Delano:

- 4 square miles
- 5,800 electric meters
- 12MW load
- Double-ended substation
- 12 miles 69kV transmission
- 65 miles / 12 looped circuits
- OH to URD competed in 2014
Delano:

- 26 MW capacity
- MISO
- (6) OP Diesel
- (1) 12MW CT
Transformers:

- Amorphous core windings (thin foil core)
- Not new – ca.1980
- $ premium (30%-50%)
- Higher efficiencies achieved
- Quantifiable savings? (70% @ no-load)
- Susceptible to inrush failures (brittle)
- Repair impossible
- Noisy & larger
What is Amorphous Metal?

Amorphous Transformer is the Solutions

What is Amorphous Transformer?

The amorphous is a non-crystal substance created by rapidly freezing liquids of high temperature. Because there is no rule of atomic arrangement, the energy loss (hysteresis loss) is small when the flux of magnetic induction passes the iron core. In addition, eddy current loss is decreased because the thickness is approximately 0.03 mm, which is about 1/10 comparing with silicon steel. Therefore, the no load loss (eddy current loss and hysteresis loss) can be decreased to about 1/5 of silicon steel's.

Atomic Arrangement

Crystalline

Amorphous [Non-crystalline]

About the loss of transformers

The load loss and no load loss occur at the same time when the transformer is operated, the loss is a useless output chiefly converted into heat.

Hysteresis loss

By magnetic induction, magnetic domain rotates to have unified direction. The loss caused by this movement is hysteresis loss.

Eddy current loss

When magnetic flux flows, eddy current flows to negate the flux. This eddy current cause loss proportional to the resistance.
What is Amorphous Metal?

- Standard iron-silicon steel
- Ferromagnetic Amorphous steel
Gen 1

Susceptible to shattering from heat and vibration
Gen 1

Metal fragments breaks off from the core under stress

Metal fragments dropping into oil tank

CRGO steel transformer
3-phase 3-legs

Amorphous metal transformer
3-phase 5-legs
Transformers:

The test:

- Single-phase, rebuilt, pad-mount XFMR
- Various capacities & customers
- Logger installed on Primary and Secondary URD

![DMU test results]
Transformers:

Variables:
“Standard” (25 years old, rebuilt)
“Amorphous” (25 year old, rebuilt)
Variable load
Transformers:

Energy Savings Conclusion:

- Not worth “new” capital investment, but Amorphous-core re-tank has sound economic mojo.
- Price premium 140% of standard re-tank.
- *(Bonus)* Larger transformer loading sweet spot.

Algorithms

**Annual kWh Savings (Ref. 1)**

\[
\text{Annual kWh Savings} = 8,766 \times \left[ \left( \frac{\text{Load}_{\text{peak}}}{\text{FIC}_{\text{base}}} \right)^2 \times \text{FILC}_{\text{base}} \times \text{LossFactor} + \text{NLL}_{\text{base}} \right] - \left[ \left( \frac{\text{Load}_{\text{peak}}}{\text{FIC}_{\text{ce}}} \right)^2 \times \text{FILC}_{\text{ce}} \times \text{LossFactor} + \text{NLL}_{\text{ce}} \right]
\]

**Peak kW Savings**

\[
\text{Peak kW Savings} = \left( \frac{\text{Load}_{\text{peak}}}{\text{FIC}_{\text{base}}} \right)^2 \times \text{FILC}_{\text{base}} + \text{NLL}_{\text{base}} - \left( \frac{\text{Load}_{\text{peak}}}{\text{FIC}_{\text{ce}}} \right)^2 \times \text{FILC}_{\text{ce}} + \text{NLL}_{\text{ce}}
\]

**Dth Savings per Year = 0**
15KV URD Cable:

- Improved conductivity
- Reduce Ohmic loss
- Quantifiable savings? Consult TRM
The test:

- DC high-pot
- Megger

**TABLE I**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Insulation</th>
<th>Acceptance</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 409</td>
<td>EPR/XLP</td>
<td>56 kV /15 Min</td>
<td>46 kV 5-15 Min.</td>
</tr>
<tr>
<td>IEEE 576</td>
<td>EPR/XLP</td>
<td>65 kV /15 Min</td>
<td></td>
</tr>
<tr>
<td>ICEA S-68-516</td>
<td>EPR</td>
<td>65 kV /15 Min</td>
<td></td>
</tr>
<tr>
<td>ICEA S-66-524</td>
<td>XLP</td>
<td>65 kV /15 Min</td>
<td></td>
</tr>
<tr>
<td>ICEA S-94-649</td>
<td>EPR/XLP</td>
<td>64 kV /15 Min</td>
<td>20 kV 5 Min.</td>
</tr>
<tr>
<td>AEIC CS6-96</td>
<td>EPR</td>
<td>64 kV / 5 Min.</td>
<td>51 kV 5 Min.</td>
</tr>
<tr>
<td>AEIC CS5-94</td>
<td>XLP</td>
<td>64 kV / 5 Min.</td>
<td>20 kV 5 Min.</td>
</tr>
</tbody>
</table>
15 KV URD Cable:

Variables:

- **XLP** (cross linked poly) susceptible to damage from test
- **TR-XLP** (tree resistant)
- **EPR** (ethylene poly rubber) more flexible
- Length of run
- 4/0 or 1/0 conductor
- Terminations
15 KV URD Cable:

Energy Savings Conclusion:

- Line loss negligible
- Economic mojo prevails due to other factors including:
  - Reliability
  - Easier installation due to flexibility
- All electrical distribution contains loss – TR XLP lowest first cost and smallest dielectric loss.

**Algorithms**

**Single Phase:**
\[\text{Annual kWh Savings} = (I_{\text{peak}})^2 \times (R_{\text{base}} - R_{\text{ee}}) \times \text{Length} \times \text{LossFactor} \times 8,766 / 1,000\]
\[\text{Peak kW Savings} = (I_{\text{peak}})^2 \times (R_{\text{base}} - R_{\text{ee}}) / 1,000\]

**Three Phase:**
\[\text{Annual kWh Savings} = 3 \times (I_{\text{peak}})^2 \times (R_{\text{base}} - R_{\text{ee}}) \times \text{Length} \times \text{LossFactor} \times 8,766 / 1,000\]
\[\text{Peak kW Savings} = 3 \times (I_{\text{peak}})^2 \times (R_{\text{base}} - R_{\text{ee}}) / 1,000\]
Distribution Voltage:

- Improved capacity
- Reduce voltage drop & line loss
- Improved reach with smaller conductor
- Quantifiable savings? \((0.8\% \text{ energy/year per } 1\%\text{V}^*)\)

\(^*\text{NEMA}\)
Distribution Voltage:

- Overhead VS. Underground

*EPRI*
Distribution Voltage:

- 2,400
- 4,160
- 7,200
- 12,470
- All XFR dual voltage
Distribution Voltage:

Energy Savings Conclusion:

- Line loss negligible
- Economic **mojo prevails** due to other factors including:
  - Reliability *(fewer outages from fuses and elbow failure)*
  - Increase capacity on circuit
## Other Delano EUI:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Management</td>
<td>hmm..AMI</td>
</tr>
<tr>
<td>kVAR control (capacitors)</td>
<td>Nope</td>
</tr>
<tr>
<td>Voltage regulators</td>
<td>Nope</td>
</tr>
<tr>
<td>Variable speed air compressor/storage</td>
<td>Complete</td>
</tr>
<tr>
<td>VFD / PLC controls water system</td>
<td>Complete</td>
</tr>
<tr>
<td>LED streetlights</td>
<td>In Progress</td>
</tr>
<tr>
<td>Geothermal (ground-source) in plant</td>
<td>Complete</td>
</tr>
<tr>
<td>Energy Star office equipment / computers</td>
<td>Complete</td>
</tr>
</tbody>
</table>
The EUI bible:

Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System

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Cmer C. Onar
Harold Kirkham
Emily Fisher
Klaehn Burkes
Michael Starke
Olama Mohammed
George Weeks

April 2015

Closing thoughts:

Think about EUI carefully

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