The DC Winding Resistance 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.

Transformer Testing Support Contacts

Brandon Dupuis
Regional Application Specialist - Transformers

OMICRON electronics Corp. USA
60 Hickory Drive
Waltham MA 02451 | USA
T +1 800 OMICRON
T +1 781 672 6230
brandon.dupuis@omicronenergy.com
www.omicronenergy.com

Fabiana Cirino
Application Engineer

OMICRON electronics Corp. USA
3550 Willowbend Blvd.
Houston, TX 77054 | USA
T +1 800 OMICRON
T +1 713 212 6154
fabiana.cirino@omicronenergy.com
www.omicronenergy.com

Moritz Pikisch
Application Engineer

OMICRON electronics Corp. USA
Sacramento, CA 95816 | USA
T +1 800 OMICRON
T +1 713 212 6150
Call me via SIP | Web
moritz.pikisch@omicronenergy.com
www.omicronenergy.com

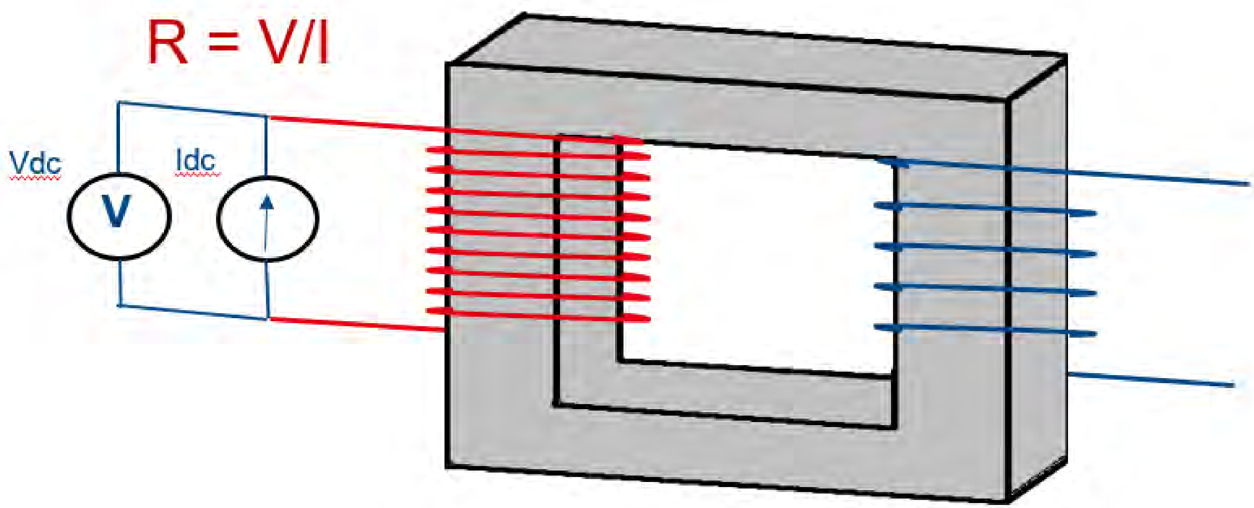
Charles Sweetser
PRIM Engineering Services Manager

OMICRON electronics Corp. USA
60 Hickory Drive
Waltham MA 02451 | UNITED STATES
T +1 800 OMICRON
T +1 781 672 6214
charles.sweetser@omicronenergy.com
www.omicronusa.com

The DC Winding Resistance Test

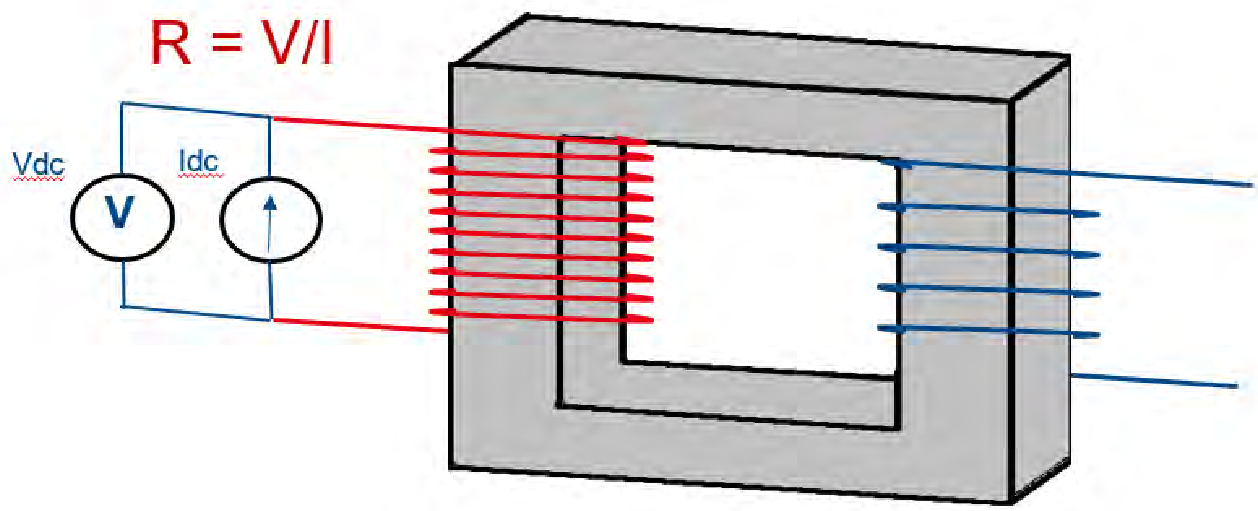
DC Winding Resistance Test Overview

- Inject **DC current** into a transformer winding
- Measure the **DC voltage** drop across the same transformer winding
- Wait for the **calculated resistance** (R = V / I) to stabilize or “bottom out”, which ensures that the core has been saturated



DC Winding Resistance Test Overview

- Conceptually, the DC Winding Resistance test is one of the easiest measurements - Simply apply ohm's law
- **In practice, the DC Winding Resistance test is one of the most difficult measurements to complete *quickly* and *accurately***



The DC Winding Resistance Test is a “Continuity Check”

- The DC Winding Resistance test is used to identify discontinuities, “bad” connections, and open-circuits involving the following transformer components,
  - ❑ Windings
  - ❑ Bushings and Bushing Connections
  - ❑ Tap-Changer Components (e.g. barrier board connections, stationary contacts, tap selectors, the diverter switch, and the reversing switch)
  - ❑ Lead Terminations (bolted joints, crimps, brazes)

The DC Winding Resistance Test - Core Saturation

- **The transformer core must be saturated before the resistance measurement is recorded**
- Incomplete core saturation may result in an incorrect measurement (and possibly a “false positive”)
- Saturation time is dependent on,
  - ❑ **Voltage** applied across the winding during the test – In general, the higher the applied voltage, the faster the core will saturate
  - ❑ **Current** injected into the winding during the test - In general, the higher the test current, the faster the core will saturate
  - ❑ **Resistance** of the winding under test – In general, the lower the resistance of the winding, the longer it may take to saturate the core

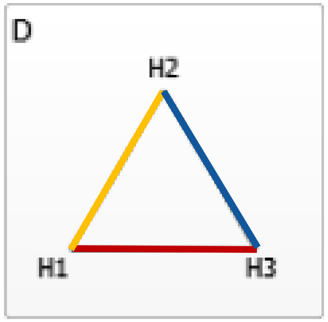
The DC Winding Resistance Test - Core Saturation

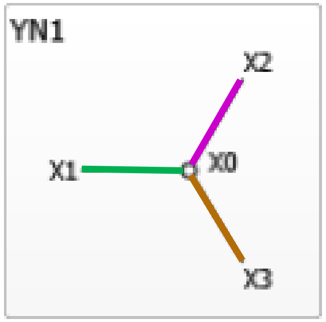
- **In most cases, the DC Winding Resistance test should be performed last, unless you have a reliable tool that quickly demagnetizes the transformer core**
- **When the DC Winding Resistance test is complete, the transformer core will still remain magnetized to some extent (which is often referred to as residual magnetism)**
- **Residual magnetism** may contaminate other transformer diagnostic test results (e.g. the Exciting Current, SFRA, and Turns-Ratio test results)
- **Residual magnetism** may result in a relatively large in-rush current when the transformer is re-energized
- Therefore, it is a good testing practice to demagnetize the transformer core immediately after the DC Winding Resistance test has been performed

The DC Winding Resistance Test – Test Current

- **In general, the lower the resistance of the winding under test, the higher the test current should be**
- The following are **general guidelines** for selecting the appropriate test current...
  - ❑ For Resistances > 100mΩ, 10A or less is typically sufficient
  - ❑ For Resistances < 100mΩ, 20-50A is often preferred
- **The test current should not exceed 10% of the rated current of the winding under test**
- Using a test current that is less than 10% of the rated current of the winding under test helps avoid heating the winding while the test is being performed – Heating the winding will cause the resistance to change, which may result in an unstable measurement
- The test current should also be low enough so that the compliance voltage of the current source is not exceeded

DC Winding Resistance Test – Dyn1 Test Connections





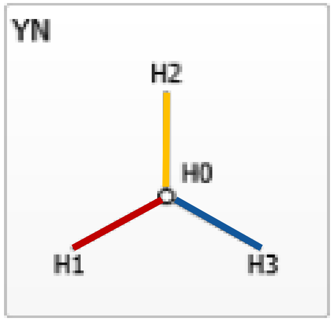
Primary Winding Tests

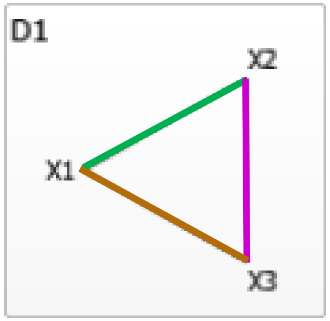
Test	Phase	Inject (I)	Measure (V)
1	A	H1-H3	H1-H3
2	B	H2-H1	H2-H1
3	C	H3-H2	H3-H2

Secondary Winding Tests

Test	Phase	Inject (I)	Measure (V)
4	A	X1-X0	X1-X0
5	B	X2-X0	X2-X0
6	C	X3-X0	X3-X0

DC Winding Resistance Test – Ynd1 Test Connections





Primary Winding Tests

Test	Phase	Input (I)	Measure (V)
1	A	H1-H0	H1-H0
2	B	H2-H0	H2-H0
3	C	H3-H0	H3-H0

Secondary Winding Tests

Test	Phase	Input (I)	Measure (V)
4	A	X1-X2	X1-X2
5	B	X2-X3	X2-X3
6	C	X3-X1	X3-X1

DC Winding Resistance Test – Analysis Strategies

1) **Compare the measured resistance amongst the three phases - Temperature correction will probably not be necessary**

   - **In general, if the measured resistance is reasonably similar amongst the three phases (e.g. within 2-3% when comparing the phases), then the DC Winding Resistance Test is "passed"**

   - **Note, when the measured resistance is relatively low (e.g. below 50mΩ), then a deviation of more than 2-3% is often allowed, since a deviation of 2-3% in this range is often insignificant**

2) Compare the measured resistance to the factory test results - Temperature correction may be necessary to compare the field results to the factory results

3) Compare the measured resistance to previous field results - Temperature correction may be necessary to compare the field results to previous field results

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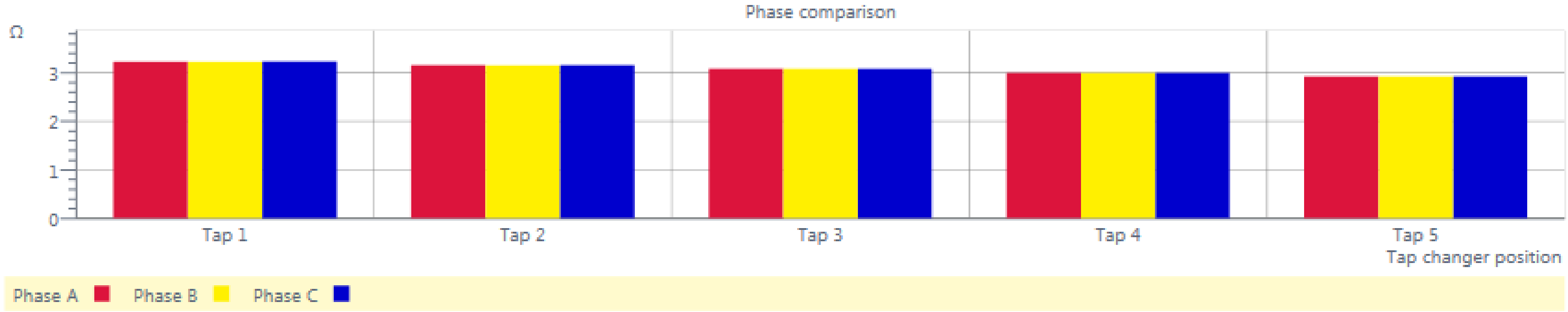
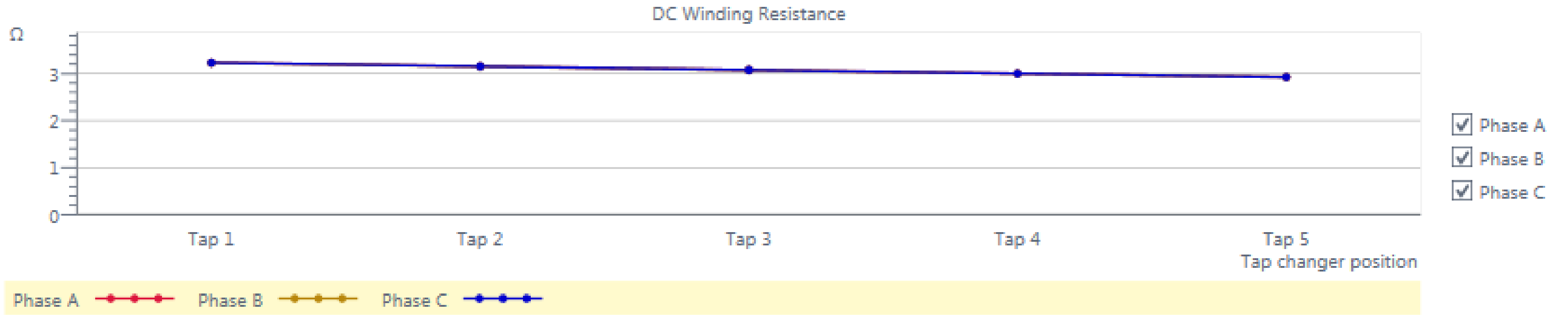
DC Winding Resistance Test Examples and Case Studies

