ID – 10757 Session 2022
B2 Over Head Lines
PS 1 / Challenges & new solutions in design and construction of new OHL

Field & laboratory Assessment of Room Temperature Vulcanizing Coated Insulators in Harsh Desert Environment

Raouf ZNAIDI *
Consultant
Tunisia
raouf.znaidi@gmail.com

Ahmad Al-THAGAFI
GCCIA
KSA
athagafi@gccia.com.sa

Abdellah BOUCHTI
OMEXOM
KSA
abdellah.bouchti@omexom.com

SUMMARY

In spite of lack of basic international Standards and very limited substantial field studies dealing with high voltage insulators coatings (HVIC), this past decade has "unpredictably" shown a sharp growth & huge use of RTV silicone & Liquid Silicon Rubber (LSR) coatings as well as on Overhead Transmission Line (OHTL) & Substations.

Among the main reported objectives, we can list mitigating pollution-related flashovers of glass & porcelain insulators, that suffer poor pollution performance due to inappropriate selection or insufficient self-cleaning properties of insulators in the one hand, and to optimize fast increasing of OHTL & Substations maintenance costs, in the other.

Such a preventive solution, more & more adopted in The Gulf region, can be technically justified by a range of several advantages, including the combination of high mechanical performance and long-term stability of traditional glass and porcelain insulators with all the advantages of Hydrophobicity Transfer material "HTM", water repellency as well as high pollution performance provided by silicone rubber material & fillers, generally leading to nearly suppressing high leakage current along insulator surfaces and minimizing heating & surface degradation due to superficial discharges.

In complement to last published Gulf Cooperation Council Interconnection Authority (GCCIA) Papers at GCC Power & Cigre Paris, this intensive field & laboratory works, conducted by GCCIA working Group, intend to assess natural ageing & attempt to estimate operating life of 3 different Silicone rubber coating of open profile removed from the Certified (ISO 9001-2015) "GCCIA Naturally polluted insulators testing Station" built at Al Fadhili site, one of the most representative area of severe service conditions in Eastern KSA.

KEYWORDS

HVIC, insulators open profile, RTV Sir, test station, natural ageing, correlation**,**

1. Introduction:

Nowadays It`s worldwide established that for any given high voltage system voltage, insulators coated with new RTV silicone rubber will withstand higher levels of pollution contamination than can do uncoated insulators.

These obvious finding have been noticed both in the laboratory as well as in the field during first years of service, but the key question is how about the excellent initial Hydrophobicity as well as pollution withstand performance & chemical stability of RTV silicone rubber after some years in service in harsh polluted conditions like prevailing in all MENA region?

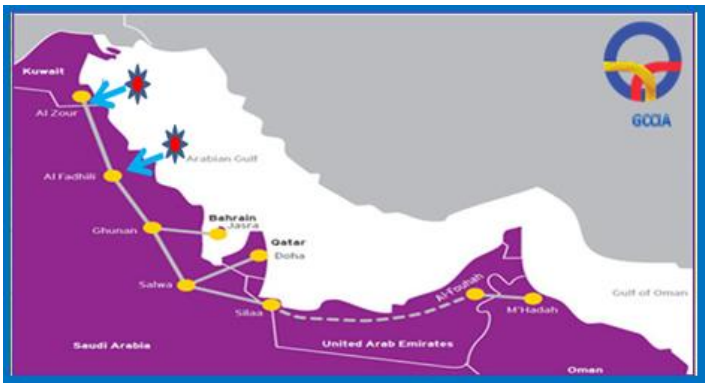
This present paper intends to assess natural service ageing first & to estimate after the “Operating” Life of 3 different Silicone rubber formulation used for coating cap & pin aerodynamic Insulators, removed, after 3 years in service, from the Certified GCCIA Naturally polluted insulators testing Station located at Al Fadhili in Eastern KSA.

The second objective of this original field work and targeted laboratory tests is to search the so expected correlation between natural ageing and Partial loss of Hydrophobicity of these different RTV silicone rubber coatings in harsh desert environment.

