# Solid Core Suspension Disc Insulators Preventing Puncture Caused by Steep Front Surge Voltage

**Samruay SANGKASAAD***

**Abstract** - This paper presents development of solid core suspension disc insulators (cap and cap suspension disc insulator) for replacing cap and pin suspension disc insulators in overhead transmission and distribution lines which expose to lightning discharges. By this means the punctured problem caused by steep front surge voltage created by lightning discharge on the lines can be solved. The solid core suspension insulator was designed and constructed based on the dimensions of conventional suspension disc insulators (cap and pin insulators). The insulators are made of alumina porcelain. The electrical and mechanical characteristics of the solid core suspension insulators were carried out. The puncture test was performed in the air by applying steep front impulse voltage with amplitude about 2.5 per unit of 50% flashover (CFO) of the insulator unit at negative standard lightning impulse 1.2/50 μs with steepness up to 9200 kV/μs. The testing results show that solid core suspension disc insulators are not punctured eventhough the steepness of the steep front impulse voltage was increased up to 9200 kV/μs.

**Keywords**: Solid core suspension disc insulators, Impulse voltage generator, Steep front impulse voltage, Puncture test on insulators in air, Porcelain insulators.

## 1. Introduction

It is recognized that most high voltage transmission lines are overhead lines. These lines are exposed to atmospheric discharge, i.e. lightning discharge which produce lightning surge overvoltage with high magnitude in electric power systems [1]. The lightning surge voltage has very high steepness at the front wave called steep front surge voltage. Such high steepness surge voltage can be also produced by backflashover on insulator string, caused by lightning discharges on overhead ground wire or on the tower. On the other hand cap and pin disc insulator (EU) or suspension insulator (USA) made of porcelain or glass which are classified as type B [2] which has the shortest puncture path through the solid insulation shorter than a half of the shortest flashover path through air outside the insulator. Up to now suspension disc insulators are still preferably utilized for supporting energized high voltage conductors.

As experience of insulators application informed by electric utilities, it is found that some insulators were punctured after having been installed in the lines for some years. It has occurred in every voltage level from 24 kV up to 500 kV [3]. The punctured insulators can cause fault and affect the reliability of the power system. Due to this effect some present national and international standards require impulse voltage puncture withstand test on insulator in air [4,5,6].

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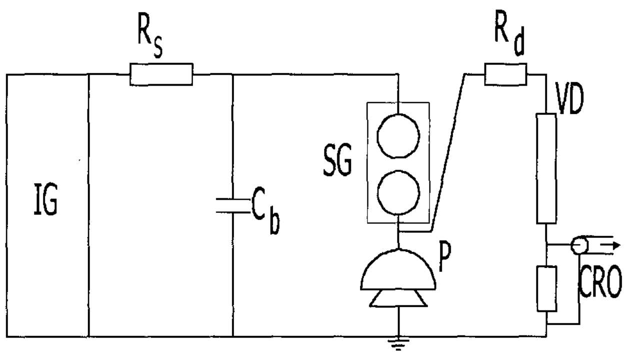
## 2. Steep Front Impulse Voltage

### 2.1 Steep front impulse voltage generation

Steep front surge voltage occurred in the transmission and distribution lines can be artificially generated in a high voltage laboratory by means of steep front impulse voltage generator represented by circuit connection as shown in Fig. 1 with detail explained in the paper [7,8].




