LOAD TAP CHANGER DESIGN, OPERATION AND MAINTENANCE CONSIDERATIONS

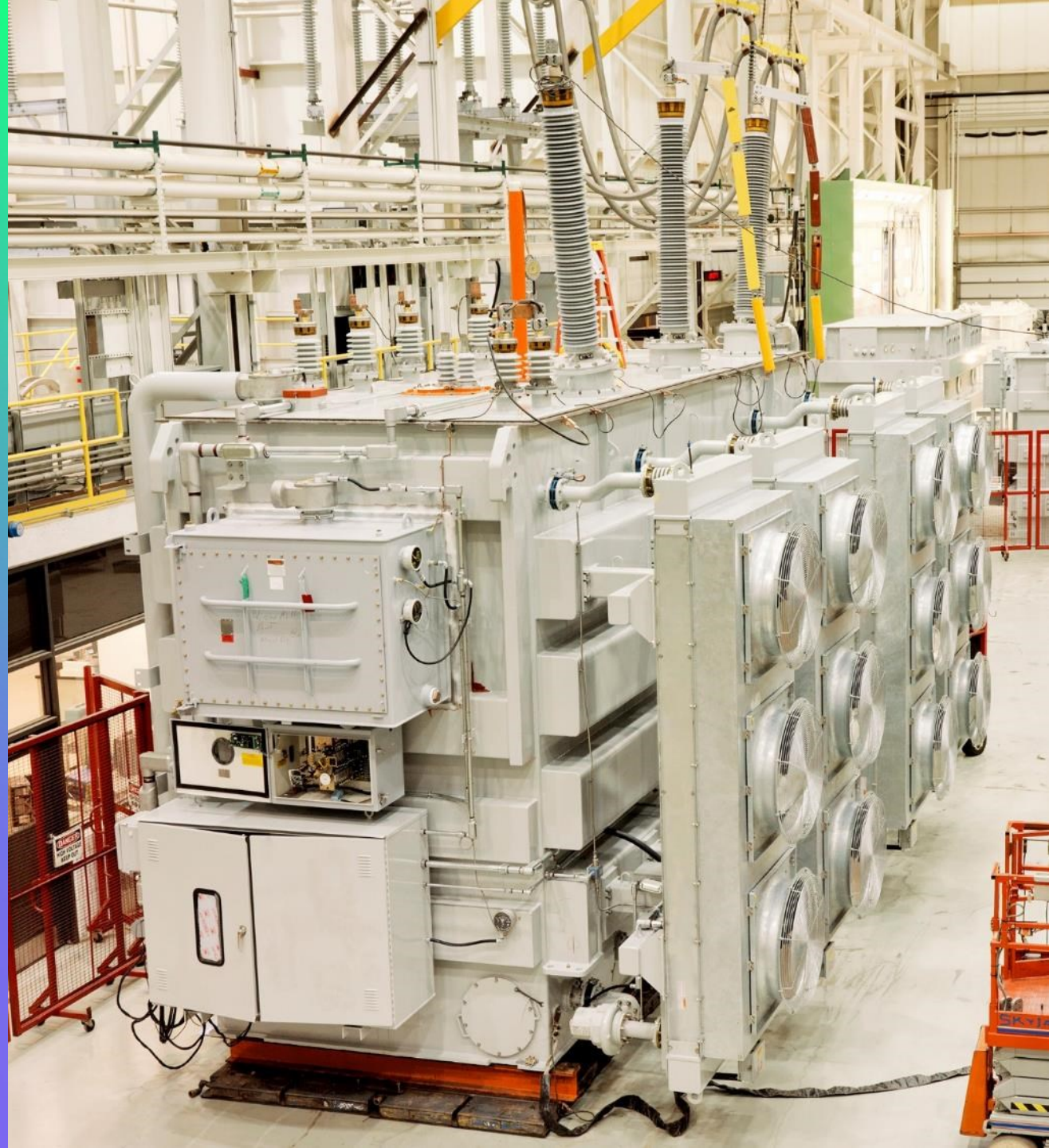
waukesha
a prolec ge company

Agenda

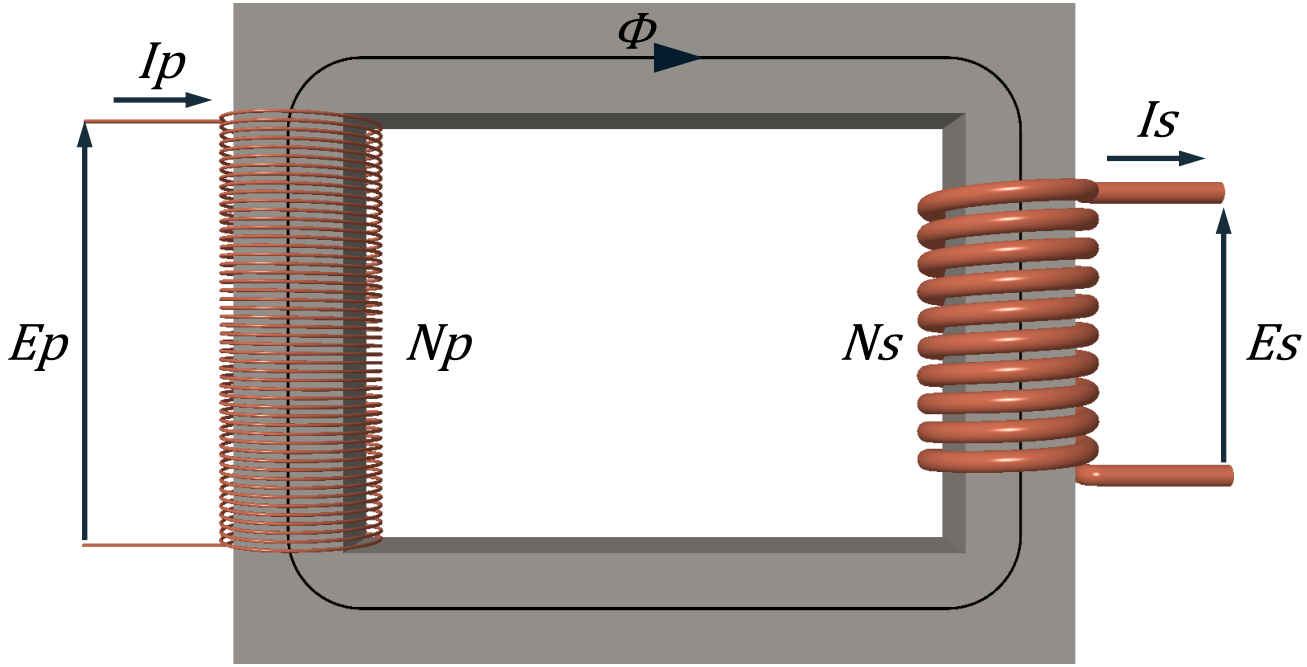
- Science Behind Tap Changers
- De-energized Tap Changer (DETC)
  - Design
  - Operation
  - Maintenance
- On-load Tap Changer (OLTC or LTC)
  - Functional Specification
  - Operational Concepts
  - Design Details
  - Operational Sequences
  - Common Manufacturers/Models
- Case Studies: Maintenance & Common Issues

waukesha
a prolec ge company

Science Behind Tap Changers



Ideal Transformer



$$\frac{E_p}{E_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

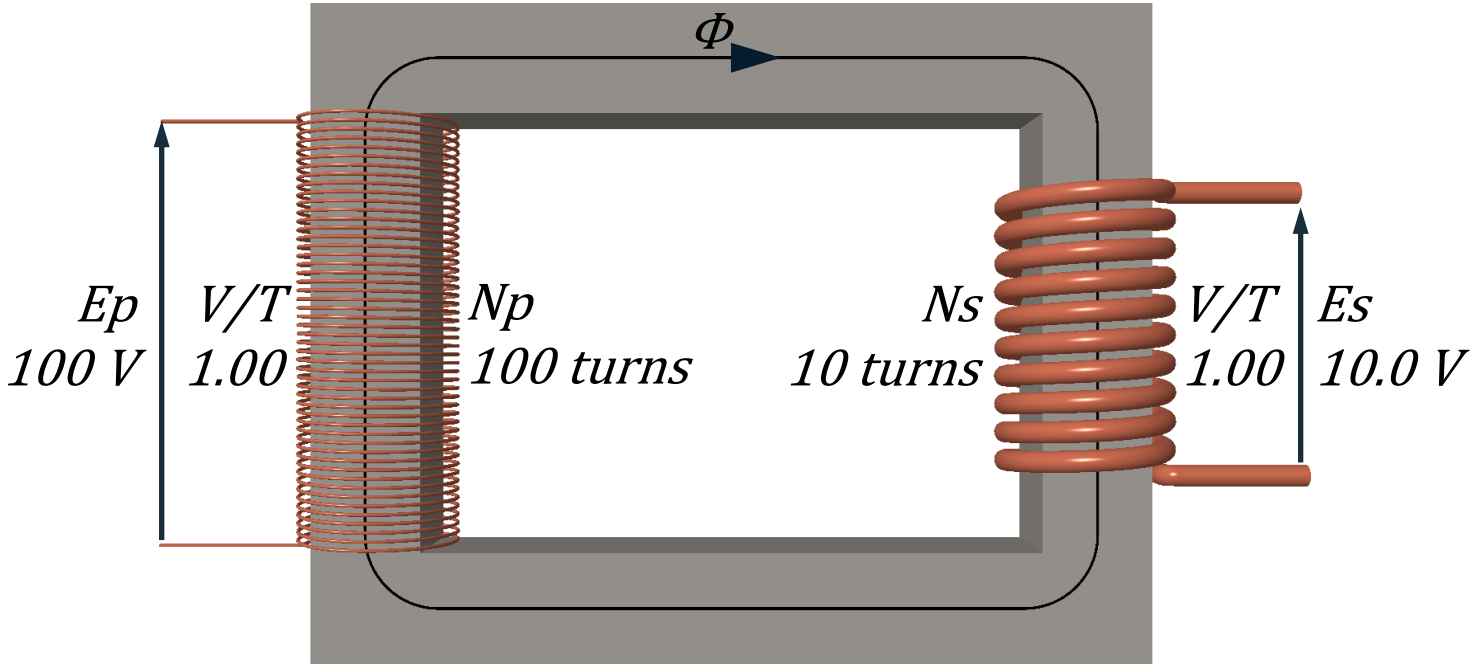
$$E_p = E_s = 4.44 f \Phi_m N$$

$$\frac{Volts}{Turn} = \sqrt{2}\pi f \Phi_m = 4.44 f B_m A$$

Where:

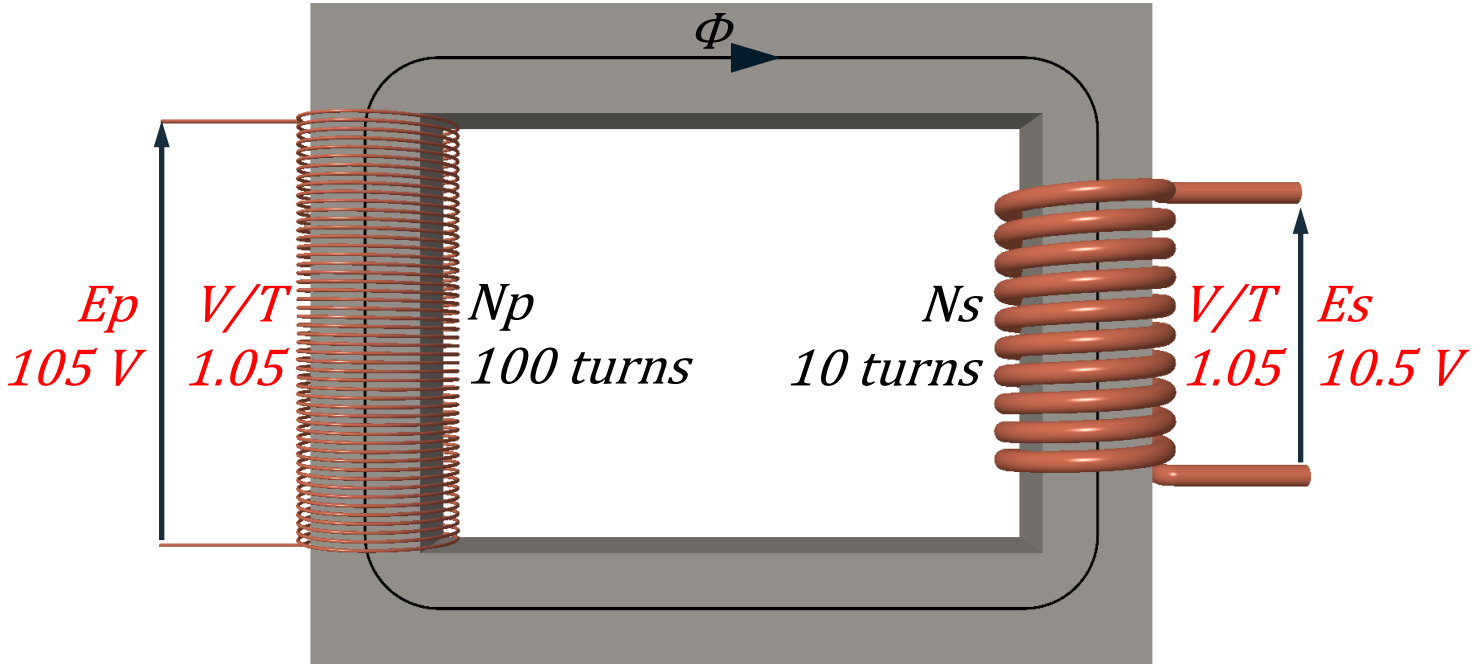
E = Voltage (volt – primary or secondary)
I = Current (ampere – primary or secondary)
A = cross section area (m^2)
B = flux density (tesla)
Φ = flux (weber)
f = frequency (hertz)

Volts Per Turn



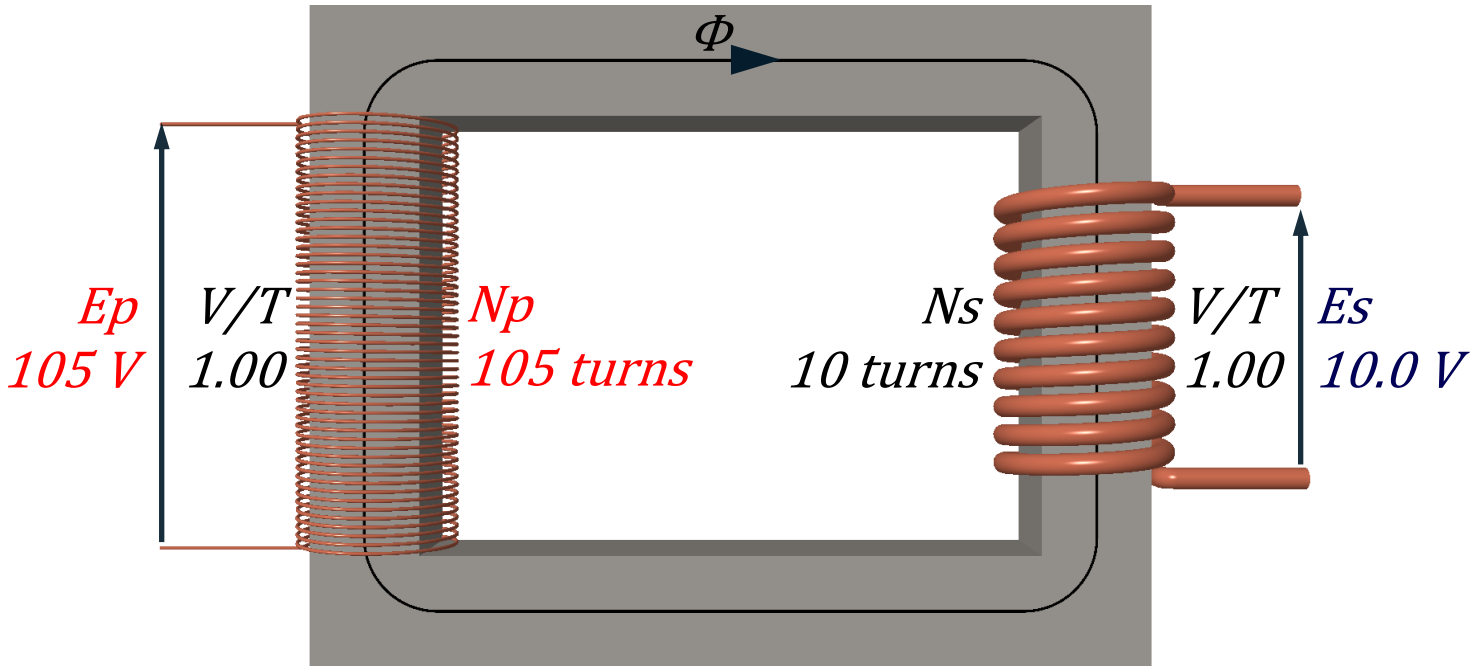
- The primary winding determines the Volts / Turn and flux density
- The secondary turns determines the output voltage

Volts Per Turn



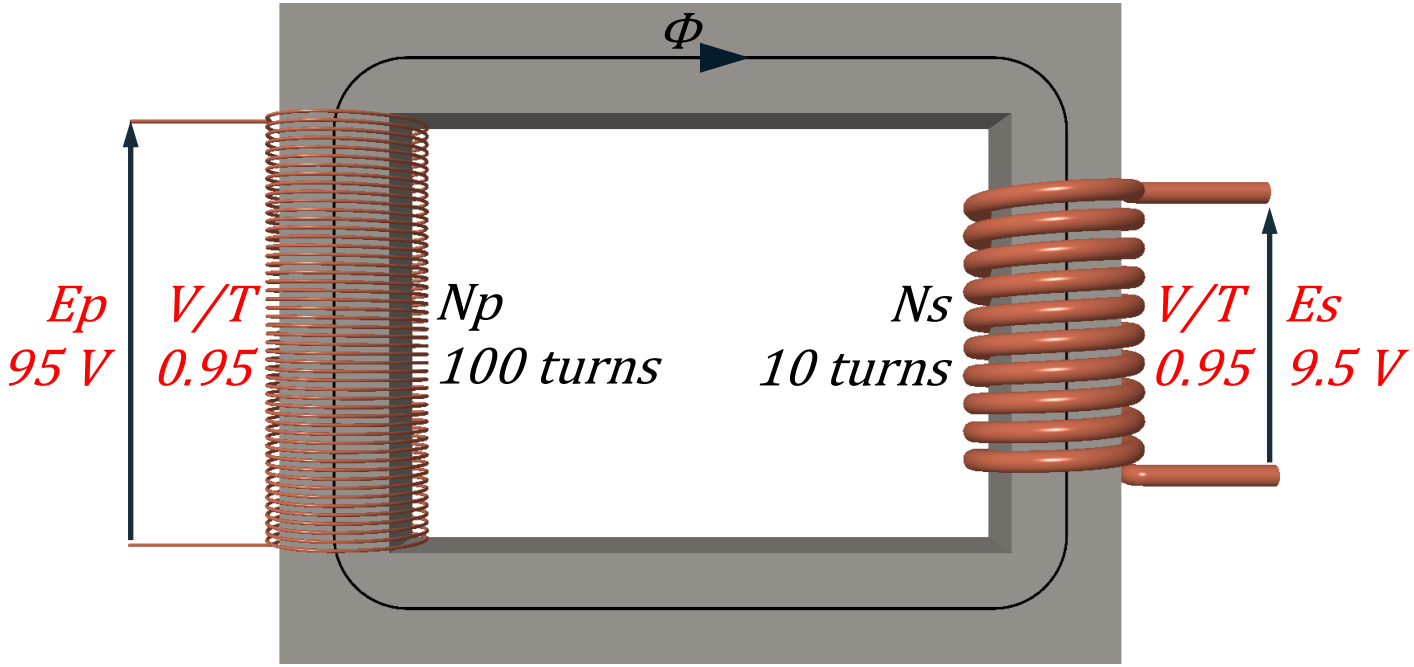
- If a higher voltage is applied to the primary, the output voltage will increase without any change to the number of turns in the secondary
- The transformer is not operating at rated inductance and flux level (over-excitation)

