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World's Lightest & Slimmest 380 kV Porcelain Long Rod Insulators for Ultra-High Pollution Levels

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Background – Design Standardisation Project

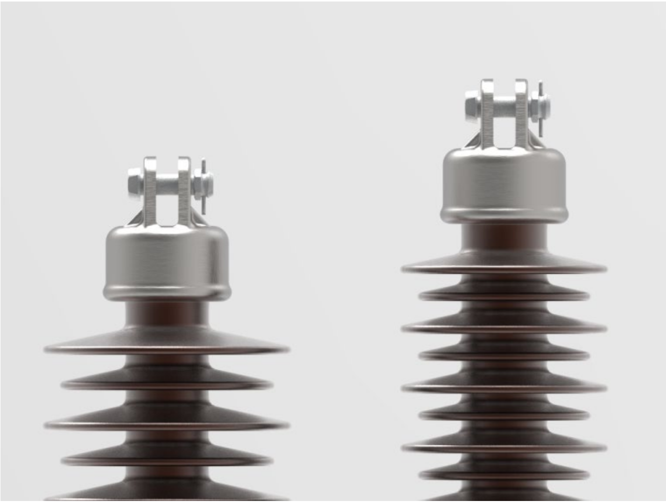
- Aim >

  Investigate operational performance of two variants (*termed as generation I for old design* & *generation II for new design*) of porcelain long rod insulators that differ in terms of physical dimensions as actual designs.

- Motivation >

  Originates from no known failure in service operations of generation I design.
  – to result in generation II design for improved pollution performance under very high pollution conditions.

  Environmental conditions in regions of Middle East lead to rapid accumulation of sand pollution on porcelain long rod insulators. To reduce and mitigate adverse effects of severe contamination – experimental results on existing generation I design show that transmission lines (up to 380 kVac) in the Kingdom of Saudi Arabia are over-dimensioned. Over-dimensioning to combat extreme pollution led to scaling up of unified specific creepage distances as high as 31 mm/kV to 50 mm/kV [at 160 kN and 330 kN mech. tensile loads].



Left: Generation I / Right: Generation II
(existing design) (new design)

Left: Generation I Design **Right: Generation II Design**

Background – Design Standardisation Project

- Scientific work presented has reference to >
  Transmission **M**aterial **S**tandard **S**pecification (**TMSS**) - National Grid, Saudi Arabia
  - specifies requirements as minimum technical requisites for design and testing of porcelain long rod insulators for use in 380 kVac Overhead Transmission Lines (OHTL).

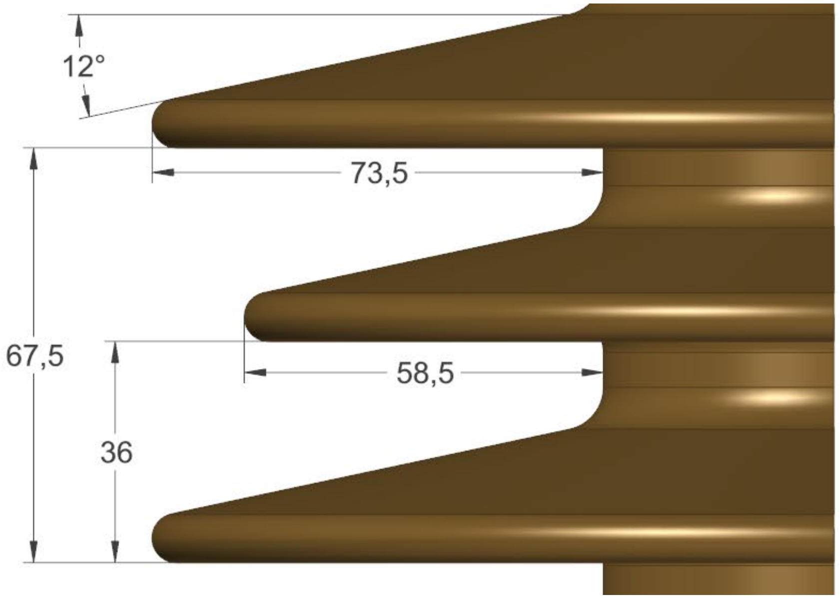
- Standardisation of porcelain long rod insulators for (future projects) >
  @ 380 kVac OHTL in inland- and coastal-installations of National Grid, Saudi Arabia.