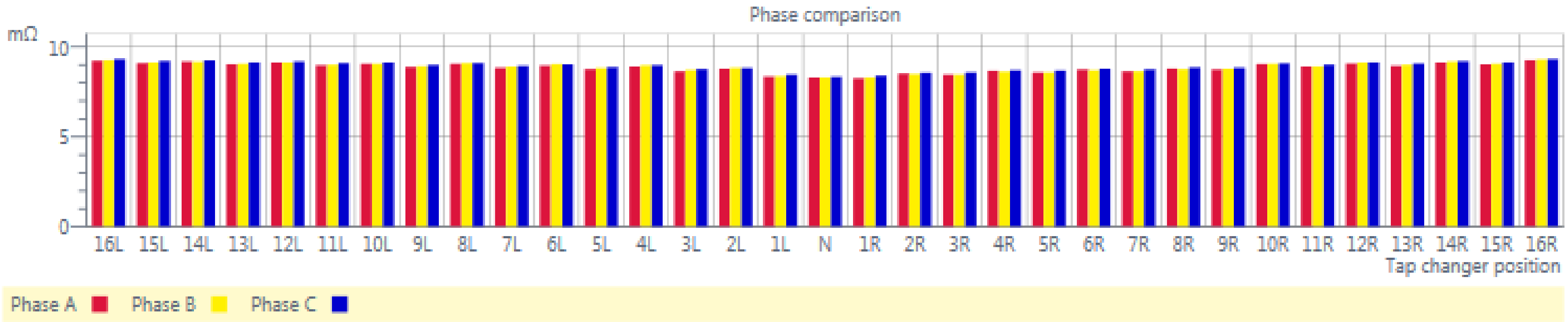
Acceptable DC Winding Resistance Test Results

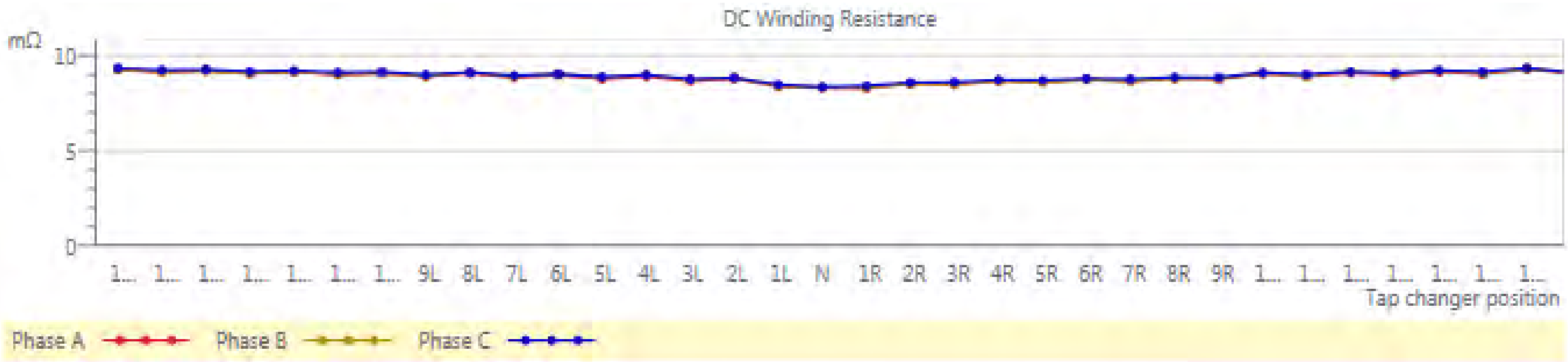
	Phase A						Phase B						Phase C					
Tap	I DC	V DC	Time	R meas	R dev	R corr	I DC	V DC	Time	R meas	R dev	R corr	I DC	V DC	Time	R meas	R dev	R corr
Tap 1	3.06 A	9.90 V	s	3.230 Ω	0.068 %	3.230 Ω	3.07 A	9.90 V	s	3.227 Ω	0.037 %	3.227 Ω	3.07 A	9.92 V	s	3.230 Ω	0.053 %	3.230 Ω
Tap 2	3.07 A	9.69 V	s	3.156 Ω	0.052 %	3.156 Ω	3.07 A	9.68 V	s	3.153 Ω	0.093 %	3.153 Ω	3.07 A	9.68 V	s	3.155 Ω	0.098 %	3.155 Ω
Tap 3	3.07 A	9.46 V	s	3.081 Ω	0.093 %	3.081 Ω	3.07 A	9.46 V	s	3.079 Ω	0.080 %	3.079 Ω	3.07 A	9.45 V	s	3.081 Ω	0.094 %	3.081 Ω
Tap 4	3.07 A	9.23 V	s	3.007 Ω	0.096 %	3.007 Ω	3.07 A	9.23 V	s	3.005 Ω	0.085 %	3.005 Ω	3.07 A	9.23 V	s	3.006 Ω	0.095 %	3.006 Ω
Tap 5	3.08 A	9.01 V	s	2.930 Ω	0.080 %	2.930 Ω	3.07 A	9.01 V	s	2.930 Ω	0.058 %	2.930 Ω	3.08 A	9.01 V	s	2.930 Ω	0.099 %	2.930 Ω





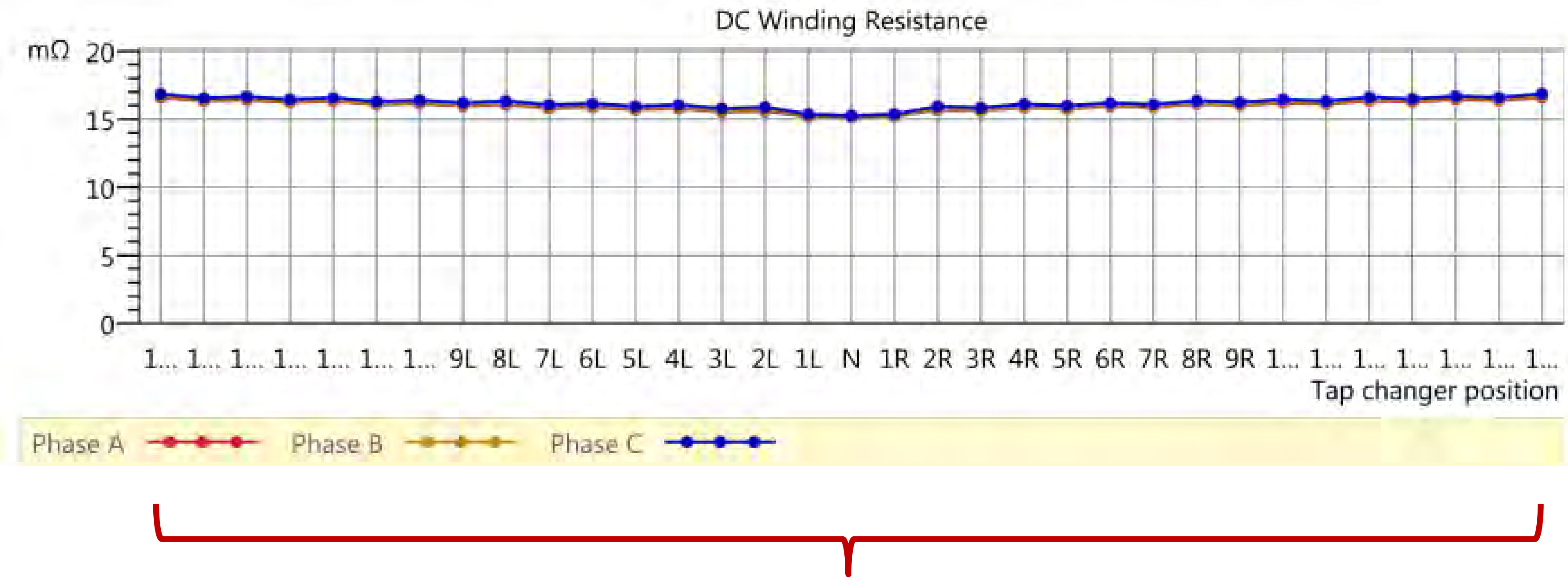
Acceptable DC Winding Resistance Test Results





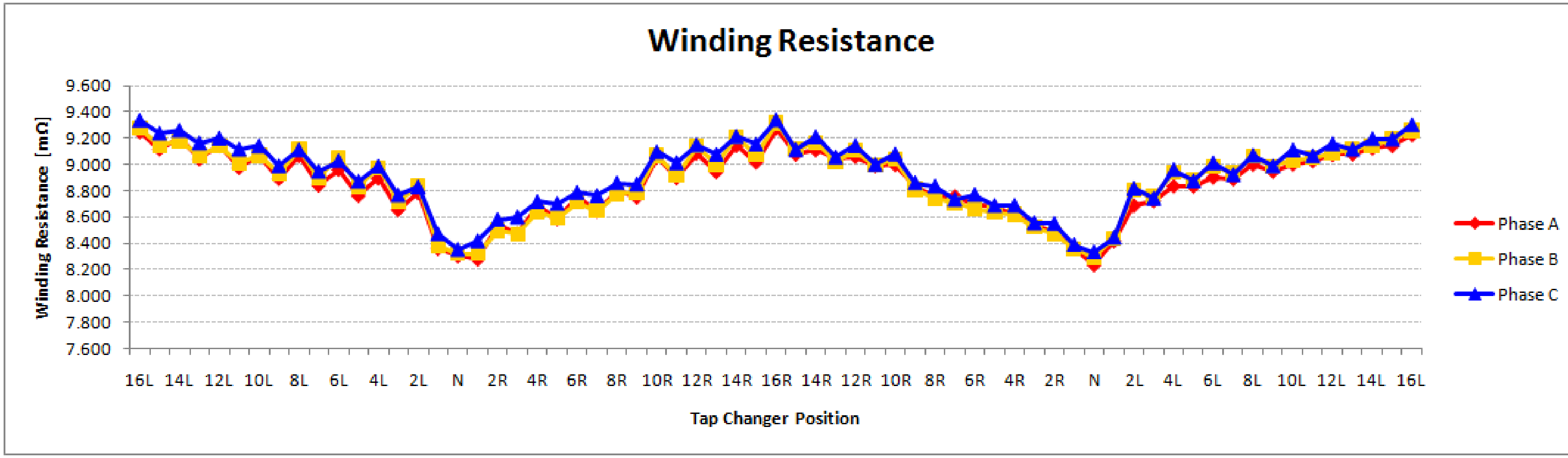
16R…N…16L

Acceptable DC Winding Resistance Test Results



16R...N...16L

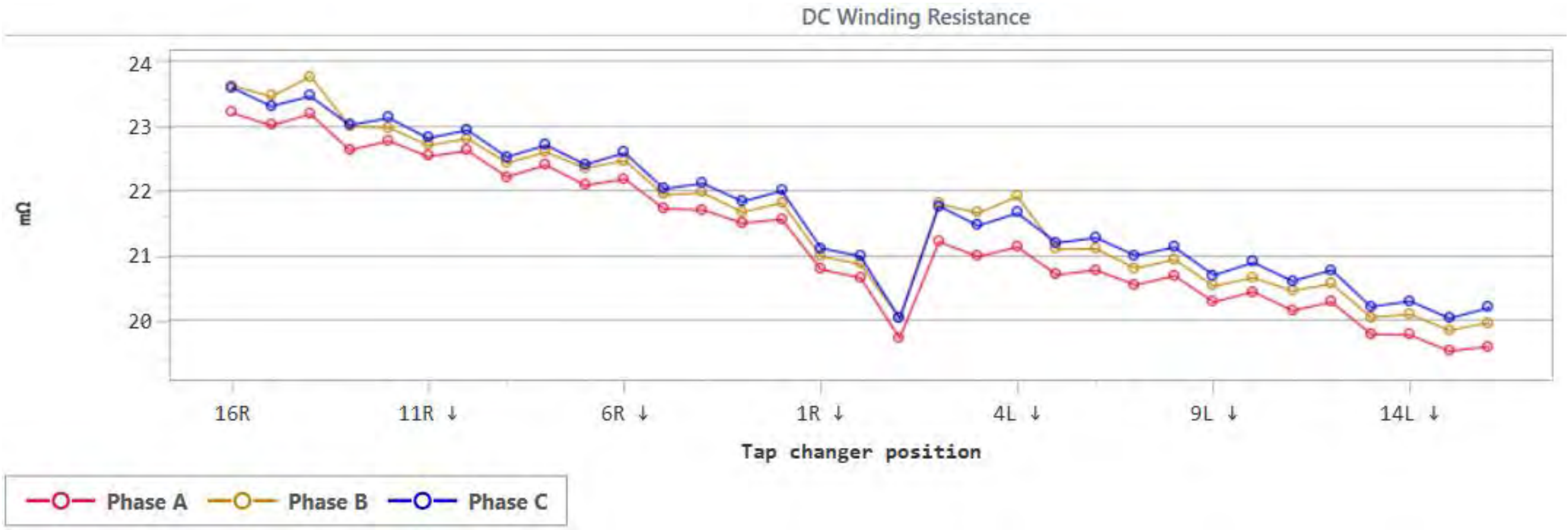
Acceptable DC Winding Resistance Test Results



