Developments of High Voltage Porcelain Post-Insulators

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***Abstract*—The main purpose of this work was to investigate the development trends of high voltage porcelain post insulators over the last decades. It also shows an analysis of the performance of a contemporary design of a shorter nonstandard layout and its agreement with the IEC standards. Despite of high demanding requirements on Ceramic Solid Core Post Insulators, the economical aspect becomes more and more important. Therefore the objective of insulator design is to develop a technically and economically optimized HV component, with a high grade of reliability over decades. If some parameters can be optimized like, arcing distance and length of the insulator, maximizing the mechanical strength and stiffness, minimizing the core diameter, maximizing the form factor and finding an optimal shed profile, material can be saved and therefore weight can be reduced also and costs. Due to a more sophisticated manufacturing process of high voltage insulator, they can be produced in a bigger length in one piece and thinner sheds than 40 years ago. The result of these measures are a longer arcing and creepage distance, less weight and most of all less electrically conducting parts. 40 years ago, the column design for an 800kV AC post insulator was a stack of 6 insulators, compared to two insulators nowadays. This work reflects the different developments of design between the past and in these days, because the question was raised: do post insulators need to have the same total height than 40 years ago despite of an improvement of manufacturing them.**

Ceramic Solid Core Post Insulator; Core Diameter; Shed Profile; Form Factor

I. INTRODUCTION

Insulators are one of the key components in our power system, but the general perspective does not pay a particular attention on this fundamental element. Despite high requirements, regarding availability and reliability, economical aspects have to be considered as well and therefore great interest in optimization is given to that subject. For an insulator, to be reliable over years, some requirements have to be fulfilled. These are mainly, electrical, mechanical and chemical. In this work the focus is on electrical aspects about post insulators and their performance, based on comparison of field simulations and test reports about insulators of traditional and advanced designs. Some of this post insulator designs in different stacked configurations are presented in Fig. 1, whereas traditional designs have shorter elements and therefore more pieces per column.

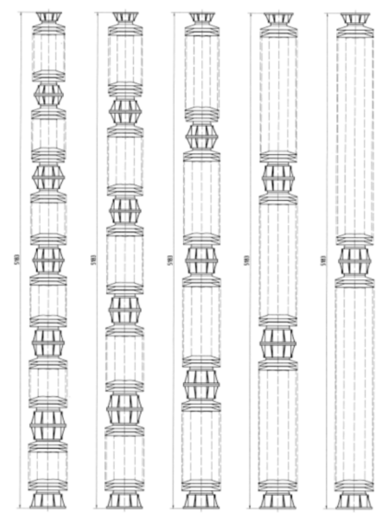

Fig. 1: Drawings of traditional and advanced column designs for 800kVAC application [1]

Not only the length of a post insulator, but also the sheds have experienced an improvement against insulators in the past. Since the sheds do not contribute to the mechanical stability, it is evident to save material here as well and make them thinner. Angle, distances to other sheds and length of the sheds are the same as of previous insulators. The differences are the tip radius and the shed thickness, as shown in Fig. 2. With this new design in length of an insulator element and shed form, arcing distances are still the same and in terms of creepage distance even enhanced. These improvements are due to advanced manufacturing methods, which are able to save material and therefore cost.

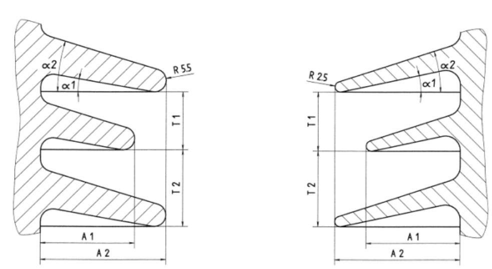

Fig. 2: Drawings of traditional and advanced shed design [1]

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This raises questions about more optimization in terms of reducing the total length of a stacked post insulator, since there are less terminal joints. But this implies that there is no impairment of the performance and that a stacked post insulator has to fulfill type tests according to the standards.

II. Type Tests - Standards

To confirm that the actual withstand voltage of the insulation is not lower than the corresponding specified withstand voltage, standard withstand voltage tests have to be performed. Only the standard rated switching impulse withstand voltage and the standard rated lightning impulse withstand voltage test provide the essential parameters to define the rated insulation level.

For this work a series of ceramic station post insulators with different shed profile and element length were investigated and tested at four different Basic Impulse Insulation Levels: BIL1300, BIL1425, BIL2050 and BIL2550. For a more appropriate comparison, insulators with similar geometric and mechanical properties were analyzed. Insulators with a Basic Impulse Insulation Level of BIL1300 and BIL2050 had to pass the requirements of ANSI C29-9/1983 (R2002) and ANSI C29-1/1988 (R2002) [2, 3]. Tests for Insulators with a Basic Impulse Insulation Level of BIL1425 and BIL2550 were carried out in accordance with IEC 60168:2001, IEC 60060-1:2010 and IEC 60437:1997 [4, 5, 6]. All insulators passed the mechanical tests in accordance with the IEC or ANSI standard. These are:

- Thermal Test
- Compression Strength Test
- Torsional Strength Test

Following electrical tests were carried out at BIL1300 and BIL2050:

- Radio-Influence-Voltage (RIV) test
- Impulse Withstand and Flashover Voltage Tests
- Low-frequency wet withstand and Flashover Voltage test

At BIL1425 and BIL2550 following electrical tests were carried out:

- Radio Interference Voltage test
- Dry and Wet Lightning Impulse Voltage Test
- Dry and Wet Switching Impulse Voltage Test
- Dry and Wet Power Frequency Voltage Test

ANSI Standard

Regarding the Creepage Distance and Dry Arcing Distance, the standards of the older ANSI C29.1-1961 and the latest ANSI C29.1-1988 (R2002) have not changed. This means that insulation requirements are still the same as for 50 years and have not been accounted for more sophisticated insulator designs. Table I. gives an overview of the results of the Impulse Withstand and Flashover Voltage Tests for BIL1300 und BIL2050 in accordance with ANSI Standard. For each Basic Impulse Insulation Level two Insulator designs where type tested, the advanced and the traditional shed design. Both insulator types passed the tests.

TABLE I. TYPE TESTS ACCORDING TO ANSI STANDARD

Type	lenght	# of Elements	Corona Ring	Guaranteed applied Voltage	Guaranteed flashover Voltage	spec.min. Impulse flashover voltage	V_{CRA}	Impulses/ Flashover +/-	Passes Standard
	mm			kV	kV	kV_{peak}	kV_{peak}		
TR. 369	2692	2	no	1300	1410	1297	+1489/	3/0 3/0 3/0	yes
TR. 369	2692	1	no	1300	1410	1297	+1528	3/0 3/0 3/0	yes
	4699	2	yes	2050	2250	2070	+2657	3/0 3/0 3/0	yes
	4699	3	yes	2050	2250	2070	+2684	3/0 3/0 3/0	yes

Despite the fact that there have been major changes in development of the shed profile and the length of an element, nearly all manufacturers decide to take a tapered insulator for BIL1300 with a length of 2,692 mm and tapered insulator with a length 4,699 mm for BIL2050.

IEC Standard

Electrical type tests under IEC-Standards were carried out for one post insulator, compared to ANSI-Standard where three test objects have to be tested. The calculated lightning-impulse withstand voltage is based on the 50% lightning-impulse flashover voltage, determined by the up-and-down method according to IEC 60060-1. For determining the switching-impulse withstand voltage the up and down method or the withstand voltage method with 15 impulses were carried out. Basically the up and down method is more significant. Table II. shows of the results of the Wet Lightning Impulse Voltage Tests for BIL1425 und BIL2550 under the IEC Standard. The creepage distance of all insulators is in accordance with IEC 60071-2:1996 within a pollution level of 25mm/kV [7].

TABLE II. TYPE TESTS ACCORDING TO IEC STANDARD

Type	lenght	Corona Ring	Rated voltage	# of Elements	Specification min. LIV	U50% LIV tested	U10% LIV tested	Impulses/ Flashover +/-	Passes Standard
	mm		kV		kV_{peak}	kV_{peak}	kV_{peak}		
C12.5-2550	5700	yes	765	2	2550	+3364/ -3384	3235	15/2 15/0	yes
C20-1425	2850	yes	400	1	1425	+1630/ -1748	+1567/ -1680	15/0 15/0	yes
C20-1425	2850	no	400	1	1425	+1700/ -1798	+1635/ -1730	15/0 15/0	yes
C20-1425	3150	no	400	2	1425	+1782/ -1874	+1712/ -1801	15/0 15/0	yes

At each Basic Impulse Insulation Level one Insulator design was type tested. For BIL2550 it was type tested a 2 element stacked insulator with the latest shed design. For BIL1425 it was type tested a traditional 2 element stacked insulator and an advanced design insulator with lower height. All insulators passed the test.

III. TYPE TEST

The latest more advanced insulators have a higher Creepage Distance–Arcing–Ratio, therefore the electrical properties are enhanced. Due to this fact an insulator for BIL1425 was type tested with a total length of 2,850 mm instead of 3,150 mm. In general for this kind of type tests a stack of two shorter elements were chosen, but with an advanced design of a shorter overall length a single insulator element was tested in this case.

IV. ELECTRIC FIELD SIMULATION

Additionally an electric filed simulation for all test subjects was also carried out with a Finite Element Method (FEM) program. Drawings of the electrical field strength alongside the insulation surface were compared for all test subjects. The main focus was on differences in the electrical stress of the height of the insulators and the influence of the terminals and particularly of the terminal joints. In the following figures a line graph was taken from the top of the post insulator to the bottom end terminal in a distance of one centimeter from the core surface. In Fig. 3, three different stacks of post insulators are compared. What they have in common is the same overall length and the Basic Impulse Insulation Level at 1300. Since the post insulator with three elements, is an older one, it fulfills prior standards. Particularly the creepage distance that instead of nowadays used values of 5,867.4 mm, the older value of 5,000 mm is given.