- Unification of shed profiles >
  380 kVac OHTL currently employs > 06 different shed profiles for 03 creepage classes (31 mm/kV, 40 mm/kV & 50 mm/kV).

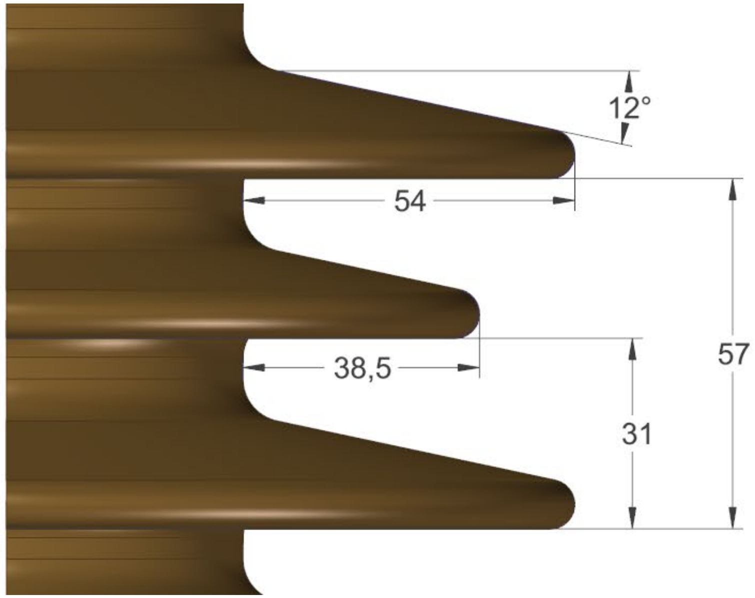
- Standardisation of insulator designs – in terms of:
  - *shed profiles*
  - *lengths*
  - *arcing distances*

Project Realisation – Design Standardisation Project

- Process of design standardisation > for all creepage classes: 31 mm/kV, 40 mm/kV & 50 mm/kV start with creepage class of 50 mm/kV [coastal installations at National Grid, Saudi Arabia]
- Further extended as unified shed profile for all creepage classes: 31 mm/kV & 40 mm/kV



Generation I Design
(Existing Design - Only 50 mm/kV)



Generation II Design
(Optimised Design - All Creepage Classes)

Project Realisation – Design Standardisation Project

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- New (generation II) design retains >
  creepage class of 50 mm/kV
  minimum mechanical tension load as 160 kN
  with creepage distance as 6340 mm [acc. to old (generation I) design]

- Difference in former design compared to latter design lies in >
  - increased length of insulation from 1700 mm to 1840 mm
    (8.23% increase)
  - increased arcing distance from 1545 mm to 1655 mm
    (7.12% increase)
  - decreased weight of assembled single short string
    - lowered to 56.8 kg [porcelain part = 50.0 kg] from 62.9 kg [porcelain part = 54.9 kg]
    (9.70% decrease)
  - decreased insulator surface area of assembled single short string
    - lowered to 2.54 m^2 from 2.81 m^2
    (9.61% decrease)

Project Realisation – Design Standardisation Project

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- Optimised design results in >
  - increased length of insulation
  - Increased arcing distance
  - decreased weight of unassembled / assembled porcelain units
  - decreased insulator surface area

Target / Intention >

- technical comply and meet the system requirements for operation of 380 kVac power transmission network of National Grid, Saudi Arabia.

