



## ADVANCES IN CHEMICAL REJUVENATION : EXTENDING MEDIUM VOLTAGE CABLE LIFE 40 YEARS

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### ABSTRACT

*Recent advances in cable life extension technology have demonstrated a greater than three-fold life improvement over earlier generations. While simply supplying an adequate amount of fluid explains a portion of these performance gains, this paper addresses several other important factors required to understand long-term post injection reliability. The mechanisms of cable failure, which are addressed by the newest injection technology, are briefly reviewed. The focus of the paper is on the chemistry of oligomerization, which determines how long a treatment persists in the cable. Three commercially available chemistry choices are compared.*

### KEYWORDS

Cable rejuvenation, cable life extension, silicone fluid treatment.

### INTRODUCTION

Over twenty years have elapsed since the authors introduced the first commercially significant solid dielectric enhancement technology described in [1]. During those two decades, this first generation technology has proven itself as an important tool to enhance the reliability of aging infrastructure saving circuit owners an estimated US\$1B of capital, which otherwise would have been spent on replacement. Additionally, approximately 30M kg of aluminum, 7M kg of copper, and 11M kg of polyethylene have been effectively recycled – conserving scarce world resources. Incremental improvements during those two decades have aided in the widespread commercial acceptance of dielectric enhancement technology on at least four continents. There are some concerns with the first generation technology, which has been utilized by over 500 circuit owners worldwide. Concerns include: (1) a higher than desirable post-injection failure profile, due to the slow permeation of the fluid into the dielectric and the resulting slow increase in post-injection dielectric performance of approximately 0.5% per day, (2) a limited cable life extension of 10-20 years, (3) safety and operational issues related to the low flash point (0°C) of the fluid and required interaction with energized circuits for 7-strand and 19-strand conductors, (4) a one-size-fits-all delivery paradigm that ignores widely divergent operating considerations, namely ambient soil temperature, load induced temperature variations, and cable geometry, and (5) an inability to successfully restore the reliability of recently failed cables.

Novel approaches, which include new installation methods and new materials to extend the life of power cables, are described. Theory, experiments, and field results demonstrate that the new approaches address the shortcomings of the first generation technology. The new technology choices can be tailored to provide: (1) more rapid

short-term reliability – the post-injection dielectric performance improvement slope is steeper by more than an order of magnitude as shown in [2], (2) longer rejuvenated cable life often exceeding the 40 year expected life for the highest performance modern cable designs as described in [3] and [4], (3) an inherently safer installation, including lower flammability fluids, which have flash points in excess of 94°C vis-à-vis the older technology, which has a flash point of 0°C as documented in [5], (4) a tailored formulation paradigm which adjusts the chemistry of the fluid to account for significant operational variables detailed in [3] and [4], and (5) process and formulation choices, which specifically address cables which may contain electrical trees described in [6].

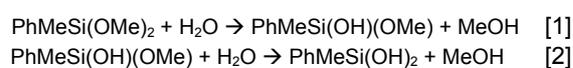
The most advanced second generation technology employs a fluid, which actively sequesters hot electrons, absorbs UV photons associated with the conversion of water trees to electrical trees, scavenges free radicals, increases the partial discharge inception and extinction voltages, and reduces the amount of damaging water in the insulation.

The balance of this paper focuses on the chemistry required to allow silanes to condense fully to allow their beneficial effects to persist for decades after treatment.

### EXUDATION

The second law of thermodynamics demands that all mobile treatment materials injected into strand interstices must ultimately exude into the soil around the cable. Treatment materials must have some mobility in order to penetrate into solid dielectric materials. Lacking mobility would preclude them from having any influence over the dielectric. Absent a chemical bond to the insulation polymer backbone, the treatment fluid will migrate radially outward from the strands into the insulation, where it exhibits its rejuvenating characteristics and then these materials migrate radially outward into the surrounding environment at which point the materials cease to provide any reliability benefit.

Optimally modern treatment fluids should migrate into the insulation quickly, but then exude into the surrounding environment slowly. Beginning with the technology of Vincent described in [1], this was accomplished with the hydrolysis and subsequent condensation of dialkoxysilanes. The most common silane used was phenylmethyldimethoxysilane or PMDMS. PMDMS or  $\text{PhMeSi}(\text{OMe})_2$  oligomerizes in two steps as follows ... first hydrolysis:



An example of the second reaction type, condensation, is:



This second kind of reaction, the condensation of two