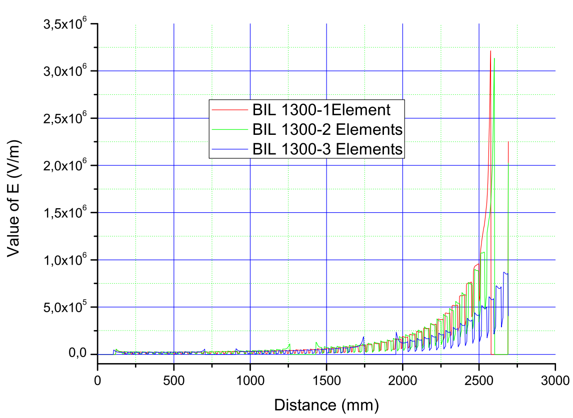

Fig. 3: Electrical field strength alongside the post insulator at BIL 1300

Insulators for the BIL 1425 have one, two or three elements on a stack. Insulators at BIL 1425, which consists of 3 Elements, has an old Class I shed design with a Creepage distance of 5,600 mm. The more advanced design of one single piece is about 300 mm shorter, due to some savings of end terminals. Therefore the drop in electrical field strength must be steeper compared to the other traditional ones, as shown in Fig. 4.

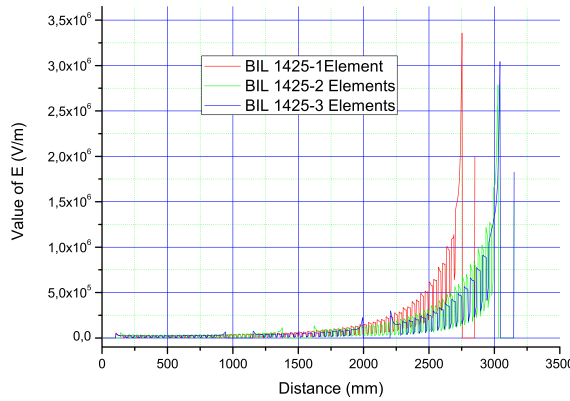

Fig. 4: Electrical field strength alongside the post insulator at BIL 1425

For Insulators at BIL 2050 both types have a minimum required creepage distance of 10,972.8 mm, but due to fewer end terminal joints, the two element insulator has a longer effective insulation length and hence the number and shape of sheds differs. Although the numbers of elements are different, it has just minor influence on the electrical field strength, as seen in Fig. 5.

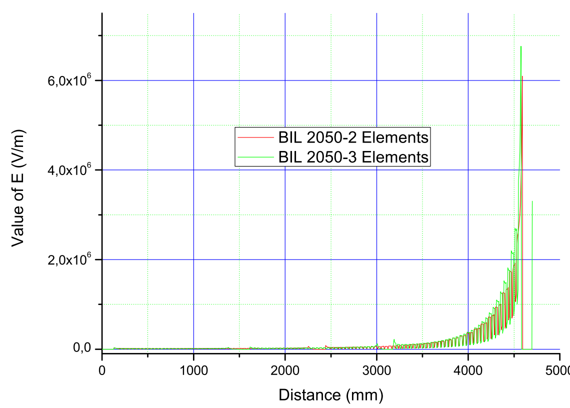

Fig. 5: Voltage drop alongside the post insulator at BIL 2050

Insulators of the BIL 2550 have an overall length of nearly 5.7 m. In Fig. 6 two, three and five element post insulators are compared.

The five unit post insulator has an old Class I shed design with a creepage distance of 9,800mm.This means that the creepage distance is shorter than that one of the other insulators, which has a minimum creepage distance of 20,500 mm.

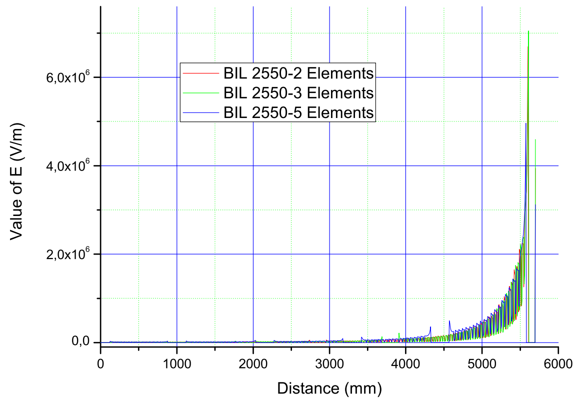

Fig. 6: Electrical field strength alongside the post insulator at BIL 2550

V. CONCLUSION

As electrically relevant factors have been improved due to an increase of the length of each insulating section of a column, further improvements are suggested. This is mainly reducing the height of a stacked insulator column, because the numbers of terminal joints are also reduced. These are of metal and hence do not contribute to a creepage distance and insulation strength. This is backed up by FEM-programs, which confirm that the electrical field distribution is similar to traditional insulator designs. Furthermore, type tests have shown that an advanced insulator also fulfills the requirements of the standards.

ACKNOWLEDGMENT

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