Volts Per Turn



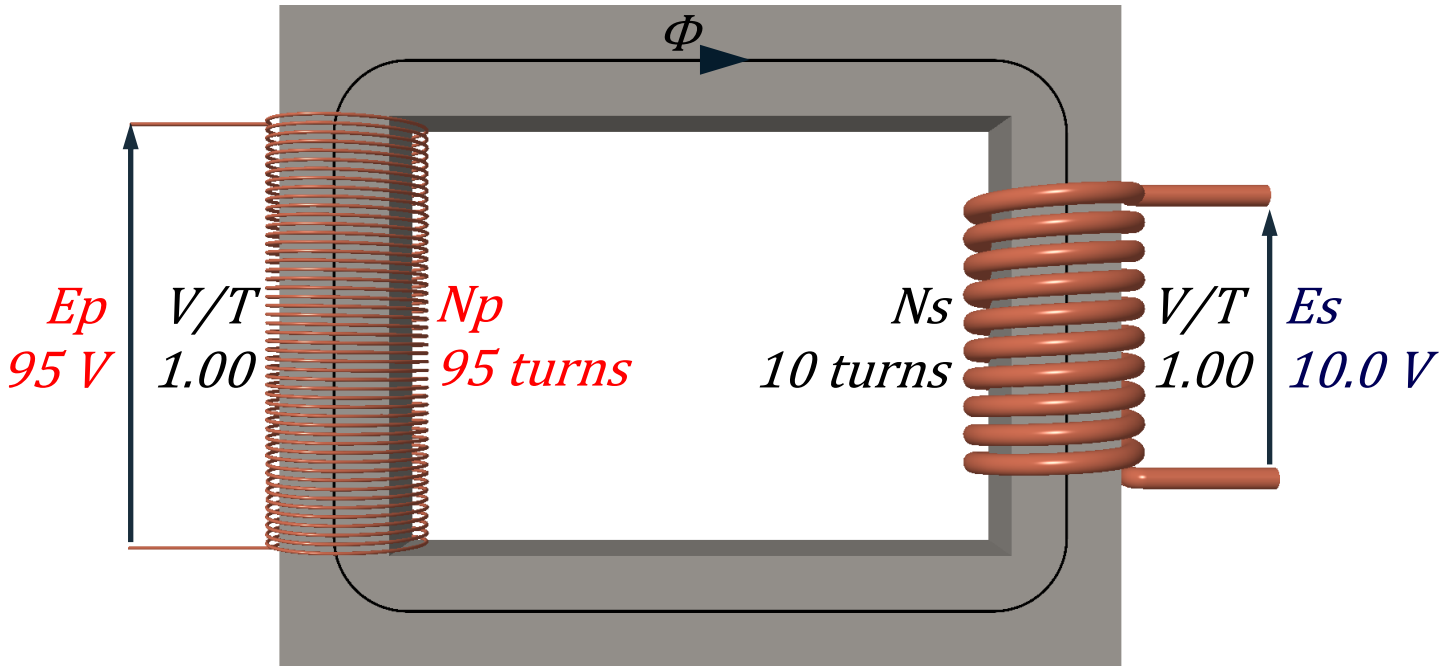
- If we add 5% more turns to the primary winding…

Volts Per Turn



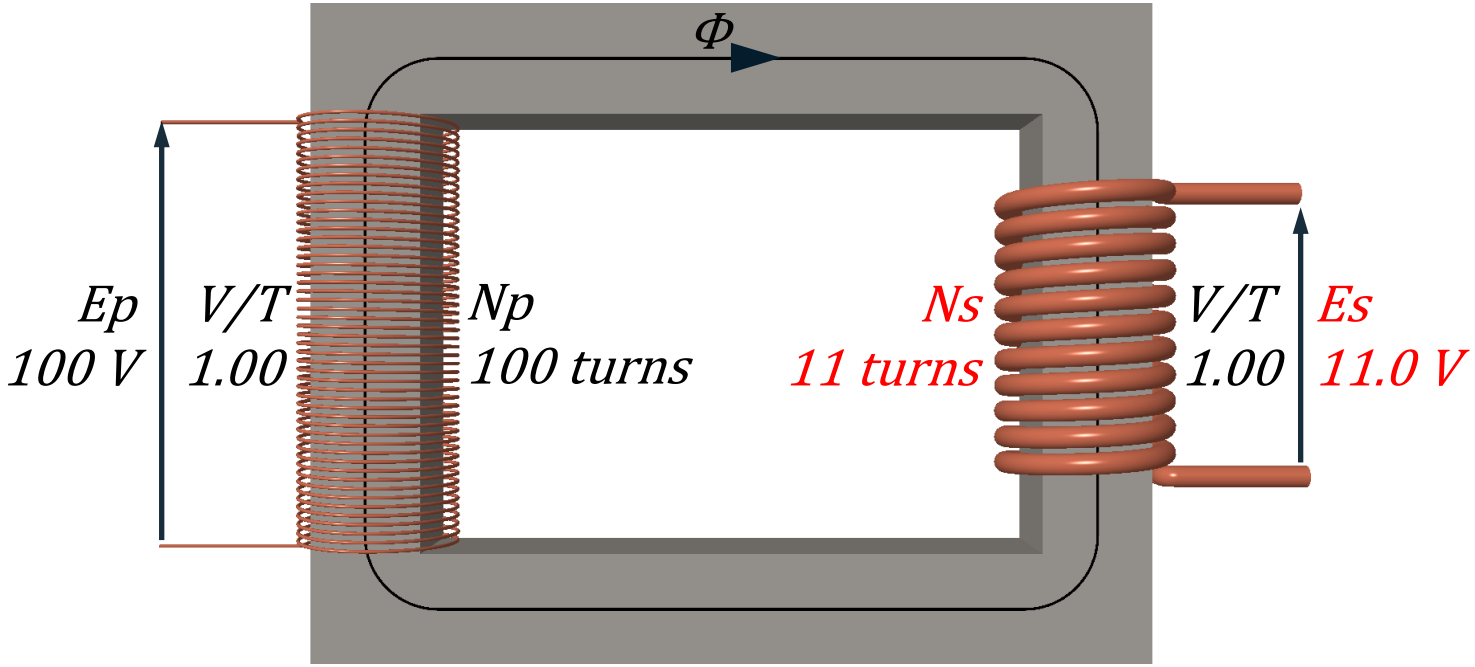
- Applying a lower voltage to the primary side results in a lower secondary voltage due to the reduction in Volts / Turn and flux density
- Output will decrease without any change in the number of turns on the secondary side

Volts Per Turn



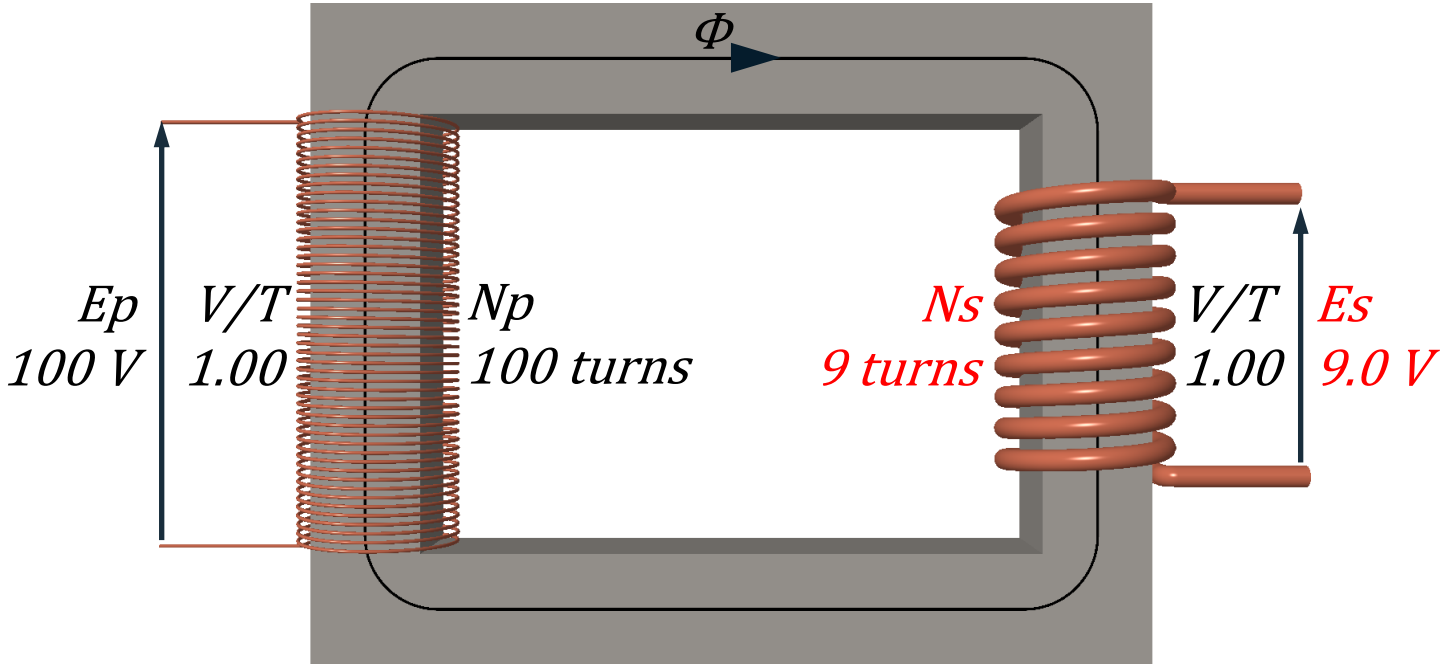
- If we remove 5% more turns to the primary winding…

Volts Per Turn



- Adding turns in the secondary side while holding the voltage and number of turns on the primary side will increase the secondary voltage

Volts Per Turn



- Subtracting turns in the secondary side while holding the voltage and number of turns on the primary side will decrease the secondary voltage

Tap Changers Defined

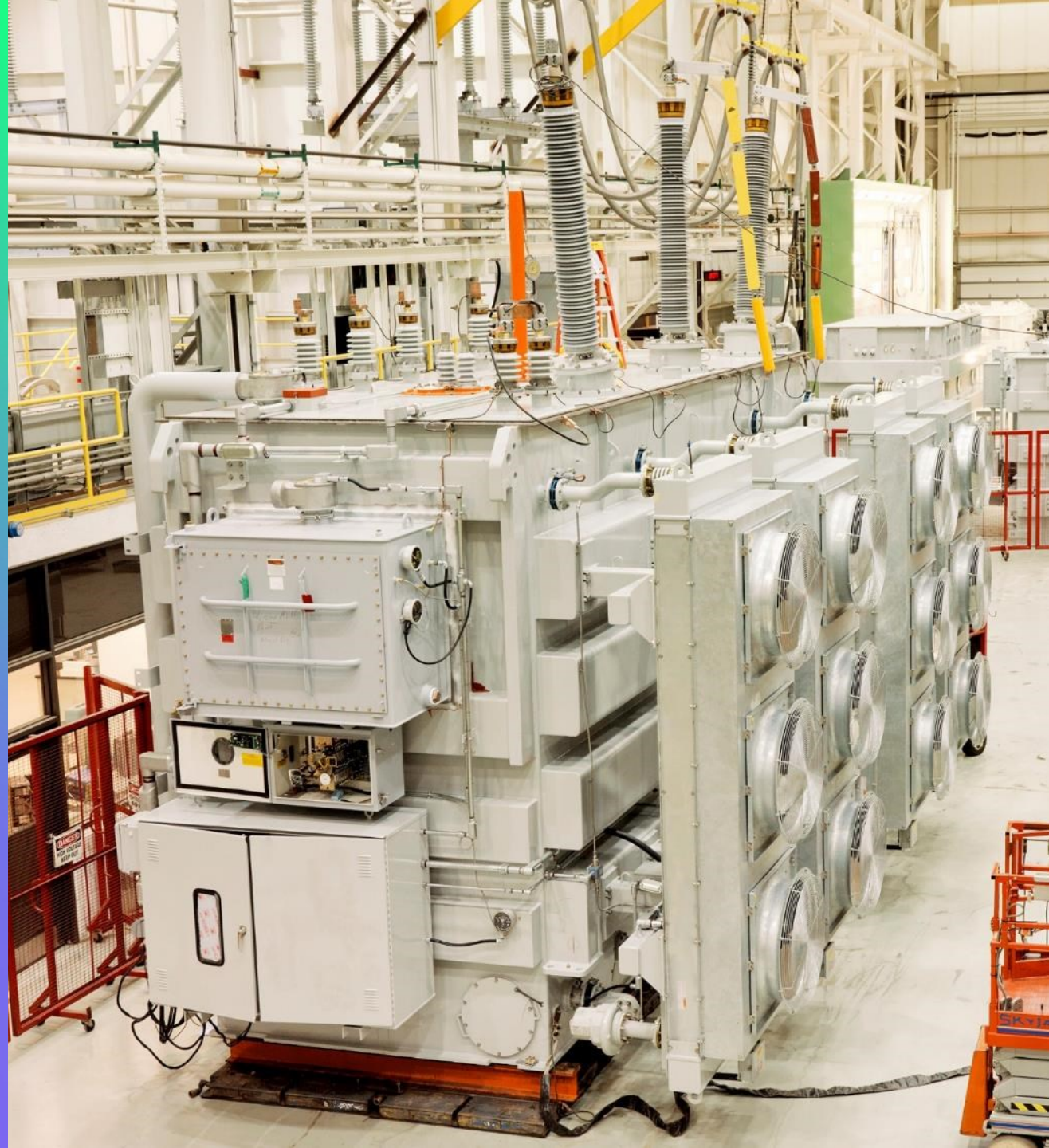
A device designed to allow changing the winding connections or more typically the number of turns in a winding to regulate voltage.

Tap Changers exist in the following two categories:

- De-energized Tap Changer (DETC) is typically applied to the primary winding
  - Mistakenly called a No-Load Tap Changer
  - Cannot be operated while the unit is energized
- On-load Tap Changer (OLTC) is typically applied to the secondary winding

waukesha
a prolec ge company

De-energized Tap Changer (DETC)



DETC Design

- Most common configurations (per ANSI and IEEE Standards):
  - 5 Tap Positions
  - 10% range (two above and two below “rated” or “nominal” tap)
  - 2.5% taps increments
  - numeric position indicator
- Other “non-standard” options are available upon request (i.e., +4 / -1), 2 to 23 positions, alphabetic indicator, etc.
- Used to match transformer primary to actual transmission line voltage
- Adjust turns to match the design core flux density
- Extend the range of the LTC

DETC Design

Effect on Core Performance:

- Core Loss goes up as excitation increases (more heat)
- Sound Level goes up as excitation increases

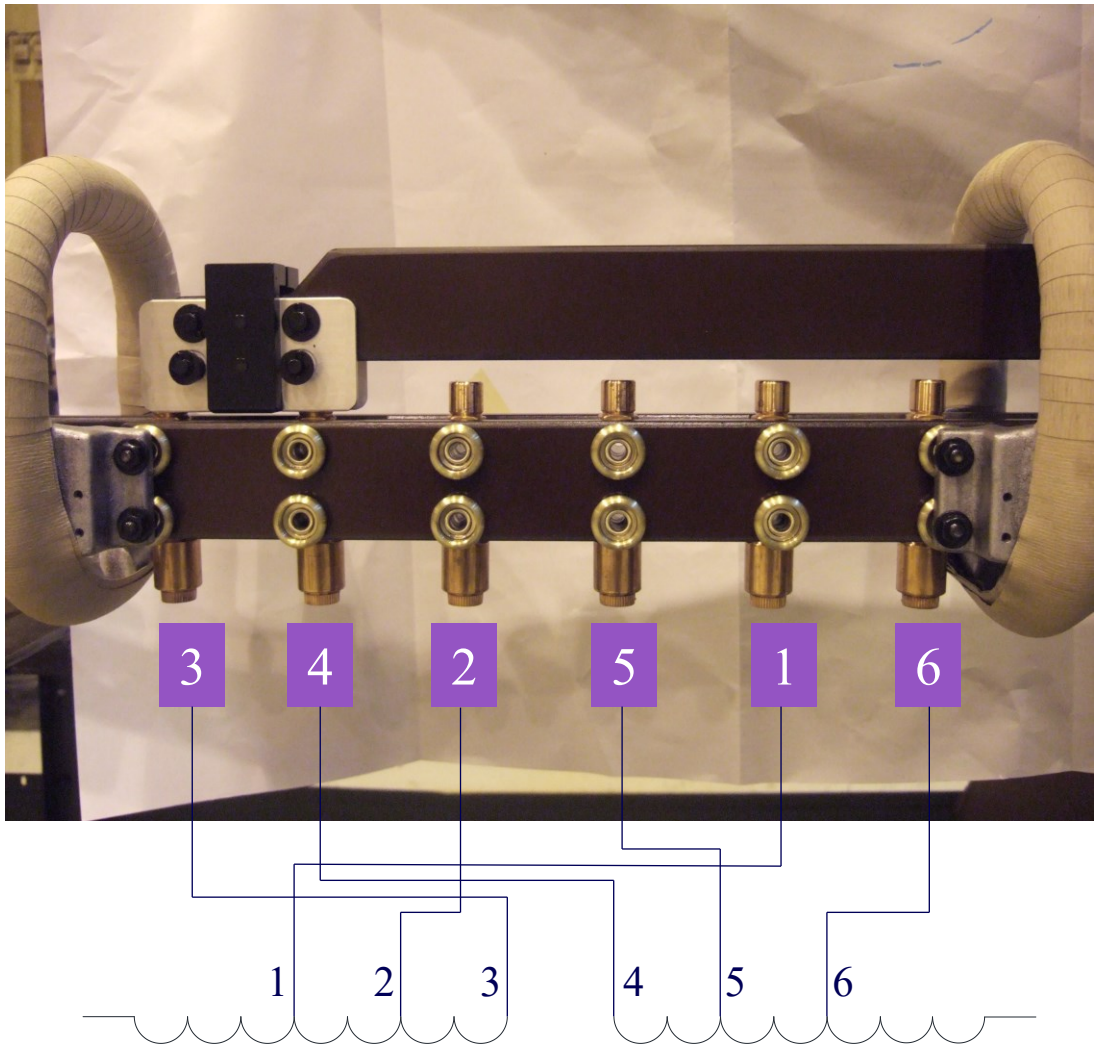
Effect on Impedance:

- Inversely proportional to the square of the volts per turn
- Can lower impedance than expected
- Impedance based relay may not have the protection expected
- Higher short circuit current and forces

Volts per Turn

High Voltage Tap Changer De-Energized Operation			
Volts L-L	Voltage % of Nominal	Position	Connects
169050	+5.0%	A	3 - 4
165025	+2.5%	B	4 - 2
161000		C	2 - 5
156975	-2.5%	D	5 - 1
152950	-5.0%	E	1 - 6

