Emerging Technologies

Liquid-Immersed Distribution Transformers: Incentives for Energy Savings

Washington State University Energy Program
Bonneville Power Administration Energy Efficiency
BC Hydro

BPA's Emerging Technologies Initiative

January 28, 2021

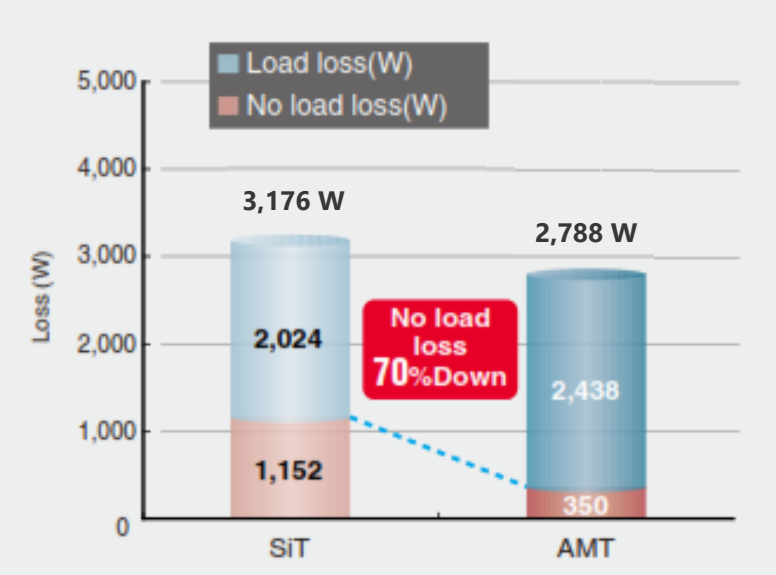
Topics and Presenters

- High Efficiency Liquid-immersed Amorphous Core Distribution Transformers Update
  - Gil McCoy, Energy Program Senior Engineer
    - WSU Energy Program
- BPA Incentive Details
  - Tony Koch, Mechanical Engineer
    - BPA
- Ferroresonance & Harmonics
  - David Bell, Electrical Engineer
    - BPA Contractor
- Amorphous Core Transformers at BC Hydro
  - Madeleine Schaefer, Distribution Standards Engineer
  - Mike McMinn, Trades Training Instructor
    - BC Hydro

Amorphous Core Distribution Transformers

- Historical Wisdom – True or False
  - No-load losses are about 60% to 70% less than for conventional transformers
  - Costs are about 20% greater
  - Amorphous core transformers are 15% to 30% larger and are heavier than their silicon steel counterparts

Reduction in Core Losses with Amorphous Metal Transformers



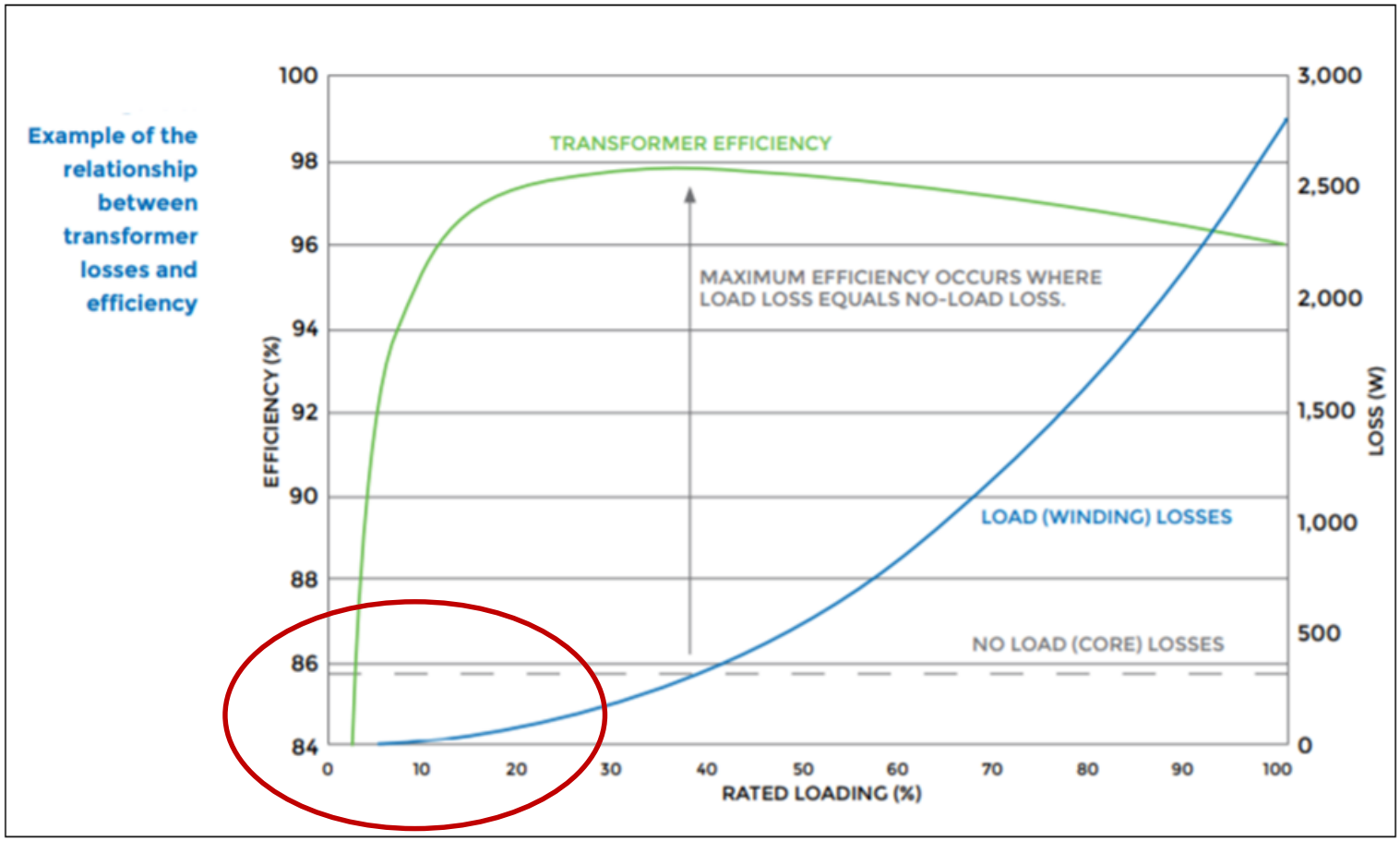
For a 1,000 kVA unit

Rating (kVA)	No-load losses (W) Regular Grain Oriented	No-load losses (W) Amorphous Metal	Loss reduction
100	145	65	55%
250	300	110	63%
400	430	170	60%
800	650	300	54%

