IMPULSE FLASHOVER OF STRINGS CONTAINING STANDARD AND SEMI-CONDUCTING DISC INSULATORS

Krystian Leonard Chrzan

Wroc• aw University of Technology
Poland

Ortwin Elsässer

University of Stuttgart
Germany

ABSTRACT

Insulators with semi-conducting glazes (SCG insulators) are used mainly in heavily polluted areas. Besides the well known application under such conditions, SCG insulators can be used for voltage upgrading in long strings supporting or replacing the grading electrodes. The paper describes electrical properties of SCG insulators including a one year-test carried out in a pollution test station. Measurements of the flashover voltage of insulator strings containing standard and SCG insulators under lightning and switching impulses are shown. The positive switching impulse flashover voltage of a string including 7 units of SCG insulators is about 19% higher than this of a string containing 7 standard insulators. The switching impulse flashover voltage of a string including 5 standard insulators and 5 SCG insulators is about 10% higher than of a string with 10 standard insulators. Under lightning impulse stress only small difference in flashover voltage is measured.

1. INTRODUCTION

The insulators with semi-conducting glazes (SCG insulators) are mainly used in heavily polluted areas. Their pollution flashover voltage is 2 times or even 3 times higher compared to standard ceramic insulators and up to 1.5 times higher compared to silicon rubber insulators. [1,2]. Nevertheless that these insulators are known since 1942 [3] their widespread application was limited due to poor long-term stability and degradation of the glazes. The influence of SCG insulators on distribution of electrical stress at a.c. voltage is well known. Therefore SCG insulators can also be used for voltage upgrading in long strings supporting or replacing the grading electrodes. The impulse behaviour of SCG insulators has also been studied. The experiments showed, that their F.O.V. (flashover voltage) can be higher compared to classical or silicon rubber insulators [4].

The SCG insulators are very expensive, not only their price but also the working cost is high. Therefore it seems interesting to consider the application of strings containing both SCG insulators and standard insulators. In such a string the energy consumption and maintenance cost are reduced. As a first step, the impulse behaviour of strings containing 5 standard cap and pin insulators and 5 SCG insulators was investigated.

2. OBJECTS, MEASUREMENT PROCEDURE

The experiments were carried out on glass disc insulators and on SCG porcelain insulator DURASSTOR manufactured by NGK Insulators LTD. The insulator characteristics are given in the table 1, the insulator cross section in fig. 1.

Tab. 1. Insulator characteristics

Characteristics		SCG cap and pin	Glass cap and pin
Diameter	mm	254	254
Assembly height		146	146
Creepage distance	mm	310	310
Capacitance	pF	27	43
Resistance	MΩ	14	
Dry lightning withstand voltage			
- one unit	kV	110	
- short string (5 units)	kV	420	
Wet 50 Hz withstand voltage			
- one unit	kV	40	
- short string (5 units)	kV	175	
50 Hz puncture voltage,	kV	110	

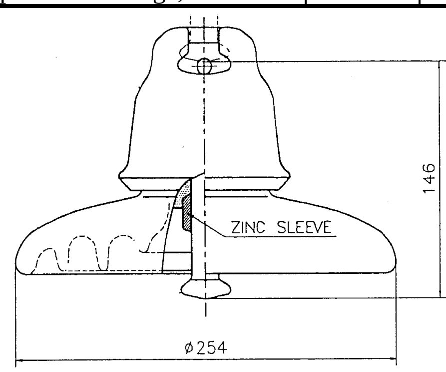


Fig. 1. SCG insulator

The resistance of one SCG unit measured at 20 °C and 10 kV was about 14 MΩ.

Seven new SCG insulators were checked in a pollution test station (pollution zone III) under a continuous voltage of 75 kVrms for a period of 15 months. Then, the insulators were taken to the laboratory to measure the impulse flashover voltage. During the tests, about 150 standard lightning impulses and 200 switching surges were applied. After this long term test and after the impulse tests no change of glaze resistance was detected.

F.O.V. measurements with lightning and switching impulses for the following arrangements were carried out: single SCG unit, single glass unit, a string of 7 SCG insulators, a string of 7 glass insulators, a string containing 5 glass insulators and 5 SCG insulators connected in three configurations. In the first case, 10 insulators were connected in the „good“ arrangement (fig. 2.), then in the „alternating“ and in the „bad“ arrangement.