Nominal Rating

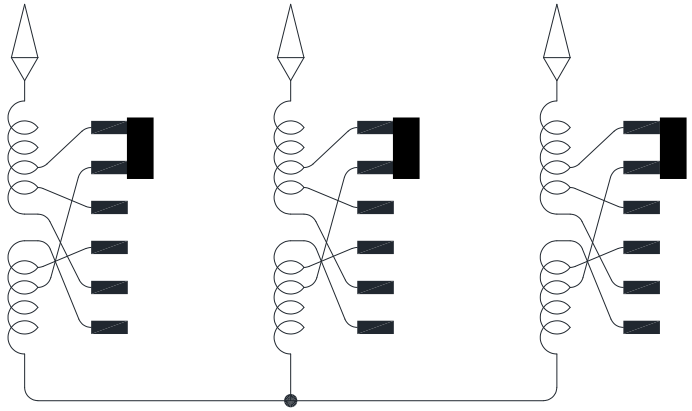


DETC Design

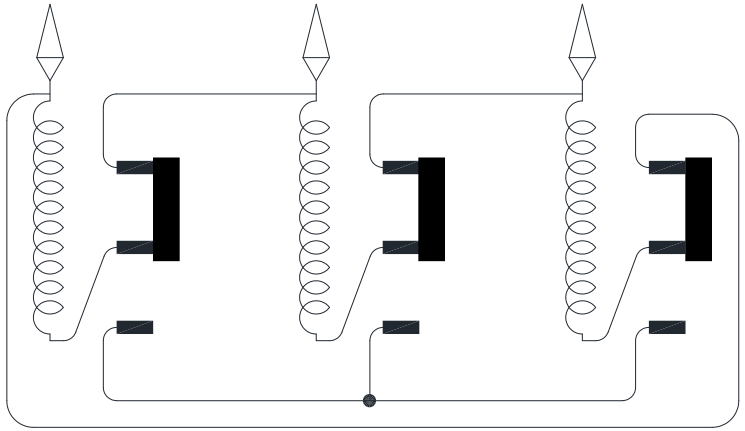
Special Considerations:

- Bridging vs Linear connections
- Voltage step regulation vs Dual voltage vs Series / Parallel vs Delta / Wye
- Greater than 10% tap range, different than 5 positions
- Silver plated contacts
- Increased dielectric capabilities
- Different handle mechanisms to change directions inside or outside of the transformer (raised / lowered to eye level, left / right offset, etc.)
- Manual / Motorized operation
- Remote position indication

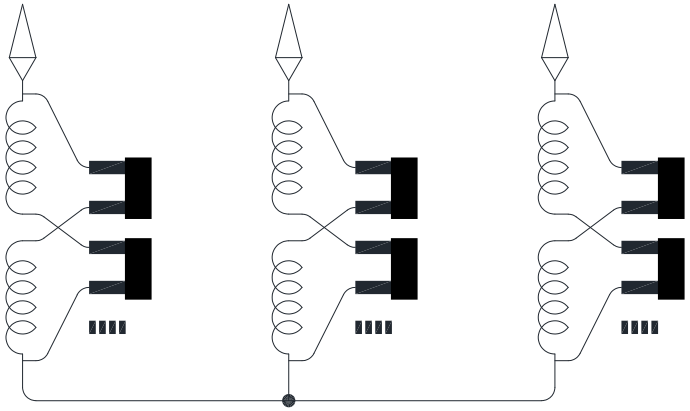
DETC Sample Connections



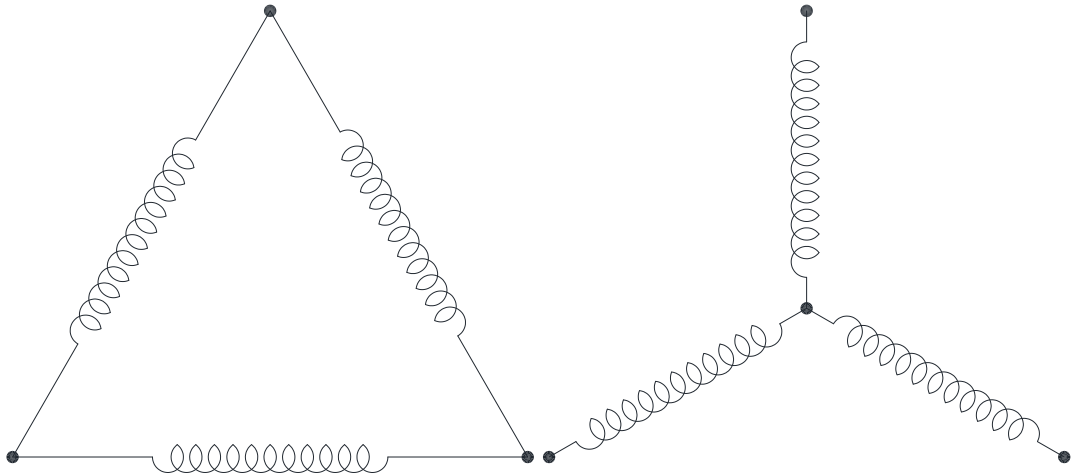
Step Regulation

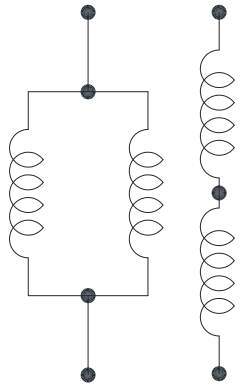


Delta / Wye

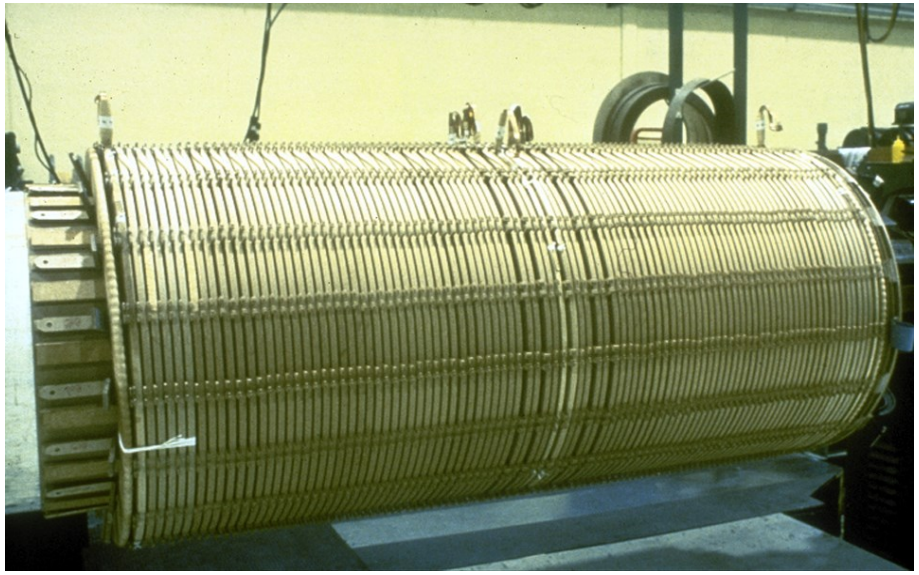


Parallel / Series



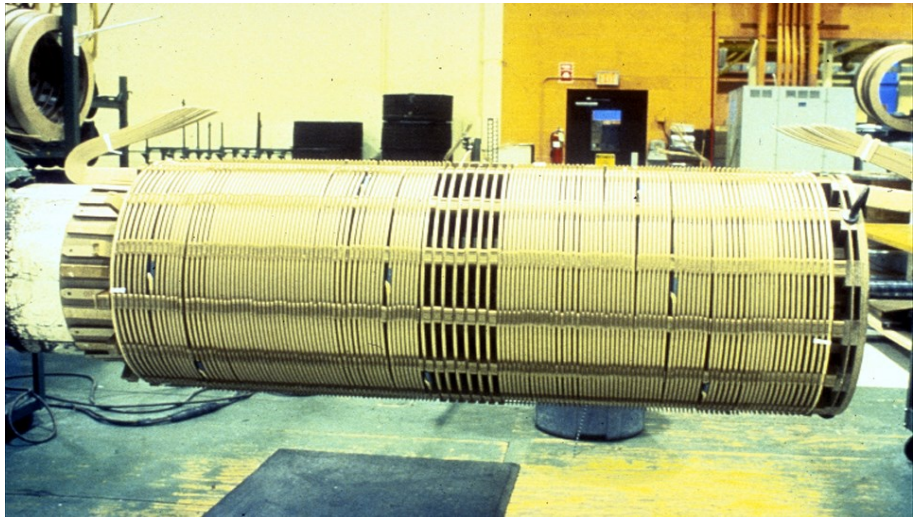


DETC Taps / Winding Configurations



Primary Winding

Single DETC for each phase



Secondary Winding

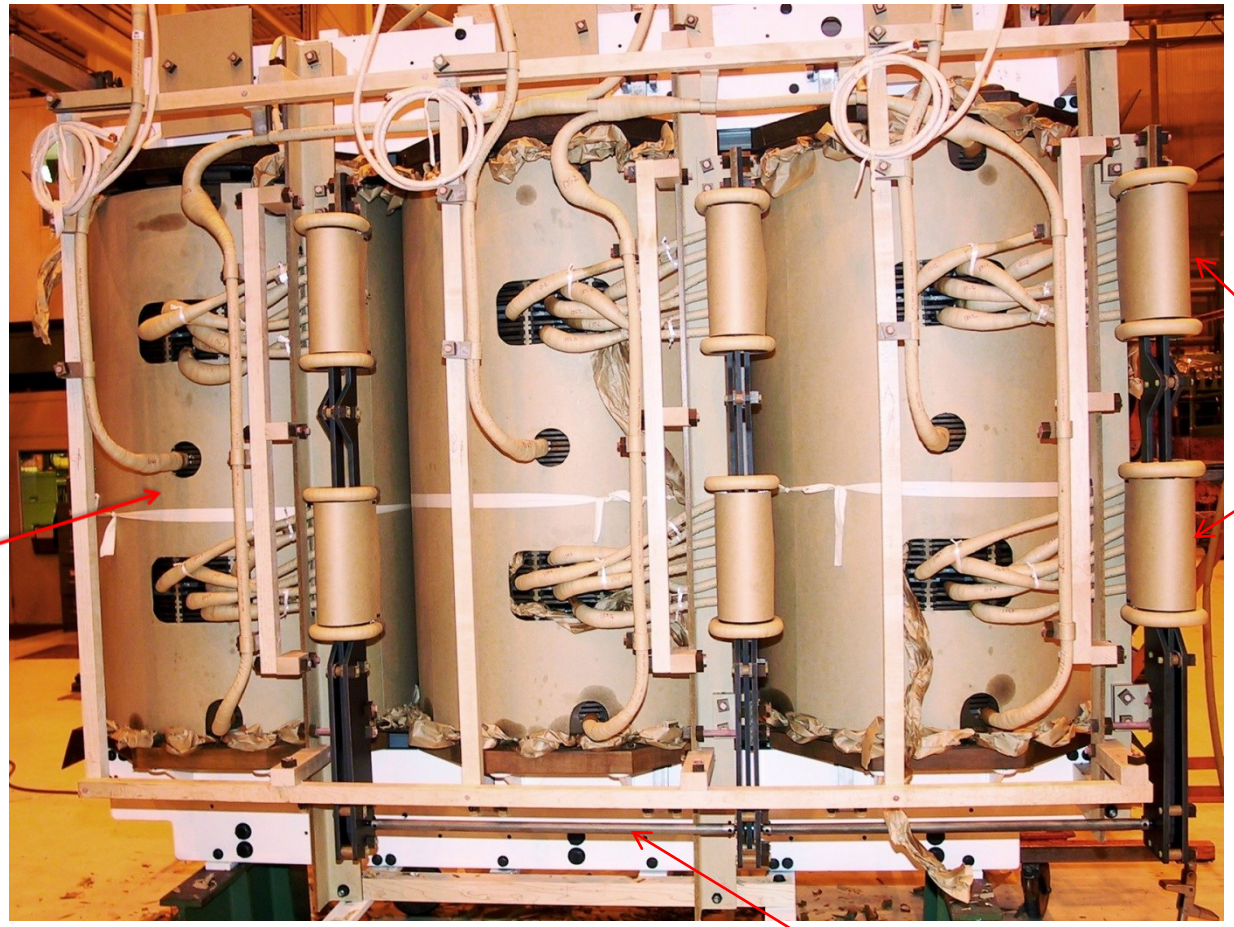
DETC Taps / Winding Configurations

Dual DETC for each phase

Primary Winding

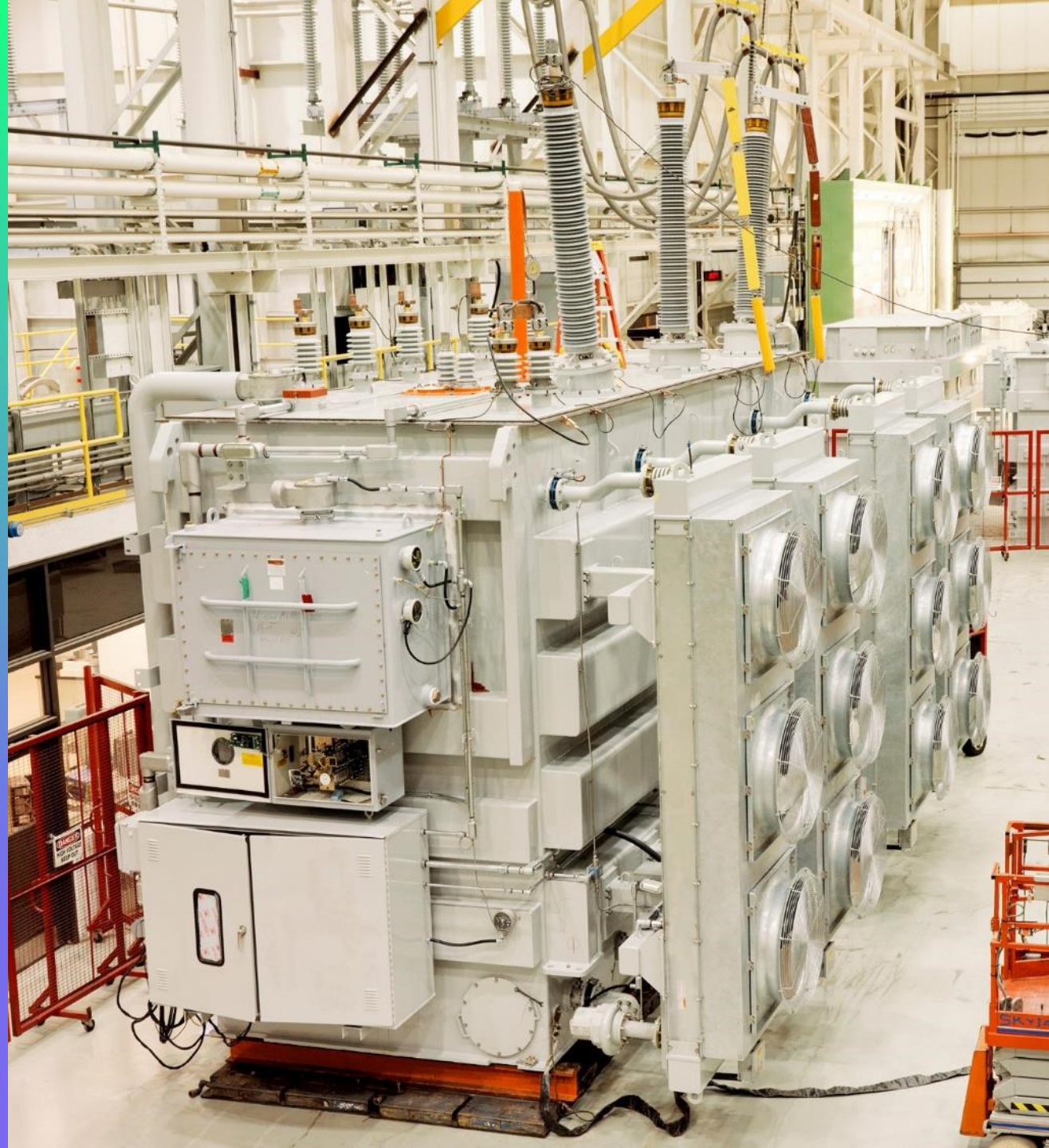
Secondary Winding

DETC Installation



waukesha
a prolec ge company

On-Load Tap Changer (OLTC or LTC)



OLTC Functional Specification

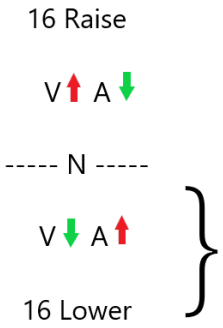
To regulate the output voltage delivered to the load while energized by performing 3 separate functions:

1. Selection of “raise” or “lower” of the winding taps by use of the reversing switch
2. Selection of voltage magnitude by use of the selector switch
3. Interruption of the arc using a “make before break” method to ensure continuous power flow to the load

This must be achieved smoothly & efficiently, without interruption, and up to the maximum transformer nameplate rating and overloading of up to 2 per unit during short term emergency overloading.

OLTC Functional Specification

- Regulate +/- 10% of the Nominal Low Voltage Rating
- 33 Steps



- 5/8% voltage change per step
- Full capacity above nominal voltage
- Can be located in the main tank or a separate tank
- Might require Series Transformer / Preventive Auto Transformer

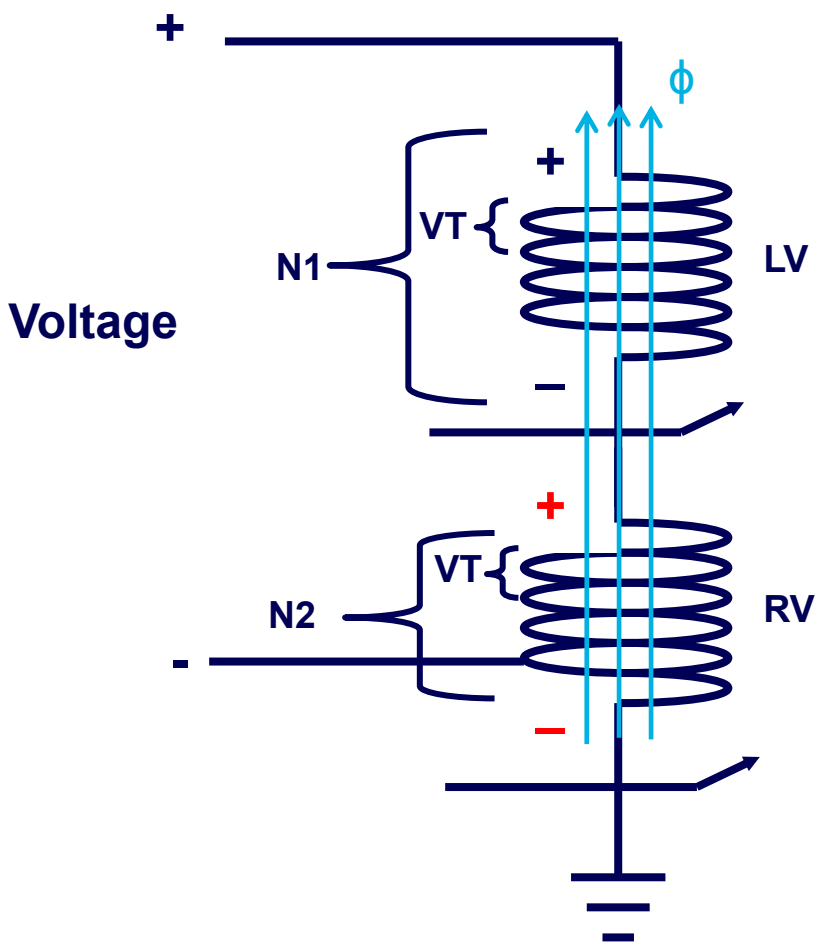
OLTC Operational Concept

Coils connected in series and wound in the same direction on a common flux path ***add voltage.***

You can ***"BOOST"*** voltage by adding turns that are wound in the same direction.

$$V = \overbrace{(VT)(N1)}^{LV} + \overbrace{(VT)(N2)}^{RV}$$

N = Number of Turns
LV = Low Volt Windings
RV = Regulating Windings
VT = Volts per turn



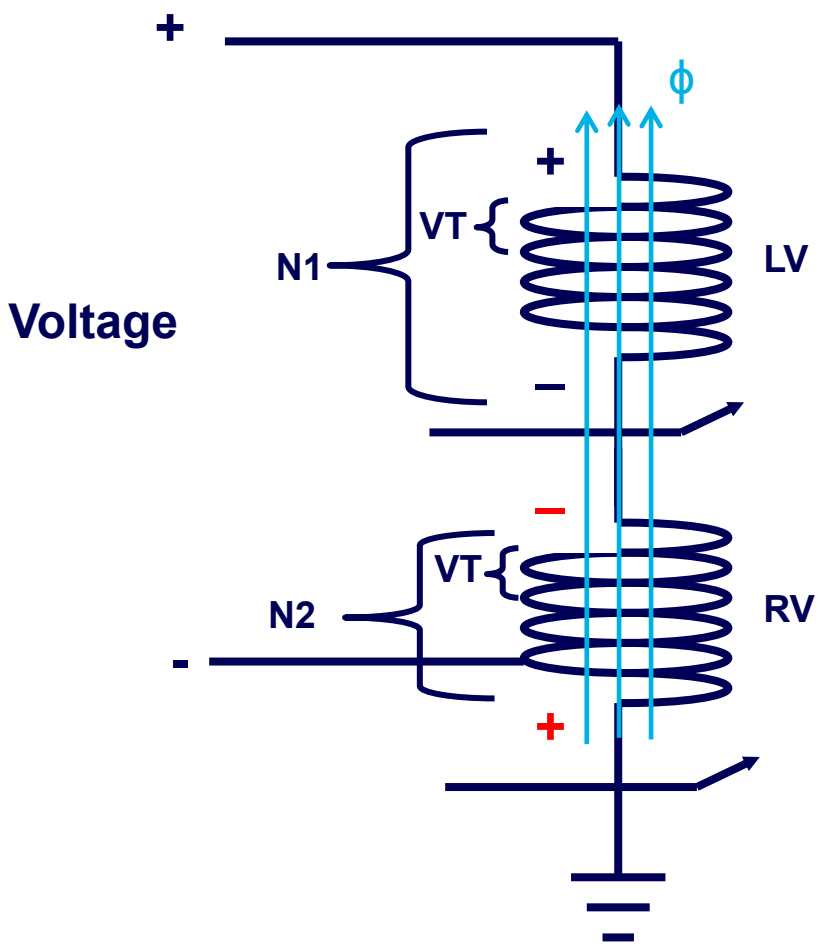
OLTC Operational Concept

Coils connected in series and wound in the opposing direction on a common flux path ***subtract voltage.***

You can ***"BUCK"*** voltage by adding turns that are wound in the opposing direction.

