Regional Technical Seminar

DETC/LTC Applications for Voltage Regulation

Transformer Regional Technical Seminar

Austin, TX

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Josh Jordan joined Prolec GE Waukesha in 2017 as an intern for the electrical design team in Waukesha. He has been designing medium and large power/EHV production order transformers since 2019, with ratings up to 712 MVA, 345kV class, 1175kV BIL and up to 800 MVA for quotation requests. Josh holds a Bachelor of Science Degree in Electrical Engineering from the University of Milwaukee School of Engineering.

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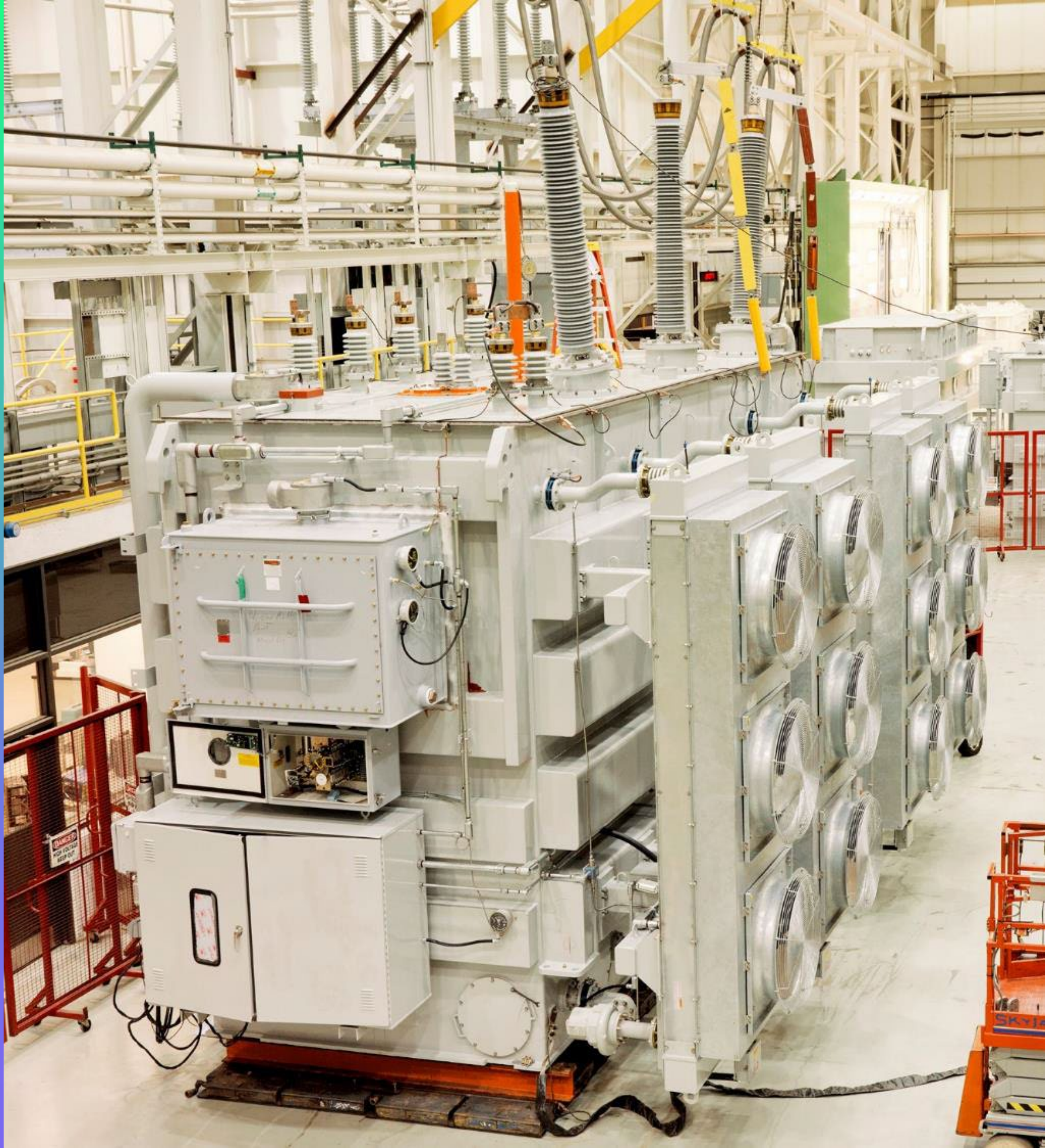

Agenda

- DETCs
- Voltage Regulation
- Load Tap Changers
- LTC Application Considerations
- Paralleling

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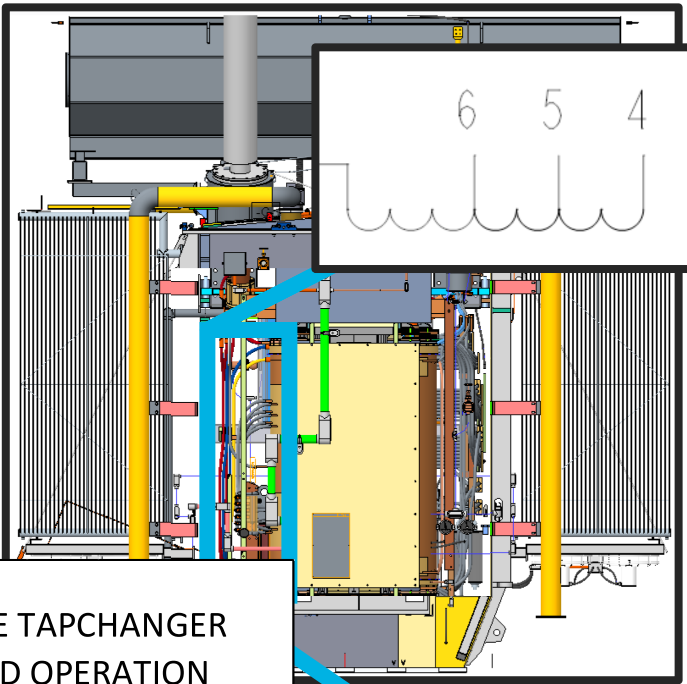
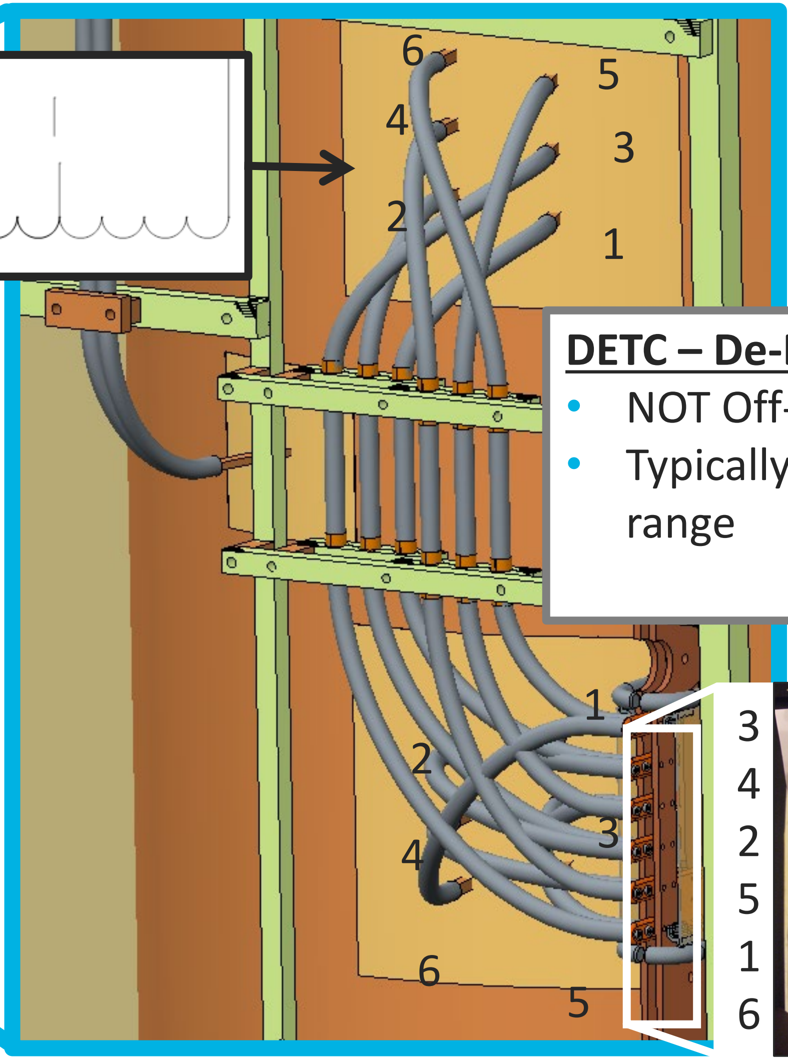
De-Energized Tap Changer (DETC)

De-Energized Tap Changers

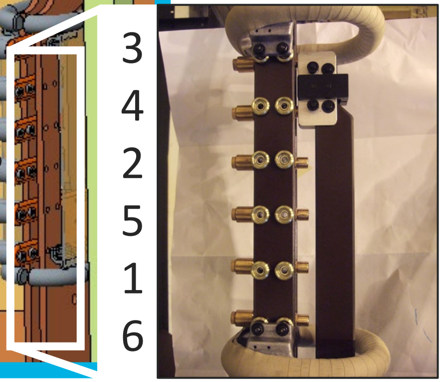


HIGH VOLTAGE TAPCHANGER DE-ENERGIZED OPERATION			
VOLTS L-L	AMPS AT 450.0 MVA	POS	CONNECTS
362250	717	A	3 - 4
353625	735	B	4 - 2
345000	753	C	2 - 5
336375	772	D	5 - 1
327750	793	E	1 - 6



