Revenue Protection via Meter Site Analysis

Marcus Zickefoose

Why Do We Test?

Legal Ramifications
Regulatory Bodies
Utility Best Practices
We've Always Done It
We've Never Done It

- Energy is consumed.
- Payment is exchanged.
- Is it a fair exchange?

Legal & Regulatory

- To ensure that a meter is meeting the accuracy requirements mandated by the PSC and management, we test it in the shop under conditions recommended by ANSI C12.1 (absorbed C12.20 in 2022) and the metering manufacturer.

- Generally, for a Class 20 CT Rated meter this means testing:
  - Full Load…120V, 2.5A, PF=1
  - Light Load…120V, 0.25A, PF=1
  - Power Factor…120V, 2.5A, PF=.5

Financial Transaction

If the meter is functioning accurately, what does that say about whether or not the customer is getting the correct bill?

POSSIBLY NOT MUCH!

“Trust…but Verify”

With a History Lesson

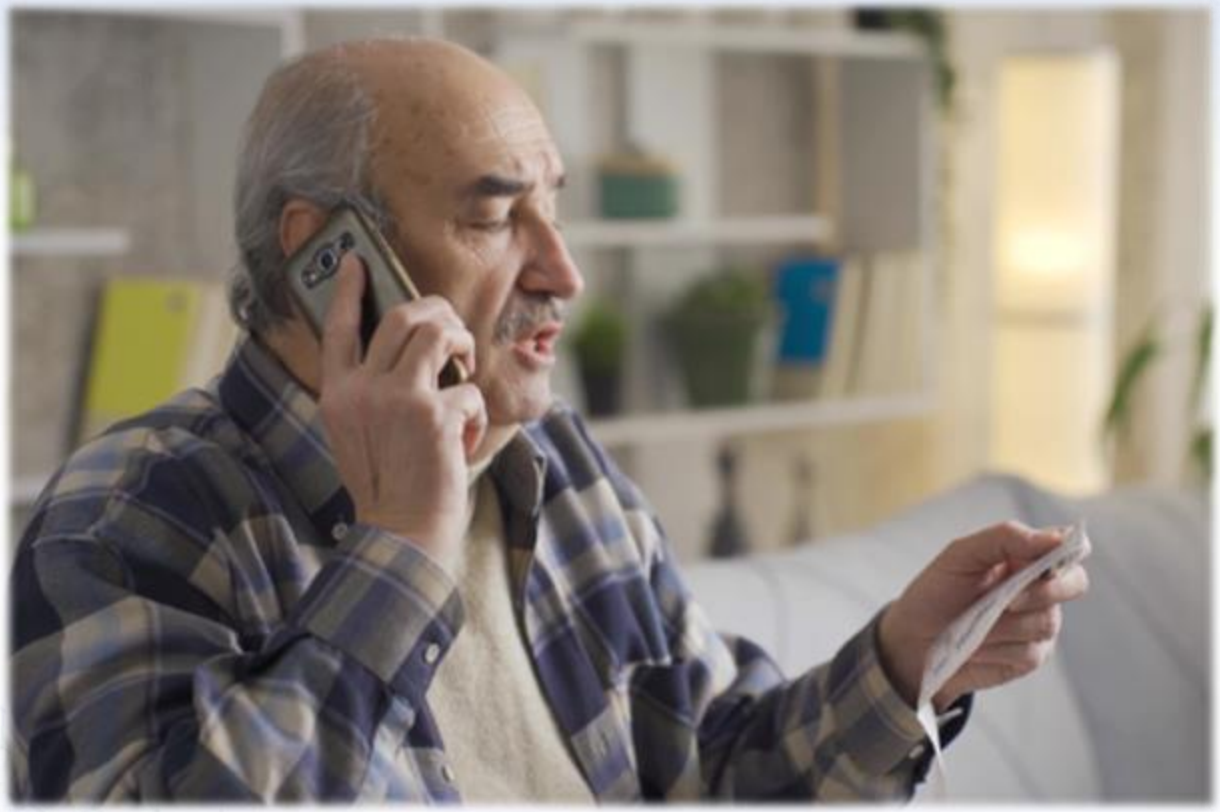
“Trust…but Verify”

Nuclear Arms Treaty 1987
Russian proverb
“doveryai, no proveryai”

Extensive verification procedures that would enable both sides to monitor compliance with the treaty.

“Trust…but Verify”

In our world, the customer and the utility TRUST that payment for watthour consumption is accurate. Both the utility and the customer may have to VERIFY their trust in the transaction.



“Trust…but Verify”

How Does a Customer Verify Their Trust in the Transaction?

High Bill Complaint

Verify With:
Meter Test

“Trust…but Verify”

How Does a Utility Verify Their Trust in the Customer?

Theft Detection
AMI or Billing Flags
Distributed Intelligence

Verify With:
Meter Test, Visual Inspection,
Complete Site Analysis

“Trust…but Verify”

How Does a Utility Verify Their Trust in the Transaction?

Meter Site Circuit Analysis

Verify With:
Vector Analysis
Meter Test
CT Test
“Billing Analysis”

“Trust…but Verify”

The Utility is Also a Customer!

Meter Manufacturers
CT and PT Manufacturers
Software Providers

Verify With:
Sample Testing
Acceptance Testing
New AMI Software Version Validation

Is This Revenue Protection?

"Trust…but Verify"

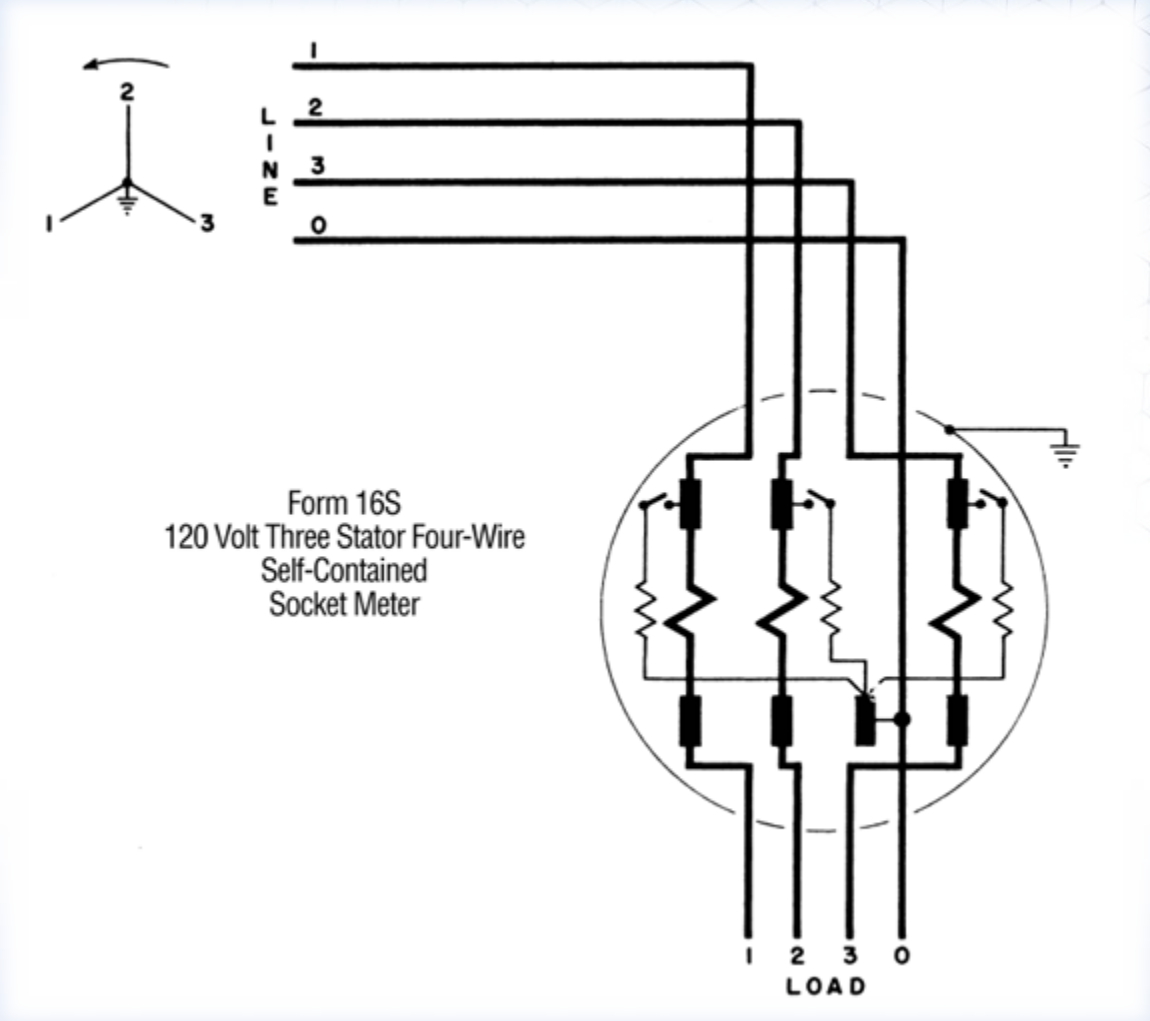
The Utility is Also a Customer!

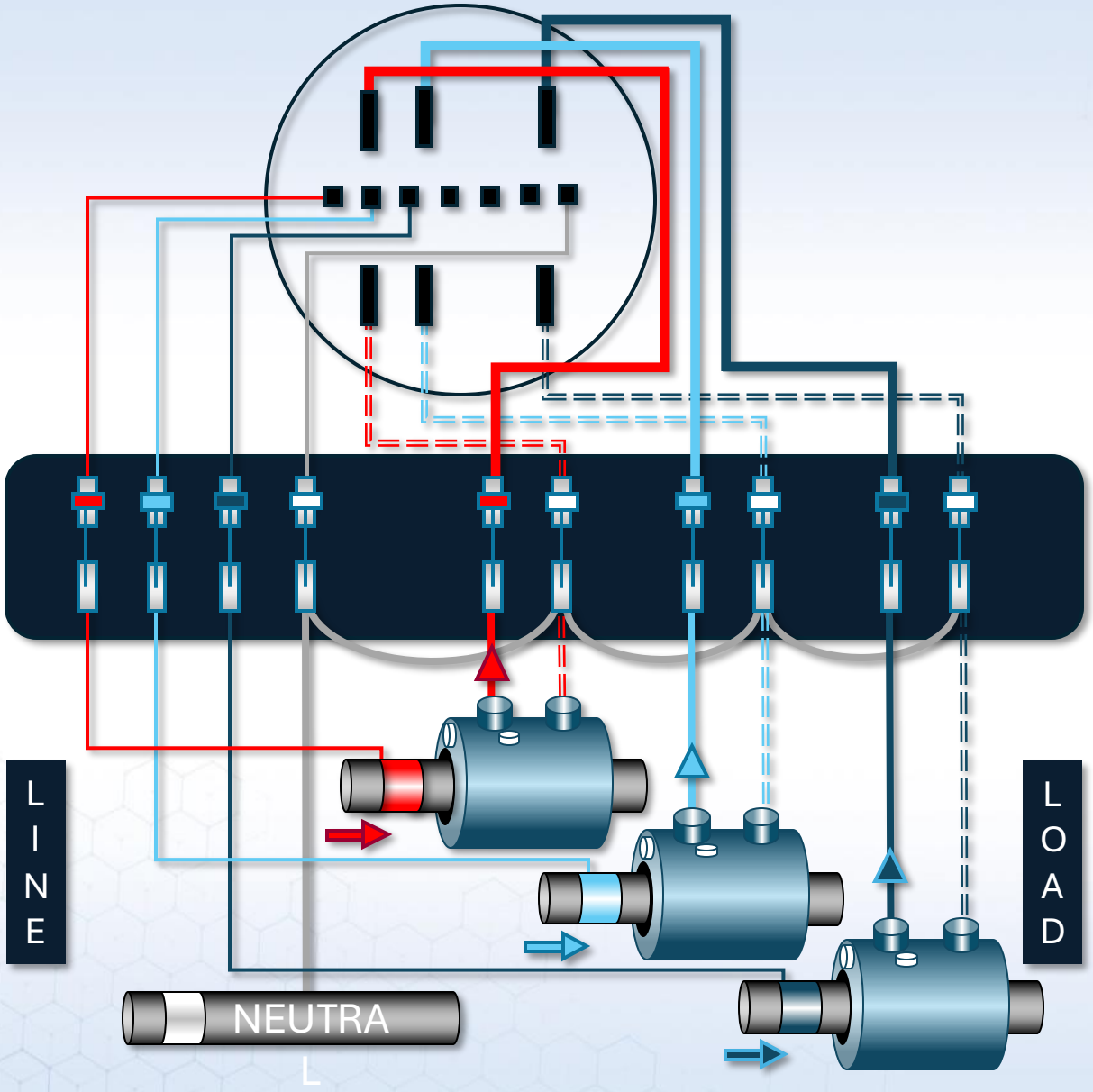
- Single Position Test Boards
- Multi Position Test Boards
- Meter Qualification Boards
- Warm-Up Boards
- Desktop Meter Stations
- Meter Farms
- Lab Calibration Systems

Types of Errors & Ramifications

Self-Contained Errors

Meter
Wiring
(socket)
Administrative
Theft





Consider a Typical Transformer Rated Metering Site

Wiring errors, meter errors, CT errors, PT errors, administrative errors and theft can all lead to lost revenue, decrease in customer confidence, and even lawsuits.

