Life Expectancy of HPS Quadri*Sil Polymer Transmission Insulators

I. Introduction

Today's Quadri*Sil™ polymer insulator, the fourth generation of polymer transmission insulators manufactured by Hubbell Power System (HPS), offers a life expectancy of over 50 years. This claim is supported by over 100 years of experience manufacturing insulators, and over 40 years expertise in designing, testing, manufacturing, and supplying polymer insulators.

II. Insualator Manufacturing Experience

A. Current Perspective

HPS manufactures their fourth generation of polymer transmission insulators under the trade mark name of *Quadri*Sil* insulators. Polymer compounds used in high voltage outdoor applications today must be able to withstand major performance degrading influences that adversely affect insulator life. It is imperative for an insulator manufacturer to understand these outside influences and their interaction with the materials used so that they can be effectively addressed in the design and testing phase. That allows the manufacturer to deliver a proven and reliable product in the field.

B. Evolution of HPS Polymer Insulators

Since first releasing a polymer transmission insulator in 1976, HPS continues to incorporate the understanding of the application challenges of an insulator into its product design. Those first-generation insulators provided invaluable field service data which allows HPS to continue improving material, testing procedures and protocols, design, and manufacturing processes. This results in improving the service life, performance and reducing cost of the new generation of these devices. Comparison tests performed on subsequent generations of insulators have provided sound guidance for the performance and life expectations of insulators manufactured today. <u>The current battery of tests utilized by HPS has been honed over time, based on field and laboratory experience, and firmly support an insulator life of over 50 years.</u>

III. Determining A Competent Material

A. What Determines the Life of an Insulator

A high voltage transmission insulator is a mechanical device which must survive the applicable stresses:

- Mechanical stress – mechanical force applied to insulator bearing member (i.e. hardware/ceramic medium or end fittings/fiberglass rod)
- Electrical stress – the presence of leakage currents, corona, or dry band arcing results in heat, oxidation, or tracking
- Environmental stress – Sun, ultraviolet (UV) radiation, and contamination exposure

For polymer insulators, the primary component of mechanical strength is the fiberglass rod. The polymer housing influences the electrical characteristics, including dry arc distance and leakage distance which correlate to flashover ratings and contamination performance, respectively. The polymer housing is also the primary source of protection from the environmental influences for the fiberglass rod. If moisture penetrates to the fiberglass core, it will certainly lead to a breakdown of the mechanical strength of the rod and mechanical failure of the insulator. This failure is referred to as brittle fracture. To avoid this failure, it is important to protect the fiberglass rod from moisture with a durable polymer and effective end fitting seals. To prolong the life of polymer insulators, fiberglass rods composed of electrical grade corrosion resistant (E-CR) fibers are the standard of the industry. However, E-CR fiberglass only delays the onset of brittle fracture, not eliminate it.

Initial design testing of polymer insulators evaluated the same material properties as porcelain insulators: dielectric strength, environmental stability, UV resistance and thermal stability. However, lab tests and field experience drove the need to evaluate the performance of specific polymer compounds for corona cutting resistance, tracking and erosion resistance, hydrophobicity, and flammability. Most of these issues were not applicable to porcelain bells. Therefore, testing needed to evolve to address these concerns in polymer insulators.

It is important to understand the factors that limit polymer insulator life. HPS uses a rigorous proprietary testing program which goes beyond applicable standards, to evaluate material performance in the presence of damaging insulator stresses.

The following tests are performed as part of the performance verification of *Quadri*Sil* polymer insulators.

B. Tracking and Erosion Resistance

A result of HPS' pioneering work was the development of the erosion test (now called tracking and erosion resistance test) to test glazes on porcelain insulators. This is also used to test the resistance of polymer materials. Moisture and contamination on all insulators result in leakage currents. Compared to porcelain bells, the reduced diameter of polymer insulators at the shank causes higher leakage current densities, as well as a greater level of Ohmic heating. Since the film dries first on the shank, arcing occurs there first. Electrical arcing across a dry gap, called "dry band arcing," generates ozone, high temperatures and UV radiation exposure on the polymer surface. The tracking and erosion resistance of a compound is a measure of its ability to withstand intense leakage currents combined with dry band arcing. This test specifically mimics these service conditions.

Silicone rubber compounds go through four stages of degradation in response to electrical activity — loss of hydrophobicity, dry band arcing, formation of silica layer, and erosion. Silicone rubber may fail as an insulator due to the formation of a thick silica layer which could lead to trapped moisture and high leakage currents. A silicone rubber insulator may also fail due to material erosion exposing the fiberglass rod.