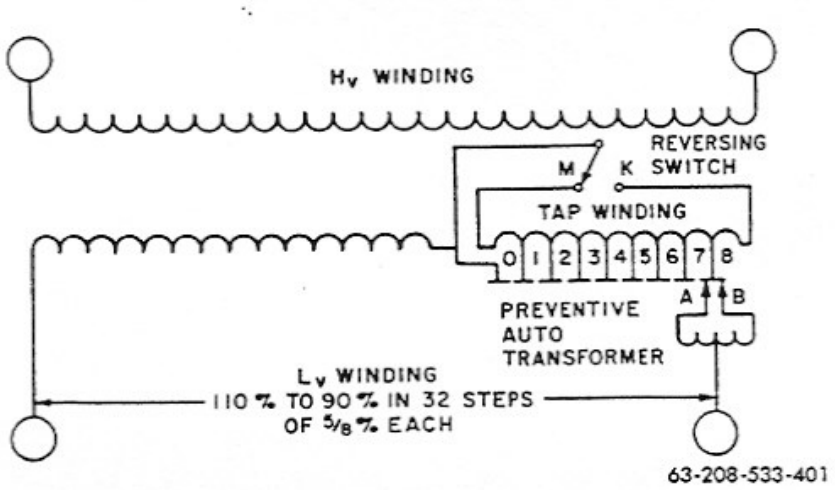
$$V = \overbrace{(VT)(N1)}^{LV} - \overbrace{(VT)(N2)}^{RV}$$

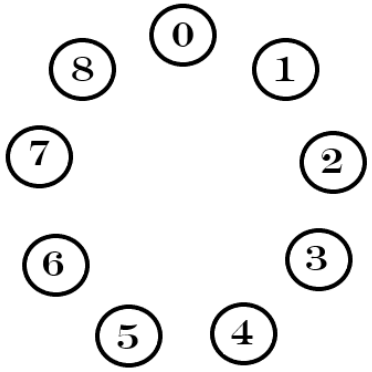
N = Number of Turns
LV = Low Volt Windings
RV = Regulating Windings
VT = Volts per turn



OLTC Functional Arrangements

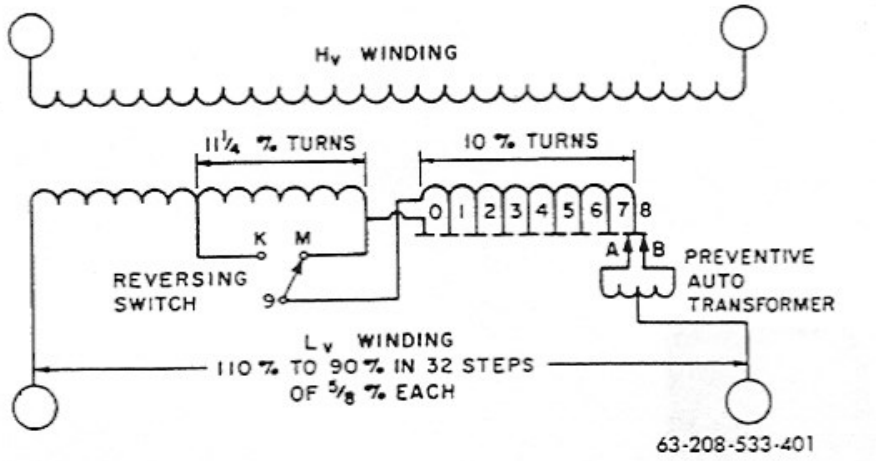
Reversing Change-Over Selector Plus/Minus Operation





- Higher load losses at minimum tap position
- Less complicated winding layout
- Less complicated dielectric design

Coarse Fine Operation (aka Isolated Reversing Switch)

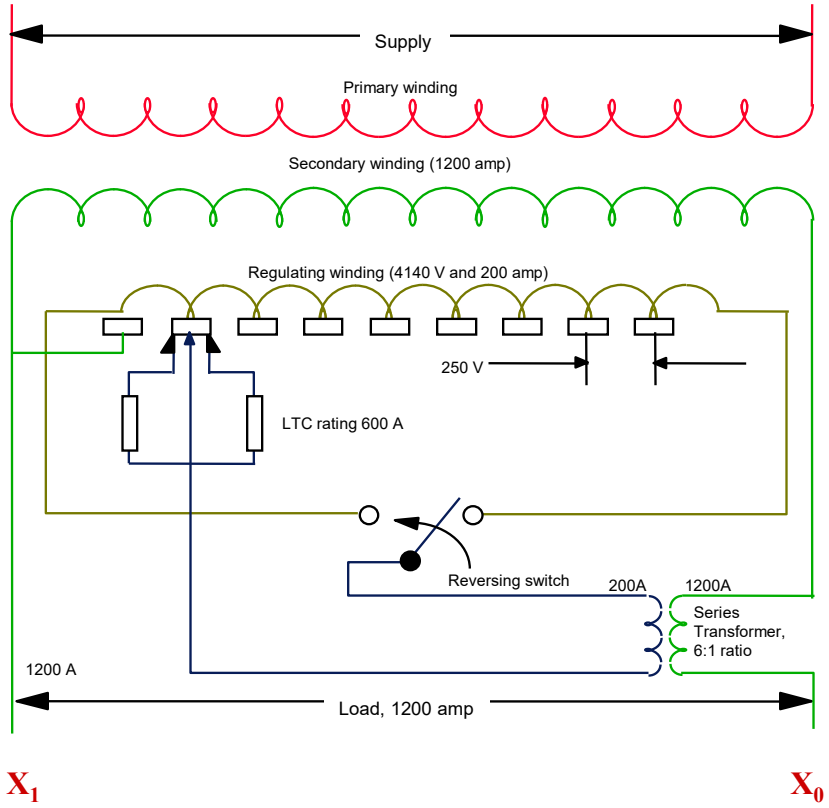


- Lower load losses at minimum tap position
- More complicated winding layout.
- More complicated dielectric design

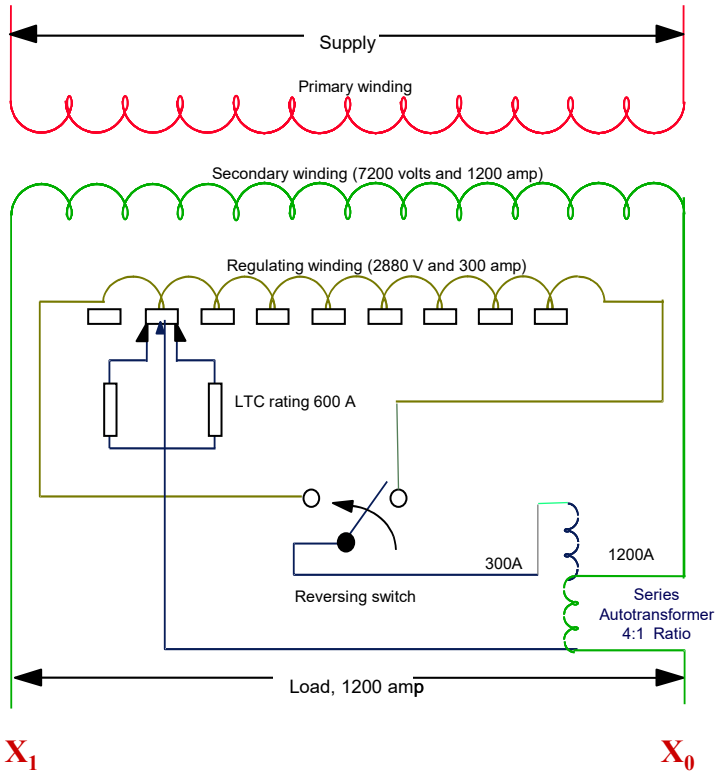
Reference ANSI C57.131-2012 Appendix E

OLTC Functional Arrangements

Two Winding Transformer



Autotransformer



Series Transformer applied when rated current exceeds OLTC capacity

OLTC Designs

Two Basic Designs

- Reactance
  - Arcing Selector Switch
  - Arcing Diverter / Transfer Switch
  - Arcing Vacuum
- Resistance
  - Arcing Selector Switch (high speed)
  - Arcing Diverter / Transfer (high voltage in-tank)
  - Arcing Vacuum

OLTC Designs

Reactance

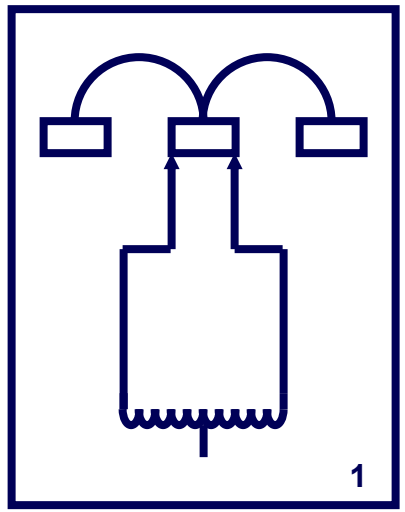
- Origin:  US Domestic design origin
- Operational Concept: Bridging Positions. Uses reactive impedance (reactor) to limit circulating current while on odd taps
- Operation Time: < 2.5 s Typically slower / longer tap change duration
- Drive Mechanism: Direct or spring charge
- Design: V↓ A↑ lower voltage, higher current
- Location: Low voltage side of transformer

Resistance

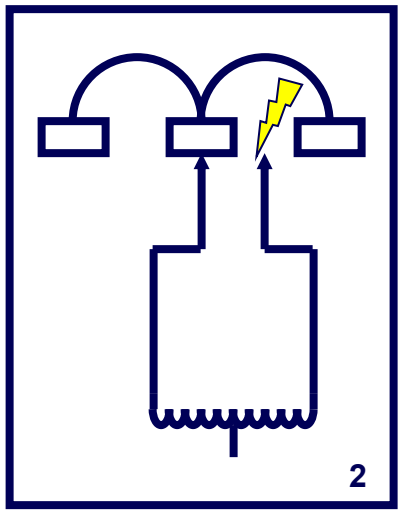
- Origin: 

European design origin
- Operational Concept: No Bridging Positions. Utilizes transition resistor(s) to limit circulating current during tap change operation
- Operation Time: < 270 ms Typically faster / shorter change duration
- Drive Mechanism: Spring charge drive mechanism
- Design: V↑ A↓ higher voltage, lower current
- Location: Either low or high voltage side of transformer

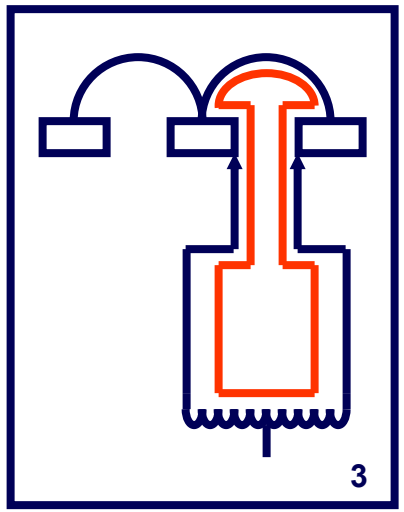
OLTC Design: Reactance with Arcing Selector



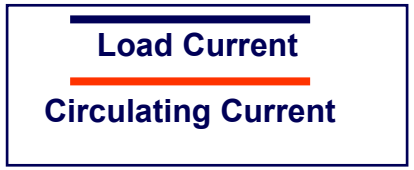
On Position (non-bridging)



Selector Switch Opens



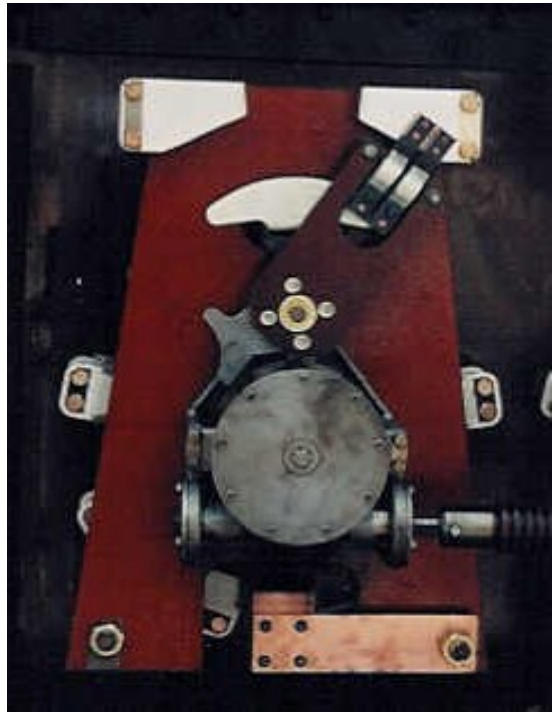
Selector Switch Closes On Position (bridging)



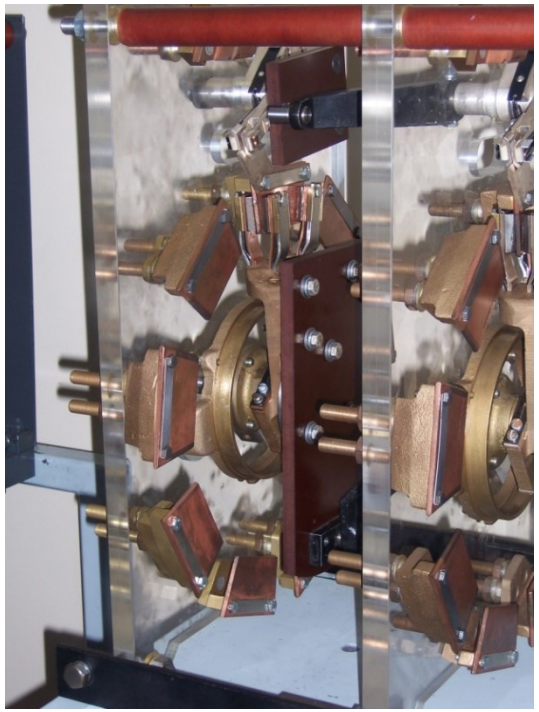
OLTC Design: Reactance with Arcing Selector

- Designed to arc on the moving and stationary Selector Switch contacts
- Produces combustible gases and carbon in oil under normal operating conditions
- Selector contact tips made with arc erosion resistant (Elkonite) material. This material has a higher electrical resistance than copper
- Contact life 100,000+ operations at rated current with filter
- As the tap changer operates, these contacts are designed to wear and erode, and require periodic replacement.
- Examples of this design:
  - Siemens TLF, TLG, TLH20/21
  - McGraw 550/550B/550C
  - General Electric LRT 38, 48, 68, 72

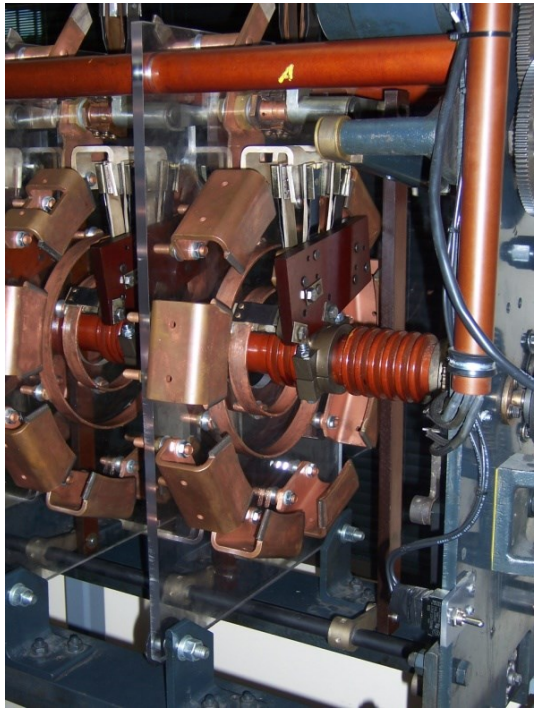
OLTC Design: Reactance with Arcing Selector



McGraw 550B

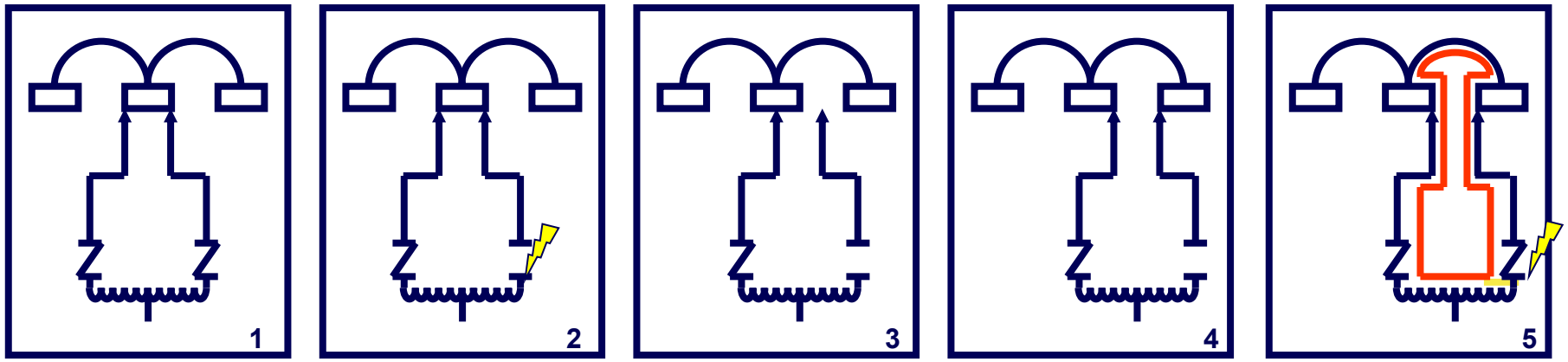


Siemens TLS



GE LRT 72

OLTC Design: Reactance with Arcing Diverter/Transfer



On Position (non-bridging) | Transfer Switch Opens | Selector Switch Opens | Selector Switch Closes | On Position (bridging)

