OMICRON

The Exciting Current Test: In-Depth

Author Biography

Brandon Dupuis received a B.S. Electrical Engineering from the University of Maine. He joined OMICRON electronics Corp, in 2013, where he presently holds the position of Regional Application Specialist for transformer testing. Brandon's focus is currently on standard and advanced electrical diagnostics for power transformers and circuit breakers. Presently, Brandon is a well-known OMICRON instructor teaching electrical transformer diagnostic testing theory, application, and test result analysis, which includes both presentations and hands-on training. Brandon is an active member of the IEEE/PES Transformers Committee.

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2019 OMICRON Academy Transformer Trainings

January 30th and 31st – Houston, TX
https://www.omicronenergy.com/en/events/training/detail/electrical-diagnostic-testing-of-power-transformers/471/

April 16th and 17th – Toronto, ON
https://www.omicronenergy.com/en/events/training/detail/electrical-diagnostic-testing-of-power-transformers/472/

August 28th and 29th – Houston, TX
https://www.omicronenergy.com/en/events/training/detail/electrical-diagnostic-testing-of-power-transformers/171/

The Exciting Current Test: In-Depth

- Introduction to the Exciting Current Test
- Exciting Current Test Procedure
- The Exciting Current “Phase-Patterns”
- Why do “Phase-Patterns” Occur?
- The Exciting Current “Tap-Changer Patterns”
- Capacitive Exciting Current Measurements

The Exciting Current Test - Failure Modes

1. **Compromised Insulation**
   - **Turn-to-turn insulation failures**
   - Inter-winding insulation failures
   - Winding-to-ground insulation failures

2. **Tap-Changer Component Failures – I call this test a “tap-changer integrity test”**
   - Regulating winding
   - **Preventative autotransformer**
   - Reversing switch
   - Tap selectors
   - Stationary contacts
   - etc.

- Note, **residual magnetism** in the core may influence the Exciting Current measurement; therefore, try to perform the DC Winding Resistance test last

The Exciting Current Test - Test Procedure

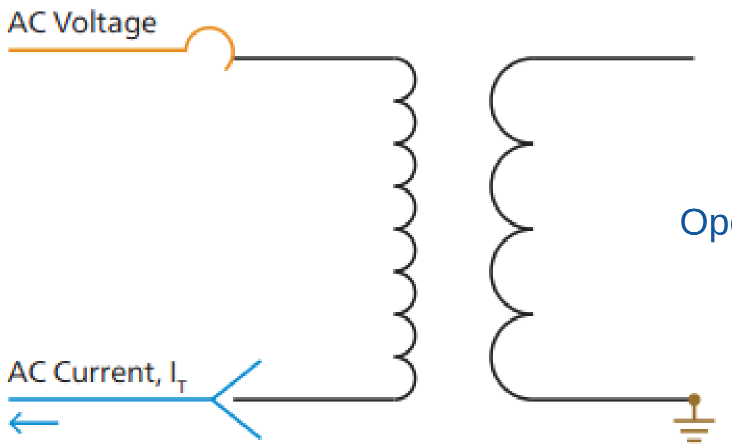
Step 1: Open-circuit the secondary-side bushing terminals

Step 2: Apply an AC voltage across one phase on the primary side (typically 10kV)

Step 3: Measure the current flowing through that primary winding (typically in the mA range)

Step 4: Perform the measurement on all three phases, and on various tap-positions

- A transformer's "Exciting Current" is essentially the minimum amount of current that we have to supply on the primary-side, for the transformer to function, without any load



Open-Circuit Test

Exciting Current: Test-Equipment Overview

- **The high-voltage (10kV) injection lead** – Used to apply an AC voltage across one phase on the primary side (typically 10kV)
- **The current measurement leads (red-A and blue-B)** – Used to measure the current flowing through the primary winding (typically in the mA range)
- **The test-instrument ground lead**
  - Typically connected to the transformer tank-ground
  - Used to solidly ground the test-equipment to earth-ground potential
- **The “guard-circuit”** - Used to isolate and test different components of the transformer
  - The Exciting Current Test is typically performed using the Ungrounded Specimen Test (UST) mode

Exciting Current: Test-Voltage

- The Exciting Current test-voltage should not exceed the line-to-ground voltage rating of the primary winding under test
- Ideally, we want to apply as high of a test-voltage as possible, to stress the insulation system as much as possible, during the time of the test
- However, the test-instrument may “trip” as a result of exceeding the output power (VA) limit of the test-instrument’s power supply
- If the test-instrument “trips” when attempting to perform an Exciting Current measurement, then the user must troubleshoot, to determine the cause of the relatively high Exciting Current required to energize the transformer

Exciting Current: Which Tap-Positions Should I Test?

1. Of course, the “best practice” is to perform the Exciting Current Test on all LTC tap-positions

2. A more “practical” approach would be to perform the Exciting Current Test from 16R-1L AND 16L...or from 16L-1R AND 16R

3. A reasonable “time-saver” approach would be to perform the Exciting Current Test on 16R, 1R, N, 1L, and 16L

Exciting Current: Why Did the Test-Instrument “Trip”?

1. User-error
2. The transformer under test has an inherently high Exciting Current
3. A fault, which is causing the Exciting Current to be “higher than normal”

- If a transformer fault is not suspected, then the user may have to lower the test-voltage to complete the Exciting Current measurement on all three phases
- Note, to assess the Exciting Current measurement, all three phases and all tap-positions must be tested at the same test-voltage

Exciting Current: When Did the Test-Instrument “Trip”?

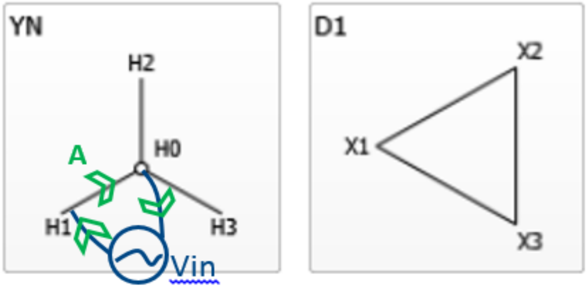
1. **When testing all three phases?** In this case, it is probably not due to a fault, but it is possible

2. **When testing a reactive-type LTC in a “bridging” tap-position(s)?** In this case, it is probably not due to a fault, but it is possible

3. **When testing a transformer that has a Delta primary winding, AND only when testing Phase-C?** In this case, it is probably not due to a fault, but it is possible

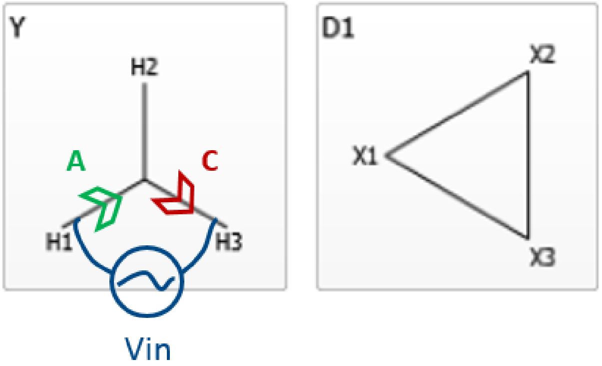
4. **When testing a transformer that has a Delta primary winding, AND when performing two of the three phase-measurements?** This is typically caused by a transformer fault, so the measurement should be investigated

Exciting Current Test-Connections: Wye Primary Winding *with* Accessible Neutral Bushing Terminal



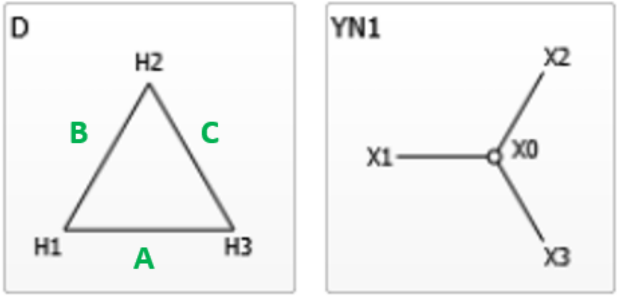
Phase	High-Voltage Lead (HV)	Low-Voltage Lead (LV)	Ground	Float	Mode
A	H1	H0	-	X1,X2,X3, H2, H3	UST
B	H2	H0	-	X1,X2,X3, H1, H3	UST
C	H3	H0	-	X1,X2,X3, H1, H2	UST

Exciting Current Test-Connections: Wye Primary Winding *without* Accessible Neutral Bushing Terminal



Phase	High-Voltage Lead (HV)	Low-Voltage Lead (LV)	Ground	Float	Mode
“A”	H1	H3	-	X1,X2,X3, H2	UST
“B”	H2	H1	-	X1,X2,X3, H3	UST
“C”	H3	H2	-	X1,X2,X3, H1	UST

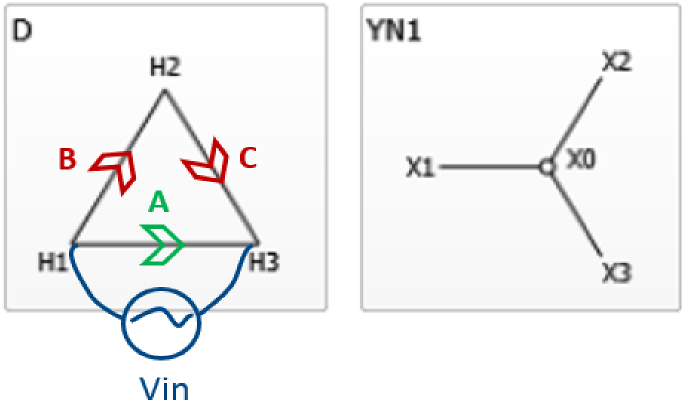
Exciting Current Test-Connections: Delta Primary Winding



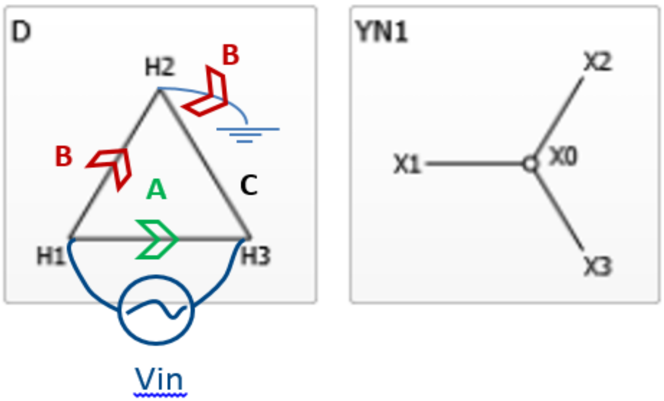
Phase	High-Voltage Lead (HV)	Low-Voltage Lead (LV)	Ground	Float	Test Mode
A	H1	H3	H2, X0	X1,X2,X3	UST
B	H2	H1	H3, X0	X1,X2,X3	UST
C	H3	H2	H1, X0	X1,X2,X3	UST

Exciting Current Test-Connections: Delta Primary Winding

Phase-A *without* H2 Grounded



Phase-A *with* H2 Grounded



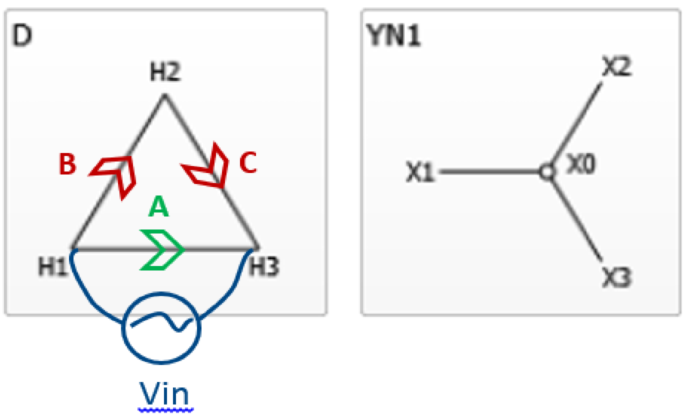
Phase	High-Voltage Lead (HV)	Low-Voltage Lead (LV)	Ground	Float	Test Mode
A	H1	H3	H2, X0	X1,X2,X3	UST
B	H2	H1	H3, X0	X1,X2,X3	UST
C	H3	H2	H1, X0	X1,X2,X3	UST

Exciting Current Test-Connections: Delta Primary Winding

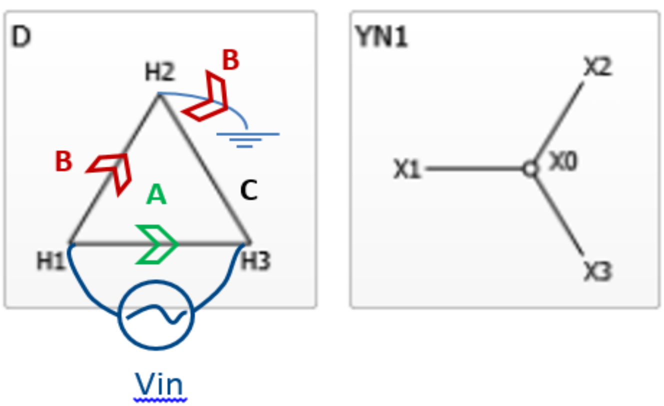
- Grounding the third bushing terminal of the Delta winding helps to isolate, and test, each individual phase-winding of the transformer

- Note, when testing a transformer with a Delta primary winding, when performing each measurement, although one phase is measured, two phases are "excited"

Phase-A *without* H2 Grounded



Phase-A *with* H2 Grounded



Exciting Current Test-Connections: Delta Primary Winding

- Grounding the third bushing terminal of the Delta winding helps to isolate, and test, each individual phase-winding of the transformer

- Note, when testing a transformer with a Delta primary winding, when performing each measurement, although one phase is measured, two phases are "excited"

	Test Connection	Ground	"Excited" Phases	Measured Phase
Phase A	H1-H3	H2	Phase A and Phase B	Phase A
Phase B	H2-H1	H3	Phase B and Phase C	Phase B
Phase C	H3-H2	H1	Phase C and Phase A	Phase C

Exciting Current Test-Connections: Delta Primary Winding

- **If the transformer has a Delta primary winding, and two of the three phase-measurements "trip", then a fault is likely on one of the two phases**
- For a Delta primary winding, although one phase is measured, two phases are "excited" simultaneously
- In this example, the fault most likely exists on the phase that is energized during both measurements that "trip" (i.e. Phase-C in the example below)

	Phase A (A and B are Excited)	Phase B (B and C are Excited)	Phase C (C and A are Excited)
16R	13.2mA	Overcurrent	Overcurrent
1R	69.2mA	Overcurrent	Overcurrent
N	11.4mA	Overcurrent	Overcurrent
1L	68.7mA	Overcurrent	Overcurrent