Design verification through >
- tests on both designs (generation I & generation II)
- to determine pollution performance under contaminated conditions as:

- pollution tests (variants acc. to CIGRE TB 691 & IEC 60507)
- dielectric tests

Test Methods to Differentiate > Performance Analyses

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- Performance Analyses > Special tests as variants of pollution tests:

- Quick Flashover Method [acc. to CIGRE TB 691]
  (for salt-fog pollution @ Salinity: 80 kg/m³)

- Rapid Flashover Method [acc. to CIGRE TB 691]
  (for solid-layer pollution @ ESDD: 0.3 mg/cm²)
  [*to also estimate inland-installations at National Grid, Saudi Arabia*]

- a.c. Pollution Tests (acc. to IEC 60507, cl. 05)
  As salt-fog tests…thereafter increase of test-voltage
  (after standard three 01hr withstand tests) to determine flashover voltages

- Dielectric tests to determine Wet Power-Frequency Flashover & Withstand Voltages
  - Wet a.c. tests / flashover & withstand voltages / on *clean long rod insulators*

- Practical in-service performance…as an evaluation through standard Wet a.c. Flashover Tests
  (solid-layer polluted long rod insulators)
  - Wet a.c. tests / flashover voltages / on *polluted long rod insulators*

1st Test Method: Quick Flashover Method (for salt-fog pollution)

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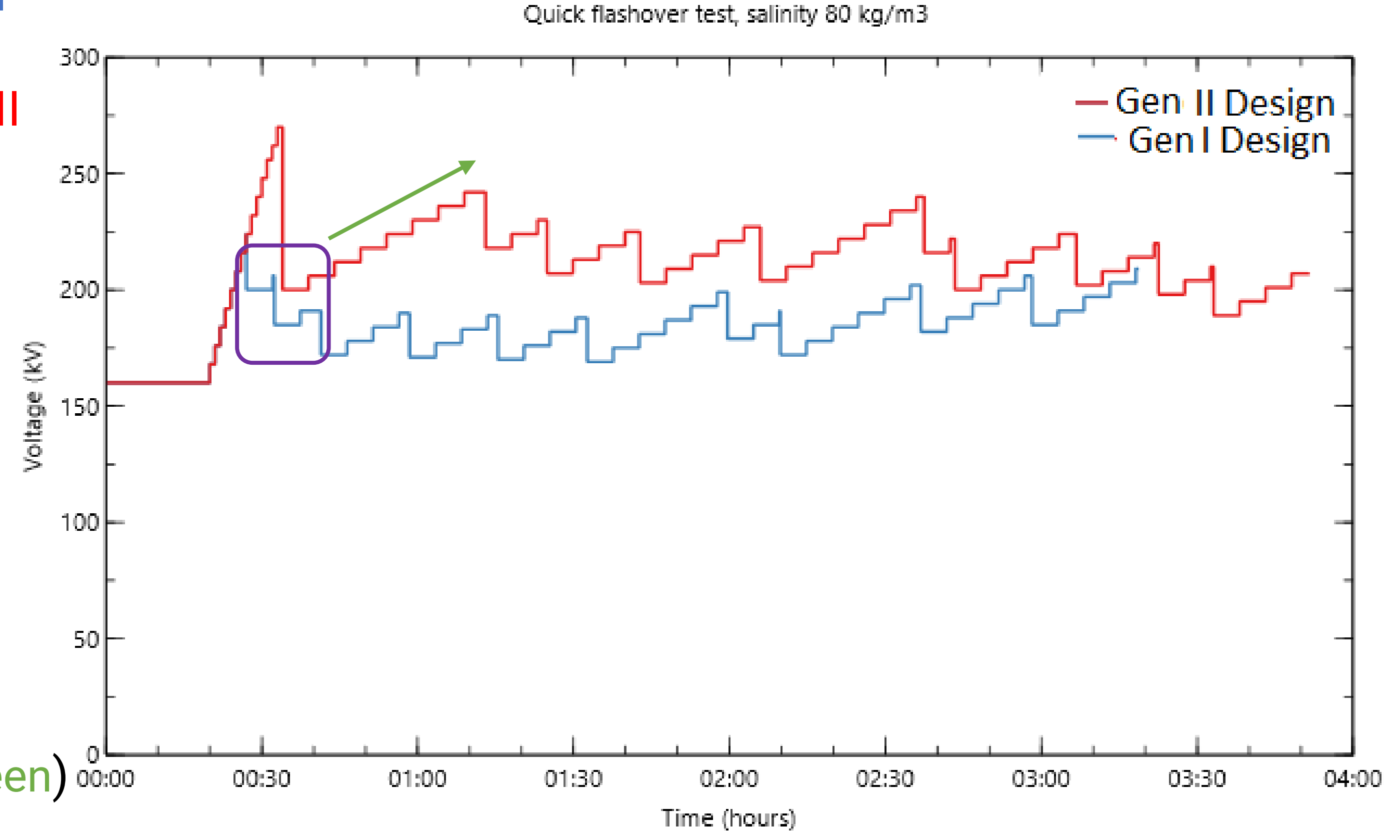
- Quick Flashover Method [acc. to CIGRE TB 691] (for salt-fog pollution @ Salinity: 80 kg/m³)
- Start of tests at test voltage: 160 kVac
- First flashover voltage for Generation I Design: **220 kV**
- First flashover voltage for Generation II Design: **280 kV**
- **Decrease** in time-duration (as build-down) in case of Generation I Design for successive flashovers (ref. graph - outlined block in purple)
- **Increase** in time-duration (as build-up) in case of Generation II Design for successive flashovers (ref. graph - arrowed upward trend in green)