2. GCCIA’s Network Maintenance Strategy: Reliability and cost optimization.

GCCIA’s Network Maintenance Strategy & its logic chaining concept, since 2014, is widely based on Cigre Technical Approach for selecting the most suitable candidate insulators in Polluted conditions. Starting with global diagnosis of its Network and resulting in the main following results achieved:

2.1. Building of two Energized Naturally Polluted Testing Stations Insulators test stations, Now Certified ISO 9001 & internationally recognized as reference (in the last Cigre TB 837/June 2021). The Pilot one is located at Al Fadhili-Eastern KSA & the second at Al-Zour–Southern Kuwait, both equipped with preselected different insulator candidates…as shown in Fig.1, 2, 3 & 4.



(a)

(b)

(c)

(d)

Fig.1-2-3 & 4. Location of "Certified ISO" GCCIA Naturally Polluted Insulators Testing Stations: (a) - GCCIA 400KV Energy Highway Interconnecting Six GCC Member States, (b) - ISO Certificate, (c) - Al Fadhili (KSA) & (d) - Al Zour (Kuwait).

2.2. Testing & Ranking by order of merit of different Ceramic & Non ceramic Insulator Material & Shape & Silicone rubber Coatings,

2.3. Selection of Open profile & outer rib Ceramic insulators & alternating sheds for Composite insulators as the best ranked profile in Eastern KSA,

2.4. Site Pollution severity estimation,

2.5. Establishment of Pollution Map of GCCIA Network & regular updating,

2.6. Optimization of "HVIC" Silicone rubber coatings for insulators, including:

- Assessment of spraying application techniques (overspray..),
- Adhesion tests namely 100 H boiling tests & Cross cut tests according to IEEE 1523/2018 & ISO 2409.
- Optimal Thickness of Silicone rubber,
- Original Sand Blasting Tests,
- Half coated VS Fully coated insulators (Cost optimization is proved) ,
- "Natural" Ageing tests,
- Ranking by order of Electrical performance of 3 Types of Silicone rubber coatings,
- Estimation of operating life of 3 different type & formulation of Sir coating…

3. Ongoing GCCIA Works & Next upcoming papers will cover:

a. Comparison between different Application Techniques, namely Spraying, Dipping, Automated systems, Compression.
b. Estimation of Loss & Time Recovery of Hydrophobicity of different preselected Silicone coating,

c. Field assessment of RTV silicone coatings resistance to the effect of high UV radiation and tracking and erosion.

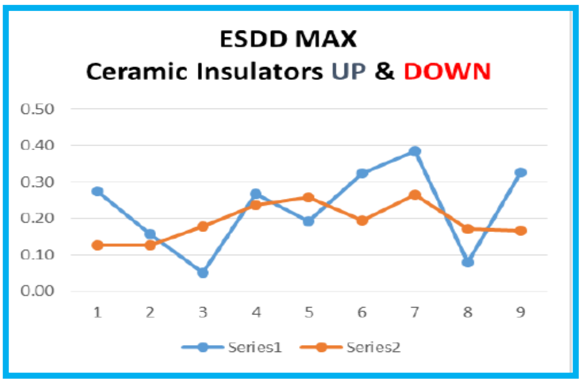
d. Selection of suitable silicone rubber for GCC Region...

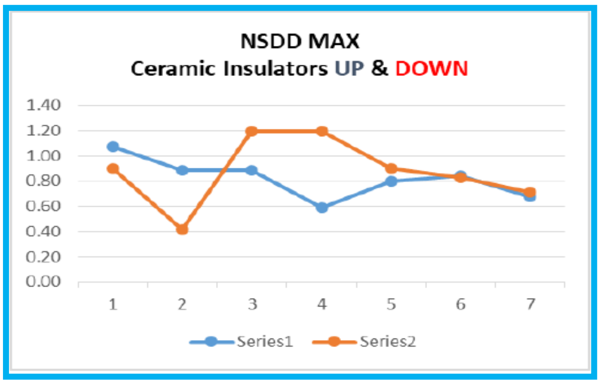
4. Site Pollution Severity Estimation & Pollution Characterization:

Based on more than three hundred (300) Equivalent salt deposit density (ESDD) & non-soluble deposit density (NSDD) Measurements, in contact in test station (fig.5) as well as on GCCIA overhead lines, four (04) times a year during three successive years, completed by chemical analysis of soluble & non soluble pollution contaminants removed from top & bottom surfaces of different insulator types & profiles including Standard insulator, as international reference, it was concluded that Eastern KSA's environment is mostly characterized by:

- Solid Pollution "Type A", due to high level of non-soluble pollution contaminant,
- High ESDD & NSDD level in the range of 0,4 mg/cm² & 1,2 mg/cm² respectively corresponding to "high solid pollution class, according to IEC 60 815/TS ", as shown in table 1&2.
- The high proportion of very conductive & corrosive Sulfur in dissolved pollution contaminant collected from candidate insulator surface in Al Fadhili testing station, as shown in table 3.

Fig 5: Site Pollution Severity estimation with ESDD/NSDD Method





Tables 1 & 2: Highest ESDD & NSDD on Different Ceramic insulators candidates

Chemical Element	Si silicon	Fe iron	Al aluminium	Ca calcium	K Potass.	Mg Magn.	Na sodi	Ti titanium	Zn zinc	S Sulfur.
Natural Pollution collected from top insulat. surface (in mg/l)	**3.4**	*36.2*	*168*	*31*	*3.14*	*29.7*	*6.7*	*0.7*	*9*	*3*
Natural Pollution collected from Down insulat. surface (in mg/l)	**0.7**	**396**	**342**	**1982**	**64**	**387**	**18**	**6.3**	*15*	*931*

Table 3. Chemical analysis of Pollution contaminant collected from top & bottom insulator surfaces.

5. Ranking By Order Of Merit & Selection Of Suitable Insulator Shapes

Today, Based on the main outcomes of the above mentioned ESDD & NSDD measurements and ranking by order of merit, in terms of self-cleaning abilities of more than 13 Different candidate Ceramic & Non Ceramic Insulator types, in Al Fadhili Naturally Polluted Insulators Testing station [1 & 2], **we are able to confirm that the OPEN PROFILE also called aerodynamic and double outer disc/rib type insulators with long spacing are the most suitable geometrical insulator profile for Eastern KSA.**

6. Natural Ageing of HV Insulators coated with RTV silicone rubber under Heavy Solar Radiation & Sand Blasting:

In complement to our previous GCCIA works and published papers [3 & 4], where we have attempted to answer targeted Power Utilities questions about the Optimum Thickness of RTV silicone Coating & the Impact of Sand Blasting On HVIC candidates, today within GCCIA strategy & its chaining procedure **we intend to answer another important Question regarding Natural Ageing of HVIC and the assessment of different RTV silicone rubber formulation under both Heavy Solar Radiation & Sand Blasting in Eastern KSA.**

6.1. Assessment Of HVIC Natural Ageing in The Laboratory:

Two lots, first one naturally polluted & second one new of the best ranked coated ceramic insulator profile, mostly open profile discs due to their excellent self-cleaning abilities in desert environment, have been submitted to electrical performance tests with the view to assess the natural ageing (residual performance) of their different RTV Silicone coating RTV1, RTV2 & RTV3 in comparison with not aged insulators coated with the same formulation.

6.1.1. Testing Method & procedure:

The internationally proved Rapid Flashover method "RFO", mostly based on Cigre TB 455/481 & 142 and especially on last TB 691/2017 [5] and partly on IEC 60 507 (solid layer method) [6], has been selected for electrical performance assessment of the above mentioned naturally polluted coated insulators, removed from Al Fadhili testing Station after 3 years in service.

✓ **Preconditioning Test:**

Each String Insulators of 3 ceramic discs have been be submitted to a preconditioning period of 20 minutes.

The voltage at this stage is about 90% of the already estimated flashover voltage.

After this conditioning period, the test voltage will be raised in 5% increments, and kept for one minute at each level, until flashover. After flashover, the coated insulator is re-energized (after a short break) at its initial voltage (90%) and the process has been repeated until 3 obtained flashovers. This part of the procedure finishes the conditioning of the insulator, as shown in Fig.6.