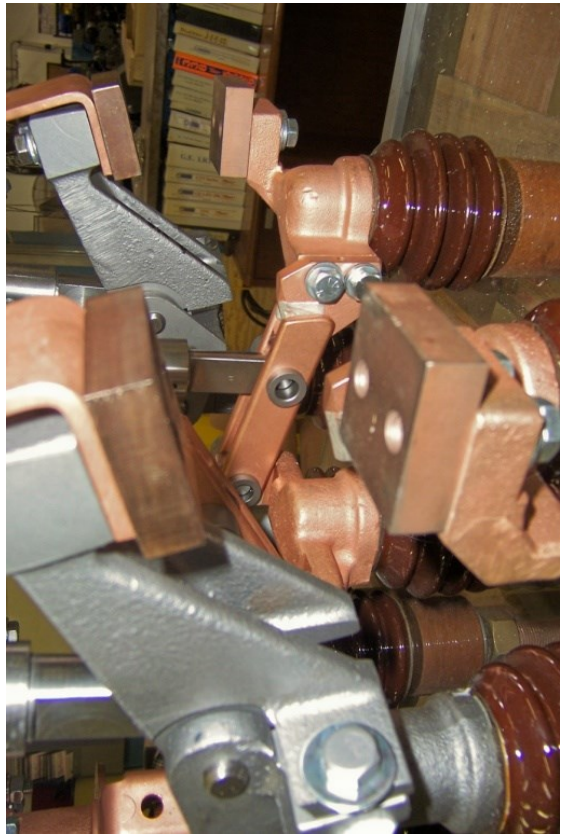
Load Current

Circulating Current

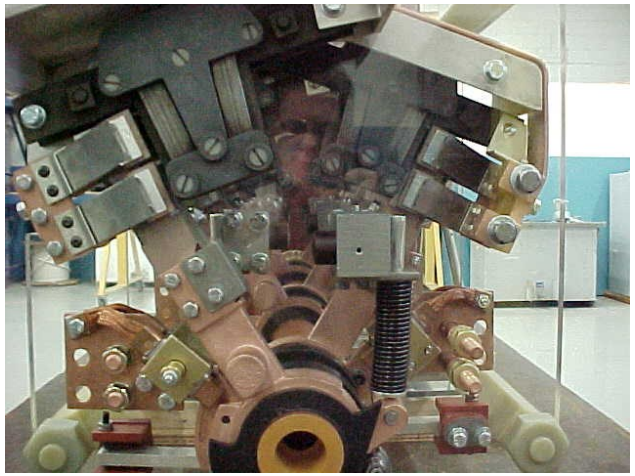
OLTC Design: Reactance with Arcing Diverter/Transfer

- Designed to arc on the moving and stationary Diverter / Transfer Switch contacts
- Produces combustible gases and carbon in oil under normal operating conditions
- Diverter/Transfer contacts made with arc erosion resistant (Elkonite) material are designed to wear and erode, and act as the sacrificial contact
- Contact life 250,000+ at rated current with filter
- Selector contacts are not designed to erode or arc
- Examples of this design:
  - Federal Pacific TC 525, 546
  - Westinghouse UTT Series, UTH, UTS
  - General Electric LRT 65, 83

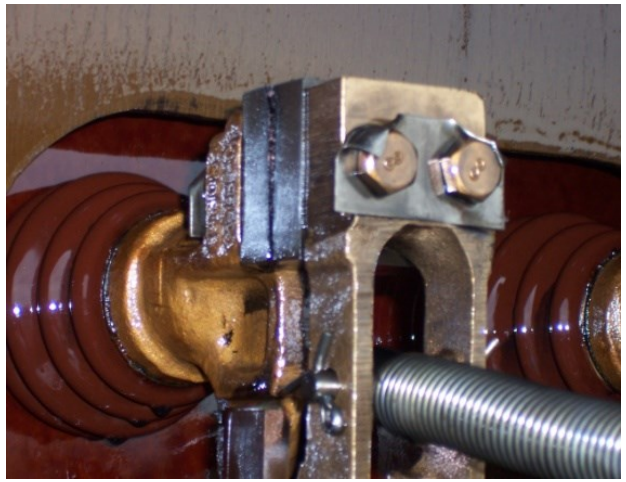
OLTC Design: Reactance with Arcing Diverter/Transfer



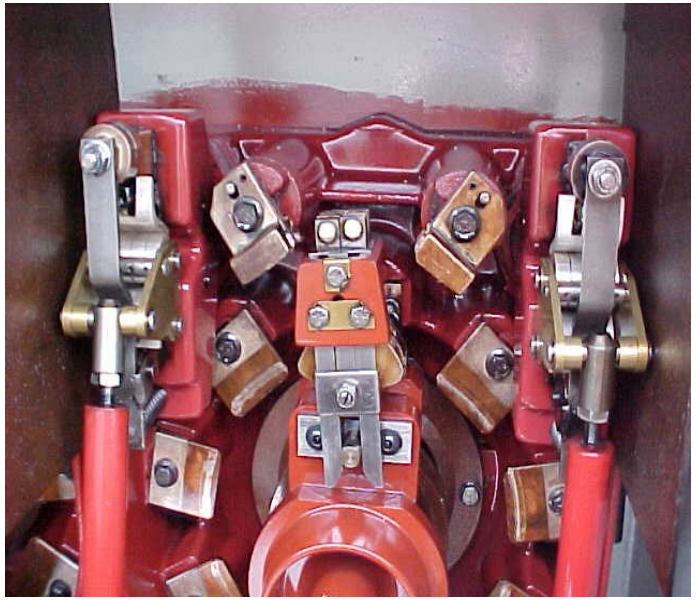
General Electric LR-83



Westinghouse UTT Series

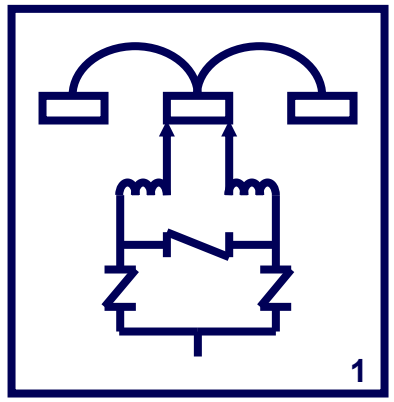


General Electric LR-65

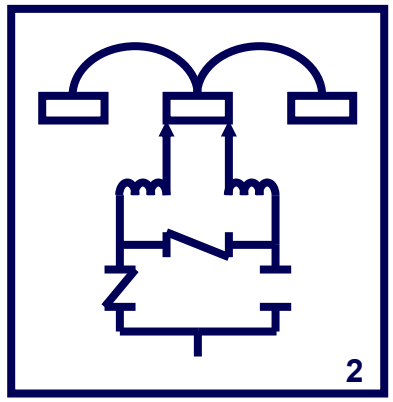


Federal Pacific TC-525

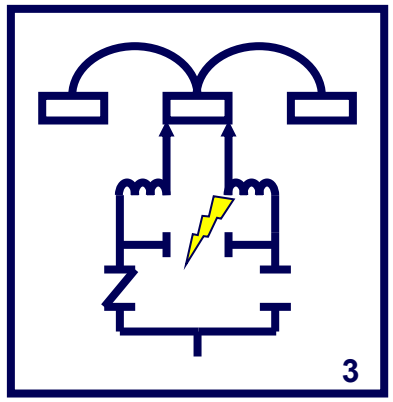
OLTC Design: Reactance Vacuum



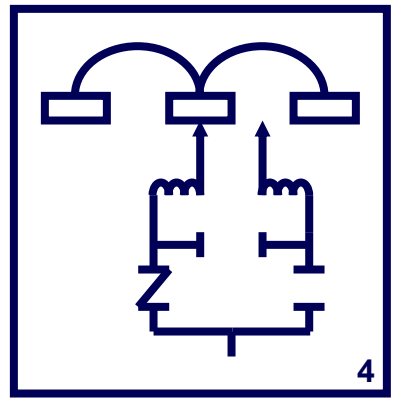
On Position
(non-bridging)



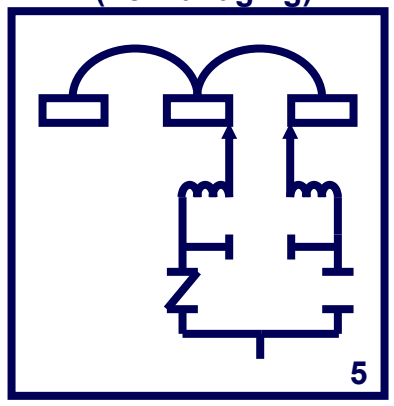
By-pass Switch Opens



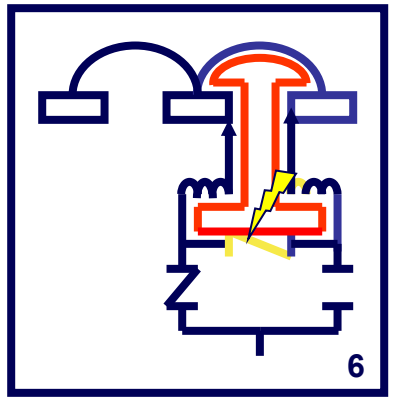
Vacuum Bottle Opens



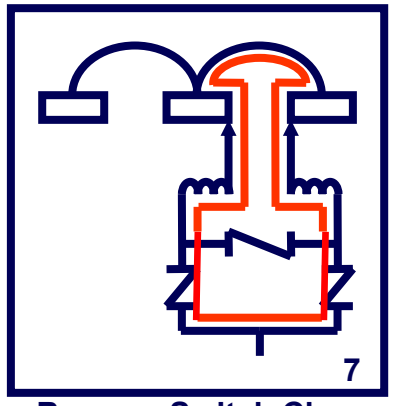
Selector Switch Opens



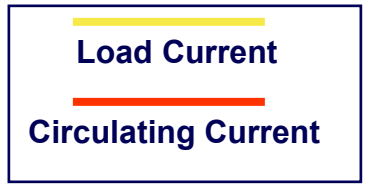
Selector Switch Closes



Vacuum Bottle Closes



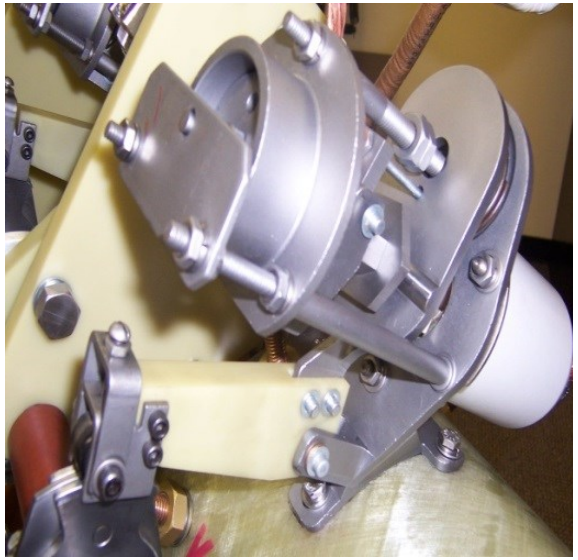
By-pass Switch Closes
On Position (bridging)



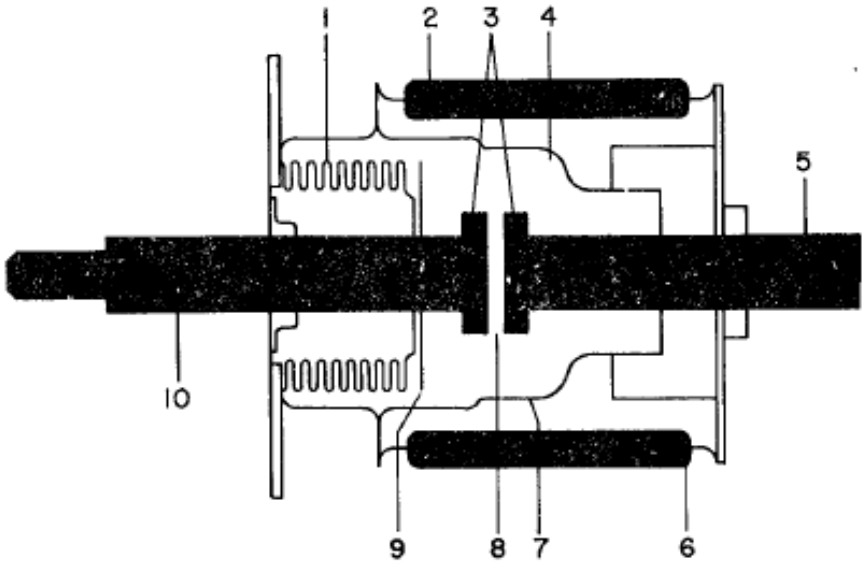
OLTC Design: Reactance Vacuum

- Designed to arc in an interrupter under vacuum
- Does not produce combustible gases and carbon in oil under normal operating conditions
- Vacuum Interrupter contacts made with arc erosion resistant (Elkonite) material are designed to wear and erode, and act as the sacrificial contact
- Contact life 1,000,000+ operations at rated current
- Requires the addition of a bypass switch
- Integrity of vacuum interrupter must be monitored continuously
- Selector contacts are not designed to erode or arc
- Examples of this design:
  - Reinhausen RMV-II
  - Westinghouse UVT
  - General Electric LRT 200, 300, 500

OLTC Design: Reactance Vacuum



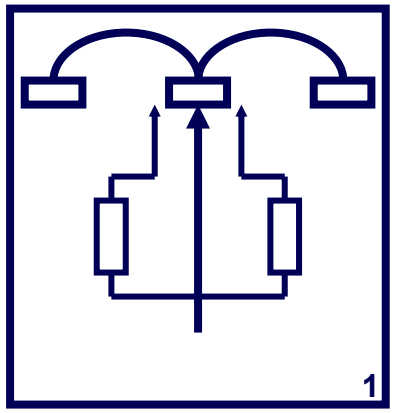
GE LRT200-2



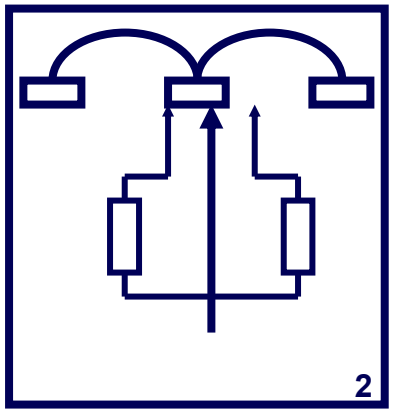
1. FLEXIBLE METALLIC BELLOWS ASSEMBLY
2. INSULATING VACUUM ENVELOPE
3. ARCING CONTACTS
4. VACUUM CHAMBER
5. STATIONARY ELECTRICAL TERMINAL
6. METAL-TO-INSULATION VACUUM SEAL
7. METAL VAPOR CONDENSING SHIELD
8. ELECTRIC ARCING REGION
9. BELLOWS SHIELD
10. OPERATING ROD (MOVABLE TERMINAL)

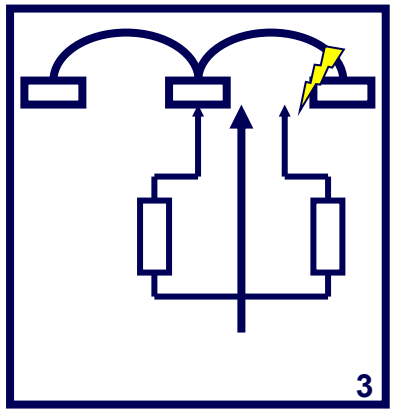
Reinhausen RMVII

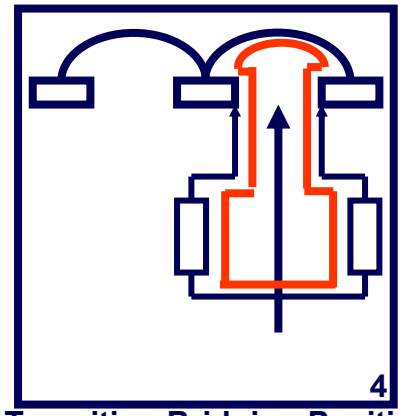
OLTC Design: Resistance with Arcing Selector



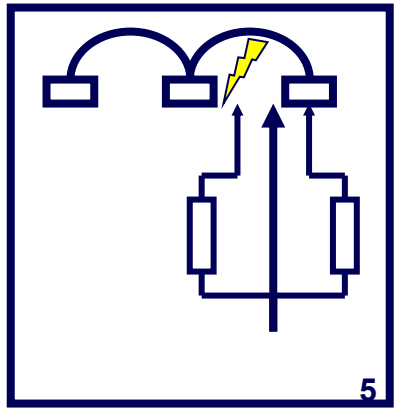
On Position

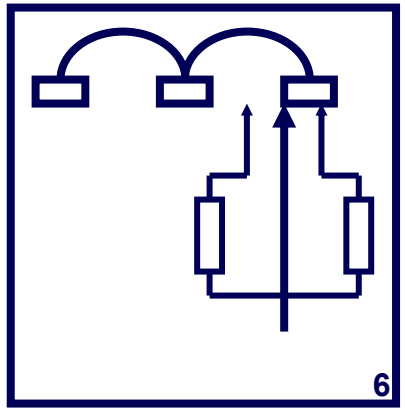


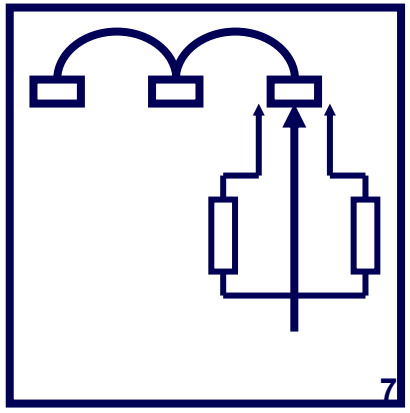




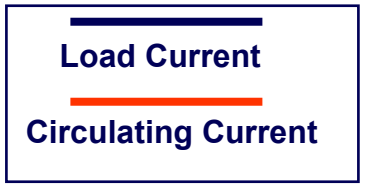
Transition Bridging Position
(does not stop)