Transformer Rated Sites

How much revenue is my utility losing through site errors?

80/20 Rule Revenue vs Sites
2-5% Have Error

Transformer Rated Sites

AVERAGE $30k Loss per Error

Type & Scope of Error

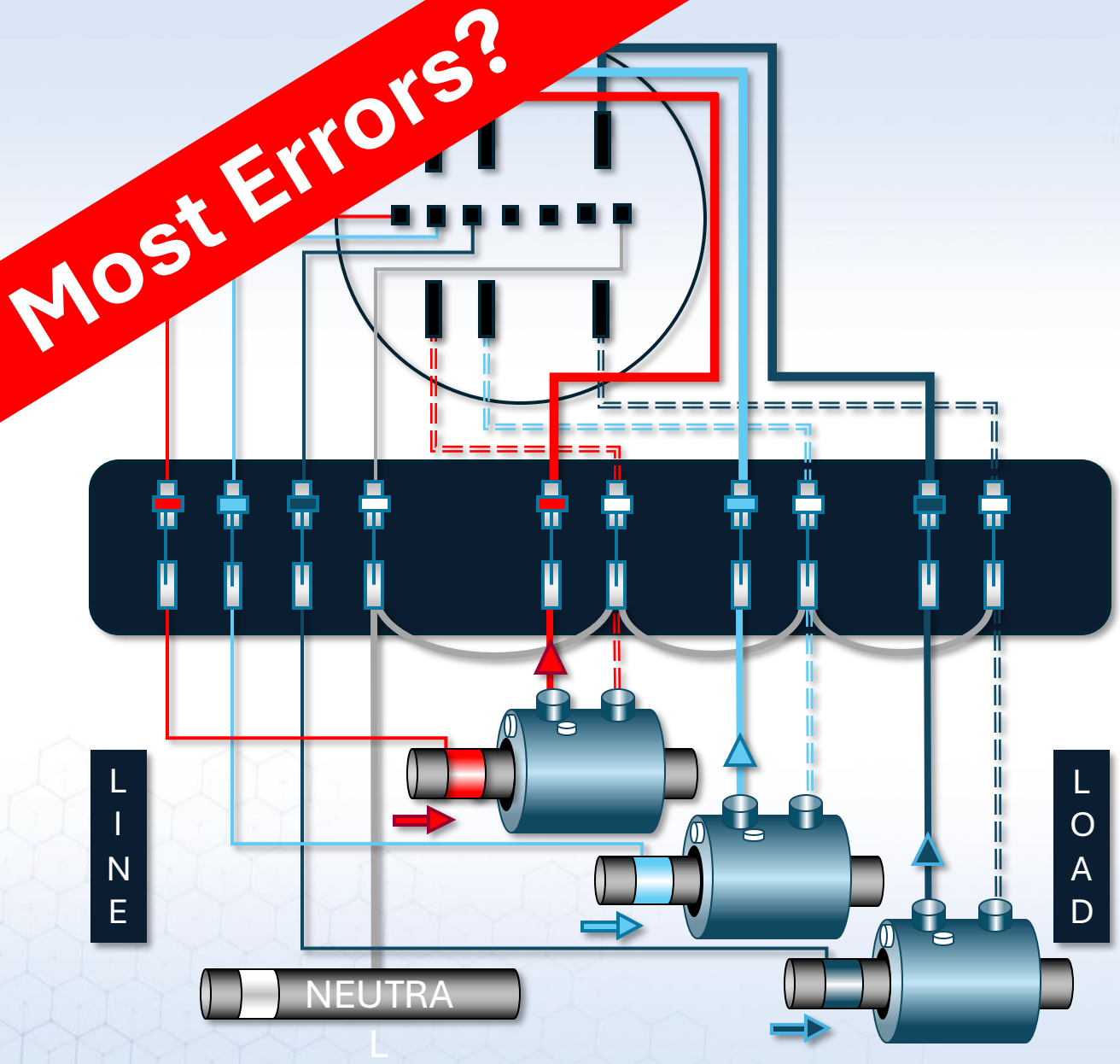
- Trickle: Couple Percent
- Stream: 10…20…30%
- River: 50…60…70%
- Tsunami: Nearing 100% Loss

Duration

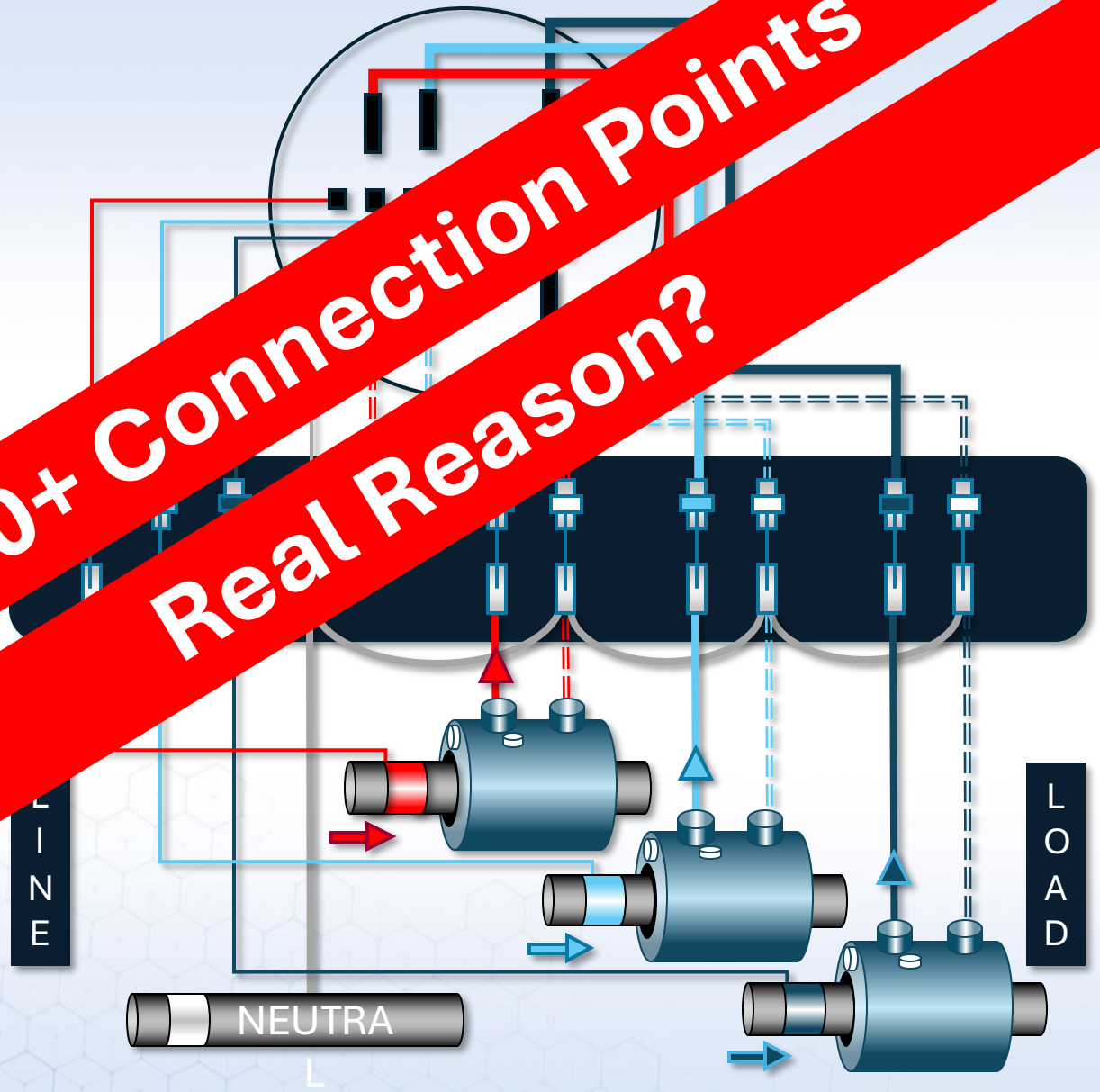
- 90 Days
- Years
- Decades

Size of Site

- Large Residential
- Small Commercial
- Large Industrial



Meter
Wiring (socket)
Wiring (CT primary)
Wiring (CT secondary)
Wiring (length & gauge)
Wiring (test switch top)
Wiring (test switch bottom)
CT
CT application
Administrative
Theft



50+ Connection Points
Real Reason?

Meter

Wiring (socket)

Wiring (CT primary)

Wiring (CT secondary)

Wiring (length & gauge)

Wiring (test switch top)

Wiring (test switch bottom)

CT

CT application

Administrative

Theft

Meter

Wiring (socket)

Wiring (CT primary)

Wiring (CT secondary)

Wiring (length & gauge)

Wiring (test switch top)

Wiring (test switch bottom)

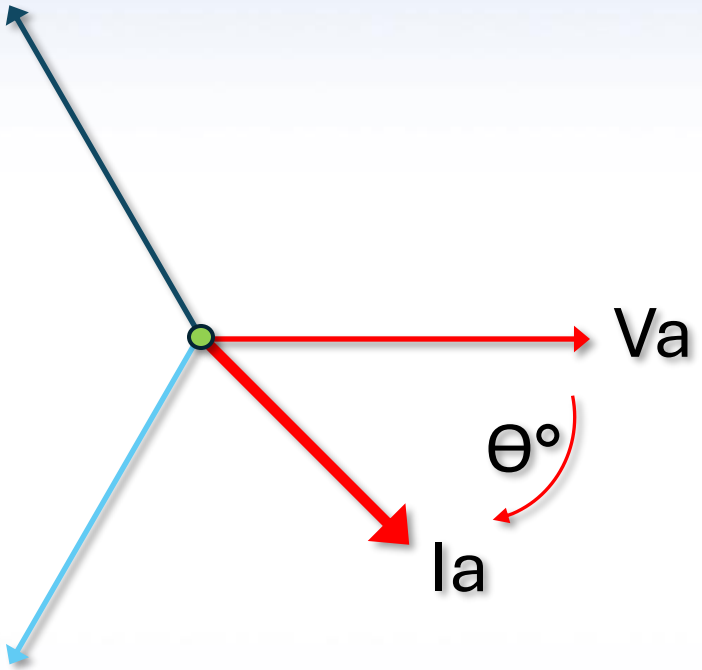
CT

CT application

* Administrative

Theft

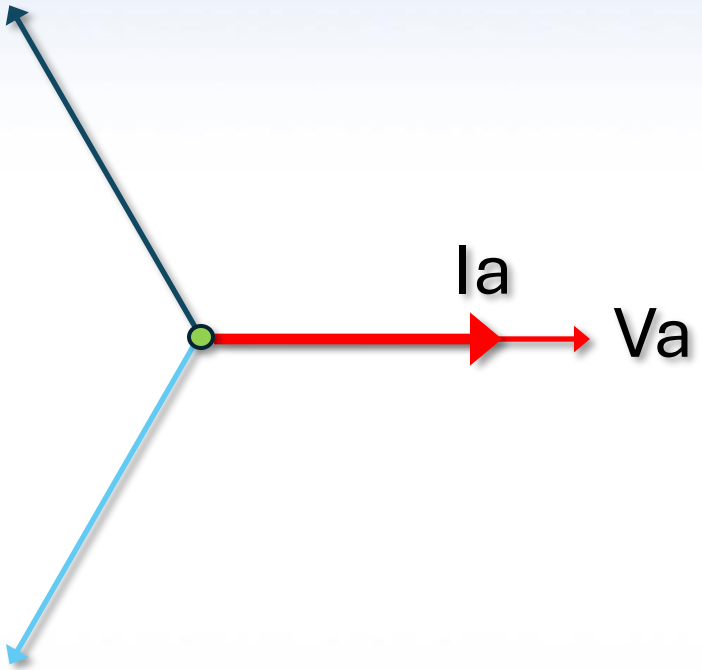
Wiring Error Ramifications



- Phase Relationships
- Negative Power & Energy
- Zero Power & Energy

Phase Angle Between V & I

- Watts = V*I*PF
- Power Factor = Cos(Θ°)
- Power Factor -1.0 to +1.0
- Watts -1.0 to +1.0 Multiplier of VA