Delta Primary Winding: Always Start with the Phase-C Measurement

- The Phase-C measurement requires the largest amount of output power from the test-instrument, so the Phase-C measurement is the most likely to “trip”
- Typically, if the Phase-C measurement can be completed without “tripping” the test set, then all three phase-measurements can be completed without “tripping” the test set

Delta Primary Winding – Measurement Summary				
		Measured Phases	“Excited” Phases	Total Current Supplied
Phase-A	H1-H3	A	A + B	High+Low
Phase-B	H2-H1	B	B + C	Low+High
Phase-C	H3-H2	C	C + A	High+High

The Exciting Current Test - Analysis

- There are no absolute limits for assessing the Exciting Current Test results
- The best way to assess the Exciting Current measurement is to use **Pattern Recognition**
- **Compare the measured phase-pattern to the expected phase-pattern**
- **There are three common phase-patterns:**

  1. **High-Low-High Pattern** – where the Phase-B measurement is lower in magnitude relative to the other two phases
  2. **High-Low-Low Pattern** – where two of the phase-measurements are lower in magnitude relative to the third phase-measurement
  3. **Low-High-Low Pattern** – where the Phase-B measurement is higher in magnitude relative to the other two phases

The Three Exciting Current Phase-Patterns

Phase-Pattern #1 - "High-Low-High"

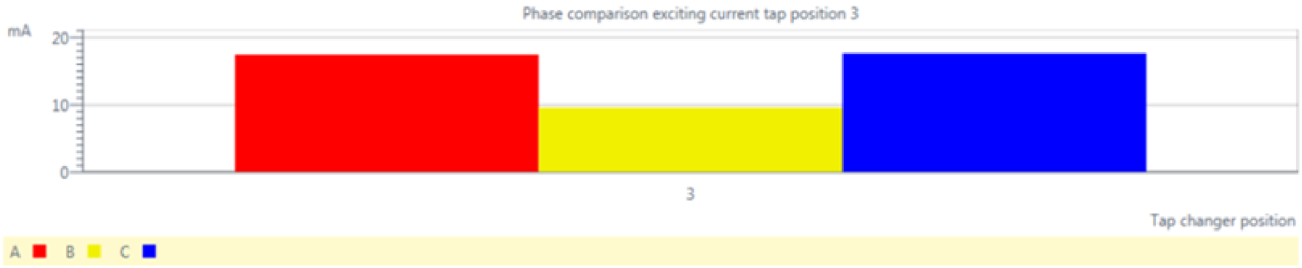
Phase-Pattern #2 - "High-Low-Low"

Phase-Pattern #3 - "Low-High-Low"

“High-Low-High” Phase Pattern

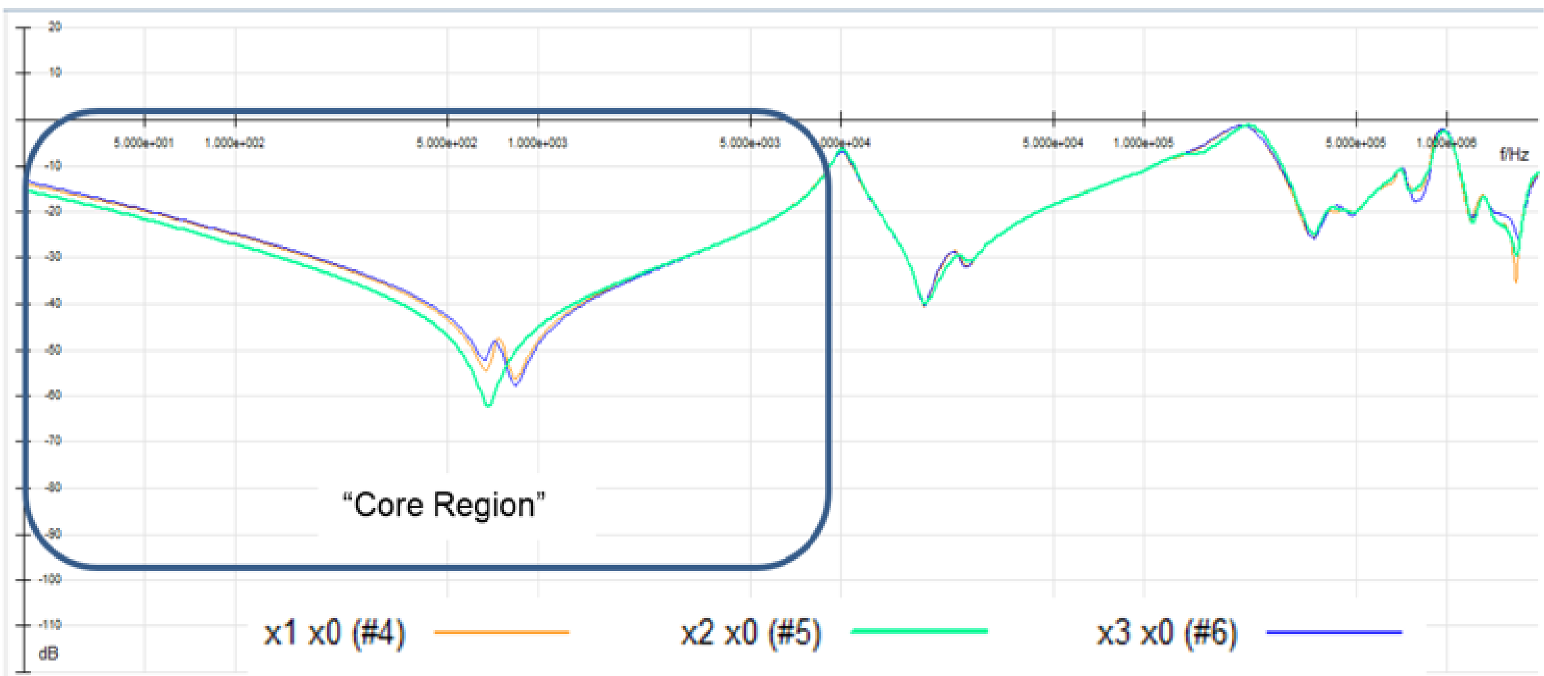
- The **High-Low-High** pattern describes an Exciting Current Test where the Phase-B measurement is lower in magnitude relative to the other two phase-measurements
- The **High-Low-High** pattern is the expected pattern for all transformers, *with the exception* of transformers that have a Wye primary winding without an accessible neutral bushing terminal

	Phase A	Phase B	Phase C
Measured Exciting Current	17.5mA	9.5mA	17.6mA



“High-Low-High” Phase Pattern Appears in the SFRA Test too

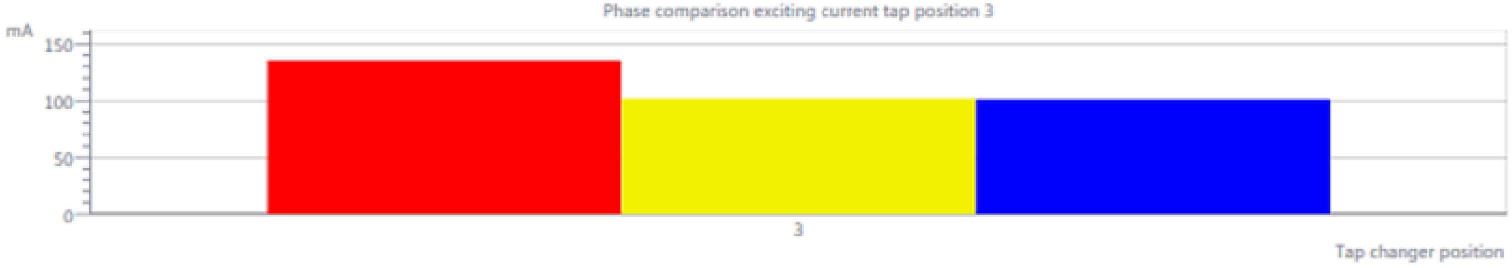
- The High-Low-High phase-pattern is exhibited in the “core region” of an SFRA trace
- In most cases, the Phase-B SFRA trace is expected to be the lowest in magnitude, relative to the other two phases



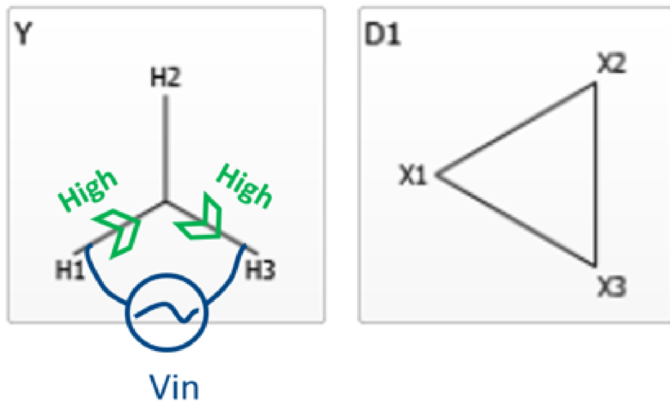
“High-Low-Low” Phase Pattern

- The **High-Low-Low** pattern describes an Exciting Current Test where two of the phase-measurements are lower in magnitude relative to the third phase-measurement
- The **High-Low-Low** pattern is the expected pattern for transformers that have a Wye primary winding without an accessible neutral bushing terminal
- The “High” magnitude measurement is expected for the **“Phase-A and Phase-C series measurement”**

	Phase A	Phase B	Phase C
Measured Current	135mA	102mA	102mA



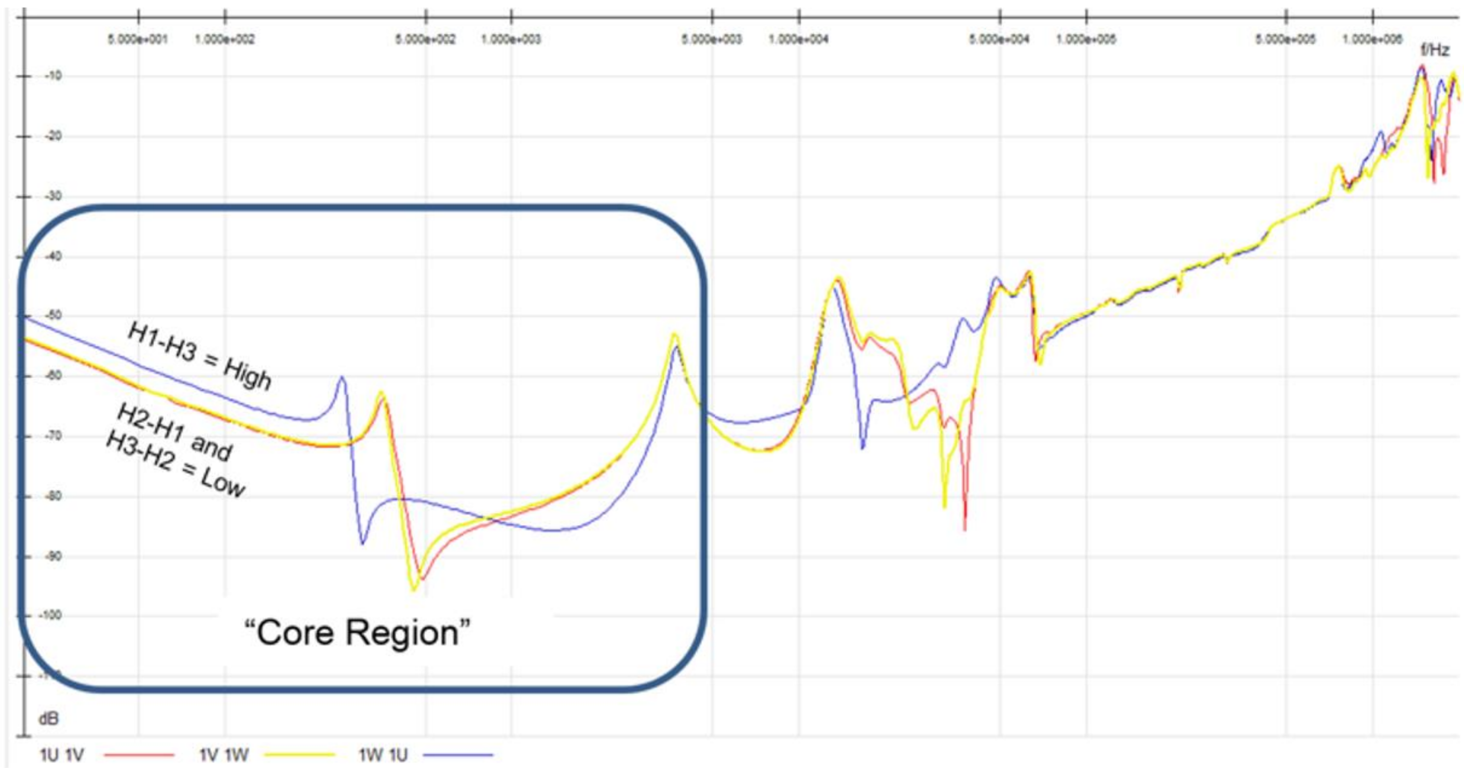
Why Does the "High-Low-Low" Phase Pattern Occur?