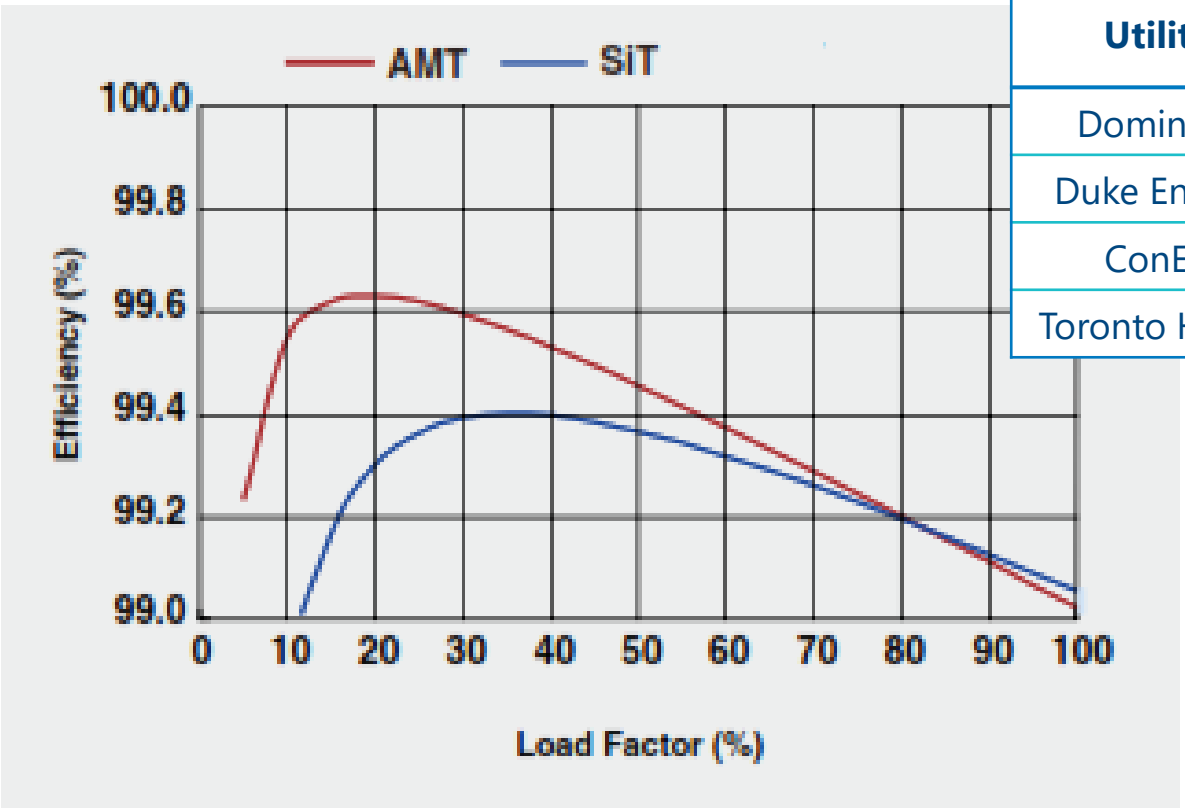
Sources: ABB, Amorphous core distribution transformers, Hitachi, Amorphous Transformers