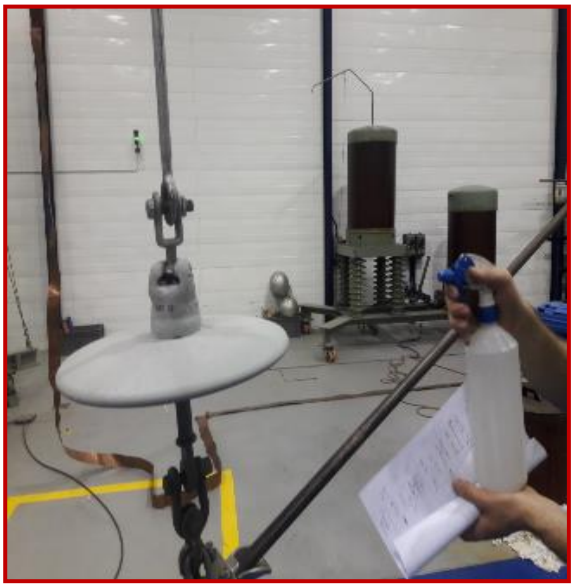


Fig 6. Preconditioning test **Fig.7. Electrical Performance tests**

✓ **"RFO" Method: Testing Procedure:**

- Checking of Temperature & relative Humidity of testing Hall, before each test lot,
- All individual RTV coated Insulator Disc (single disc for our case) has been tested in vertical position, as shown in Fig.7.
- With the view to simulate as close as possible the early dew impact on outdoor insulation all top & bottom tested insulator surfaces have been manually wetted, using distilled water spray, before and after each RFO test (Distance between spraying bottle and insulator disc should be in the range of 15-20 cm).
- Hydrophobicity class estimation has been simultaneously checked before and after each RFO tests,
- 90% of the average of 3 obtained FO Voltage values during preconditioning tests has been applied to the insulator as a reference voltage,
- The test voltage is then raised by a smooth ramping process about 5% of flashover voltage every 3 minutes until flashover,
- Leakage or current impulses have been partly monitored and Critical highest current impulses (generally before FO), have been registered,
- The relevant value of this RFO tests is characterized by the mean of 3 successive FO voltage values for each disc,
- Maximum total test duration should do not exceed 100 min.

6.2. Main Laboratory testing Results:

6.2.1. Aged Insulators VS Not aged Insulators:

a. Case of Fully coated insulator with RTV silicone rubber "RTV1".

As shown in Tables 4 & 5, the residual electrical performance tests of naturally aged insulators, fully coated with silicone rubber RTV1, are in the range of 40kV while the average of FO voltage for Not aged insulators coated with the same RTV1 were in the range of 56 kV corresponding to a decreased performance in the range of 29%, after 3 years in energized test station (fig.8).

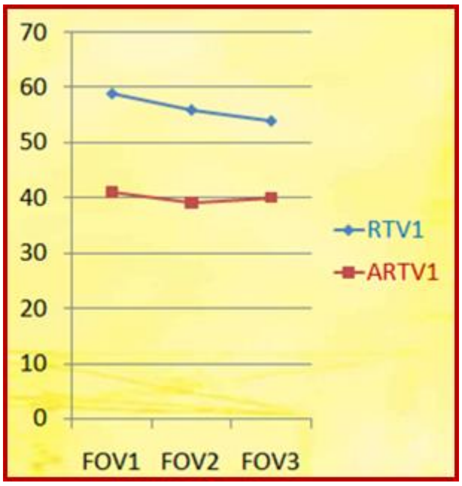
In addition, the partial losses of initial hydrophobicity (HC1 for new coated) have been also demonstrated after each flashover (HC2).

	FOV1 kV	FOV2 kV	FOV3 kV	Av. KV	HC1
Disc V1. 1	61	59	57	59	1
Disc V1.2	57	54	56	56	1
Disc V1.3	51	56	56	54	1

Table 4. Not aged fully coated insulators

	FOV1 kV	FOV2 kV	FOV3 kV	Av. KV	HC2
Disc V 1 A1	57	33	33	41	4
Disc V1 A 2	53	32	33	39	6
Disc V1 A3	40	42	38	40	5