DETC – De-Energized Tap Changer

- NOT Off-Load Tap Changer
- Typically five positions, 10% range



De-Energized Tap Changers

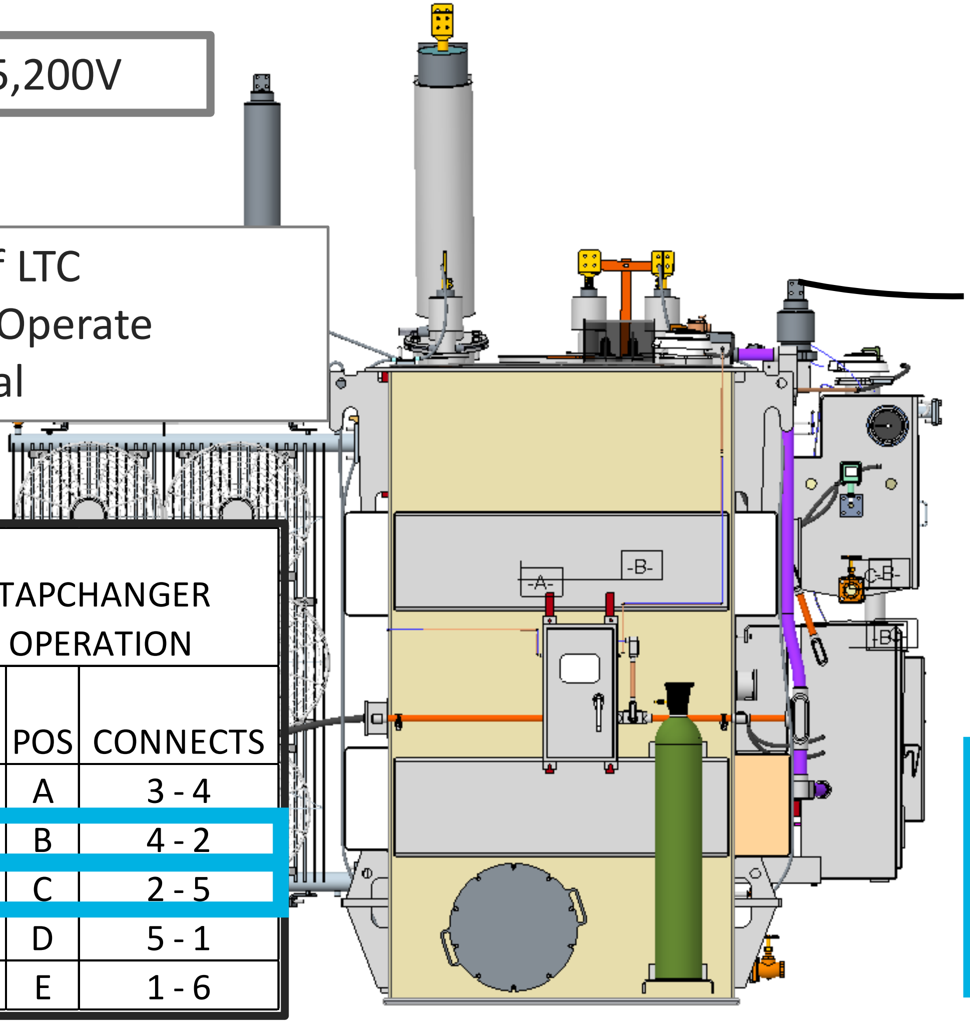
- 4.5 Taps
- 4.5.1 High-voltage winding taps for de-energized operation
- If specified, the de-energized tap changer (DETC), the following four high-voltage rated kilovoltampere taps shall be provided: 2.5% and 5.0% above rated voltage, and 2.5% and 5% below rated voltage.
- Voltages and currents should be listed in accordance with 5.4.
- **When a load tap changer (LTC) is furnished per 4.5.2, the high-voltage DETC may not be required.**

IEEE C57.12.10 IEEE Standard Requirements for Liquid-Immersed Power Transformers

De-Energized Tap Changers

V_system = 115,200V

Adjust Travel of LTC Mechanism to Operate Through Neutral



HIGH VOLTAGE TAPCHANGER DE-ENERGIZED OPERATION			
VOLTS L-L	AMPS AT 25.0 MVA	POS	CONNECTS
120750	120	A	3 - 4
117875	122	B	4 - 2
115000	126	C	2 - 5
112125	129	D	5 - 1
109250	132	E	1 - 6

LOW VOLTAGE TAPCHANGER ENERGIZED OPERATION		
VOLTS L-L	AMPS AT 450.0 MVA	POS
13094	1052	8R
13016	1058	7R
12938	1064	6R
12860	1071	5R
12782	1077	4R
12704	1083	3R
12626	1089	2R
12548	1096	1R
12470	1102	N
12392	1109	1L
12314	1116	2L
1236	1122	3L
12158	1129	4L
12080	1136	5L
12002	1143	6L
11924	1150	7L
11847	1157	8L

De-Energized Tap Changers

Core performance

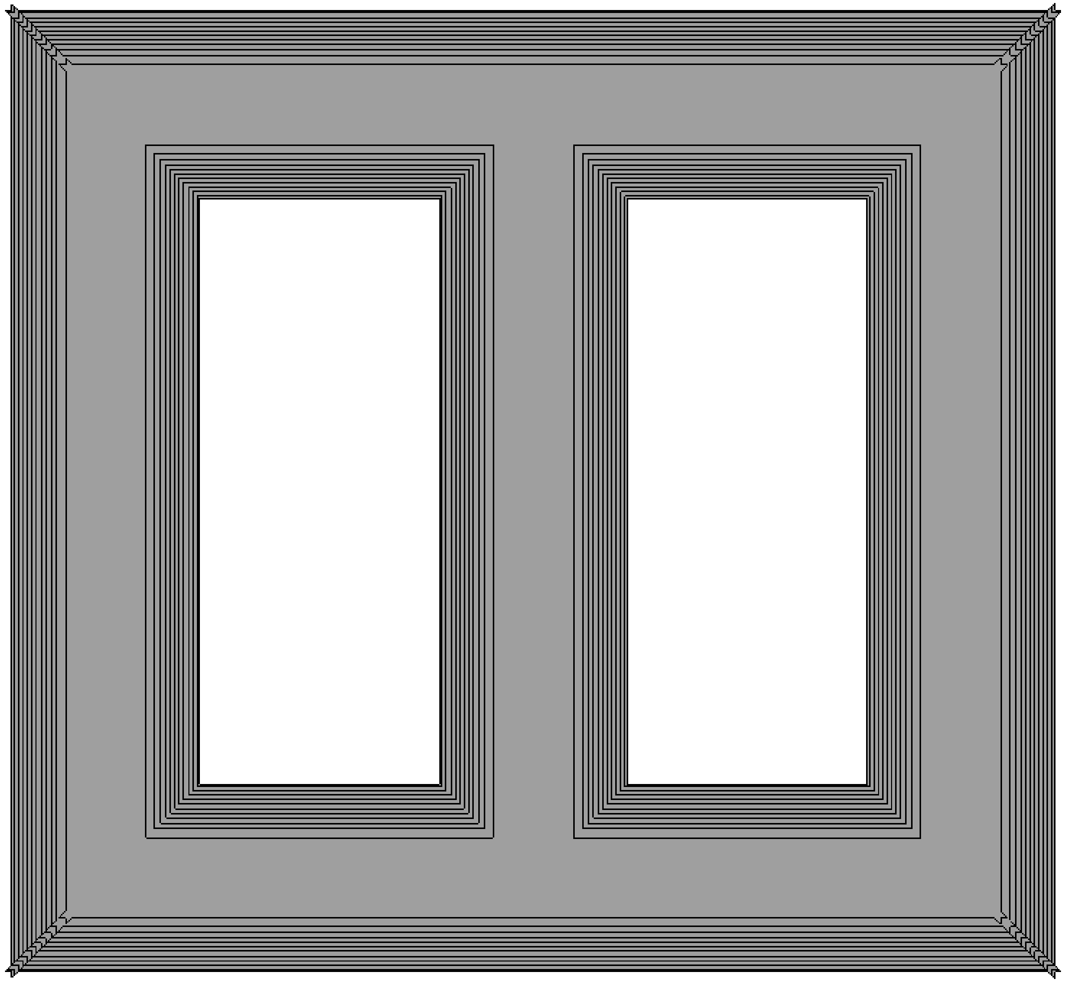
- Core Loss
- Sound Levels
- Impedance
- Inversely proportional to the square of the volts per turn

$$\frac{Volts}{Turn} = E_t = 4.44BAf$$

$B = Flux\_Density$

$A = Core\_Area$

$f = Frequency$

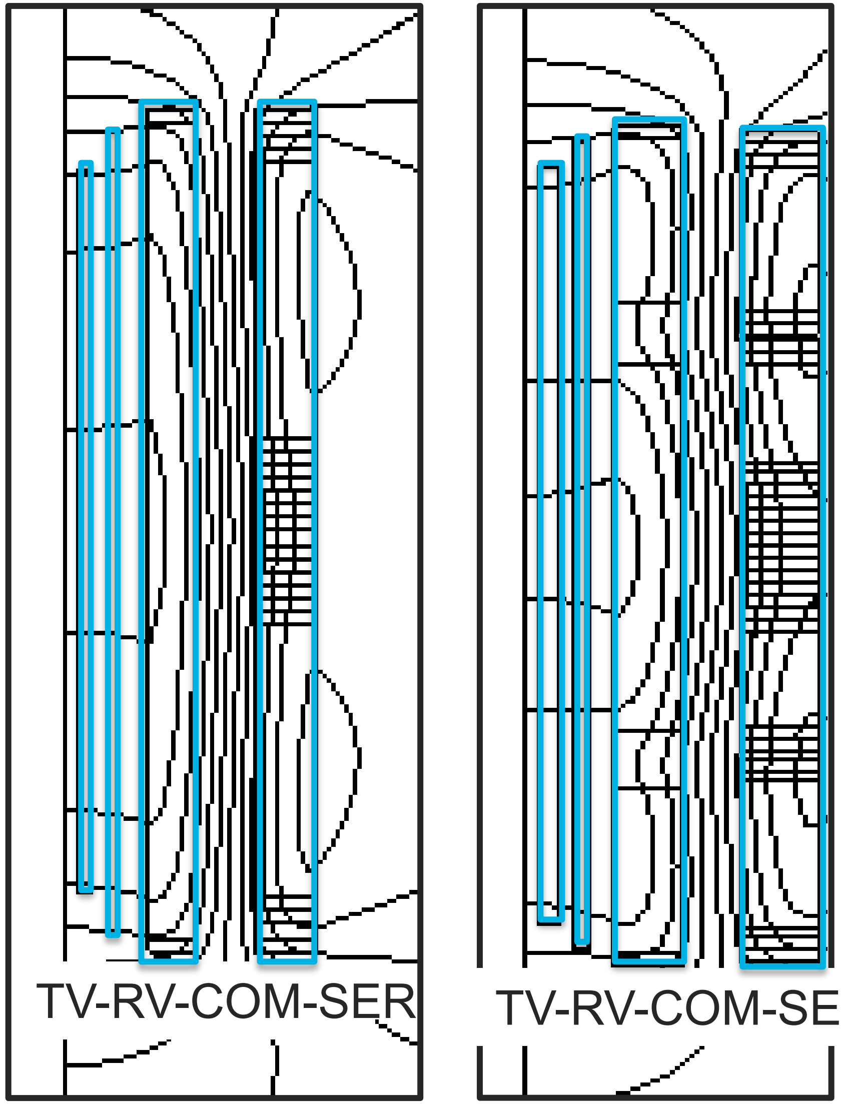


De-Energized Tap Changers

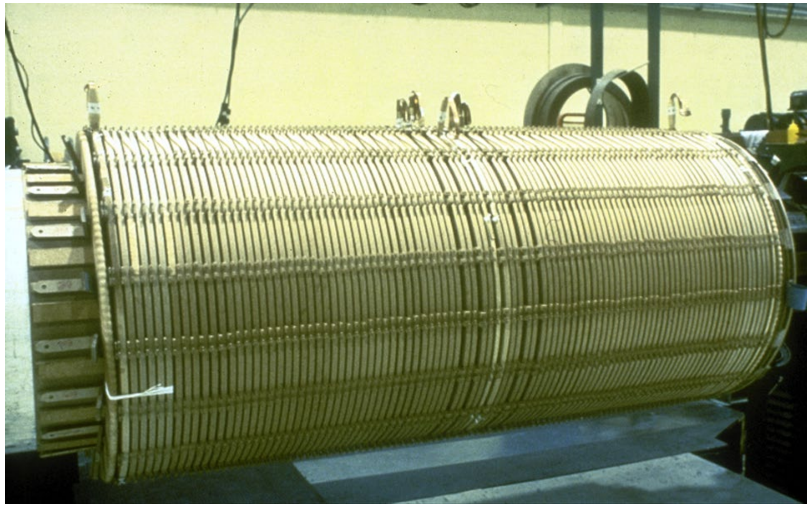
Special Considerations

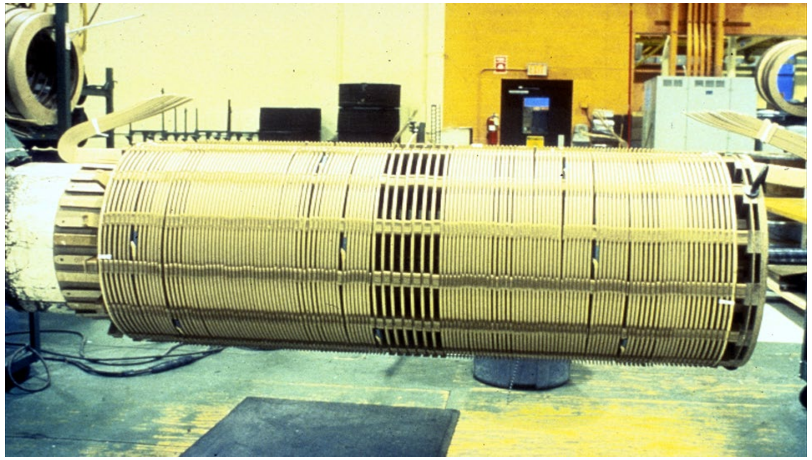
- Low impedance
- Reconnectable (Non Integer Series Parallel) Windings
- Alternative is Greater than 10% LTC tap range

