Reliability approach to cost-optimized ESP cable designs

SPE - European Artificial Lift Forum

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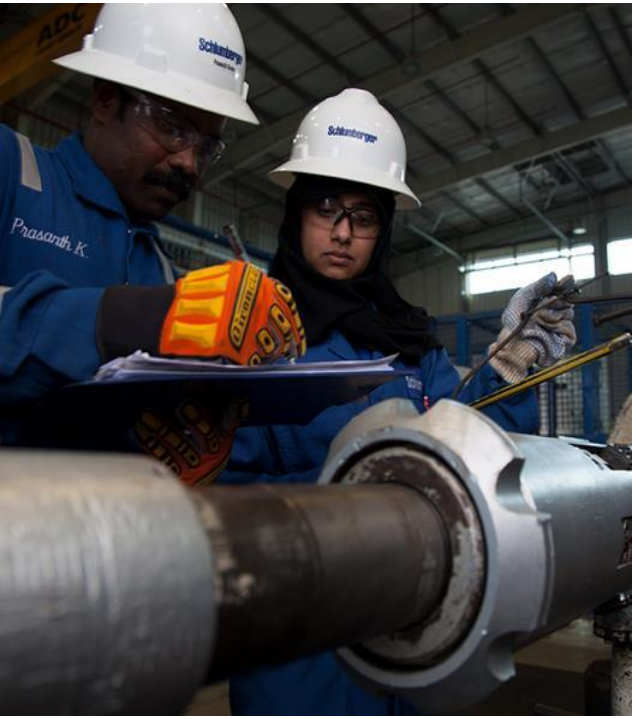

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Context: Understanding the opportunity

Customer Requirements

- Cost Effective
- Fit-for-purpose
- Reliable

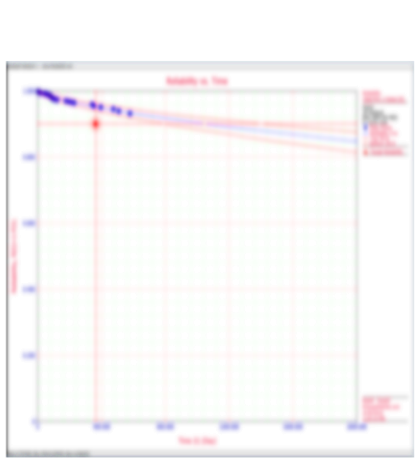
- Higher reliability traditionally associated with higher product cost.
- Lower oil prices provided a unique opportunity to create a cable design optimized for reliability and cost.
- Strategic approach on reliability during design and qualification process to offset traditional costs

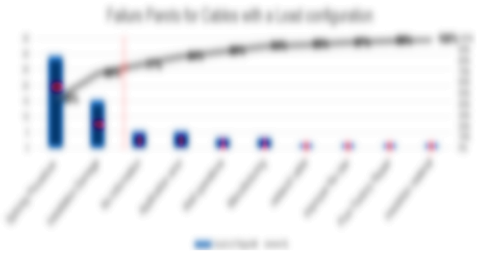
Initiation: Establishing a reliability baseline

- Analysis of operating conditions was completed to determine necessary cable specifications for a fit-for-purpose cable design

- Gap in operating conditions vs. cable specifications was identified to the current product (standard leaded ESP power cable). Use of over-specified designs yielded an opportunity for product tiering.

- A vast majority of all ESP failures related to electrical causes attributed to a *"Power Cable"* root cause were from splicing or damages suffered during installation, than well related factors. Therefore, an opportunity window in terms of a reliable fit-for-purpose design existed.



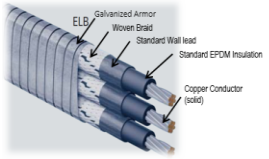


Development: Quantifying reliability targets

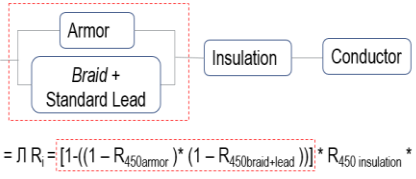
- Reliability block diagrams were created for existing designs (ELB) to quantify effects of components on overall reliability

- Testing methodology was driven by the criticality of each component, with benchmarks to the established survivability of the existing design.

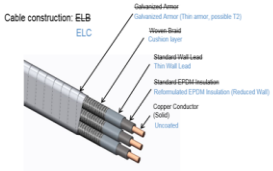
- As a result of the RBD, particular focus was given to:
  - Ensuring equal or greater performance of new electrical insulation materials.
  - Ensuring the integrity of the lead barrier over the entire lifetime of the cable.



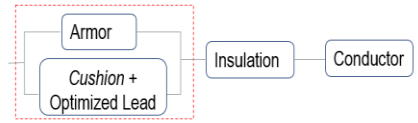
Redalead 450



$R_{RL450} = \prod R_i = [1-((1 - R_{450armor})* (1 - R_{450braid+lead}))] * R_{450\ insulation} * R_{conductor}$



Candidate



$R_{RL350} = \prod R_i = [1-((1 - R_{armor})* (1 - R_{cushion+lead}))] * R_{insulation} * R_{conductor}$

$\rightarrow R_{Legacy\_Design} = \prod R_i = [1-((1 - R_{Legacy\_armor})* (1 - R_{Legacy\_braid+lead}))] * R_{Legacy\_\ insulation} * R_{conductor}$

$\rightarrow R_{New\_Design} = \prod R_s = [1-((1 - R_{New\_armor})* (1 - R_{New\_cushion+lead}))] * R_{New\_\ insulation} * R_{conductor}$

(Rewriting $R_{New\_}$'s reliability in terms of $R_{Legacy\_}$)