16L…N…16R

16R…N…16L

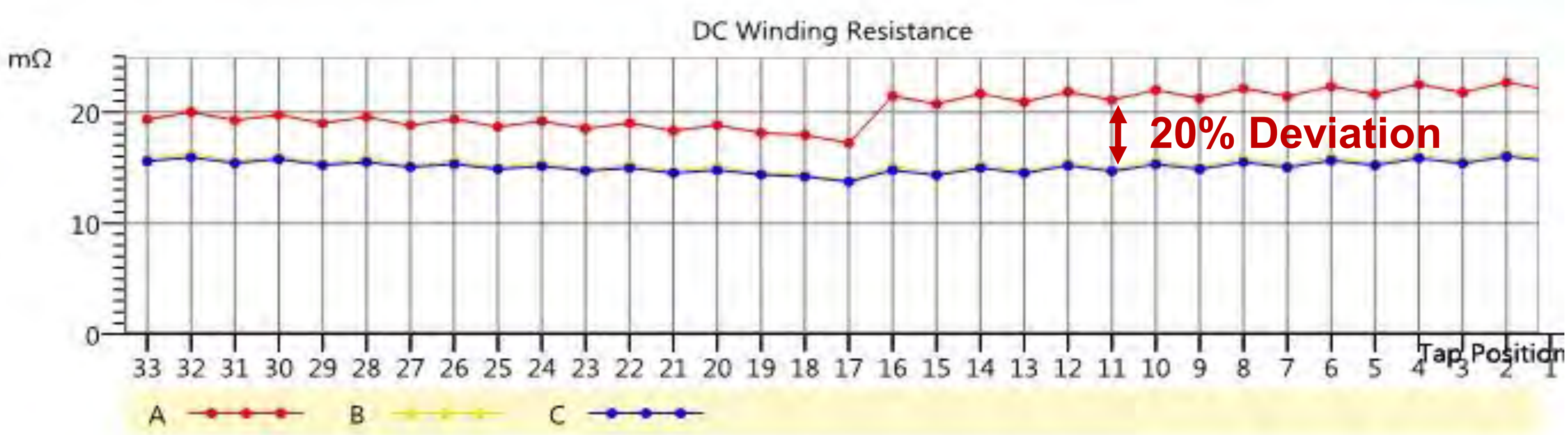
Acceptable DC Winding Resistance Test Results



16R…N…16L

DC Winding Resistance Test – Case Study #1

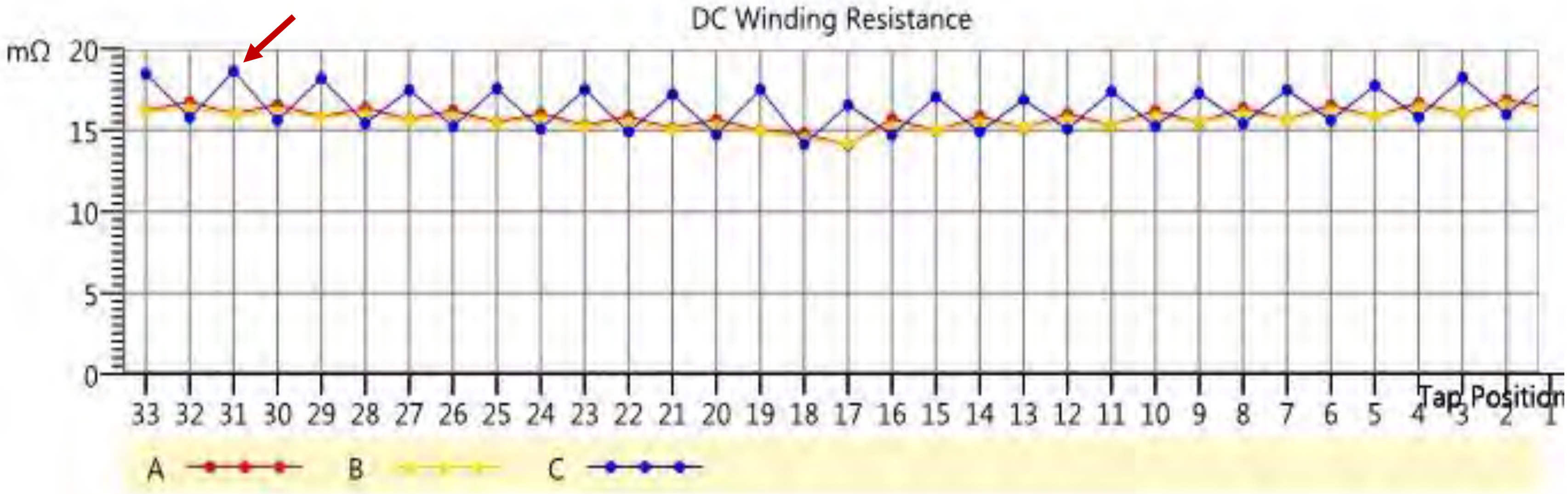
- Two-Winding Transformer
- 134kV-13.8kV
- Ferranti-Packard LTC (33 positions) – Resistive-type LTC
- To investigate further, resistance measurements were performed on the internal components of the LTC, and a high-resistive path was identified on Phase-A



DC Winding Resistance Test – Case Study #2

- Two-Winding Transformer
- 134kV-13.8kV
- Ferranti-Packard LTC (33 positions) – Resistive-type LTC

Phase-C is 12% higher than the other two phases for all odd tap-positions



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DC Winding Resistance Test – Case Study #2

- This particular transformer has a resistive-type LTC with two alternating tap selectors
- It is conceivable that there was an issue with one of the two tap selectors (or its associated lead circuit)
- The tap selector (and its associated leads) that is carrying the current when the LTC is in an odd position should be investigated further
- No additional information was provided by the customer

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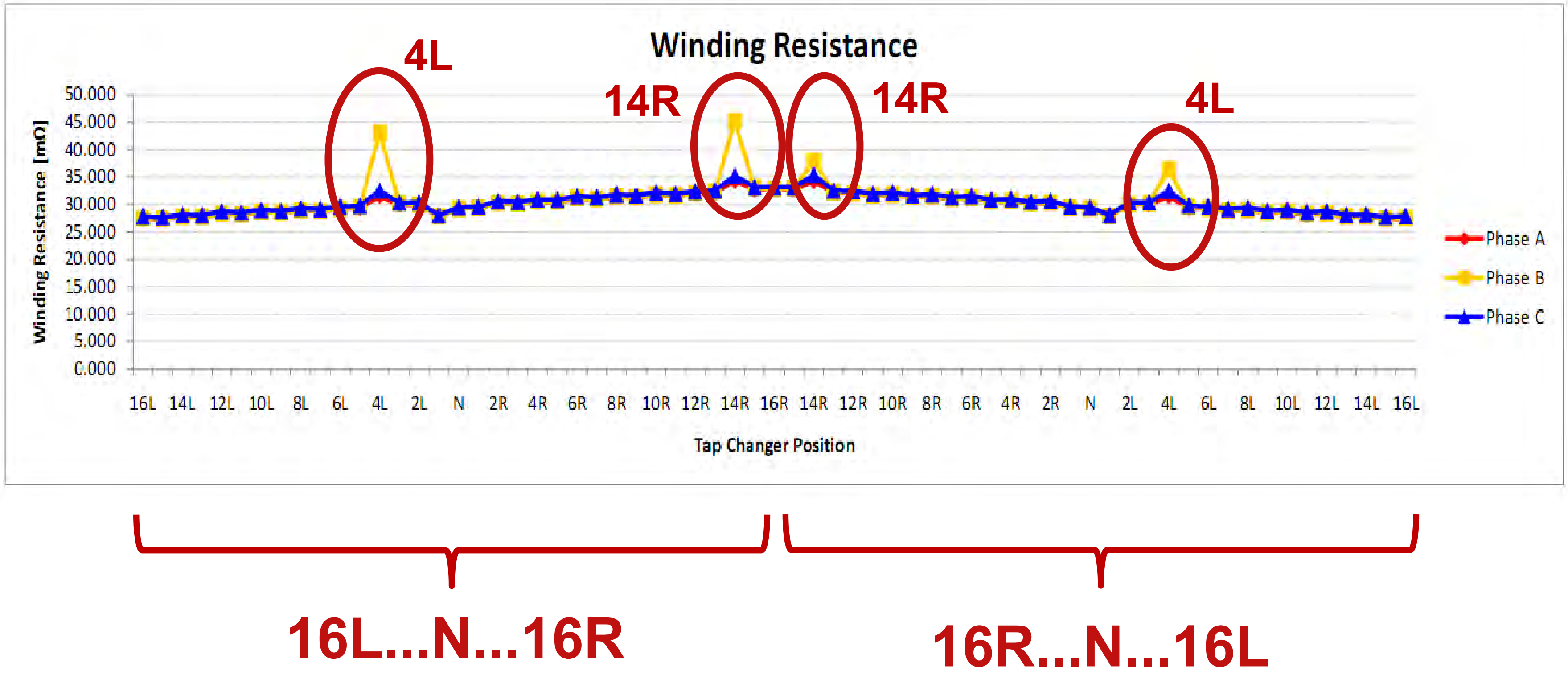
DC Winding Resistance Test – Case Study #3

- Two-Winding Transformer – Dyn1
- LTC with 33 positions (16L-16R) – Reactive-type LTC



DC Winding Resistance Test – Case Study #3

POS	Volts	LTC		
		A	B	9
16R	15180	8	8	M
15R	15095	7	8	
14R	15010	7	7	
13R	14920	6	7	
12R	14835	6	6	
11R	14750	5	6	
10R	14660	5	5	
9R	14575	4	5	
8R	14490	4	4	
7R	14405	3	4	
6R	14320	3	3	
5R	14230	2	3	
4R	14145	2	2	
3R	14060	1	2	
2R	13970	1	1	
1R	13885	0	1	
N	13800	0	0	

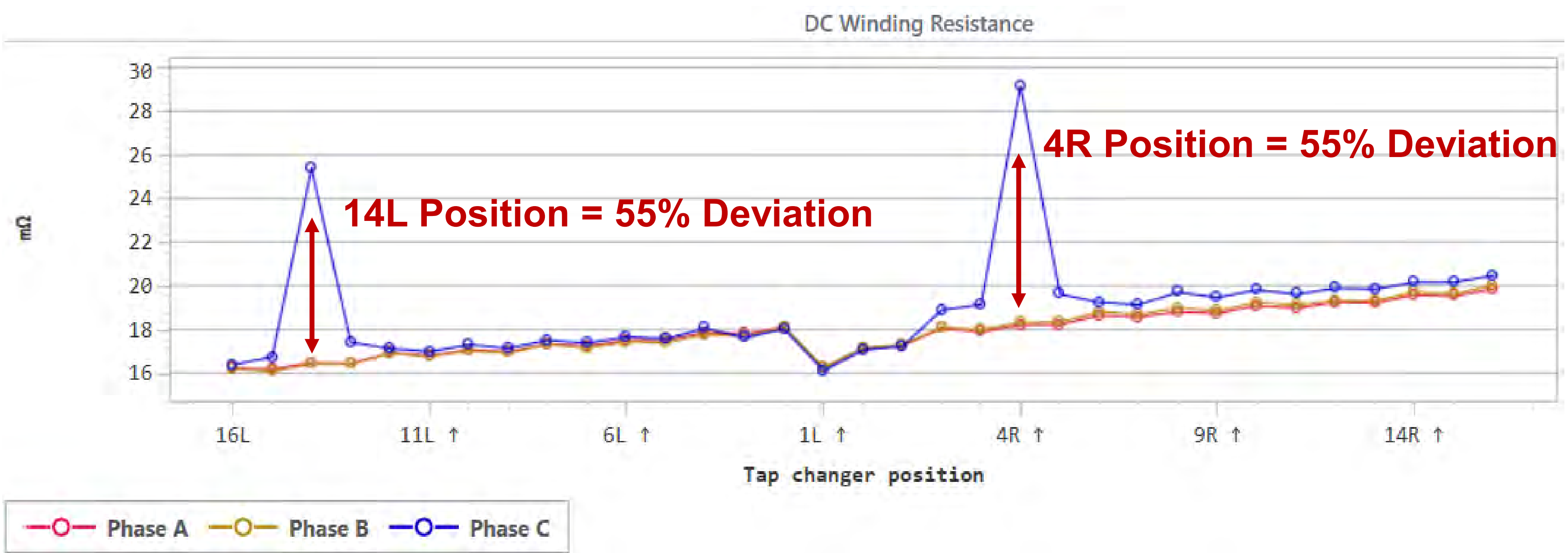
N	13800	0	0	
1L	13715	8	0	K
2L	13360	8	8	
3L	13540	7	8	
4L	13455	7	7	
5L	13370	6	7	
6L	13280	6	6	
7L	13195	5	6	
8L	13110	5	5	
9L	13025	4	5	
10L	12940	4	4	
11L	12850	3	4	
12L	12765	3	3	
13L	12680	2	3	
14L	12590	2	2	
15L	12505	1	2	
16L	12420	1	1	