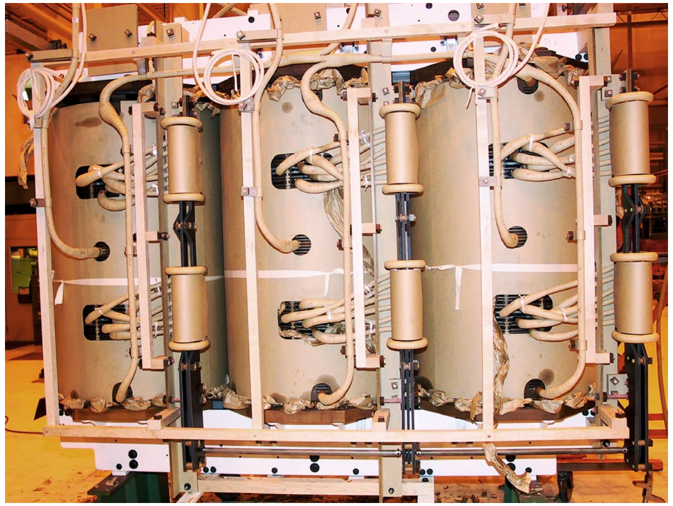
Leakage flux pattern different with and without DETC – Generally increased axial force with DETC



De-Energized Tap Changers

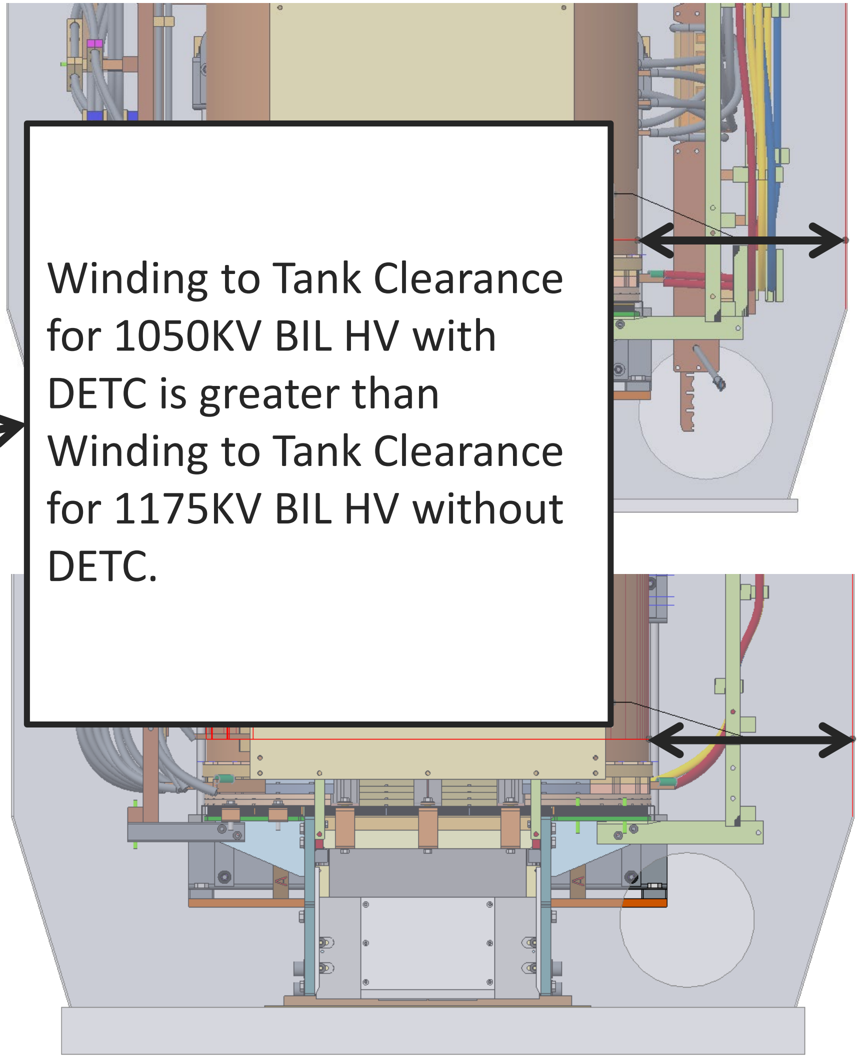






De-Energized Tap Changers

- Short circuit forces are higher
- More turns (5%)
- Load loses are higher
  - Stray
  - I2R
- Tank may be larger
- Core window is larger



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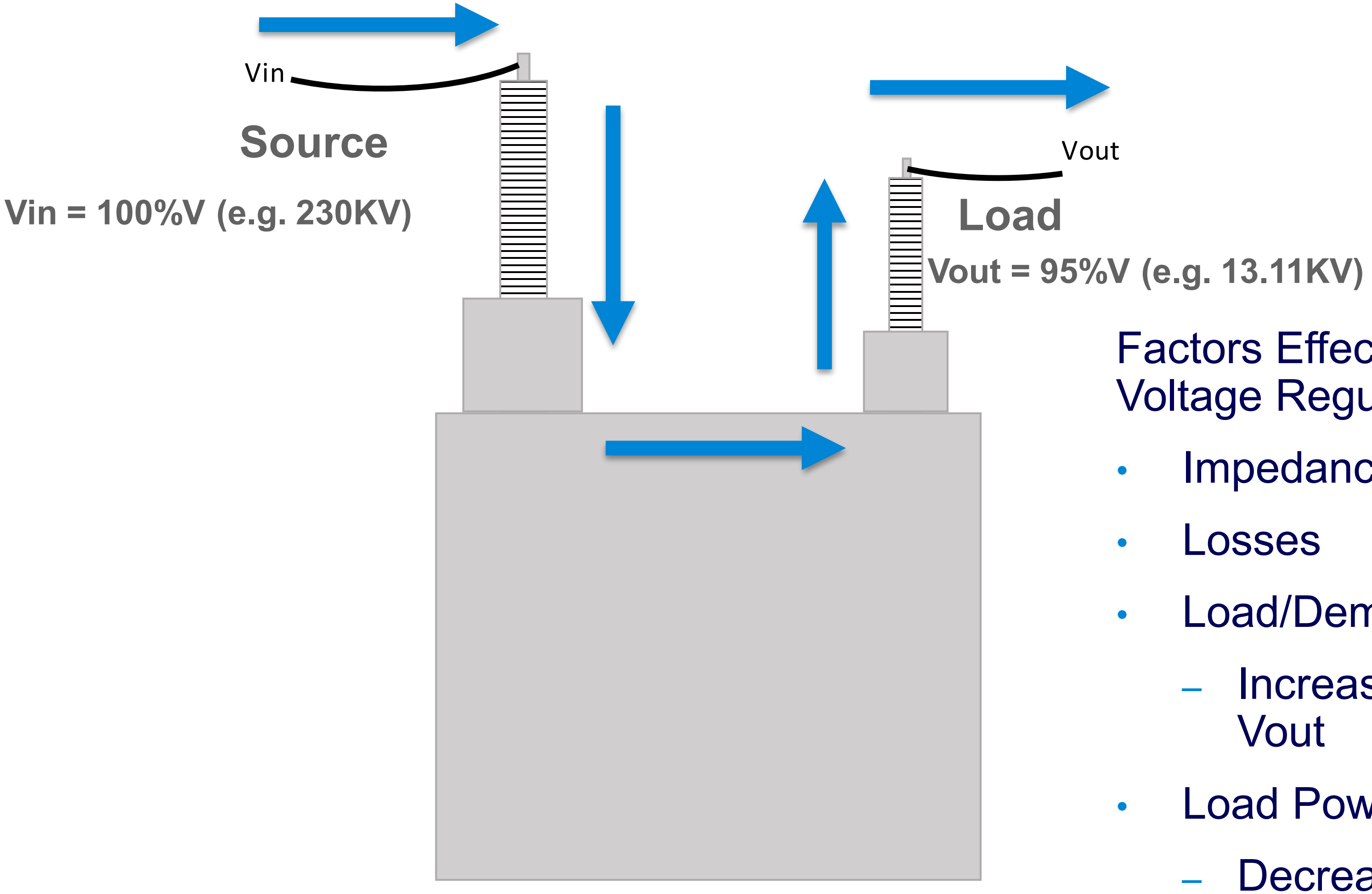
Voltage Regulation

Voltage Regulation



Factors Effecting
Voltage Regulation

- Impedance
- Losses
- Load/Demand
  - Increase in load/demand means drop in Vout
- Load Power Factor
  - Decrease in load power factor means drop in Vout

Voltage Regulation

The exact formula for calculating Regulation are as follows:

When the loading is lagging:

Per Unit regulation = $\sqrt{(R + F_P)^2 + (X + q)^2} - 1$

When the loading is leading:

Per Unit regulation = $\sqrt{(R + F_P)^2 + (X - q)^2} - 1$

where:

F_P	is Per Unit load power factor
q	is Per Unit $\sqrt{1 - {F_P}^2}$
R	is Per Unit Resistance = $\frac{kW\ Load\ Loss}{kVA\ Transformer\ Rating}$
Z	is Per Unit Impedance = $\frac{kVA\ Impedance}{kVA\ Transformer\ Rating}$
X	is Per Unit Reactance = $\sqrt{Z^2 - R^2}$

Voltage Regulation IEEE C57.12.90

Voltage Regulation

18/24/30 MVA Transformer, Load Losses = 60 kW @ 18 MVA; **Z = 8.0** @ 18 MVA base = 166.67 kW @ 30 MVA, Z = 13.33 @ 30 MVA base			
18 MVA		**30 MVA**	
Power Factor	% Regulation	Power Factor	% Regulation
1.0	0.64	1.0	1.43
0.9	4.02	0.9	6.95
0.8	5.24	0.8	8.92

18/24/30 MVA Transformer , Load Losses = 65kW @ 18 MVA; **Z = 10.0** @ 18 MVA base = 185.56 kW @ 30 MVA, Z = 16.67 @ 30 MVA base			
18 MVA		**30 MVA**	
Power Factor	% Regulation	Power Factor	% Regulation
1.0	0.86	1.0	1.99
0.9	5.05	0.9	8.82
0.8	6.57	0.8	11.25 (> 10% LTC)