Transformer Losses versus Loading

Transformer No-load and Load Losses versus Loading



Amorphous Core Transformer Performance

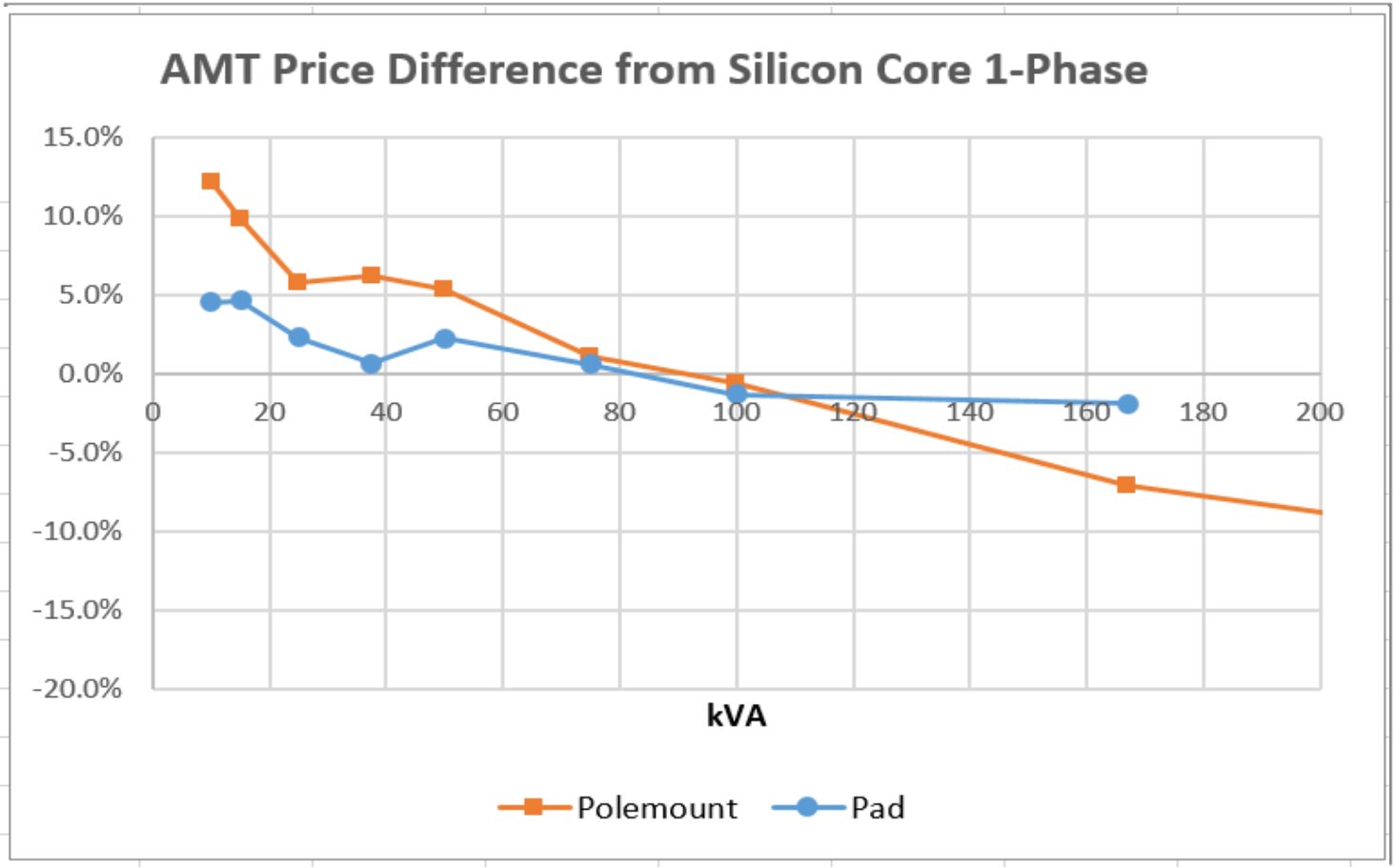


Utility	Transformer Per-Unit Load, %
Dominion	10%
Duke Energy	15%
ConEd	26%
Toronto Hydro	24%

Source: Hitachi, Amorphous Transformers

Incremental Costs for AMTs: Single-Phase

Incremental Costs for Liquid-Immersed Single-Phase Pole and Pad-Mount Amorphous Metal Transformers (AMT) Relative to Standard Transformers

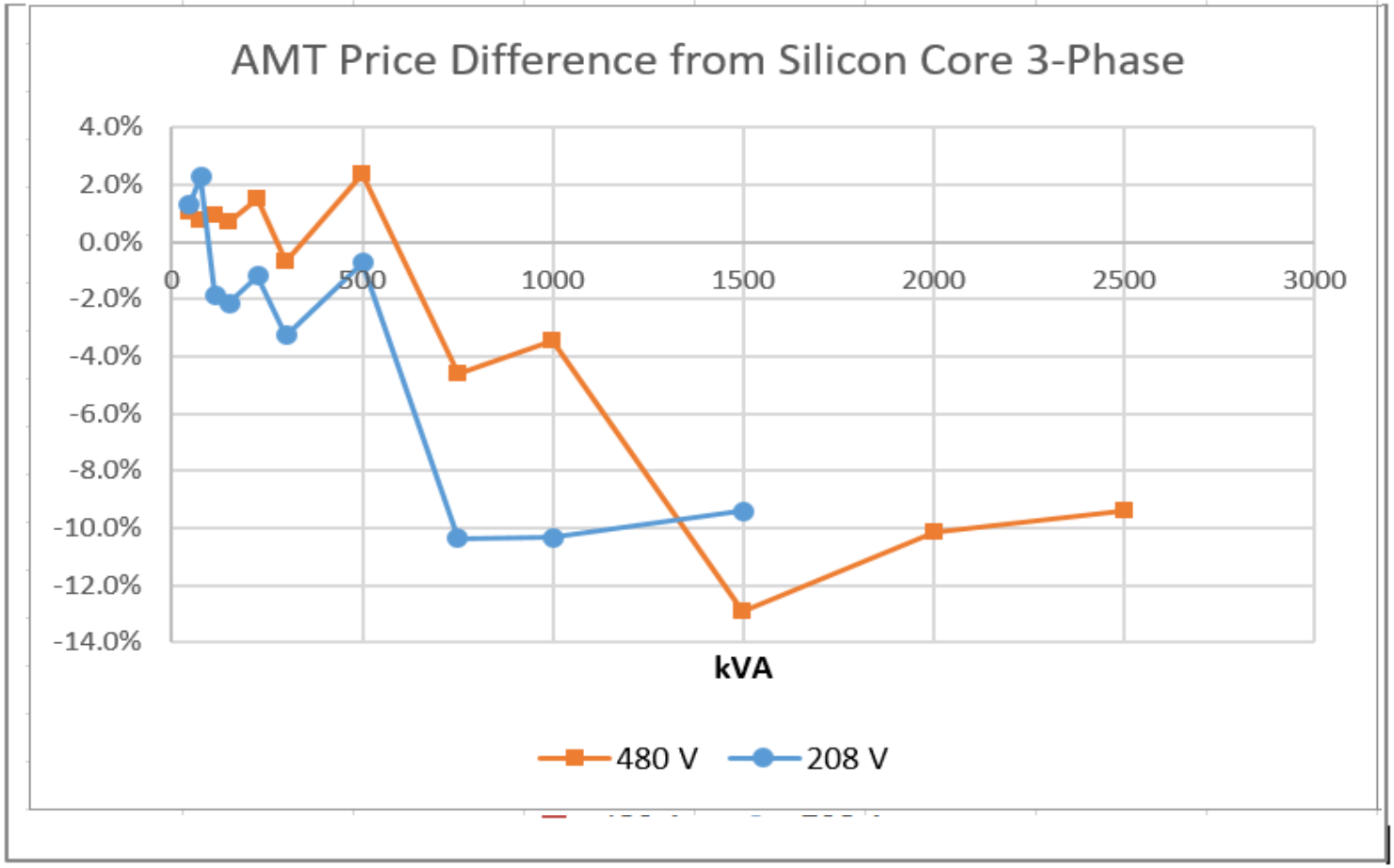


Cost and Performance Data from a major US Transformer Manufacturer

Cost differences are for Transformers that Just Meet the DOE 2016 Efficiency Standards

Incremental Costs for AMTs: Three-Phase

Incremental Costs for Liquid-Immersed Three-Phase Pad-Mount Amorphous Metal Transformers (AMT) Relative to Standard Transformers

