ENVIROTEMP™ NATURAL ESTER FLUID

Formulated for performance.

Envirotemp™ FR3™ Natural Ester Transformer Fluid Overview

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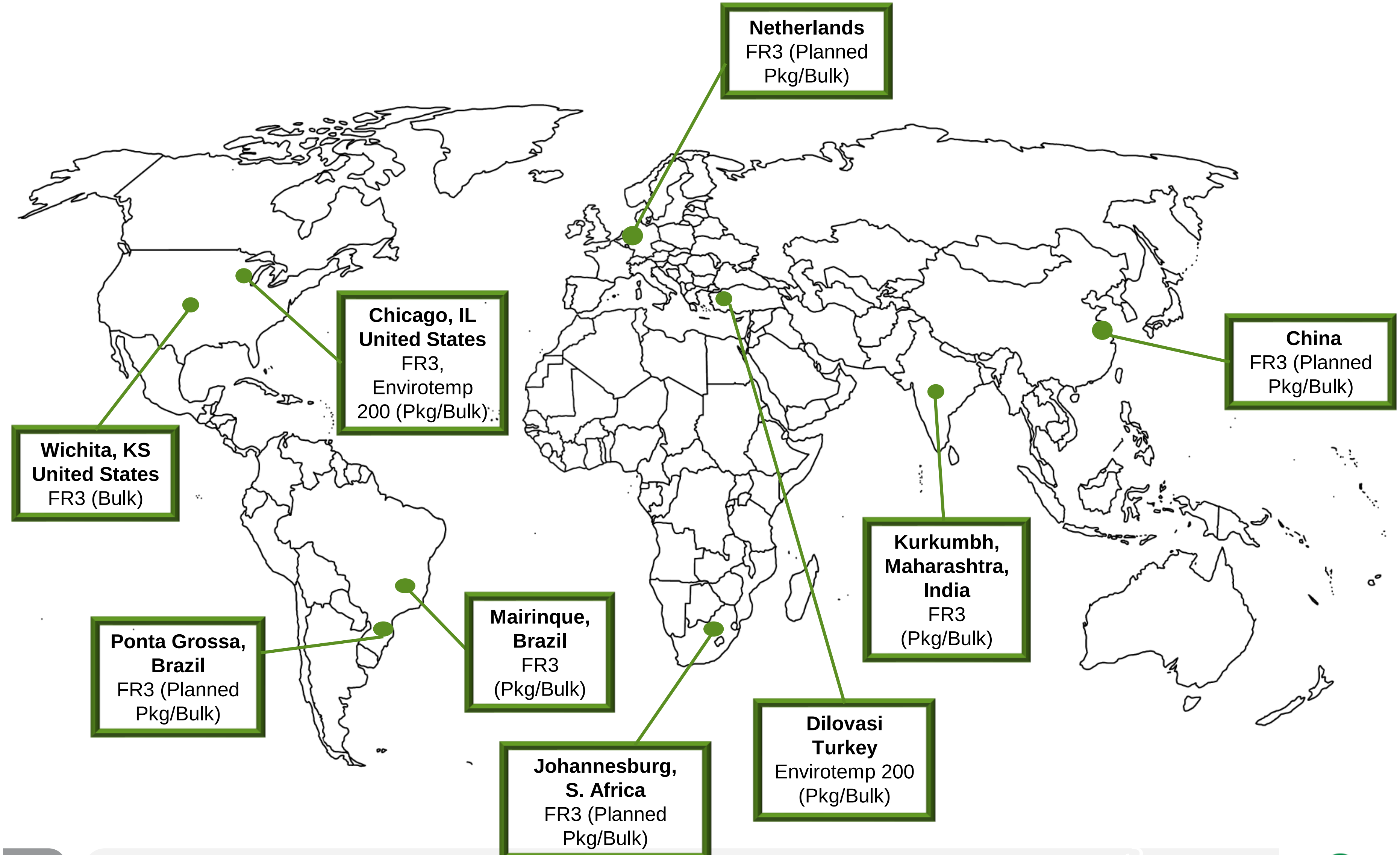
Global producer of natural and synthetic ester transformer fluids

Cargill dielectric fluid production sites



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ENVIROTEMP™ NATURAL ESTER FLUID

FR3 fluid designed to deliver:

1. **Cost efficiencies, optimized transformer performance, grid reliability**
   - **Extend insulation system life**
   - **Increase loadability**

2. **Increased fire safety**

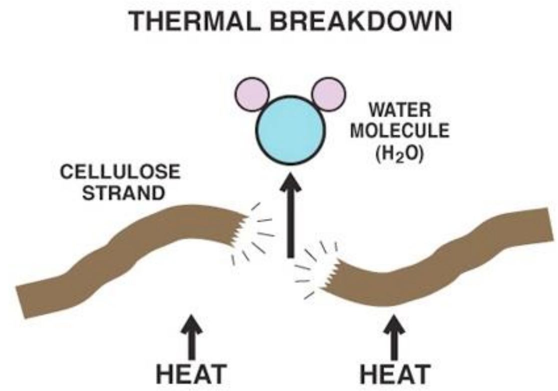
3. **Improved environmental footprint with best-in-class environmental properties**

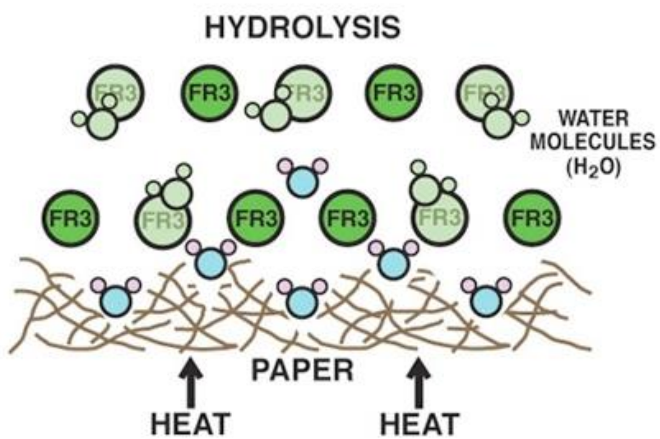
FR3 Chemistry

Insulation system aging process

Degradation Process

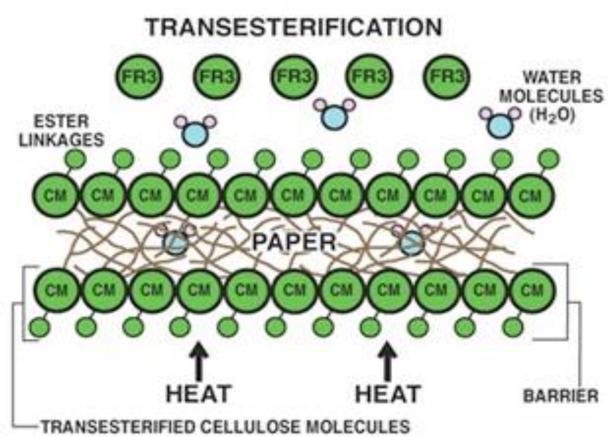
- Heat breaks chemical bonds of cellulose molecules
- Higher the heat, faster the process
- Byproducts of breaking down cellulose is water





Hydrolysis

- Hydrolysis of natural ester “consumes” the water and produces fatty acids. This process removes dissolved water
- FR3 Fluid is ‘self drying’. Water concentrations in the fluid will be reduced due to hydrolysis over time.



Trans-Esterification

- Combination ester attaches to weak points of the cellulose.
- Molecules formed by Hydrolysis attach to the cellulose, strengthening the paper.

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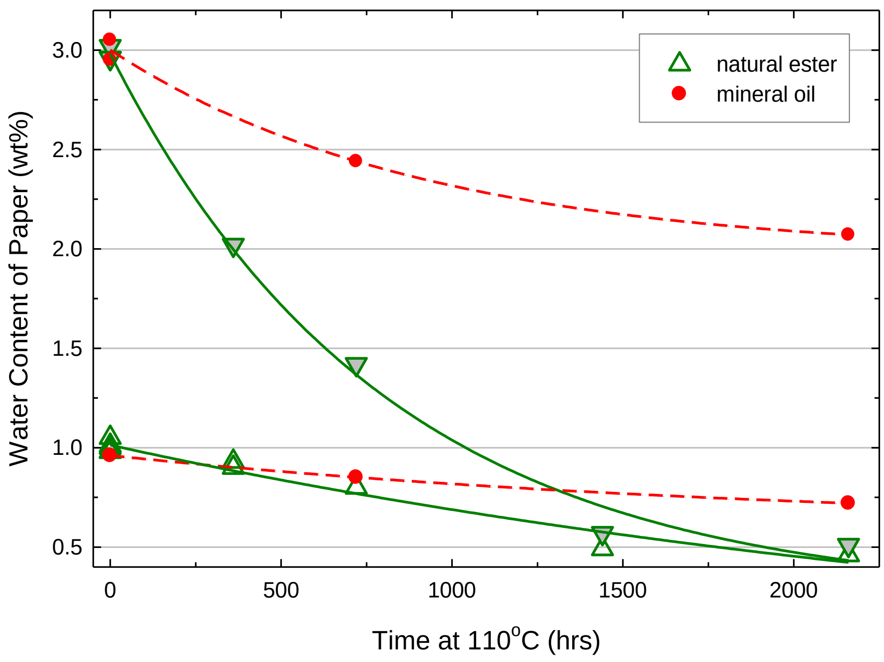
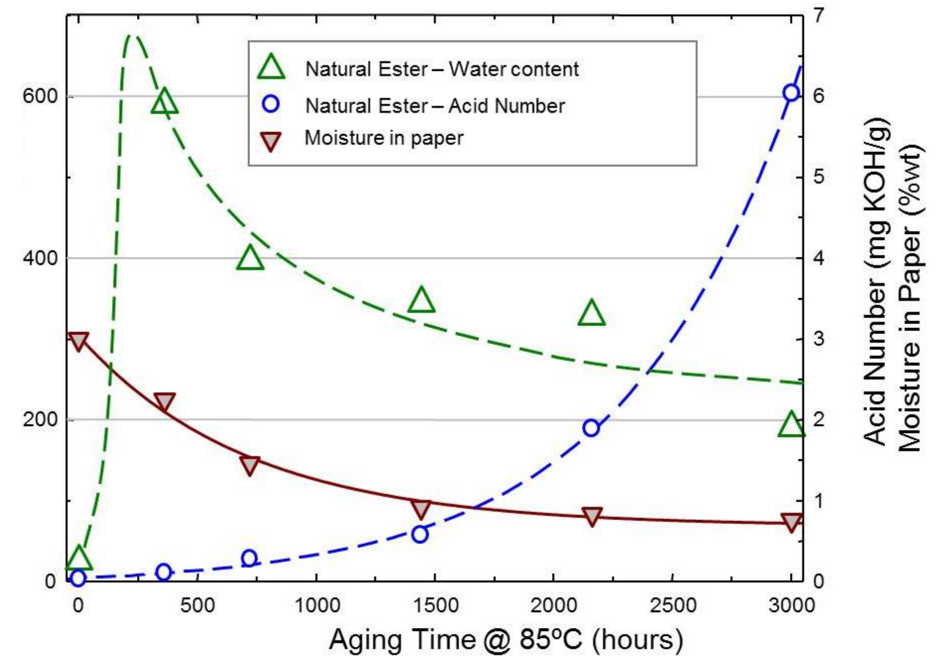
FR3 fluid dries the solid insulation system