DC Winding Resistance Test – Case Study #3

- An internal inspection was performed and an over-heated tap-lead (from the regulating winding to the barrier board) was found
- This tap-lead is the only tap-lead carrying the test current when the transformer is in the 4L and 14R positions


DC Winding Resistance Test – Case Study #4

- Two-Winding Transformer – Dyn1
- 69kV - 13.2kV
- 15MVA
- LTC with 33 positions (16L-16R) – Reactive-type LTC



DC Winding Resistance Test – Case Study #4

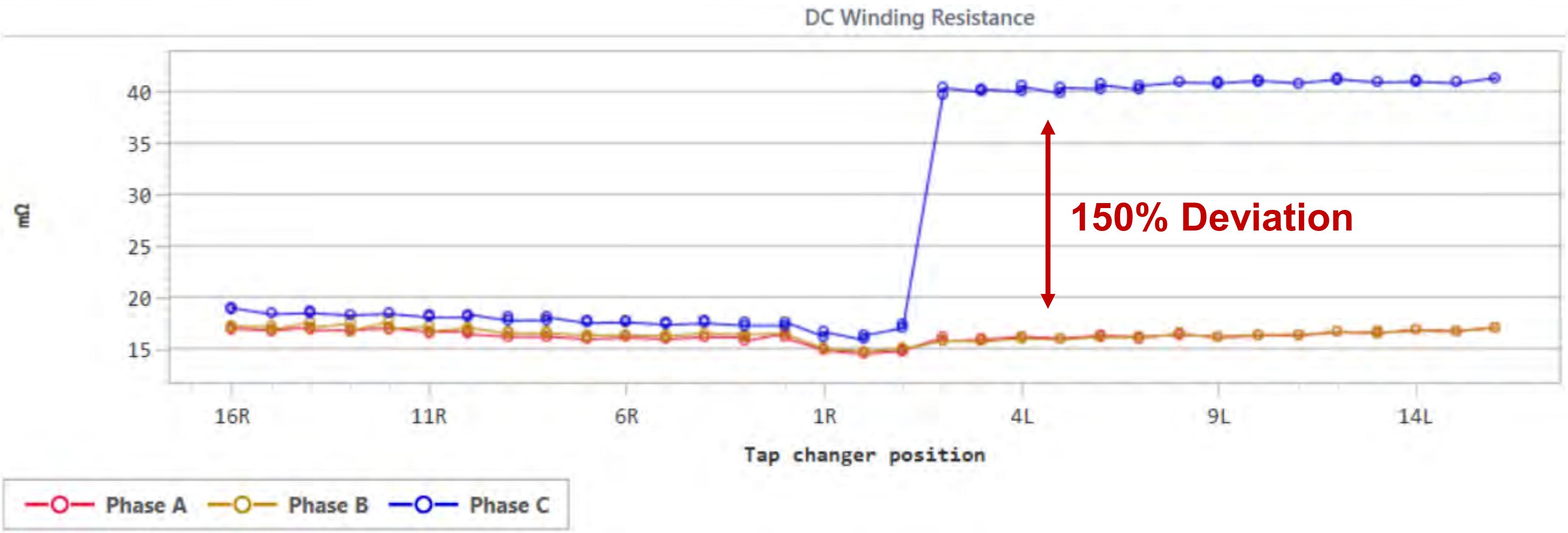
- The #2 stationary contact, its associated connections, and its associated leads should be investigated further to determine the cause of the higher than expected resistance
- No additional information was provided by the customer

POS	Volts	LTC		
		A	B	9
16R	14520	8	8	M
15R	14440	7	8	
14R	14355	7	7	
13R	14270	6	7	
12R	14190	6	6	
11R	14110	5	6	
10R	14025	5	5	
9R	13940	4	5	
8R	13860	4	4	
7R	13780	3	4	
6R	13695	3	3	
5R	13610	2	3	
4R	13530	2	2	
3R	13450	1	2	
2R	13365	1	1	
1R	13280	0	1	
N	13200	0	0	

N	13800	0	0	
1L	13120	8	0	K
2L	13035	8	8	
3L	12950	7	8	
4L	12870	7	7	
5L	12790	6	7	
6L	12705	6	6	
7L	12620	5	6	
8L	12540	5	5	
9L	12460	4	5	
10L	12375	4	4	
11L	12290	3	4	
12L	12210	3	3	
13L	12130	2	3	
14L	12045	2	2	
15L	11960	1	2	
16L	11880	1	1	

DC Winding Resistance Test – Case Study #5

- Two-Winding Transformer, Dyn1
- 43.8kV-12.47kV
- 15MVA
- Siemens-Allis THL-21 LTC (33 positions) – Reactive-type



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DC Winding Resistance Test – Case Study #5

- An investigation test was performed to confirm the higher than normal resistance on Phase-C
- The customer performed a “continuous recording measurement” to monitor the behavior of the resistance as the LTC was operated from position-to-position
- The “continuous recording measurement” procedure was as follows...
  - ❑ Apply DC voltage across the transformer winding - 10VDC was applied
  - ❑ Measure the current flowing through the transformer winding (which is dictated by the resistance of the winding under test)
  - ❑ Operate the LTC continuously from 6R-6L and then from 6L-6R

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DC Winding Resistance Test – Case Study #5

- Expectations for the “continuous recording measurement”
  - The lower the resistance of the winding, the higher the measured current should be
  - The higher the resistance of the winding, the lower the measured current should be
  - When the “higher than normal” resistance is introduced into the test circuit, we expect that the measured current will decrease...

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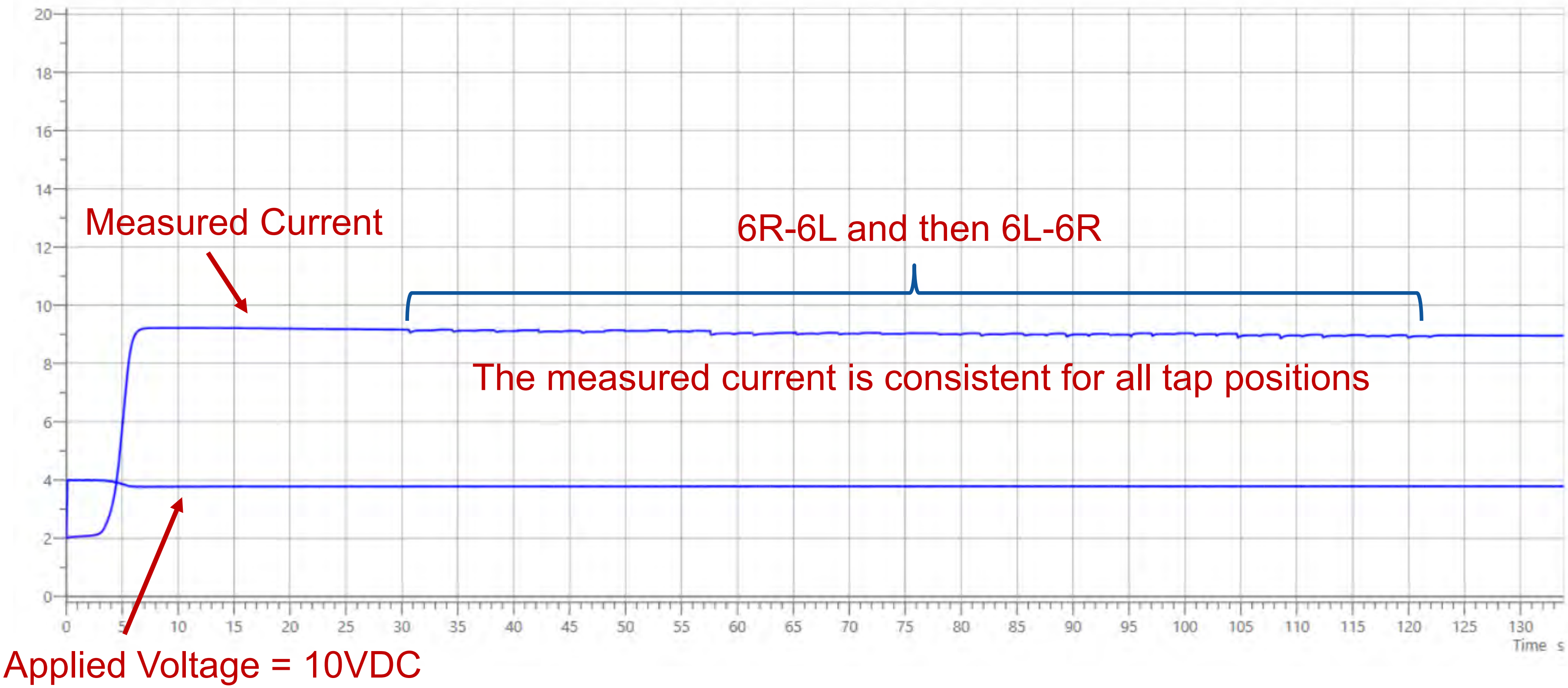
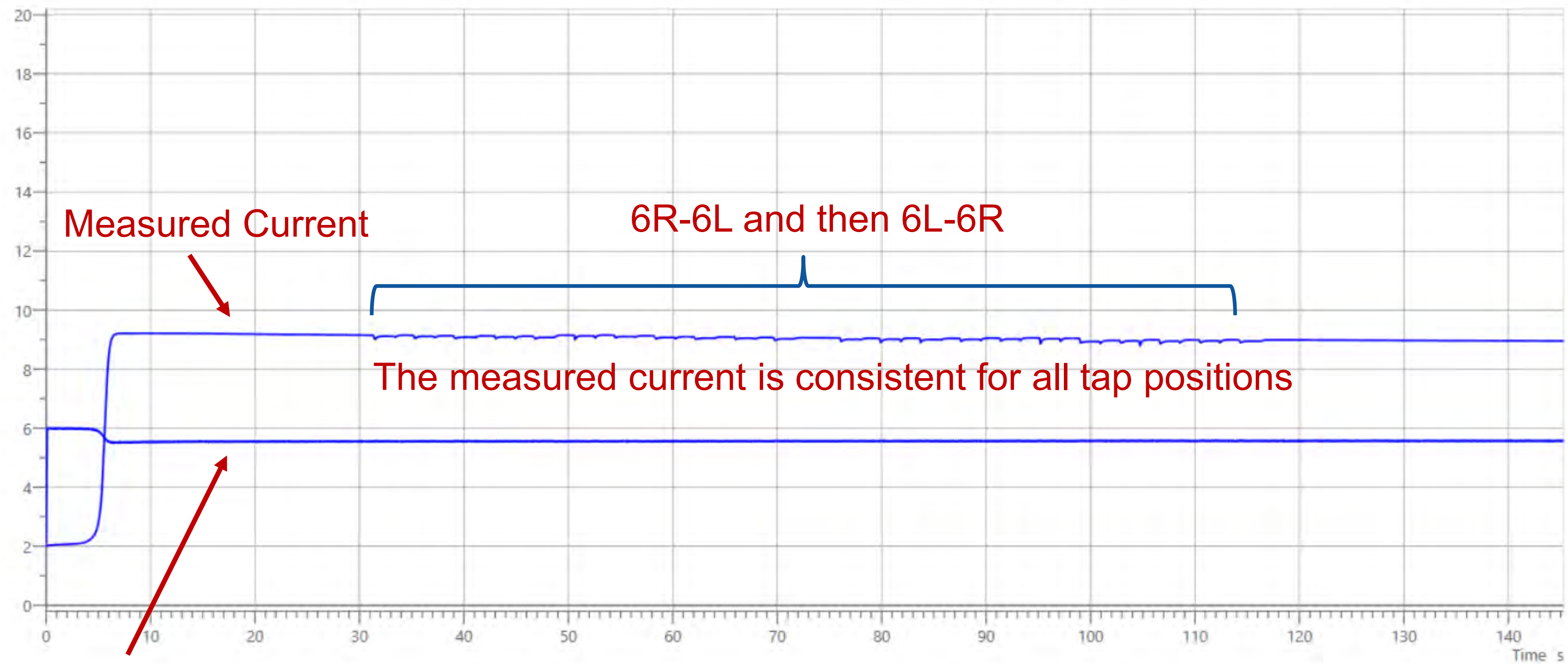
DC Winding Resistance Test – Case Study #5