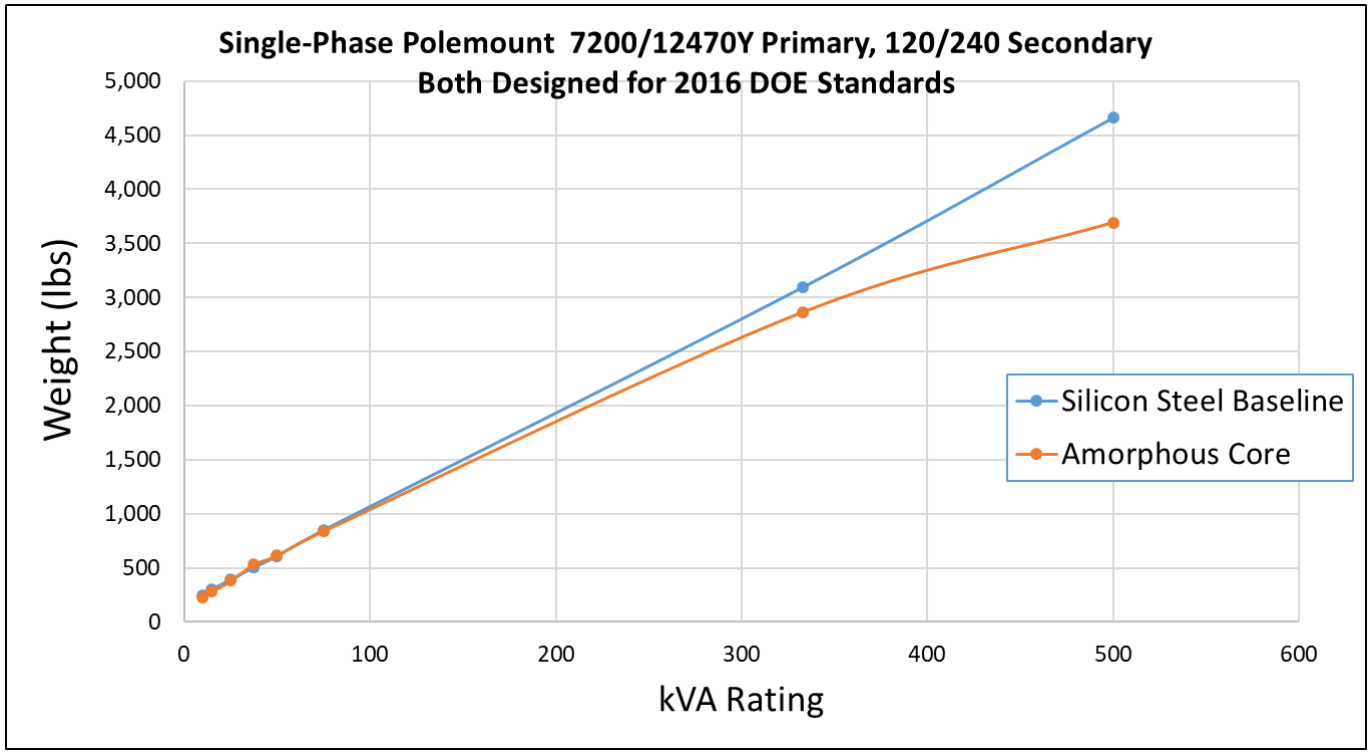


Cost and Performance Data from a major US Transformer Manufacturer

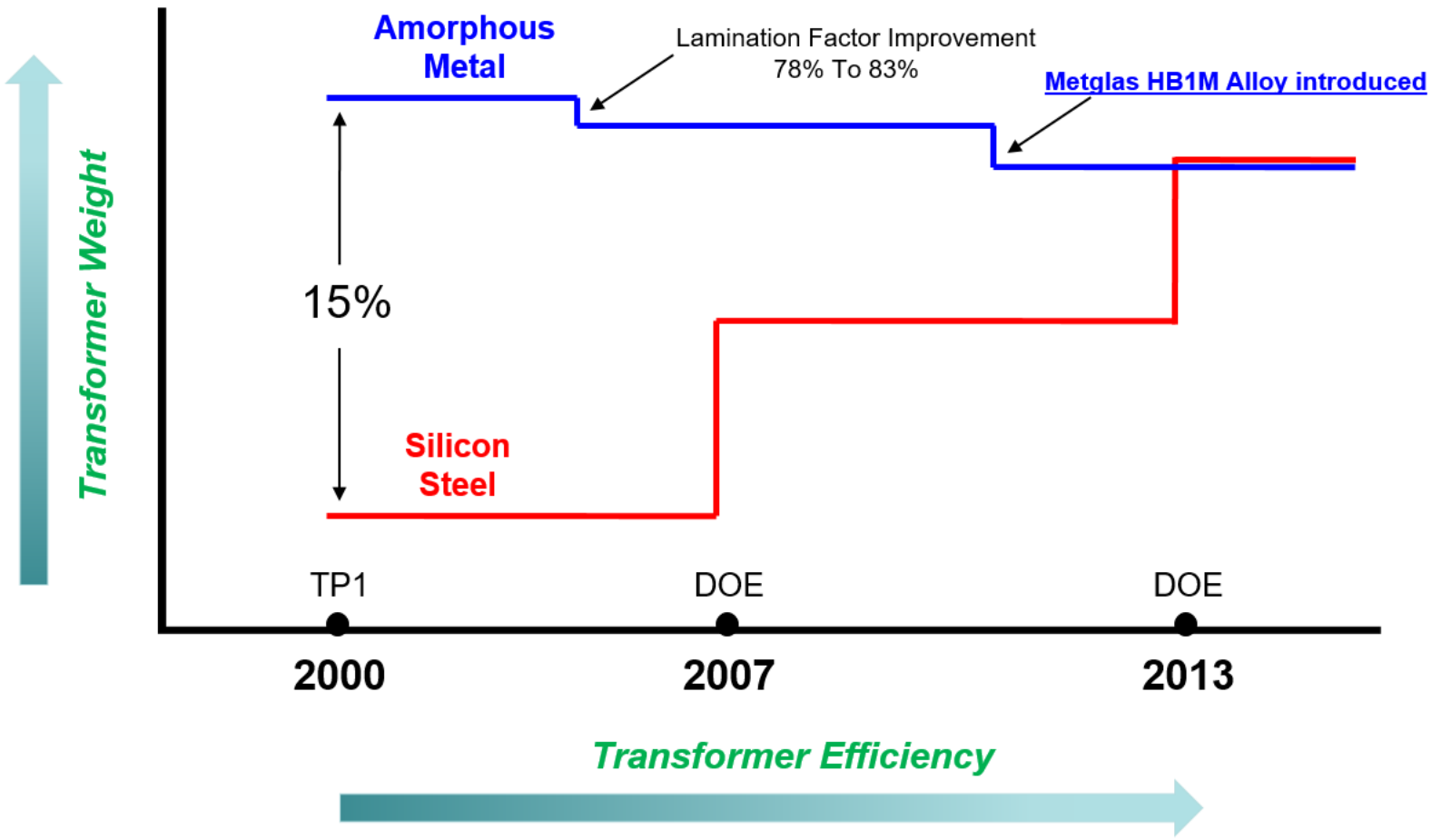
Cost differences are for Transformers that Just Meet the DOE 2016 Efficiency Standards

Comparison of Amorphous Core Transformers

Amorphous core transformers initially were bigger and weighed about 20% more than conventional units. Conventional transformers designed to meet the DOE 2016 efficiency standards have increased weight and manufacturers have improved "steel-to-air gap" ratios for their amorphous core designs. As a result, weight penalties have decreased.