Table 5. Naturally Aged fully coated insulators



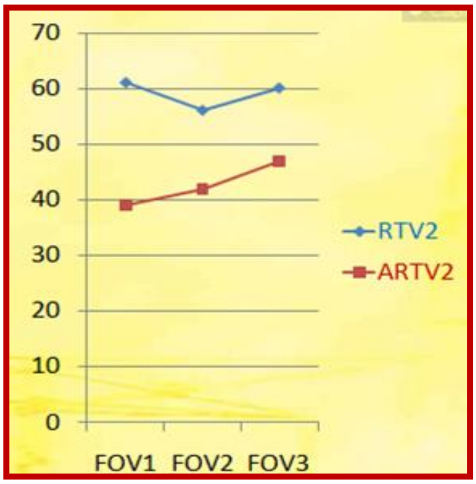


Fig.8 & 9. Significant decline of electrical performance of naturally aged RTV1 & RTV2 coating.

b. Case of Fully coated insulator with RTV silicone rubber "RTV2".

As shown in Tables 6 & 7, the residual electrical performance tests of naturally aged insulators, fully coated with different silicone rubber formulation RTV2, are in the range of 43kV while the average of FO voltage for Not aged insulators coated with the same RTV1 were in the range of 59 kV corresponding to a same decreased performance in the range of 28%, after 3 years in energized test station (fig.9).

In addition, the partial losses of initial hydrophobicity (HC1 for new coated) have been also demonstrated after each flashover (HC2).

	FOV1 kV	FOV2 kV	FOV3 kV	Av. FO. KV	HC.1
Disc V2.1	64	60	59	61	2
Disc V2.2	58	56	55	56	2
Disc V2.3	61	59	60	60	2

Table 6. Not aged fully coated insulators.

	FOV1 kV	FOV2 kV	FOV3 kV	Av.FOV kV	HC.2
Disc V 2 A1	32	35	49	39	5
Disc V2 A 2	33	41	51	42	4
Disc V2 A3	34	52	54	47	6

Table 7. Naturally Aged fully coated insulators

c. Case of Bottom coated insulator with RTV silicone rubber "RTV3".

As shown in Tables 8 & 9, the residual electrical performance tests of naturally aged insulators, 50% coated (bottom side only) with another silicone rubber formulation RTV3, are in the range of 28kV while the average of FO voltage for Not aged insulators coated with the same RTV1 were in the range of 49 kV corresponding to a same decreased performance in the range of 42%, after 3 years in energized test station (fig.10).

In addition, the monitored highest leakage currents were in the range of 240 mA while partial losses of initial hydrophobicity (HC1 for new coated) of coated bottom side have been also demonstrated after each flashover (HC2).

	FOV1 kV	FOV2 kV	FOV3 kV	Av. FOV	Av. I.h*	HCn
Disc 1–V3	52	43	54	50	65	1
Disc 2 –V3	50	43	54	49	58	1
Disc 3 - V3	55	43.5	45	48	53	1

Table 8. Not aged half coated insulators & highest Leakage current

	FOV1 kV	FOV2 kV	FOV3 kV	Av. FOV	Av. I.h.*	HCa
Disc 4 AV3	31	27	24	27	150	6
Disc 5 AV3	32	32	24	29	225	6
Disc 6 AV3	30	30	28	29	240	6

Table 9. Noticeable Naturally Aged half coated insulators & highest Leakage current

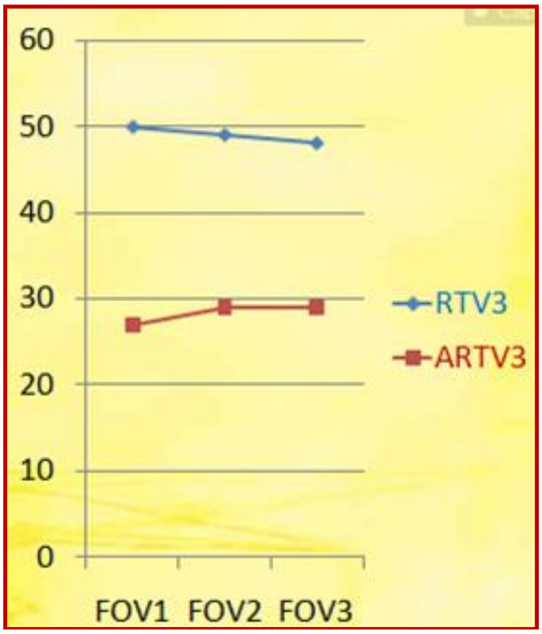


Fig.10. significant decline of electrical performance of naturally aged insulators half coated with RTV3 coating.

d. Correlation between Leakage Current (I. Highest) & Non Soluble Pollution Accumulation & Natural ageing of RTV coatings.