Comparison of Quick Flashover Test (as salt-fog test) / flashover values for Generation I & Generation II Designs [acc. salt-fog method – evaluation acc. to CIGRE TB 691]



2nd Test Method: Rapid Flashover Method (for solid-layer pollution)

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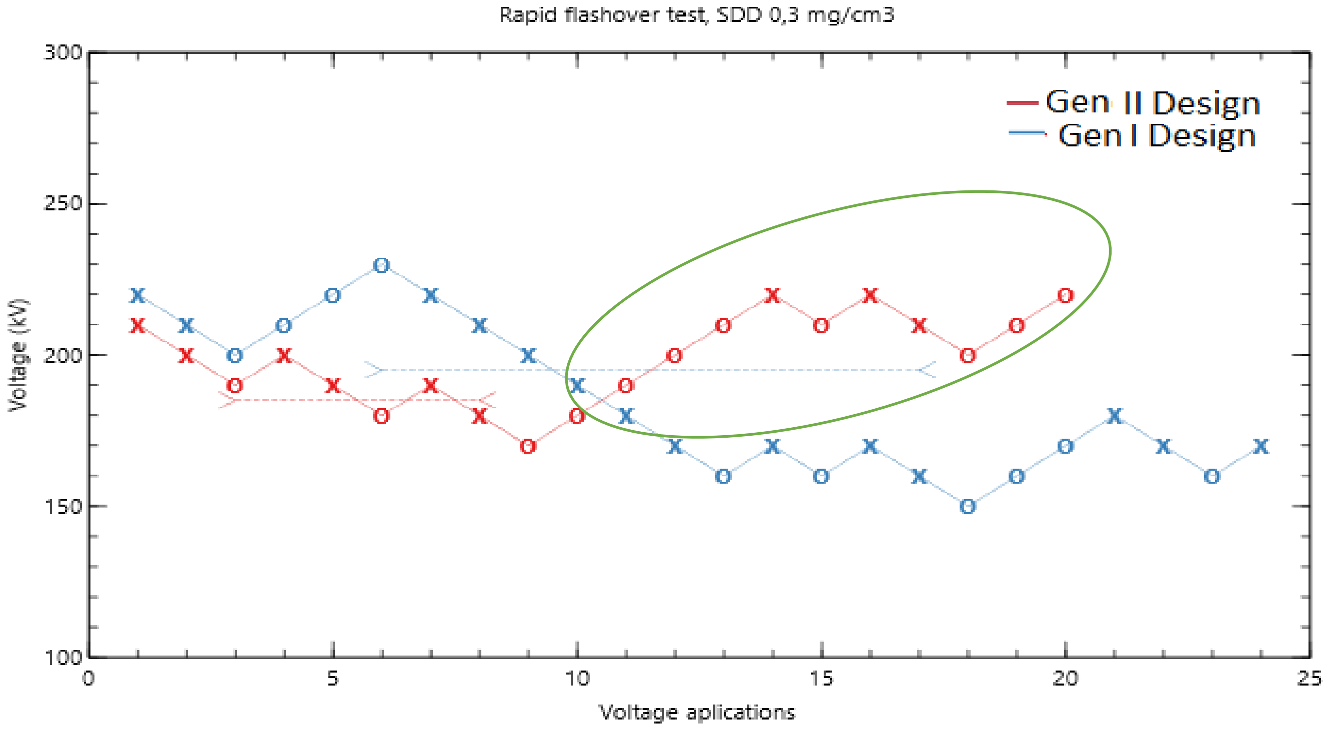
- Rapid Flashover Method [acc. to CIGRE TB 691]
  (for solid-layer pollution @ ESDD: 0.3 mg/cm²)
- Start of tests at test voltage: >205 kVac