WATER EXTRACTED FROM PAPER IS CONSUMED BY THE CHEMICAL REACTION WITH THE FLUID, RESULTING IN CONTINUOUS PAPER AND FLUID DRYING (LONG TERM)

FR3 fluid absorbs water from wet paper



FR3 fluid consumes the water



At nominal operating temperature, FR3 fluid readily absorbs and converts water which slows aging rate, 'drying out' paper

Leveraging thermal properties

- **Degradation rate of cellulose based materials is reduced when immersed in FR3 → Increased Paper Thermal Class**
- **Limitation for max liquid temperature is increased by filling the transformer with FR3 → Increase Liquid Thermal Class**
- **Both solid and liquid insulation of high thermal class.**

This expands transformer's loadability, the base point of:

FLEXIBLE LOADING CONCEPT

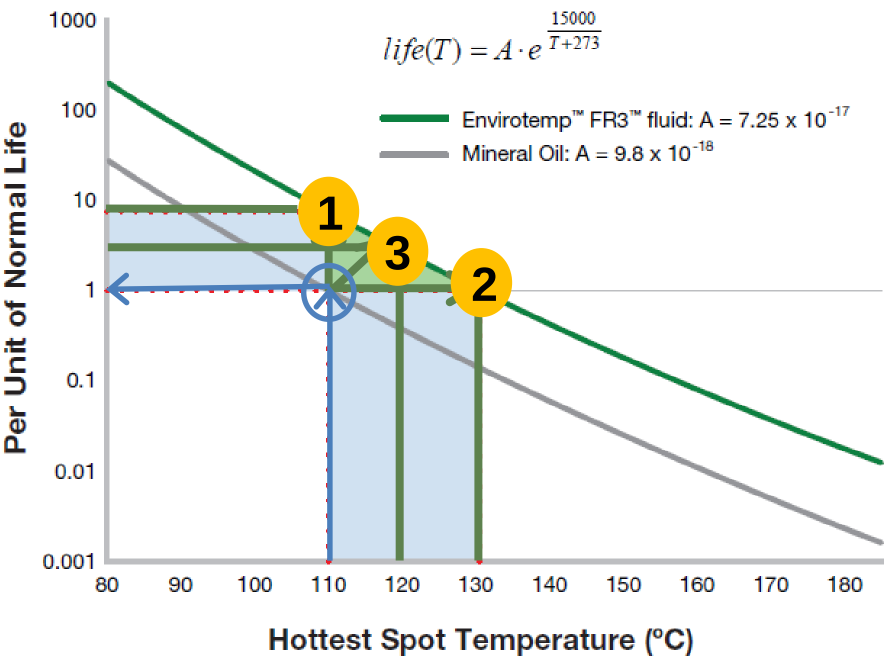
FLEXIBLE LOADING: increase load capacity, extend asset life, or partially both

High temperature insulation system standards

IEEE C57.154 or IEC 60076-14

1. Conventional temperature rise limits = full benefit on **life extension** + reserve capacity for peak
2. High temperature design = full benefit on **high temperature optimization** + extra overloading
3. Some increase of temp rise limits (AWR 75C) = **Some optimization + life + extra overloading**

- Envirotemp™ FR3™ fluid-based insulation systems can be run 20ºC warmer without accelerated life degradition
- Design new transformers smaller with same or more load capacity
- Existing transformers can be upgraded to potentially provide additional load capacity



High temperature curve based on Thermally Upgraded Kraft (TUK) paper

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Leveraging thermal properties for load capacity gains

FR3 Fluid + TUK

=

High Temperature Insulation System

(not a *hybrid*)

Natural esters reduce paper degradation rate 5-8 times slower than mineral oil

AWR = Average Winding Rise / Top Liquid = Top Oil / HS = Hottest Spot.

IEC 60076-14 Informative Annex C	Thermal Class of Insulation Components		Suggestion of temperature rise limits
Insulation System	**Liquid (Oil)**	**Solid (Paper)**	**AWR / Top Liquid / HS**
Kraft+MO	105°C	105°C	65 / 60 / 78 K
Kraft+ FR3 fluid	130°C	120°C	75 / 75 / 90 K
TUK+MO	105°C	120°C	75 / 60 / 90 K
TUK+ FR3 fluid	130°C	140°C	95 / 90 / 110 K

FR3™ natural ester fluid vs. Mineral oil
Sealed Tube Test - IEEE C57.100, Annex B

Improved capacity for overloading

OVERLOADING LIMITATIONS ARE ALSO INCREASED BY THE USE OF NATURAL ESTER LIQUIDS, FOR SHORT AND LONG TERM EMERGENCY CONDITIONS

- Conventional mineral oil design rated at AWR 65°C
- Hot spot 160°C temperature limit is often not achieved because:
  - MO top oil limit (105°C/115°C). Temperatures higher pose the risk of cracking the oil (thermal degradation and darkening of the oil)
  - MO is unable to absorb the moisture at a rate equivalent to the rate which moisture is generated from the paper causing “bubbling” (microbubbles in the oil)

IEC 60076-7 - Loading guide for liquid-immersed power transformers

Table 2 –Maximum permissible temperature limits applicable to loading beyond nameplate rating

Types of loading	Distribution transformers	Large and medium power transformers
Normal cyclic loading		
Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C)	120	120
Other metallic hot-spot temperature (in contact with oil, aramid paper, glass fibre materials) (°C)	140	140
Top-oil temperature, in tank, (°C)	105	105
Long-time emergency loading		
Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C)	140	140
Other metallic hot-spot temperature (in contact with oil, aramid paper, glass-fibre materials) (°C)	160	160
Top-oil temperature, in tank, (°C)	115	115
Short-time emergency loading		
Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C)	See 7.3.1	160
Other metallic hot-spot temperature (in contact with oil, aramid paper, glass fibre materials) (°C)	See 7.3.1	180
Top-oil temperature, in tank, (°C)	See 7.3.1	115

Improved capacity for overloading

OVERLOADING LIMITATIONS ARE ALSO INCREASED BY THE USE OF NATURAL ESTER LIQUIDS, FOR SHORT AND LONG TERM EMERGENCY CONDITIONS

- Conventional mineral oil design rated at AWR 65°C
- Hot spot 180°C temperature limit is often not achieved because:
  - MO top oil limit (110°C). Temperatures higher pose the risk of cracking the oil (thermal degradation and darkening of the oil)
  - MO is unable to absorb the moisture at a rate equivalent to the rate which moisture is generated from the paper causing "bubbling" (microbubbles in the oil)

IEEE Std C57.91-2011
IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators

Table 9— Maximum temperature limits used in the examples in this guide

	Normal life expectancy loading	Planned loading beyond namepla te rating	Long-time emergency loading	Short-time emergency loading
Insulated conductor hottest-spot temperature, °C	120 [a]	130	140	180 [b]
Other metallic hot-spot temperature (in contact and not in contact with insulation), °C	140	150	160	200
Top-oil temperature,°C	105	110	110	110

[a] 110 °C on a continuous 24 h basis (80 °C winding hottest spot rise over a 40 °C maximum ambient).
[b] Gassing may produce a potential risk to the dielectric strength of the transformer. This risk should be considered when this guide is applied refer to Annex A.
[c] The time and temperature limits shown in Table 9 to develop the examples, are appropriate for the system development and system operations philosophy of some companies. Other companies have developed and use other limits that are consistent with their philosophies.

Flexible loading

Why is this important for you?

Understanding the definitions of “Loadability”

Nominal Condition

The “usual” definition of IEEE C57.12.00 for rated loading considers the limit of AWR as 65°C, based on the “unit of life” of TUK paper immersed in Mineral Oil.
Exception may be applied for a High Temperature Transformer, following the IEEE C57.154, as for Compact Loading case.

Additional Capacity

The improved thermal class of the TUK paper (if agreed) increases the nominal life temperature to AWR 85°C (hotspot temperature rise of 100°C).
The extra degrees from the “rated” (either 65°C or 75°C) to the “unit of life” temperature allows additional capacity **without accelerated life consumption** (as per the informative data showed in Annex B of IEEE C57.154 and Annex C of IEC 60076-14).