The tracking and erosion test measures the response of the silicone rubber through all four stages of degradation, with a focus on the final stage. Materials without inherent resistance to tracking and erosion do not perform well in this test because a silica layer forms very early in the test. The tracking and erosion test is accelerated because the hydrophobicity is removed in the first few cycles, and the test sample is not given an opportunity to recover hydrophobicity. The recovery time is the reason silicone rubber compounds were not originally expected to perform as well as porcelain glaze in this test.

C. UV Resistance

Polymer insulating compounds are exposed to UV radiation not only from sunlight, but also from corona and dry band arcing. Resistance to degradation resulting from UV radiation exposure is an important factor in determining the service life of a polymer.

The energy from sunlight that is most destructive to polymers is classified as UVB, with a wavelength between 320 and 290 nanometers. UVB constitutes less than five percent of the total radiation reaching the surface of the planet. Absorbing this UV radiation results in mechanical and chemical degradation of the polymer structure that can affect its dielectric, physical and weathering properties. These effects are accelerated in the presence of moisture on the polymer surface. Polymer compounds used in outdoor environments should be evaluated in the combined presence of UV radiation and high humidity.

D. Corona Resistance

Corona discharges form at the surface of an insulator when the electric field gradients on the surface exceed the breakdown strength of air. Corona generation is dependent upon atmospheric conditions such as air density, humidity, and geometry of the insulator.

Corona accelerates the aging of polymers by generating ozone and ultraviolet light. The UV light produced includes the spectra of light damaging to polymers. In addition, the electric discharge subjects the insulator to severe electrical strain and chemical degradation. Electrical insulation that may be subject to corona must be made from a properly compounded silicone rubber.

The presence of corona combines UV and heat with a high level of ozone. HPS' corona-cutting chamber combines this with mechanical stress to accelerate the degradation of a polymer. Polymer insulator samples are subjected to a mechanical stress of approximately 300,000 microstrain by bending the sample over a grounded electrode.

IV. Polymer Testing Results

As outlined above, HPS uses a comprehensive battery of tests to qualify and attempt to quantify the performance and longevity of its polymer weathershed materials. Starting with the original polymer developed for use in 1976, an ethylene propylene monomer (EPM) rubber known as Dirigo 7345, HPS continued to evolve the polymer formulation to increase performance and prolong the life of its polymer insulators. The original 1976 HPS polymer formulation now has over 40 years of field experience.

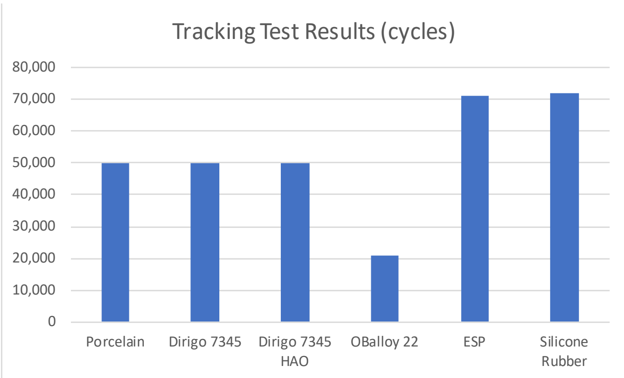
The proprietary HPS silicone rubber compound used on *Quadri*Sil* insulators was specially formulated with the intent to resist the effects of damaging electrical and environmental stresses for transmission insulators and extend their service life.

The results of the tests follow:

A. Tracking and Erosion Resitance Test

Adapted from the porcelain glaze verification test used for decades, the minimum threshold for porcelain was 50,000 cycles. Therefore, the same threshold was set as the minimum requirement for polymer compounds. When silicone rubber was alloyed with EPM rubber to form OBalloy 22, the tracking resistance was reduced. That reflected the typically lower values obtained with silicone rubber. ESP™ polymer (a EPDM/SR compound) was formulated to overcome this reduction. Further development paid special attention to this performance for the proprietary HPS silicone rubber compound.

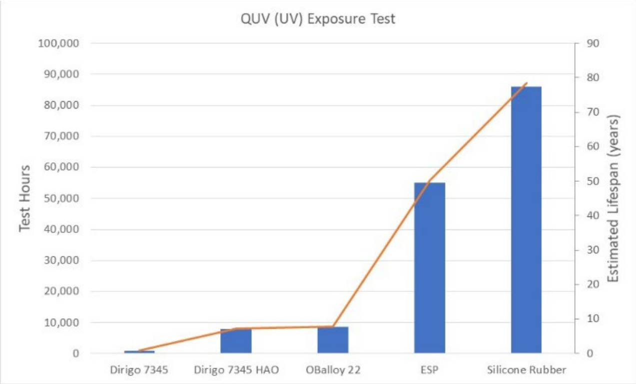
- Minimum Threshold of 50,000 Cycles (i.e. performance of porcelain and previous EPM polymer Dirigo 7345).
- HPS Silicone Rubber has ~50% improvement over porcelain and Dirigo 7345 at 72,000 cycles, confirming superior resistance to electrical activity on the surface of the polymer material.