AM Transformer Weight Comparison



From "Metglas Continuous Quality Improvement"

AM Transformer Size and Weight Reduction

- Weight & Volume reductions occur due to:
  - Higher lamination factors
    - flatness and increased thickness of the ribbon
  - Easier manufacturing of ductile material obtained with an improved annealing process

Next Generation	2nd Generation	First Generation
88 min LF	84 min LF	80 min LF
88 SF Design	86 SF Design	82 SF Design
310 kg	335 kg	430 kg
0.119 m^3	0.134 m^3	0.212 m^3

From "Metglas Continuous Quality Improvement"

DOE Rebates for Distribution Transformer Upgrades

DOE to provide $10M in rebates
($5 million each in FY2021 and FY2022)

- This is what we know to date:
  - Single and three-phase oil-filled transformers up to 2500 kVA and installed during 1987 and 2011 are eligible.
  - Incentive is $2/W times the improvement in no-load Watts.
  - DOE will develop no-load loss default tables.

BPA offers incentive funding for energy savings achieved

BPA Incentive for Distribution Transformers

Option 1

- Utilities are encouraged to use Re-conductor Transformer (RT) Calculator, in lieu of C1 custom project

Option 2

- Utilities report savings to BPA via C2 file
- Do not use RT Calculator
- BPA technical staff will provide an Excel file to quantify energy savings

RT Calculator Versions

Current version is: RT_V1-0

- Intended for re-conductor and substation transformer measures
- BPA technical staff can help populate the fields and prepare for submittal

Updated version is: RT_V1-1

- Becomes available April 1, 2021
- V1-0 is retired at that same date
- V1-1 keeps all features of V1-0 and adds:
  - Transformer measures have a quantity entry to support group purchases
- BPA technical staff can help populate the fields and prepare for submittal
- BPA technical staff can migrate V1-0 to V1-1 as needed

Baseline versus Higher Efficiency

- All newly manufactured transformers meet DOE-2016
- BPA recommends utilities request amorphous core submittals along side silicon steel to allow more options
  - Consider alternate bid for AMT: A = $8/W B = $2/W
- Baseline unit is the model that would have been purchased absent BPA incentive
- BPA compares the Baseline model to other models, whether amorphous core or silicon core, and presents energy savings and incentives
- Utility makes final decision on transformer purchase

Transformer Purchase, Storage and Energization

- Booking of energy savings and incentives needs to occur after the subject transformer is installed and serving intended load
- After a group purchase, a utility might submit incentive paperwork to BPA once or twice annually, reflecting installed units
- Incentive calculations need to be performed and coordinated with BPA technical staff prior to purchasing of energy saving transformers but the incentive paperwork can be done following the installation of units

Technical Inputs for Energy Savings

Assumptions to be used in the calculation of energy savings:

1. Annual peak: 50% of nameplate kVA
2. Avg load: 25% of nameplate kVA

We recognize these loadings are generally "high"

We are open to discuss more specific loadings from metered data recorded by the utility for specific projects

Generally, the energy savings incentive is lesser of:

Retrofit:	$0.35/kWh and 70% of incremental equipment cost
New Construction:	$0.25/kWh and 70% of incremental equipment cost

Example Incentive Calculation

- Independent of kVA size, pole or pad, 1-ph or 3-ph
- Incentive is based on annual energy savings and incremental purchase cost
  - Lesser of: energy savings x incentive rate and 70% of incremental cost

Energy Savings Assumptions:

$ 0.25	per kWh/year New Construction	Peak Load	0.5
$ 0.35	per kWh/year Retrofit	Load Factor	0.25
70.0%		Loss Factor	0.091

0.85(LF^2) + 0.15(LF)

					← Relative to Baseline Unit →				
25 kVA , 1-ph, pole	NL Loss (W)	FLL Loss (W)	Purchase Cost	Baseline unit	Cost Incentive cap (70%)	Net Annual Energy Savings (kWh)	Load Savings Only (kWh)	New Const energy cap	Retrofit energy cap
Transformer A	60	340	$ 900	X	N/A	N/A	N/A	N/A	N/A
Transformer B	80	260	$ 1,050		$ 105	-158	17	N/A	N/A
Transformer C - AMT	20	490	$ 1,100		$ 140	318	-32	$ 80	$ 111

Ferroresonance Summary
What is it ?

- What is ferroresonance in power systems?
- Factors affecting system susceptibility
  - Structural factors, particular sensitivity to transformer connections
  - Operational circumstances and conditions
  - Asset dissipation, specifically distribution and service transformers?
- Occurs in circuit configurations resulting in stray capacitance nominally series with a de-energized transformer (ground path almost always present)
- Core configuration affects flux coupling to dead phases
- Available simulation and field study: *approach cautiously!*

Ferroresonance Summary
What is it?

- Spectrum of resonance of power systems is (almost always) lower than the nominal operating frequency
- "Ferro" resonance simply means that the magnetic energy storage element is nonlinear
- Excitations with broad spectrum and sufficient magnitude can result in resonance condition
  - Switching operations, particularly single phase
  - Almost any class of fault
- Persistence of resonance depends on dissipative elements
  - Consumer loads or transformers

