV by the new technique which is 27% higher than that of conventional technique $U_{convention}$ (52kV). And the scattering ΔU (by the new conditioning technique) is 14kV on average reduced by 22% compared with the conventional one. When the positive lightning voltages are applied to the fixed contact, the U_{new} is 57kV for both conditioning techniques and the ΔU is 20kV by the new conditioning technique, which is reduced by 31% compared with the conventional one. This new conditioning technique can improve the efficiency by decreasing the conditioning process duration from several minutes to tens of seconds. And the conditioning energy can be reduced to several J compared with that of a standard lightning impulse voltage of several kJ.

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