SIMULATION AND PRACTICAL TESTING OF SUBSTATION COMPOSITE POST INSULATORS FOR EXTREME CONDITIONS – RESULTS AND ANALYSIS

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Abstract- Design of high voltage station post insulators is critical in mechanical and electrical aspects considering wide variations of in-service conditions. In this context numerous simulations were carried out using Finite Element Modelling software (ANSYS) to understand the mechanical characteristics of deflection under static and dynamic load. Dynamic load simulations ware based on the forcing function model well defined in CIGRE publication. Simulation showed positive results with damping of the oscillations in a very short time highlighting the stability of composite post insulators.

To extend it further actual testing by the application of very high short circuit current was performed at a NABL, STL lab. The current levels for actual short circuit test was chosen to be much higher than the existing short circuit levels of substation for near futuristic possibilities. These laboratory tests were modelled and performed on the basis of actual substation arrangement of tubular bus bars with spacing between each composite post insulator and spacing of bus bars typical of a substation arrangement. The tests clearly demonstrated that composite post insulators are very stable during high forces created at times of short circuit with deflection levels very low under extreme fault levels [1-14].

I INTRODUCTION

High Voltage Insulators in an electrical system perform the dual role of providing mechanical support and electrical isolation. In general the common materials used for this application are silicone composite, porcelain and glass for providing the insulation. Traditionally high voltage insulators that were used throughout the world were primarily Glass/Porcelain until late 1960's. Numerous issues that were experienced throughout the world primarily on pollution related failures led to the development of composite insulators in late 60's. Globally numerous countries like China, Switzerland started using the composite insulators in late 70's for applications of both long rod, composite post insulator for railways and so on. In India use of composite insulators has completed more than 25 years of successful operation with Tata power installing them in 1993.

II. GLOBAL TREND

With the composite insulator technology maturing in the last few decades the initial concerns that were present have been duly addressed. Global usage of different insulating materials is shown in Figure 1. It can be observed that considering the introduction of composite to the world market in 80's it occupies a significant percentage today in the global market. Table 1 summarizes the advantages on various features.

Table 1: Unique features of Silicone composite post insulators

Features	*Silicone composite post insulators*
Pollution Performance	Excellent – Hydrophobic
Seismic performance	Excellent
Maintenance	Not Required
Short circuit loading & Reliability	Superior damping ; high energy absorbing; less sensitive
Shattering, Explosion, (Severe loading)	No Shattering, Explosion Failure safe mode
Metal flange attachment	Superior technology - Crimping Methodology
Stress concentration due to difference in core and shed cross sectional area	Elasticity of Silicone rubber sheds higher than core hence no issues
Mounting structure and foundation cost	Cost is lower due to lesser weight of polymer post insulator
Design for similar technical needs	Compact design, space saving, lower weight

The benefits of composite insulators have been realized widely across and their use is rapidly increasing in line insulation system, substation applications of post, isolator, hollow core in current/voltage transformer, circuit breakers, etc. Currently the use of silicone rubber insulating material for high voltage station post application is on a significant increase worldwide with few hundred thousands already installed. The countries like China, UK, Russia, Slovenia, Germany, Sweden, New Zealand are among them.

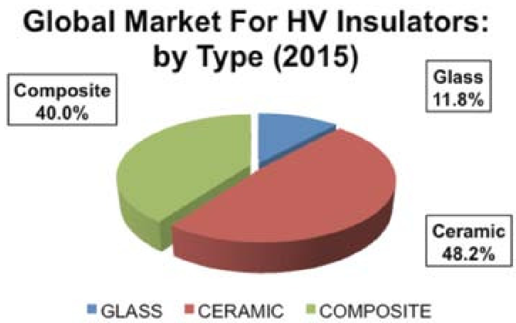

Figure 1: Recent survey on use of different insulating materials demonstrate the rapid growth of composite use globally [1]