P = Test object
IG = Normal impulse generator
$R_s$ = Series resistor for adjusting standard waveform of IG
$C_b$ = Coupling capacitor (load capacitor of IG)
SG = Spark gap for chopping standard waveform
VD = Voltage divider
CRO = Digital oscilloscope

**Fig. 1** Circuit connection for generating steep front impulse voltage

### 2.2 Effect of steep front impulse voltage on insulators

In the previous work [9], effect of steep front impulse voltage on insulators was studied by conducting experimental investigation of puncture characteristics of different classes of porcelain insulators type B. The experimental results showed that :

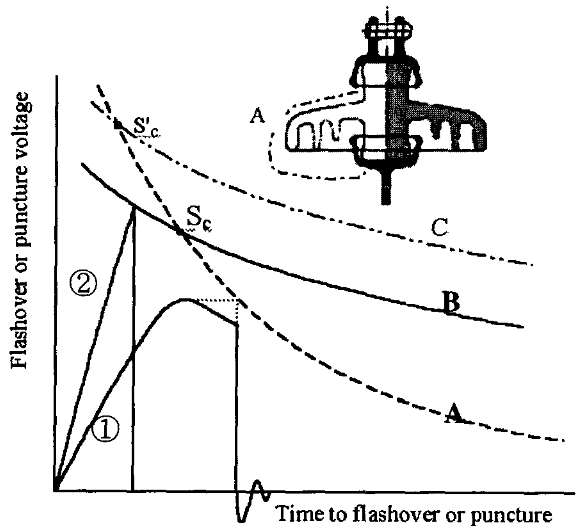
1) The steep front impulse voltage with steepness of 2500 kV/μs can cause the suspension disc porcelain insulators to be punctured if the quality is not good enough. The percentage of puncture will be increased with the increasing steepness of steep front impulse voltage.

2) The puncture on insulator by steep front impulse voltage depends also on the kind of body material, type or configuration of insulator. Insulator with longer flashoveer or arcing distance can be punctured more easily than the insulator with shorter flashover distance.

3) The punctured characteristics depends on the polarity and the amplitude of the applied impulse voltage. The polarity of the steep front impulse voltage with higher CFO (critical flashover) can puncture on insulator easier than that with lower CFO.

## 3. Measures to Prevent Insulator Punctured

As mentioned the insulators type B can be punctured by steep front impulse voltage and cause fault affecting the reliability of the power systems. Therefore the punctured problem has to be solved. Pin type insulator, which is one of the insulator type B, was replaced by the solid core line post or pin post insulator which are classified as insulator type A [2]. However by some reasons concerning with installation and maintenance aspects, suspension disc insulator is still preferable to utilize for supporting high voltage transmission lines. That means the puncture problem still exists. It was suggested to prevent the insulator punctured by increasing the strength of insulator body material or by increasing thickness of solid insulation between electrodes described by V-t curves as shown in Fig. 2 [10]. In this work, the thickness of solid insulation was increased to be solid core of insulator and called solid core suspension disc insulator.



A : flashover in air
B : puncture of solid insulating material
C : increased strength of solid insulation

**Fig. 2** V-t curve of an insulator unit

## 4. Solid Core Suspension Disc Insulators

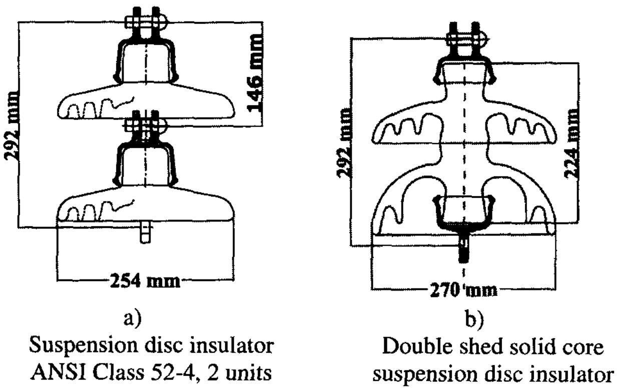
The punctured problems on conventional or standard suspension disc insulators were proposed to be solved by utilizing solid core suspension disc insulators.

### 4.1 Double shed solid core suspension disc(DSS) insulator

First study was conducted on doubled shed solid core suspension disc insulator made of alumina porcelain body. The various dimensions such as leakage distance, arcing distance, diameter of disc and the length of insulator were designed based on dimensions of the standard suspension disc insulator ANSI Class 52-4 two units connected in a string.