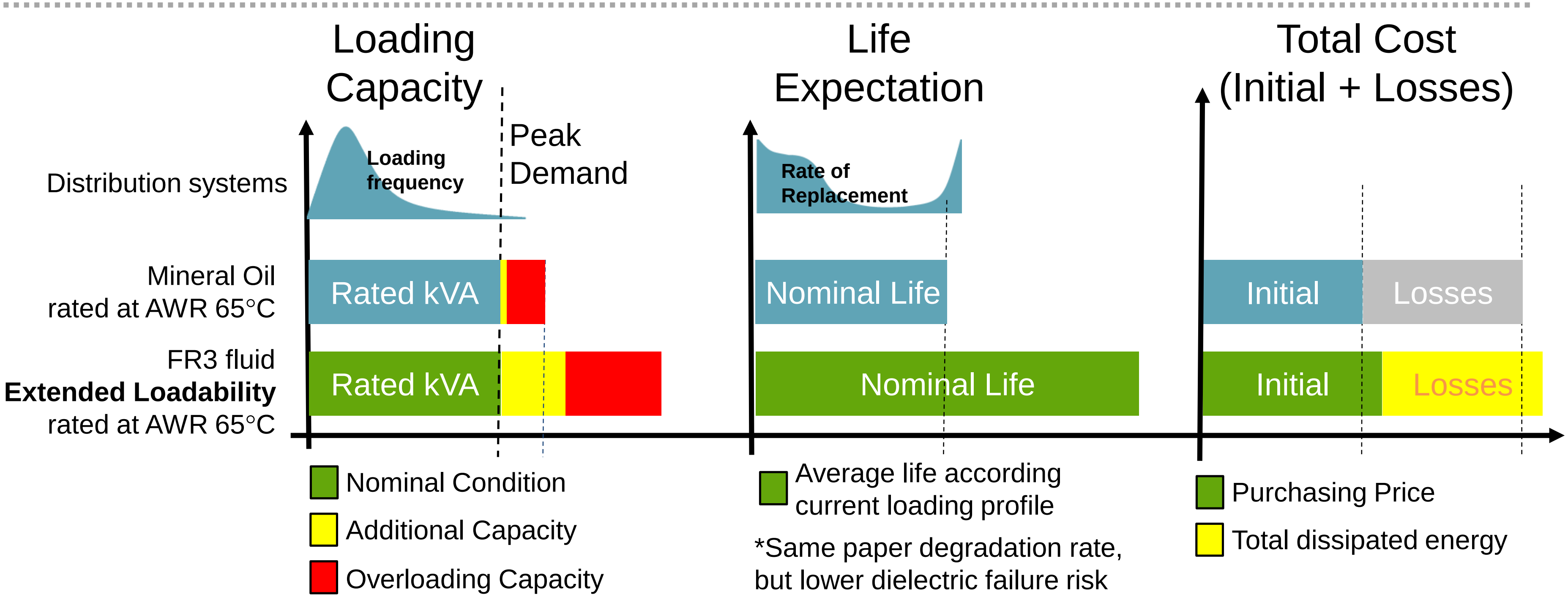
Overloading Capacity

According IEEE C57.91, the effective temperature limits are much superior than the “unit of life” temperature. Each hour at such temperatures represents many hours of “normal life”. Thermal degradation of mineral oil is typically the effective limit for overloading, as this is a permanent effect (darkening of the oil, forming sludge). For natural ester the limit is much superior. Since the risk of bubbling is also mitigated, overloading may be used as a routine for the emergency / peak hours

Extended loadability

Ideal for:
- Life extension – NPV savings
- Postponing replacement due to increasing demand
- May prevent extra unit at (N-1) condition

- Rated load at AWR 65°C
- Same transformer, only change from MO to FR3 fluid
- Additional permanent capacity ~30% (keeping same lifespan)
- Higher overloading capacity



Example: Consider total cost savings by extending asset life

COMPARE MINERAL OIL 30-YEAR LIFE WITH 40-YEAR EXTENDED LIFE WITH FR3 FLUID

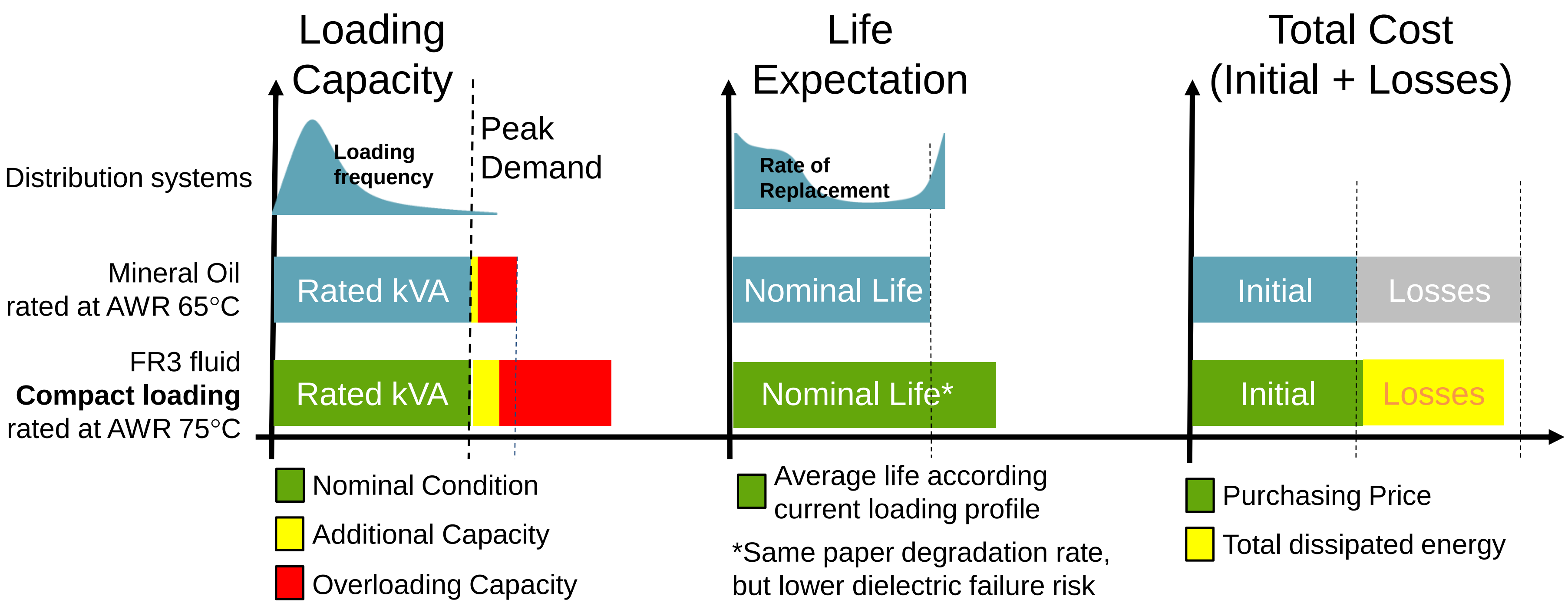
Transformer description	Purchase price	PV TOC with mineral oil dielectric (30-year life)	PV TOC with FR3 fluid (40-year life)	PV TOC difference	Present value benefit over purchase price
15kVA Pole Type	$385	$1,317	$1,187	$130	**34%**
50kVA 1 Phase Pad	$1,102	$3,001	$2,688	$313	**28%**
150kVA 3 Phase Pad	$4,385	$7,967	$7,026	$941	**21%**

Compact loading

Ideal for:

- Footprint and weight limitations
- Competitive initial cost compared traditional mineral oil solution
- Reduction of no-load losses
- Mostly viable for large transformers

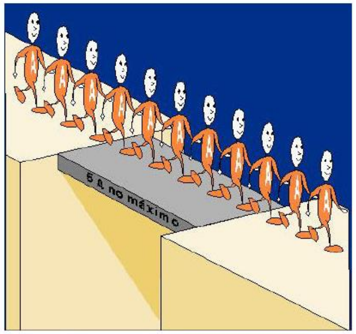
- Rated load at AWR 75°C
- Same nominal rating at higher temperature rise limit
- Optimized to minimal material usage
- Enabling higher capacity with installation or transportation restrictions
- Higher overloading capacity

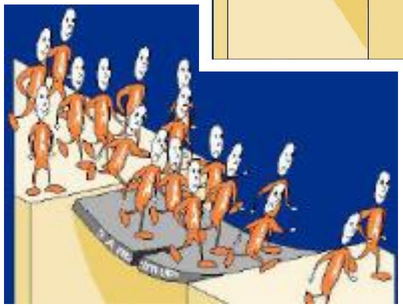


Important Concepts

- The higher temperature limits enhanced by the interaction of FR3 fluid and cellulosic materials is paradigm breaking. New nominal condition.
- Usual “typical values” must be reviewed, since the nominal condition is not the same.
- Applying same Core & Coil as per an overloading condition is not optimization.

Nominal Load





Overloading…

Thermal Optimization

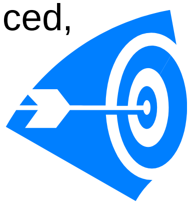
CAN BE ACHIEVED BY INCREASING THE HEAT GENERATION OR REDUCING THE HEAT DISSIPATION

INCREASING HEAT GENERATION

Basic idea is to reduce the conductor cross section, and weight, increasing current density (A/mm^2).

Certainly is the most effective driver to reduce cost, as windings are 35%~40% of transformer cost.

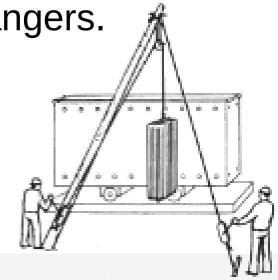
Trend to reduce losses is a limitation, but No Load losses are more critical and can be reduced, compensating partially the increasing of the Load Losses due to higher current density.

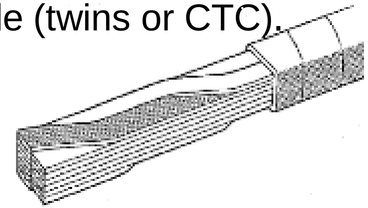


REDUCING HEAT DISSIPATION

When losses are limited, there are alternatives of optimization, always prioritizing the savings on the windings: reducing cooling ducts, using better materials (replace aluminum by copper), increasing the volt/turn to reduce the total quantity of turns, subdivide the cable (twins or CTC).

Reduce the quantity of radiators, capacity of heat exchangers.