As Shown in Table 10, significant Correlation between Leakage Current & Site Pollution Severity (mostly NSDD) & Natural Ageing has been demonstrated.

	I. highest Not Aged	I. high Naturally. Aged	ESDD max	NSDD max.
Disc 1	65	150	0.075	0,270
Disc 2	58	225	0,078	0,358
Disc 3	53	240	0,206	0,376

Table 10. Correlation between Leakage Current (I. Highest) & Non Soluble Pollution Accumulation & Natural ageing of RTV coatings.

6.2.2. Partial Loss & Time recovery of Tested Sir Coating.

As well as for coating insulators & for polymeric insulators, It's world widely agreed by almost all Silicone rubber Sir's Specialists & Experts that "Hydrophobicity" of Silicone rubber is shown to be the key indicator of their natural aging, Fig.11 & 12 emphasize what is widely reported but not yet totally mastered at least in terms of Hydrophobicity transfer, Partial or total Loss of Hydrophobicity & then Time recovery estimation.

After visible superficial discharges by daylight, several Cap & pin 120KN insulators, removed from GCCIA Network, have showed a complete Hydrophilic states on both top & bottom sides of discs surfaces.

In an attempt to confirm if it was the beginning of end of life of silicone coating or just Partial loss issue of hydrophobicity we have performed hydrophobicity measurements after 24 H & 48 H successively on Disc 7 & 9 (removed from the same 400KV suspension string) that have showed a progressive partial hydrophobicity recovery (from HC5 & HC6 to HC4…) of their coating after 48 Hours rest in the laboratory.

Fig.11

Fig.12

6.2.3. Ranking by Order of Electrical Performance Of tested Silicone Rubber Coating & Estimation of Operating Life.

As clearly shown in tables 11, 12 & 13, a significant decrease of electrical performance in the range of 30% of 3 tested Sir Coating RTV1, RTV2 & RTV3, more especially RTV3, removed after 3 years exposure in Al Fadhili Testing station (KSA).

Ranking by order of merit Procedure, in terms of electrical performance, makes it possible to place RTV2 as the relatively first ranked followed by RTV1.

Based on linearity approach, we can attempt to estimate the average ageing factor (decrease of electrical performance) of 3 tested Sir Coating in the range of 30% after 3 years exposure to desert & industrial pollution in Naturally polluted insulators testing station & as corollary we can attempt to estimate an operating life of RTV1 & RTV2 in the range of 8-9 years average in similar environmental conditions.

U160 KN full Coated with RTV2.Type B.	AV.FO Not aged	AV.FO Aged	Ageing factor In %
	61	39	36%
	56	42	25%
	60	47	22%

U160 KN full Coated with RTV1 Type A.	AV.FO Not aged	AV.FO Aged	Ageing factor in %
	59	41	31%
	56	39	30%
	54	40	26%

U120 KN Full Coated with RTV3.Type C.	AV.FO Not aged	AV.FO Aged	Ageing factor in %
	50	27	46%
	49	29	41%
	48	29	40%

Tables 11, 12 &13: Significant Ageing ratios of tested Sir Coating.

7. Conclusions:

7.1. Interpretation & Conclusion Of Previous Works:

Based on the main outcomes of previous published GCCIA works we were able to give first answers to the main asked questions raised by Power Utility Engineers such as:

- **Site pollution Severity along GCCIA Network & in Naturally polluted insulators testing stations has been Characterized & Estimated & Ranked respectively as Solid Pollution Type "A" & as Very Heavy Pollution Class,**
- **OPEN PROFILE & outer rib Ceramic insulators in the one hand & alternating sheds for Non-ceramic insulators in the other, are the best ranked profile in Eastern KSA and therefore have been selected as the Most suitable Insulator profile for prevailing environmental & service conditions in Eastern KSA & for similar regional environment,**
- **RTV coating application using Spraying Technique leads to COSTLY OVERSPRAY & not uniform thickness on both top side & especially on bottom side of the insulator discs,**
- **Optimal Coating thickness Of RTV Coatings in the range of 280-300µm Have showed Equal Performance in Comparison With much higher coating recommended by almost all Silicone Manufacturers,**
- **No Notable Impact of Artificial Sand Blasting Tests on some RTV Coatings.**
- **Localized Partial Loss & late Recovery of RTV Silicone coating hydrophobicity have been observed after each RFO test…**