Measurement	Test Connection	Measured Phases	Relative Current Magnitude for Both Phases	Total Relative Current Magnitude
"Phase A"	H1-H3	Phase A and Phase C	High+High	High
"Phase B"	H2-H1	Phase B and Phase A	Low+High	Low
"Phase C"	H3-H2	Phase C and Phase B	High+Low	Low

“High-Low-Low” Phase Pattern Appears in the SFRA Test too

- The High-Low-Low phase-pattern is exhibited in the “core region” of an SFRA trace
- The “High” magnitude measurement is expected for the **“Phase-A and Phase-C series measurement”**



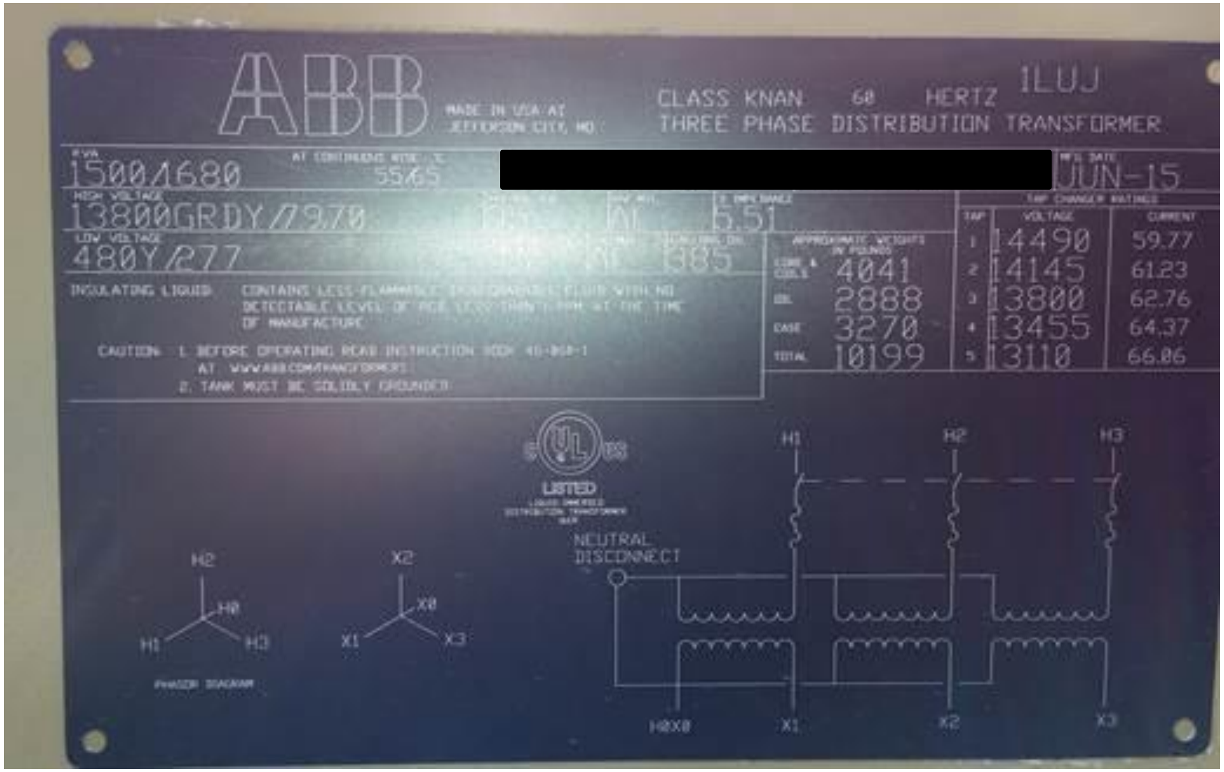
"Low-High-Low" Phase Pattern

- The **Low-High-Low** pattern describes an Exciting Current Test where the Phase-B measurement is higher in magnitude relative to the other two phase-measurements
- The **Low-High-Low** pattern is very difficult to predict
- The **Low-High-Low** pattern may be produced by a relatively-low power-rated transformer, which we will define here as a transformer rated below 5MVA

“Low-High-Low” Phase Pattern

- If a relatively-low power-rated transformer produces this pattern, AND all other electrical tests are acceptable, AND there is no reason to suspect that there is a problem with the transformer, then the Exciting Current Test results should be “passed”
- If a “power transformer” produces this phase pattern, then the transformer should be investigated, with emphasis on the “higher than normal” Phase-B current measurement

“Low-High-Low” Phase Pattern Example



	Phase A	Phase B	Phase C
Measured Current	113mA	127mA	110mA

"Low-High-Low" Phase Pattern Examples

Example #1 – Low-High-Low Phase Pattern

Two-Winding Transformer (Oil-Filled) – Ynyn0

24.9kV (14.376kV) - 0.480kV (0.277kV) – 1.5MVA

	Phase A	Phase B	Phase C
Measured Exciting Current	32.8mA	34.8mA	32.9mA

Two-Winding Transformer (Oil-Filled) – Ynyn0

24.9kV (14.376kV) - 0.208kV (0.120kV) – 150kVA

	Phase A	Phase B	Phase C
Measured Exciting Current	10mA	14mA	10mA

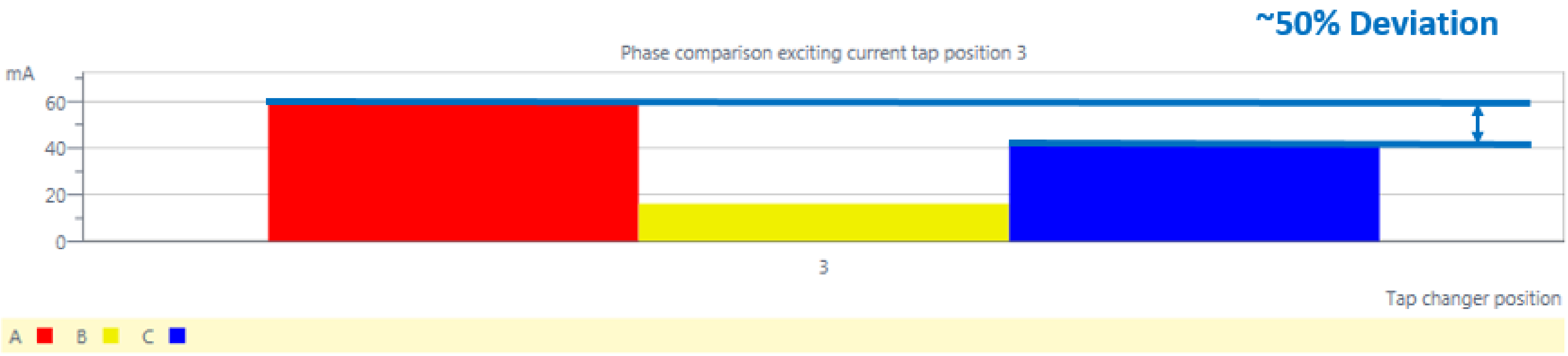
Always Compare the Two "Similar" Measurements

- Regardless of which of the three phase patterns you expect to measure, there should be two measurements that have a similar exciting current value
- A dissimilarity of more than 15%-20% when comparing these two "similar" measurements should be questioned
- A dissimilarity between the two measurements may be caused by,

1. **User-error**
2. **Residual magnetism** – Demagnetize the core and repeat the Exciting Current Test
3. **A capacitive Exciting Current measurement** – Please refer to the section on capacitive Exciting Current measurements
4. **A fault within the transformer**

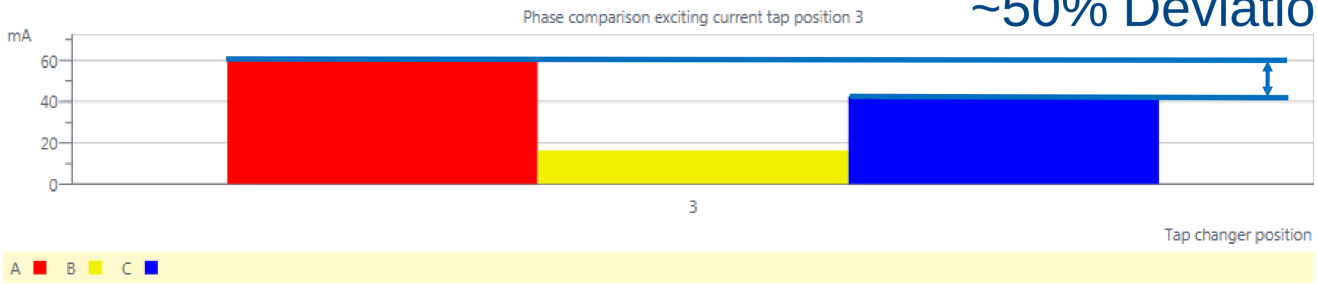
Exciting Current Test - Dissimilarity Example

- A dissimilarity between the two measurements may be caused by,
  1. **User-error**
  2. **Residual magnetism** – Demagnetize the core and repeat the Exciting Current Test
  3. **A capacitive Exciting Current measurement** – Please refer to the section on capacitive Exciting Current measurements
  4. **A fault within the transformer**



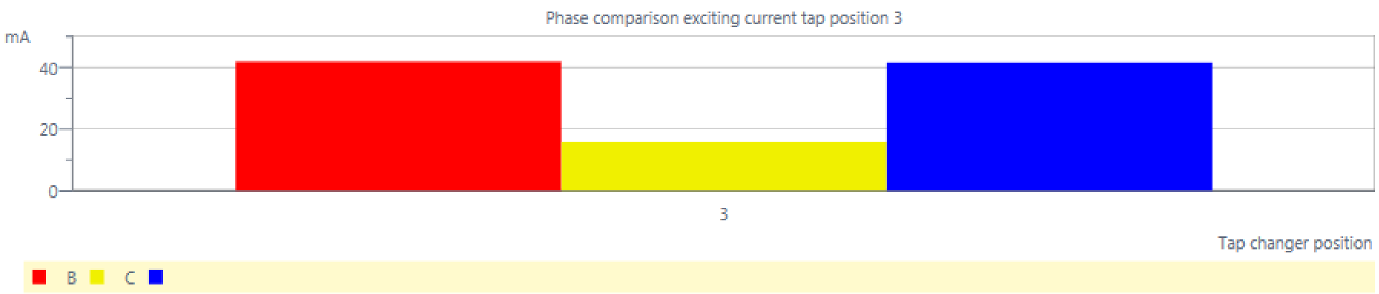
Residual Magnetism Example

~50% Deviation



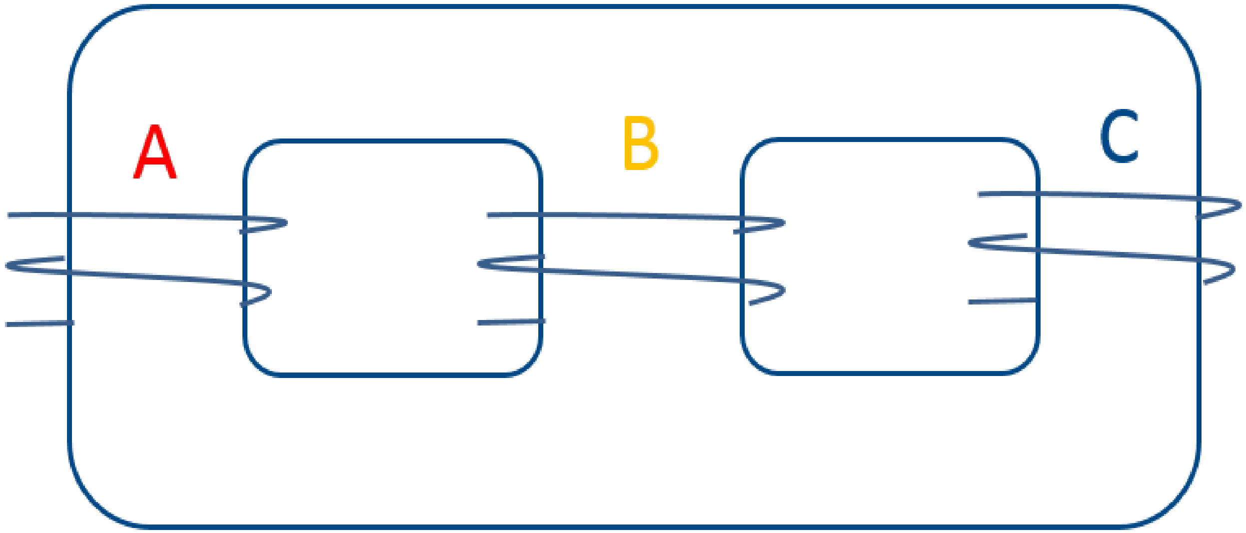
Demagnetize Core

Repeat Test

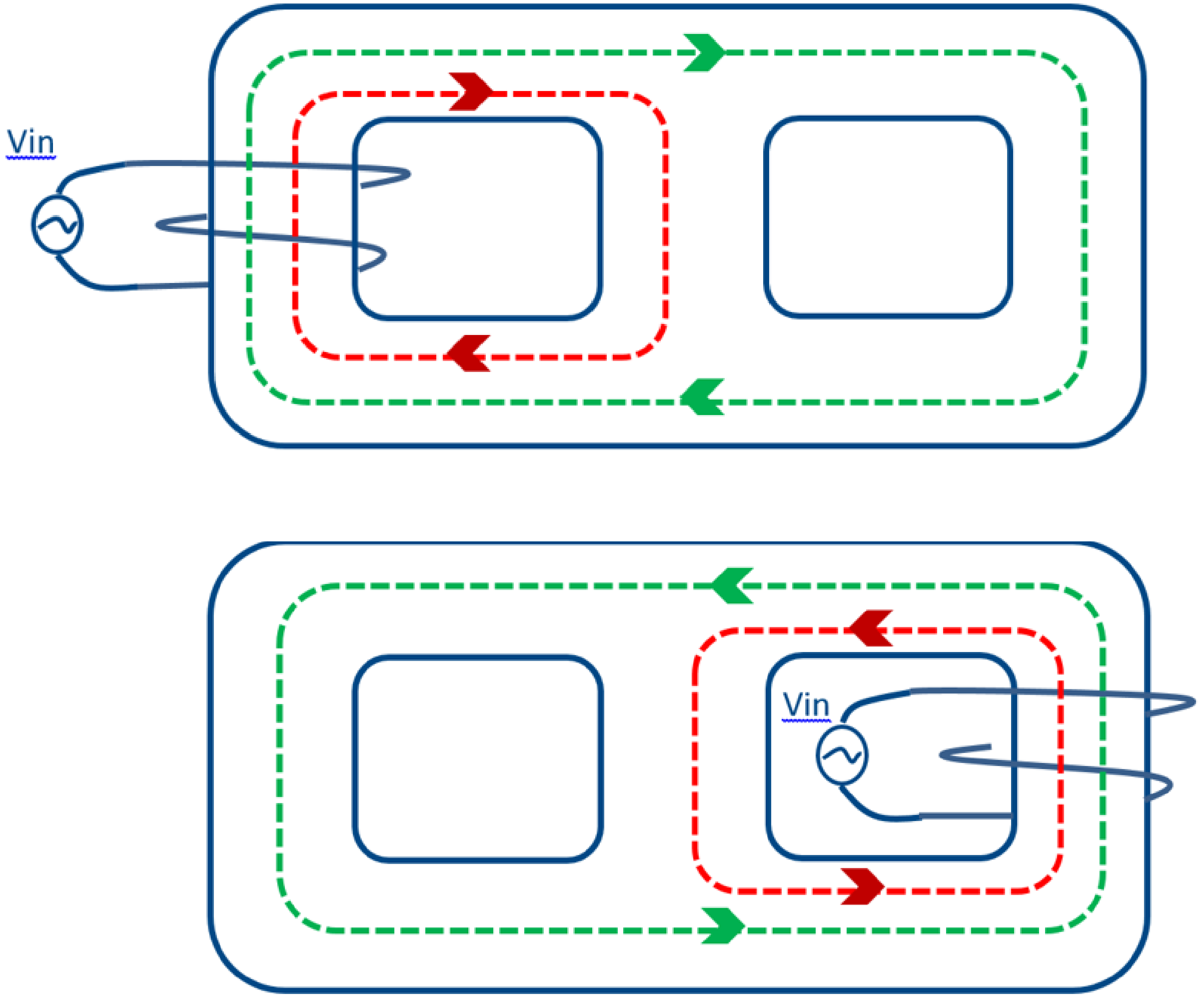


Why do the Exciting Current Phase-Patterns Occur?