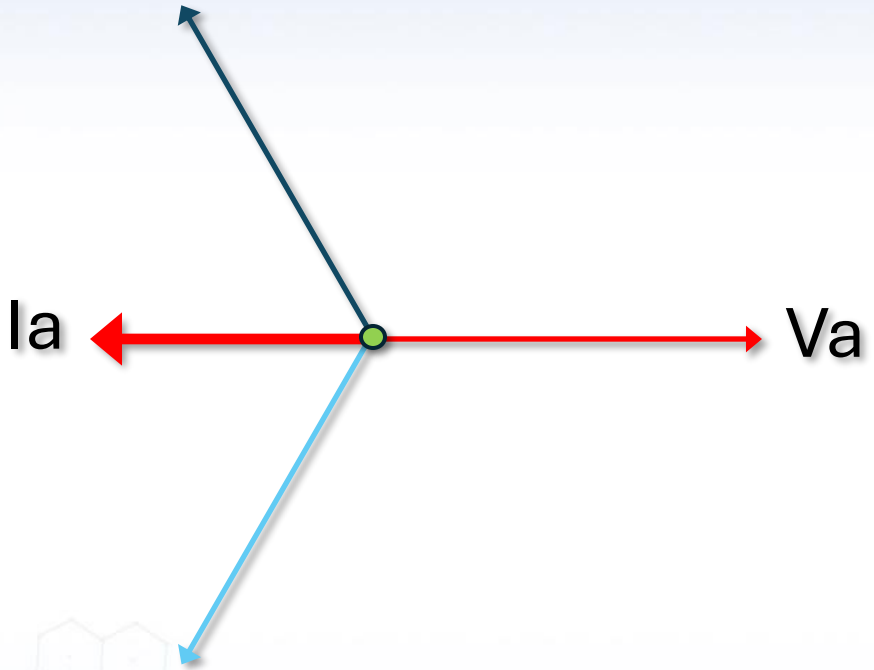


Wiring Error Ramifications

- Phase Relationships
- Negative Power
- Zero Power

Phase Angle Between V & I

- What is Θ?
- What is PF?
- PF = +1.0
- Watts are 100% of VA
- Watts are Positive (+)



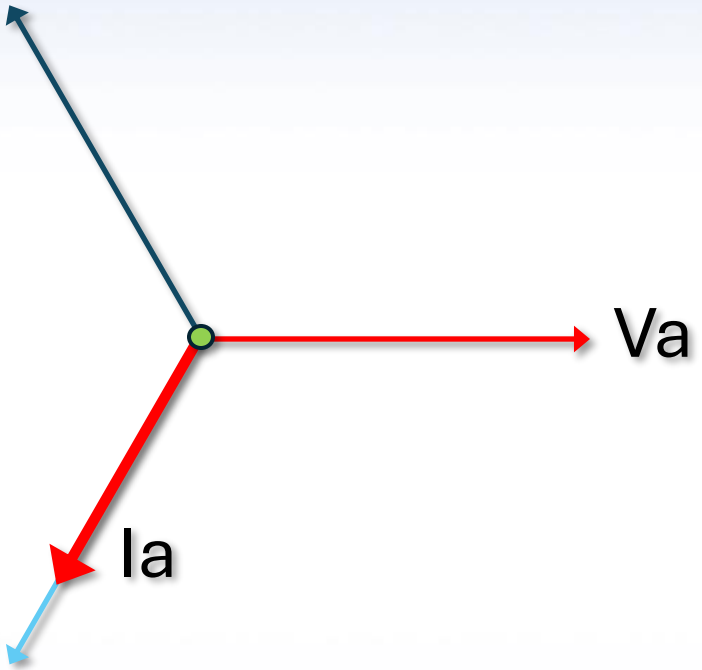
Wiring Error Ramifications

- Phase Relationships
- Negative Power
- Zero Power

Phase Angle Between V & I

- What is Θ?
- What is PF?
- PF = -1.0
- Watts are 100% of VA
- Watts are Negative (-)

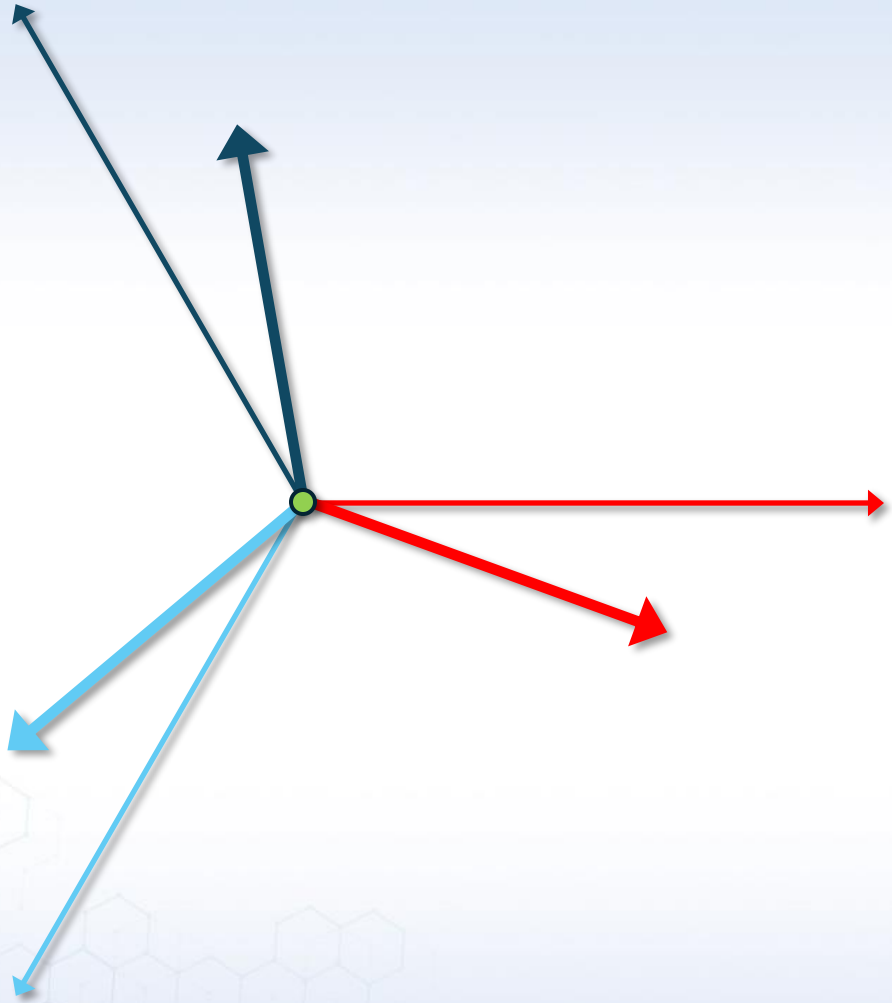
Wiring Error Ramifications



- Phase Relationships
- Negative Power
- Zero Power

Phase Angle Between V & I

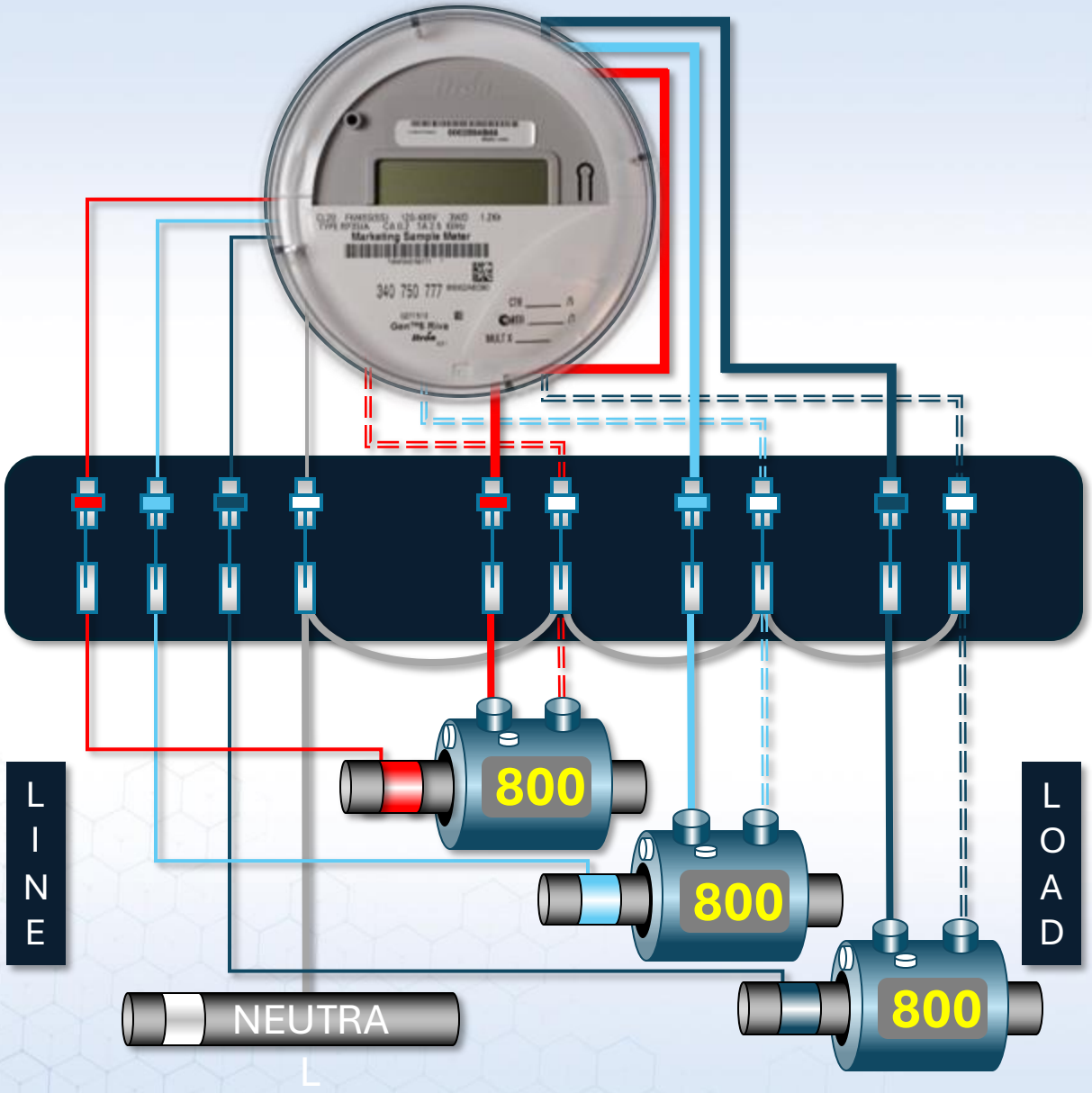
- What is Θ?
- What is PF?
- PF = -0.5
- Watts are 50% of VA
- Watts are Negative (-)



Could This Very Normal Looking Vector Be the Biggest Cause of Revenue Loss?
It Depends on How You Define “Loss”.