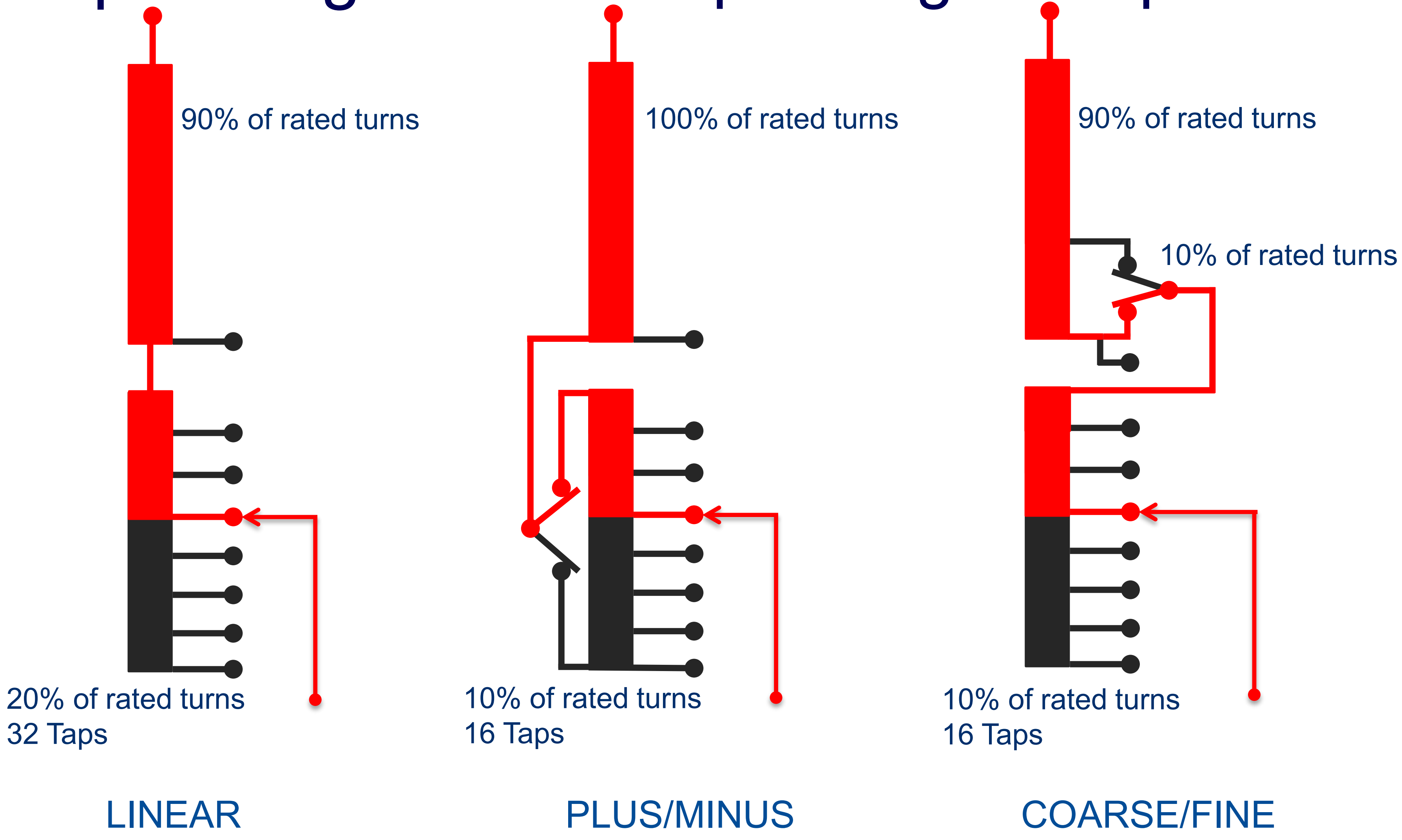
Impedance Effects on Voltage Regulation

Voltage Regulation

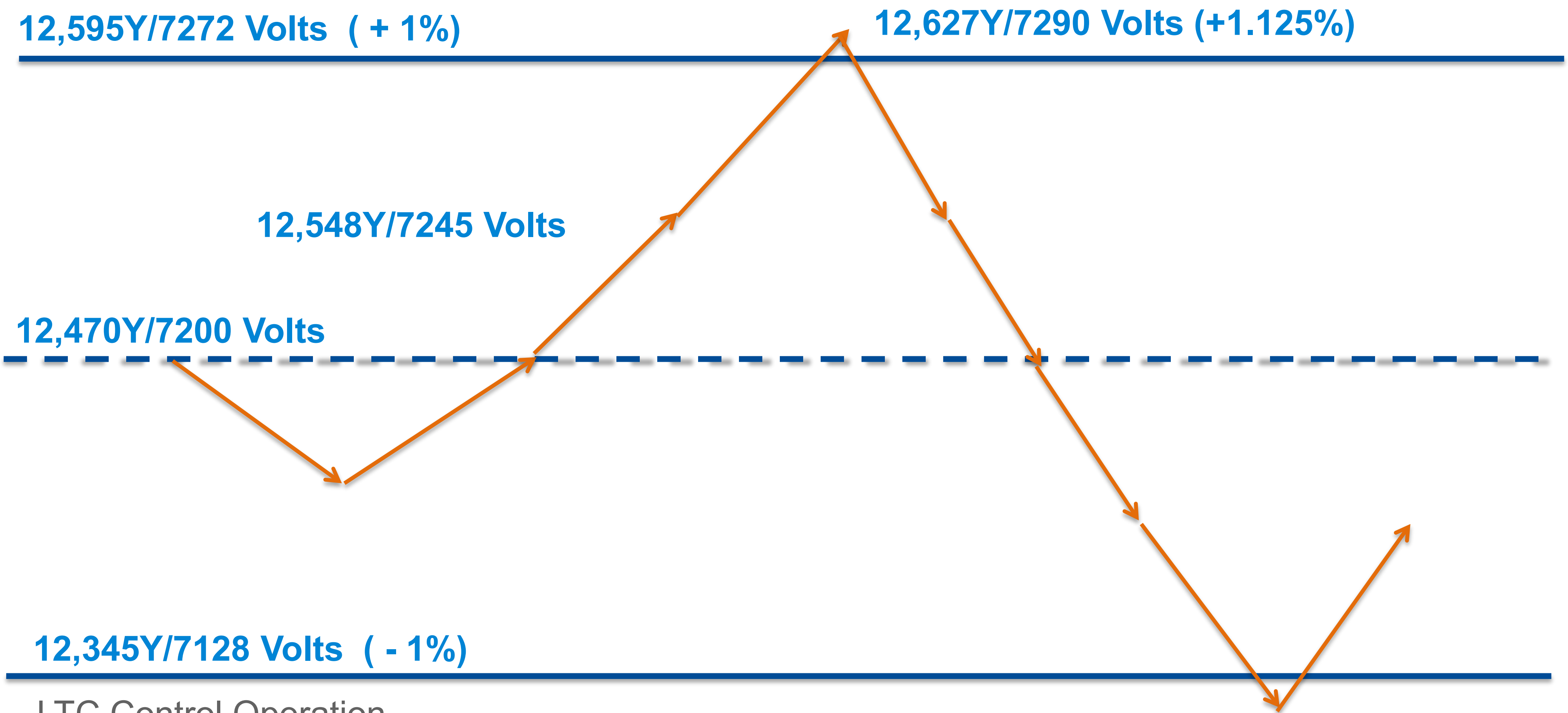
- Regulators
- Power Factor Correction
- Load Tap Changers (LTCs)

Load Tap Changers

Load Tap Changers - LTC Operating Principles



Load Tap Changers

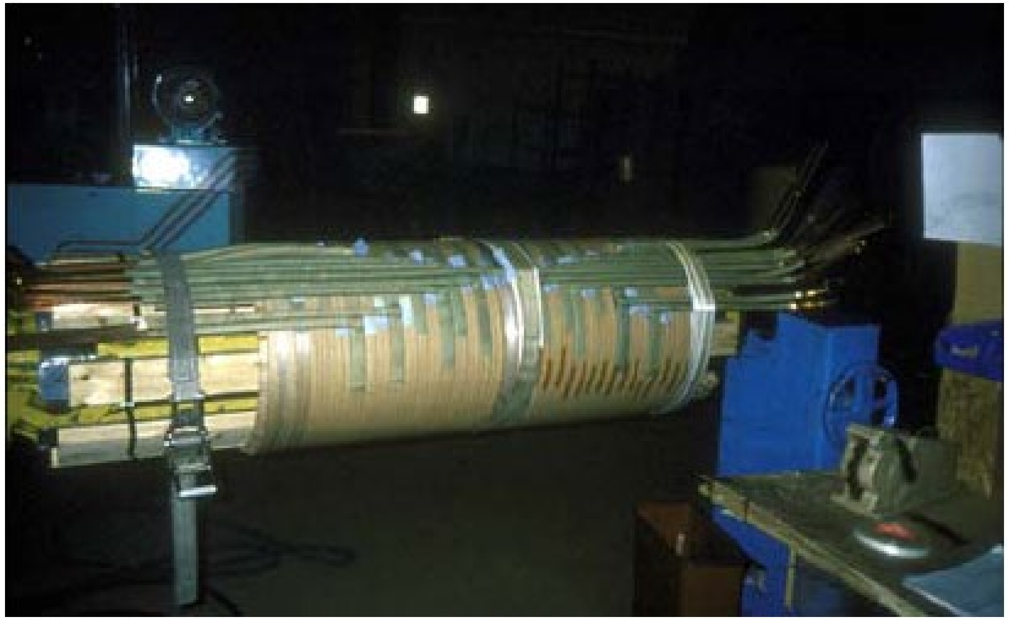


LTC Control Operation

Load Tap Changers

Multi Start Winding

Tapped Winding



Regulating Voltage Winding Design

Load Tap Changers

LTC Lead Connections – Multi Start Windings

Load Tap Changers

Resistance:

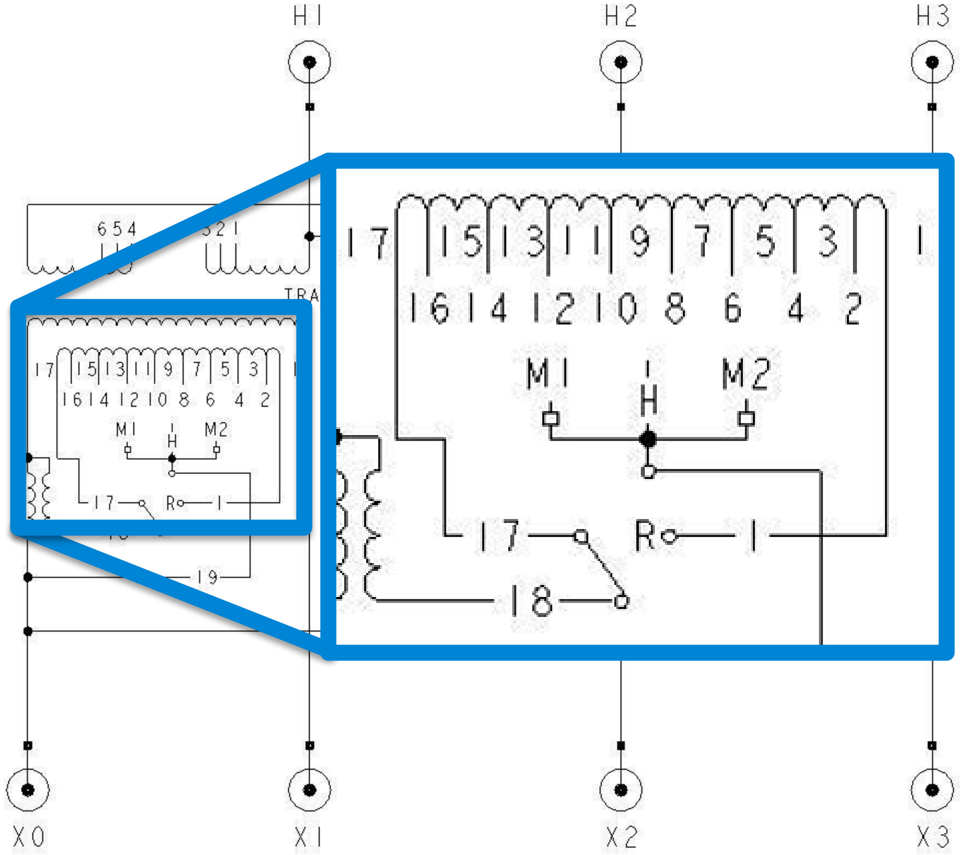
- European design
- High Speed
- Transition impedance is a resistor, bridging operation