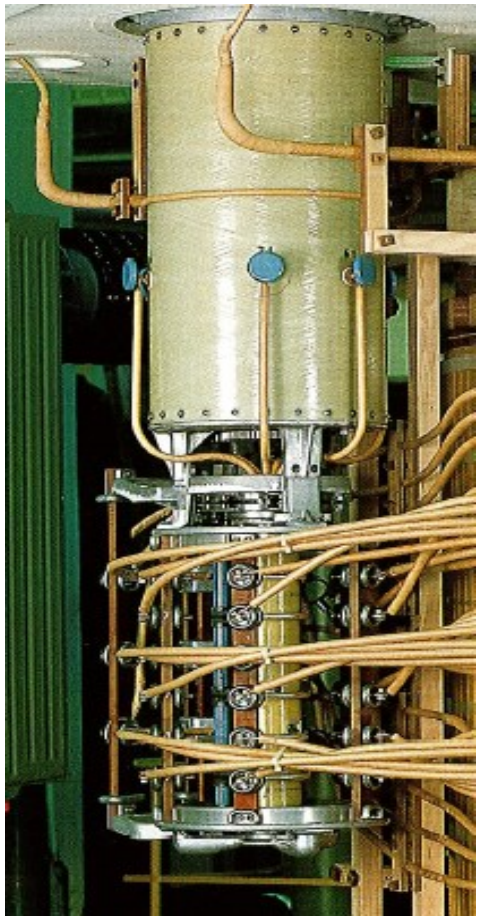
On Position



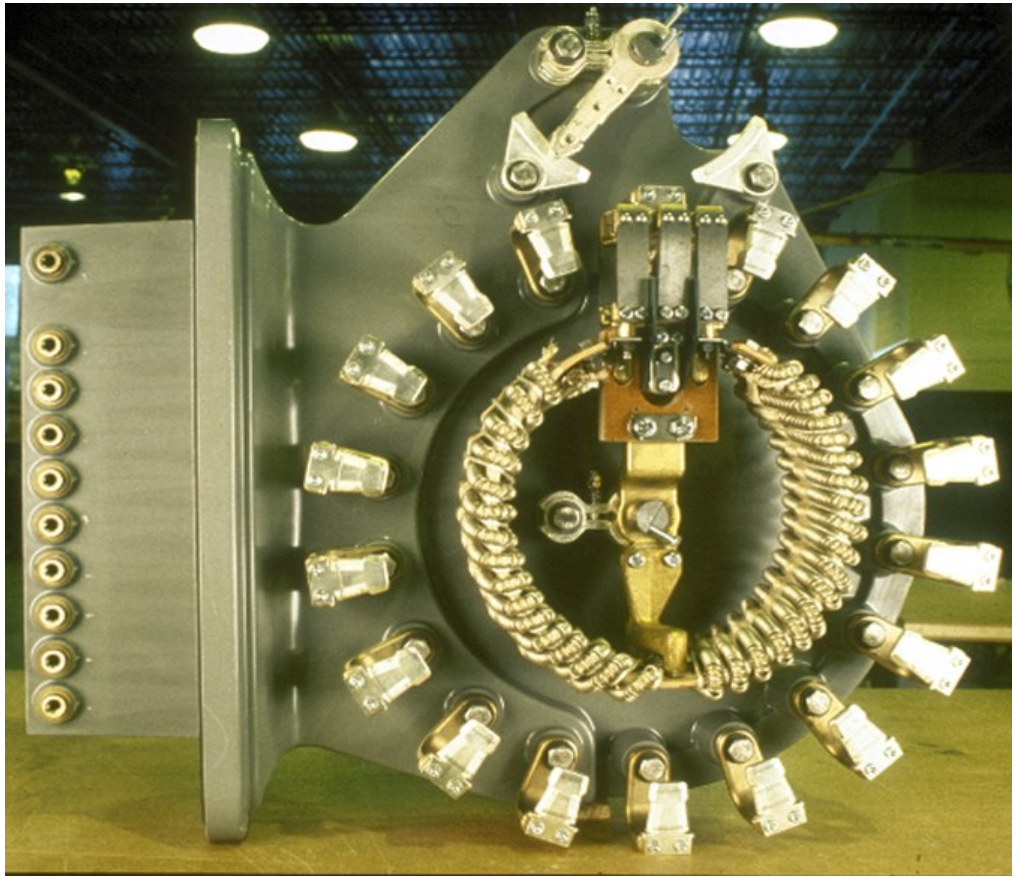
OLTC Design: Resistance with Arcing Selector

- Designed to arc on the moving and stationary selector switch
- Circulating current is limited by transition resistor while the LTC passes through bridging contacts
- Produces combustible gases and carbon in oil under normal operating conditions
- Typically, high speed (<100 ms tap change time)
- Contact life 500,000+ operations at rated current with filter
- Selector contacts equipped with arc erosion resistant (Elkonite) material
- As the tap changer operates, these contacts are designed to wear and erode and require periodic replacement
- Examples of this design:
  - Waukesha UZD
  - ABB UZE, UZF
  - Most of HV in-tank models

OLTC Design: Resistance with Arcing Selector

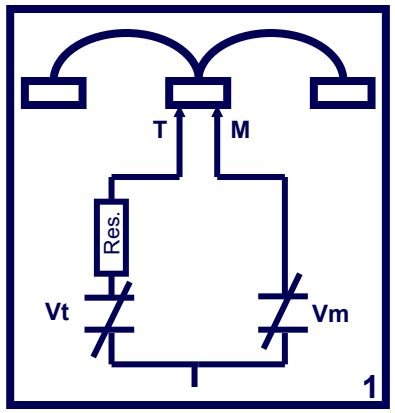


Reinhausen Type M In-Tank

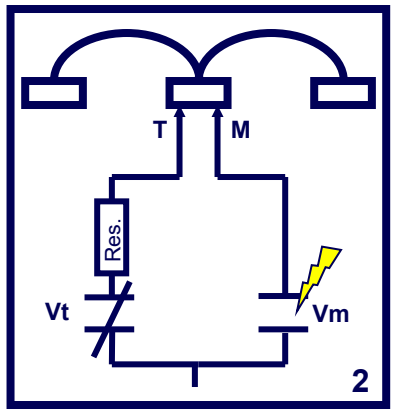


Waukesha® UZD®

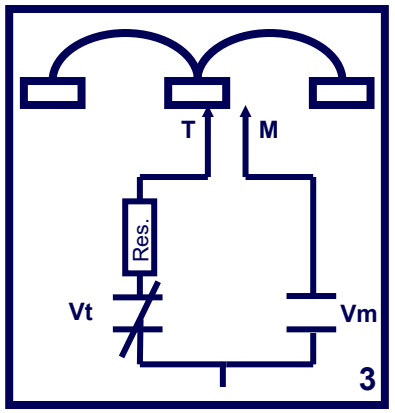
OLTC Design: Resistance Vacuum



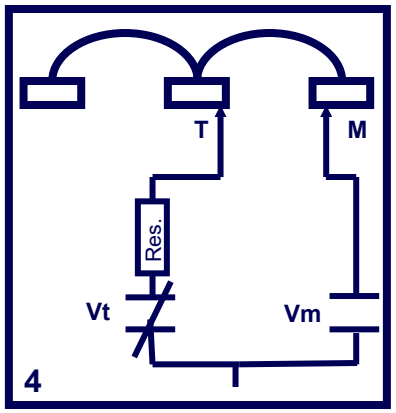
On Position



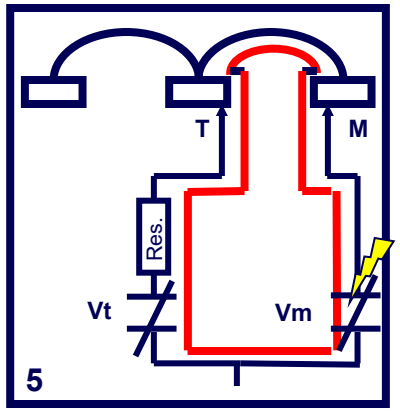
VM Interrupter Opens



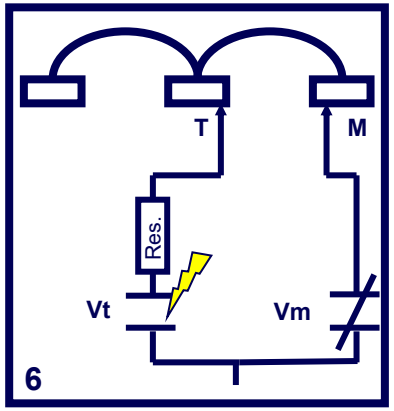
"M" Contact Moves



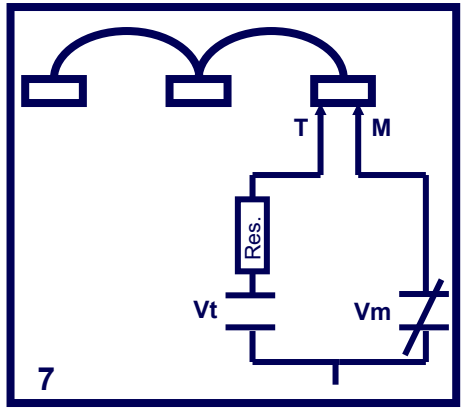
Transition Bridging Position



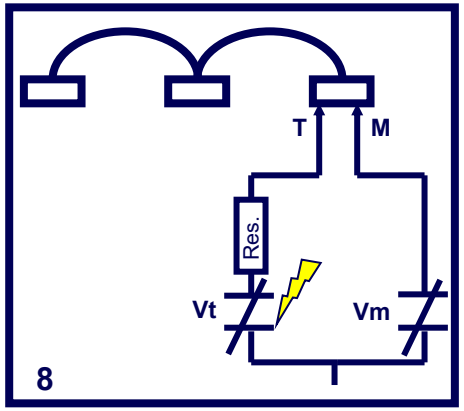
Vm Interrupter Closes



Vt Interrupter Opens



"T" Contact Moves



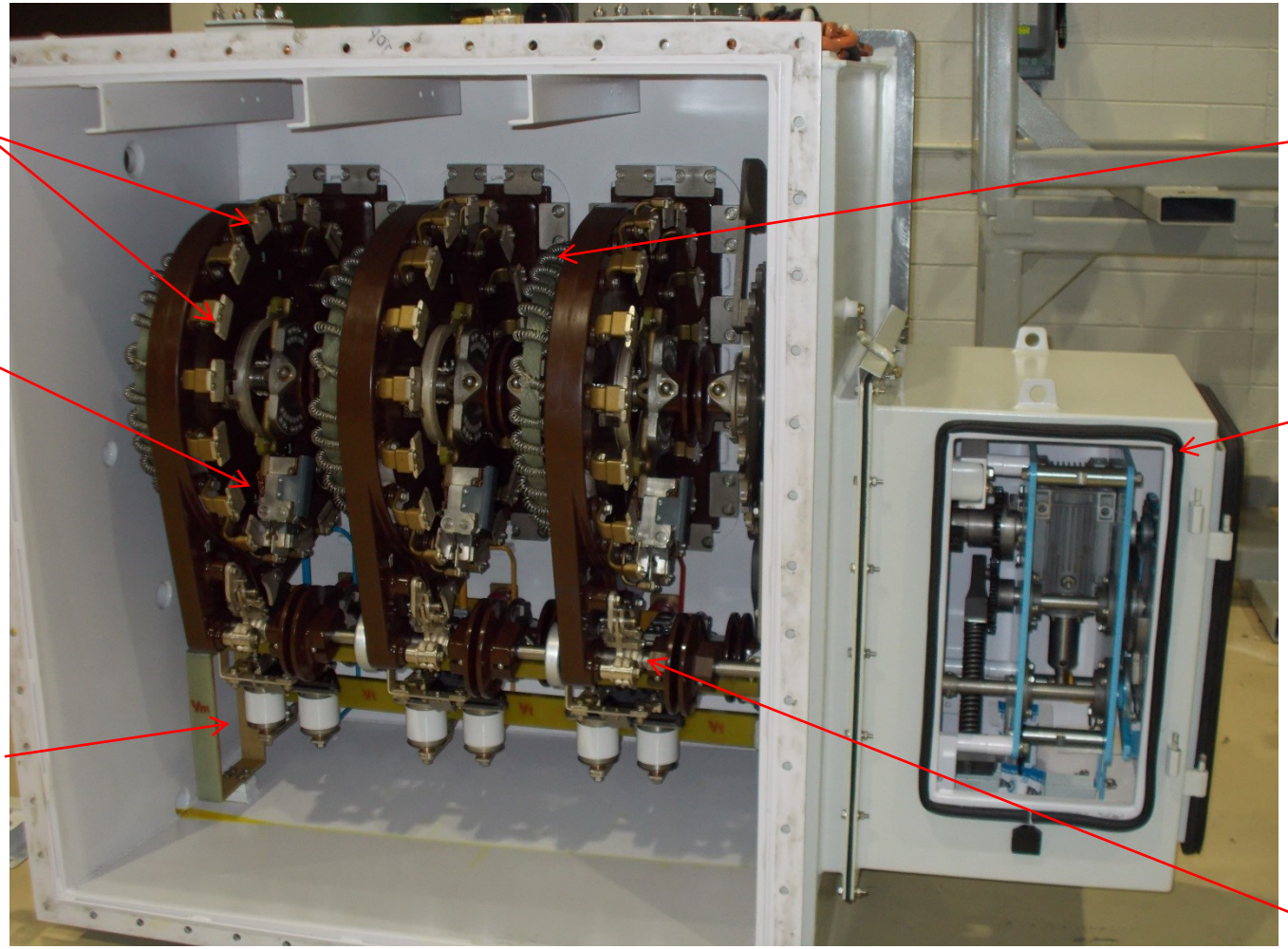
Vt Interrupter Closes
On Position

Circulating Current **Load Current**

OLTC Design: Resistance Vacuum

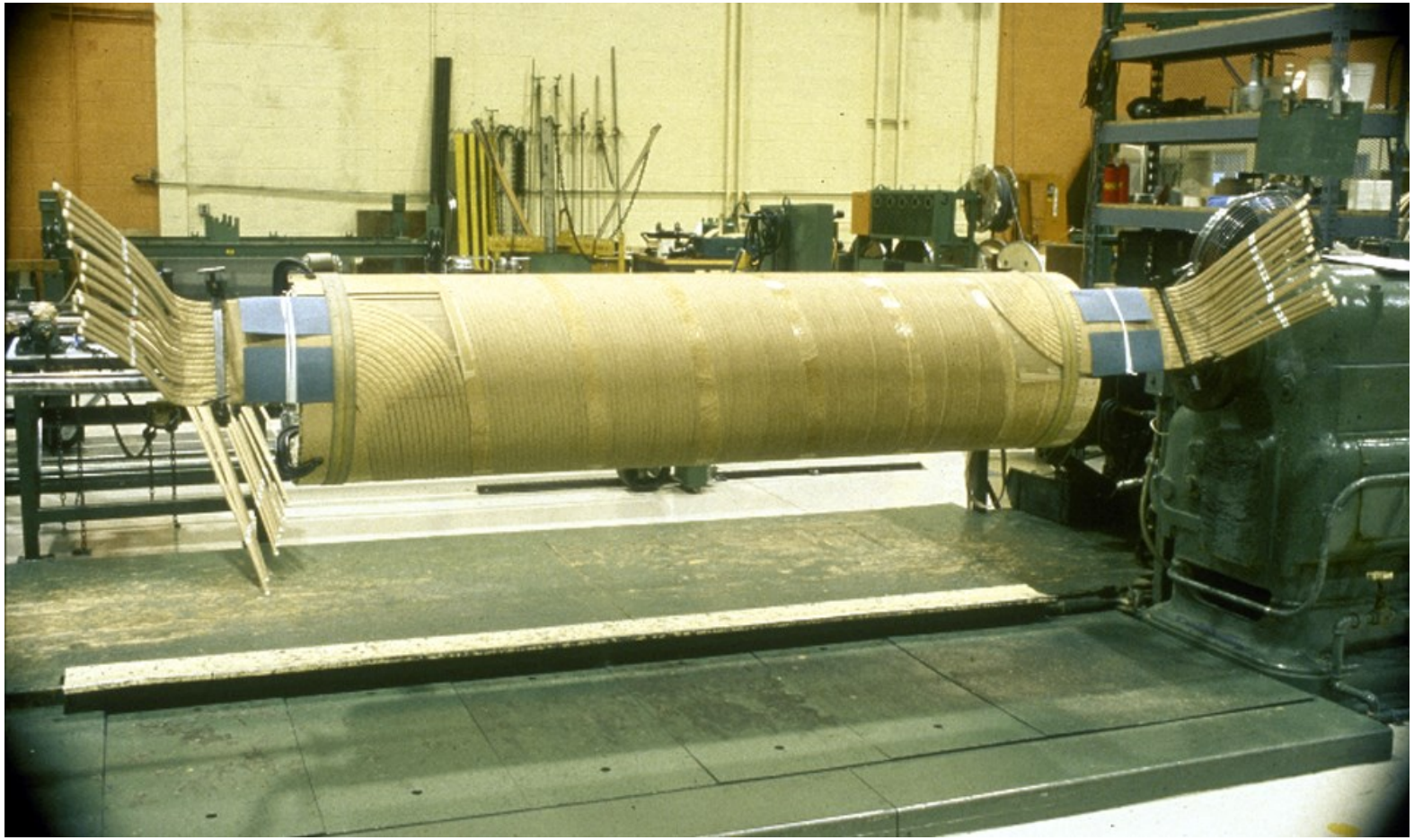
- Designed to arc in an interrupter under vacuum
- Circulating current limited by transition resistor while passing through bridging contacts
- Does not produce combustible gases and carbon in oil under normal operating conditions
- Vacuum Interrupter contacts made with arc erosion resistant (Elkonite) material are designed to wear and erode, and act as the sacrificial contact.
- Contact life 1,000,000+ operations at rated current
- Typically high speed (<270 ms tap change time) spring driven
- Selector contacts are not designed to erode or arc under normal operating conditions
- Examples of this design:
  - Waukesha UZDvac®