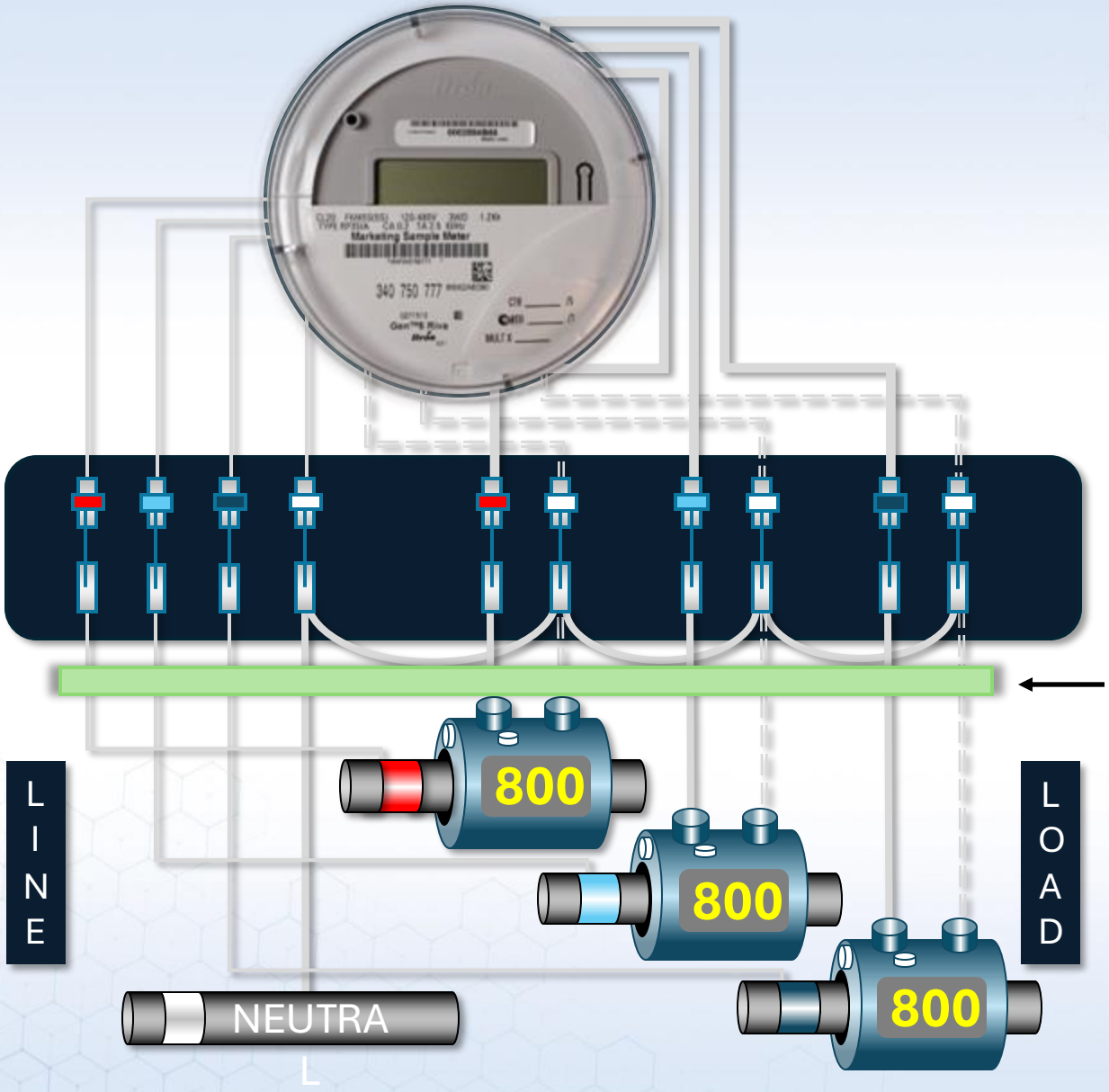
Let’s Get Your Opinion Later…

Visual Inspections



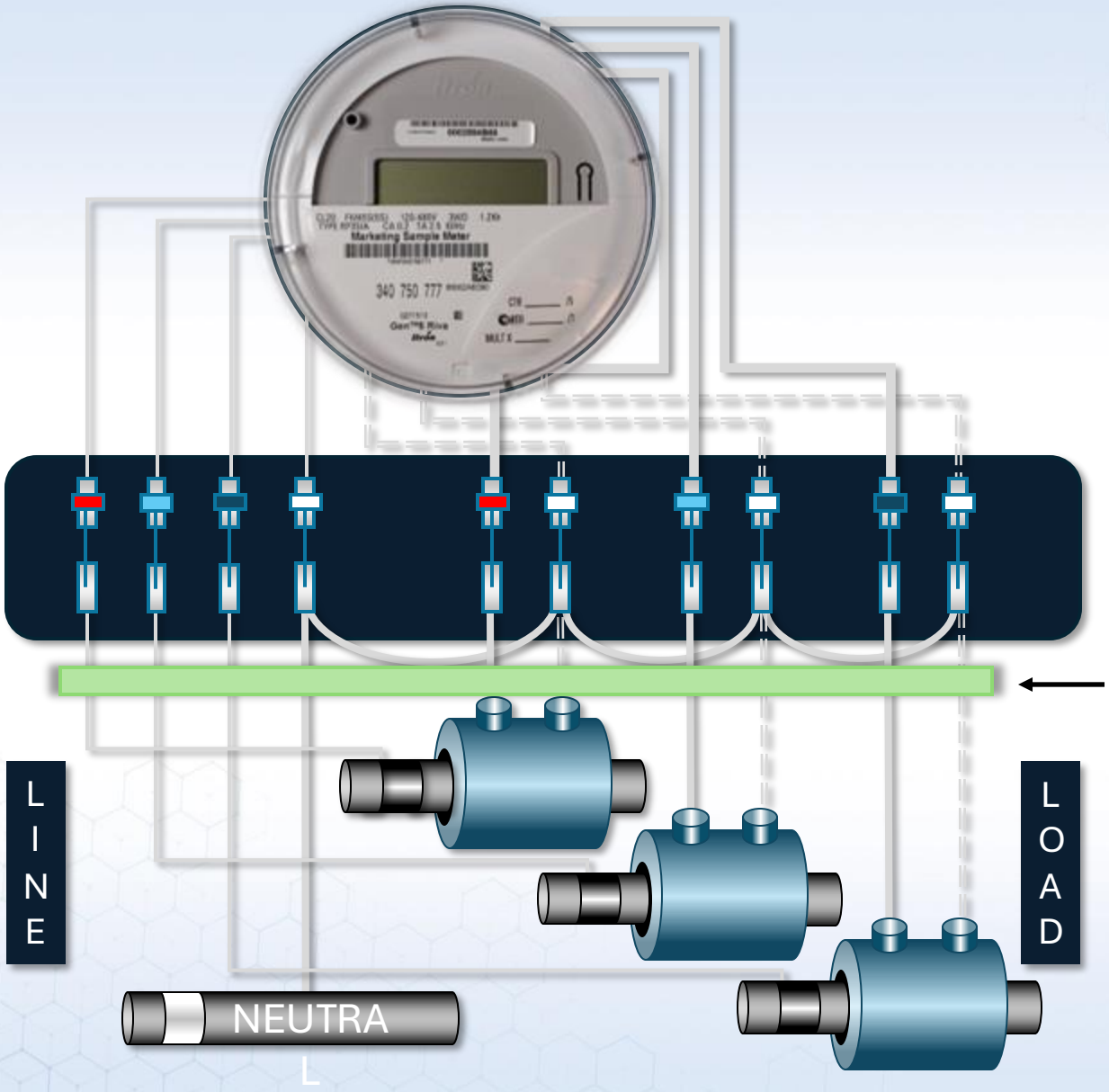
Visual Inspections Might be Difficult or Nearly Impossible

- Meters Hide Socket Connections
- Dirty Wires Make Phasing & Polarity Hard to Determine



Visual Inspections Might be Difficult or Nearly Impossible

- Meter Hides Socket Connections
- Dirty Wires Make Phasing & Polarity Hard to Determine
- Difficult to Trace Wires from CT Cabinet to Meter
- Hard to See CT Nameplate, Polarity Marks/Primary Phases



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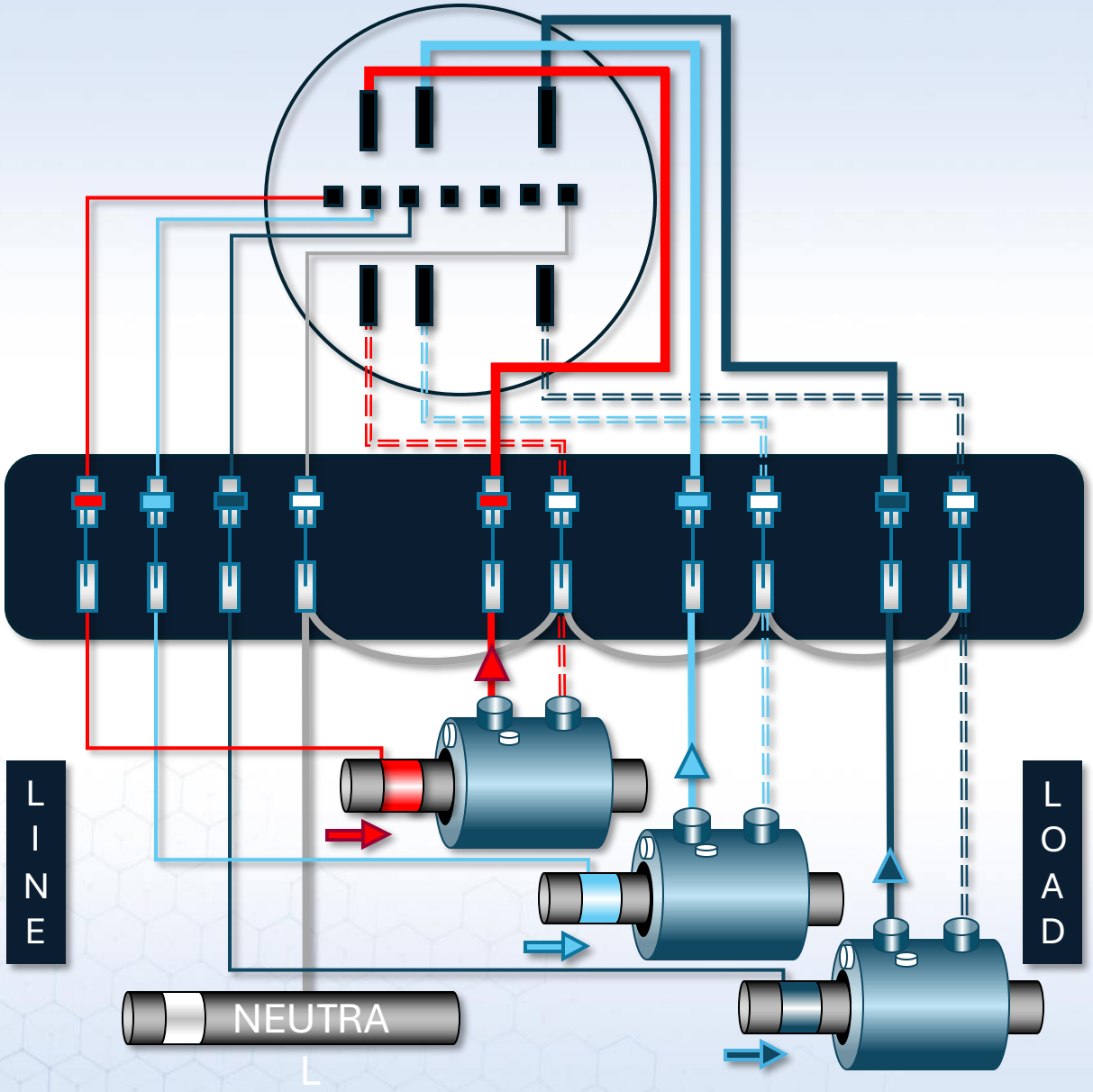
Types of Tests Available