Phase-A Measurement



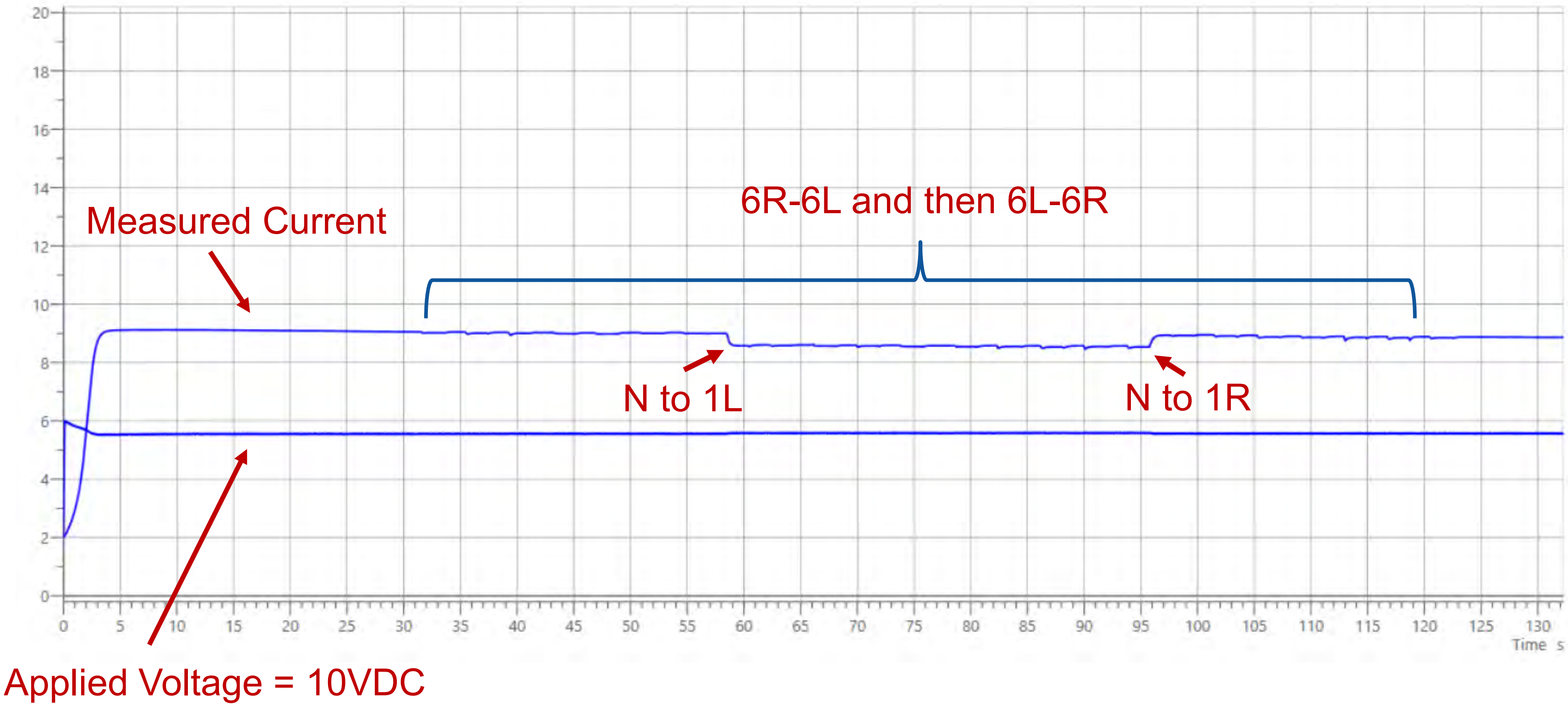
DC Winding Resistance Test – Case Study #5

Phase-B Measurement



DC Winding Resistance Test – Case Study #5

Phase-C Measurement



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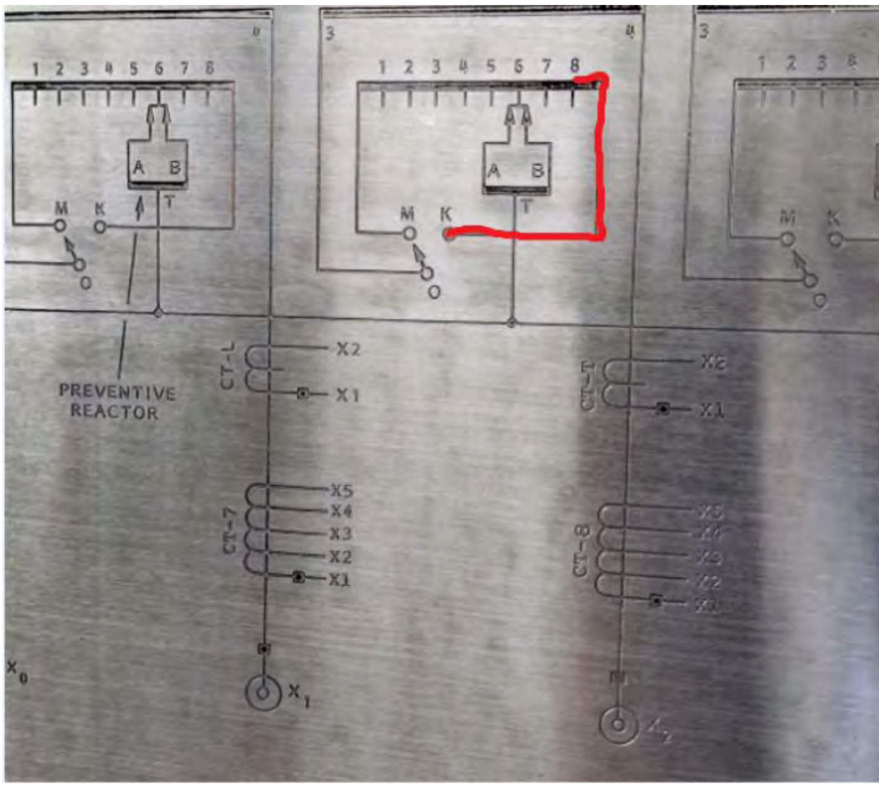
DC Winding Resistance Test – Case Study #5

- The “higher than normal resistance” on Phase-C appears when the circuit from K-to-8 is introduced into the test circuit



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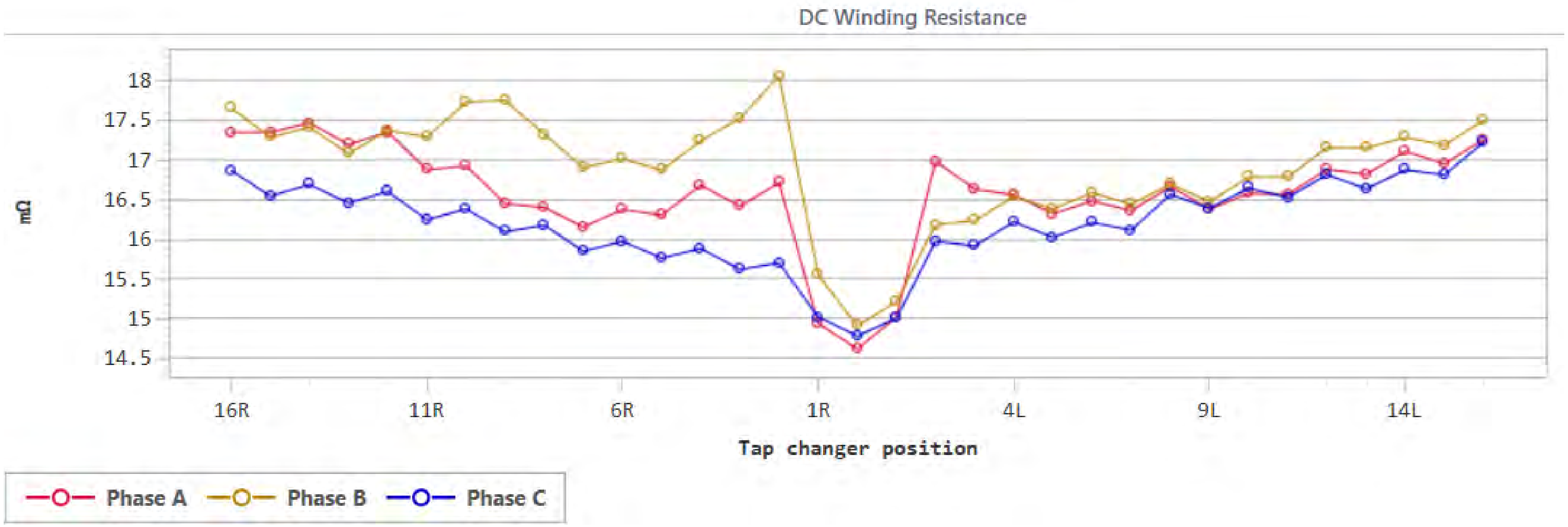
DC Winding Resistance Test – Case Study #5

- The plot below shows the “test results after tightening connections on “K” lead in LTC compartment”
- The Phase-C measurements were “normal” after making adjustments to the “K” lead



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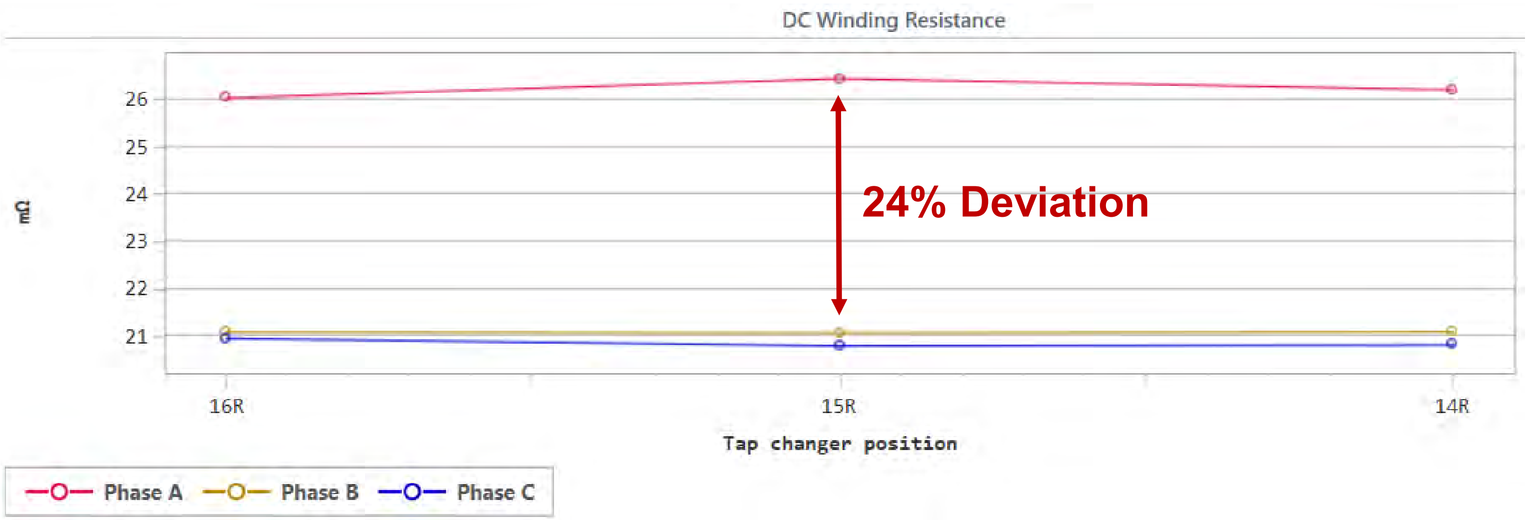
DC Winding Resistance Test – Case Study #6

- Two-Winding Transformer, Dyn1
- 66kV-13.8kV, 25MVA
- LTC with 33 positions (16L-16R) – Reactive-type LTC