x First flashover voltage for Generation I Design: 220 kV
o **Last withstand voltage for Generation I Design: 160 kV**

x First flashover voltage for Generation II Design: 210 kV
o **Last withstand voltage for Generation II Design: 240 kV**

- **Decrease** in performance in Generation I Design for successive voltage applications…as test progressed.
- **Increase** in performance in Generation II Design for successive voltage applications…as test progressed. (ref. graph - outlined in green)

Comparison of Rapid Flashover Test (as clean fog test) / flashover values for Generation I & Generation II Designs [acc. solid-layer method – evaluation acc. to CIGRE TB 691]



3rd Test Method: a.c. Pollution Tests (as salt-fog pollution)

- a. c. Pollution Test (acc. to IEC 60507 - cl. 5) Method
  (for salt-fog pollution @ Salinity: 80 kg/m³)

- Standard test procedure >
start with pre-conditioning followed by three 01 hr withstand tests at test voltage: 81 kVac

- Test Results:
  Generation I Design: Passed (with no flashovers during all three 01 hr withstand tests)
  Generation II Design: Passed (with no flashovers during all three 01 hr withstand tests)
  > Comparable peak leakage current values of approx. 400mA – similar in both generation designs

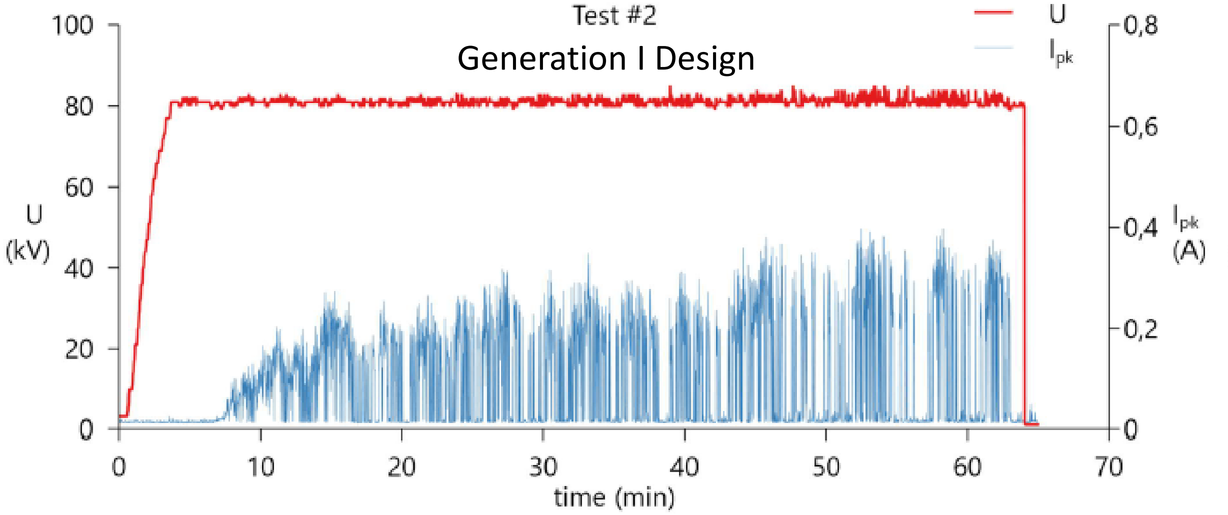


Figure Withstand tests – records of test voltage U and peak values of leakage current I_{pk}

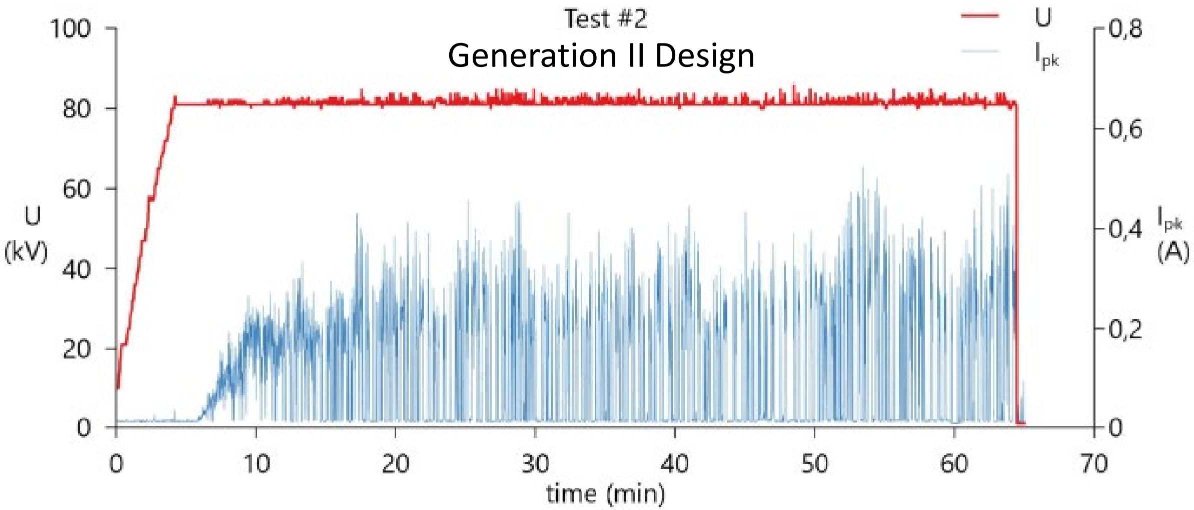


Figure Withstand tests – records of test voltage U and peak values of leakage current I_{pk}

3rd Test Method: a.c. Pollution Tests (as salt-fog pollution)