Meter Testing

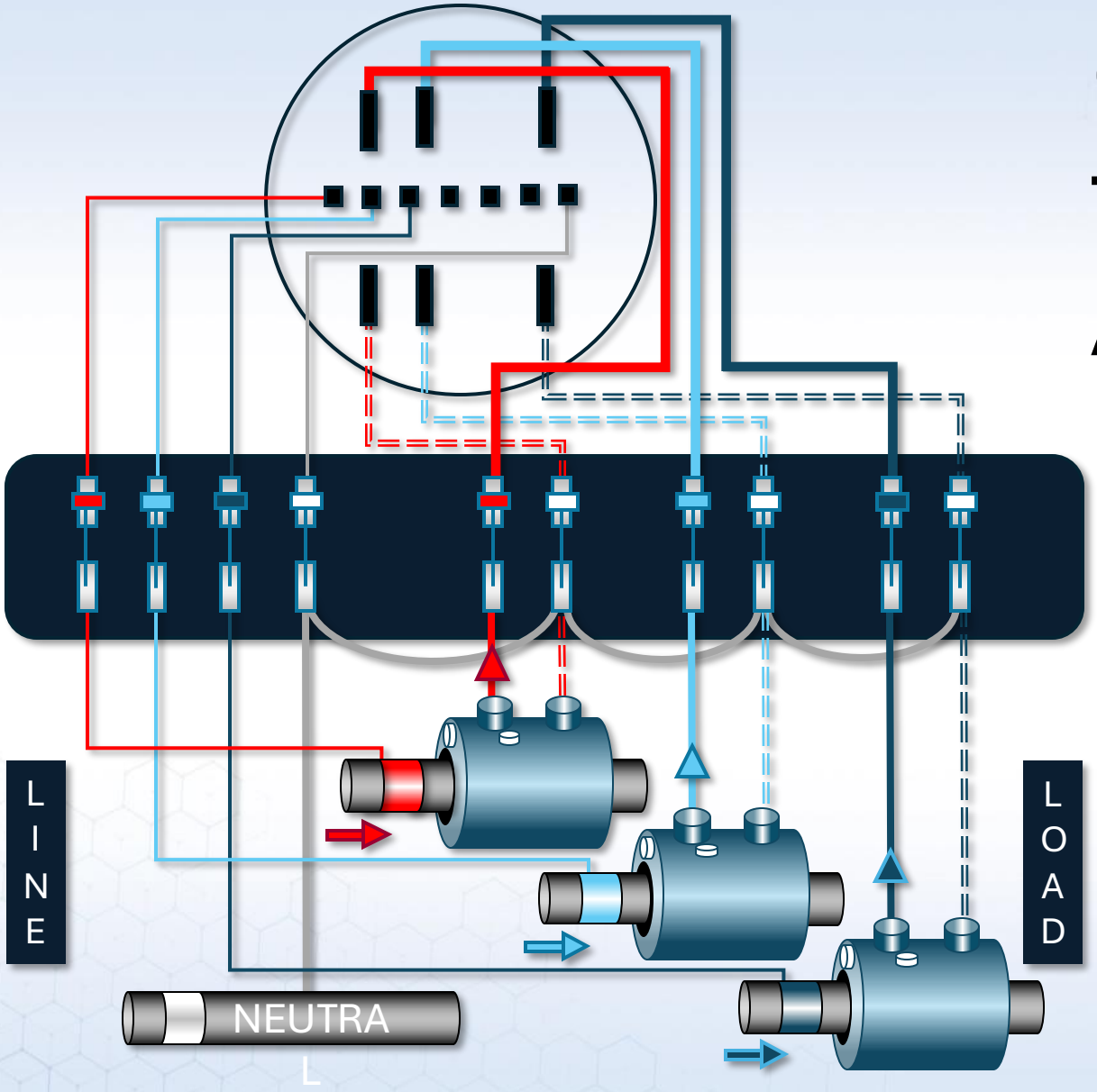
- Customer Load
- Phantom Load

CT Testing

- Ratio - Amp. & Phase
- Burden
- Admittance

Wiring Verification

- Vectors, Waveforms, Power & Energy Metrics



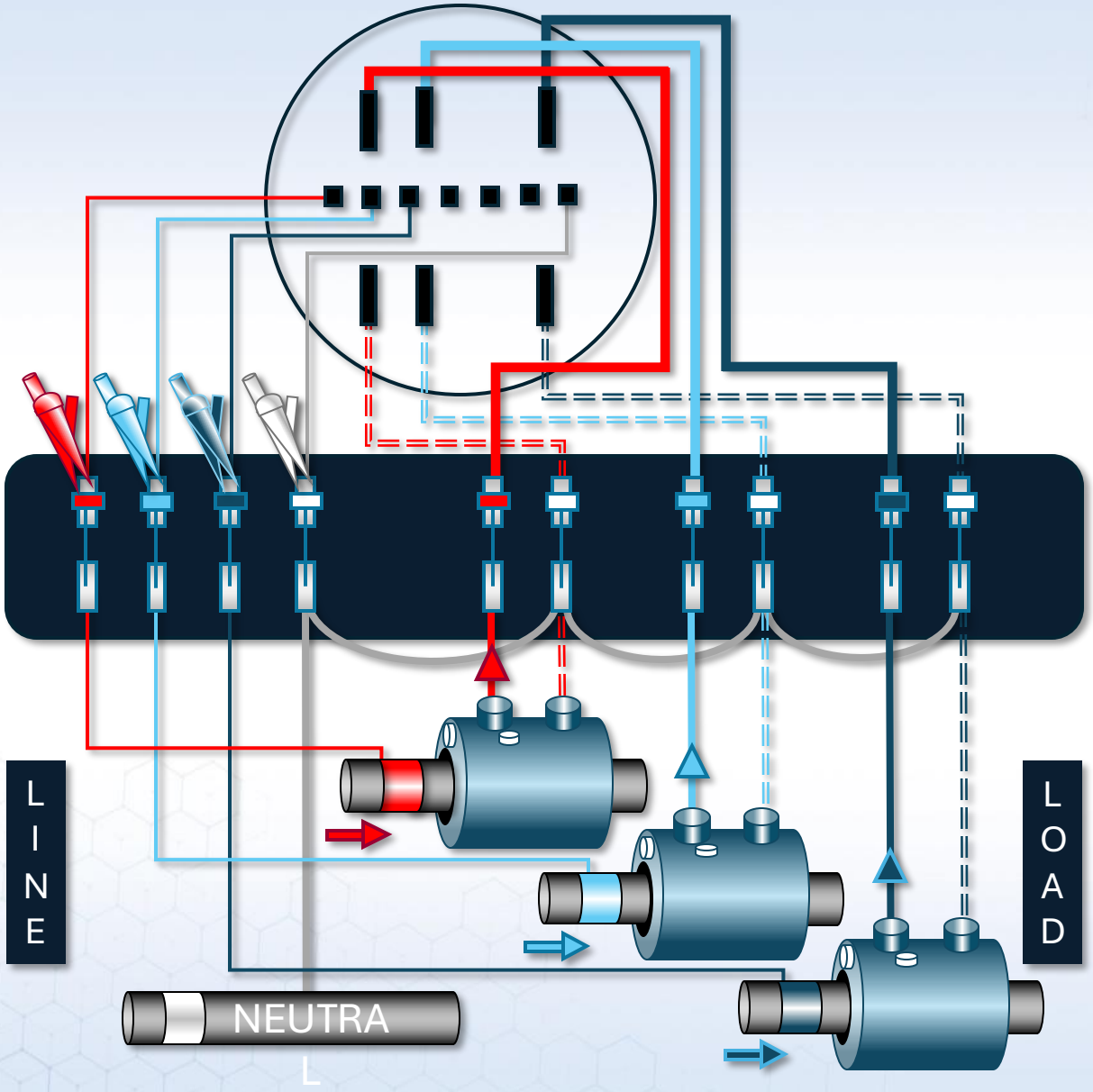
Customer Load Testing

Actual Billing Conditions

- Incorrect Wiring
- Harmonics
- Varying Loads
- Imbalanced Loads
- Non-Linear Loads
- Extreme Temps
- Loose Connections
- UV, Saltwater Degradation

Test Switch Connections

Customer Load Testing



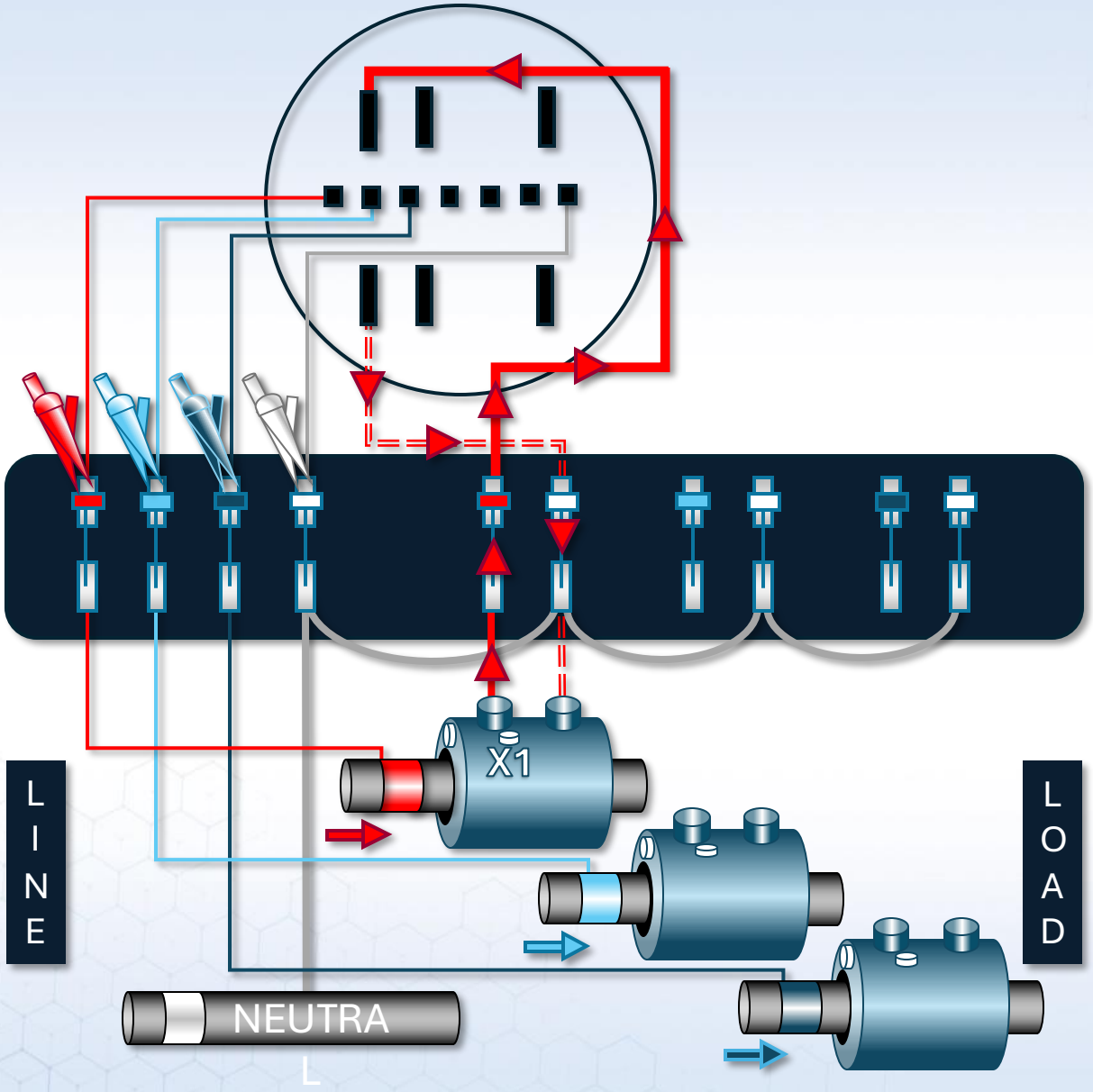
Customer Load Testing

Secondary Voltage Connections

Attach Alligator Clips

Can Use Bottom Side or Top Side of Test Switch

Test Switch Stays Closed



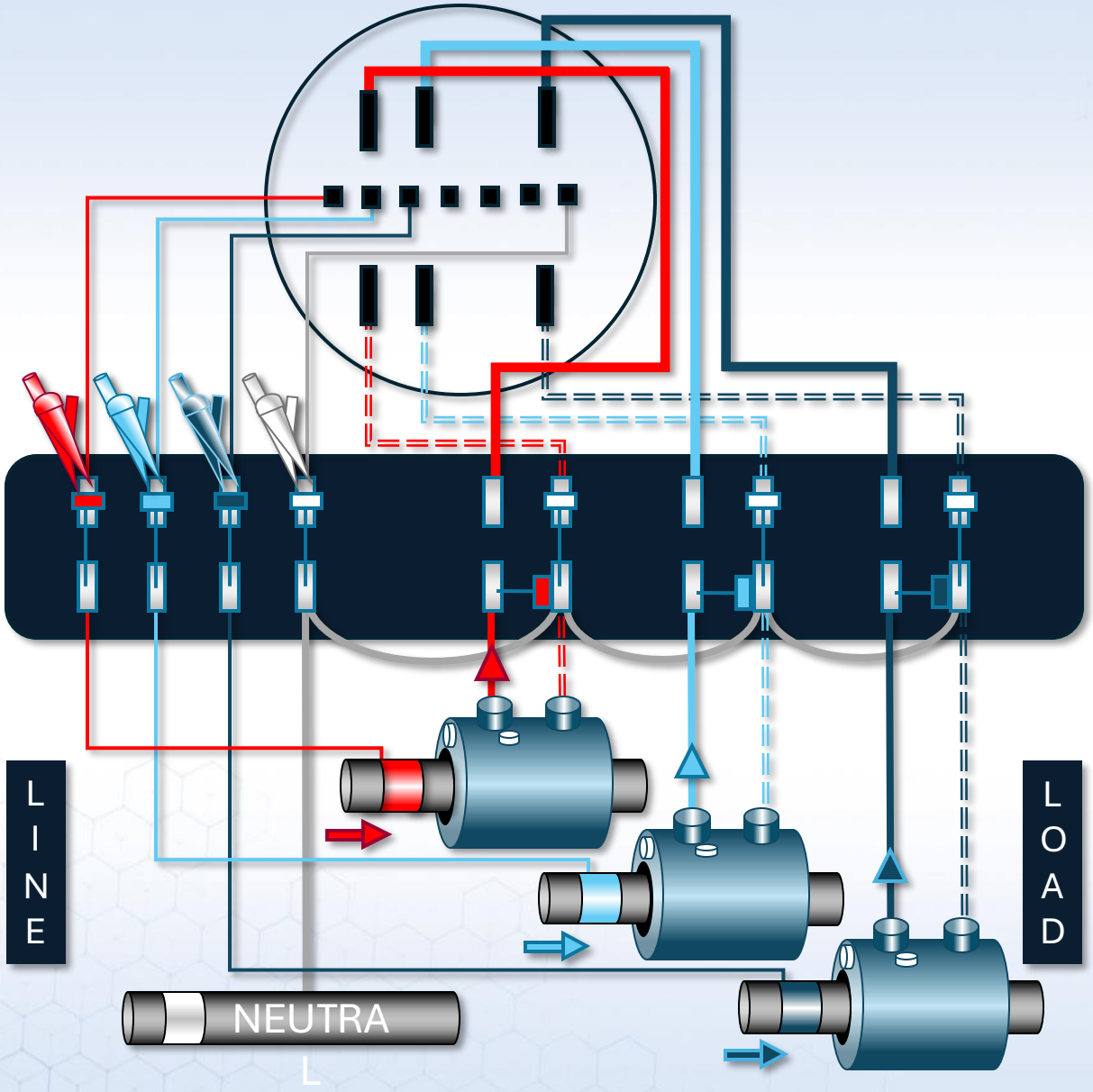
Customer Load Testing

Secondary Current Connections

Normal Current Flow

- Current Flows from X1
- Current Flows thru Meter
- Current Returns to Neutral

How Do We Get in Series with the Secondary Current to Measure it Accurately & Safely?