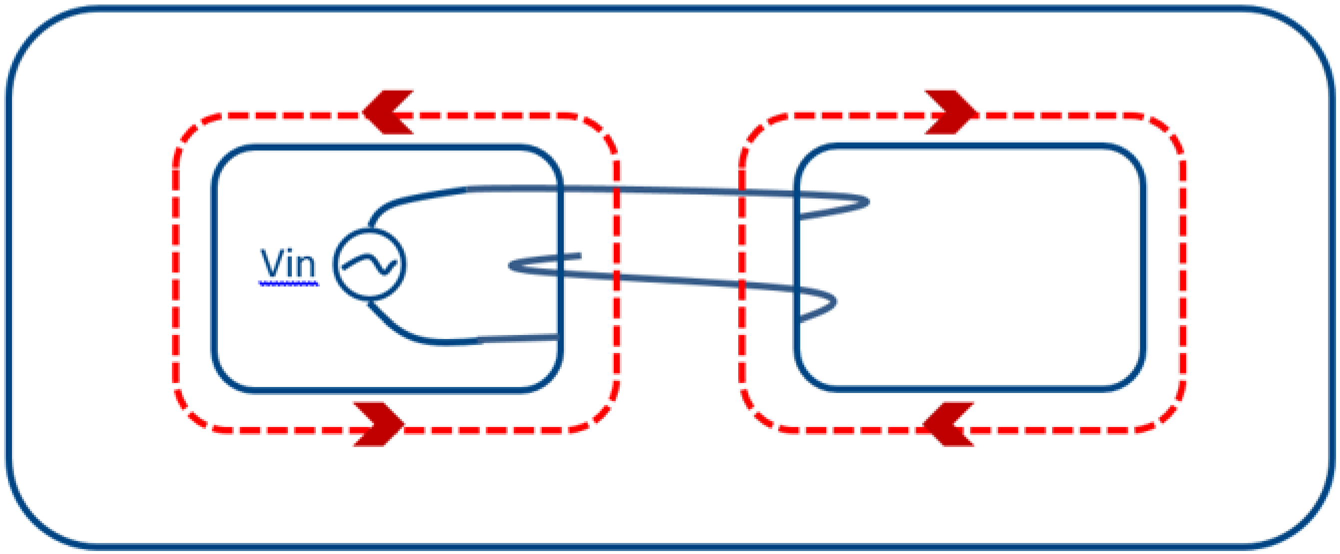
- Most power transformers have a 3-limb core-form construction
- The Phase-B winding is typically located on the center-limb of the core, while the Phase-A and C windings are typically located on the "outer limbs" of the core
- The Exciting Current phase-patterns are mainly determined by the **core construction** and **the configuration of the primary winding** (delta vs. wye)



The Phase-A and Phase-C Exciting Current Tests



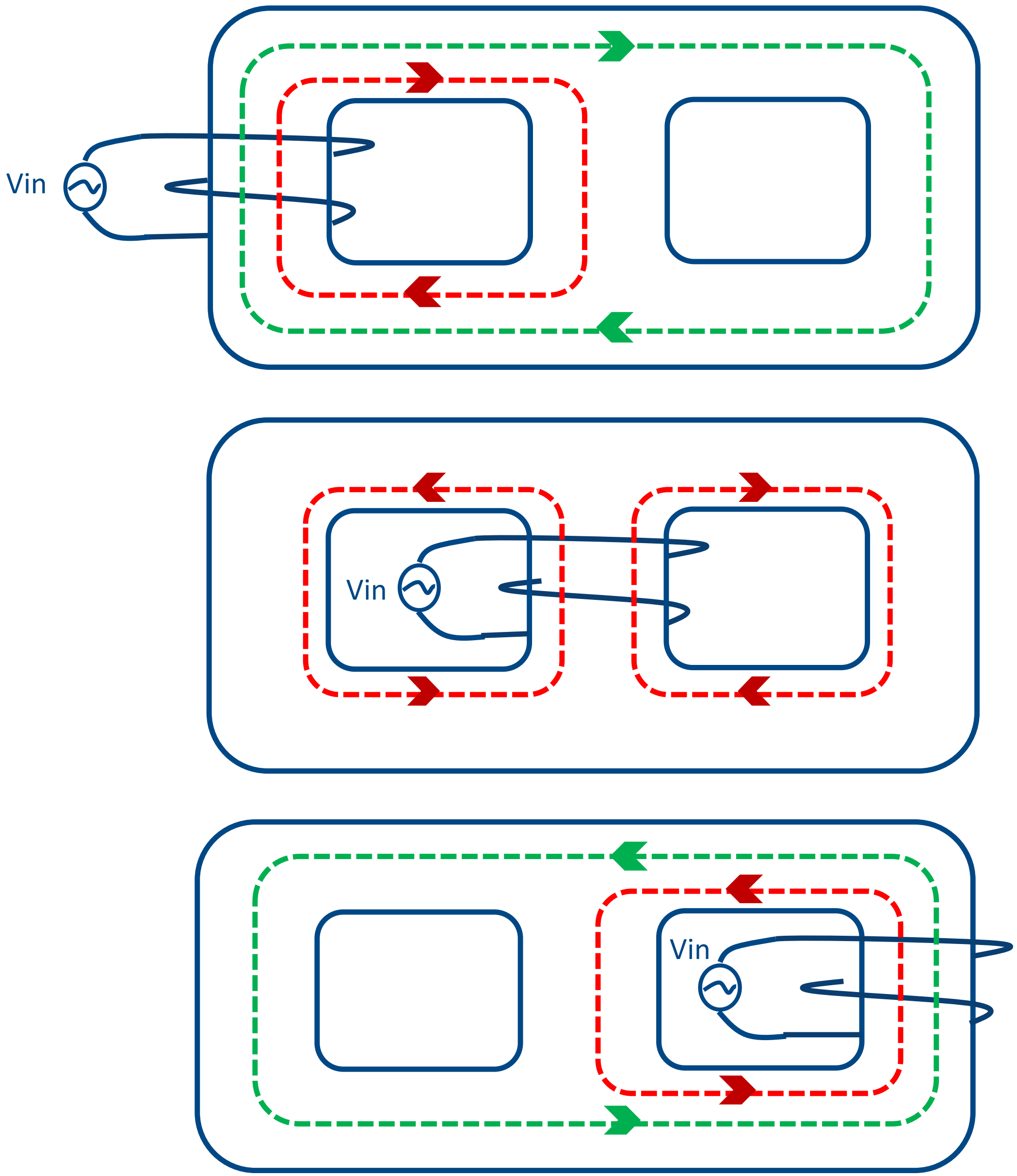
The Phase-B Exciting Current Test



Phase-A

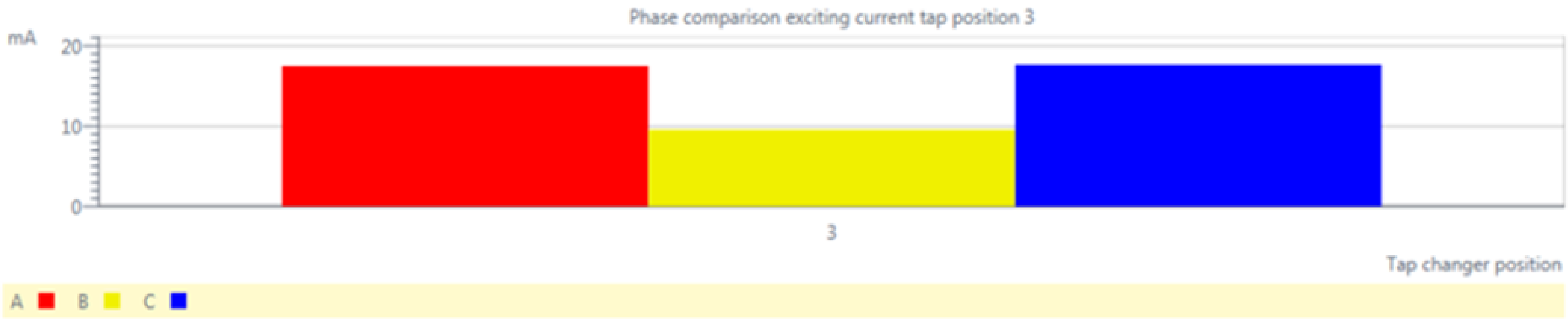
Phase-B

Phase-C



Why do the Exciting Current Phase-Patterns Occur?

- For inductive Exciting Current measurements, the magnitude of Exciting Current is proportional to the sum of the length of the two main flux paths
- The length of the flux paths for Phases A and C = long flux path + short flux path = relatively longer = relatively higher Exciting Current
- The length of the flux paths for Phase B = short flux path + short flux path = relatively shorter = relatively lower Exciting Current



The Exciting Current Test - Tap-Changer Patterns

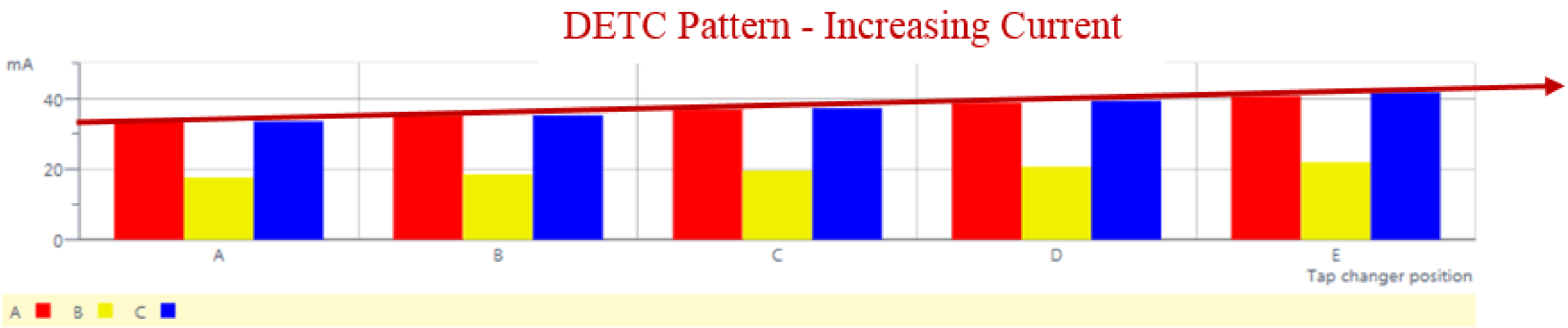
1. De-Energized Tap-Changer Patterns (relatively simple to analyze)
2. Resistive-Type Load-Tap-Changer Patterns (relatively simple to analyze)
3. **Reactive-Type Load-Tap-Changer Patterns (the most challenging to analyze)**

- ➢ **In most cases, the expected phase-pattern should not change versus tap-position**
- ➢ For more information, please refer to my paper, **"A Systematic Approach to Analyzing Exciting Current Measurements on Power Transformers"**

De-Energized Tap-Changer (DETC) Patterns

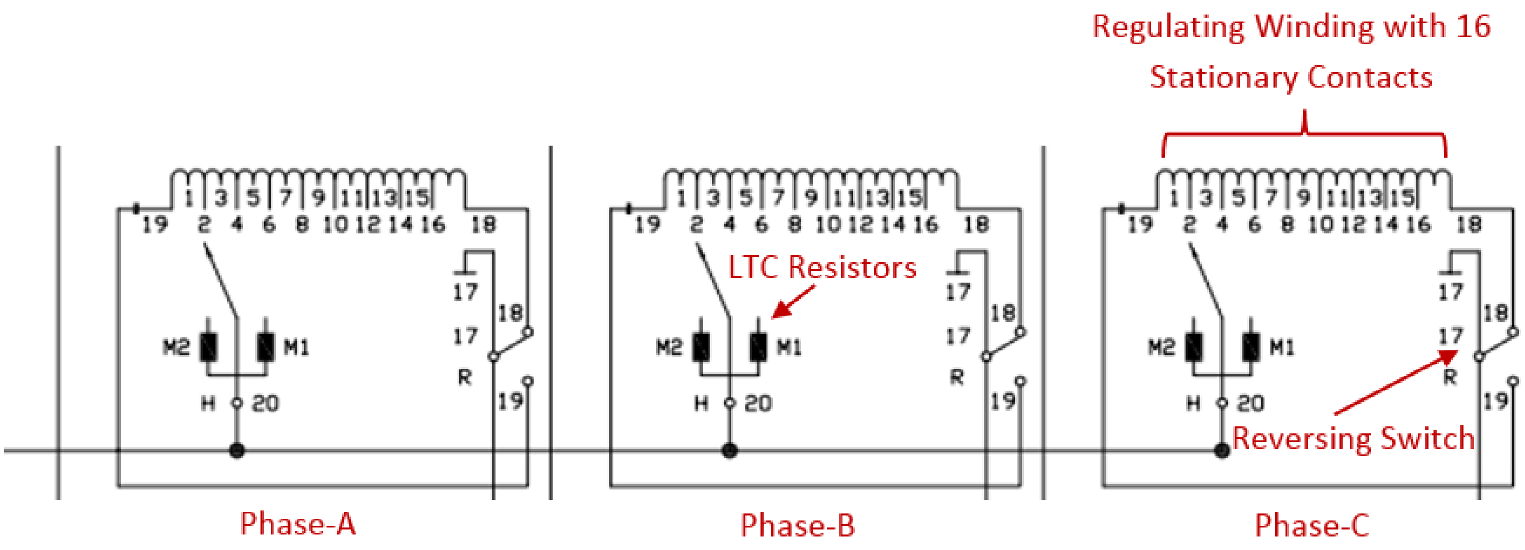
- In North America, the DETC is typically located on the primary side of a power transformer
- In North America, the DETC typically has 5 tap-positions (e.g. 1-5 or A-E) but any number of positions is possible
- The DETC Exciting Current pattern is easy to predict
- As the DETC position is varied, the measurement Exciting Current should increase or decrease more-or-less linearly versus tap-position – Any other pattern should be questioned