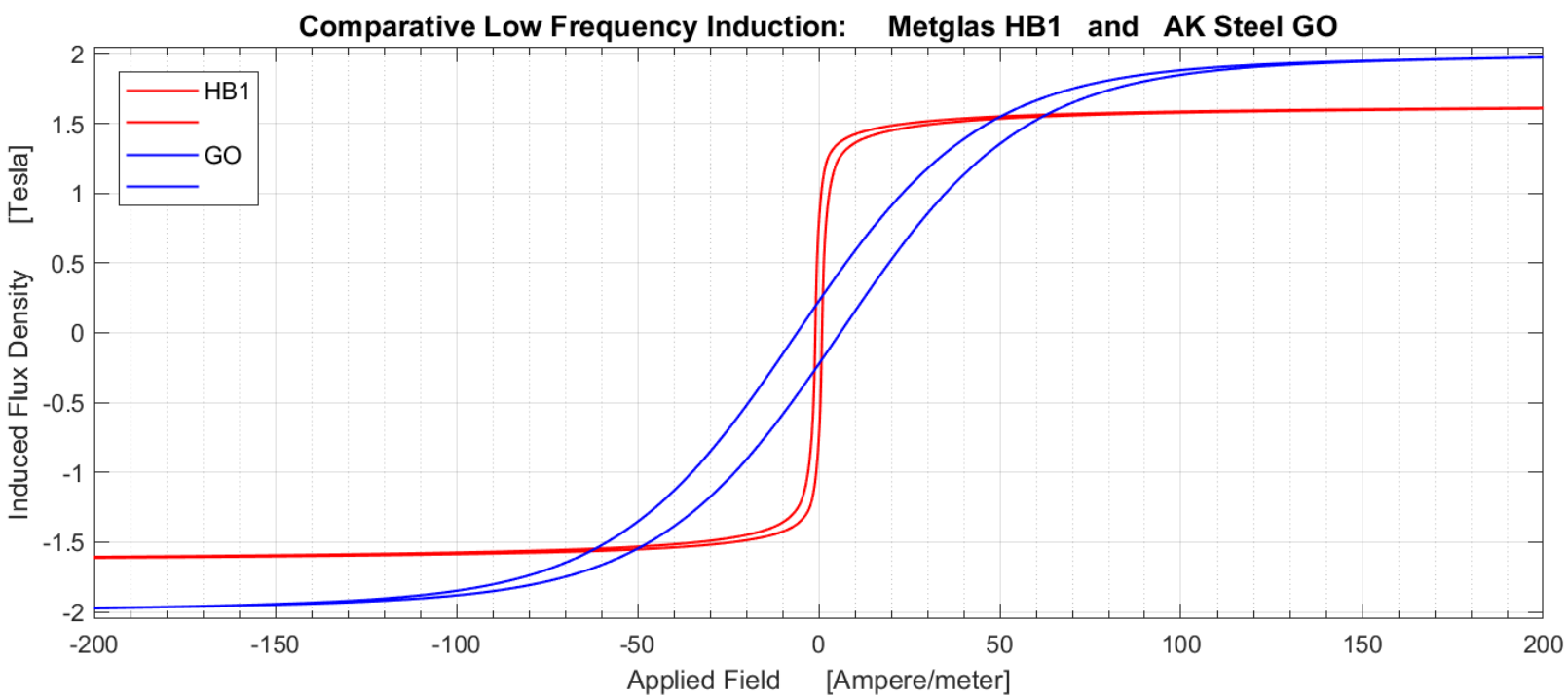
Ferroresonance Summary

- Some loads remain ‘connected’ when nominal voltages at operating frequency vanish
  - Most consumer loads without designed protection
  - Some loads effectively disconnect
- Some load elements remain, collectively contributing to dissipation greater than that of transformer no-load loss
- Amorphous metal core transformers do not significantly increase the probability or severity of ferroresonance incidents

System Harmonics

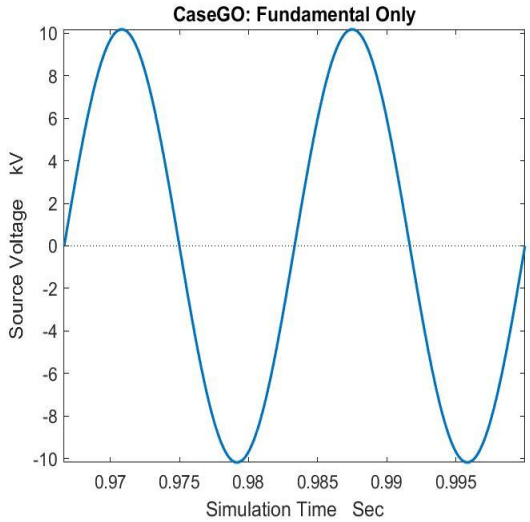
- Primary harmonic voltages originate in current harmonics from both consumer loads and transformer excitation
  - Mainly switch-mode consumer (and industrial) devices
  - Induction nonlinearity in transformer core materials
- Amorphous core materials induction characteristics are similar to some ferrites
  - 'Sharp' transition to saturation
  - Saturation permeability much closer to vacuum than that of SiFe
- Harmonic content of excitation currents greater in Amorphous metal than in SiFe GO cores