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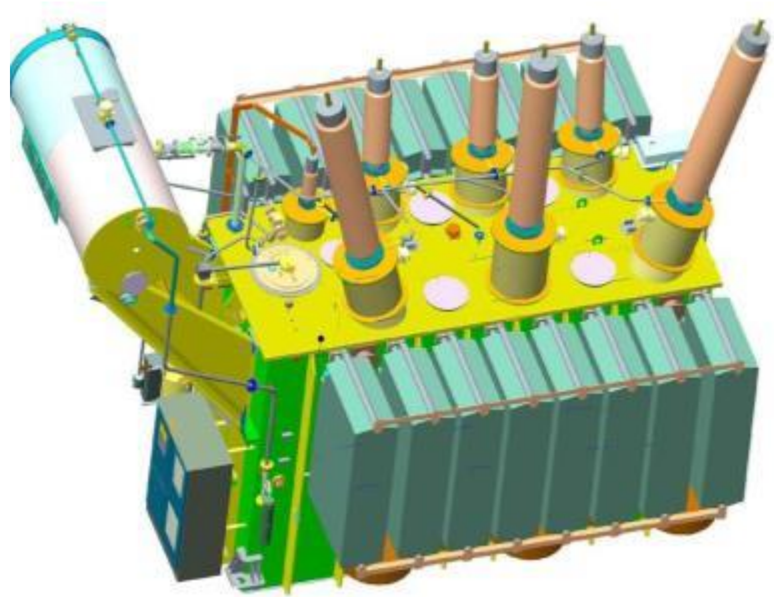
Case Study – 100MVA – 230/69kV

FOUR COMPLETE DESIGNS HAVE BEEN PREPARED FOR COMPARISON OF TOTAL COST AND OPTIMIZATION

A new design has been prepared for each condition:

1. **Mineral oil / TUK paper, limits 65-65-80**
2. **FR3 fluid / TUK paper, limits 65-65-80**
3. **FR3 fluid / TUK paper, limits 75-90-90**
4. **FR3 fluid / TUK paper, limits 85-90-100**

Case	Cost %
1 – OMI at 65K	Nominal
2 – FR3 at 65K	More costly than 1
3 – FR3 at 75K	Approximately same cost as case 1
4 – FR3 at 85K	Less costly than case 1



Client				Standard		Phases	Hz	Instalation	
CARGILL				IEC		3	60	1000m	
Wind	Power			Con.	Relation (no load)	Insulation Level			
	MVA					Applied - kV		Impulse - kV	
	ONAN	ONAF	ONAF		kV	Phase	Neutral	Phase	Neutral
AT	65	80	100	Yo	230 ± 2 x 2,5%	360	120	850	325
BT	65	80	100	D	69	140		350	

Additional comparisons for the case study of 100MVA / 230kV

Case	Fluid Volume	Total Weight	Trpt Weight
1 – OMI at 65K	100%	100%	100%
2 – FR3 at 65K	98%	101%	101%
3 – FR3 at 75K	96%	99%	100%
4 – FR3 at 85K	91%	92%	93%

Case	Total Mass	Mass of Copper	Mass of Core
1 – OMI at 65K	100%	100%	100%
2 – FR3 at 65K	102%	103%	100%
3 – FR3 at 75K	100%	99%	98%
4 – FR3 at 85K	92%	88%	96%

Case	Mass of Tank and Cover	Cooling System
1 – OMI at 65K	100%	100%
2 – FR3 at 65K	99%	100%
3 – FR3 at 75K	95%	94%
4 – FR3 at 85K	88%	89%

Case	Eficiency ref 85°C - 1p.u.	Losses
1 – OMI at 65K	99,677%	100%
2 – FR3 at 65K	99,679%	99%
3 – FR3 at 75K	99,671%	102%
4 – FR3 at 85K	99,648%	110%

Simplified optimization for Wind Generator Step-Up Transformer

Reference is a real produced transformer of 2500kVA - 34.5kV ±2x2.5% / 0,69kV, Dyn1

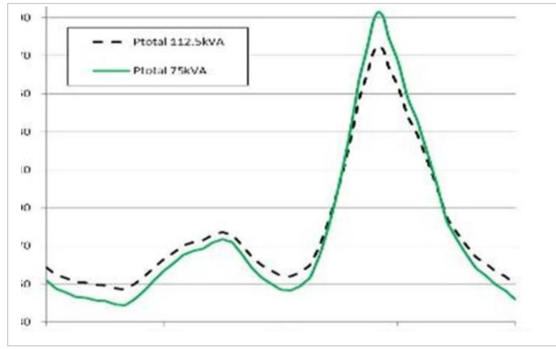
Description	Temperature rise limit of θ_W	Temperature rise limit of $\theta_{O\ MAX}$	Temperature rise limit of $\theta_{W\ MAX}$
Mineral oil filled	65K	65K	80K
FR3 Fluid and TUK paper	85K	90K	100K
FR3 Fluid and Aramid Paper	115K	90K	140K
Dry-Type Transformer	105K	-	115K

Configuration	Cost	Fluid Volume	Total Losses	Volume	Total Weight	Paper Life Expectation (years)
MO + TUK	100%	100%	100%	100%	100%	84
FR3 + TUK	104%	91%	103%	93%	94%	73
FR3 + Nomex	122%	84%	105%	78%	89%	> 1000
Dry Type	180%	-	47%	97%	124%	~90

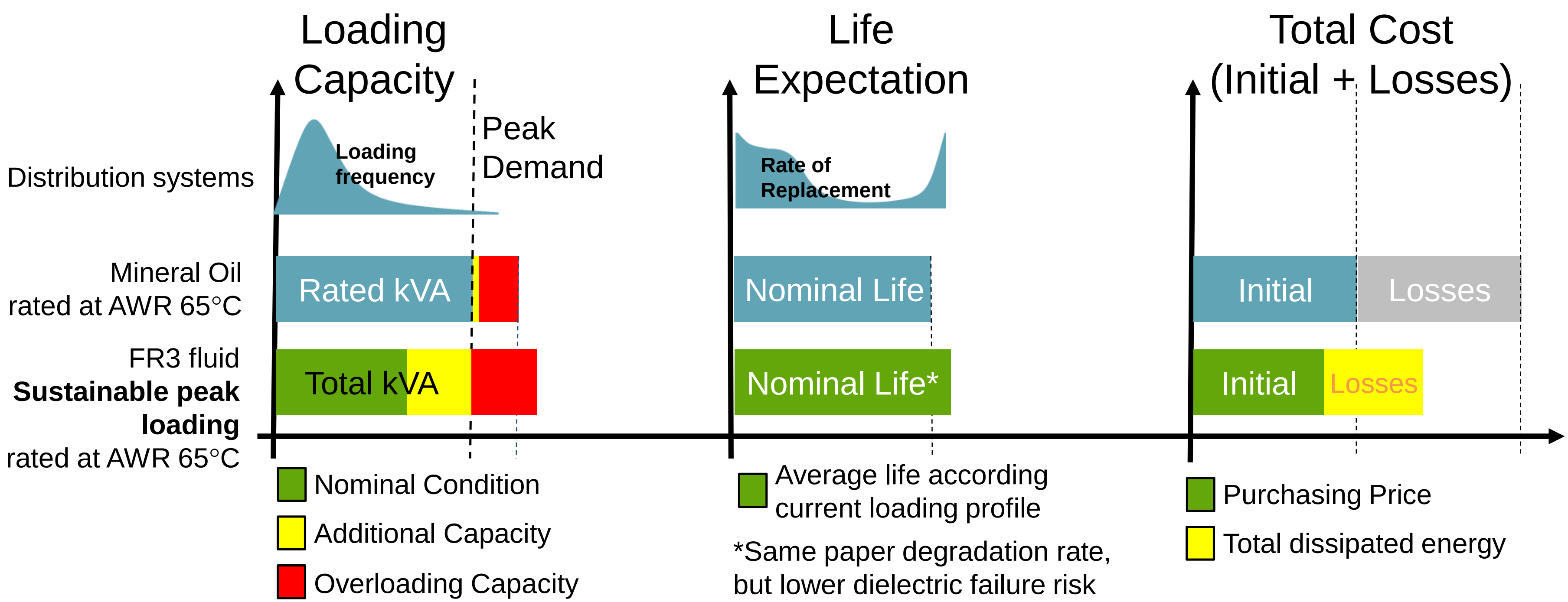
Sustainable peak loading

Ideal for:

- High seasonality on demand curve
- Higher efficiency for average loading
- Smaller nominal rating to match same peak demand
- Savings on total investment



- Rated load at AWR 65°C
- Nominal rating "1 step" smaller, yet permanent capacity matches original rating
- Optimized to loading flexibility
- Lower price, footprint and weight compared to original MO option
- Higher overloading capacity



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Example in USA: Nominal rating ≠ Application rating

	Single Phase Transformer Nominal Power (kVA)							
Nominal Rating	10	15	25	37.5	50	75	100	167
	Max Admissible Loading for Selection							
Acceptable Max Load No additional life consumption	14	21	34	51	63	94	125	200

	Single Phase Transformer Nominal Power (kVA)							
Nominal Rating	10	15	25	37.5	50	75	100	167
	Considered Additional Loading							
Corresponding Percentage	40%	40%	35%	35%	25%	25%	25%	20%

+ Extra Overloading Capacity

Current situation: Nominal rating must match peak demand.

New Proposal: Peak demand can be higher than nominal, due to the increased loadability of the transformers. Average loading would be increased.