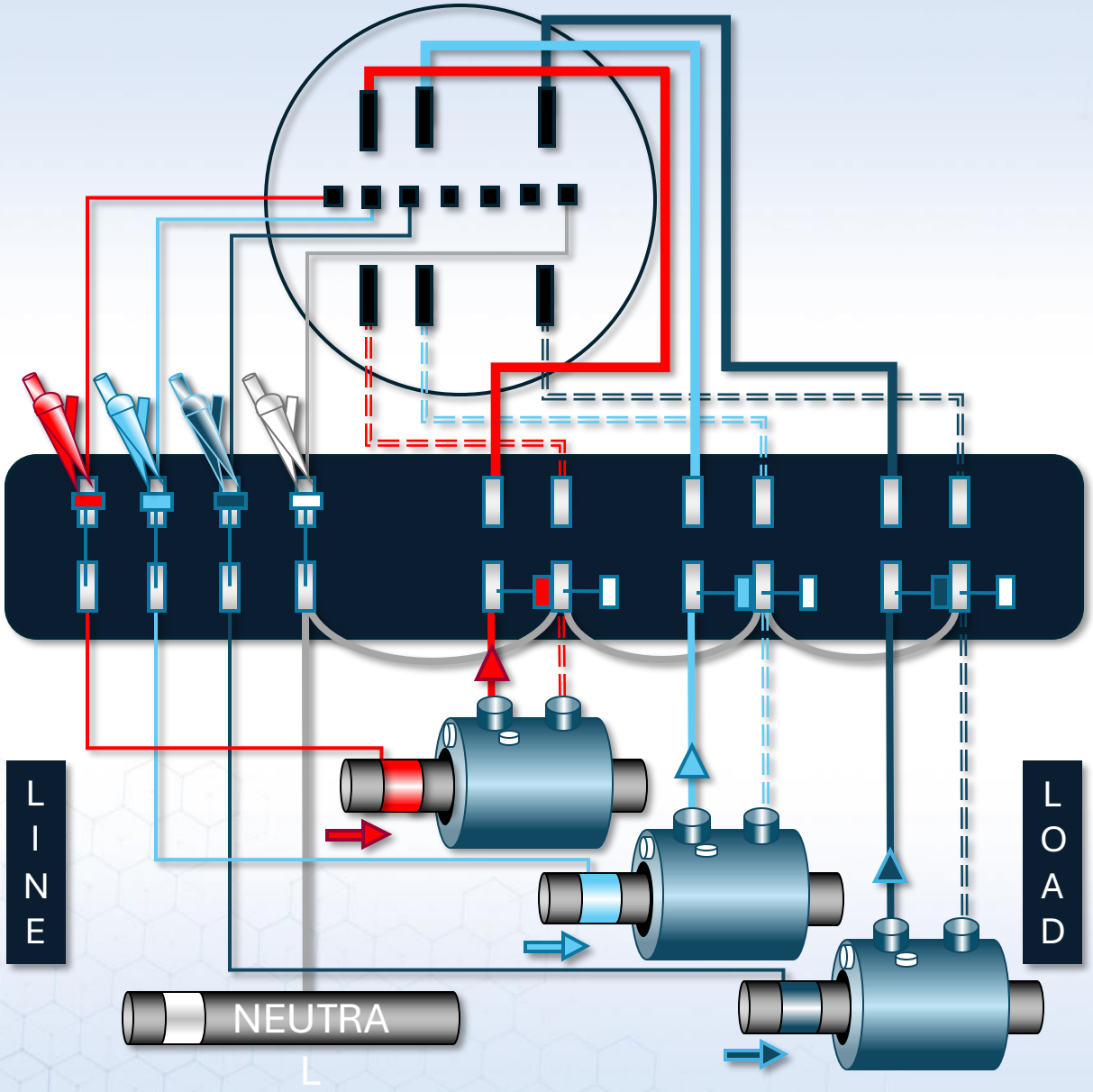


Customer Load Testing

Secondary Current Connections

Engage Shunts on Test Switch

- Safely Shorts Secondary Current of CT to Neutral
- Generally, on Polarity Side of CT Secondary



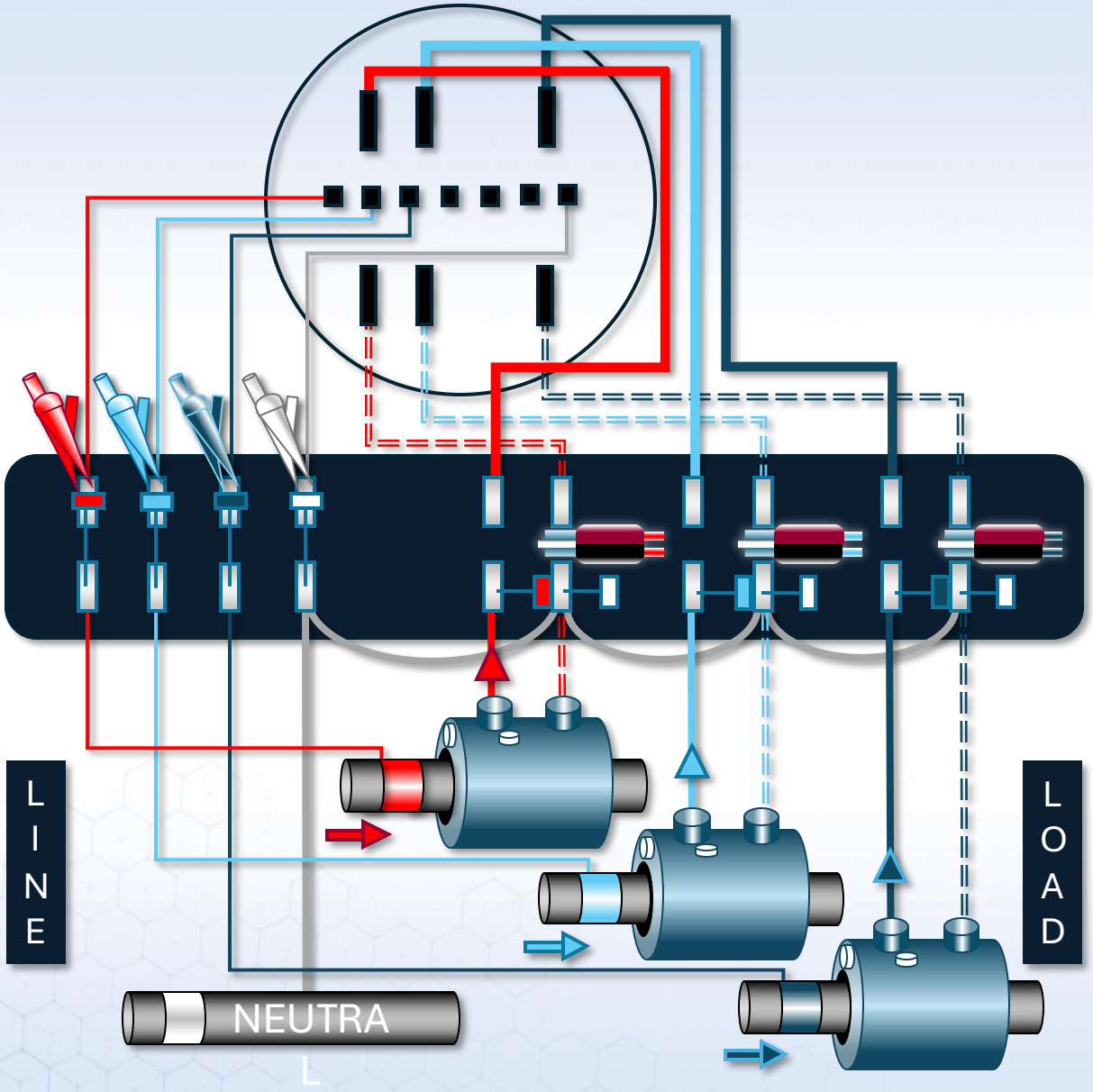
Customer Load Testing

Secondary Current Connections

Engage Shunts on Test Switch

Open Returns on Test Switch

- Allows for Insertion of Duckbill Probe
- Generally, on Return Side of CT Secondary