B. QUV Test

Testing resistance to UV exposure, also referred to as the accelerated aging test, is performed per ASTM G53 test protocol. The results of this test are accepted to have an approximate 8:1 conversion to real life experience. Based upon QUV and EMMAQUA testing performed on original polymer compound Dirigo 7345, the initial estimates proposed a 20-year life for HPS' first-generation polymer insulators. However, further testing and concrete field results have now proven a life span of over 40 years. Comparing the original test results and field performance of Dirigo 7345 to the latest test results for the HPS proprietary silicone rubber provides strong support for the latest generation of HPS polymer insulators to exceeding a 50-year life expectancy:

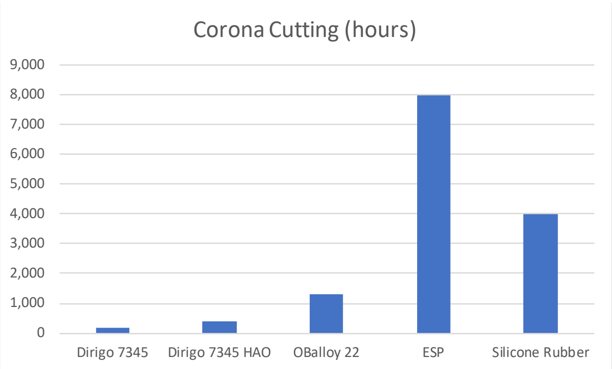
- Proprietary HPS silicone rubber used in *Quadri*Sil* insulators has 80,000+ hours more than Dirigo 7345, or equivalent to an additional 70+ years of expected UV exposure.



C. Corona Cutting Test

The proper context of the corona cutting test is to understand the defense mechanism of the polymer material against the applicable stresses an insulator endures. The alloy of EPDM and Silicone rubber (SR) uses the high mechanical strength of EPDM and the hydrophobicity of SR to withstand the damaging effects of the electrical and environmental stresses. Silicone rubber compounds rely on hydrophobicity to prevent degradation from electrical activity. HPS' proprietary silicone rubber compound was specially formulated to not only take advantage of hydrophobicity but also to have superior resistance to damage due to electrical activity as compared to commercially available silicone polymers.

- Minimum threshold of an acceptable polymer material for outdoor insulators is 1,000 hours for estimated 40 years of life.
- Proprietary HPS silicone rubber exceeded 4,000 hours in testing, indicating a life expectancy well beyond 50 years.



D. Hydrophobicity

Hydrophobicity is the property that prevents water from forming a sheet on the surface of a polymer. Hydrophobicity also aids in cleaning polymer surfaces, as water will readily bead and run off a hydrophobic surface. Hydrophobicity can be measured using STRI Guide 1, 92/1 which rates hydrophobicity by comparison to standard images or by using a contact angle measurement. The contact angle is measured between a water drop and the sample surface. The proprietary HPS silicone rubber compound is typical of most silicone compounds with a contact angle measurement of approximately 120°.

This hydrophobic characteristic coupled with the weathershed geometry of the *Quadri*Sil* insulator design allows for effective cleaning of contaminants from the surface of the insulator. This provides superior field performance in areas exposed to desert, agricultural, industrial, or coastal contamination sources.

E. Flammability

SR compounds depend on the addition of additives and fillers to define the desired characteristics. Alumina trihydrate (ATH) is a common additive for SR. ATH is an effective flame retardant and extinguishing medium. In essence, once the effective testing for flammability is defined in standards such as IEC 60695, then competent silicone compounds used in electrical applications will meet the necessary standards.

F. Multi-Stress / Environmental Chamber Testing

Methods of testing in a multi-stress chamber to effectively verify life-performance of a polymer were established through silicone rubber compounding. These methods involve testing for the impacts of temperature, humidity, UV, contamination (salt spray), and voltage. With the support of the North American-based Electrical Power Research Institute (EPRI), the *ESP* polymer insulators were verified to withstand over 44 months of testing in a 500 kV multi-stress aging chamber. This same North American research institute also performed multi-stress testing of *Quadri*Sil* silicone rubber insulators for an extended duration. The results demonstrated a life expectancy well over 50 years of field service. The test report is available through EPRI. HPS performed similar testing per the IEC standard on the *Quadri*Sil* insulator to 8,000 hours, which exceeded the standard of 5,000 hours. It still met the passing criteria. This provided further confirmation of the superior performance of the weathershed material under extreme environmental conditions.