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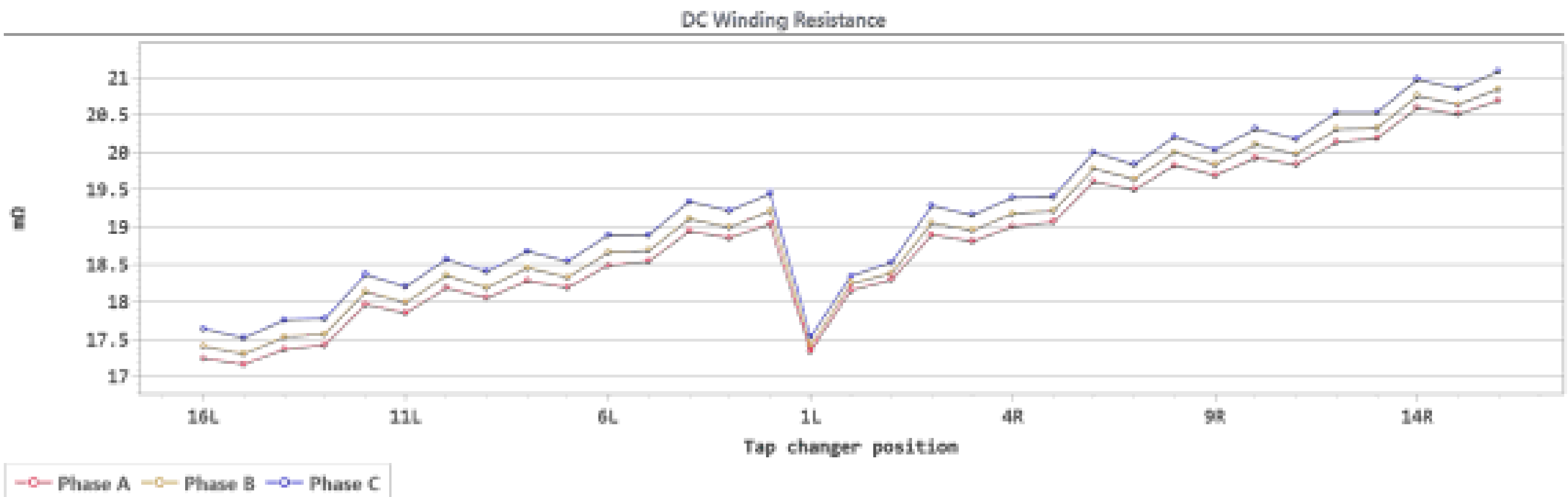
DC Winding Resistance Test – Case Study #6

- The higher than normal resistance measurements “led to our changing out the LTC contacts. The following results were taken following our LTC work”
- After replacing the LTC contacts, the Phase-A measurements were normal

Graphs for standard test



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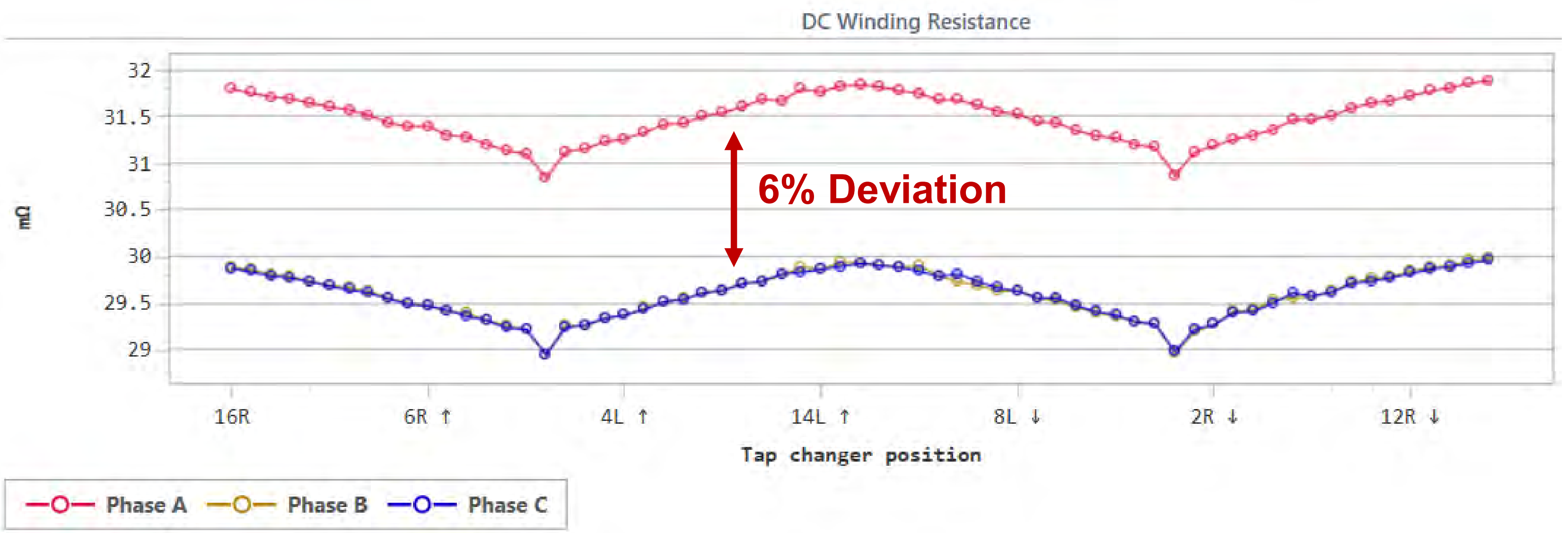
DC Winding Resistance Test – Case Study #7

- Two-Winding Transformer, Dyn1
- 70kV-12.47kV, 10MVA
- ABB UZERT (33 positions) – Resistive-type

2014 Measurement



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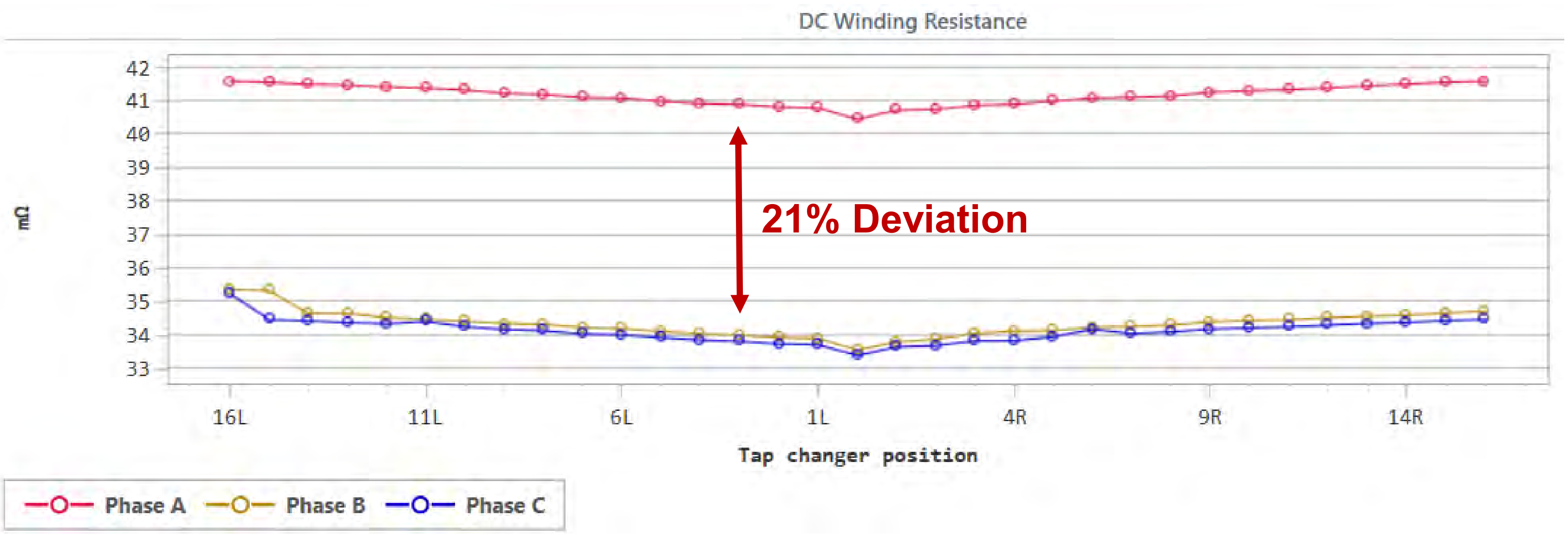
DC Winding Resistance Test – Case Study #7

- Two-Winding Transformer, Dyn1
- 70kV-12.47kV, 10MVA
- ABB UZERT (33 positions) – Resistive-type
- No additional information was received from the customer

2017 Measurement



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DC Winding Resistance Test – Case Study #8

- Two-Winding Transformer, Dyn1
- 69kV-12.47kV, 7.5MVA
- The secondary side has a dual position switch that can place the low-voltage windings in series or in parallel
- In the series winding configuration, the Phase-A measurement is approximately 21% higher than the other two phases
- In the parallel winding configuration, the Phase-A measurement is approximately 17% higher than the other two phases
- No additional information was received from the customer

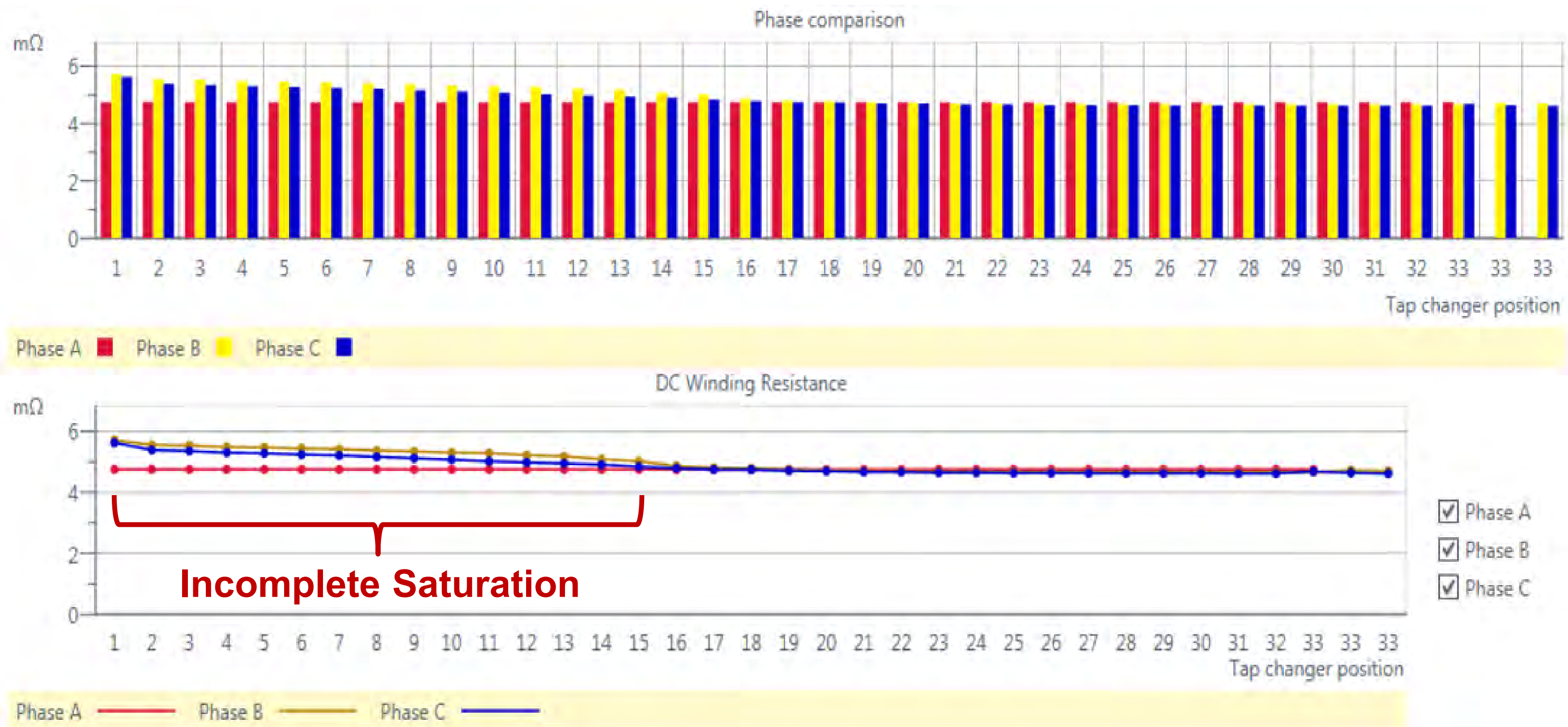
		Phase-A		Phase-B		Phase-C	
SER	LV	161.520	mΩ	132.570	mΩ	137.650	mΩ
PAR	----	39.208	mΩ	33.422	mΩ	34.442	mΩ

DC Winding Resistance Test
Examples of Incomplete Core Saturation

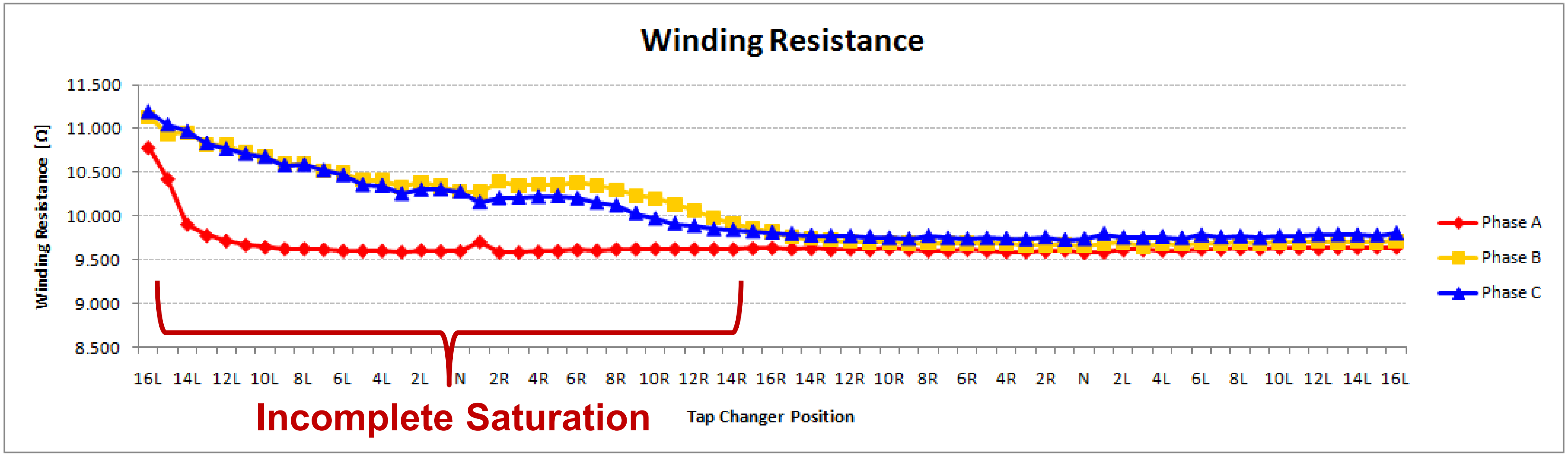
The DC Winding Resistance Test - Core Saturation