DETC Pattern Example

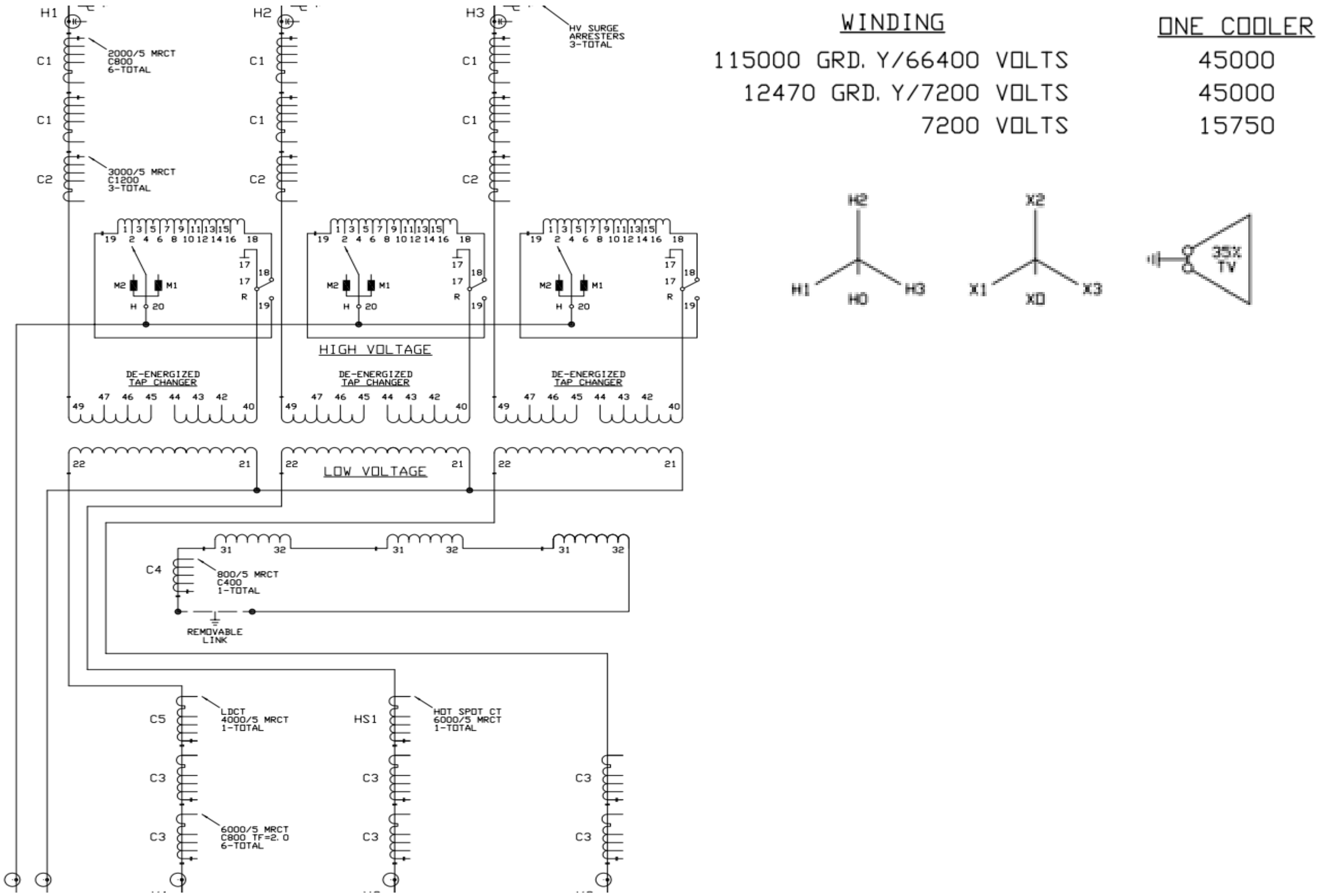


Resistive-Type Load Tap Changer (LTC) Patterns

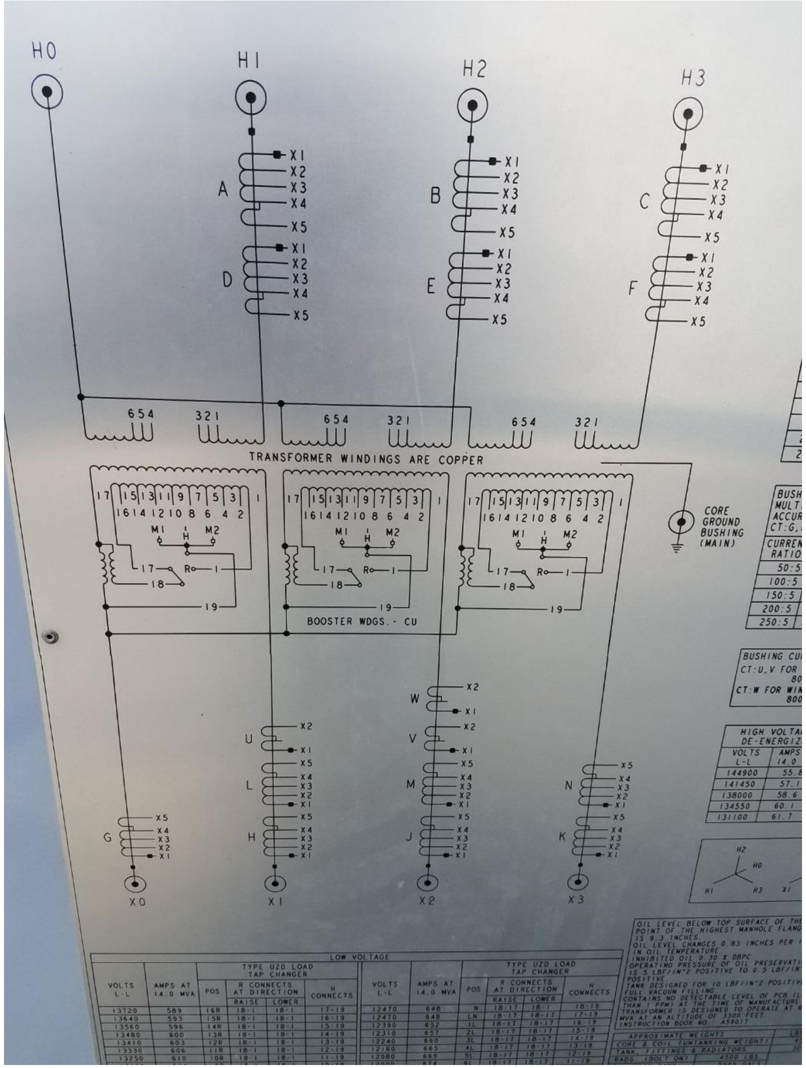
- In North America, an LTC is typically located on the secondary side of a power transformer
- In North America, an LTC typically has 33 tap-positions (e.g. 16R-16L or 1-33)
- Resistive-type LTCs typically have a regulating winding with **16 stationary contacts** (17 including the neutral)



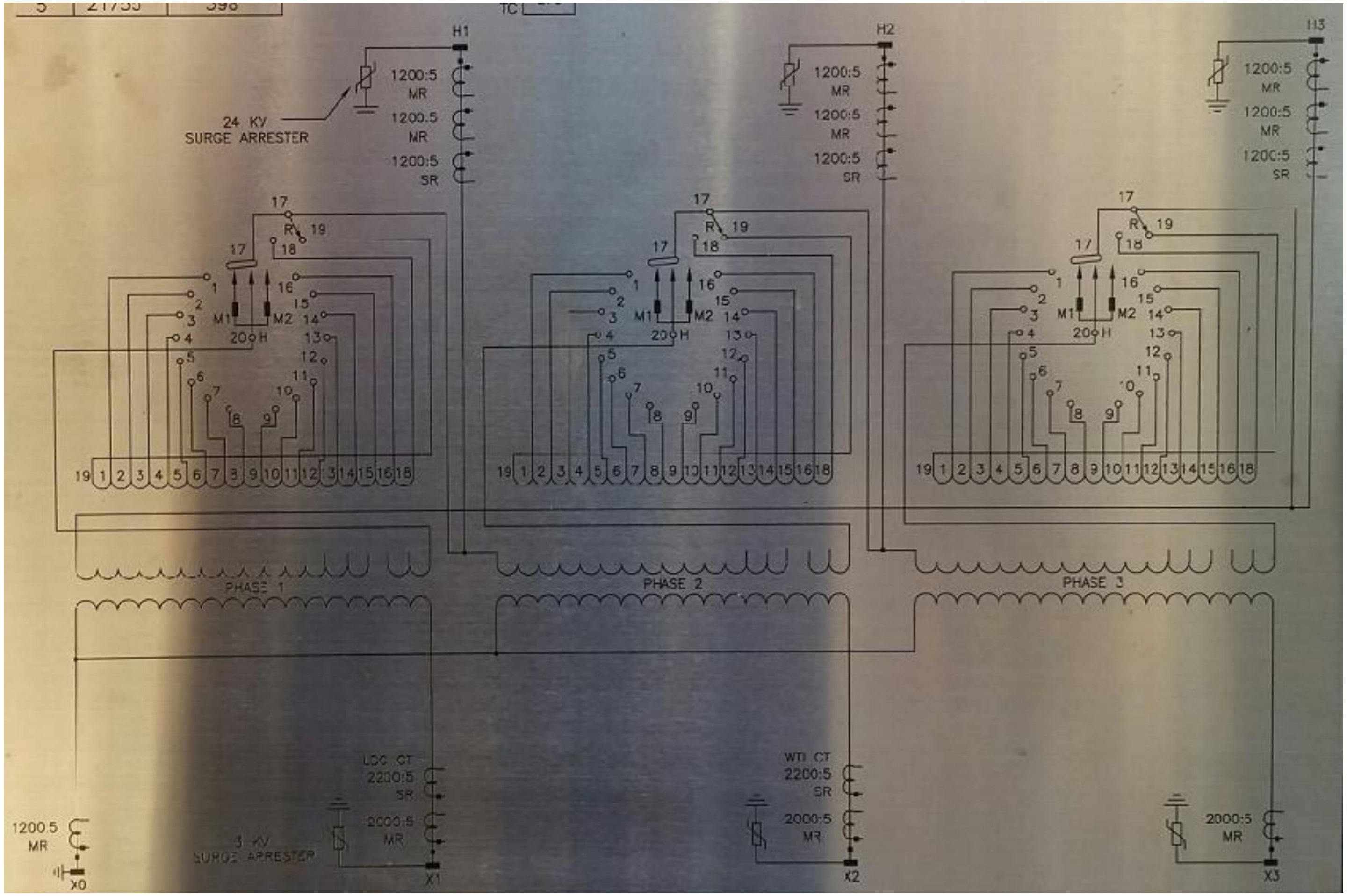
Resistive-Type LTC Nameplate Example



Resistive-Type LTC Nameplate Example



Resistive-Type LTC Nameplate Example



Resistive-Type LTC Patterns

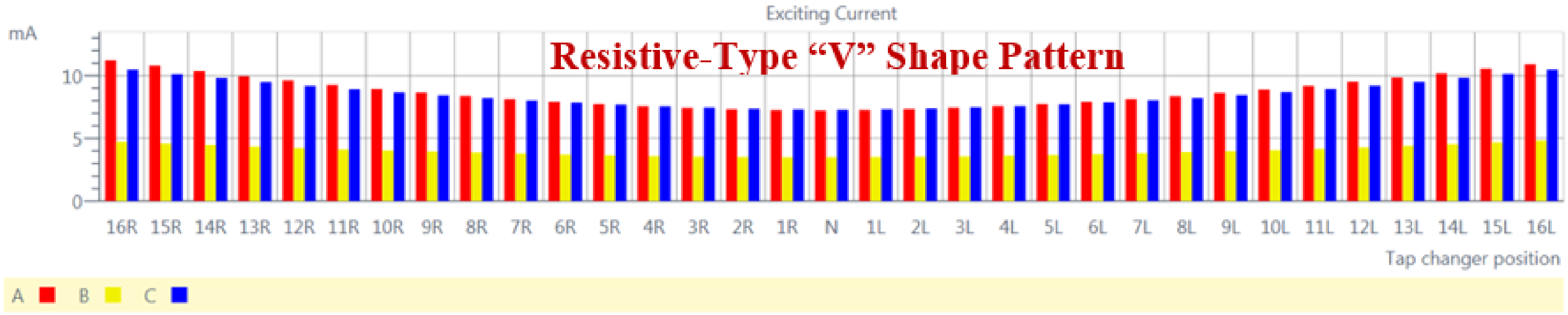
- **As the resistive-type LTC position is varied, the measured Exciting Current should increase or decrease more-or-less linearly**

- There are two common resistive-type patterns, which includes,

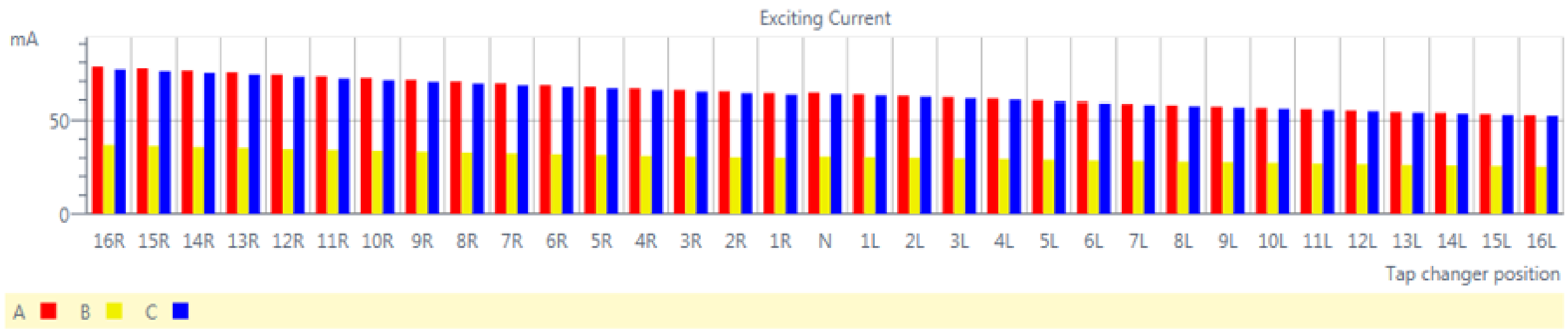
  1. **The “V-Shape” pattern, from extreme to extreme**