#### 4.1.1 Insulator samples and dimensions of DSS insulator

The important criteria for designing to be considered are the length of DSS insulator one unit to be equal the length of the two unit string of ANSI Class 52-4 as shown in Fig. 3 and the electrical characteristics should be approximately the same [11].



a) Suspension disc insulator ANSI Class 52-4, 2 units

b) Double shed solid core suspension disc insulator

**Fig. 3** Double shed solid core suspension disc insulator comparing with standard suspension disc insulator 2 unit in a string

The test samples were 20 strings ( two units connected for each string) for standard suspension disc insulator ANSI Cl. 52-4 and 20 units for double shed solid core suspension disc insulator.

### 4.1.2 General characteristics of DSS insulator

The general characteristics of the designed double shed solid core suspension disc insulator were carried out for comparing with the standard suspension disc string two units as shown in table 4.1 [11].

**Table 1** General characteristics of suspension disc insulators

| Characteristics | Standard suspension disc 2 units | Double shed solid core suspension disc |
|---|---|---|
| Leakage distance (mm) | 607 | 720 |
| AC 50 Hz flashover voltage dry (kV) | 155 | 145 |
| Critical impulse flashover voltage (kV) | | |
| • positive | 236 | 247 |
| • negative | 244 | 231 |
| Combined M&E strength (ton) | One unit 6.8 | 8.9 |

### 4.1.3 Impulse puncture test in air on DSS insulator

The puncture test by steep front impulse voltage in air on double shed solid core suspension disc insulator was conducted in accordance with IEC 1211-1994 [4] and CAN/CSC-C411.1 M89-1989 [6], that means steepness ≥ 2500 kV/μs and the peak flashover voltage should be in the range 2-3 p.u. of CFO. The steep front impulse test voltage generated by a steep front impulse voltage generator 1000 kV 30 kJ [8]. The steep front impulse test voltage was measured by means of an shielded resistor voltage divider 600 kV with response time of 13.7 ns .

The insulator sample under tested was mounted under the spark gap chamber SG as shown in Fig. 4 The test voltage was applied at lowest steepness of 2500 kV/μs with negative polarity first and followed by positive polarity for 16 times for each polarity with steepness up to 10000 kV/μs. The time between successive impulses was 2 min. The test results are shown in Table 2.

The test results show that double shed solid core suspension disc insulators are not punctured by steep front impulse eventhough the steepness of the test voltage increased up to 10,000 kV/μs with magnitude of flashover voltage were 2.7 to 3.1 p.u.

**Table 2** The results of steep front impulse voltage test in air

| Characteristics | Flashover voltage in kV and in p.u. of CFO | |
|---|---|---|
| | Positive | Negative |
| Flashover voltage kV(p.u.) | 661 (2.7 p.u.) | 718 (3.1 p.u.) |
| Time of flashover μs | 82 | 85 |
| Steepness in average kV/μs | 9,800 | 10,000 |

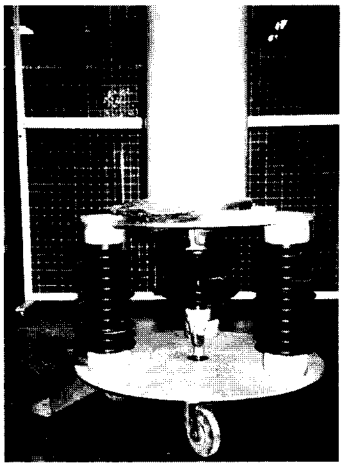


**Fig. 4** Mounting DSS insulator under impulse puncture test in air

By these results, it can propose that the normal suspension disc insulators puncturedable can be replaced by using double shed solid core suspension disc insulators one unit for two units of suspension disc insulator ANSI Class 52-3 or 52-4 at the same length.