Reactance:

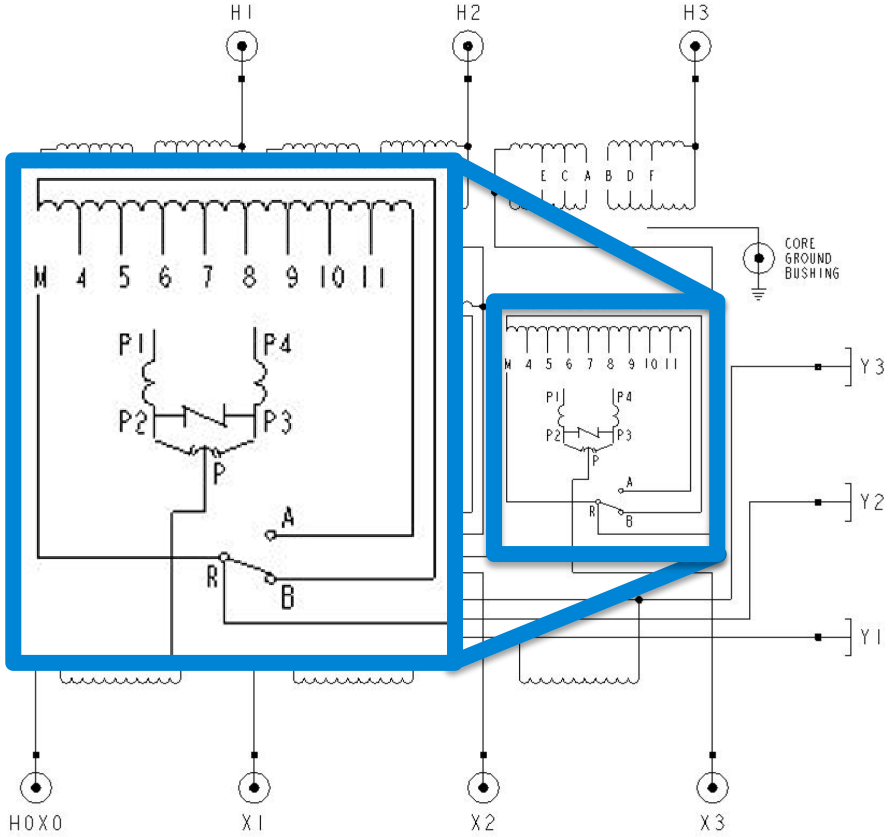
- United States LTC development
- Reactance transition impedance inserted into the tap circuit to limit circulating current (Preventive Autotransformer)
- Vacuum Interrupters introduced – 1960s

Load Tap Changers

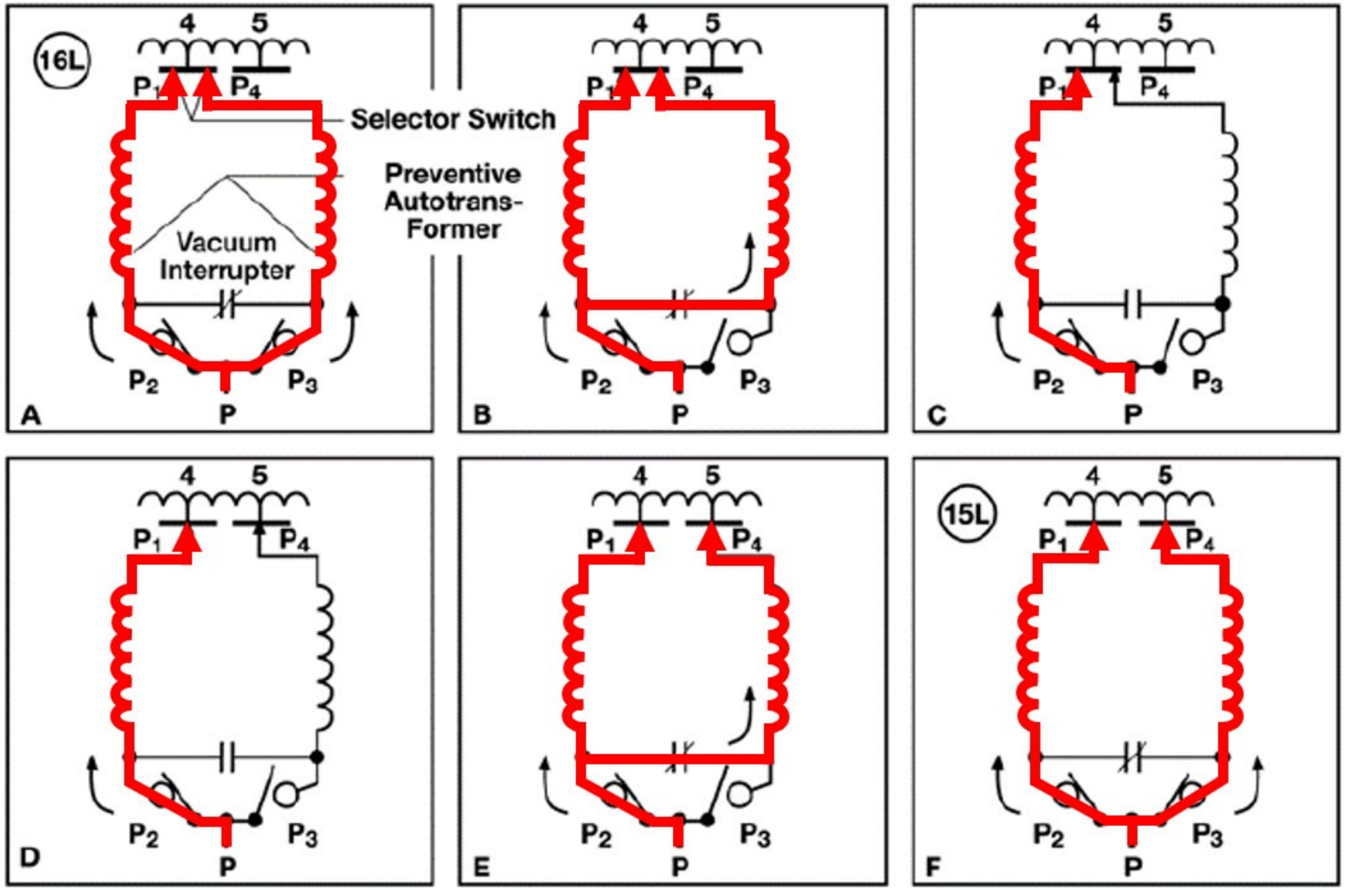
Resistance LTC



Reactance LTC



Load Tap Changers



Reactance Type LTC – With Vacuum Interrupter

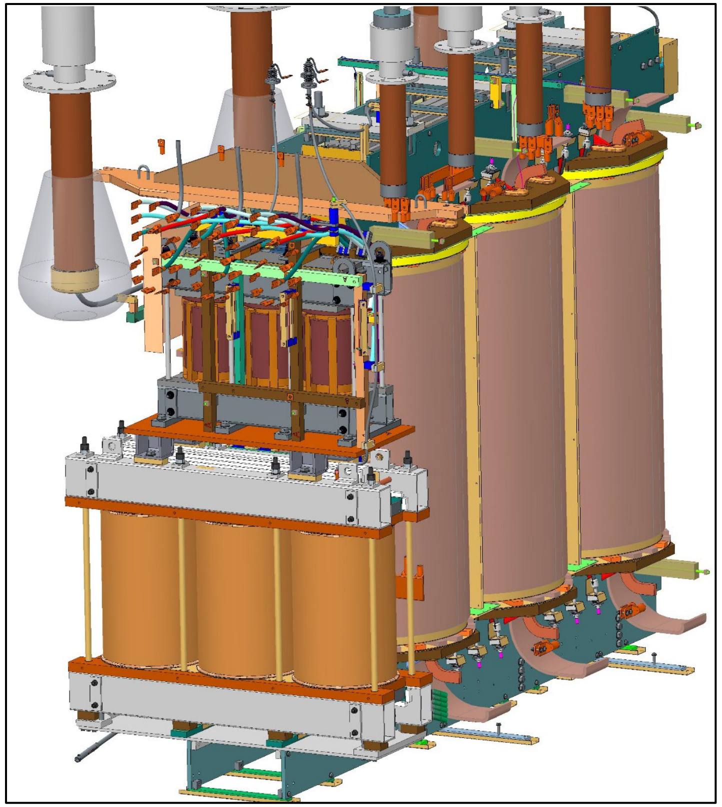
Load Tap Changers

Preventive Auto Transformers

- Gaped Core, Operates saturated
- Fully excited only in odd positions
- High sound level in all odd (bridging positions) taps

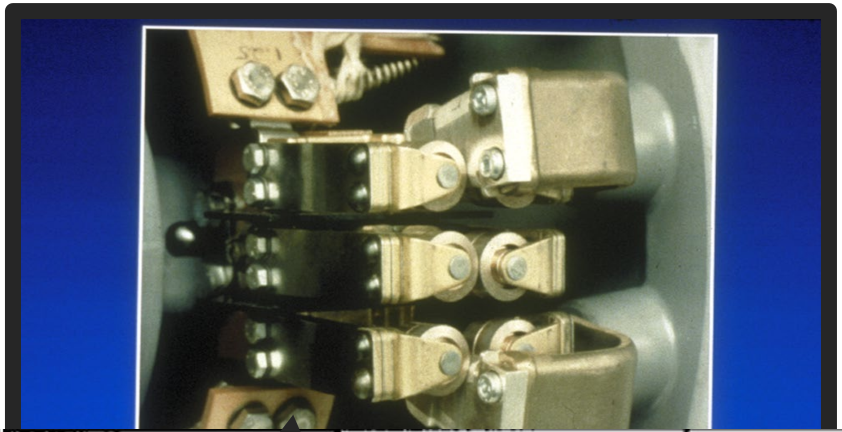
Rating 1.25% of main unit, full current, 1.25% voltage