  2. **A linear increase or linear decrease pattern, from extreme to extreme**

Resistive-Type LTC Patterns

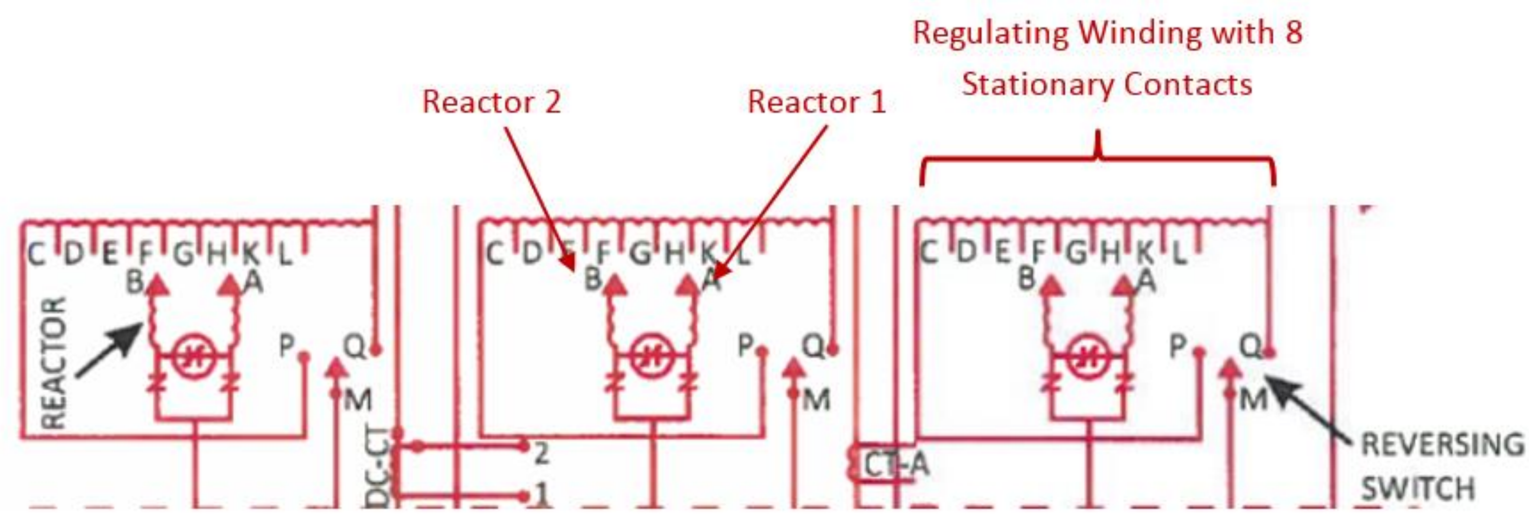


Linear Decrease (or Increase) Pattern

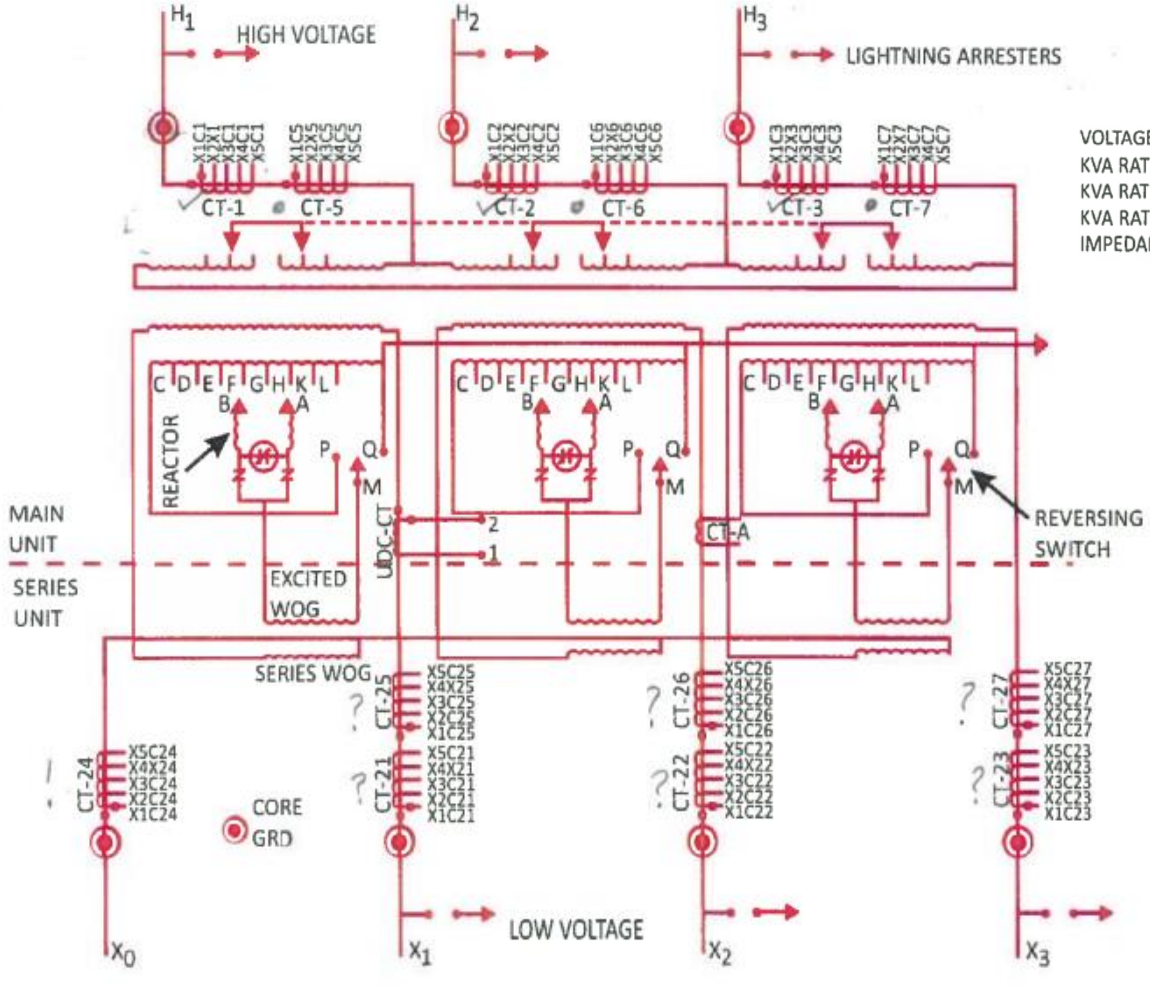


Reactive-Type Load Tap Changer (LTC) Patterns

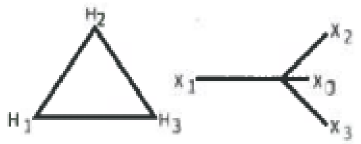
- In North America, an LTC is typically located on the secondary side of a power transformer
- In North America, an LTC typically has 33 tap-positions (e.g. 16R-16L or 1-33)
- Reactive-type LTCs typically have a regulating winding with **8 stationary contacts** (9 including the neutral)



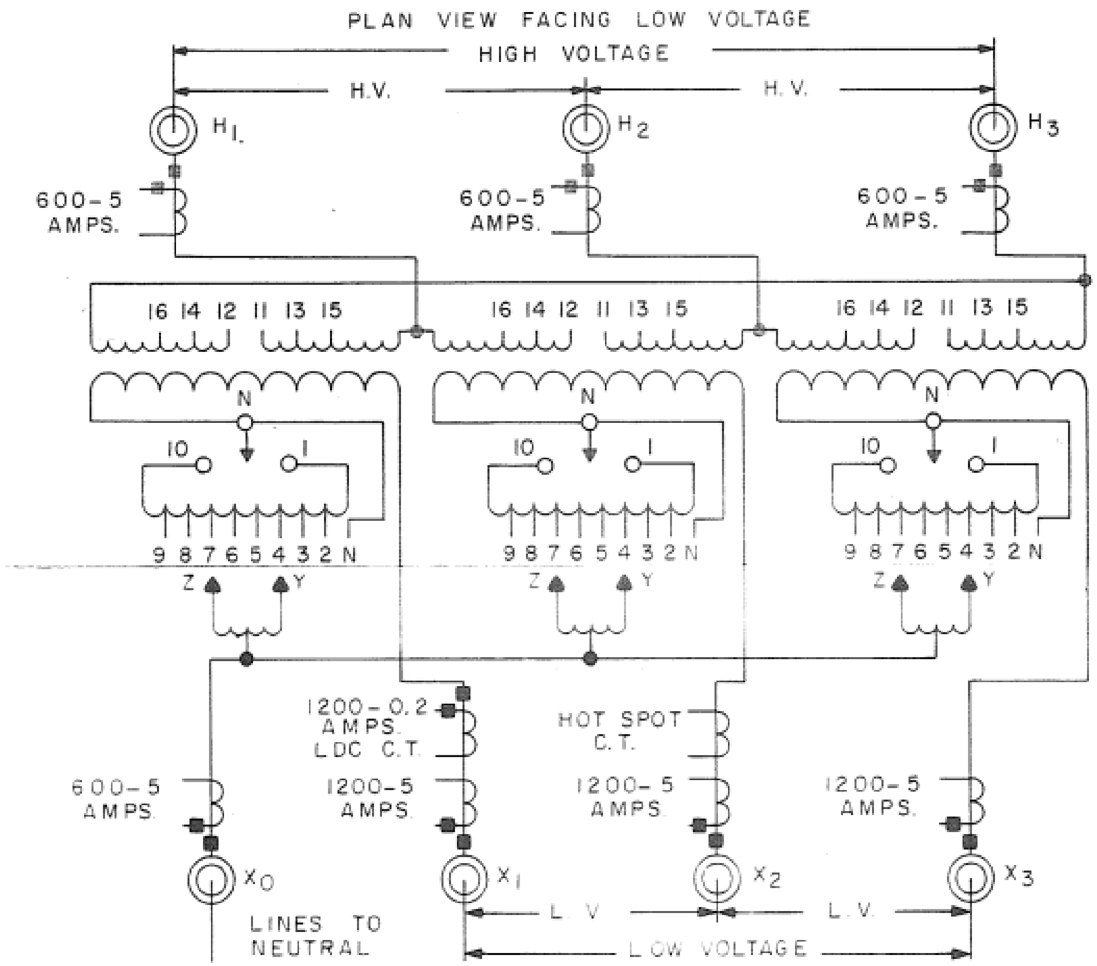
Reactive-Type LTC Nameplate Example



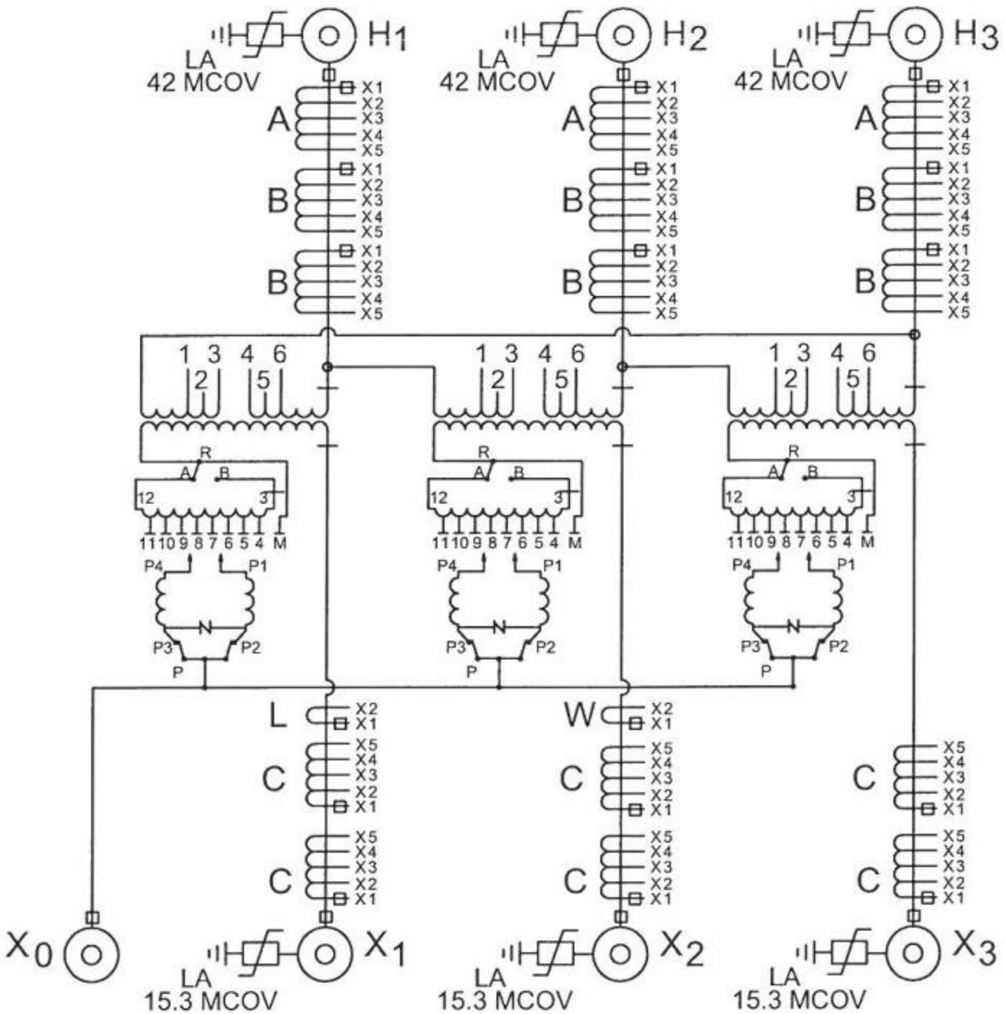
VOLTAGE RATING 67000-4160Y/2400
KVA RATING 7500 CONTINUOS 55 C RISE SELF COOLED
KVA RATING 9375 CONTINUOS 55 C RISE FORCED AIR
KVA RATING 10500 CONTINUOS 65 C RISE FORCED AIR
IMPEDANCE VOLTS 8.61% 67000-4160Y VOLTS AT 7500 KVA



Reactive-Type LTC Nameplate Example

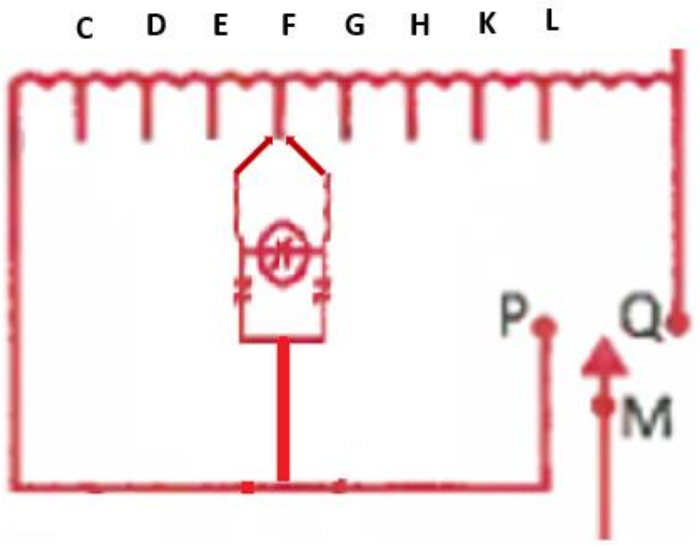


Reactive-Type LTC Nameplate Example



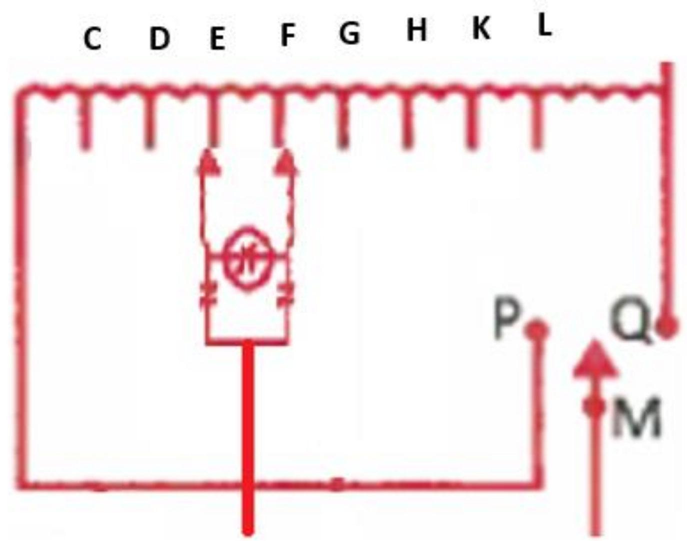
Reactive-Type LTC “Non-Bridging Tap Positions”