III. THEORY FOR ANALYTICAL METHODS

The mechanical design of composite post insulator is rather more complicated compared to composite long rods. The analytical method is based on conventional beam bending theory. This methodology can also be used to calculate the maximum deflection of the insulator at the point of application of load. The formula for the maximum deflection *f* of a post insulator of length *L*, rod diameter *D*, modulus of elasticity *E*, and subject to the load F_b, is given by:

$$f = (F_b * L^3) / (3 * E * I)$$

In the above formula *I* represents the moment of Inertia which for the circular rod cross section will be

$$I = \pi * D^4/64$$

To give a realistic idea of the levels of deflection as an example, we can consider 66 kV, 4 kN post insulator of typical length 770 mm, & *E* value of 54 GPA.

At a maximum operational/working load of 1.6 kN, which is 40 % of SCL, the maximum deflection for the above will be theoretically 10 mm.

IV. STATIC & DYNAMIC LOAD ANALYSIS – DESIGN, SIMULATION vs ACTUAL

The silicone composite post insulator is typically subjected to conductor weight primarily contributing for the static loading. Design and modelling of composite post insulator requires extensive considerations on the mechanical and electrical aspects to ensure it meets all the requirements. Numerous simulations were carried out using Finite Element Modelling software (ANSYS) to understand the mechanical characteristics of deflection under static load.

Table 2: Comparison of simulated vs actual levels of deflection variation in terms of percentage.

Voltage	*kN*	*% difference in deflection between ANSYS simulation & actual values*
66 kV	2	3.5
	3	0.3
	4	1.7
132 kV	4	0.8
	6	4.3
220 kV	2	4.1
	4	4.3
	6	2.4
	8	1.4

Table 2 shows the details of the percentage variation between the simulated deflection and actual deflection. Different geometry loads were modelled for various ratings and simulations of deflection were observed to be within 5 % of actual measured deflection which is well within acceptable range as per textbook guidelines.

Dynamic loading:

Silicone Composite Post insulators are subjected to dynamic loading when externally subjected to wind, vibrations induced by wind, ice loading and so on. The objective is to study Composite Station Post Insulator's mechanical response (deflection) during short circuit. The basic force by unit length between infinitely long conductors provides in most cases an overly conservative estimate of the maximum force that will occur in practice. Many inherent hypotheses underlying this equation are not realistic in practice. Infinite conductor length is assumed: in practice, the conductors are of finite length. The peak current is considered as twice the RMS value; in practice, the peak current is function of the time constant of the circuit. It is assumed that the structure responds instantaneously to the electromagnetic load and reaches its maximum response at the same time the current is at its peak. However, in practice the maximum response of the structure is attained after the current has reached its peak value, due to the flexibility of the supporting structure and of the conductors themselves. The contribution of damping of the insulator, supporting structure and conductors is significant in these conditions.

Based on the above mentioned points the corrected basic force equation

$$Fsc\_corrected = D_f^2 * K_f * F_{sc}$$

where: D_f *is the half-cycle decrement factor*
K_f *is the mounting structure flexibility factor,*
F_{sc} *is the basic force Equation*

Due to the DC decreasing component, the maximum force on the conductor will theoretically occur in the first half cycle of fault current if the dynamic response of bus and supporting structure is not taken into account. The actual correction when maximum conductor span deflection occurs is usually less because most conductor spans will not reach maximum deflection until after the first quarter-cycle. Additional current decrement occurs as the fault continues for low *X/R* ratios. The combination of these two factors results in a lower maximum deflection than the deflection caused by steady-state force equal to the maximum force in the first quarter cycle. Tests have demonstrated that conductor spans with natural frequency of *1/10* of the power frequency or less, and in a system with an *X/R* ratio of *13* or less, will have fault current forces that is typically less than one half the calculated first half-cycle force when the conductor span reaches full deflection

In order to simulate the dynamic loading conditions, CIGRE model as shown in Figure 2 was taken as reference [10]. Figure 3 shows the modelling for 132 kV insulator with a 10m conductor on top. Figure 4 shows the momentary deflection and also confirms that it settles down very quickly in less than a second. Similarly Figure 5 shows the modelling for 220 kV post insulator with conductor of 13m on top of it. Figure 6 indicates the momentary deflection.