- **The transformer core must be saturated before the resistance measurement is recorded**
- Incomplete core saturation may result in an incorrect measurement (and possibly a “false positive”)
- Saturation time is dependent on,
  - ❑ **Voltage** applied across the winding during the test – In general, the higher the applied voltage, the faster the core will saturate
  - ❑ **Current** injected into the winding during the test - In general, the higher the test current, the faster the core will saturate
  - ❑ **Resistance** of the winding under test – In general, the lower the resistance of the winding, the longer it may take to saturate the core

Incomplete Core Saturation Example #1

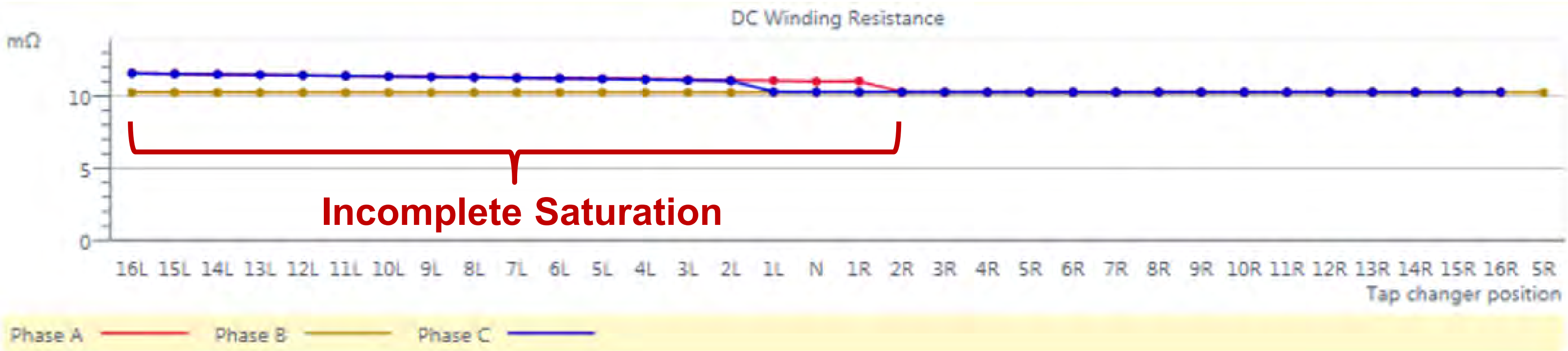


Incomplete Core Saturation Example #2

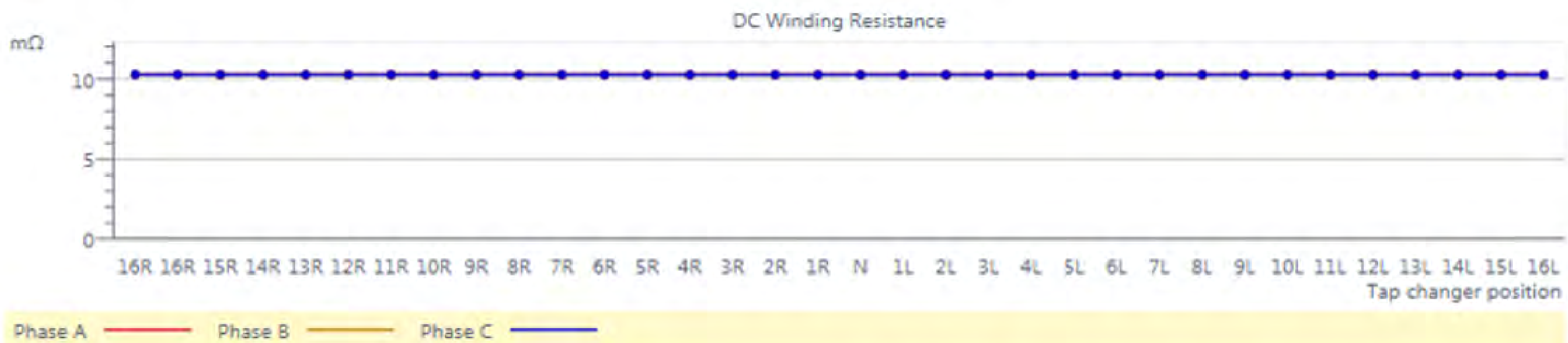


Incomplete Core Saturation Example #3

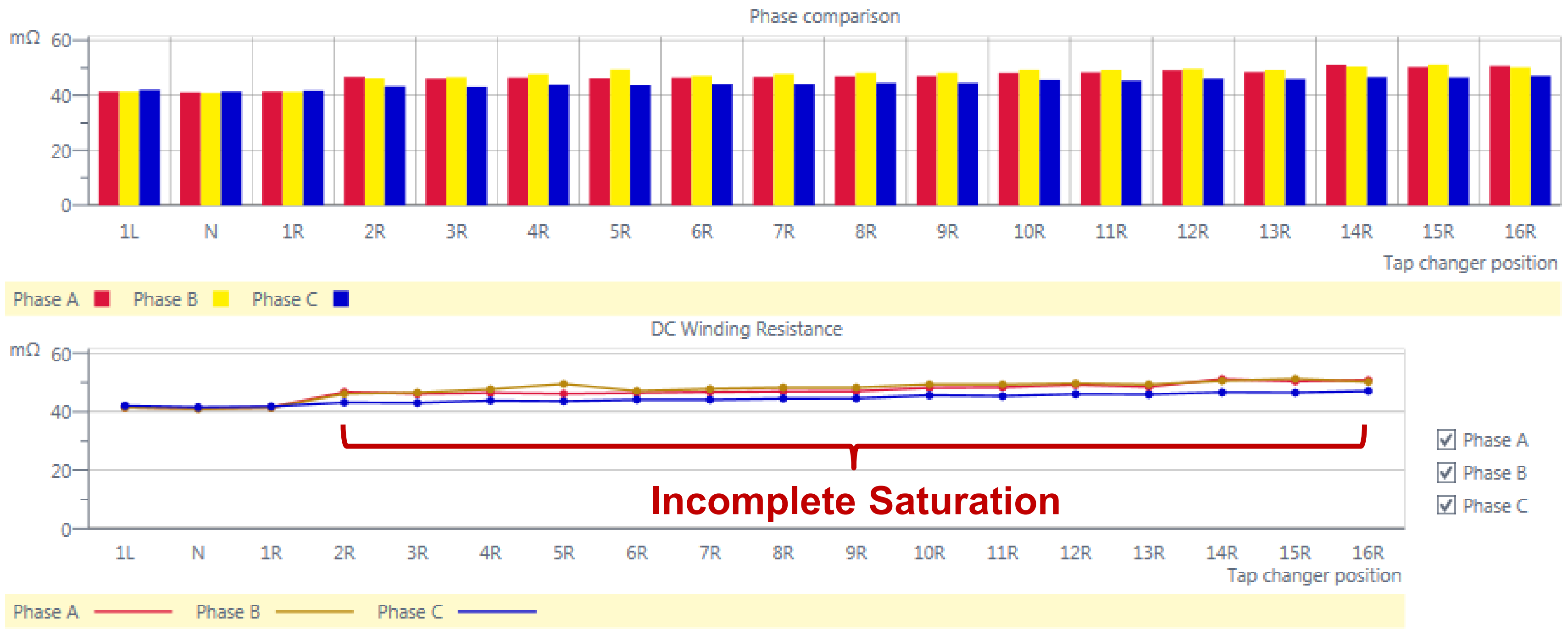
Attempt #1



Attempt #2



Incomplete Core Saturation Example #4



Series Transformers and their Influence on the DC Winding Resistance Test

Series Transformer Introduction

- A **Series Transformer** is a two-winding transformer that is typically used to step down the load current, so that the regulating winding and its associated LTC components can be rated for a lower load current

- In North America, most **Series Transformers** are located on the secondary side of a power transformer, since the LTC is typically located on the secondary side

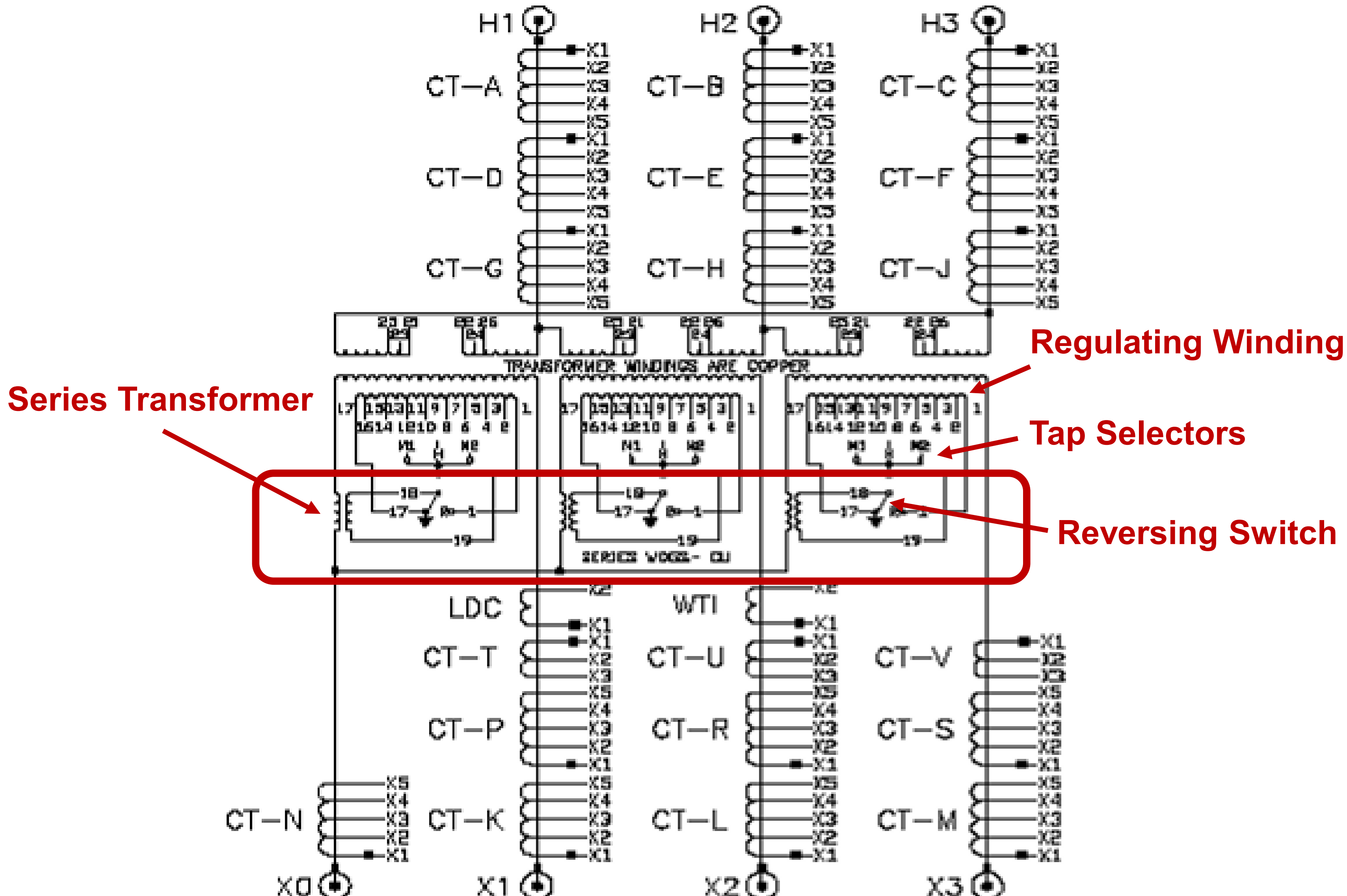
- If a transformer winding has an **isolated** Series Transformer,

  - ❑ Then the DC Winding Resistance test only has to be performed on one LTC tap-position

  - ❑ Then regardless of the LTC position, the measured resistance will remain constant (i.e. the resistance will not change versus tap-position)

