MARCH 13 – 14, 2014
CHAMONIX – FRANCE
International Lightning Protection Association Symposium

Lightning Protection @ Burj Khalifa, Dubai.

Technical **P**aper

Sonjib **B**anerjee
(Member IEEE, CIGRE, NFPA, CBIP)
Manav **G**roup **o**f **C**ompanies
Middle **E**ast **C**hapter
Dubai
sonjib.banerjee@gmail.com

This paper deals with LPS as implemented at the Burj Khalifa, the tallest structure in the World. The LPS amalgamates the advantages of Early Streamer Emission systems and Passive Air Termination systems to safely dissipate the lightning using structural steel. The piles and peripheral earth pits which are treated with permanent earth enhancing compounds provide effective dissipation of lightning.

I. Design Concepts

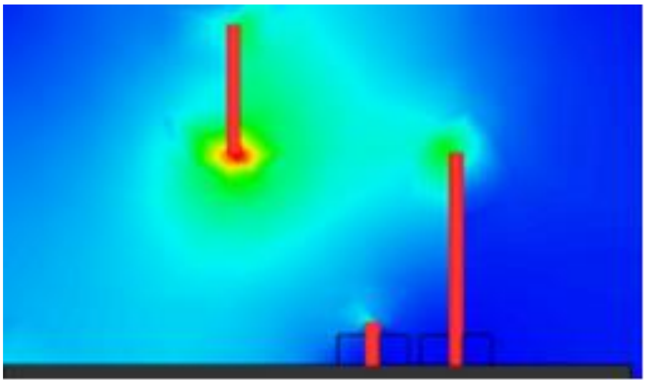
Detailed environmental data, dimension of the structure, Isochronic number of the location, Geometry of structures in the vicinity enabled the calculation of probability strike at various levels of the humongous structure. An appropriate combination of LPS was then designed and accepted by Mr. John Walker of Hyder Consultants and other relevant bodies.

A. Clouds in UAE

Stratus, Cumulis Humilis, Cumulis Mediocris and Nimbostratus which may occur at heights between 500 – 2000 m in UAE, appear to be touching the intermediate levels of the Burj. Of the above-mentioned clouds, only the Nimbostratus clouds may show the property of precipitation and involve low intensity lightning. The remaining low level clouds are either too fragmented or an extension of a high level fog. There is no danger of a flash-over to the tower from clouds other than Nimbostratus clouds.

The charges of the Nimbostratus clouds which come in contact with the building shall get grounded due to solidly grounded steel structure and equi-potential bonding. The real lightning hazard is from Class B (Middle Level) and Class D (Vertical) Nimbostratus clouds. These clouds start from 2000 m and can go a few thousand meters high based on the upward thrust of hot air which is prevalent in the region. Hence, in case of any static discharge on Burj Khalifa, an over whelming percentage of the discharges shall be at the top of the structure as envisaged in NFC, BS and NFPA.

The photograph shows the static field distribution, interaction and overlap that occurs from the topmost point of the Burj.

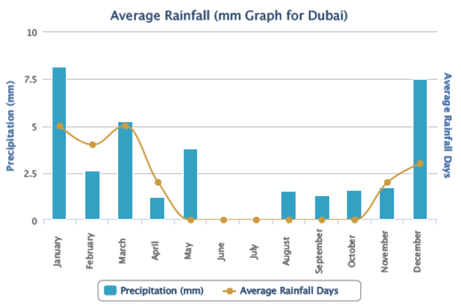


B. Metrology & Seismology Data from NCMS UAE

During winter, cold and dry North Easterly winds called "Elnashi" and North Westerly winds called "Shamal" brings temperature down causing strong wind and rain. The amount and frequency of rainfall vary significantly. During spring, rain and thunder storm can appear through an active weather over the Northern Gulf.

The summer may see thunderstorms develop on Hajar Mountains due to side effects of the Indian monsoon over Oman Sea causing local instability.

During September, early morning fog is noticed. November may see extensive clouds.



C. *Dimensional Challenges of the Burj Khalifa*

The Burj Khalifa is approx. 828 m tall, having a length of approx. 216 m and a width of approx. 189 m. It is an isolated structure in the vicinity of other towers having a height of approx. 80 to 150 m. The entire structure is built around a core with an onion peel support system balancing the massive structure from wind stress.

The design of Burj Khalifa is derived from patterning systems embodied in Islamic architecture. The spiral minaret coils and grows slender as it rises. The Y-shaped plan is ideal for residential and hotel usage, with the wings allowing maximum outward views and inward natural light. As the tower rises from the flat desert base, there are 27 setbacks in a spiraling pattern, decreasing the cross section of the tower as it reaches towards the sky and creating convenient outdoor terraces. At the top, the central core emerges & is sculpted to form a finishing spire. At its tallest point, the tower sways a total of 1.5 m.

The unprecedented height of the building, is supported by buttressed core which consists of a hexagonal core reinforced by three buttresses that form the ‘Y' shape. This structural system enables the building to support itself laterally and keeps it from twisting.