Simulation (Figures 4 and 6) showed positive results with damping of the oscillations at a very short time highlighting the stability of silicone composite post insulators. It is to be noted that simulation was performed for extremely worst-case scenario with a very long conductor alone on top of the post insulator. In actual substations there are several equipments which are connected to the post insulator further restricting the movement that arise during dynamic conditions. To further confirm this point, it was decided actual laboratory testing with severe short circuit conditions will be performed. This is discussed in-depth in Section V.

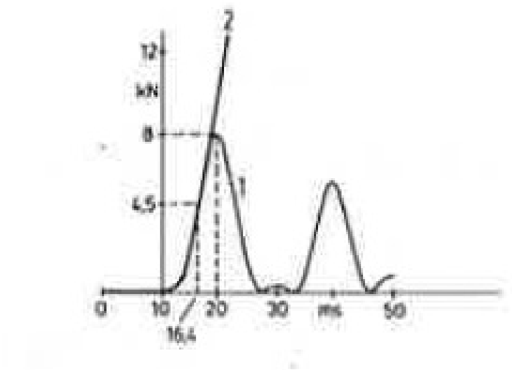

Figure 2: CIGRE model used for dynamic loading

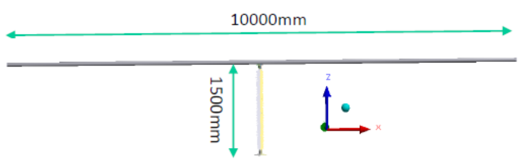

Figure 3: 132 kV post insulator modelled with a conductor of length 10m on top

Finally, to understand the influence of wind at various speed levels calculations were made as per STD: 605-2008; IEEE Guide for the Design of Substation Rigid Bus structures. Table 3 shows the summary of the results for wind speeds of 100 km/hour and 200 km/hour for various ratings of the post insulator.

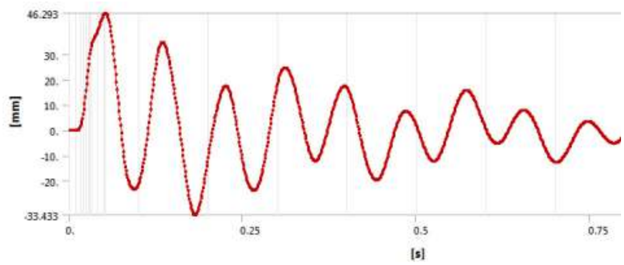

Figure 4: Simulation results of subjecting 132 kV post insulator for CIGRE model dynamic loading

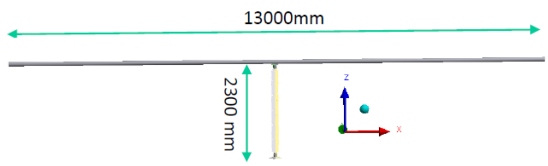

Figure 5: 220 kV post insulator modelled with a conductor of length 13m on top

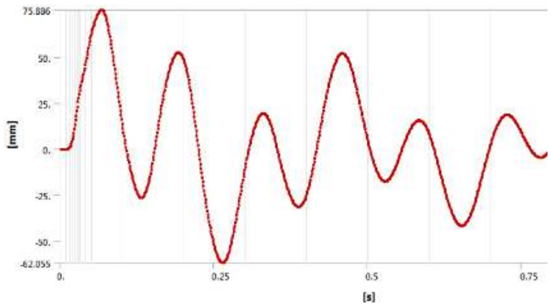

Figure 6: Simulation results of subjecting 220 kV post insulator for CIGRE model dynamic loading

Table 3: Influence of wind force on post insulator

Rating of Station Post Insulator	Wind Force on Insulator in kN, at wind speed of 100 km/hr	Wind Force on Insulator in kN, at wind speed of 200 km/hr
132 kV, 6 kN	0.18	0.63
220 kV, 8 kN	0.25	1.0
400 kV, 8 kN	0.43	1.69