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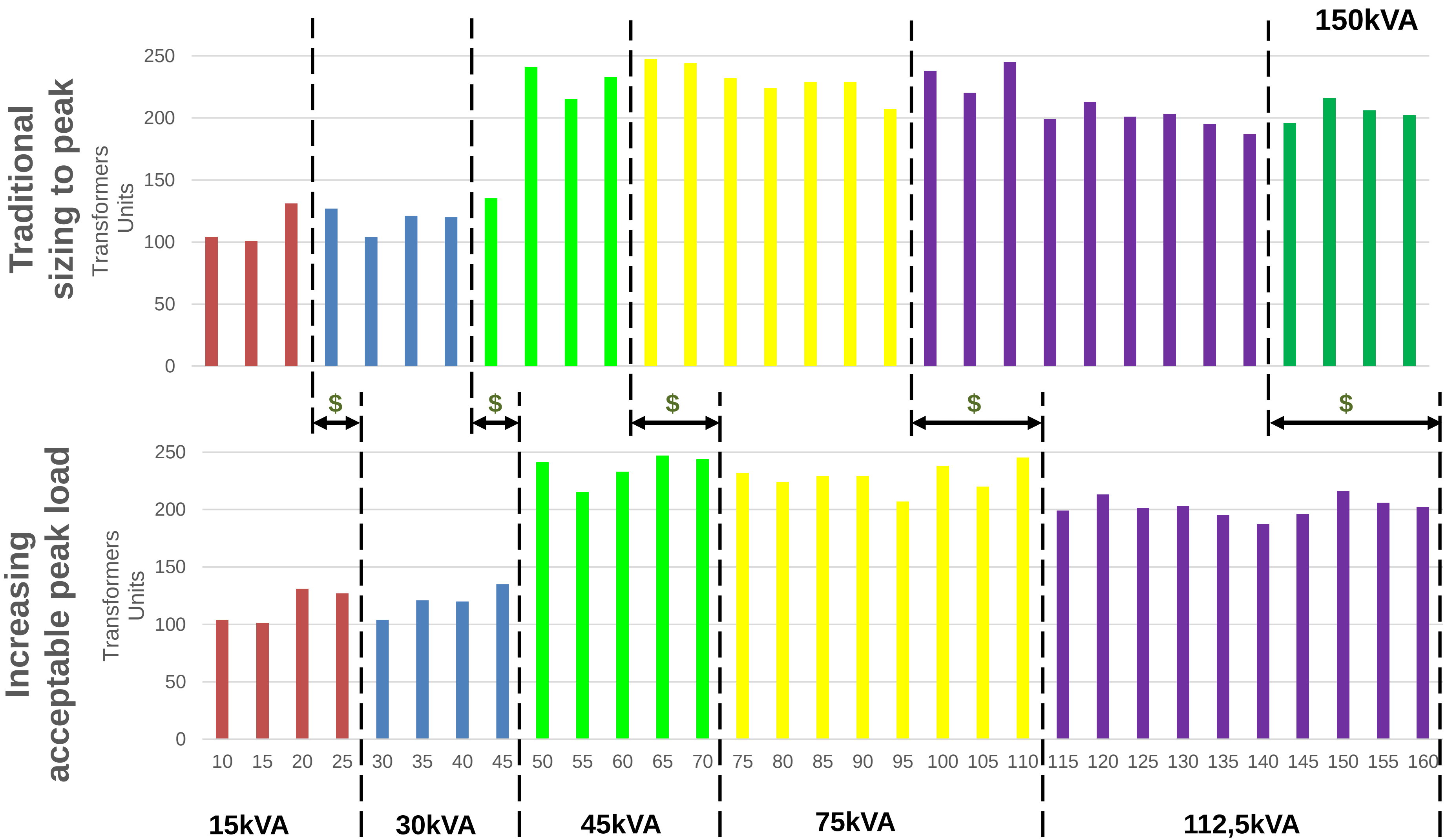
Potential Earnings:
Fulfill the demand buying less nominal kVA's



For the “Lockie Method” tests, full transformers were loaded during long periods high temperature

LOCKIE TEST FOCUS ON ACCELERATED LIFE DEGRADATION OF COMPLETE TRANSFORMERS, INCLUDING ACCESSORIES

Transformers are loaded at 3 different Hotspot temperatures: 167°C, 175°C and 183°C.

Top liquid temperature much higher than nominal for many hundreds of hours.

After the long term ageing, all accessories were verified, as well as the insulation material.

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Can the components handle higher temperature limits?

CASE STUDY: TWO TRANSFORMERS, 37.5kVA AND 50kVA, TESTED FOR HIGH OVERLOADING CYCLES

Component	Results
3 Polymer LV Bushing	No Leaks / Damages
2 Ceramic HV bushings	No Leaks / Damages
PRV (Qualitrol)	No Leaks / Damages
Tap changer Polymeric	“As new” condition
Insulation leads	“As new” condition
Gaskets	“As new” / No change in hardness

	Day	Loading	Duration
37.5 kVA	1	170% = 63.75kVA	4h
	2	170% = 63.75kVA	8h
	3	170% = 63.75kVA	24h
	4	223% = 83.63kVA	1h

	Day	Loading	Duration
50 kVA	1	170% = 85kVA	4h
	2	170% = 85kVA	8h
	3	170% = 85kVA	24h
	4	240% = 120kVA	1h

Source: Temperature rise tests conducted on a 37.5 kVA and a 50 kVA distribution transformer in accordance with IEEE standard 57.12.90, “IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers”. PowerTech Labs. January-February 2017.

Fluid characteristics impact performance capabilities in transformer application

		Mineral Oil	Natural Ester	Synthetic Ester	Silicone Oil
Base Fluid		Petroleum Oil	Vegetable Oil	Hydrocarbons	Polydimethylsiloxanes
Diagnostic Capability		Yes	Yes	Yes	Less
Fire point		160˚C	360˚C	310˚C	340˚C
Biodegradability		Low	Readily	Readily	No
Biobased		No	Yes	No	No
Toxicity		Toxic	Non-toxic, non-hazardous in soil and water	Non-toxic, non-hazardous in soil and water	Toxic
Oxidation	Non-free breathing	Good	Very good	Very good	Very good
	Free breathing	Good	Not applicable	Very good	Very good
Cellulose-based materials aging		Average	Best	Better	Average
Cost		$	$$	$$$	$$$

Fluid differences impact performance

Fluid Characteristics	Mineral Oil	FR3™ Fluid
Transformer performance	65 AWR 110ºC hottest spot	85 AWR 130ºC hottest spot Allows for additional load capacity or life extension
Reliability-dielectric strength	Dielectric strength declines as heat increases due to water saturation	Ability to hold 10 times more water Retains dielectric strength as heat increases Self Drying Hydrolysis “consumes” the water
Fire safety	Flash point 155ºC Fire point 160ºC	Flash point 330ºC Fire point 360ºC
Environmental footprint	Non-biodegradable Costly spill remediation	Non toxic, non-hazardous in soil and water Carbon neutral Readily biodegradable
Field experience	120 years of field experience	20 years of field experience

Technology Comparative Summary

MINERAL OIL
- Low Temperatures
- Diagnostic Testing Capability
- Fires when happen major hazard
- Fire Hazard in Sensitive Areas
- Increasing Environmental Regulation
- Instability of Supply & Price
- Lowest Cost

NATURAL ESTER (FR3 FLUID)
- 100% Fire Safety
- Readily Biodegradable
- Sustainable, Renewable Supply
- Superior Moisture Tolerance
- Extends solid insulation lifespan
- Sealed transformer only
- Diagnostic testing capability
- Higher cost

SYNTHETIC ESTER
- 100% Fire Safety
- Readily Biodegradable
- Best Moisture Tolerance
- Low Temperature
- Superior Oxidation resistance
- Diagnostic testing capability
- Applicable in true free-breathing transformers
- Highest Cost

CAST RESIN DRY TYPE
- Main use Indoor Locations (susceptible to dirt/moisture)
- Higher Temperatures & Losses
- Sensitive to Overload & Harmonics
- Regular Cleaning Required
- Minimal Diagnostic Testing
- Service Life Concerns
- Large size
- Highest Initial & Operating Cost

SILICONE
- Good Fire Safety & Overall Reliability
- Low Temperature
- Not above 36kV
- Less Diagnostic Testing Capability
- Inferior Coolant & Dielectric
- Not Suitable as Switching Medium
- Not Biodegradable
- Higher Cost

Standards

ASTM, IEEE and IEC natural ester standards

	Natural Esters	Mineral Oil
New Oil	ASTM D6871 IEC 62770	ASTM D3487 IEC 60296
Use and Maintenance	IEEE C57.147	IEEE C57.106 IEC 60422
Transformers	IEEE C57.12.00 IEC 60076 series IEEE C57.154 IEC 60076-14	IEEE C57.12.00 IEC 60076 series IEEE C57.154 IEC 60076-14
Loading Guide	*In development*	IEC 60076-7 IEEE C57.91
Dissolved Gases	IEEE C57.155	IEEE C57.104 IEC 60599
Fire	FM Global Property Loss Prevention Data Sheets, 5-4 Transformers IEC 61936-1 Power installations exceeding 1 kV a.c. – Part 1: Common rules	

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High Temperature Transformers Std IEC 60076-14 and IEEE C57.154

BOTH STANDARDS ALREADY RECOGNIZING THE BENEFITS OF NATURAL ESTERS

- IEC 60076-14 brings the following table at the Annex C, where the increasing of the thermal class of paper is clearly stated when paper is impregnated with Natural Esters.
- IEEE C57.154 presents exactly same table at its Annex B
- Ahrrenius parameters are defined (b=15000, a from table)

Table C.2 – Comparison of ageing results

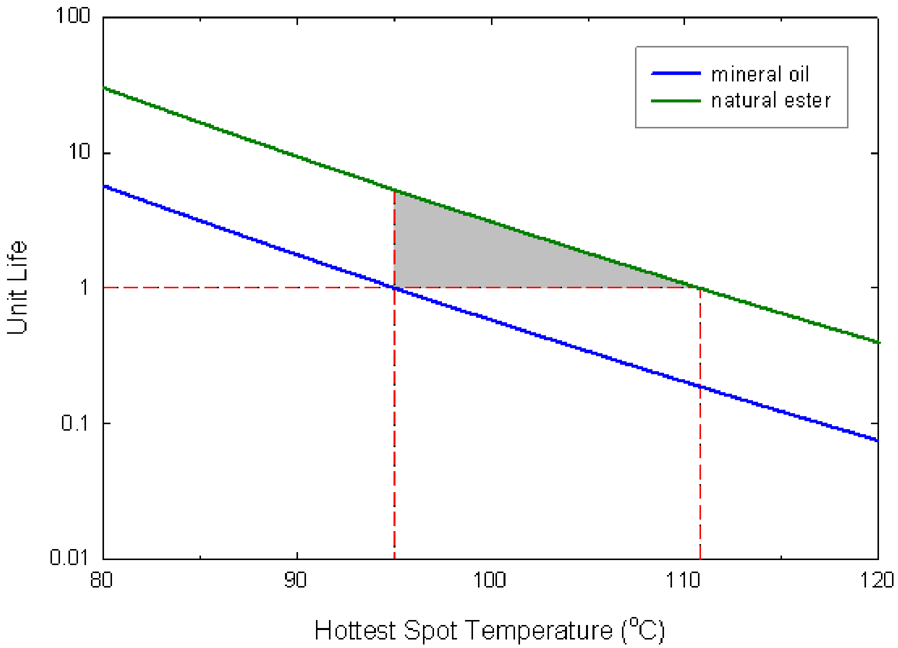
	Constant a	Temperature T °C	Thermal index	Thermal class
IEEE mineral oil/thermally upgraded paper	$9,80 \times 10^{-18}$	110,0	110	120
Natural ester liquid/thermally upgraded paper	$7,25 \times 10^{-17}$	130,6	130	140
IEEE mineral oil/kraft paper	$2,00 \times 10^{-18}$	95,1	95	105
Natural ester liquid/kraft paper	$1,06 \times 10^{-17}$	110,8	110	120