- The two tap-selectors of the Preventative Autotransformer (PA) are connected to the same stationary contact of the regulating winding
- In a non-bridging position, the PA is short-circuited and has no voltage potential applied across its windings (and thus, there will be zero circulating current through the PA)
- In a non-bridging position, the measured exciting current is not influenced by the PA



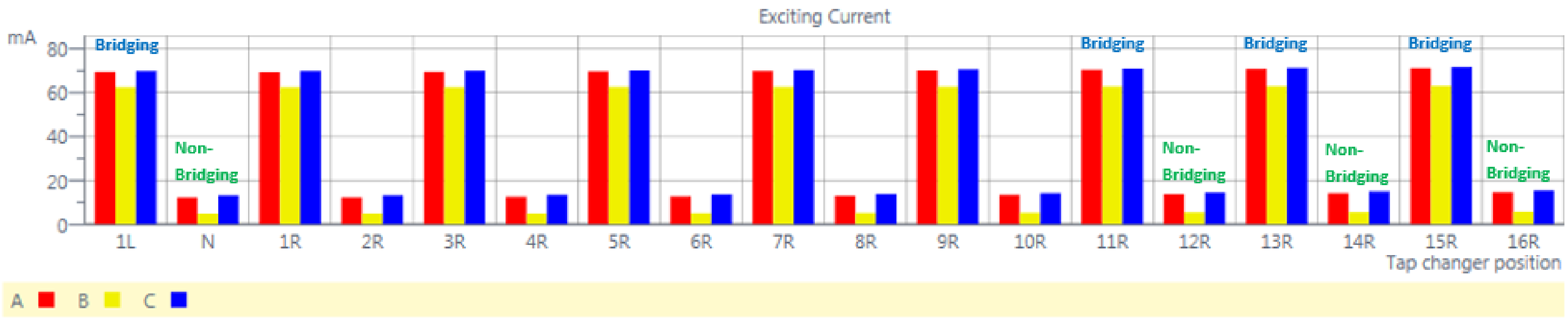
Reactive-Type LTC “Bridging Tap Positions”

- The two tap-selectors of the Preventative Autotransformer (PA) are connected to two adjacent stationary contacts of the regulating winding
- In a bridging position, a voltage potential is applied across the PA windings, which “excites” the PA, causing a circulating current to flow through the PA
- In a bridging position, the measured exciting current is significantly influenced by the PA



Reactive-Type LTC Patterns

- Due to the excitation of the Preventative Autotransformer, **bridging positions should have a higher exciting current than non-bridging positions**
- The Neutral (N) position is a non-bridging position, so the exciting current should be relatively low in the Neutral position
- **The expected phase-pattern should not change versus tap-position**



Reactive-Type LTC “Bridging Patterns”

- The measured Exciting Current may vary when comparing only the bridging positions, due to construction of the regulating winding
- If a **bridging pattern** exists, then the bridging positions will typically produce two different magnitudes of Exciting Current

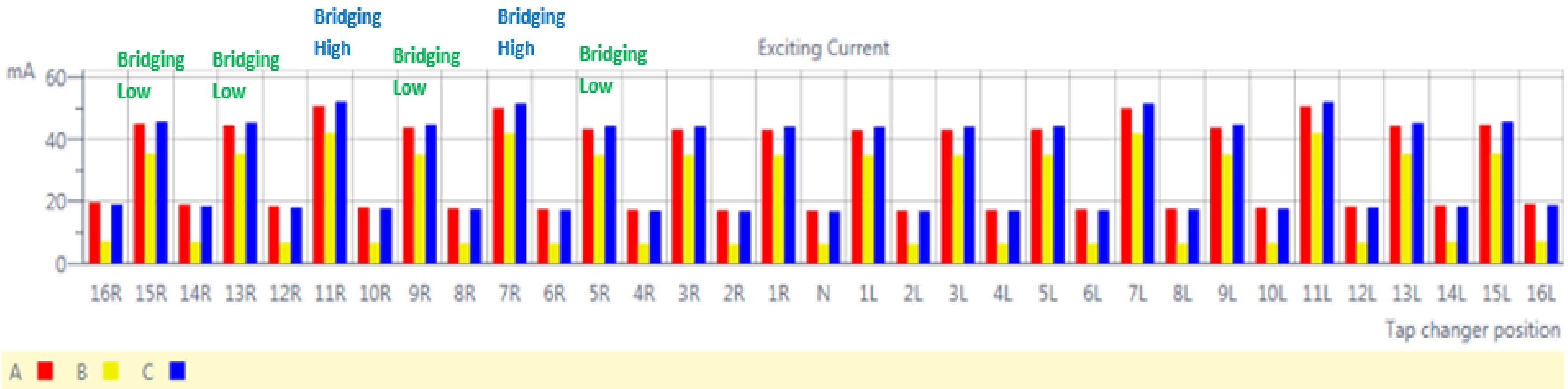
    1) **“bridging high”**

    2) **“bridging low”**

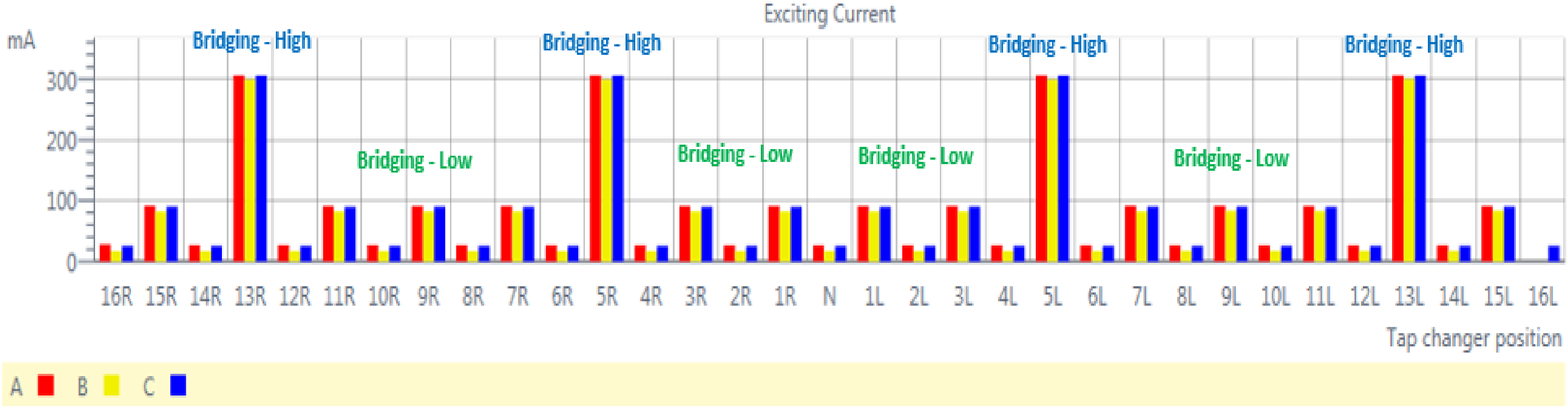
- In most cases, a **bridging pattern** is normal and is not indicative of a transformer failure

“Bridging Pattern” Example

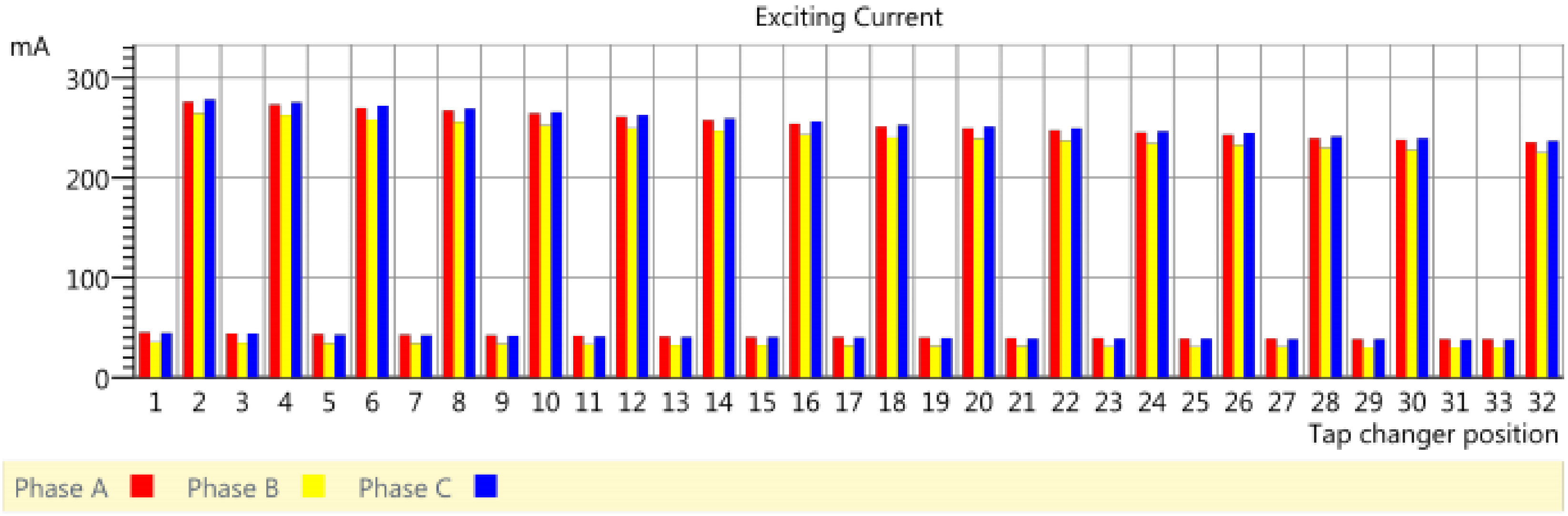
“Bridging Pattern” Example



“Bridging Pattern” Example



Unique “Bridging Pattern”



Inductive Exciting Current Measurements

- Most transformers produce inductive Exciting Current measurements
- Inductive Exciting Current measurements have a **negative signed current phase angle,** and a positive signed reactance value
- **Inductive measurements typically produce predictable Exciting Current phase-patterns**

	Phase A	Phase B	Phase C
Current (mA)	17.5mA	9.5mA	17.6mA
Current (°)	- 42°	- 45°	- 42°

Capacitive Exciting Current Measurements

- Some transformers produce capacitive Exciting Current measurements, but they are far less common than inductive Exciting Current measurements
- Capacitive Exciting Current measurements have a **positive signed current phase angle,** and a negative signed reactance value
- **A capacitive Exciting Current measurement may result in an unusual or unexpected phase pattern, regardless of the primary winding configuration and core construction**

	Phase A	Phase B	Phase C
Current (mA)	9mA	8.2mA	8.2mA
Current (°)	+ 32°	+ 55°	+ 27°

Inductive-Capacitive Hybrid Measurements

- Some transformers produce both inductive and capacitive Exciting Current measurements
- In most cases, an inductive-capacitive hybrid measurement produces the “expected” phase-pattern, so the measured current (mA) can be analyzed
- In most cases, when this phenomenon occurs, the Phase-B measurement is capacitive, while the Phase A and C measurements are inductive

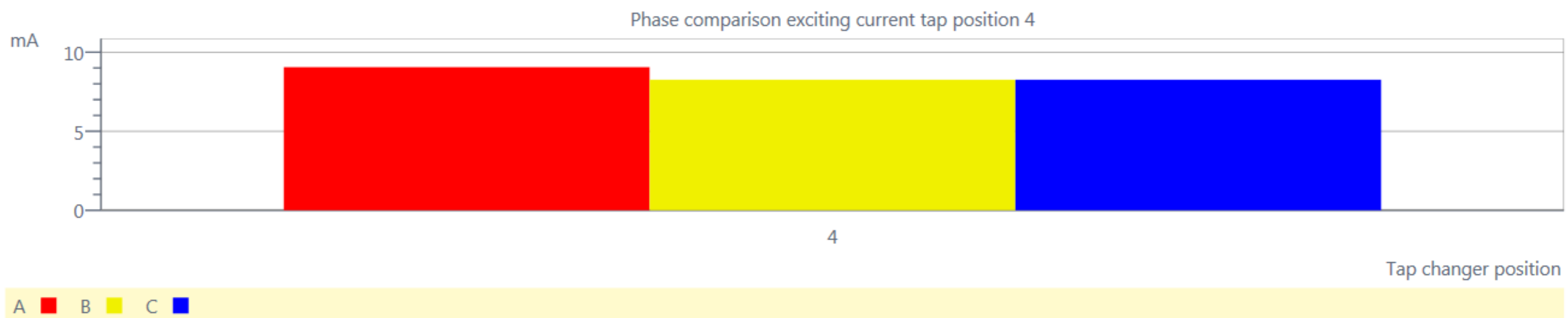
	Phase A	Phase B	Phase C
Current (mA)	11.7mA	7.6mA	12mA
Current (°)	- 15°	+ 35°	- 24°

Analyzing Capacitive Exciting Current Measurements

- If a capacitive Exciting Current measurement produces an unusual phase-pattern, then typically, the Exciting Current (mA) values will not be analyzed
- If a capacitive Exciting Current measurement produces an unusual phase-pattern, then the analysis should focus on the **Watt Losses (W)** values
  - The measured **Watt Losses (W)** values are not influenced by either the inductive or capacitive current - Only the resistive current component
  - The measured **Watt Losses (W)** values should produce the expected phase-pattern, regardless of whether the measurement is inductive or capacitive
  - **If the Exciting Current measurement is capacitive and the measured Watt Losses produce the expected phase-pattern, AND all other electrical tests are acceptable, AND there is no reason to suspect that there is a problem with the transformer, then the Exciting Current Test results should be "passed"**