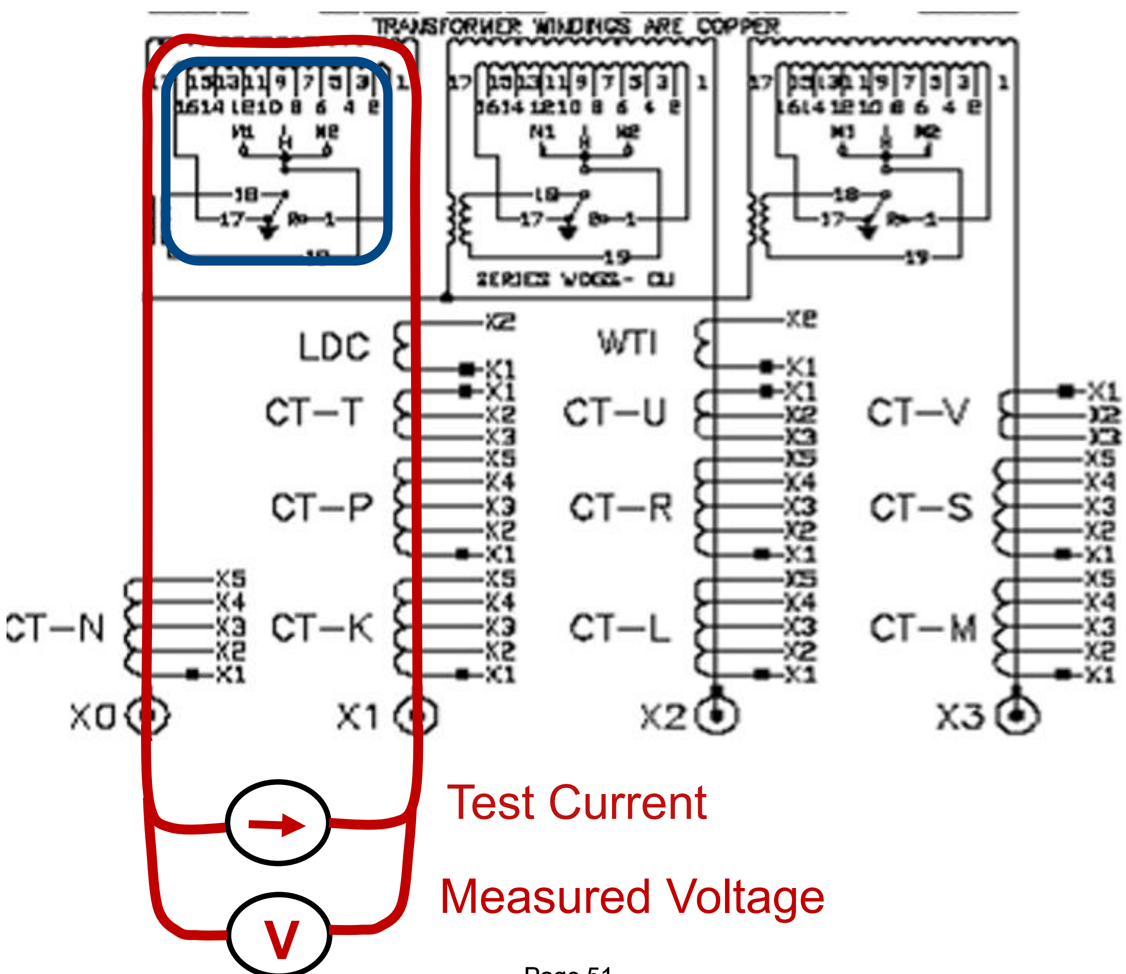
  - ❑ Then unfortunately, we lose the ability to perform a “continuity check” on the LTC’s tap-selectors, stationary contacts, regulating winding, barrier board connections, among other LTC components

Isolated Series Transformer Example #1

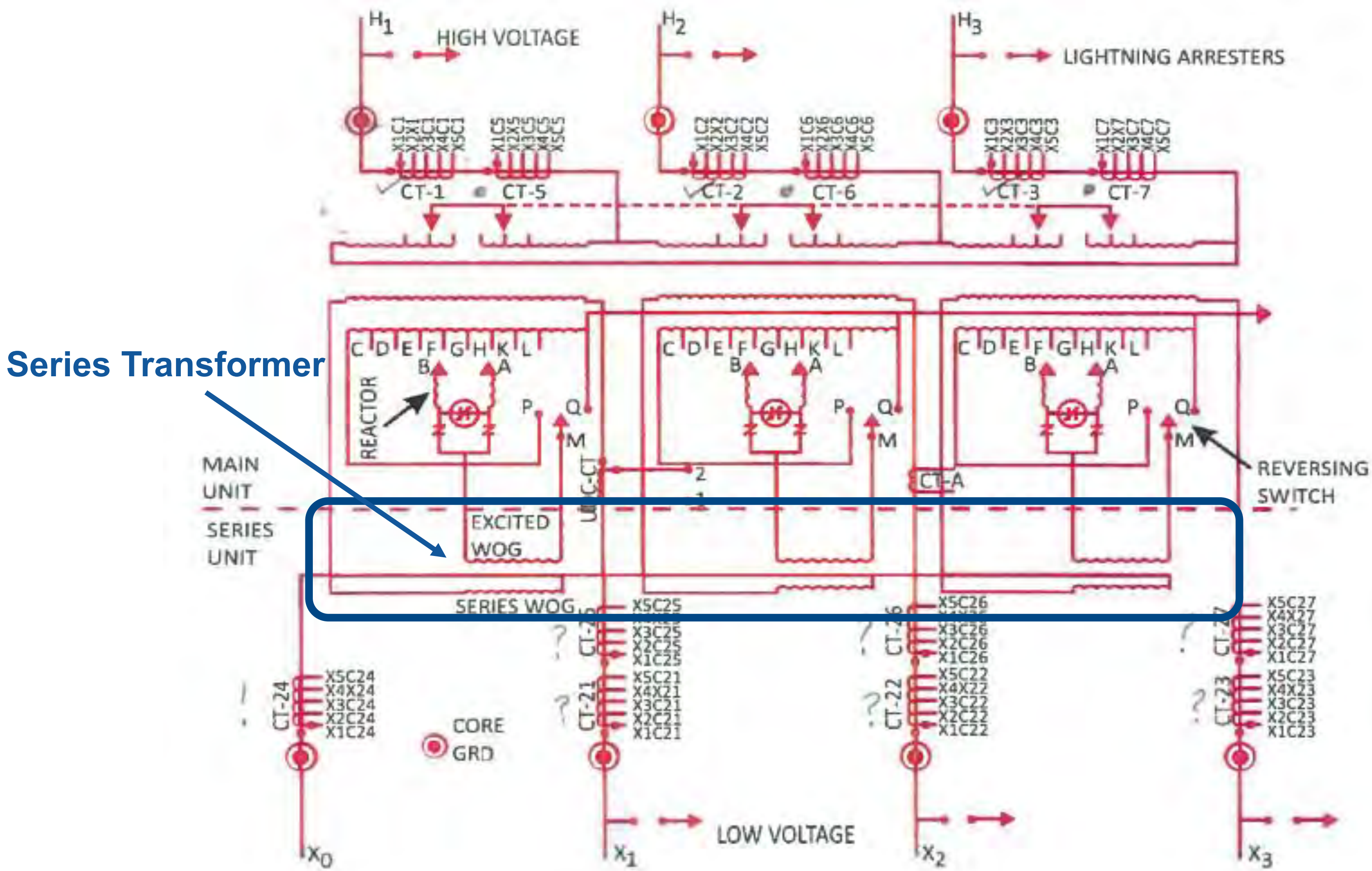


Isolated Series Transformer Example #1

- Once the core of the series transformer is saturated, the secondary circuit of the series transformer (shown in blue) has a negligible influence on the resistance measurement

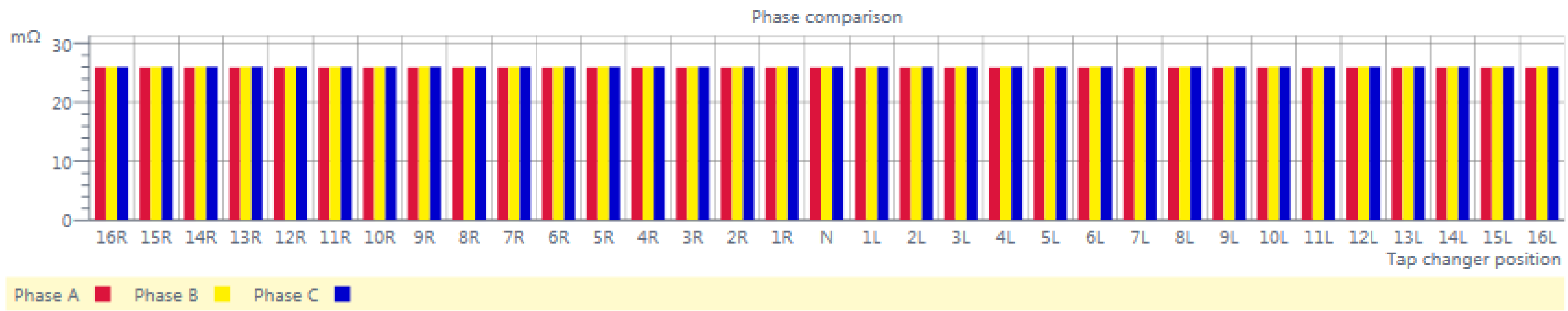


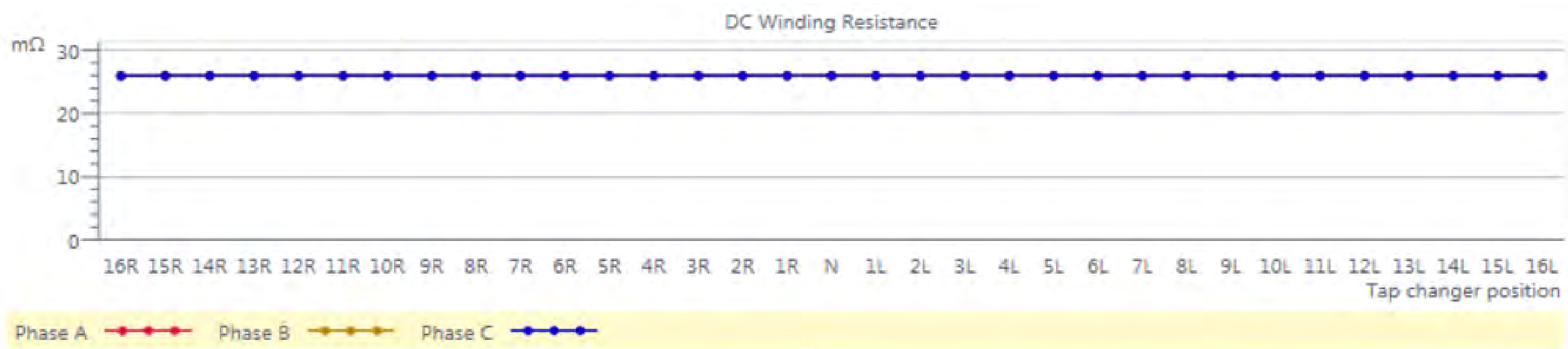
Isolated Series Transformer Example #2



DC Winding Resistance Results for a Winding with an Isolated Series Transformer – Example #1

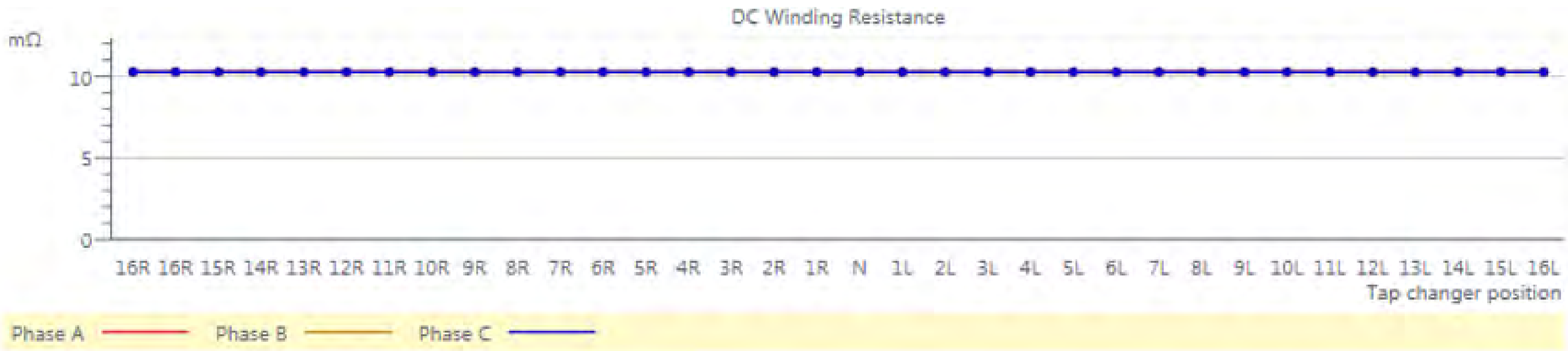
- Notice that the measured resistance remains constant as the LTC is operated from 16R-16L
- Only one LTC position needs to be tested





DC Winding Resistance Results for a Winding with an Isolated Series Transformer – Example #2

- Notice that the measured resistance remains constant as the LTC is operated from 16R-16L
- Only one LTC position needs to be tested



Thank you!