Use high temperature capability to increase load capacity extend asset life or both

High temperature insulation system standards

IEC 60076-14 and IEEE C57.154

- Current standard 95ºC (Kraft) or 110ºC (TUK) hot spot with 55/65 AWR limits (respectively) transformer capability
- Envirotemp™ FR3™ fluid-based insulation systems can be run 15-20ºC warmer without degrading life
- Design new transformers smaller with same or more load capability
- Existing transformers can be upgraded potentially provide additional load capability

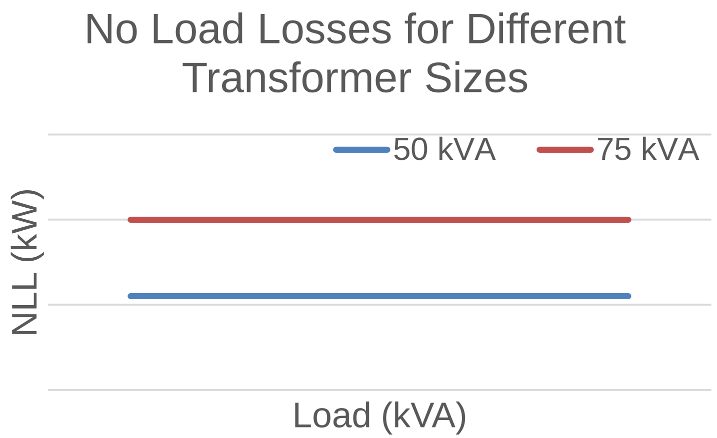


High temperature curve based on standard Kraft paper

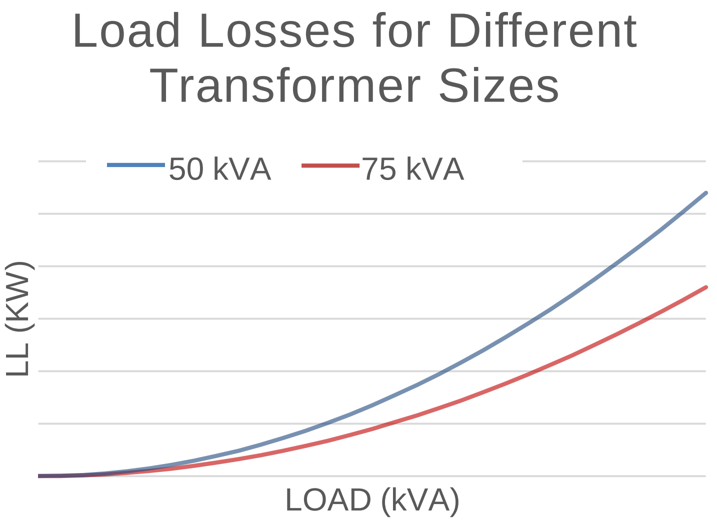
Understanding losses

There are two types of transformer losses

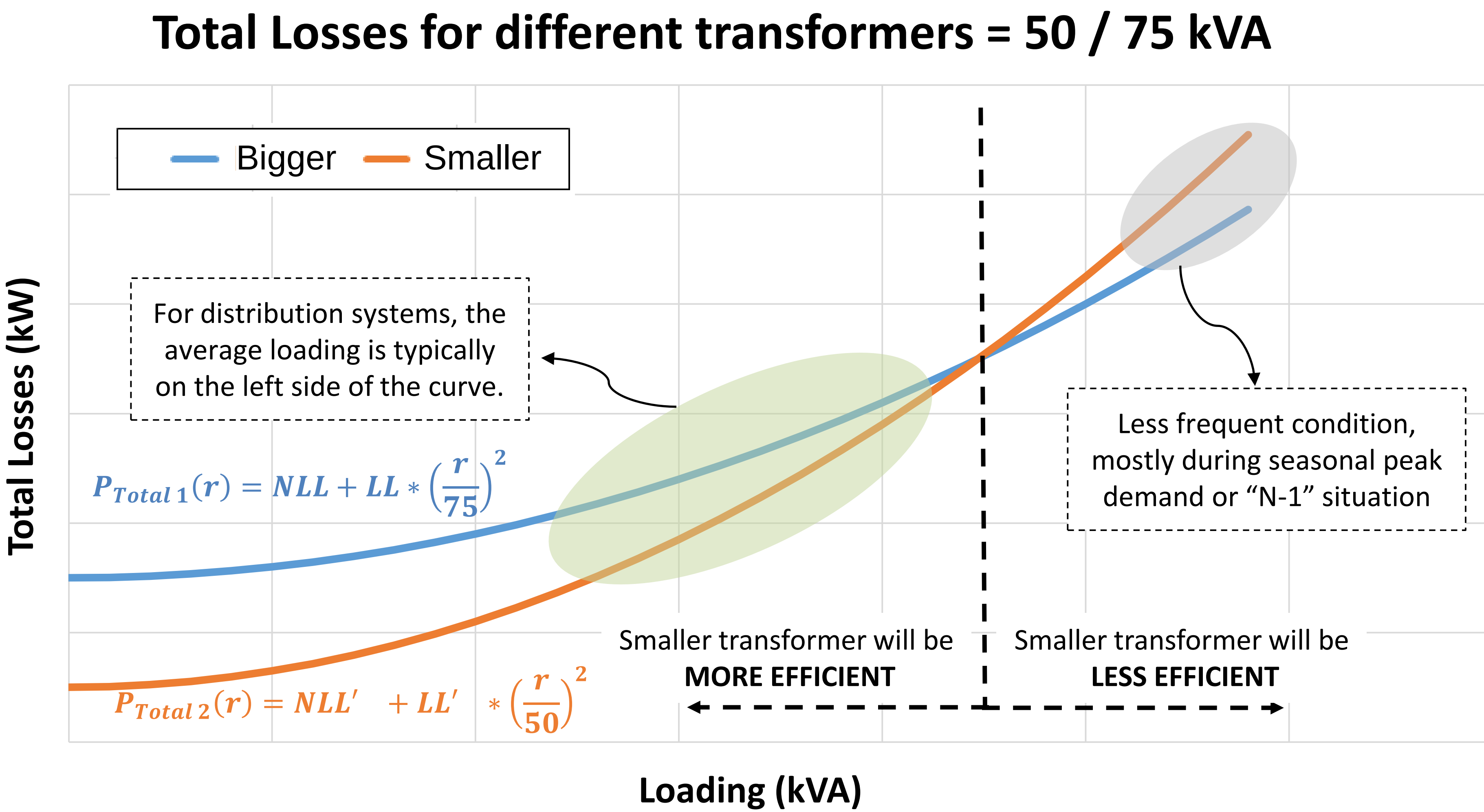
- No-Load Losses (NLL)
  - Eddy losses on core sheets + magnetostriction
  - Remain constant across all loads (voltage dependent)
  - Depend on excitation voltage (minor variation)



- Load Losses (LL)
  - Essentially Ohm's Law (I^2R) + Stray Losses
  - Proportional to the square of the current /load
  - Also depend on temperature (resistivity increases with temperature)