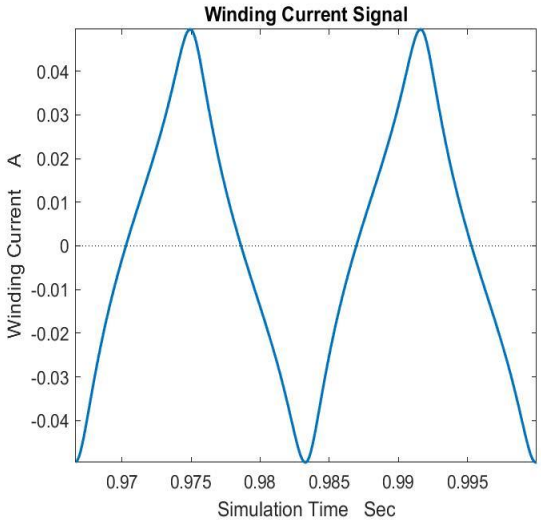
System Harmonics: Comparative Induction

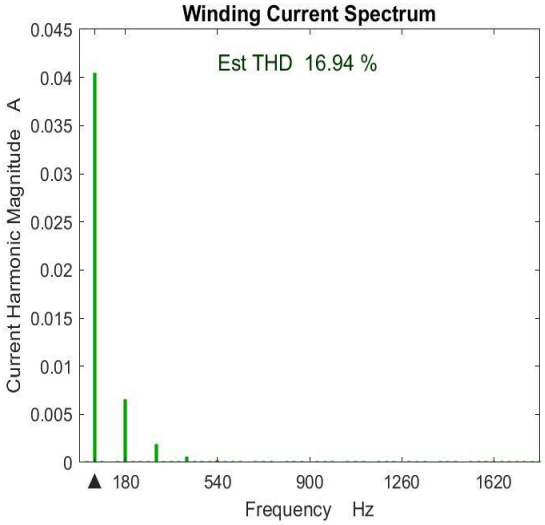


System Harmonics: SiFE GO No-Load Current

25kVA 7.2kV 1ph transformer

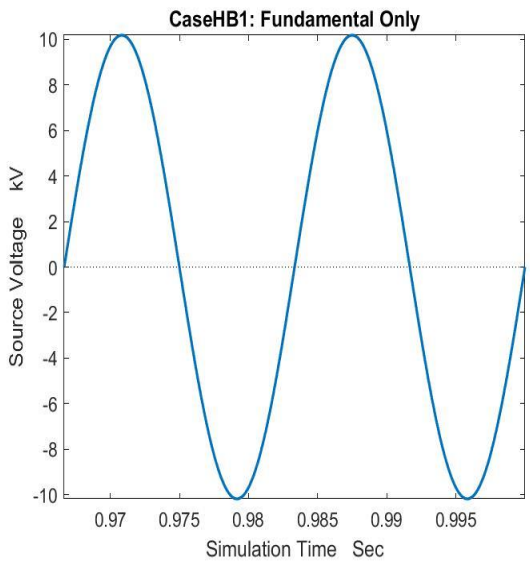


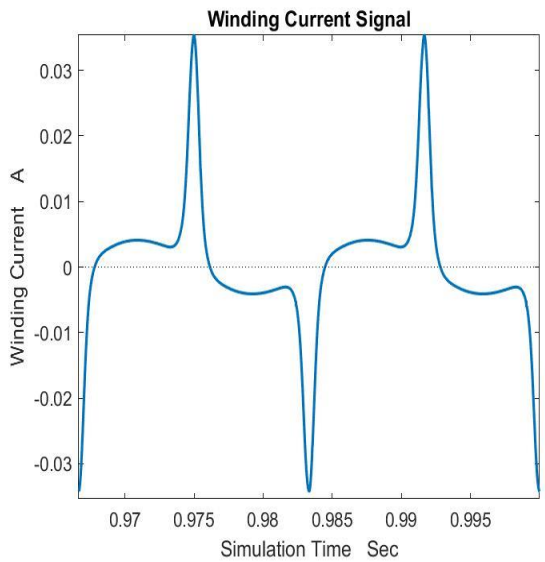


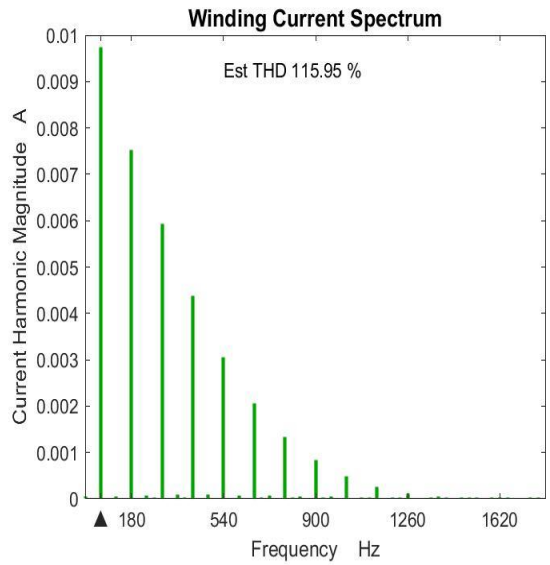


System Harmonics: Metglas HB1 No-Load Current

25kVA 7.2kV 1ph transformer



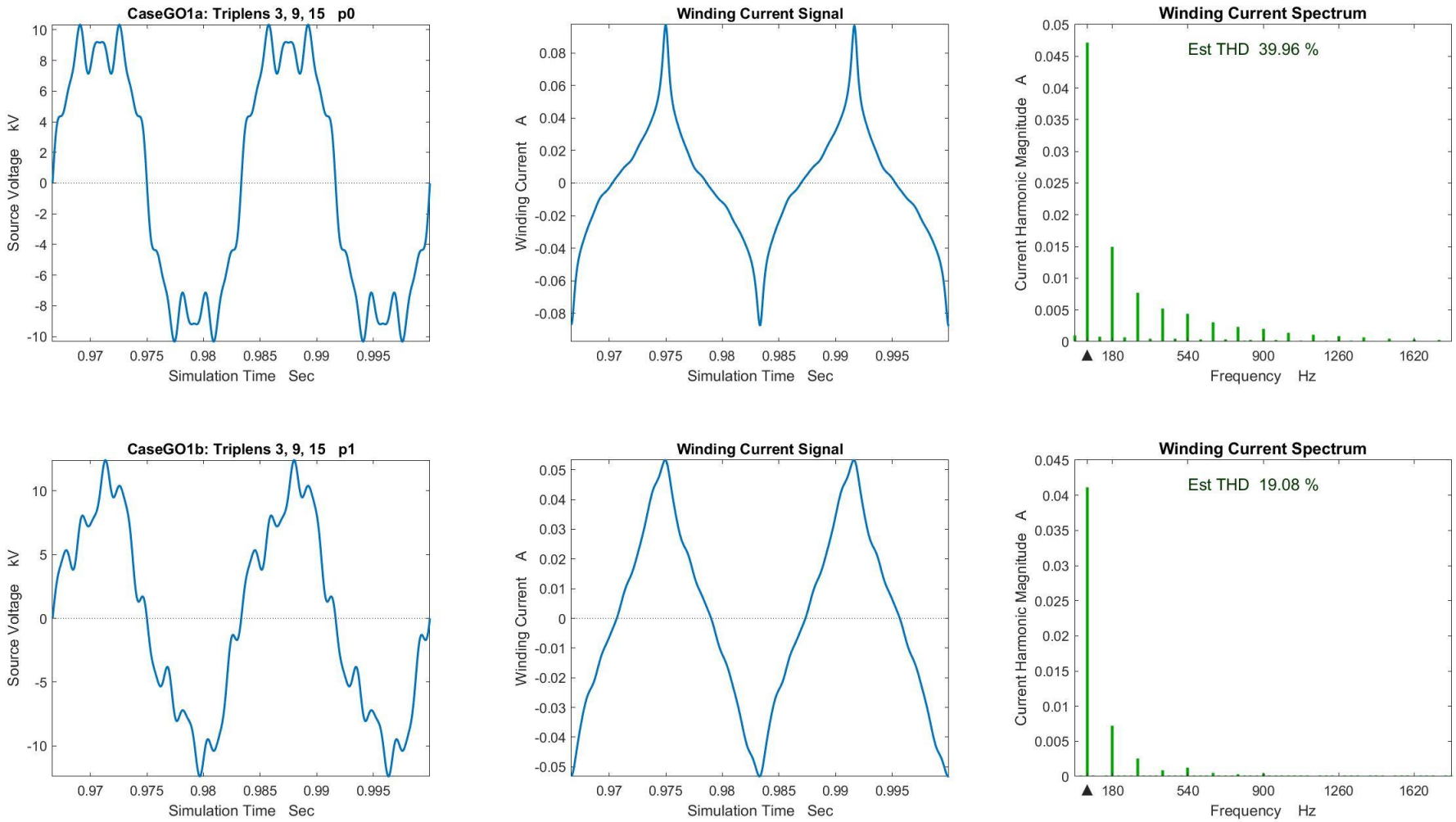




System Harmonics

- Beware non-specific claims regarding harmonic currents
  - Harmonic attenuation (dissipation!) in transformers depends on:
    - Winding material and cross section geometry (skin effect)
    - Frequency dependent core material induction (BH)
    - Core material resistivity and structure (eddy vs freq)
    - Connection
  - Induction nonlinearity
- Induction losses depend on harmonic spectrum, both amplitude and <u>phase</u>
  - Induction response dependent on rate of change of applied field, thus sensitive to waveform of applied voltage