## 4.2 Single shed solid core suspension disc insulators

In the previous study it clearly showed that the application of double shed solid core suspension disc insulator can solve the punctured problems. However from practical point of view, the application of double shed solid core suspension disc insulator may cause inconvenient at installing due to its weight (about 11.6 kg/unit). It is therefore of great interest to design a single shed solid core suspension disc insulator with lighter weight for preventing puncture caused by steep front surge voltage.

### 4.2.1 Insulator samples and dimensions of SSS insulator

The various dimensions of single shed solid core suspension disc insulator were designed based on standard suspension disc insulator ANSI Class 52-4, including leakage distance, arcing distance, diameter of disc and the length of insulator (spacing) as shown in Fig. 5 The important design criteria to be considered were the length or spacing and leakage distance. The dimensions of 5 units SSS insulator are equivalent to 7 units of ANSI Class 52-4 and 3 units of SSS insulator are equivalent to 4 units of ANSI Class 52-4 , as shown in Table 3.

The test samples of single shed solid core suspension disc insulators of 20 units were provided for this study.

### 4.2.2 General characteristics of SSS insulator

Each unit of all insulator samples has to be performed under tested of AC 50 Hz flashover first and followed by critical impulse flashover (CFO) with both positive and negative polarities in accordance with ANSI standard C29.1 [12]. The test results of 20 units in average values are shown in Table 3.

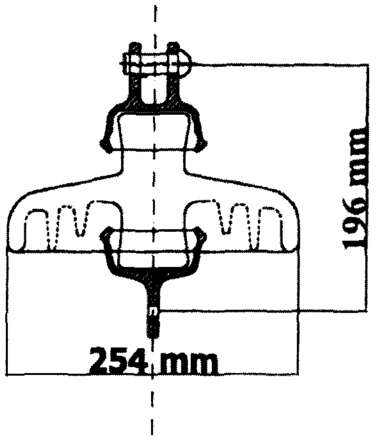



**Fig. 5** Single shed solid core suspension disc (SSS) insulator

**Table 3** General characteristics of suspension disc insulator

| Characteristics | Standard suspension disc ANSI Class 52-4 | Single shed solid core suspension disc |
|---|---|---|
| Leakage distance (mm) | 1 unit = 303<br>4 units = 1212<br>7 units = 2121 | 1 unit = 425<br>3 units = 1275<br>5 units = 2125 |
| Spacing or length (mm) | 1 unit = 146<br>4 units = 584<br>7 units = 1022 | 1 unit = 196<br>3 units = 588<br>5 units = 980 |
| AC 50 Hz flashover (kV) | 85 | 94 |
| Critical impulse flashover voltage (kV)<br>• positive<br>• negative | <br><br>125<br>130 | <br><br>162<br>153 |

### 4.2.3 Impulse puncture test in air on SSS insulator

After the insulator samples passing the AC 50 Hz flashover and critical impulse flashover tests, the puncture test by steep front impulse voltage were performed similarly to the puncture test on double shed solid core suspension disc insulators. The tests were conducted at different steepness by increasing steepness in three steps including about 3000 kV/μs, 5000 kV/μs and 7500 kV/μs. At each steepness the test was performed on insulator samples at least 10 units for positive and negative polarities by applying the test voltage 10 times per steepness per polarity with the time between successive impulses of 2 min. The steep front test voltage was measured by a 500 kV damped capacitor impulse voltage divider with partial response time of measuring system 2.2 ns [13]. The waveform oscillograms of steep front impulse flashover voltage as examples are shown in Fig. 6 with the test results of flashover voltage in kV and in p.u. and time to flashover in ns.