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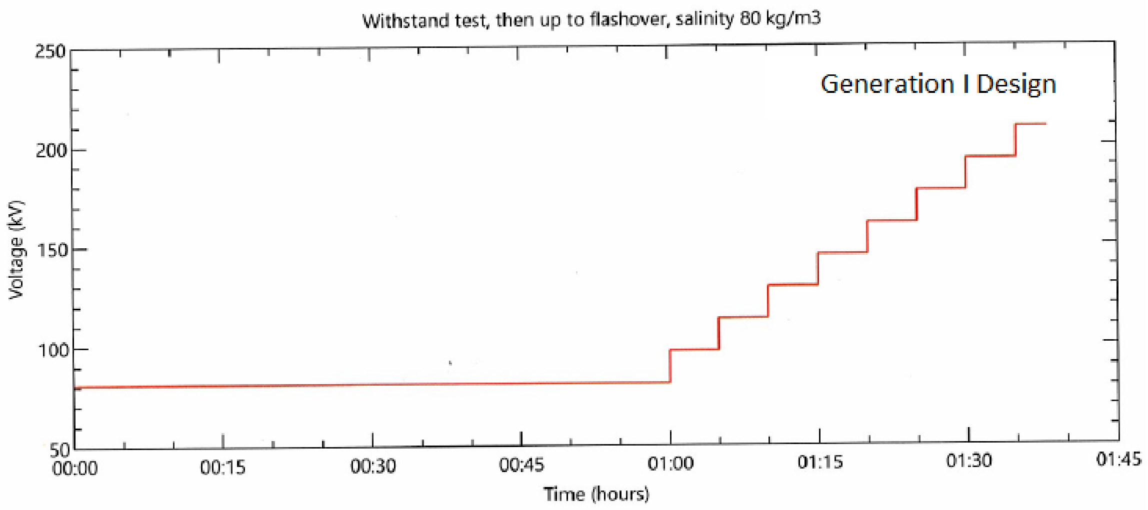
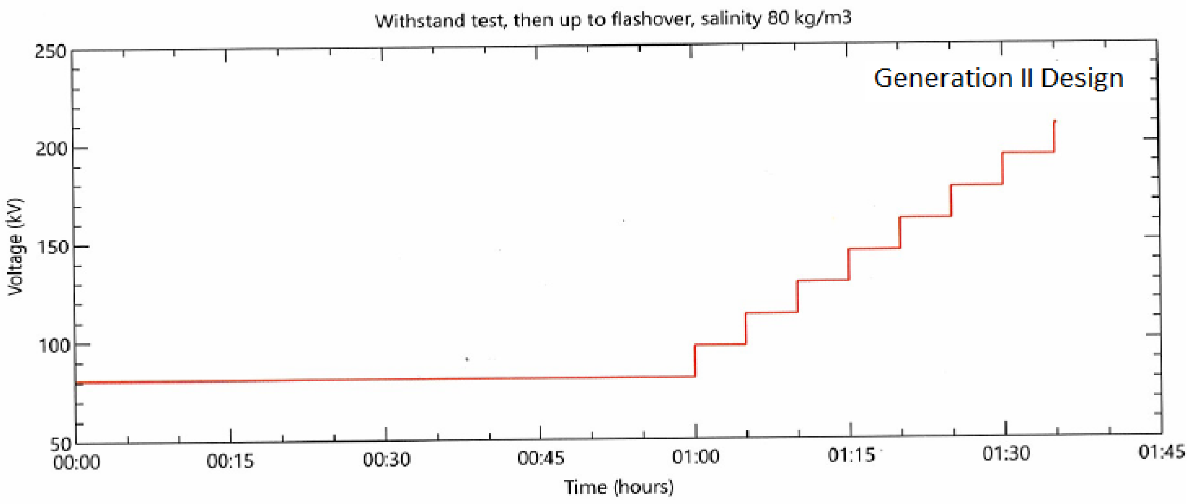
- a. c. Pollution Test (acc. to IEC 60507 - cl. 5) Method
  (for salt-fog pollution @ Salinity: 80 kg/m³)

- **Additional Procedure**: After standard pre-conditioning process – three consecutive withstand voltage tests (of 01 hr each) were performed at a test voltage of 81 kVac.
  After resp. withstand voltage tests >
  test voltage raised in defined voltage steps (@ 16 kV per 05 minutes) until flashover occurred.