System Harmonics: Effects of harmonic phases



Amorphous Core Transformers at BC Hydro

Madeleine Schaefer, Distribution Standards Engineer

Mike McMinn, Trades Training Instructor

January 28, 2021

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Agenda

- Background on BC Hydro
- Application of amorphous core
- Transformer details
- Lessons learned

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Background on BC Hydro

- Owned by the province of British Columbia
- 1.9 million residential, commercial, and industrial customers
- 342,700 distribution transformers
    - 280,000 overhead
    - 47,600 1ph pad mount
    - 15,000 3ph pad mount
    - 100 submersible

Safely provide **reliable, affordable, clean** electricity throughout B.C.

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Application of Amorphous Core

- Overhead transformers up to 100 kVA
- Benefits:
  - Lower core losses (60% reduction)
  - Lower life cycle cost
- Drawbacks:
  - Increased unit cost
  - Increased mass and height
  - Higher sound level

Timeline:
2009 – 25 kVA transformers
2017 – 50 kVA and 75 kVA
2018 – 10 kVA and 100 kVA

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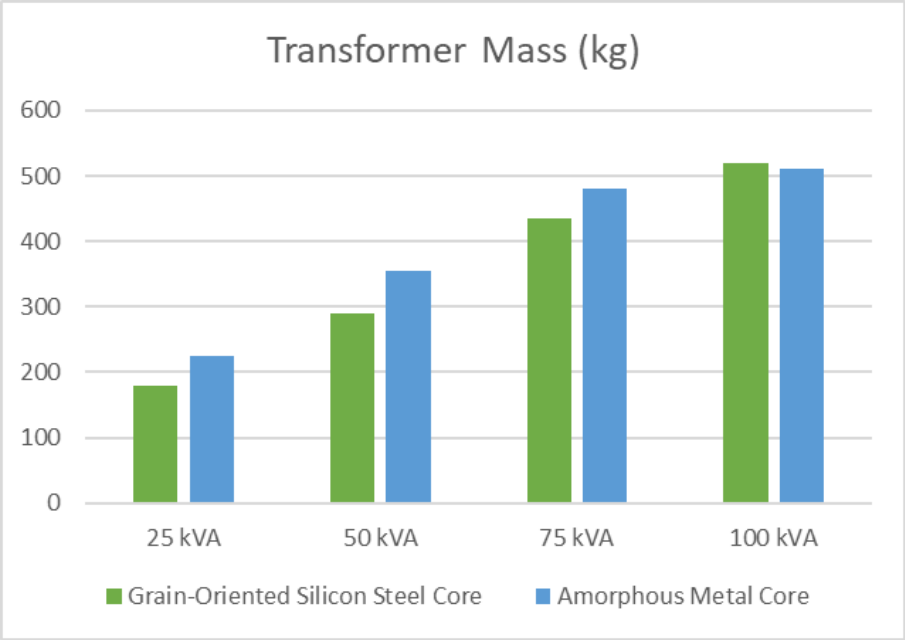
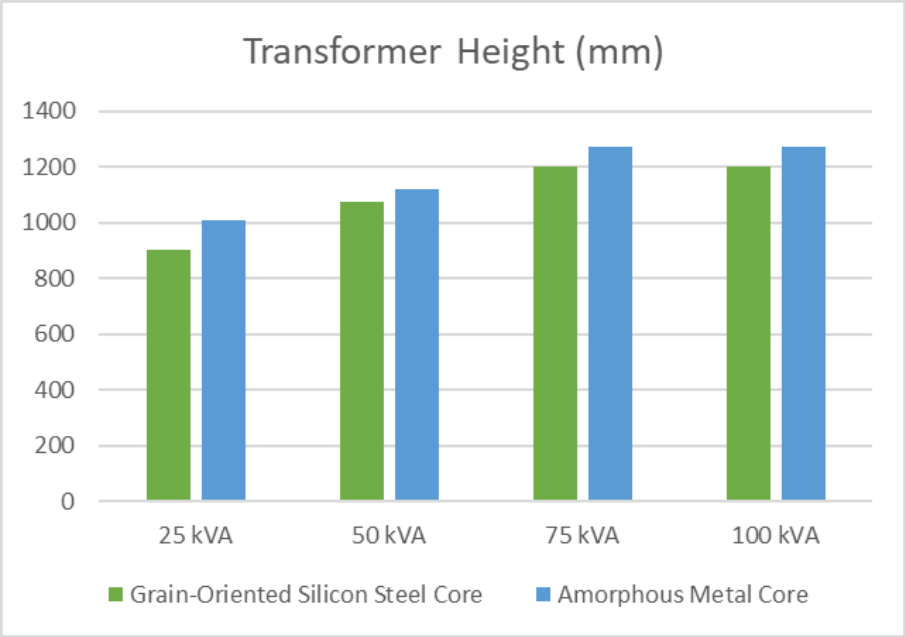
Transformer Details





Typical increase in **mass** between:

45 kg and 65 kg

(100 lb and 140 lb)

Typical increase in **height** between:

45 mm and 110 mm

(1.77” and 4.33”)

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Lessons Learned

- Build experience slowly
- Identify amorphous transformers on nameplate or with decal
- Request amorphous and grain-oriented silicon steel proposals

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Lessons Learned

- Understand impact of increased sound
  - 50 kVA increased from 37 dBA to 43 dBA (limit is 48 dBA)
  - Variability in sound
  - Engage customer call center early
- Understand impact of increased weight
  - Locations without truck access
  - Pole class

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THANK YOU!

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