OLTC Design: Resistance Vacuum



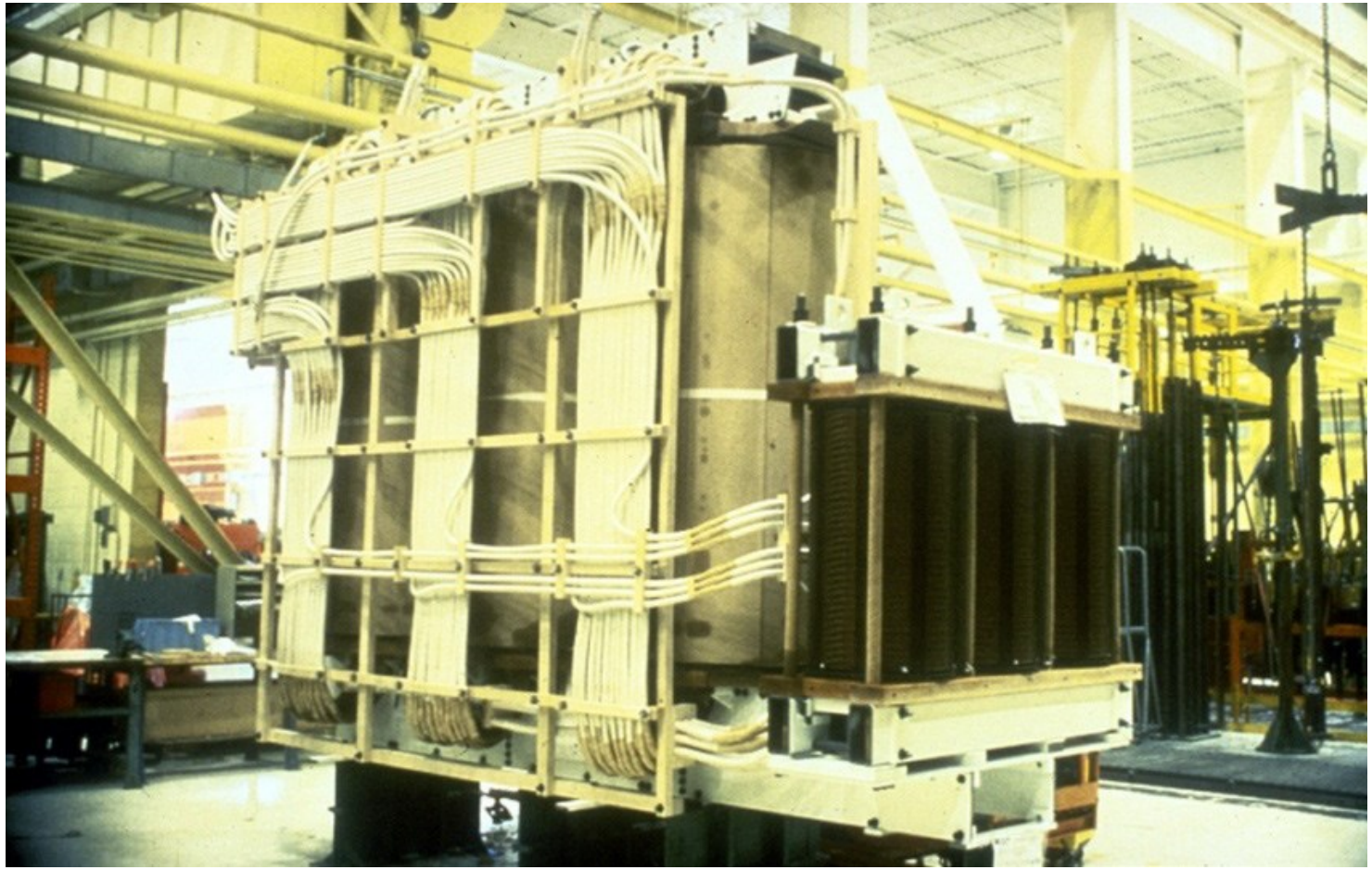
Prolec GE Waukesha UZDvac® LTC

Winding Design for LTC Application:
Multi Start Tap Winding



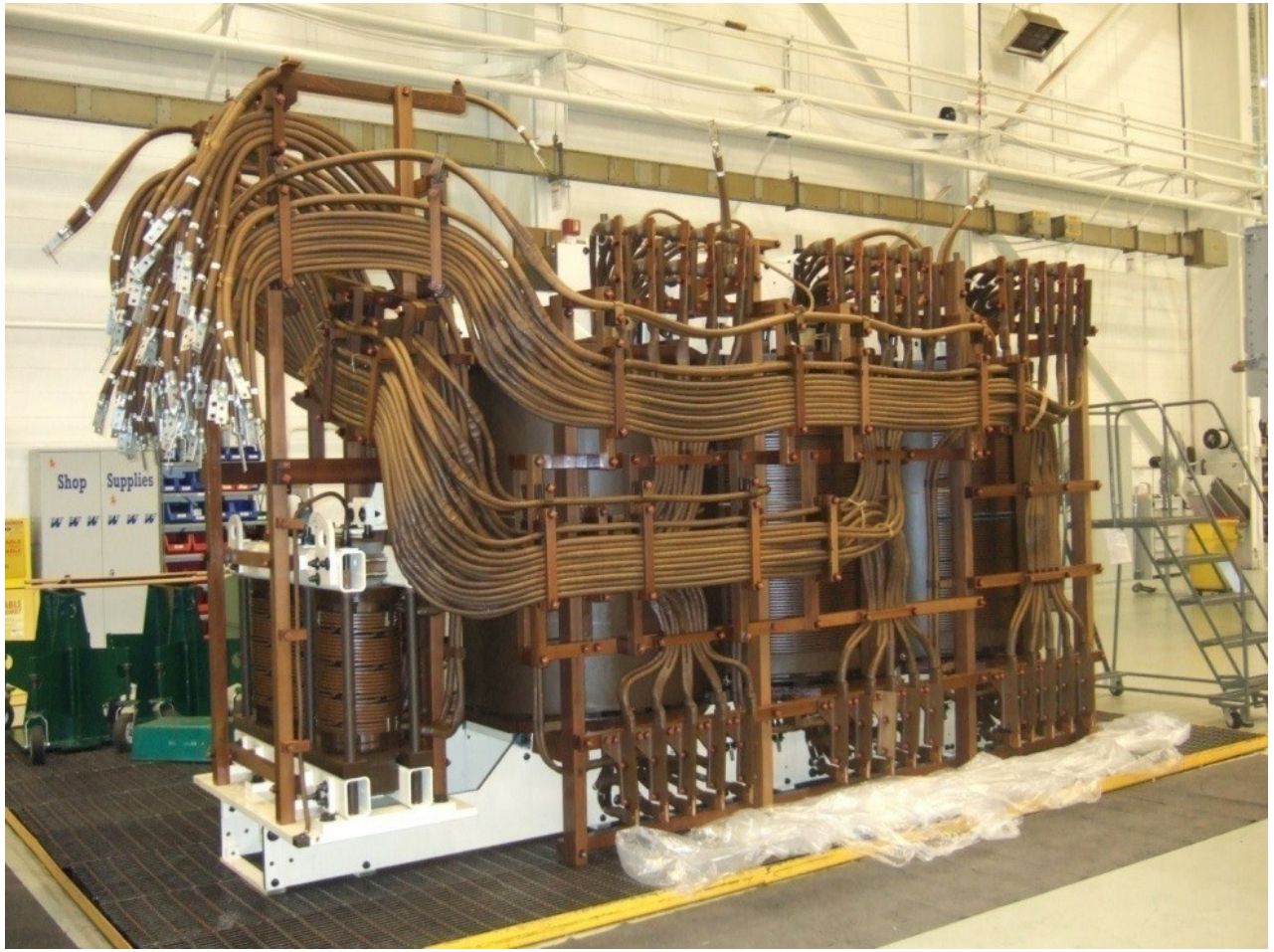
17 Leads, Fully Distributed Tap Winding

Transformer Design for LTC Application:
Series / Booster Transformer



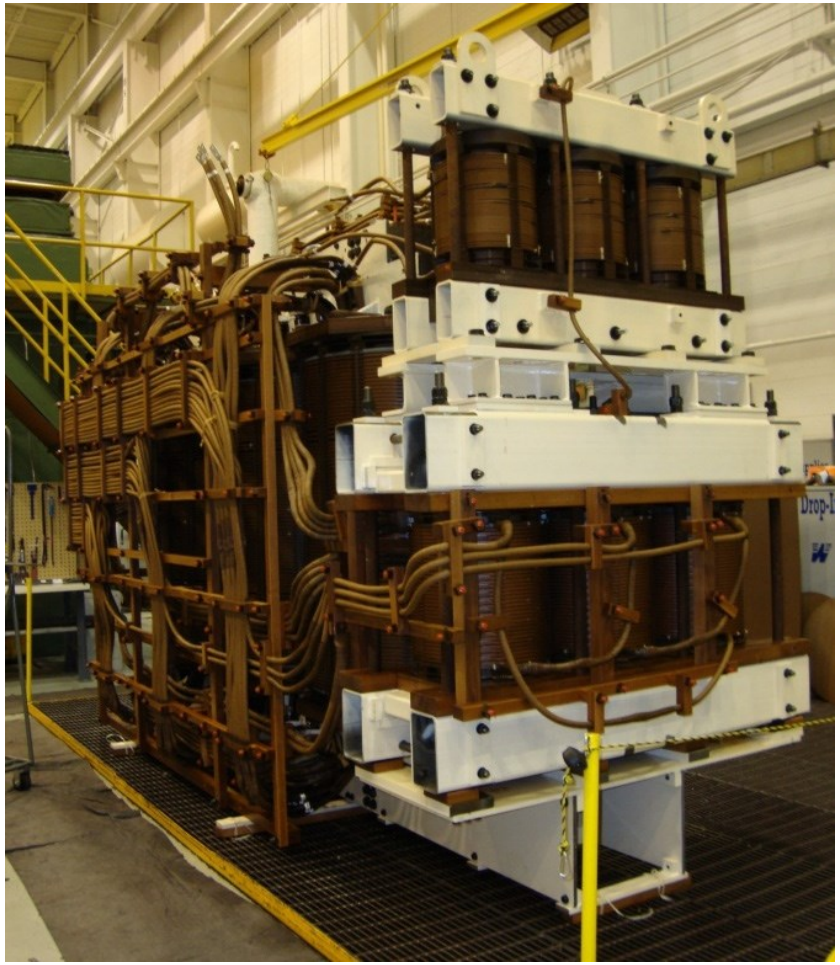
Transformer designed with a series/booster transformer for use with 600 A resistance bridging load tap changer.

Transformer Design for LTC Application:
Preventive Auto Transformer



Transformer designed with a preventive autotransformer for use with 2,500 A reactance bridging load tap changer.

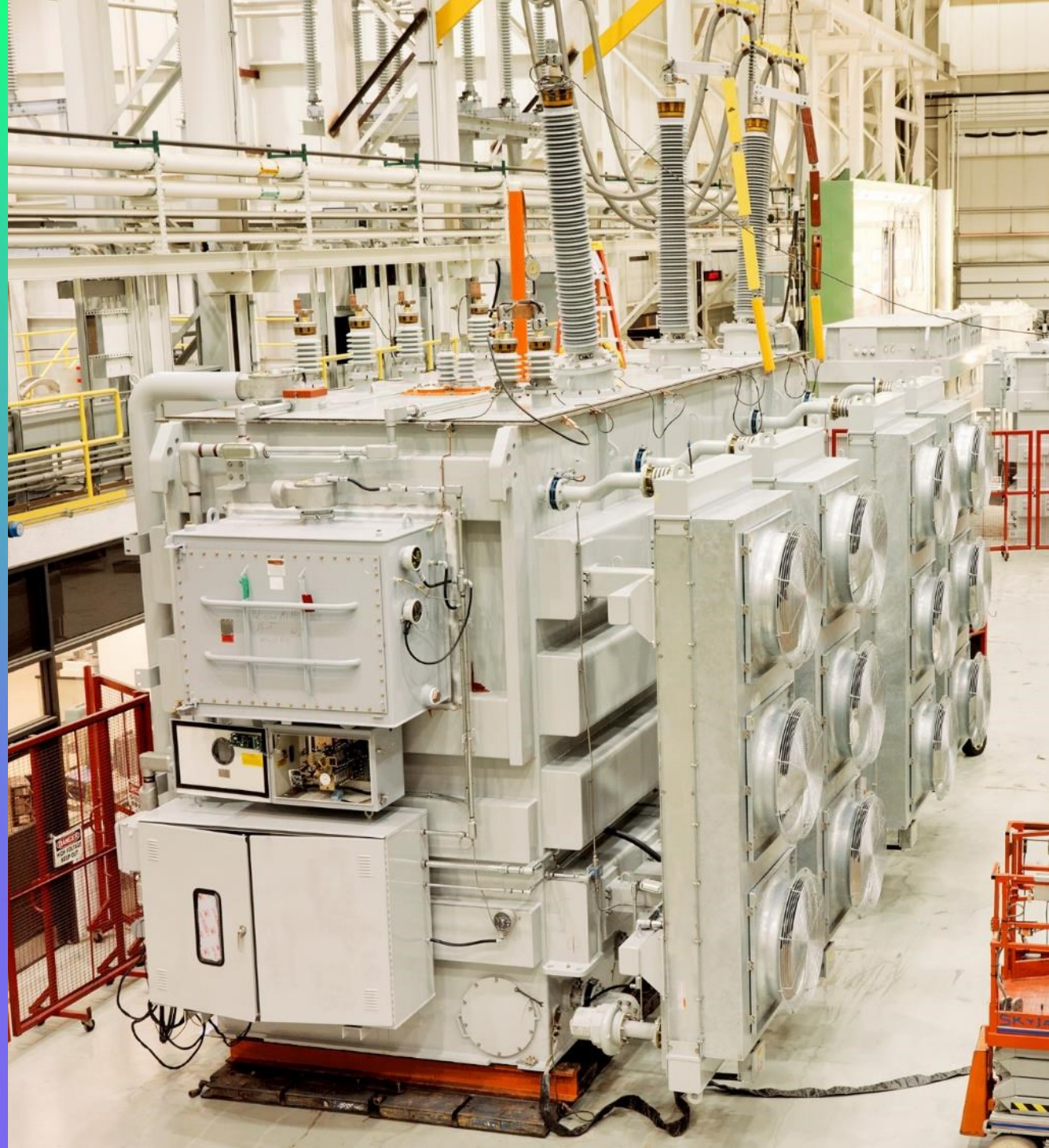
Transformer Design for LTC Application:
Series and Preventive Auto Transformers



Transformer designed with reactance bridging load tap changer with preventive auto (on top) and series transformer (on bottom).

waukesha
a prolec ge company

Case Studies: Maintenance & Common Issues



Load Tap Changer Overhauls:
Siemens TLH 20

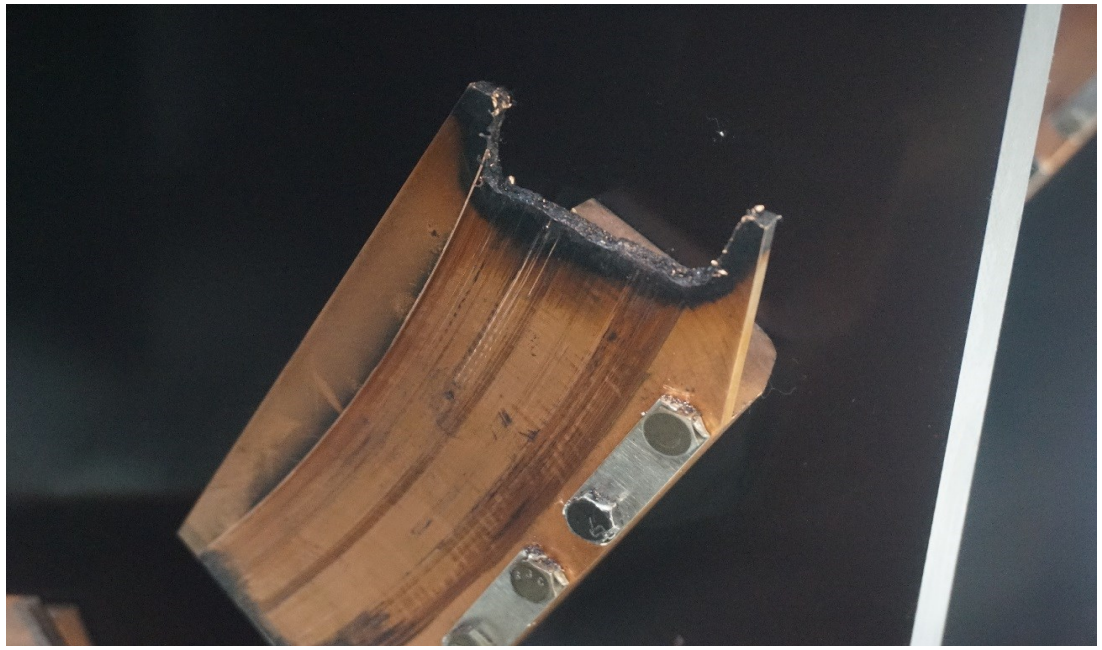
Customer had recently performed major maintenance on this TLH-20 LTC mechanism, replaced all the contacts and did not have them adjusted properly. The LTC drive mechanism operated “sluggishly” and did not complete a tap operation with the selector moving contacts all the way on the stationary contacts due to the excessive contact spring pressure. This led to stripping the gears on the drive motor transmission. The heating of the Reversing switch neutral contact was also due to the improper adjustment of the Revering switch moving contacts. Also when replacing contacts on this style LTC, the adjustment of the latch finger on the drive index plate should be verified and adjusted if needed to ensure the charging springs are charged adequately prior to releasing the mechanism for a tap operation. This was not done.

Load Tap Changer Overhauls:
Siemens TLH 20

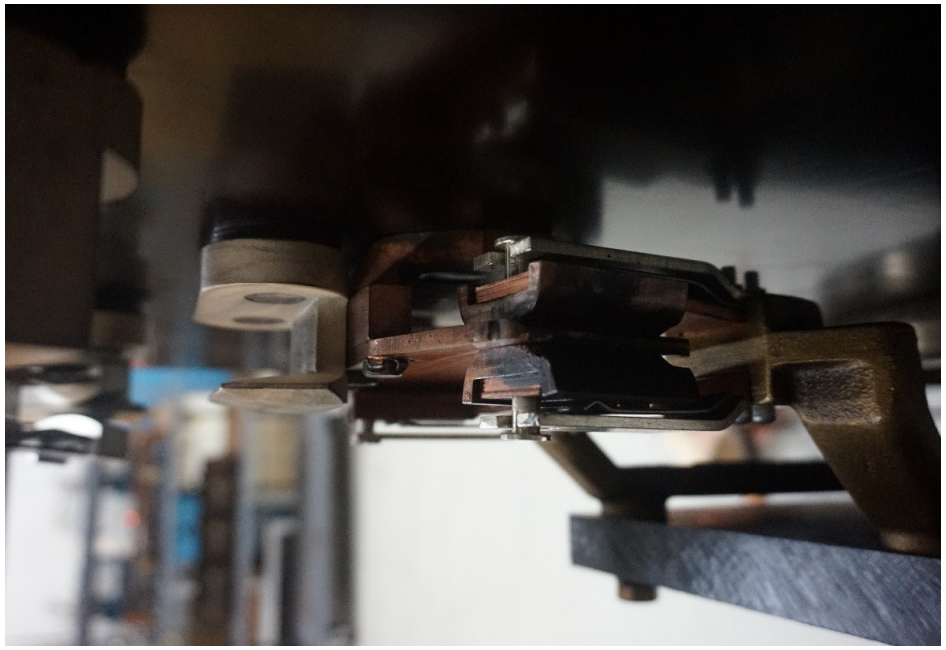
Reversing Switch Isolated Neutral:
Heating & Carbon Buildup

Tap Leads with Insulation
Damage & Heating

Load Tap Changer Overhauls:
Siemens TLH 20



Selector Switch Stationary Contact with
Severe Arcing Damage

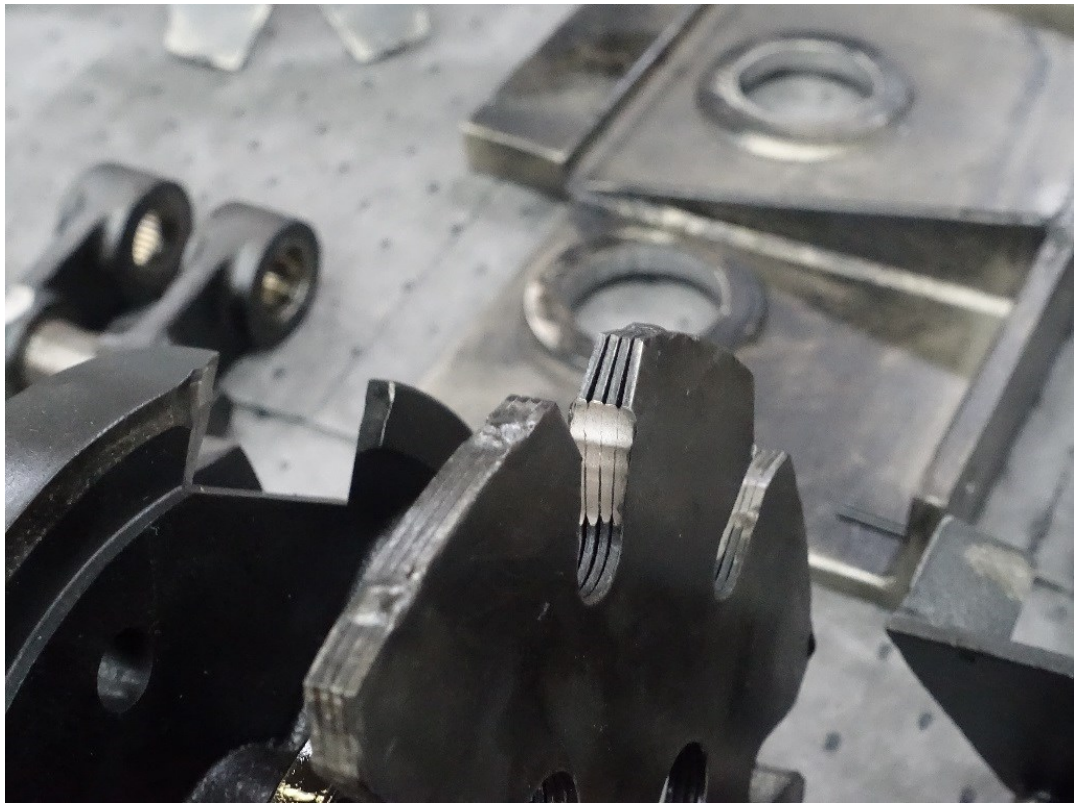


Selector Switch Moving Contact with
Severe Arcing Wear

Proper installation and alignment of components is key to reliable operation.