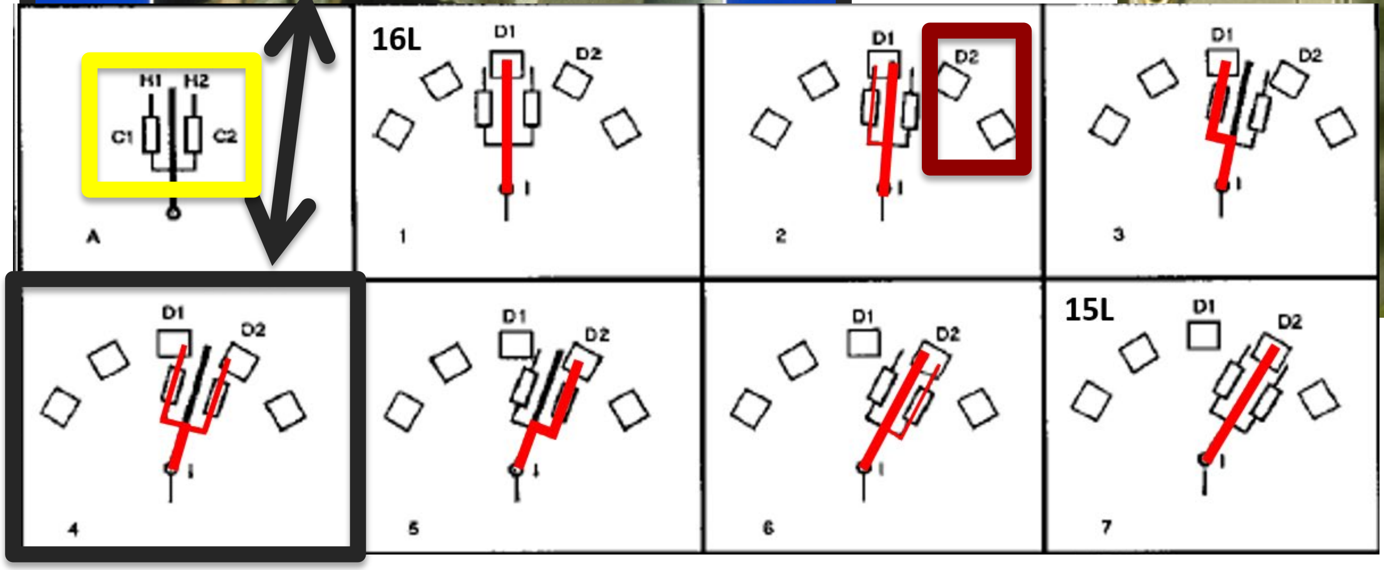
- 50 MVA transformer, Preventive Auto is rated 625 kVA

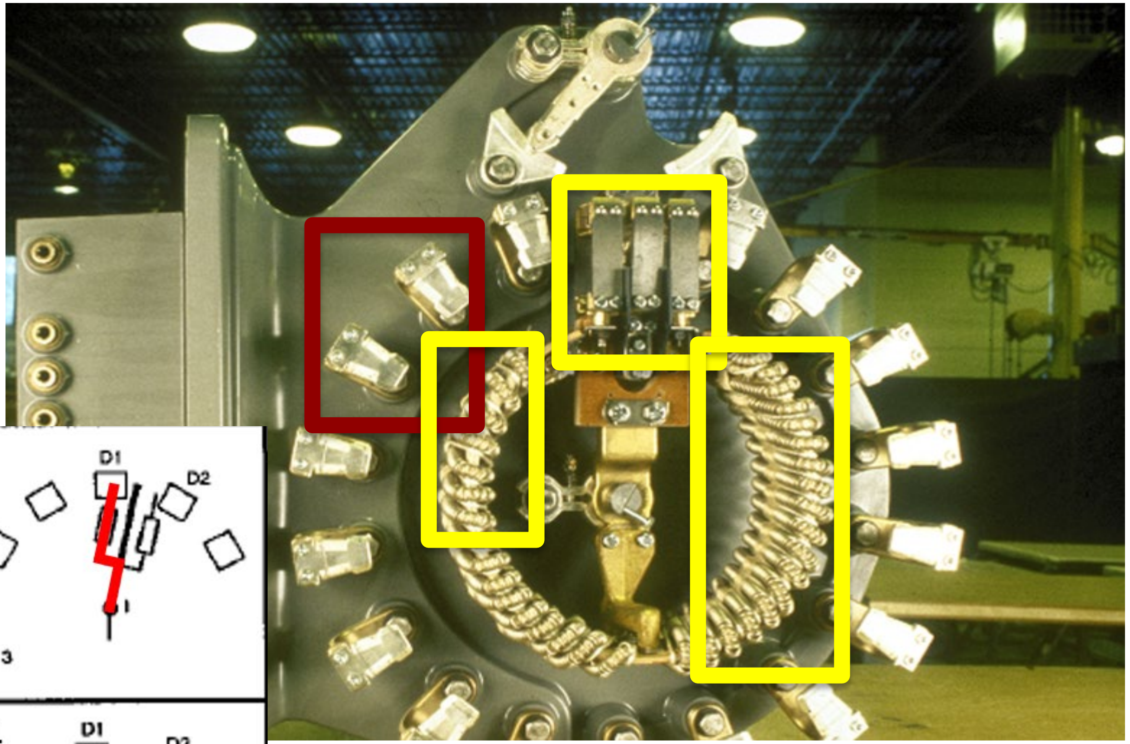


Reactance Bridge

Load Tap Changers







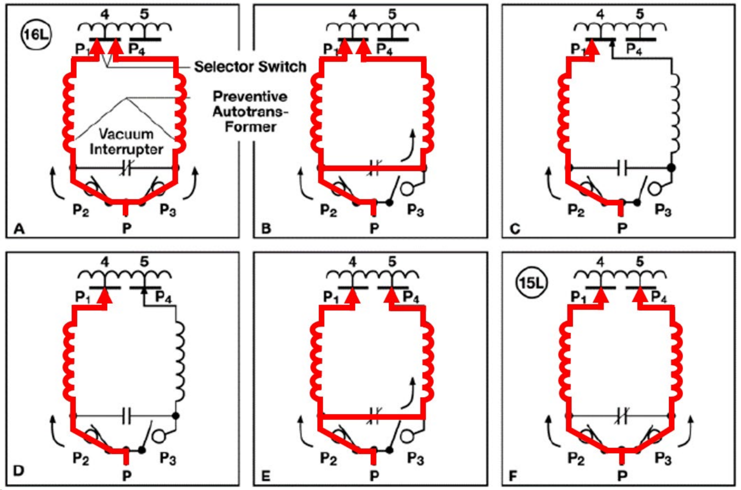
VIDEOS

- Reversing Switch, Stationary & Moving Contacts
- Spring Drive

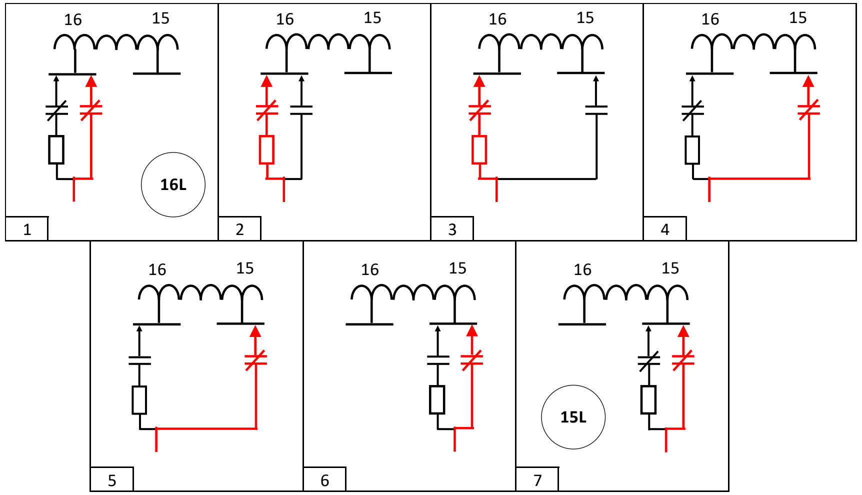
Resistance Bridging UZD LTC

Load Tap Changers

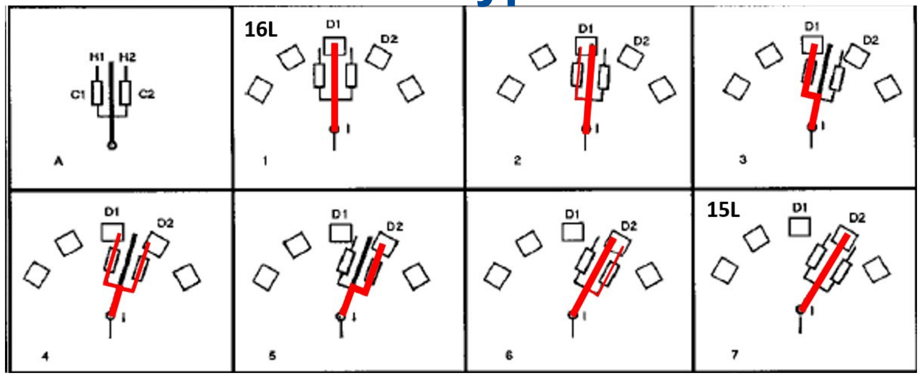
Reactive Type - RMVII



Resistive Type - UZDVac



Resistive Type - UZD



Load Tap Changers

- Used to reduce the current through the load tap changer where load current exceeds the current rating LTC