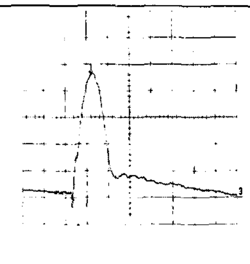
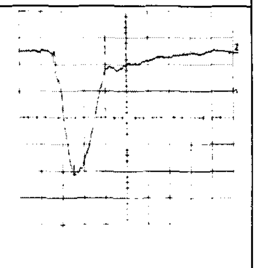
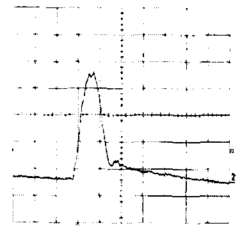
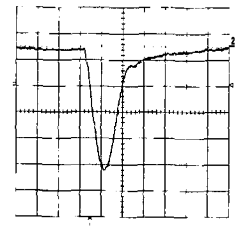
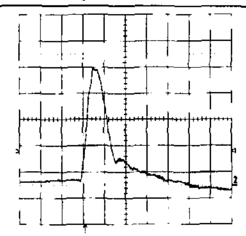
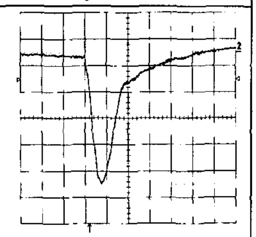
| Steepness kV/μs | Positive | Negative |
|---|---|---|
| 3000 | <br>FO 283 kV (1.7 p.u.)<br>$T_c$ = 102 ns | <br>FO 280 kV (1.8 p.u.)<br>$T_c$ = 106 ns |
| 5100 | <br>FO 355 kV (2.2 p.u.)<br>$T_c$ = 94 ns | <br>FO 407 kV (2.7 p.u.)<br>$T_c$ = 99 ns |
| 7500 | <br>FO 391 kV (2.4 p.u.)<br>$T_c$ = 64 ns | <br>FO 435 kV (2.8 p.u.)<br>$T_c$ = 70 ns |

**Fig. 6** Oscillogram of steep front impulse flashover voltage on SSS insulators at different steepness (time scale 100 ns/div, voltage scale 60.8 kV/div for 3000 kV/μs and 86.5 kV/div for 5100 and 7500 kV/μs), p.u. based on $CFO^+$ = 162 kV and $CFO^-$ = 153 kV
$T_c$ = time to flashover (ns)

## 5. Discussion

### 5.1 Specification of steep front test voltage

By the results of steep front impulse puncture withstand test in air on solid core suspension disc insulators, the test voltage can not be specified to comply with both standards. For example in Fig. 6 at steepness of 3000 kV/μs complied with CAN standard but the amplitude of steep front flashover voltage for both polarities are lower than 2 p.u. not complied with IEC standard. If the amplitude of flashover voltage is adjusted to meet IEC requirement, the steepness will be much higher than 2500 kV/μs (specified by AS standard 2947-1989). For this case the test voltage specification should be further investigated by taking natural phenomena of steep front surges into account. The punctured characteristics depends on various factors as mention in section 2.2.

### 5.2 Electrical characteristics of solid core suspension disc insulators

The experimental results clearly show that the solid core suspension disc insulators can withstand the steep front impulse voltage in air with steepness up to 1000 kV/μs for double shed solid core suspension disc (DSS) insulator and up to 7500 kV/μs for single shed solid core suspension disc (SSS) insulator. It can therefore propose that the puncture problems caused by steep front surge voltage produced by lightning discharge on electrical power transmission and distribution lines can be solved by utilizing solid core suspension disc insulators to replace the normal suspension disc insulators.

In general applications the electric utilities use suspension disc insulator ANSI Class 52-3 or 52-4 four units in a string for system voltage of 72.5 kV or 7 units for 123 kV lines and 14 units for 245 kV lines. By the test results, these normal suspension disc insulator two units can be replaced by one unit of DSS insulator, that means using DSS insulator two units for 72.5 kV system.

From practical point of view the application of DSS insulator may not convenient for installing due to its weight. On this aspect single shed solid core suspension disc insulator can be applied. Based on the design, the normal suspension disc insulator ANSI Class 52-3 or 52-4 for 4,7 and 14 units in a string can be replaced by SSS insulators for 3, 5 and 10 units respectively.