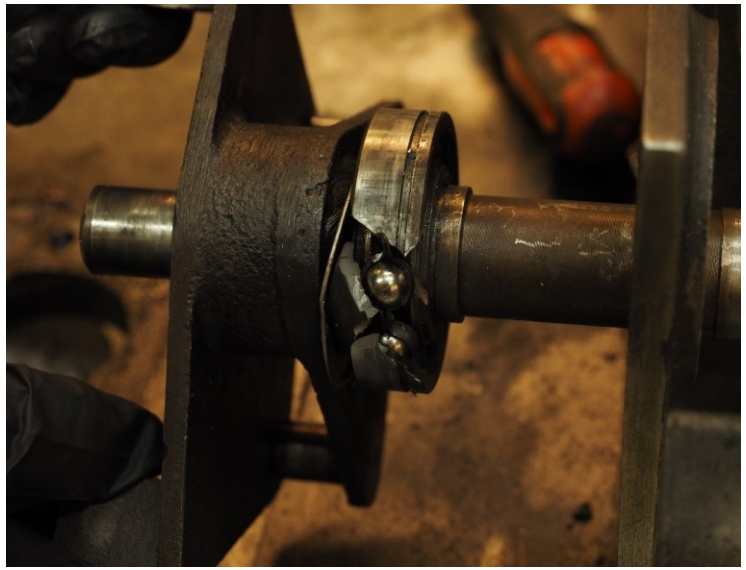
Load Tap Changer Overhauls:
FPE TC 546 Spring Drive Mechanism

Vertical Worm Gear Drive Shaft Damage



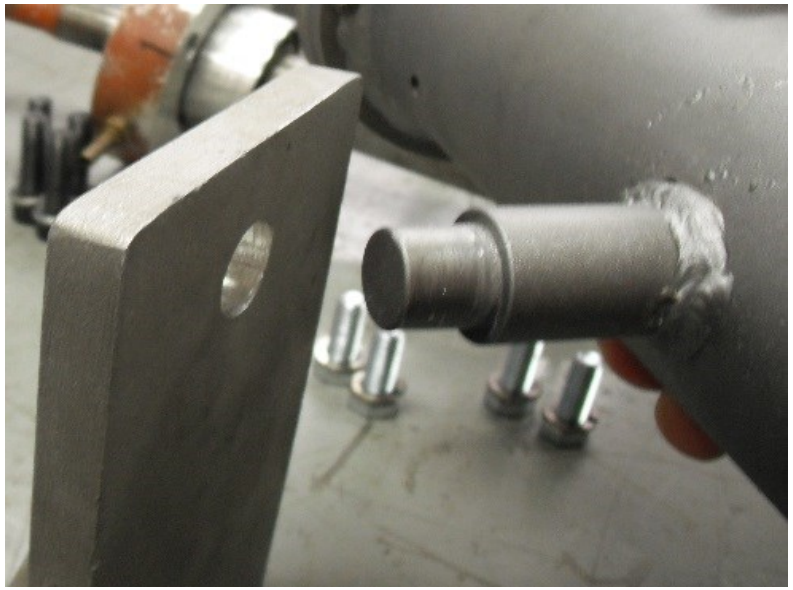
Wear on Second Shaft Geneva Gear

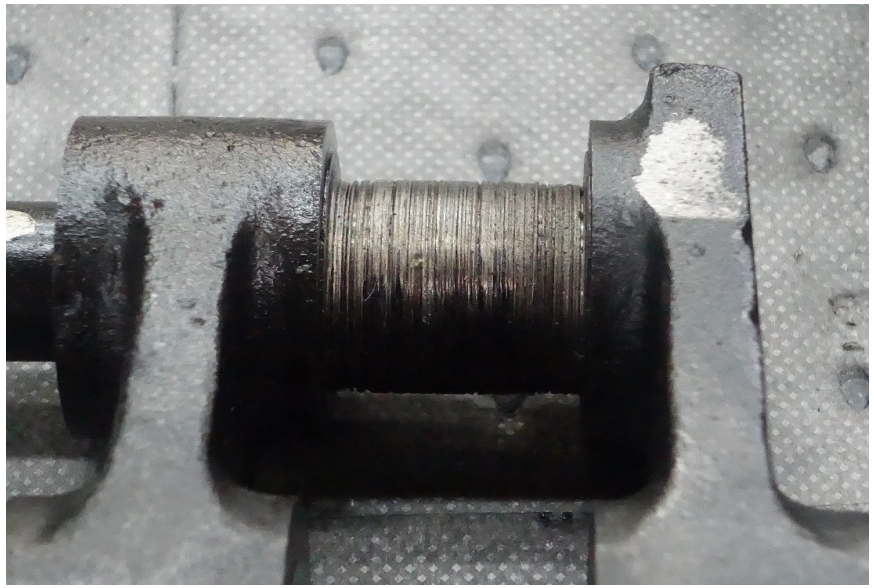
Load Tap Changer Overhauls:
FPE TC 546 Spring Drive Mechanism



Shattered Bearing on
First Shaft Assembly

Wear on Mounting Ears and
Support Plate for Spring Barrel

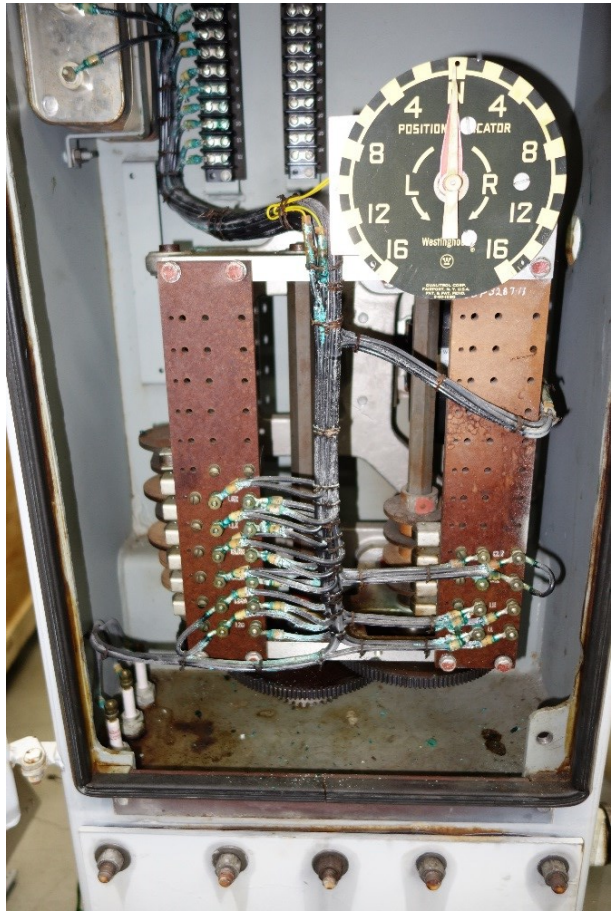




Wear on Spring Drive Crank

White Paper: FPE Spring Drives

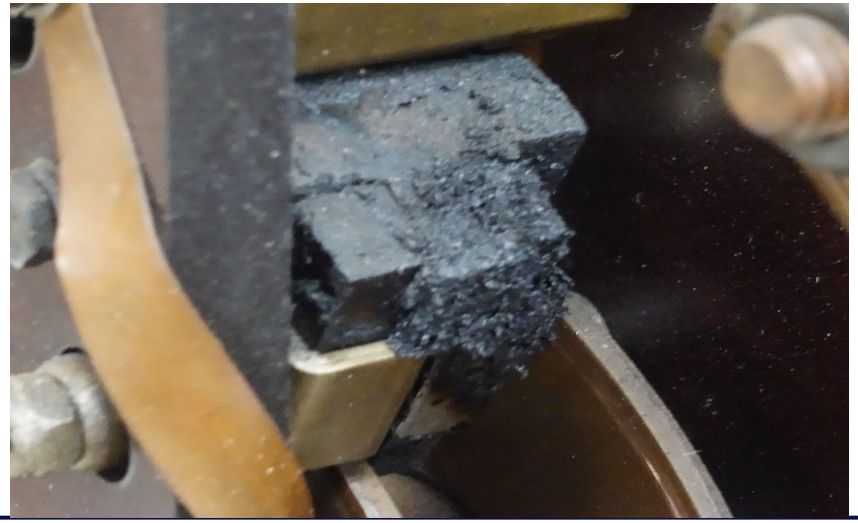
Load Tap Changer Overhauls:
Westinghouse UTT



Corrosion and Wiring Insulation Degradation in Cam Switch Compartment

Cracks in Phase Board Insulation

Tap Lead Insulation Damage

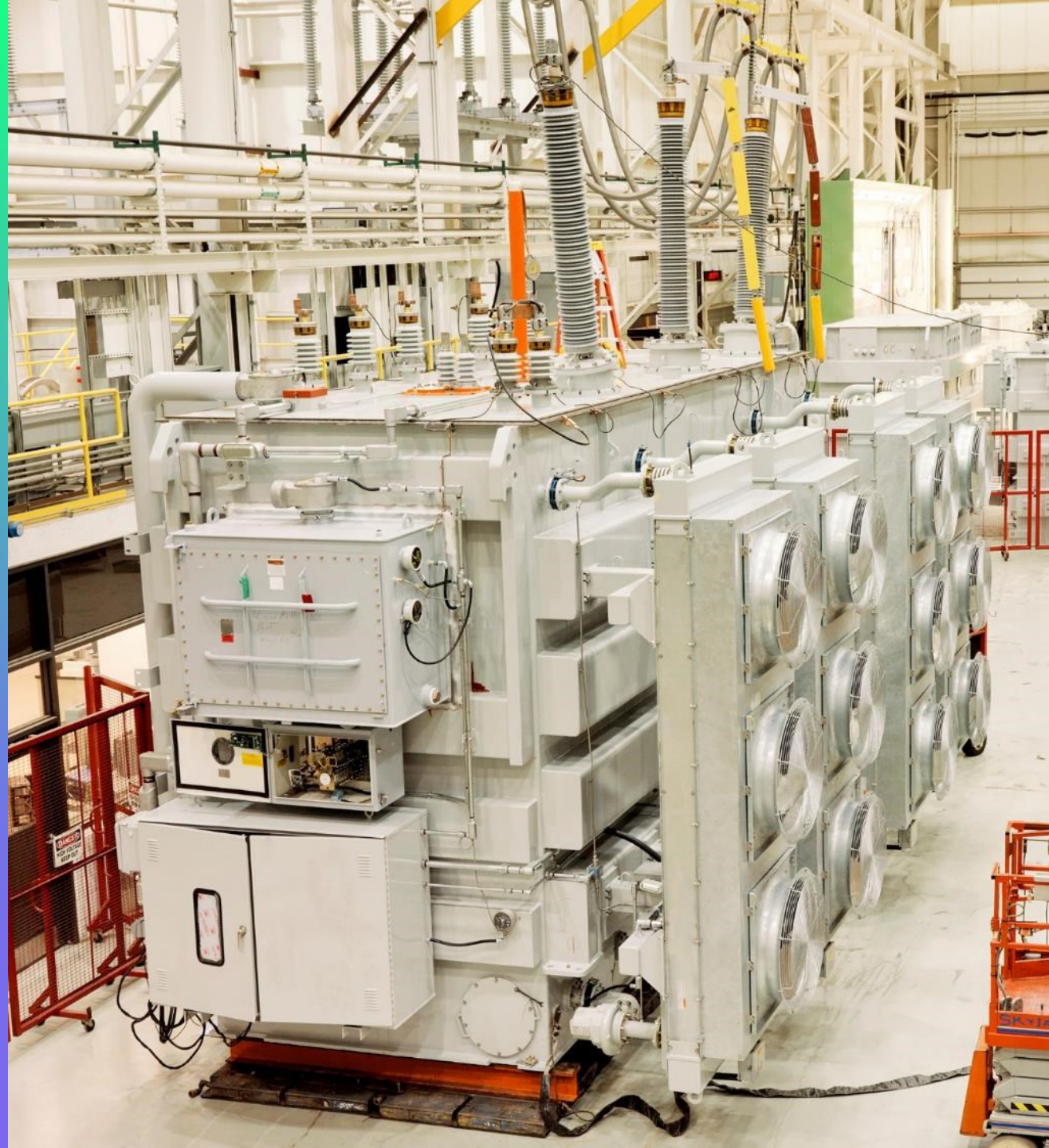


Coking on Selector Switch Moving Contact Assembly

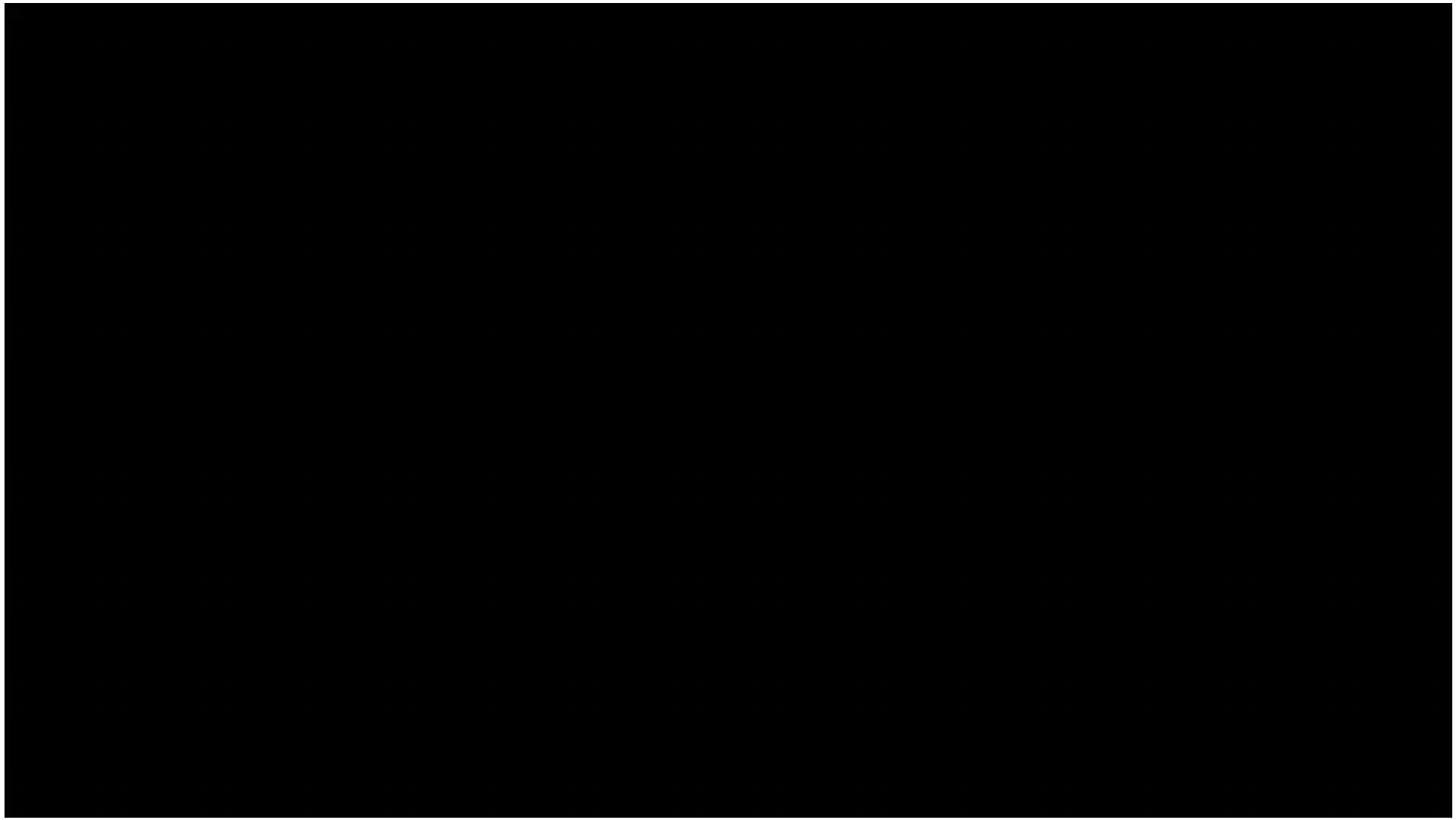
Westinghouse UTT: White Papers

waukesha
a prolec ge company

Free Technical Resources Available to You



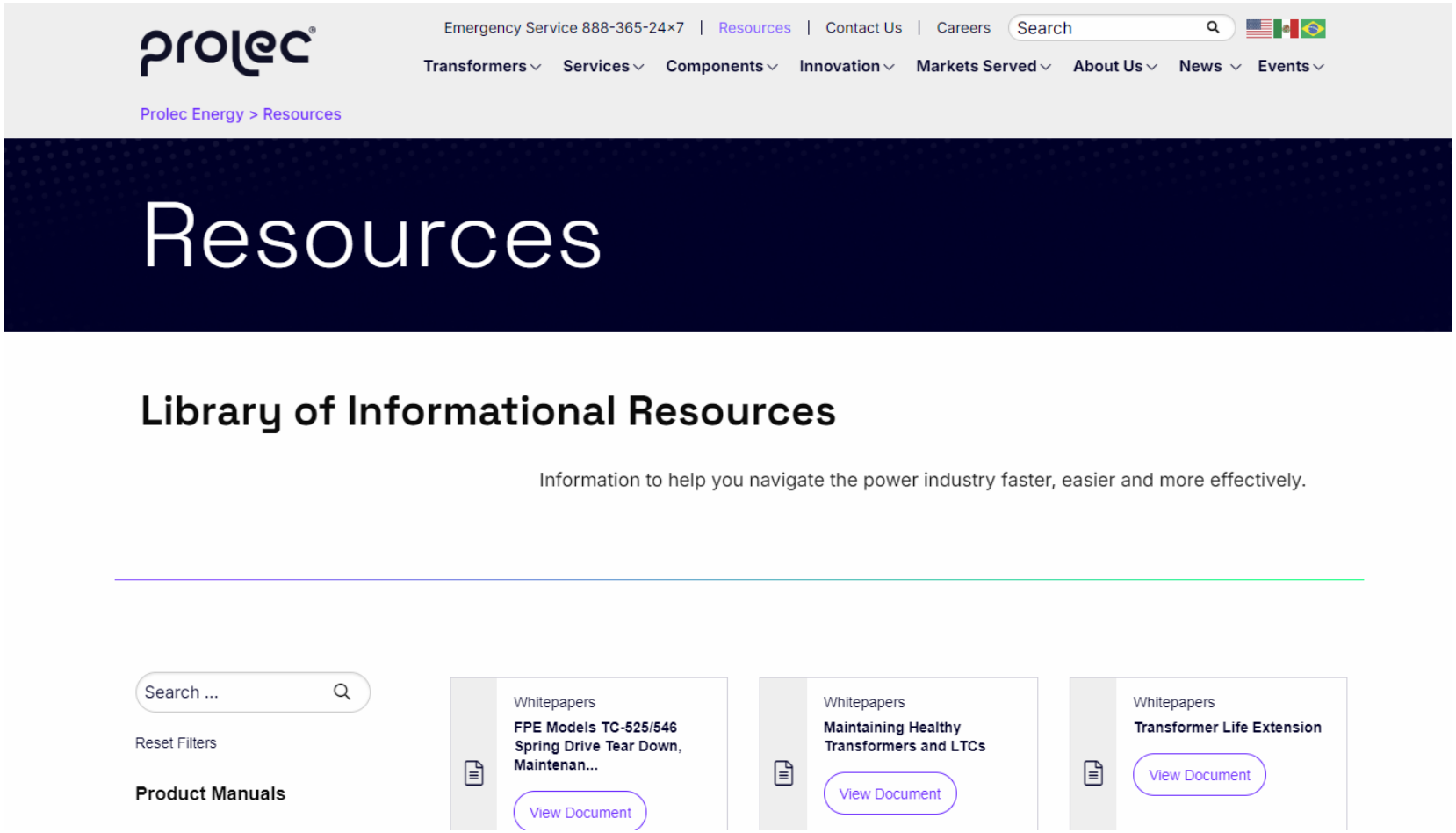
Flipping Book



Constant Contact

https://www.prolec.energy/resources/

Use the filters on the left
to see all the Whitepapers.



Contact
Florin Faur
Lead Product Engineer – Components Group
469-263-5759
Florin.Faur@prolec.energy

www.waukeshatransformers.com