The spire of Burj Khalifa is composed of more than 4,000 tons of structural steel. The central pinnacle pipe weighs 350 tons. It was constructed from inside the building and jacked to its full height of over 200 m (660 ft). The spire also houses communications equipment.

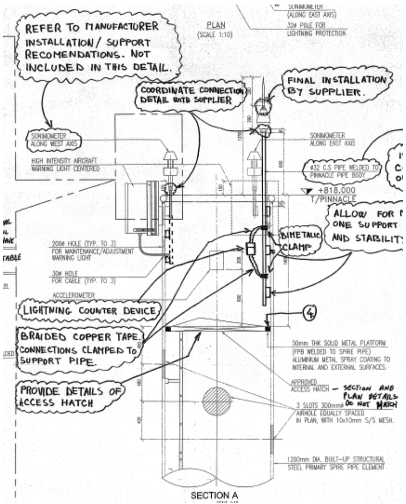
D. *Lightning Protection System*

The lightning protection system comprises of air terminal, down conduction and Earthing.

1) *Air Terminal*

The air termination system used at the pinnacle is an ESEAT-SATELIT 3 60 manufactured by Duval Messien, France. This system receives the maximum brunt of the lightning on the Burj. There have been approx. 18 discharges on the unit since the time of installation. The unit was brought down for a thorough check and physical inspection before being reinstalled.

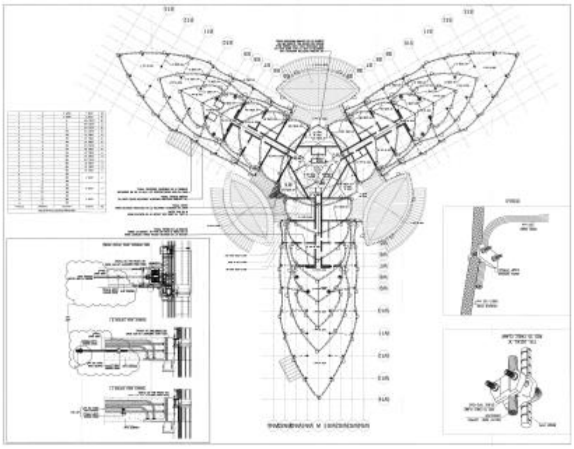
The side flashes are protected by Satelit 3 system along with the Class 1 mesh protection created by the metallic frame of the Façade. The Satelit 3 system is installed on a mast which is directly welded to the metallic structure. A Duval Messien lightning counter is installed to count the no of lightning flashes. The pinnacle assembly drawing shows the Installation details.



On a lighter note, dignitaries often scale the pinnacle to touch and feel the very tip of the Burj Khalifa

2) Down conductor

The metallic frame of the façade forms the external spatial shield whereas the column reinforcement forms the internal spatial ring. The external and internal spatial rings are bonded to form an equi-potential zone as per BSEN 62305 part 3. The effective earthing and bonding has been carried out by M/s Furse, UK. A snap-shot of the bonding is detailed as under.



3) Earthing System

The earthing system comprises of pile earthing and treated earth pits.

a) Pile earth

The pile earth should comply with Clause 14.6 of IEEE 80 2000 in order to effectively dissipate energies of the surge without heating the concrete. Ollendroff formula gives the effective dissipation of current through each pile.

b) Treated earth pits

TEREC+ artificial treatment compound has been suitably modified to form an effective curec slurry as per clause 14.5 (d) of IEEE 80 2000. Some earth pits use the SIGMA EARTH technique to create reflection free earthing to achieve low resistance even in harsh soil conditions.

Cross-section area as per equation 37 of IEEE 80 2000, surface area of conductor in touch with soil as per clause 15 of BS 7430 1998 and potential gradients on the ground as per clause 16.2 of BS 7430 1998 had to be followed.

4) Lightning Risk Analysis based on BSEN 62305 Part-2

The probability of lightning strike was calculated at various levels of the tower and a detailed risk analysis was performed as per BS6651 1999. The risk analysis of the structure as per the current BS EN 62305 Part-2 is as follows:

Calculated Risks

	Tolerable Risk (RT)	Direct Strike Risk (RD)	Indirect Strike Risk (RI)	Calculated Risk (R)
Loss of Human Life	1.00E-05	7.26E-06	2.77E-07	7.54E-06
Loss of Public Service	1.00E-03	0.00E+00	0.00E+00	0.00E+00
Loss of Cultural Heritage	1.00E-03	2.90E-06	1.11E-07	3.01E-06
Economic Loss	1.00E-03	2.90E-05	1.11E-06	3.01E-05

Conclusion: STRUCTURE IS PROTECTED

SUGGESTIONS TO PROTECT THE STRUCTURE AGAINST LIGHTNING:

Type of Loss	Tolerable Risk	Solution for Input Data			Suggestion - 1	
		Protection Measures	Calculated Risk	% of Risk	Protection Measures	Calculated Risk
Loss of Human Life	1.00E-05	LPS of Metal roof and a reinforced concrete framework, Co-ordinated SPD of Class I at incoming power line, Co-ordinated SPD of Class I at the telecom line with Shock Protection measures of Effective soil equipotentialization; Warning notices; Reinforcement of structure used as down-conductor; and Fire Protection measures of Hydrants; Fire proof compartments; Protected escape routes; Fixed automatically operated extinguishing installations; Automatic alarm installations	7.54E-06	075%	LPS of Metal roof and a reinforced concrete framework, Co-ordinated SPD of Class I at incoming power line, Co-ordinated SPD of Class I at the telecom line with Shock Protection measures of Effective soil equipotentialization; Warning notices; Reinforcement of structure used as down-conductor; and Fire Protection measures of Hydrants; Fire proof compartments; Protected escape routes; Fixed automatically operated extinguishing installations; Automatic alarm installations	7.54E-06
Loss of Public Service	1.00E-03		0.00E+00	000%		0.00E+00
Loss of Cultural Heritage			3.01E-06			3.01E-06
Economic Loss			3.01E-05	003%		3.01E-05

E. Installation Challenges

Burj Khalifa, at the time could be mechanically accessed up to approx.. 620 meters. Rest of the height, (approx. 200 meters) had to be climbed using monkey ladders. Resting ring at intermediate heights provided the necessary relief to the commissioning team.

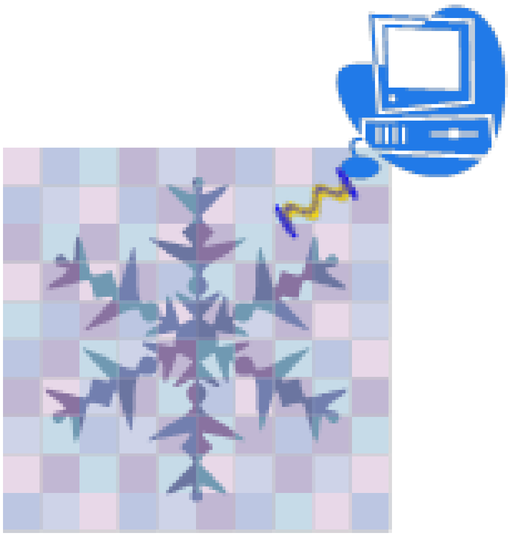
A 1.2 meter diameter primary spire element needed to house 3 High Intensity Aircraft warning lights, 3 Sonimometers and a Satelit 3 system. With tremendous space restriction, the Satelit 3 was mounted on to a 32mm CS pipe that was directly welded to the Pinnacle body at multiple places to avoid fatigue. The lightning counter had to be mounted parallel to the Pipe using a braided copper tape that was clamped to the mounting pipe using Bimetallic clamps. It was one of the most challenging ESEAT installations in the world.

The installation was carried out in very tight place. A commission team comprising of Mr. Pankaj Dixit and Mr. Arun Kumar Bhat from Manav Enterprise Middle East FZCO successfully commissioned the Satelit 3 system experiencing structural sway of approx. 1.0 mt at the top due to wind. The

Satelit 3 system, along with the PATS today protects a vertical city.

F. *Advancements in LPS and ES for Future Towers*

It is becoming obligatory to connect LPS and ES to the BMS or BIS of the towers. A significant development has been made in the world in this regard. These systems are already under trial for various applications. IP connectivity helps these systems to be used for conditioned monitoring enabling preemptive actions to save life, livestock and assets



II. CONCLUSION

The use of ESEAT in conjunction with PATS forms an effective air termination defense from descending lightning. Down conductors along with structural reinforcements keep all the components of tower at equi-potential. The piles and peripheral earth ring can effectively discharge faults or surges. Safety is achieved through design. Products can form only a component of a safe design.

Technical organizations like the Manav Group provides end-to-end solutions for safe-guarding structures from damaging effects of electric and magnetic fields through effective lightning protection systems, static compensation systems and safe earthing solutions. The end-to-end solution must encompas audit, design, supply, installation and commissioning as per International Standards compliant to local regulatory requirements.

III. TERMINOLOGY & ABBREVIATIONS

Term	Description
ESEAT	Early Streamer Emission Air Terminal
PATS	Passive Air Terminal System
FCS	Faraday Cage System
LPS	Lightning Protection System
EP	Earth Pit
PEC	Permanent Earth Enhancing Compound
UAE	United Arab Emirates
NCMS	National center of Metrology and Seismology of UAE
ES	Earthing System
BMS	Building Management System
BIS	Building Intelligence System

IV. REFERENCES

Document	Document No./Location
Protection of structure & open area against lightning using active air terminal	NFC 17 102 2011
British Standard: Protection against lightning	BSEN 62305
Standard for the Installation of Lightning Protection Systems	NFPA 780
IEEE Guide for AC	IEEE 80 2000
IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems	IEEE 142 1991
IEEE Recommended Practice for Powering & Grounding Electronic Equipment	IEEE 1100 2005
IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems	IEEE 81-2-1991
IEEE Guide for Generating Station Grounding	IEEE 665 - 1995

.