- Test Results:
  Generation I Design: 209 kV - 209 kV - 209 kV (flashover voltage after 01 hr withstand test @ 81 kVac)
  Generation II Design: 209 kV - 177 kV - 209 kV (flashover voltage after 01 hr withstand test @ 81 kVac)
  > Comparable flashover voltage values of 209 kV – similar in both generation designs





3rd Test Method: a.c. Pollution Tests (as salt-fog pollution)

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- a. c. Pollution Test (acc. to IEC 60507 - cl. 5) Method
  (for salt-fog pollution @ Salinity: 80 kg/m³)

  - Tabulated data to outline the time to flashover and resp. flashover voltage values:

Generation I Design		
Test No.	Time of Flashover	Flashover Voltage (kV)
1	1:38:00	209
2	1:35:59	209
3	1:41:12	209

Generation II Design		
Test No.	Time of Flashover	Flashover Voltage (kV)
1	1:35:10	209
2	1:29:10	177
3	1:35:01	209

4^{th} Test Method: Wet a.c. Tests (on clean insulators - no pollution)

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- Dielectric tests to determine Wet Power-Frequency Flashover & Withstand Voltages
  (wet a.c. tests / flashover & withstand voltages on clean long rod insulators)

  IN ABSENSE OF POLLUTION

  - Test Results:
    Generation I Design: 433.40 kV
    Generation II Design: 560.20 kV
    > Higher value of wet a.c. withstand voltage in case of Generation II Design compared to Generation I Design (500 kV > 420 kV)

Table: Wet AC flashover test results / clean insulator surface (no pollution)

Generation I Design		Generation II Design	
Test No.	Flashover Voltage (kV)	Test No.	Flashover Voltage (kV)
1	436	1	570
2	408	2	554
3	424	3	551
4	464	4	564
5	435	5	562
Average	433.40	Average	560.20

Max. Withstand Voltage Values:

Generation I Design	420 kV	(Arcing Distance 1.57m)
Generation II Design	500 kV	(Arcing Distance 1.7m)

5^{th} Test Method: Wet a.c. Tests (on polluted insulators – solid-layer)

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- Dielectric test to determine Wet Power-Frequency Flashover Voltages
  (wet a.c. tests / flashover voltages on polluted long rod insulators – acc. to solid-layer pollution)

  IN PRESENSE OF POLLUTION @ ESDD: 0.3 mg/cm²

- Test Results:
  Generation I Design: 210.70 kV
  Generation II Design: 314.30 kV
  > Higher value of wet a.c. flashover voltage in case of Generation II Design compared to Generation I Design (314.3 kV > 210.7 kV)

Table: Wet AC flashover test results / polluted insulator surface

Generation I Design		Generation II Design	
Test No.	Flashover Voltage (kV)	Test No.	Flashover Voltage (kV)
1	215	1	301
2	205	2	305
3	212	3	337
Average	210.70	Average	314.30

Conclusions

- Design standardisation through optimisation of 380 kVac porcelain long rod insulators for very heavy polluted conditions >
  - adopted methods of tests to validate *generation II design* vs. *generation I design*
  - through to pollution tests & dielectric tests (on both: polluted and unpolluted variants)
    > test results show improved performance under actual artificial pollution conditions
- Harmonised shed profile >
  - across all creepage [31 up to 50 mm/kV] and mechanical strength classes [160 up to 330kN]
- Improved electrical performance under polluted- and non-polluted conditions
- Design optimisation additionally complements through >
  - reduction in physical parameters of insulation design – better design of shed profile >
    - increased length of insulation & arcing distance
    - decreased porcelain weight
    - decreased insulator surface area

    > results in *slimmest and lightest* possible variants of 380 kVac porcelain long rod insulators for very heavy polluted conditions of the deserted regions of Middle East
- Design standardisation >
  in full compliance to IEC 60815-2 & SEC Standards: *15-TMSS-04 Rev.2 Amd.1* and *01-TMSS-01 Rev.3*

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Thank you for your attention!

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APPENDIX

Self-cleaning efficiency under consideration of exposed creepage section

Generation I Design
(Existing Design – 50 mm/kV)

Generation II Design
(Optimised Design – All Creepage Classes)

Description	Generation I Design (31 mm/kV)	Generation I Design (40 mm/kV)	Generation I Design (50 mm/kV)	Generation II Design (All Creepage Classes)
Open Profile (in %)	59%	58%	58%	60%