$\rightarrow R_{RLNew\_} = \prod R_s = [1-((1 - (\Delta_{armor} * R_{Legacy\_armor}))* (1 - (\Delta_{c+l} * R_{Legacy\_braid+lead}))] * (\Delta_{insulation} * R_{Legacy\_insulation})* R_{conductor}$

Thinner Armor
Cold Bend

New Cushion layer, Thinner lead
Pressure vessel Ageing w/ AC BD

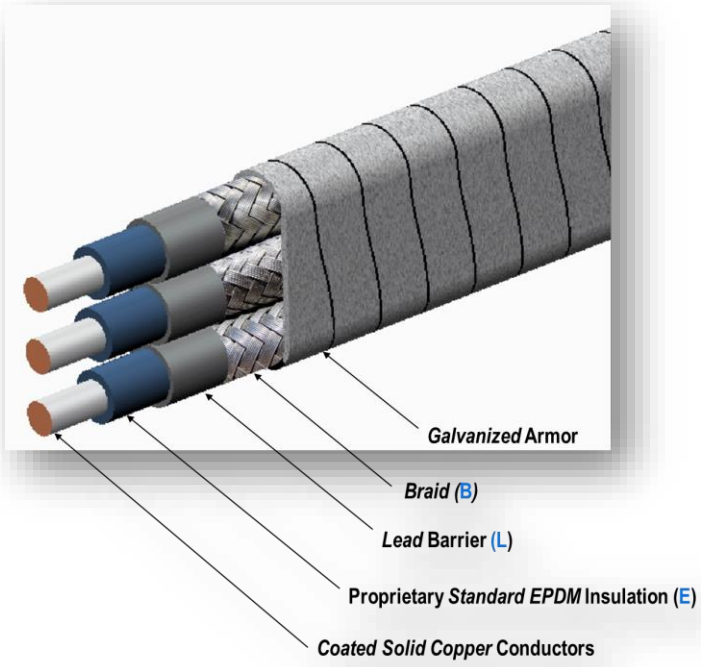
New Formulation
Partial Discharge Testing
High-Frequency Ageing Test
AC Breakdown Testing (AC BD)

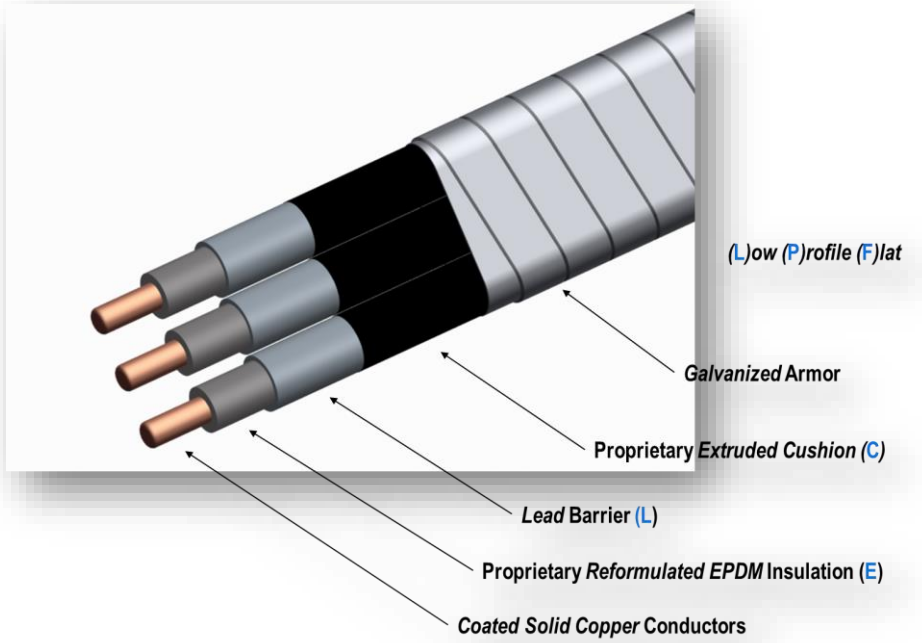
No change

All Δ values should be closer to 1; to achieve RL Legacy_'s reliability numbers*

*Assuming Splicing, Installation, Acid treatment & other operational risks remain the same

Design: *REDALead ELC-LPF* Key Characteristics





ELB **ELC-LPF**

** - Design of ELC-LPF Construction and Materials are Patent Pending*

Testing: Verification & Validation

Lab-scale reliability target verification

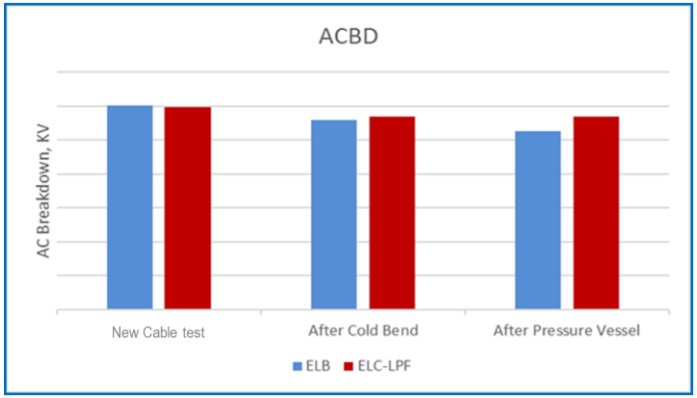
- **Extensive electrical aging (insulation integrity)**
- **Extensive bending testing (lead barrier integrity)**
- Thermal conditioning
- Fluid aging
- Simulated well conditioning

Field reliability target verification

- Extensive field trials
- **47 installations to date**
- **Longest running cable = 402 days (still in service)**

Post-Bending

Post-Aging



Thank you!