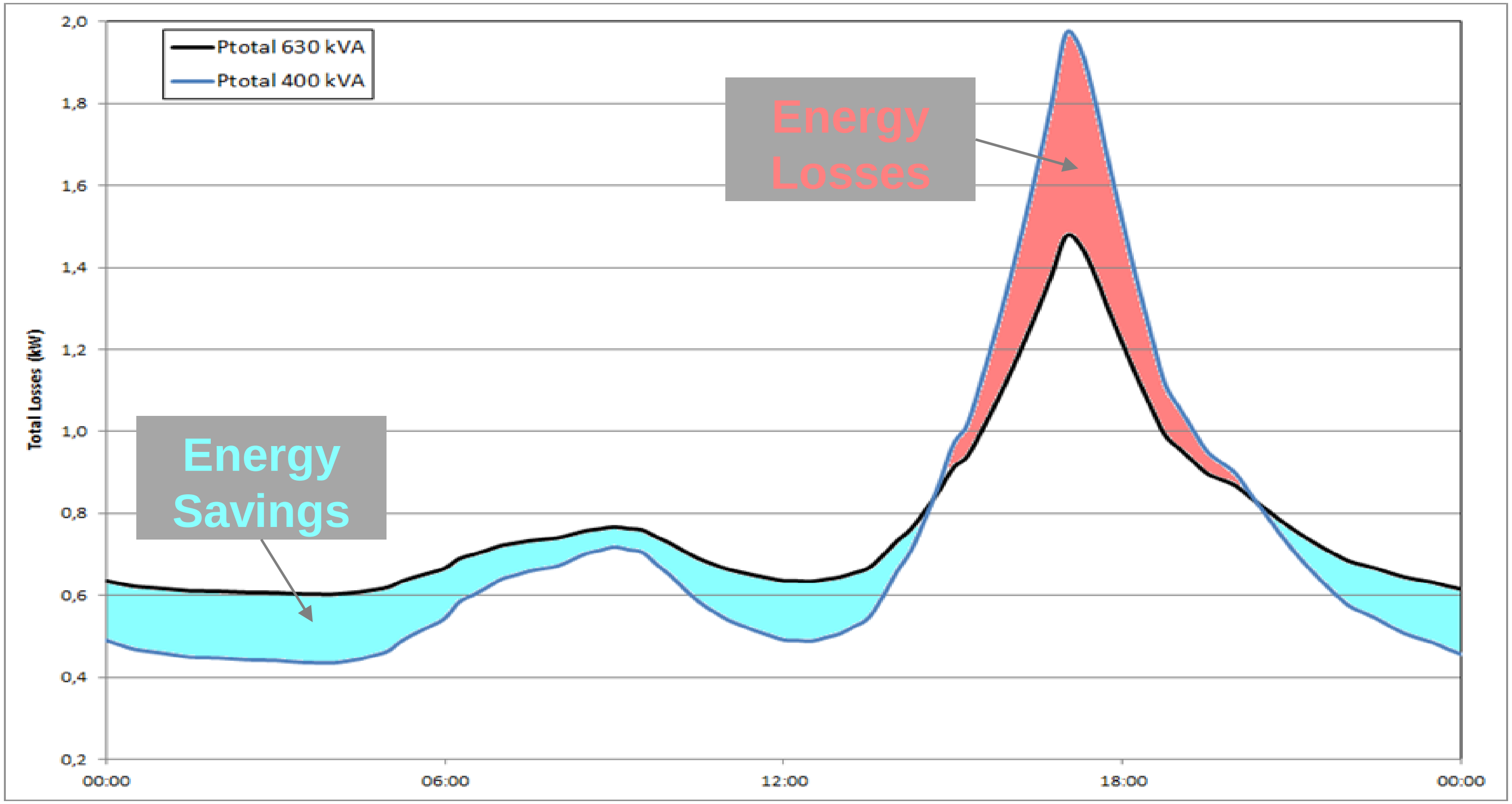


Total losses affected by average loading (loading profile). Efficiency varies with load.



Cargill

REAL-WORLD EXAMPLE



	630 kVA MO	400 kVA FR3 Liquid	Savings	
No-Load Losses (NLL)	600 W	430 W	170 W	28,3%
Average Load Losses (LL) for loading profile	174,6 W	304,5 W	-129,9 W	-74,4%
Average total losses for loading profile	774,6 W	734,5 W	40,1 W	5,2%
Energy dissipated per day	18,59 kWh	17,63 kWh	0,963 kWh	5,18%

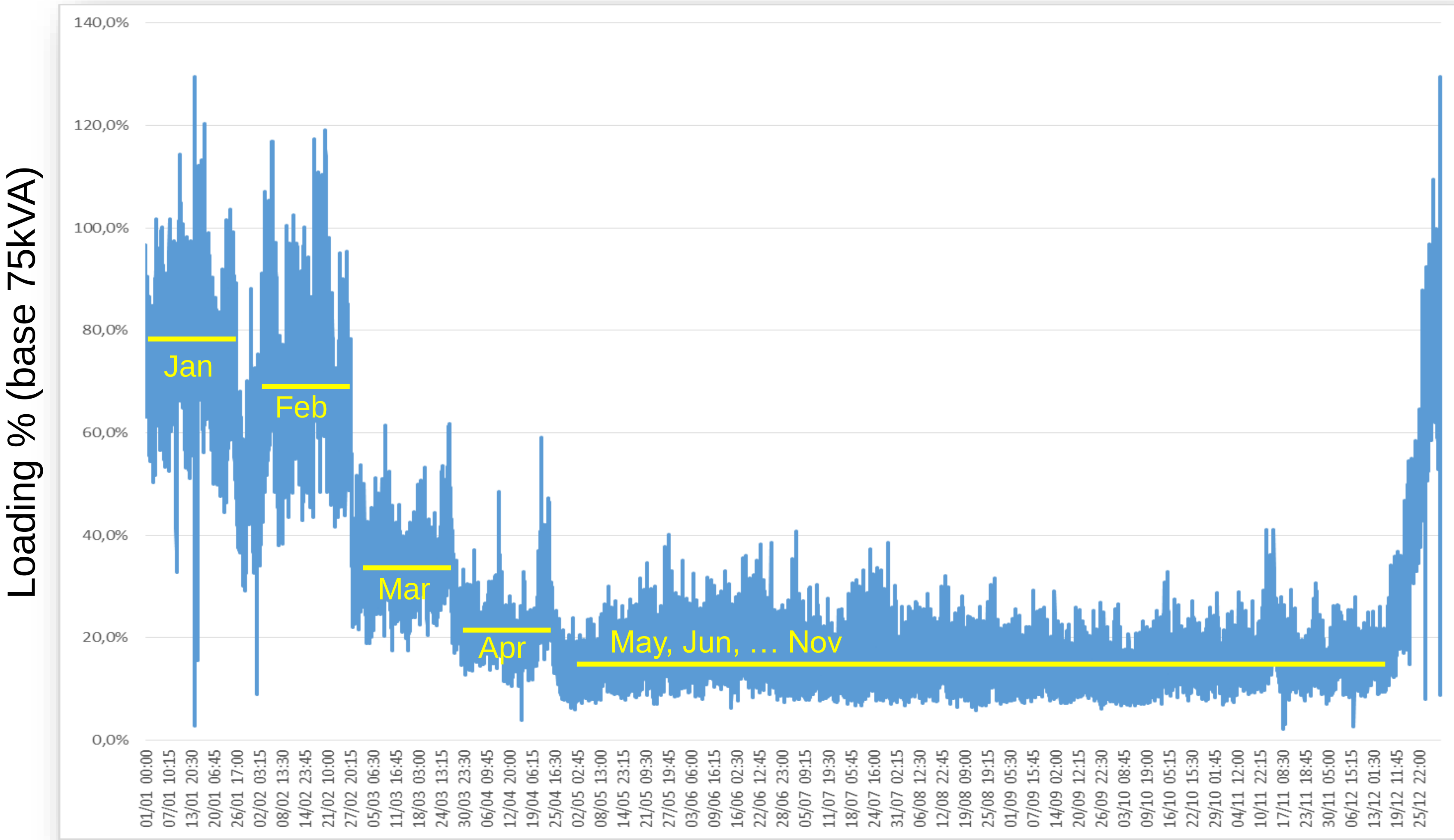
Less dissipated energy and saving on total purchasing.

Less nominal kVA's to same demand!

Applying the concept to a real case: overhead distribution transformers measured during one year

- 15 prototypes were produced in Nov/2015
- 10 of the energized units monitored during 2016
- Chosen installation points have very high peak demand during summer
- Load measured every 15’ for calculating the losses

Measured loading of the transformer, based on 75kVA 3Ø FR3 filled units



Comparison of the losses

- Losses evaluated at nominal rating, while yearly average is much lower.
- A smaller transformer will have higher total losses when overloaded. But lower total losses at low loading conditions. Threshold in the range of 35%.
- The 10 measured transformers had a yearly average load of 15.77kVA or 21%. At such condition, the total losses of the 75kVA are 25.8% lower than a 112.5kVA loaded with the same value of kVA's.

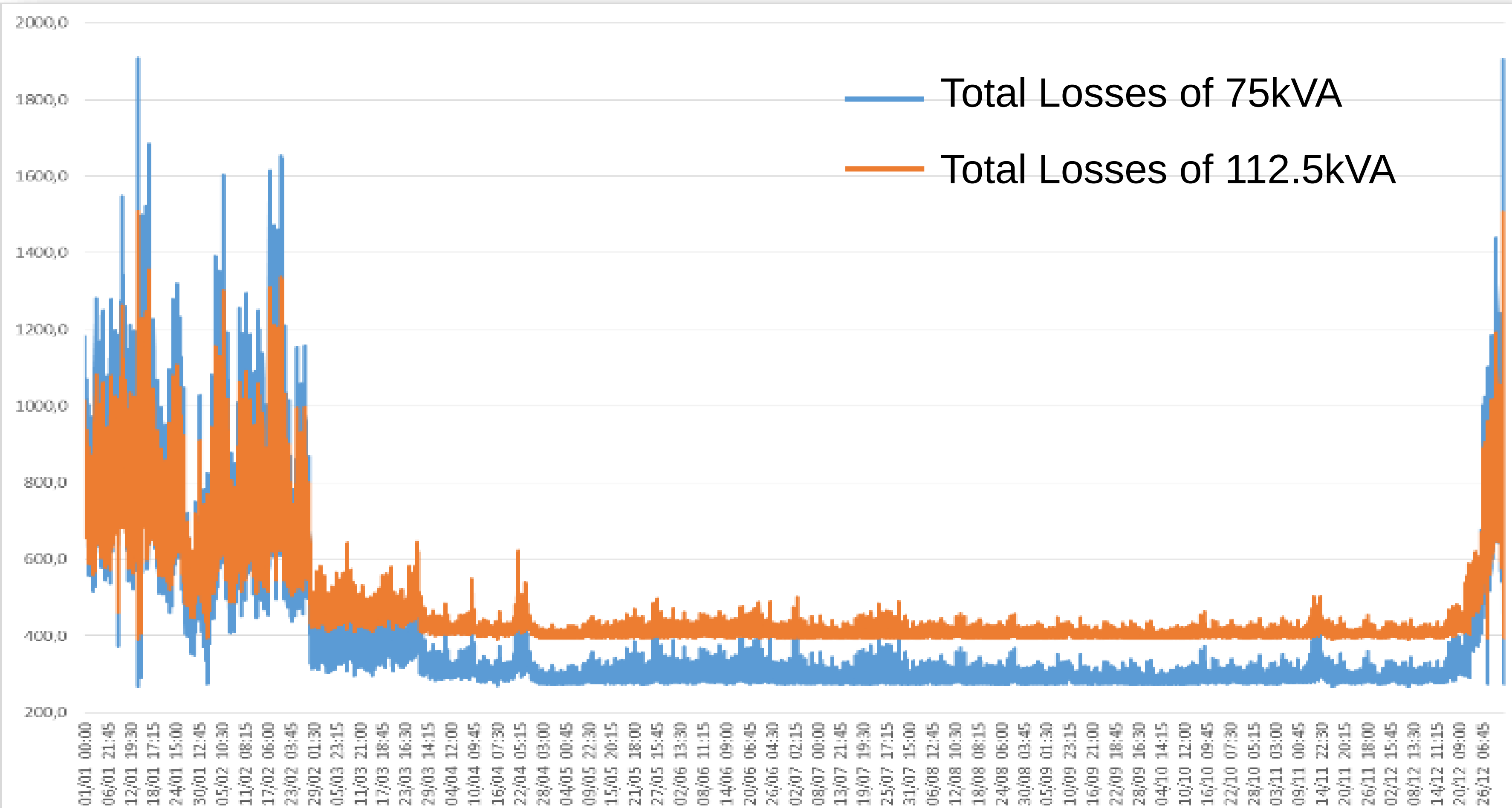
Loading at Nominal Rating

Condition	Losses [W]		
	75kVA	Brazilian Limits (75kVA)	112.5kVA
No Load Losses	267.9	295	267.9
Load Losses	976.8	1100	2197.8
Total Losses	1244.7	1395	2465.7