V. Insulator Design

In addition to developing a proprietary silicone rubber with superior properties to withstand the damaging effects of an electrical environment, HPS also implemented important changes to the design and construction of this fourth generation polymer insulator.

For the design of the *Quadri*Sil* transmission insulators, HPS focused on a redundant four seal system to protect the triple interface point. This is where the fiberglass rod, polymer and end fitting keep moisture from penetrating to the fiberglass core.

- Surface 1 – Counter-bore Compression Seal
- Surface 2 – Radial Compression Seal
- Surface 3 – Internal O-ring Seal
- Surface 4 – Overlap Compression Seal

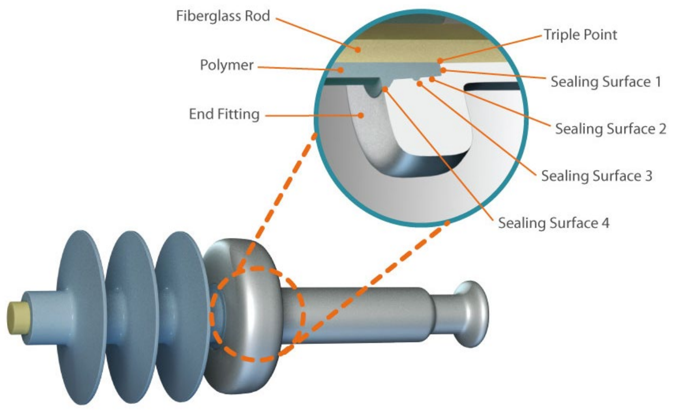


Figure 4: Detail of Quadri*Sil Sealing System

The *Quadri*Sil* insulator design also includes a corona shielding ring (CSR) integral to the end fitting. This limits electric field gradients at the triple point. By reducing the field gradients, the insulator is better protected from the damaging effects of corona at this critical junction of the end fitting and rubber. The internal end fitting geometry is also important to maintain an effective seal to protect the fiberglass rod from the environment. The integral CSR also has enhanced power arc performance to protect the *Quadri*Sil* insulator in the event of a high-power flashover. Even with the extensive damage to the end fitting following a 150 kA-cycle power arc, the sealing system of the *Quadri*Sil* insulator was not compromised and passed the dye penetration test (see Figure 5).

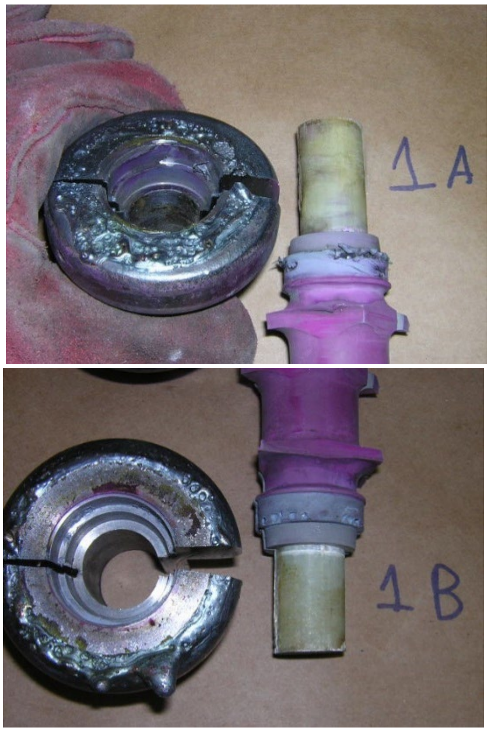


Figure 5: Power Arc Test Results of *Quadri*Sil* Insulator Sealing System

VI. Conclusion

HPS designed the *Quadri*Sil* polymer insulator with extensive insulator manufacturing and polymer development experience. Testing the silicone rubber compound of *Quadri*Sil* insulators exceeded the performance of previous generations that already served over 40 years in the field. The test results for the *Quadri*Sil* insulator surpassed thresholds by a significant margin in critical areas that are important to extend the life of a polymer insulator. Design details in *Quadri*Sil* polymer insulator end fittings serve to improve the sealing interface between rod, rubber, and end fitting. They also help dissipate electric field gradients, reduce corona activity, and protect against the damaging effects of power arc.

<u>While the best measurement is time itself, the improved test results from a 40+ year proven insulator and the enhancements in material and design for the *Quadri*Sil* polymer insulator support a 50+ year life-expectancy.</u>

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[3] EPRI Aging Chamber Reference Letter

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[5] Quadri*Sil™ Insulators

[6] HPS Polymer Insulator Field Experience >15 years

[7] EMMAQUA and QUV Studies of Ohio Brass' Polymeric Compounds