## 6. Conclusion

By this test results and discussion above the conclusion may be made as follows :

1) Solid core suspension disc insulators with single shed or double shed can withstand steep front impulse voltage specified by all present standards.

2) All normal suspension disc insulators can be replaced by solid core suspension disc insulators.

3) The punctured problems caused by steep front surge in high voltage power systems produced by lightning discharges can be solved by using solid core suspension disc insulator made of alumina porcelain.

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## Reference

[1] Ragaller, K., Surges in High-Voltage Networks, Plenum Press, New York, 1980, pp. 9-12

[2] IEC 383-1, Insulators for overhead lines with a nominal voltage above 1000 V Part 1: Ceramic or glass insulator units for a.c. system definition, test methods and acceptance criteria, 1993

[3] Sangkasaad, S. and et-al, Effects of Steep Fronts Impulse Over voltage on Porcelain Insulators, Research report submitted to The Thailand Research Fund, June 2001

[4] IEC 1211-1994, Insulators of ceramic material or glass for above 1000 volt overhead lines with a nominal voltage greater than 1000 V - Puncture testing, Technical report-type 2, 1994-06

[5] Australian Standard, AS 2947-1989, Insulators Porcelain and glass for overhead power line voltage greater than 1000 V.a.c. Part 1 : Test methods

[6] Canadian standard, CAN/CSA-C411.1-M1989, AC Suspension insulators

[7] Nikolopoulos, P.N., On the generation of steep front high voltage impulse, 4th International Symposium on High voltage Engineering, Athens-Greece, 5-9 Sept. 1983

[8] Sangkasaad, S., Ngarmpradit, V. and Limsetthagan, N., Steep Front Impulse Voltage for Puncture Test on Cap and Pin Insulators, Proceeding of the international Power Engineering Conference (IPEC '99) Vol. I 1999, pp. 358-362

[9] Sangkasaad. S., Limsetthagan, N., and Soontornapa, Effect of Steep Front Impulse Voltage on Insulators, ACED-2000, Kyoto, Japan, B-204, pp. 131-134

[10] Naito, K., Sussuki, Y., Insulator selection criteria for transmission line reliability, NGK Review, Overseas Edition, No. 14 Dec 1990, pp. 8-9

[11] Sangkasaad, S. and Suntornapa, T., Design and Construction of Solid Core Suspension Insulators for

High Voltage Line, Research report submitted to Center of Excellence in Electrical Power Technology, Chulalongkorn University, Dec. 2001

[12] ANSI C29.1 American National Standard for electrical power insulators - test methods 1988

[13] Sangkasaad, S., Rungsrisoponaeporn, P., Development of Voltage Divider for Steep Front Impulse Voltage Measurement (500 kV damped capacitor type), Research report submitted to the Thailand Research Fund, February 2002

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He joined the teaching staff of Chulalongkorn's Faculty of Engineering during 1961-1996. From 1995 till 2001, he was appointed to be the director of the Center of Excellence in Electrical Power Technology (CEPT), Faculty of Engineering, Chulalongkorn University. His research activities have been mainly involved with application of gas $SF_6$ as insulation, high voltage testing equipment, lightning phenomena studies and Electromagnetic Compatibility (EMC).

In 1991, he was awarded the Outstanding Researcher of the year 1991 by the National Research Council and he was voted as Distinguished Engineer for study and research of the year 1993 by the Engineering Institute of Thailand. In 1995, he was recognized and announced as the Senior Research Scholar in Electrical Engineering Field with obtaining Scholarship of the Thailand Research Fund (TRF).

Dr. Sangkasaad is a member of IEEE. During 1995 - 1998 he was appointed to be the section chair of IEEE Thailand Section. Since 1999 he has been voted to be the chair of PES chapter of IEEE Thailand Section. He is a member of the Engineering Institute of Thailand under H.M. the King's Patronage. He is also the International Steering Committee of ACED.