- Can be used to reduce voltage level at the load tap changer

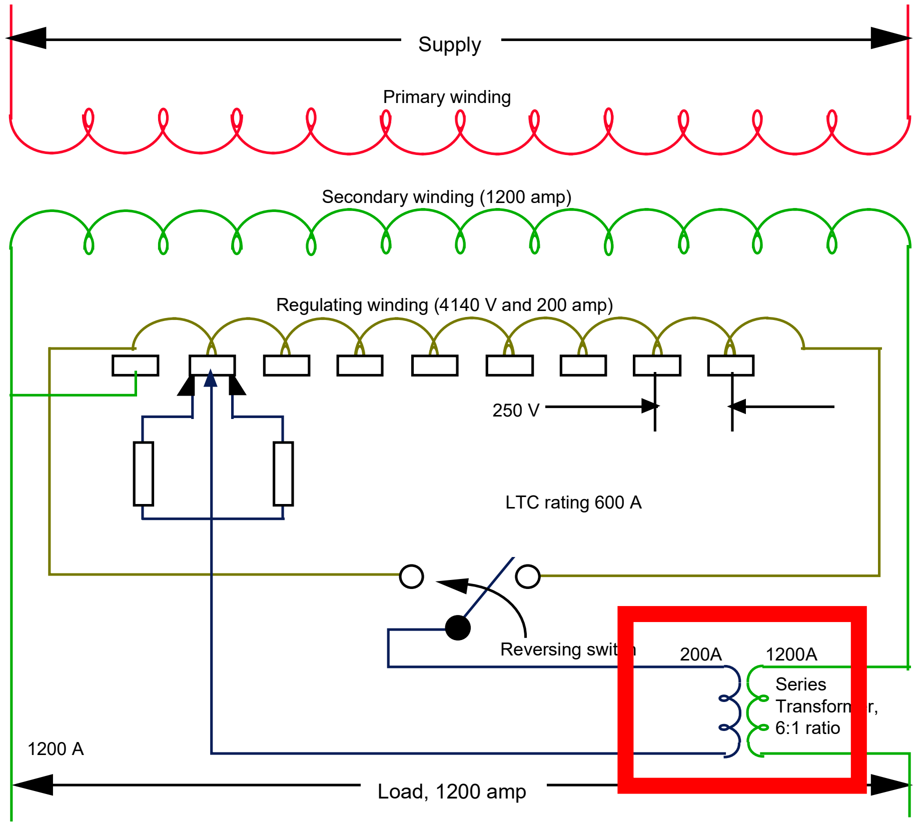
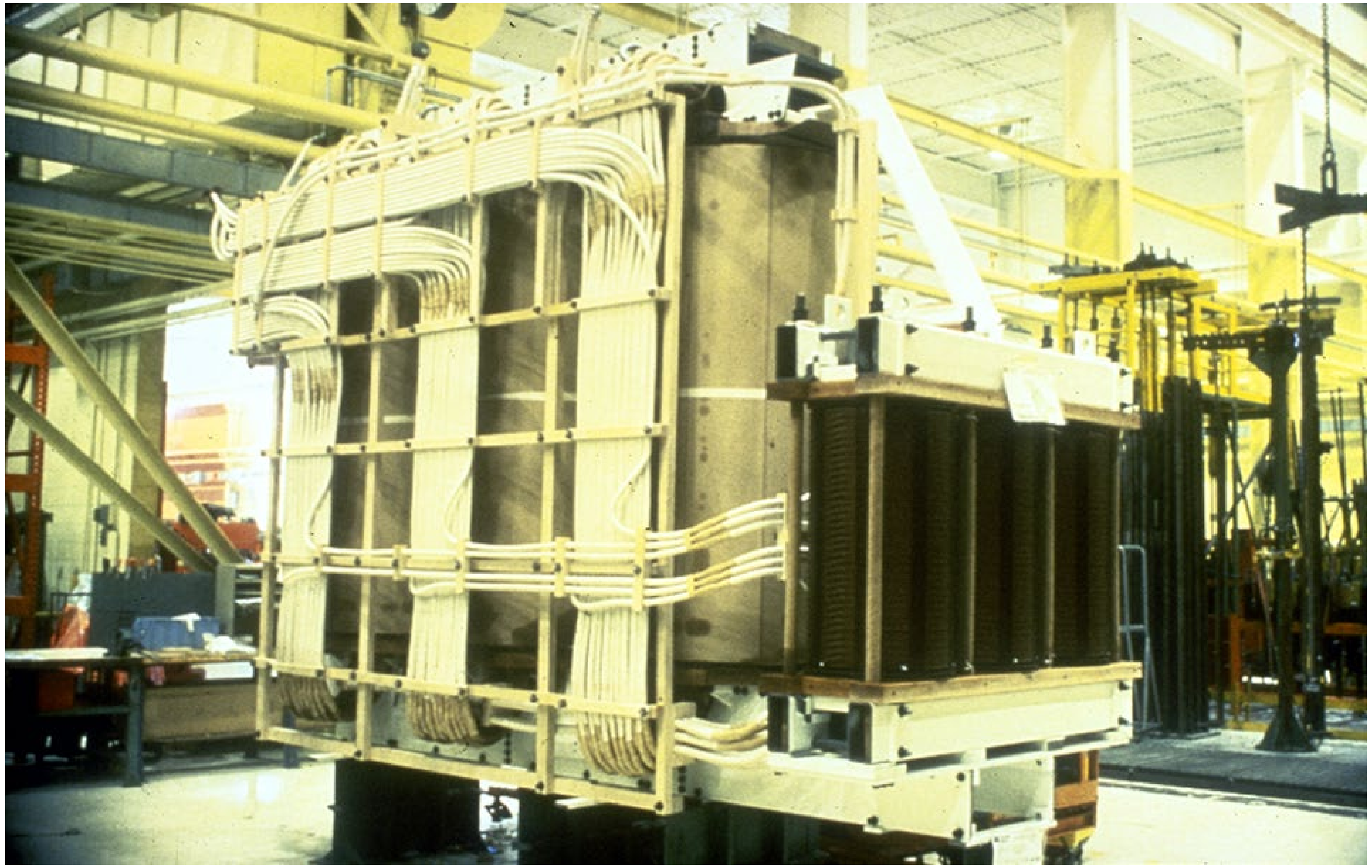


FIGURE 7   SERIES TRANSFORMER APPLICATION

Booster/Series Transformers

Load Tap Changers



Booster/Series Transformer

LTC Application Considerations

LTC Application Considerations

CFVV

(**C**onstant **F**lux **V**oltage **V**ariation)

- Impedance is “Constant”
- Sound Level is “Constant”
- Step Voltage is “Constant”

VFVV

(**V**ariable **F**lux **V**oltage **V**ariation)

- Impedance is Variable
- Sound Level is Variable
- Step Voltage is Variable

Power Transformer CFVV and VFVV Comparison

LTC Position	P.U. Impedance		P.U. Voltage	
	CFVV	VFVV	CFVV	VFVV
16R	1.02	0.80	1.10	1.11
N	1.00	1.00	1.00	1.00
16L	0.98	1.30	0.90	0.89

LTC Application Considerations

Power Transformer

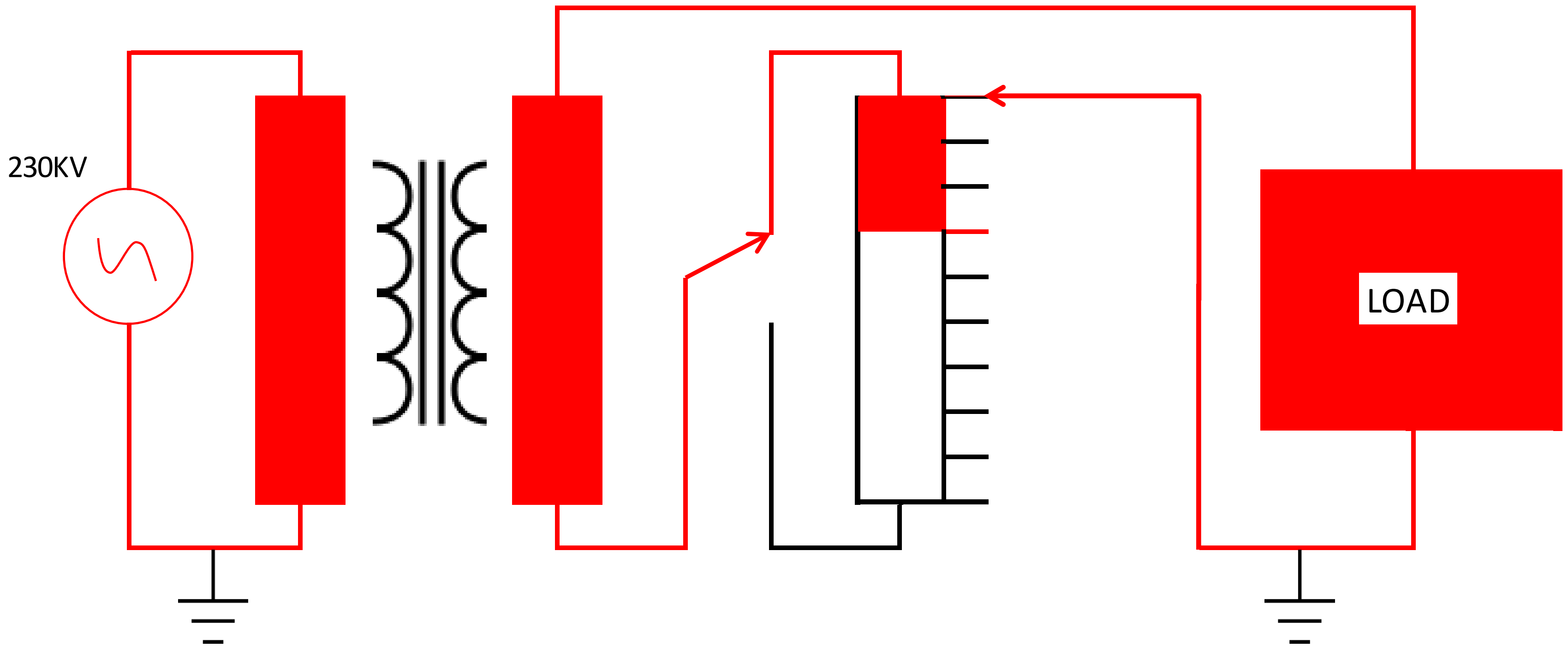
- Installation in neutral end of a wye winding – CFVV
- Installation in HV winding to regulate the LV – VFVV
- Installation in HV winding to regulate HV winding – CFVV

Autotransformer

- Installation in neutral – VFVV
- Installation in XV line – CFVV
- Installation in common end of HV series winding to regulate HV – CFVV
- Installation in common end of HV series winding to regulate LV – VFVV

LTC Application Considerations

CFVV (**C**onstant **F**lux **V**oltage **V**ariation)

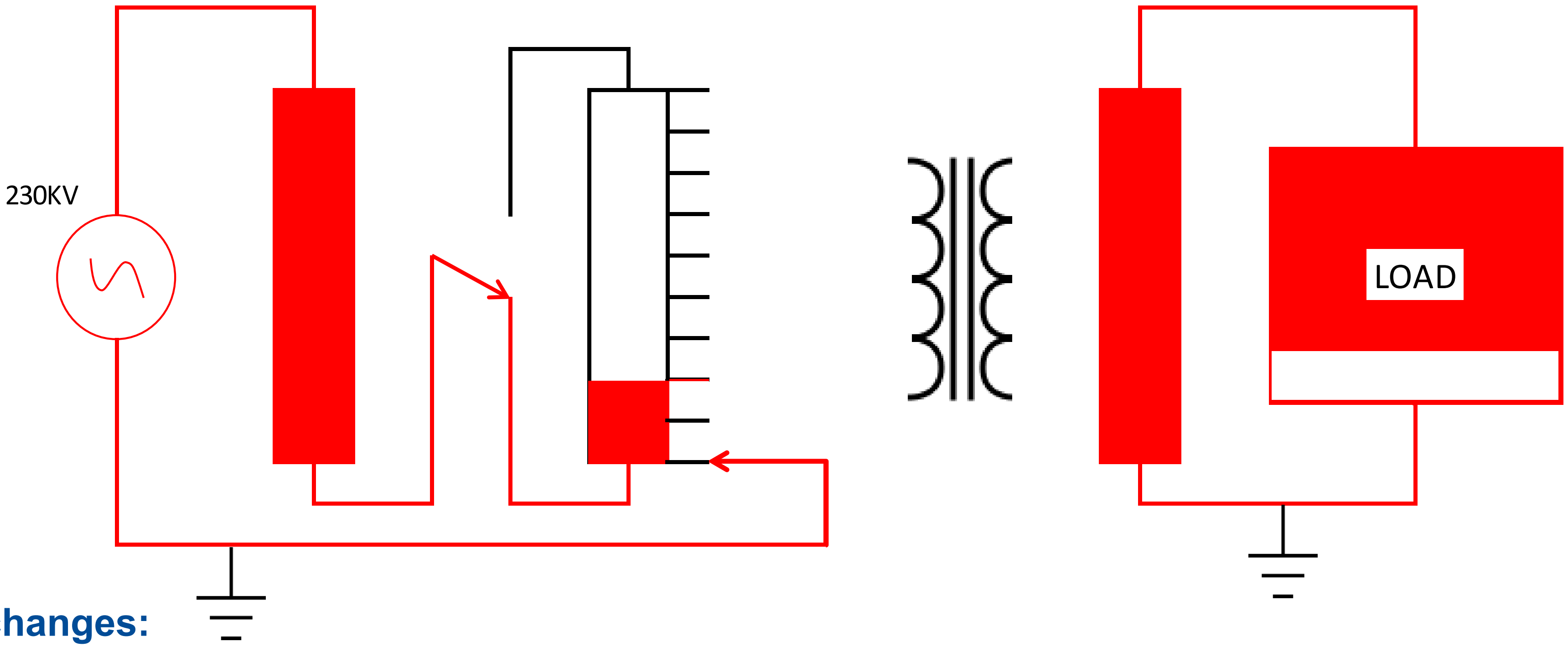


V/T remains constant

Number of turns changes, therefore voltage changes

LTC Application Considerations

VFVV (**V**ariable **F**lux **V**oltage **V**ariation)