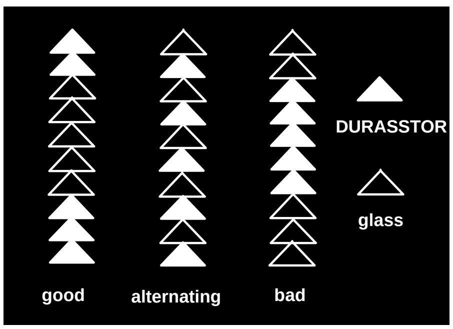


Fig. 2. Test configuration of 10 insulators

The attribute bad or good means that SCG insulators improve or make worse the voltage distribution compared to the string with glass insulators only.

A 1.6 MV; 64 kJ Marx generator with RCR voltage divider and digital impulse analyser DIAS 730 has been used. The 50% F.O.V. was estimated according to the up and down method. Each series of measurements consisted of at least 20 voltage applications; the voltage steps were smaller than 3 % of 50% F.O.V. value. The 50% F.O.V. was estimated as the mean value from 20 voltage amplitudes.

The insulators were hanging vertically on a model steel pole about 4 meters above the ground and at a distance of 3.5 meters from the grounded vertical construction.

The voltage distribution was measured on three insulator configurations. A special modified field probe with a bandwidth of 10 kHz was used. A voltage of 1 kV at frequencies of 50 Hz or 4 kHz was applied to the string. The probe was attached to the insulator rod (length 4 m) and connected to a single insulator by short wires (length 0.5 m). Measurement data were transmitted to a notebook by an optical link. The capacitance of the probe (40 pF) was similar to the capacitance of glass insulators (43 pF) and SCG insulators (27 pF). To reduce the influence of the probe capacitance, it was decreased by a factor of 10 (to 3.8 pF).

Calculations of voltage distribution were carried out with PSPICE program. The stray capacitance between an insulator and the HV line C_i or between an insulator and the ground C_i' were taken according to publication [8].

$$C_i = 1.2 - 0.012\,(i - 9)$$
$$C_i' = 1.7 - 0.007\,(1 - i) \qquad (1)$$

3. RESULTS OF IMPULSE VOLTAGE TEST

The measured F.O.V of strings with one insulator type only are shown in table 2, the same results for strings containing two types of insulators are shown in table 3.

Table 2. F.O.V of strings with a one insulator type

Number of insulators	Insulator Type	Impulse type and polarity	50% F.O.V kVpeak
1	Glass	+ LI	125
1	NGK	+ LI	135
7	Glass	+ LI	590
7	NGK	+ LI	630
7	glass	+ SI	510
7	NGK	+ SI	605
7	glass	- SI	600
7	NGK	- SI	695
10	glass	+ SI	725
10	glass	- SI	790

Table 3. F.O.V. of strings with two types of insulators

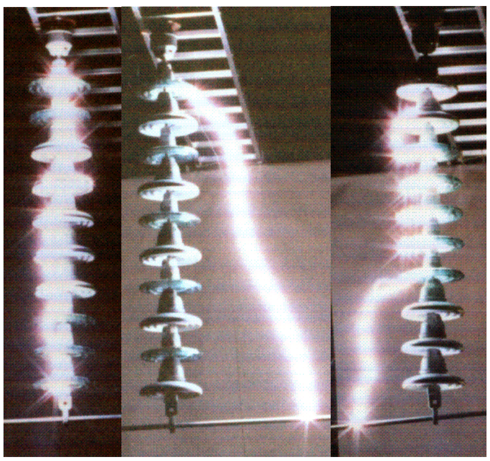
Number Of Units	impulse type and polarity	F.O.V. at configuration in kVpeak		
		bad	Alternating	good
13	+ LI	1050	1070	1045
10	+ SI	705	805	800
10	- SI	825	845	865

The positive switching impulse flashover voltage of a string including 7 units of SCG insulators is about 19% higher than of a string containing 7 standard insulators. Under negative polarity this difference was nearly the same – 16% (standard deviation is about 4% of 50% F.O.V value).