V – Short Circuit Tests

In order to ensure the tests are very realistic of the actual sub-station arrangement, the size of the bus bar, the spacing between bus bars, spacing between the composite bus post insulators were chosen in line with substation arrangement. The fault levels were chosen considering futuristic requirements. Typically for 132 kV the fault level is 31.5 kA and for 220 kV it is 40 kA in existing design. However, for testing purposes fault level of 40 kA was applied for one second for the 132 kV system and 50 kA for one second was applied for the 220 kV system. Figs. 7 to 12 show the testing schematic and pictures of pre and post short circuit tests for 132 kV and 220 kV silicone composite post insulators.

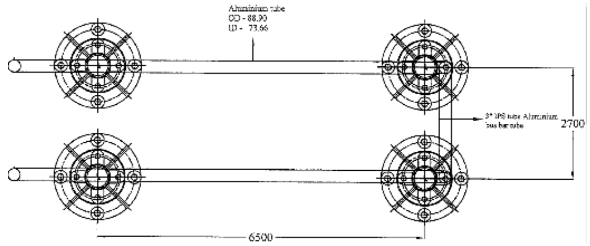

Figure 7: Testing schematic of 132 kV post insulators

Figure 8: Pictorial testing arrangement of 132 kV post before short circuit test

Figure 9: Post short circuit testing of 132 kV post.

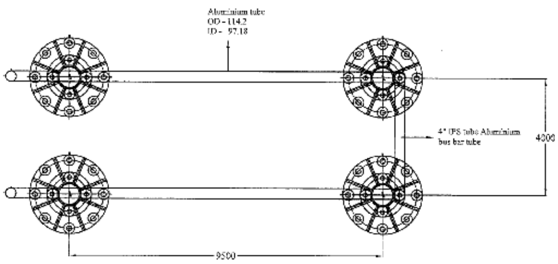

Figure 10: Testing schematic of 220 kV post.

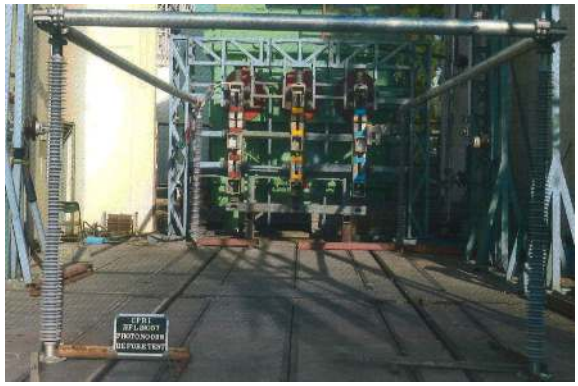

Figure 11: Testing arrangement of 220 kV post before short circuit test

Figure 12: Post short circuit testing of 220 kV post

Table 4: short circuit test results

Rating	Insulator number	Deflection (mm)
132 kV	1	5
132 kV	2	3
132 kV	3	3
132 kV	4	6
220 kV	1	5
220 kV	2	1
220 kV	3	0
220 kV	4	1

Inference from test results:

The short circuit tests evidently confirmed that composite post insulators exhibit excellent stability under extreme conditions of short circuit. The maximum levels of the permanent deflection was 6 mm. These results further confirm the CIGRE publication claim of positive aspects of composite post insulators in short circuit loading [11].

VI. CONCLUSIONS

Deflection level of composite station post insulator for different ratings were modelled under both static and dynamic loading. The model results and actual results of static deflection was observed to be very close. CIGRE published model for dynamic loading was used to simulate the composite post insulator's dynamic response. Actual short circuit tests showed, the deflection levels were extremely minimal and confirming excellent response of composite post insulator for short circuit loading. Based on numerous positive attributes of composite post it is expected to dominate the world market in near future.

VII. ACKNOWLEDGEMENTS

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