Example - Capacitive Exciting Current Measurement

	Phase A					Phase B					Phase C				
Tap	V out	I out @10 kV	I phase	Watt losses @10 kV	Reactance	V out	I out @10 kV	I phase	Watt losses @10 kV	Reactance	V out	I out @10 kV	I phase	Watt losses @10 kV	Reactance
4	10.00 kV	9.049 mA	32.04 °	76.709 W	-586.200 kΩ	10.00 kV	8.259 mA	55.68 °	46.571 W	-999.961 kΩ	10.00 kV	8.262 mA	27.50 °	73.288 W	-558.803 kΩ



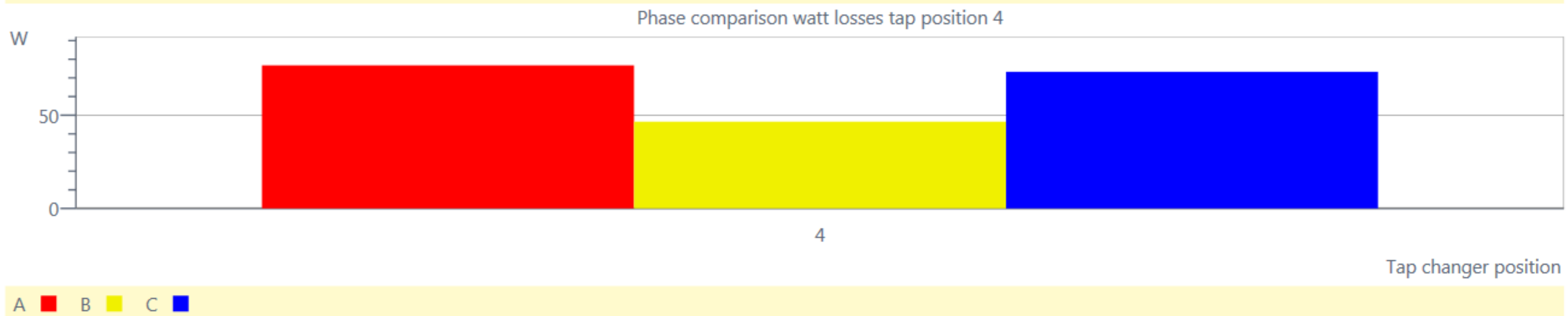
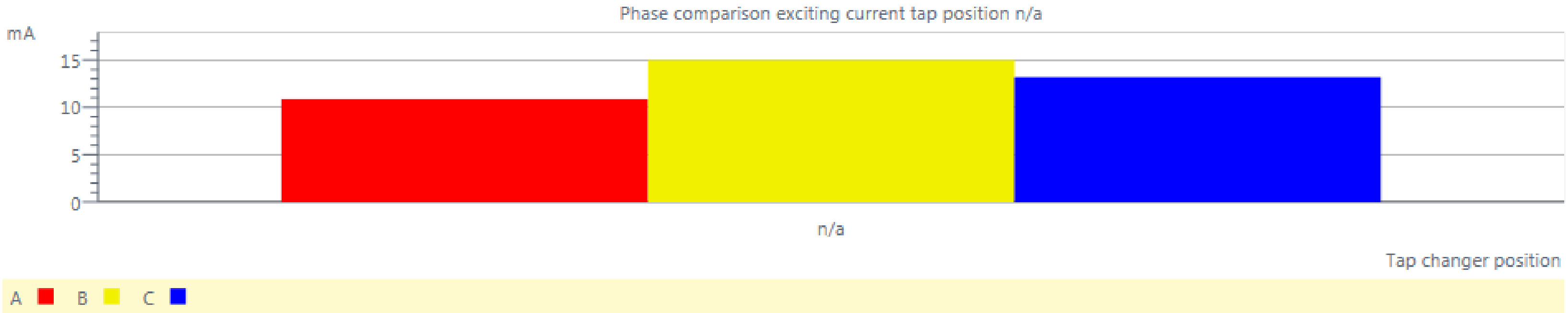
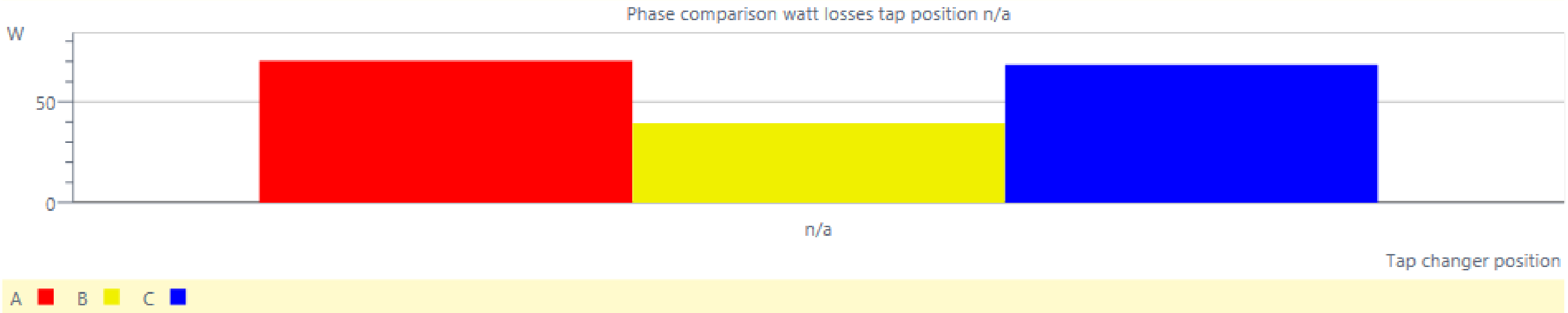


ABB Two-Winding Transformer – 1993 – Dyn1
69kV-12.47kV, 7.5MVA

Example - Capacitive Exciting Current Measurement

Phase A					Phase B					Phase C				
V out	I out	I phase	Watt losses	Reactance	V out	I out	I phase	Watt losses	Reactance	V out	I out	I phase	Watt losses	Reactance
10.00 kV	10.866 mA	49.59 °	70.439 W	-700.753 kΩ	10.00 kV	14.978 mA	74.75 °	39.399 W	-644.138 kΩ	10.00 kV	13.182 mA	58.69 °	68.494 W	-648.152 kΩ

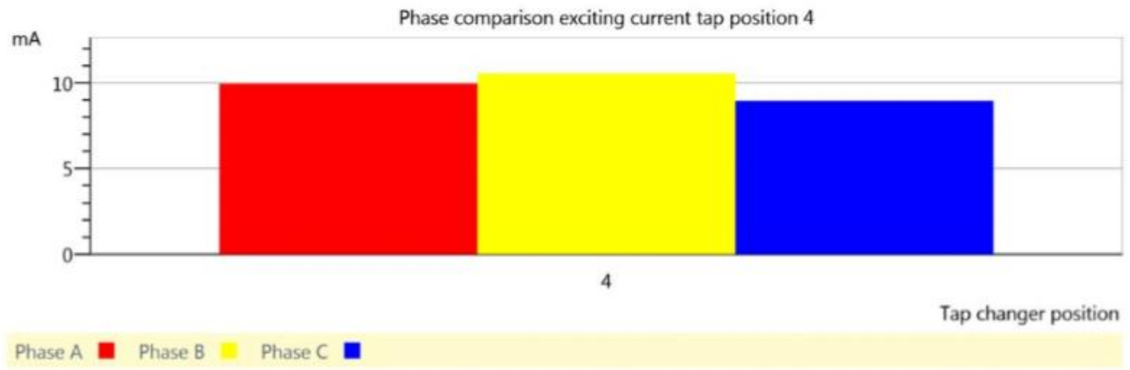




GE Two-Winding Transformer – Dyn1
67kV-24.9kV, 10MVA

Example - Capacitive Exciting Current Measurement

	Phase A			Phase B			Phase C		
Tap	I out	Watt losses	Reactance	I out	Watt losses	Reactance	I out	Watt losses	Reactance
4	9.944 mA	83.376 W	-547.992 kΩ	10.549 mA	43.362 W	-864.017 kΩ	8.960 mA	84.178 W	-382.100 kΩ



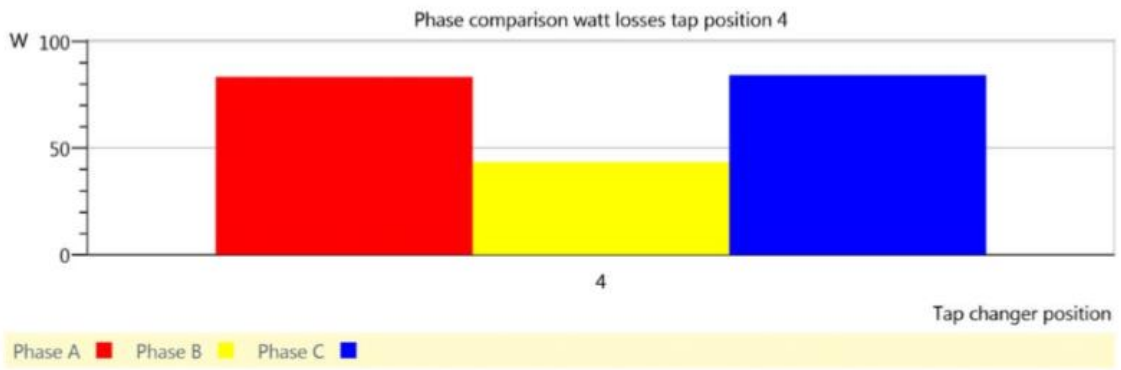


ABB South Boston, Two-Winding Transformer – Dyn1, 69kV-12.470kV, 7.5MVA

Example - Capacitive Exciting Current Measurement

Phase A

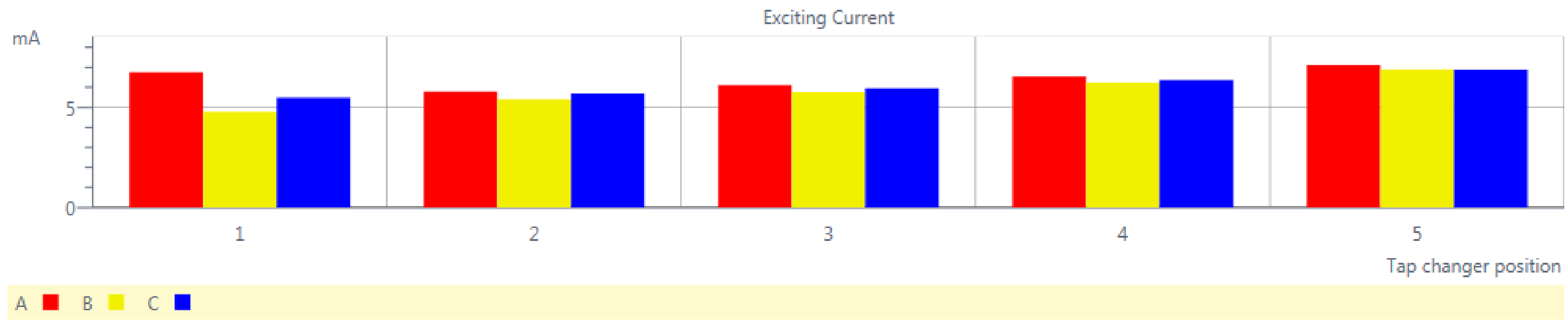
Tap	V out	I out @10 kV	I phase	Watt losses @10 kV	Reactance
1	10.01 kV	6.755 mA	8.32 °	66.844 W	-214.174 kΩ
2	10.00 kV	5.793 mA	31.72 °	49.280 W	-907.544 kΩ
3	10.00 kV	6.109 mA	32.08 °	51.761 W	-869.474 kΩ
4	10.00 kV	6.549 mA	34.21 °	54.159 W	-858.485 kΩ
5	10.00 kV	7.125 mA	36.30 °	57.428 W	-830.741 kΩ

Phase B

Tap	V out	I out @10 kV	I phase	Watt losses @10 kV	Reactance
1	10.00 kV	4.792 mA	61.24 °	23.054 W	-1829.429 kΩ
2	10.00 kV	5.416 mA	57.91 °	28.775 W	-1564.285 kΩ
3	10.00 kV	5.763 mA	58.69 °	29.947 W	-1482.446 kΩ
4	10.00 kV	6.250 mA	58.88 °	32.303 W	-1369.682 kΩ
5	10.00 kV	6.890 mA	59.84 °	34.615 W	-1254.927 kΩ

Phase C

Tap	V out	I out @10 kV	I phase	Watt losses @10 kV	Reactance
1	10.00 kV	5.491 mA	25.03 °	49.753 W	-770.570 kΩ
2	10.00 kV	5.692 mA	25.06 °	51.559 W	-744.199 kΩ
3	10.00 kV	5.959 mA	27.64 °	52.789 W	-778.509 kΩ
4	10.00 kV	6.370 mA	29.20 °	55.606 W	-765.819 kΩ
5	10.00 kV	6.887 mA	32.30 °	58.213 W	-775.867 kΩ



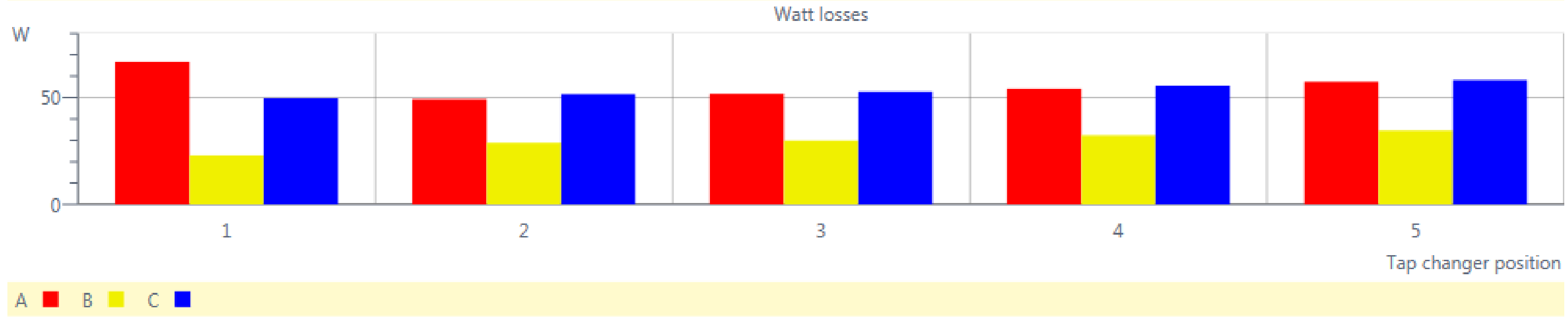


ABB Two-Winding Transformer – 2016 – Dyn1, 34.5kV-0.380kV, 0.1MVA

Thank you!