V/T changes:

- Supply voltage remains constant
- Number of turns changes

Since V/T changes, voltage changes

LTC Application Considerations

ABB UZ Series
ABB VRLTC

Reinhausen RMV-II

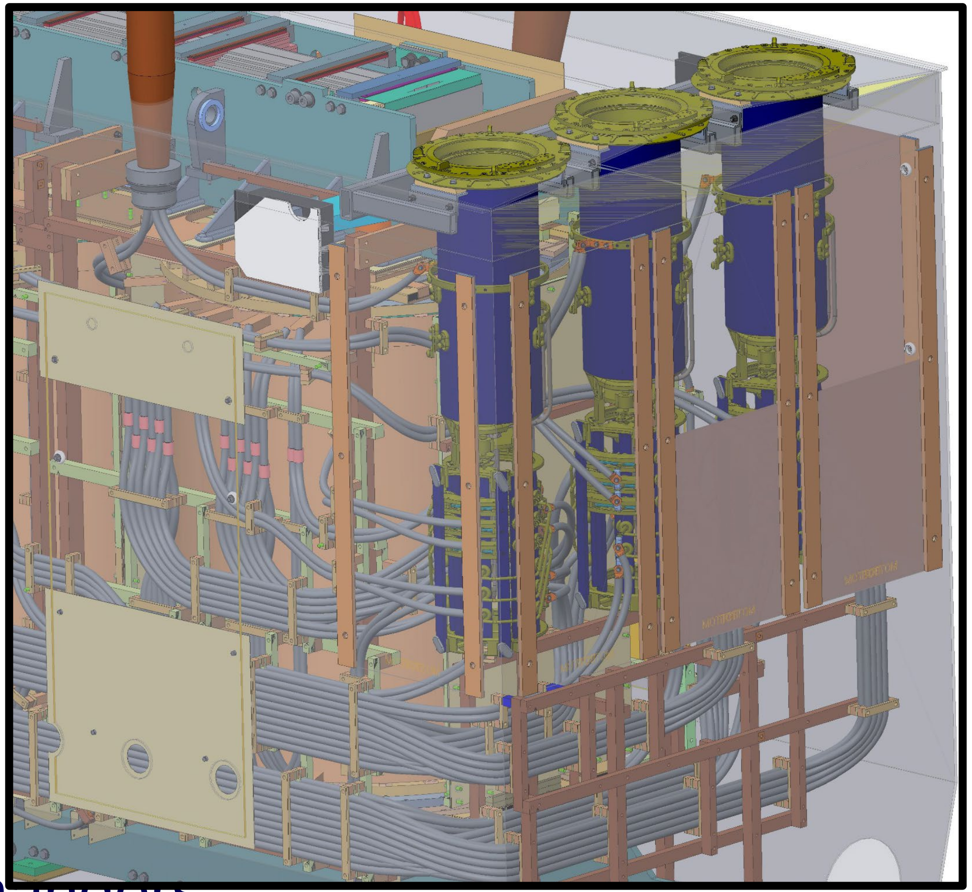
Waukesha® UZD ®
Waukesha UZDVac

On Tank Load Tap Changers

LTC Application Considerations

ABB UC Series

Reinhausen
VACUTAP® VR Series



In Tank Load Tap Changers

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Paralleling

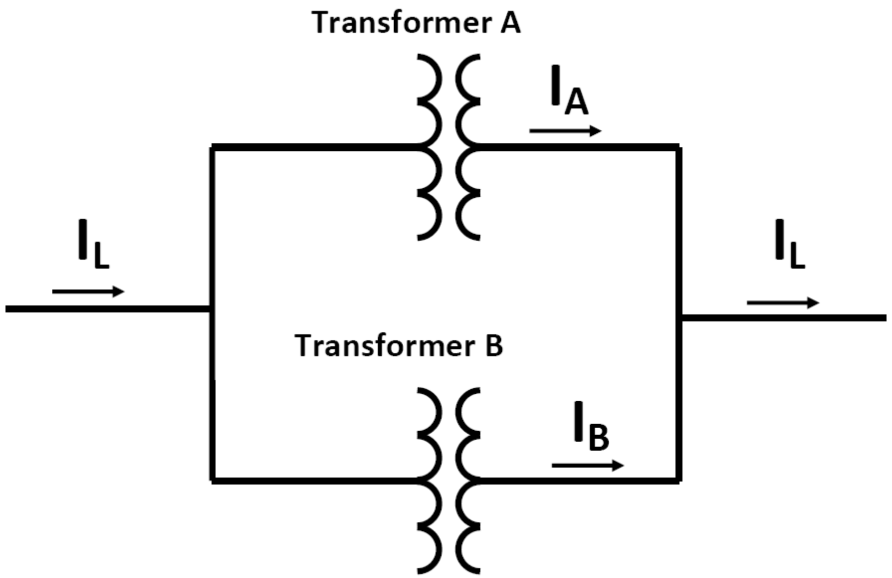
Paralleling

Where:
Z_A, Z_B = Per Unit Impedance of transformers A and B
I_A, I_B = Per Unit Load current of transformers A and B
I_L = Per Unit Load current of transformer A and B in parallel
Assuming the voltage drop through both transformers is equal

Then:
$I_A \times Z_A = I_B \times Z_B$ and $I_L = I_A + I_B$

Solving these equations, we get the following load distribution between the two transformers

$$I_A = \frac{Z_B}{Z_A + Z_B} \quad \text{and} \quad I_B = \frac{Z_A}{Z_A + Z_B}$$



Design for Transformer Parallel Operation

Paralleling

Given / Known

Bank A 10/12.5 MVA Impedance 0.08 per unit at 10 MVA base
Bank B 12/16/20 MVA Impedance 0.08 per unit at 12 MVA base

Step 1

Bank A 0.100 per unit at 12.5 MVA base
Bank B 0.083 per unit at 12.5 MVA base

Step 2

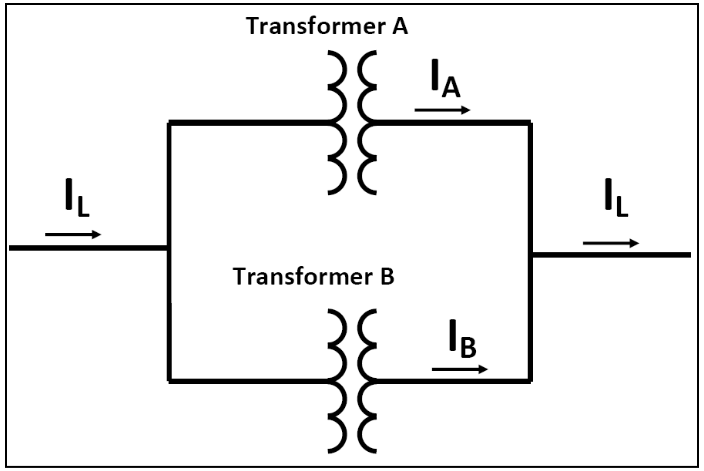
Bank A loading = $\frac{Z_B}{Z_A + Z_B} = \frac{0.083}{0.100 + 0.083}$ = 0.454 per unit load

Bank B loading = $\frac{Z_A}{Z_A + Z_B} = \frac{0.100}{0.100 + 0.083}$ = 0.546 per unit load

Step 3

The maximum total load of Bank A and B paralleled without overloading Bank A is $\frac{12.5}{0.454} = 27.5\ MVA$

Therefore, the maximum loading of Bank B without overloading Bank A is
27.5 – 12.5 = **15.0** MVA (less than the 20 MVA rating of Bank B transformer).



Parallel Operation Case I – Different Cooling Classes

Paralleling

Given / Known

Bank A impedance = 0.16 per unit at 20 MVA base, the top rating of the proposed new transformer.

Anticipated total load = 32.5 MVA

Step 1

Bank A rated per unit load capacity of 12.5 MVA is $\frac{12.5}{32.5} = 0.385$ per unit of the paralleled bank loading of 32.5 MVA.

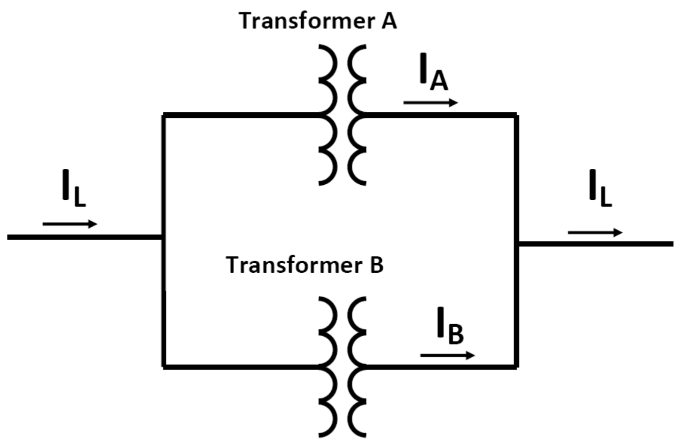
Bank B rated load capacity of 20 MVA is $\frac{20.0}{32.5} = 0.615$ per unit of the paralleled bank loading of 32.5 MVA.

Bank B impedance needs to be calculated to carry 0.615 per unit of the bank capacity.

Step 2

Bank B loading of 0.615 per unit = $\frac{Z_A}{Z_A + Z_B}$ = $\frac{0.16}{0.16 + X}$ solving for X.

X = 0.10 per unit on 20 MVA base. Converting to a 12 MVA base, the impedance needs to be 0.0625 per unit on the self cooled nameplate rating of 12 MVA.



Parallel Operation Case II – Different Cooling Classes

Paralleling

If the transformers are both rated with two identical stages of cooling and both have identical impedances on their self cooled based, each transformer will share load according to it's rating:

Bank A	12/16/20 MVA	Impedance 0.08 per unit at 10 MVA base
Bank B	24/32/40 MVA	Impedance 0.08 per unit at 24 MVA base

First state the per unit impedance of each bank on the same MVA base:

Bank A	0.267 per unit on 40 MVA base
Bank B	0.133 per unit on 40 MVA base

The transformers share load inversely to the ratio of the impedance of the bank to the sum of the impedances of the banks in parallel.

$$\text{Bank A load share} = \frac{Z_B}{Z_A + Z_B} = \frac{0.133}{0.133 + 0.267} = 0.333 \text{ per unit load}$$

$$\text{Bank B load share} = \frac{Z_A}{Z_A + Z_B} = \frac{0.267}{0.133 + 0.267} = 0.667 \text{ per unit load}$$

This validates that transformers of equal per unit impedance (expressed on their own MVA base) will share load proportionate to their ratings.

Parallel Operation Case III – Same Cooling Classes, Different Ratings

Questions

Contact

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