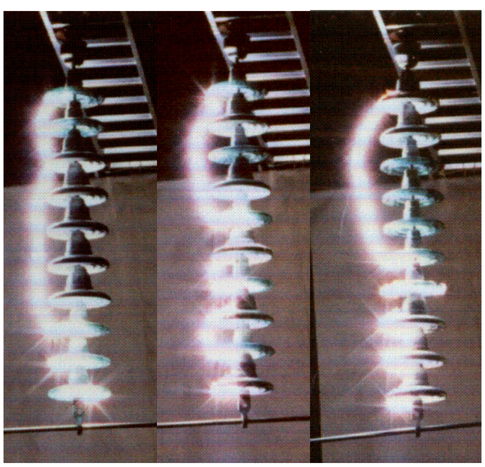
The switching impulse flashover voltage of a string which consisted of 5 standard insulators and 5 SCG insulators is about 10% higher than of a string with 10 standard insulators. The F.O.V of alternating configuration is nearly the same as of the good configuration.

Under lightning impulse stress on the long strings with 13 units of both types of insulator (table 3.) only small differences in flashover voltage were measured. The F.O.V of 7 SCG insulators was about 7% higher than that of 7 glass units. Thus the electrical strength of different strings (only glass units; only SCG insulators; glass and SCG units) depends, among other factors, on string length too. It seems that under lightning impulses, the resistance of SCG insulators is too high to change the capacitive voltage distribution. As a result, the F.O.V. of these insulators is similar to the F.O.V. of standard insulators.

It has been observed that the discharges at negative polarity burn close to the insulator surface and at positive polarity far from it (fig. 3.). Similar phenomena were observed earlier during impulse test with glass cap and pin insulators [5, 6].



+ SI, bad   + SI, alternating   + SI, good



- SI, bad   - SI, alternating   - SI, good

Fig. 3. Electrical discharges at switching impulses depending on polarity and insulator configuration

4. VOLTAGE DISTRIBUTION ALONG A STRING

The voltage distribution along a long string of SCG cap and pin insulators (30 units) under a.c. voltage is fairly uniform. The ratio K of voltage on most stressed unit to the mean stress (applied voltage to number of insulator in the string) is about 4,5 in the case of standard insulators and only 2,3 in the case of SCG insulators [7].

The voltage distribution along a standard insulator string does not depend on the voltage frequency. It is the same for a.c. voltage, switching impulse and lightning impulse. For a string consisting of 10 standard disc insulators the factor K amounts 2,3. For string containing 10 SCG insulators the factor K amounts 1,1; 1,9 and 2,3 respectively for a.c. voltage, switching impulse and lightning impulse (table 3.).

Tab. 3. Ratio K of voltage on the most stressed unit to the mean voltage in the strings containing 10 disc insulators

Insulator type	a.c. voltage	Switching impulse	Lightning Impulse
Standard	1.9	1.9	1.9
SCG	1.05	1.9	2.3

The calculation results for strings containing both types of insulators are listed in table 4.

Tab. 4. The ratio K of voltage on most stressed unit to the mean voltage in the strings containing 5 standard insulators and 5 SCG insulators

Insulator Configuratio n	a.c. voltage	Switching Impulse	Lightning Impulse
Alternating	2.7	1.9	2.0
Good	2.3	2.0	2.4
Bad	2.7	1.9	1.7

An apparent phase shift could be observed between voltages on standard insulators and SCG insulators under a.c. voltage and switching impulse (fig.4., fig. 5.). Additionally , the voltage on standard insulators is a bit higher than on SCG insulators. Under lightning impulse the phase shift is nearly zero and the voltage on standard insulators is only a little higher than on SCG insulators (fig. 6).

The voltage distribution is of course most uniform on a string containing SCG insulators only. Surprisingly, under lightning impulse the voltage distribution is similar for all strings (K=2,3 for all 5 cases), which means that the voltage depends on the capacitance only.