Loading on Yearly Average

Loading condition	Losses [W]			
	75kVA @		112.5kVA @	
	rated	15.8kVA	rated	15.8kVA
No Load Losses	267.9	267.9	390	390
Load Losses	976.8	43.19	1500	29.5
Total Losses	1244.7	311.1	1890	419.5

Resultant values of total losses to the same load



Detailed results, each transformer

Equipment	Total dissipated energy accumulated in one year			
	75kVA kWh	112.5kVA kWh	Savings kWh	Savings %
10560	3.095,5	3.930,6	835,1	21,3%
11638	2.921,1	3.811,5	890,5	23,4%
12248	2.748,5	3.693,8	945,3	25,6%
12354	3.345,4	4.101,0	755,7	18,4%
13473	2.793,8	3.724,7	930,9	25,0%
13514	3.166,4	3.979,0	812,6	20,4%
12379	3.176,7	3.982,0	805,4	20,2%
12828	3.002,0	3.859,5	857,6	22,2%
12404	2.030,8	2.902,3	871,5	30,0%
Total	**26.280,2**	**33.984,4**	**7.704,6**	**22,7%**

Additional Cost Saving Examples

Consider total cost of ownership in value to your organization

Cost Factor	Cost relative to mineral oil	Value to utility
Fluid only	More	• Increase fire safety – 2x flash and fire point as mineral oil, no pool fires, self-extinguishing fluid • Reduce time for spill remediation • Safer for environment – Renewable resource, biodegradable, non-toxic, carbon neutral solution
Transformer with FR3 fluid	Within 2-5% of mineral oil	• Increase load capacity up to 20% • Extend insulation life 5-8x longer • Eliminate fire walls and fire mitigation systems • Eliminate expense of water spray system • Dual rating designs offer potential to combine usage and optimize inventory management • Improve transformer reliability
Transformer Systems	Lower cost	• Improve transformer reliability • New transformer designs use up to 15% less fluid and up to 3% construction materials • Reduce inventory of transformers required • Potentially reduce liability reserves for insurance – property, personal injury, environmental

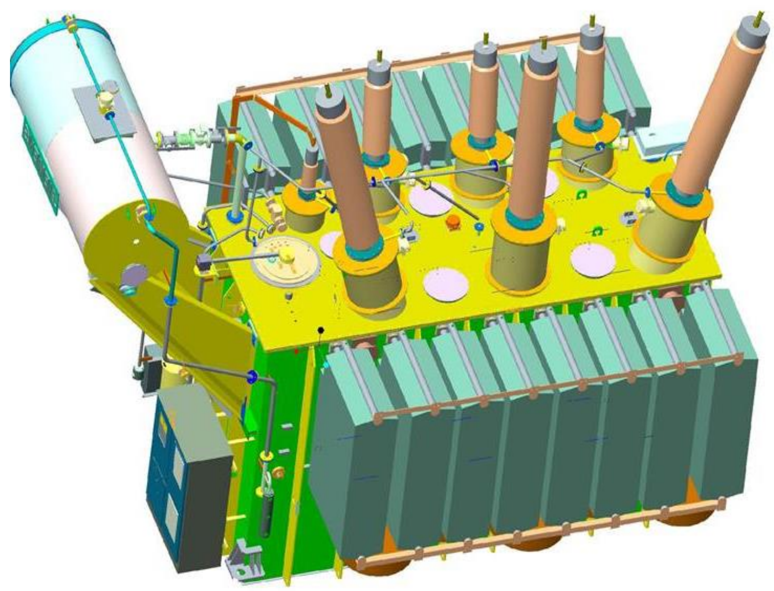
Example: Redesign transformer to optimize performance and cost

CASE STUDY – 100MVA – 230/69KV

A new design has been prepared for each condition:

1. Mineral oil / TUK paper, limits 65-65-80
2. FR3 fluid / TUK paper, limits 65-65-80
3. FR3 fluid / TUK paper, limits 75-90-90
4. FR3 fluid / TUK paper, limits 85-90-100

Case	Cost %
1 – OMI at 65K	Nominal
2 – FR3 at 65K	More costly than 1
3 – FR3 at 75K	Approximately same cost as case 1
4 – FR3 at 85K	Less costly than case 1



Client				Standard		Phases		Hz	Instalation
CARGILL				IEC		3		60	1000m
Wind	Power MVA			Con.	Relation (no load) kV	Insulation Level			
						Applied - kV		Impulse - kV	
	ONAN	ONAF	ONAF			Phase	Neutral	Phase	Neutral
AT	65	80	100	Yo	230 ± 2 x 2,5%	360	120	850	325
BT	65	80	100	D	69	140		350	

High temperature designs deliver additional design benefits

AT 75K AND 85K, FR3 FLUID TRANSFORMERS REDUCE WEIGHT, MASS, AND TANK/COOLING SYSTEM WITH ONLY SLIGHT REDUCED EFFICIENCY

Case	Fluid Volume	Total Weight	Trpt Weight
1 – OMI at 65K	100%	100%	100%
2 – FR3 at 65K	98%	101%	101%
3 – FR3 at 75K	96%	99%	100%
4 – FR3 at 85K	91%	92%	93%

Case	Total Mass	Mass of Copper	Mass of Core
1 – OMI at 65K	100%	100%	100%
2 – FR3 at 65K	102%	103%	100%
3 – FR3 at 75K	100%	99%	98%
4 – FR3 at 85K	92%	88%	96%

Case	Mass of Tank and Cover	Cooling System
1 – OMI at 65K	100%	100%
2 – FR3 at 65K	99%	100%
3 – FR3 at 75K	95%	94%
4 – FR3 at 85K	88%	89%

Case	Eficiency ref 85°C - 1p.u.	Losses
1 – OMI at 65K	99,677%	100%
2 – FR3 at 65K	99,679%	99%
3 – FR3 at 75K	99,671%	102%
4 – FR3 at 85K	99,648%	110%

Simplified optimization for wind generator step-up transformer

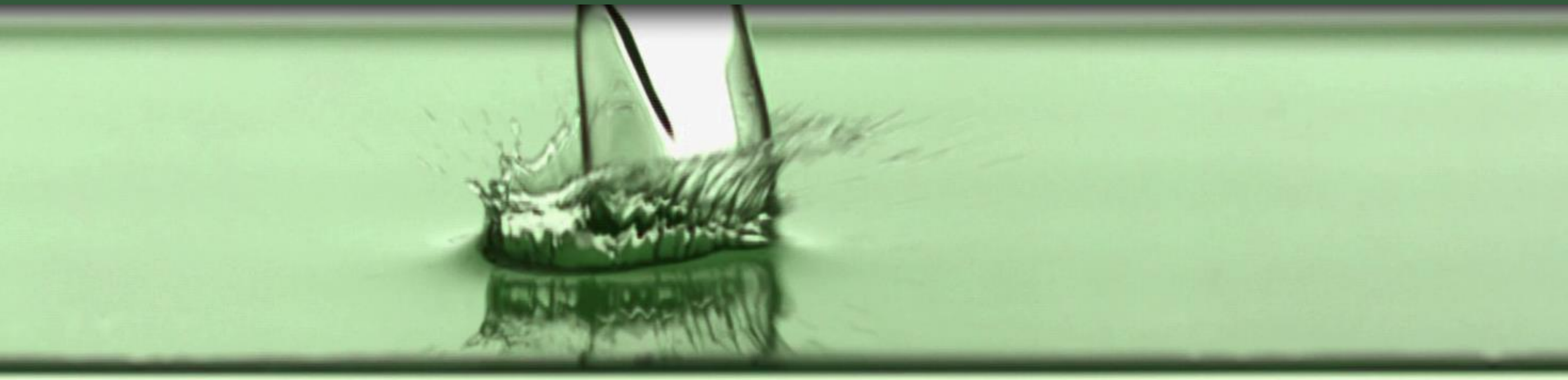
REFERENCE IS A REAL PRODUCED TRANSFORMER OF 2500KVA 34.5KV ±2X2.5% / 0,69KV, DYN1

Description	Temperature rise limit of θ_W	Temperature rise limit of $\theta_{O\ MAX}$	Temperature rise limit of $\theta_{W\ MAX}$
Mineral oil filled	65K	65K	80K
FR3 Fluid and TUK paper	85K	90K	100K
FR3 Fluid and Aramid Paper	115K	90K	140K
Dry-Type Transformer	105K	-	115K

Configuration	Cost	Fluid Volume	Total Losses	Volume	Total Weight	Paper Life Expectation (years)
MO + TUK	100%	100%	100%	100%	100%	84
FR3 + TUK	104%	91%	103%	93%	94%	73
FR3 + Nomex	122%	84%	105%	78%	89%	> 1000
Dry Type	180%	-	47%	97%	124%	~90

Reduce maintenance costs

- Better long term stability
  - Non free breathing application
  - Sludge formation 40x less
  - Long chain acids → Less corrosive
  - Life expectation of FR3 more than 42 years
  - FR3 fluid is self-drying - no frequent oil replacement
- Eliminate expense of water spray system
  - Up front purchase expense (up to $250K)
  - Ongoing maintenance (typically $5K annually)



FR3™

ENVIROTEMP™ NATURAL ESTER FLUID

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