Customer Load Testing

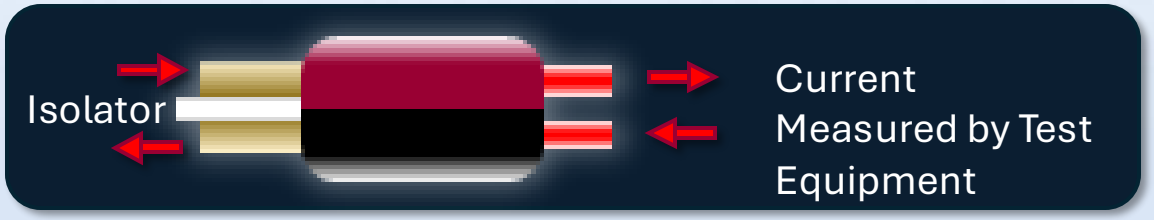
Secondary Current Connections

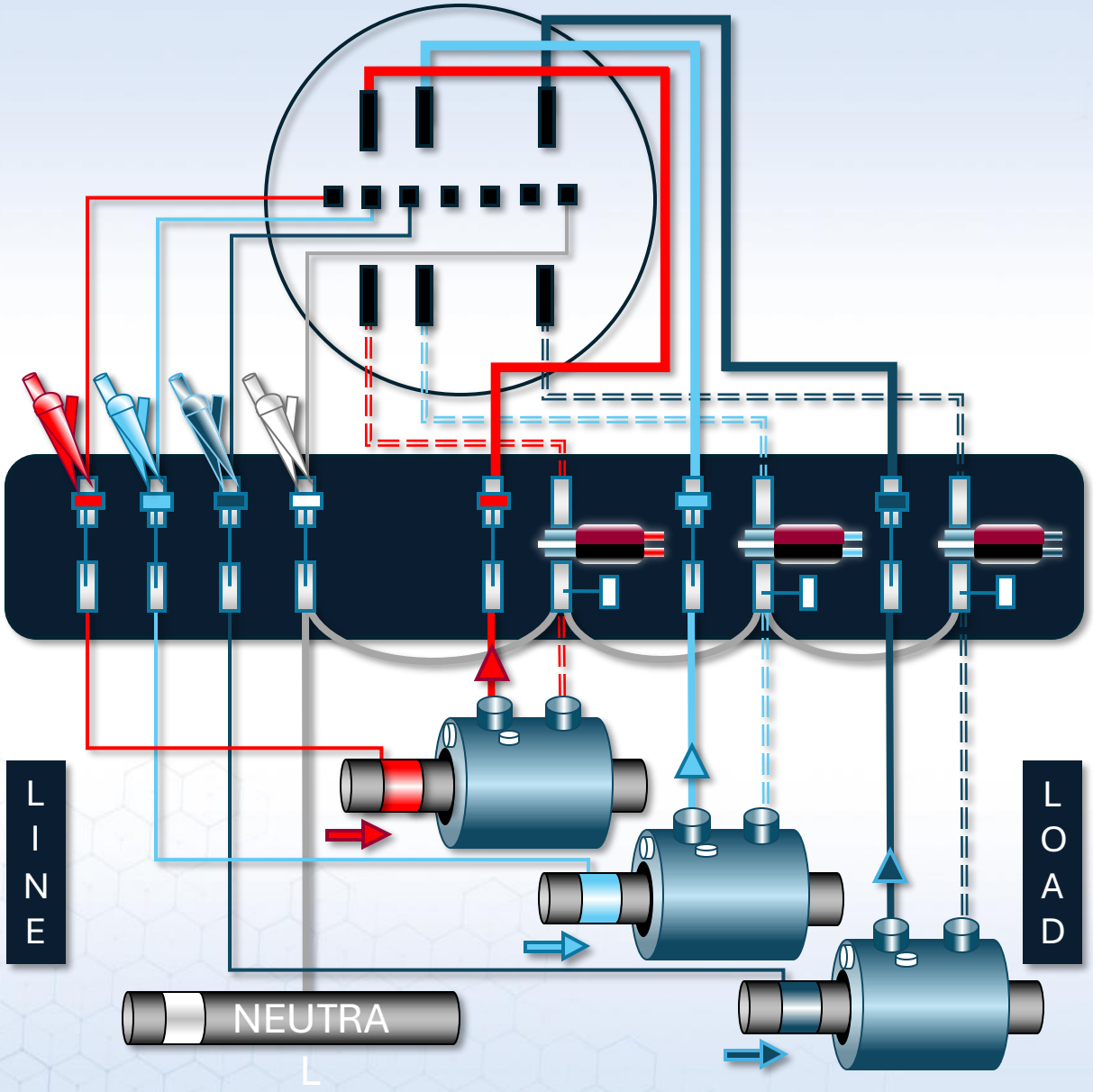
Engage Shunts on Test Switch ✓

Open Returns on Test Switch ✓

Insert Duckbill Probes

- Polarity Sensitive





Customer Load Testing

Secondary Current Connections

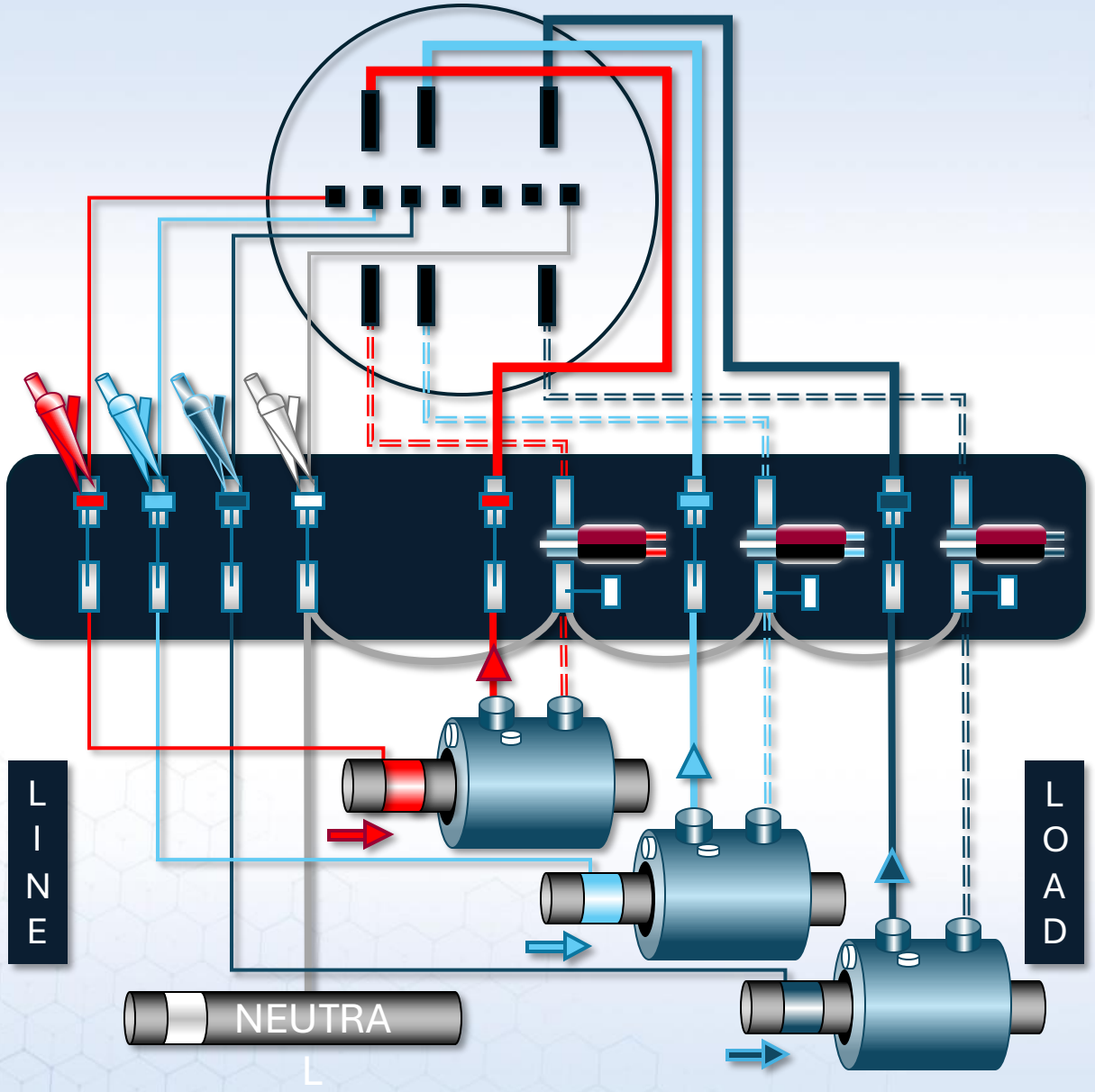
Engage Shunts on Test Switch ✓

Open Returns on Test Switch ✓

Insert Duckbill Probes ✓

Disengage Shunts on Test Switch

- Re-Establishes Current Path



Customer Load Testing

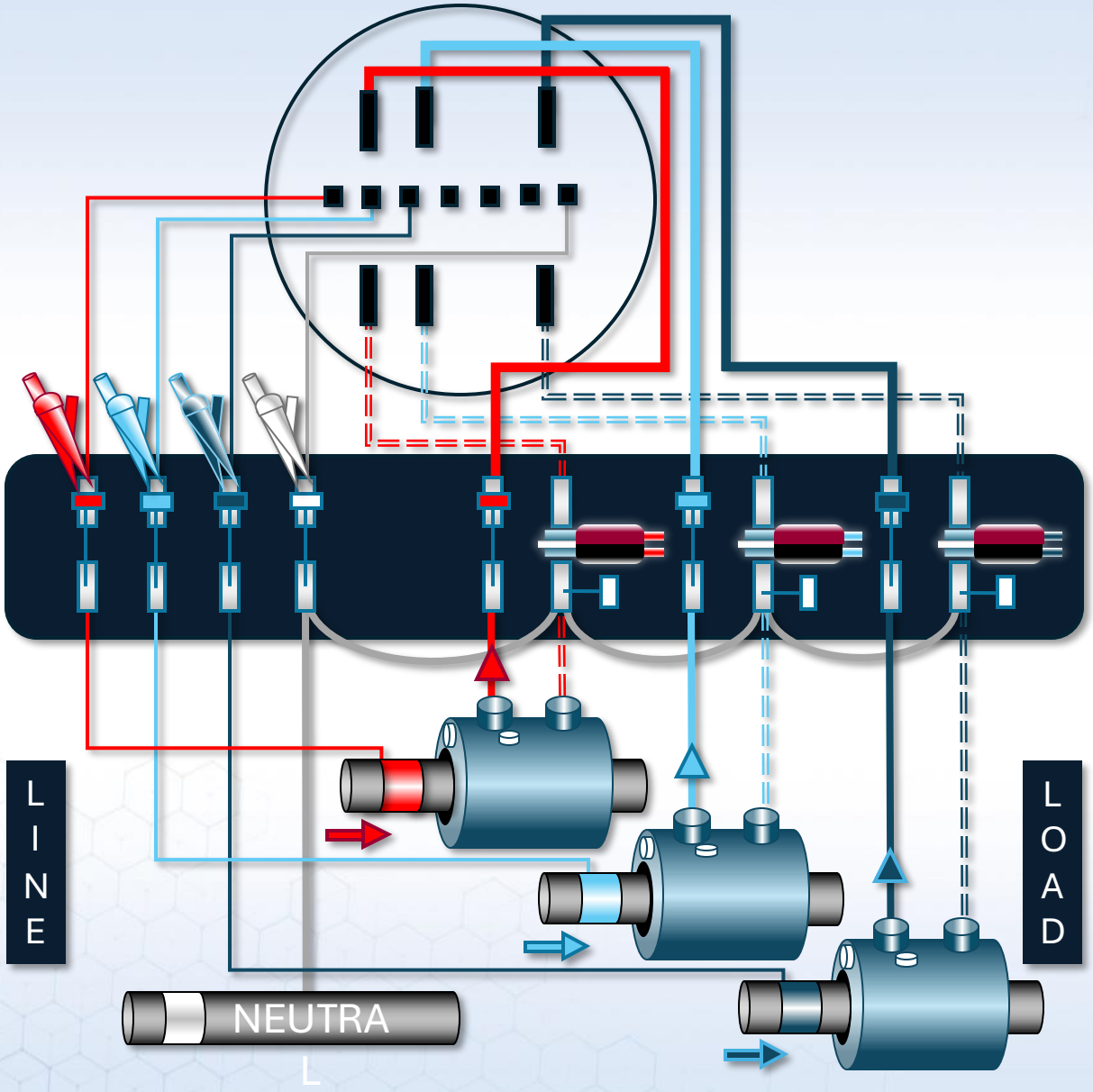
Secondary Current Connections

Engage Shunts on Test Switch ✓

Open Returns on Test Switch ✓

Insert Duckbill Probes ✓

Disengage Shunts



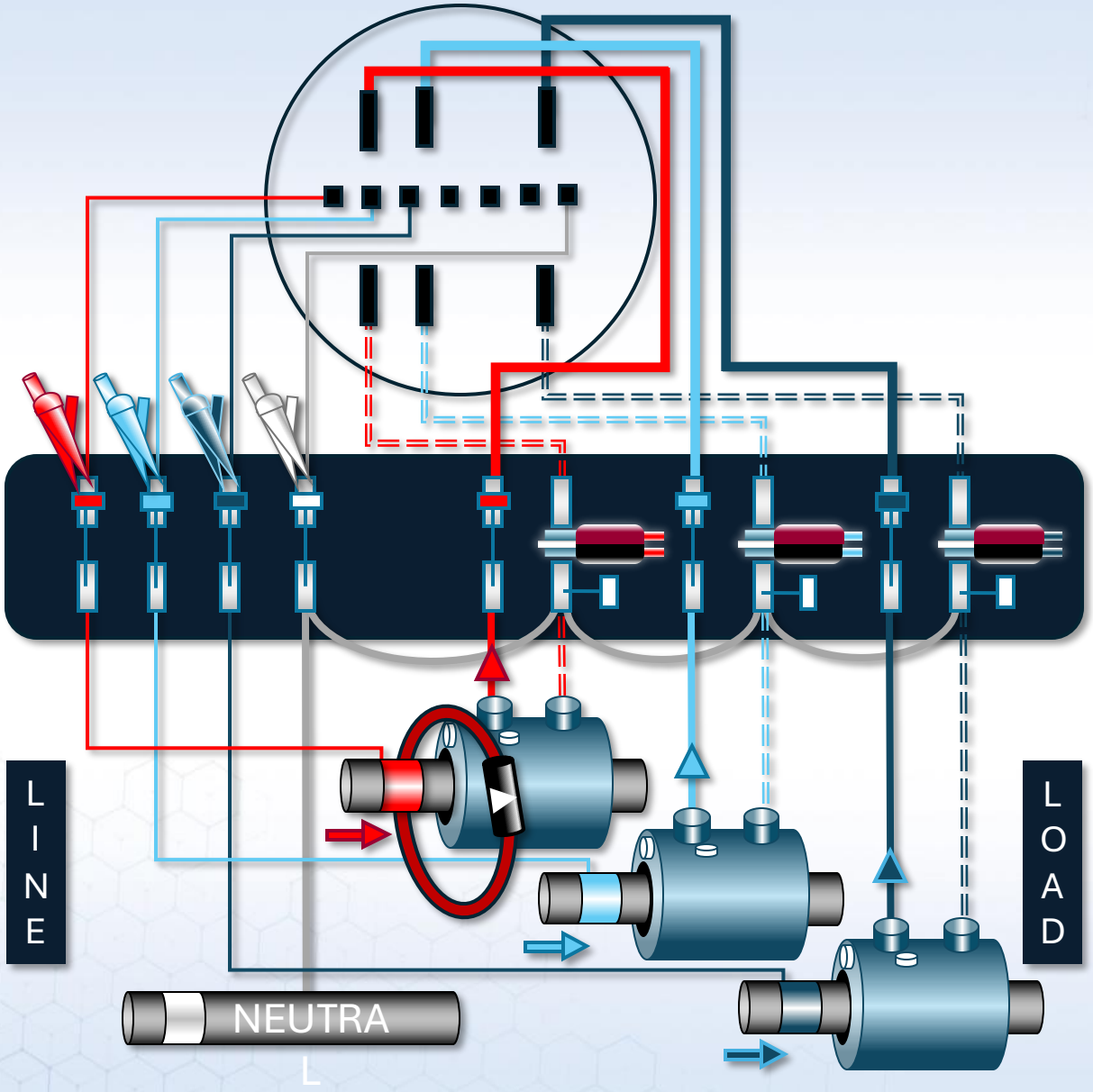
Customer Load Testing

Secondary Connections

Meter and Test Equipment

- Same Voltages
- Same Currents
- Same Phase Angles
- Same Power & Energy
- Same Harmonics

* If No Wiring Errors!