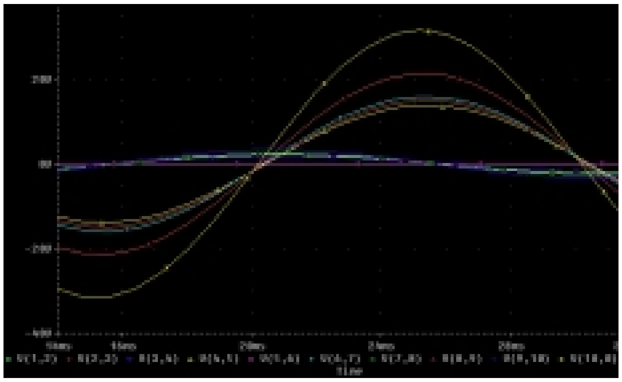


Fig. 4. A.C. voltage distribution on 10 insulators, configuration alternating

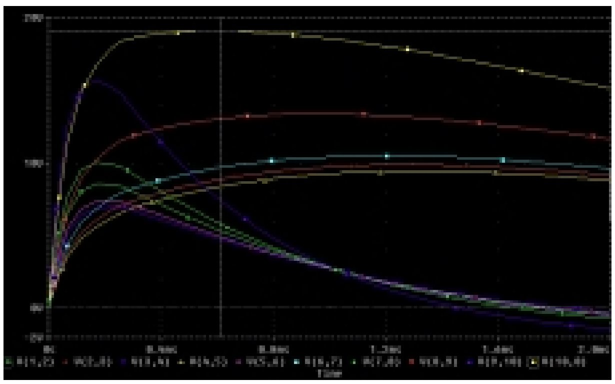


Fig. 5. Switching voltage distribution on 10 insulators, configuration alternating

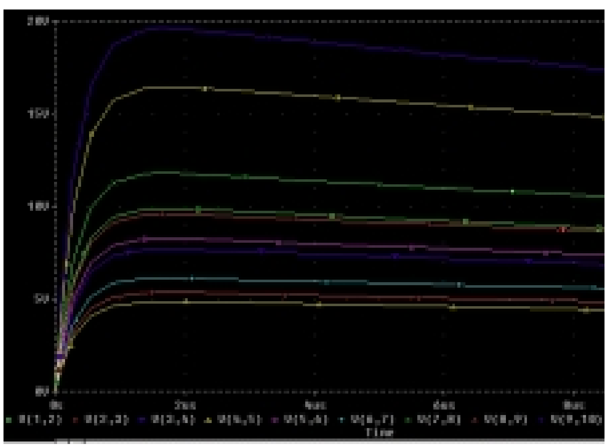


Fig. 6. Voltage distribution under lightning impulse on 10 insulators, configuration alternating

CONCLUSIONS

1. Under clean and dry condition, the impulse behaviour of a string containing 5 standard and 5 SCG insulators is similar to a string containing 10 SCG insulators.
2. Under lightning impulses, the resistance of SCG insulators is too high to change the capacitive voltage distribution. As a result, the F.O.V. of these insulators is similar to the F.O.V. of standard insulators.
3. The power loss on strings containing SCG and standard glass cap insulators is nearly zero. Therefore the concept of such strings seems to be interesting for reliability improvement of transmission lines.

LITERATURE

[1] Forrest J.S. *The characteristics and performance in service of HV porcelain insulators*, Journal of IEE, Vol. 89, Part II, 1942, pp.60-92

[2] Fujimura T., Naito K., Irie T. *Performance of semiconducting glaze insulators under adverse conditions*, IEEE Trans. Power Apparatus. and Systems PAS, May/June 1978, pp. 763-771

[3] Naito K., Matsuoka R., Irie T., Kondo K. *Test methods and results for recent outdoor insulation in Japan*, IEEE Trans. on Dielectric and Electr. Insulation DEI, Oct. 1999, pp. 732-743

[4] Moran J.H., Powell D.G., *Resistance graded insulators - the ultimate solution to the contamination problem ?* IEEE Trans. on Power Apparatus and Systems, PAS-91, 1972, pp. 2452-2458

[5] Hutzler B., Riu J. *Behaviour of long insulators in dry conditions*, IEEE Trans. on Power Apparatus and Systems, Vol. PAS-98, no. 3, 1979

[6] Chrzan K., Kowalak T. *Hygroscopic properties of pollutans on high voltage insulators*, IEEE Trans. on Electr. Insul., Vol. EI - 24, No 1, 1989, pp. 107

[7] Fukui H., Naito K., Irie T., Kimoto I. *A practical study on application of semiconducting glaze insulators to transmission lines*, IEEE Trans. on Power Apparatus and Systems, PAS-93, No. 5, 1978, pp. 1430-1443

[8] Mizuno Y., Naito K., Suzuki Y., Mori S., Nakashima Y., Akizuki M. *Voltage and Temperature distribution along semiconducting glaze insulator strings*, IEEE Trans. on DEI, Feb. 1999, pp. 100-104

ACKNOWLEDGEMENTS

The work presented was partly financed by the first author. We thank Prof. K. Feser, Dr. W. Koehler from University of Stuttgart and NGK Insulators LTD for their support.

Krystian L. Chrzan
Wroclaw University of Technology
Institute I-7
50-370 Wroclaw, Poland
chrzan@elektryk.ie.pwr.wroc.pl