7.2. Interpretation & Conclusion of last RFO Test Results:

All First "RFO" Test Results, performed in different accredited laboratory & under the same conditions on Open Type coated Glass Insulator Discs Have Showed:

- ✓ **After 3 years exposure to combined desert & industrial pollution in energized test station, Noticeable Natural Ageing, in varying degrees, in terms of electrical performance, of 3 Types Of RTV Coating (RTV1, RTV2 & RTV3) have been observed,**
- ✓ **As an attempted of extrapolation & to answer to most popular question regarding Shelf Life of Sir Coating we can scientifically estimate that :OPERATING life expectancy* of Sir coatings RTV2 & RTV1 could be in the range of 8-9 years…,**
- ✓ **According to RFO test results performed in different accredited laboratories on aerodynamic insulators coated with 3 different Sir coating formulation Silicone Rubber RTV2 is the best ranked in terms of ageing performance,**
- ✓ **Manifest loss of initial hydrophobicity** (HC1 for not aged disc) have been clearly demonstrated after each flashover (HC2).**
- ✓ **After localized Partial loss of Silicone rubber Hydrophobicity, Progressive hydrophobicity recovery have been observed day after day,**

- ✓ **Significant Correlation between “highest” Leakage Current Impulses & Pollution accumulation (SPS) & Natural Ageing has been widely demonstrated,**

Note of Author:
(*) - More similar field & laboratory works are needed with the view to refine & to validate such shelf life estimation.
(**) - Testing on time recovery of Hydrophobicity is a major issue on the Cigre Experts’ Agenda…

8. References & Author Publication:

[1] “GCCIA Insulators Test Station II: Field Assessment & Test Station Results” R. Znaidi, A. Al Thagafi, M. Bouchti. D1-318. Cigre Paris.2018.

[2] “Maintenance Strategy Designed to Support Gulf Regional Energy Security”. R. Znaidi. INMR Journal-Q3-2017

[3] “First Assessment of RTV Silicone Coated Insulators in MENA Region”. R. Znaidi. Cigre-CBIP Conference-Nov. 12, 2018-New Delhi-INDIA.

[4] “Coating Insulators To Prevent Pollution Flashover In Kuwait” R. Znaidi. INMR Journal. N 16 –April 2018**.**

[5] Polluted Test of Naturally & Artificially Contaminated Insulators” R. Znaidi-Cigre Member & Co-author. Cigre Technical Brochure N 691- July 2017.

[6] IEC 60 507 Artificial pollution tests on high-voltage insulators to be used on a.c. systems

[7] “Expanded Test Station helps Greek Power System Operator Assess Insulator Design & performance”. INMR journal. Issue 107.Q.1.2015.

[8] “Outdoor Insulation in polluted Conditions: Guidelines for selection & dimensioning. Part.2: The DC Case” Cigré Working group C4.303. Co-author.

[9] “Moroccan Power Utility adjusts Priorities to new Network Challenges” INMR Journal. Issue 98.Q4.2012.

[10] “Algerian Grid focuses on challenges of Harsh Service Environment” INMR journal. Issues 96 & 97 Part 1 .Q2.2012 & Part II. Q3. 2012.

[11] “Turkish Transmission Utility Looks to silicone Insulators to Reduce Construction & Maintenance Cost “INMR. Journal.Q.1.2012.

[12] “Qatar Power Grid faces Combined Challenges of Pollution & Rapid Expansion”. INMR journal.Q.2.2011.

[13] “Outdoor Test Station: Optimizing tool for Insulator selection & Maintenance”. 2011 INMR World Congress. Seoul. Korea.

[14] “Expanding Grid in Pakistan Confronts Challenges of Pollution, Icing & Lightning-Parts 1 & 2. INMR -5-2019.