Customer Load Testing

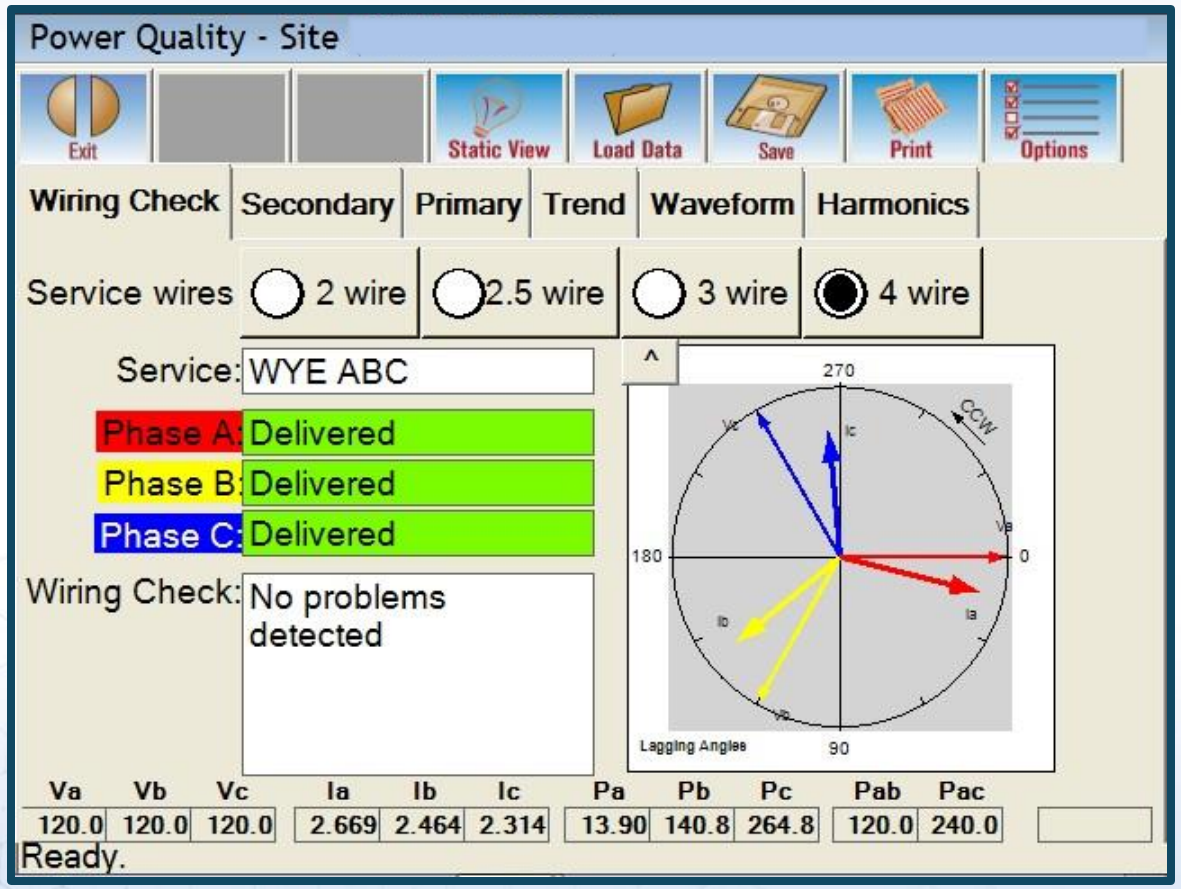
Primary Current Connections

Many Types of Probes

- Polarity Sensitive
- Rogowski Coils (Flex Probes)
- Large Diameter Clamps
- High Voltage Current Probes
  - Overhead or HV on Hotstick
  - Safe Distance Requirements

Customer Load Testing

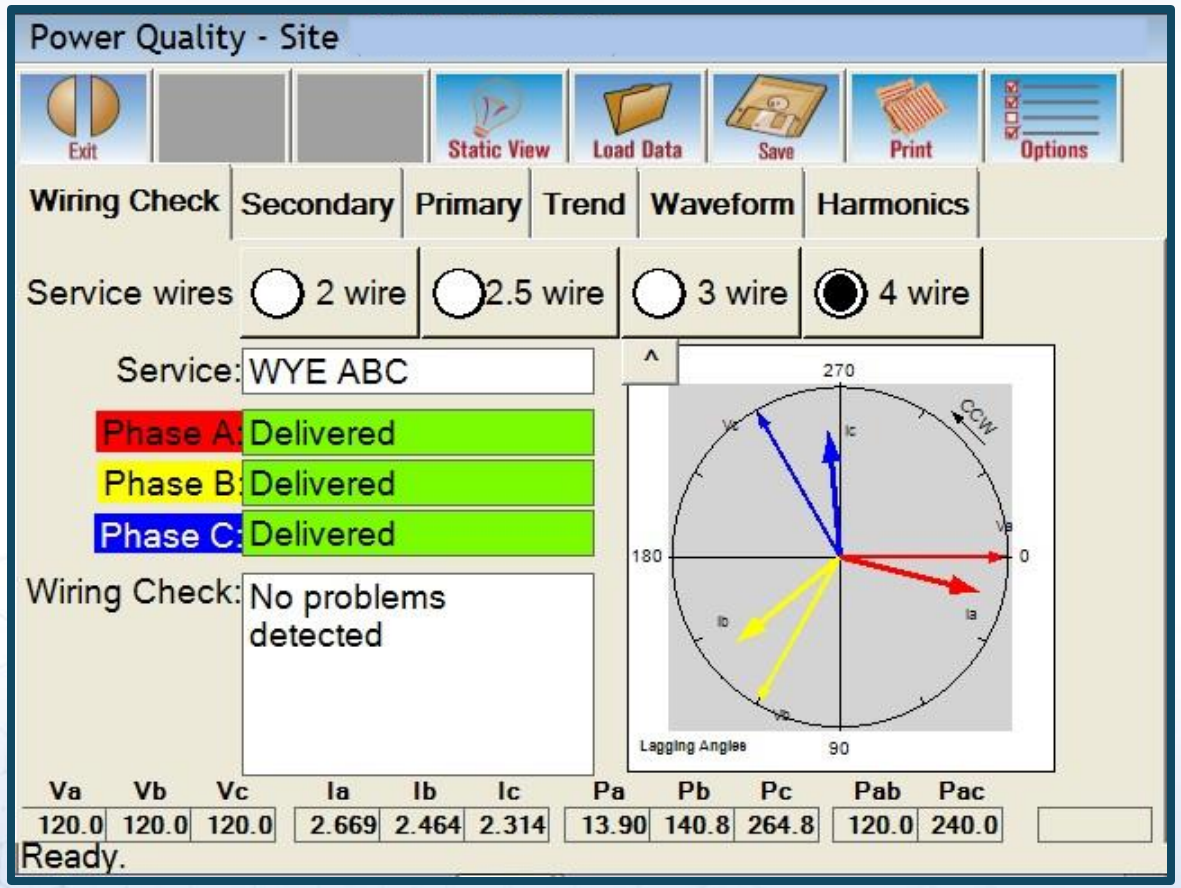
Vector and RMS Values

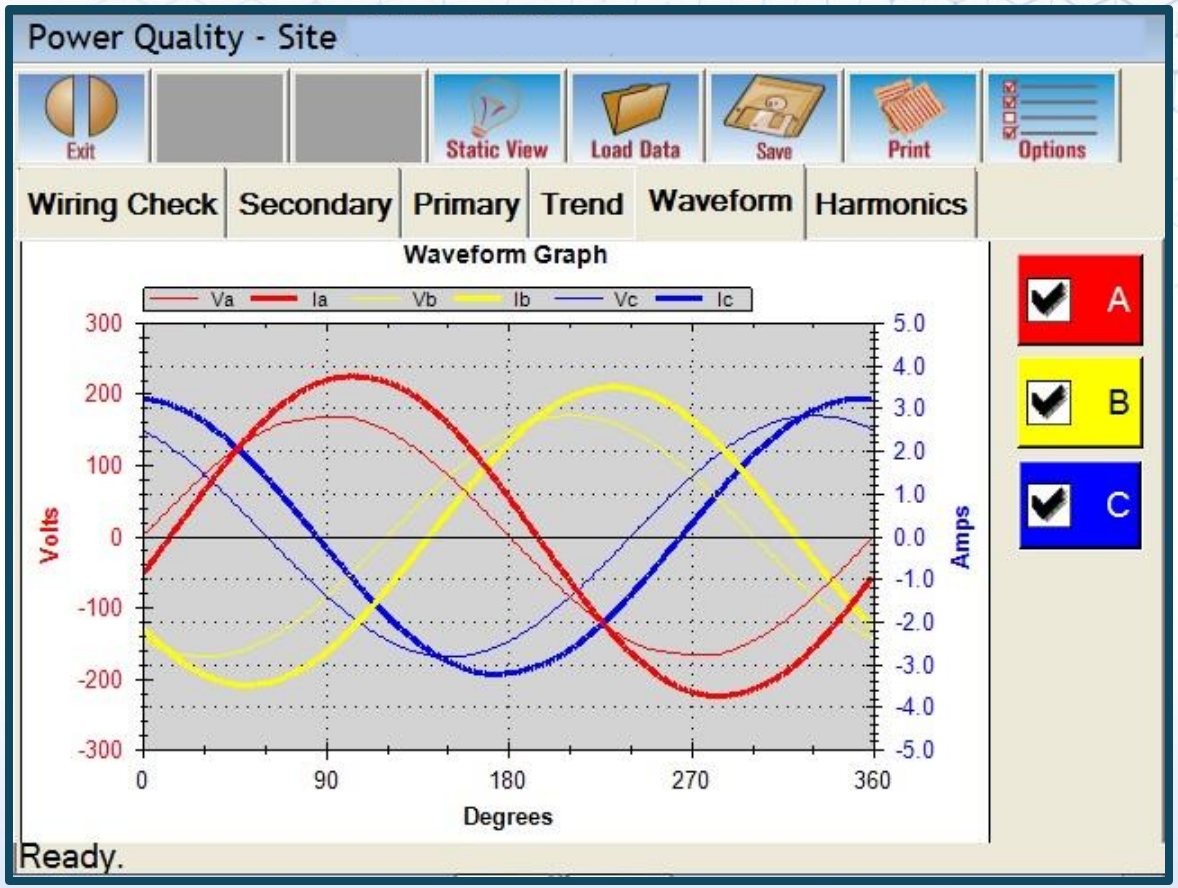


Instantaneous	A	B	C	Net
Volts:	120.00	120.00	119.99	
Amps:	2.6649	2.4652	2.2948	
V L-L & NeuA:	207.85	207.94	207.73	0.4816
Phase:	13.900	140.85	264.75	19.575
P.F.:	0.9706	0.9344	0.9080	0.9422
Delta Phase:		120.00	240.00	
Freq:	60.000	59.999	60.000	
Voltage THD:	0.9597	0.1837	0.2146	
Current THD:	0.4465	0.2820	0.7319	
WATTS:	310.38	276.42	250.02	837.46
VARS:	76.886	105.38	115.33	297.79
VA:	319.78	295.83	275.35	891.61

Customer Load Testing

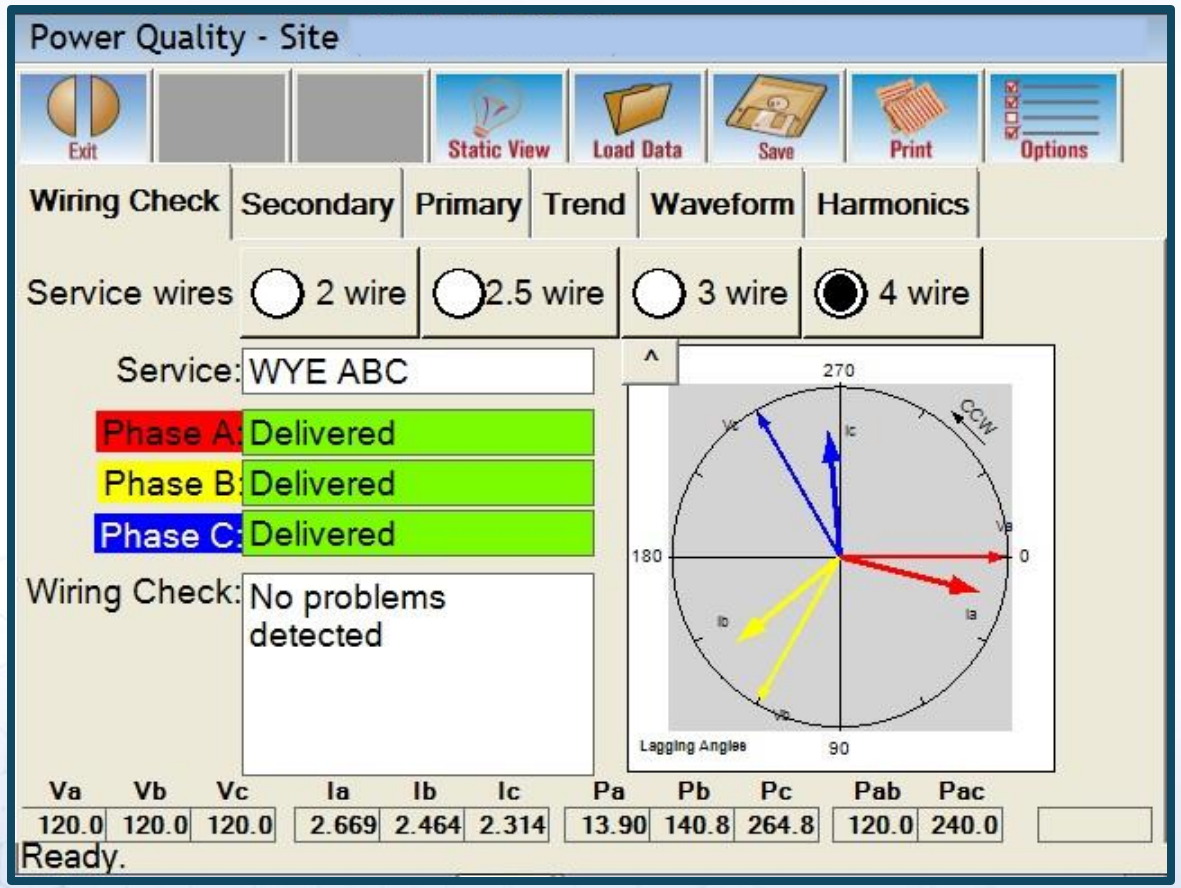
Vector and Waveforms

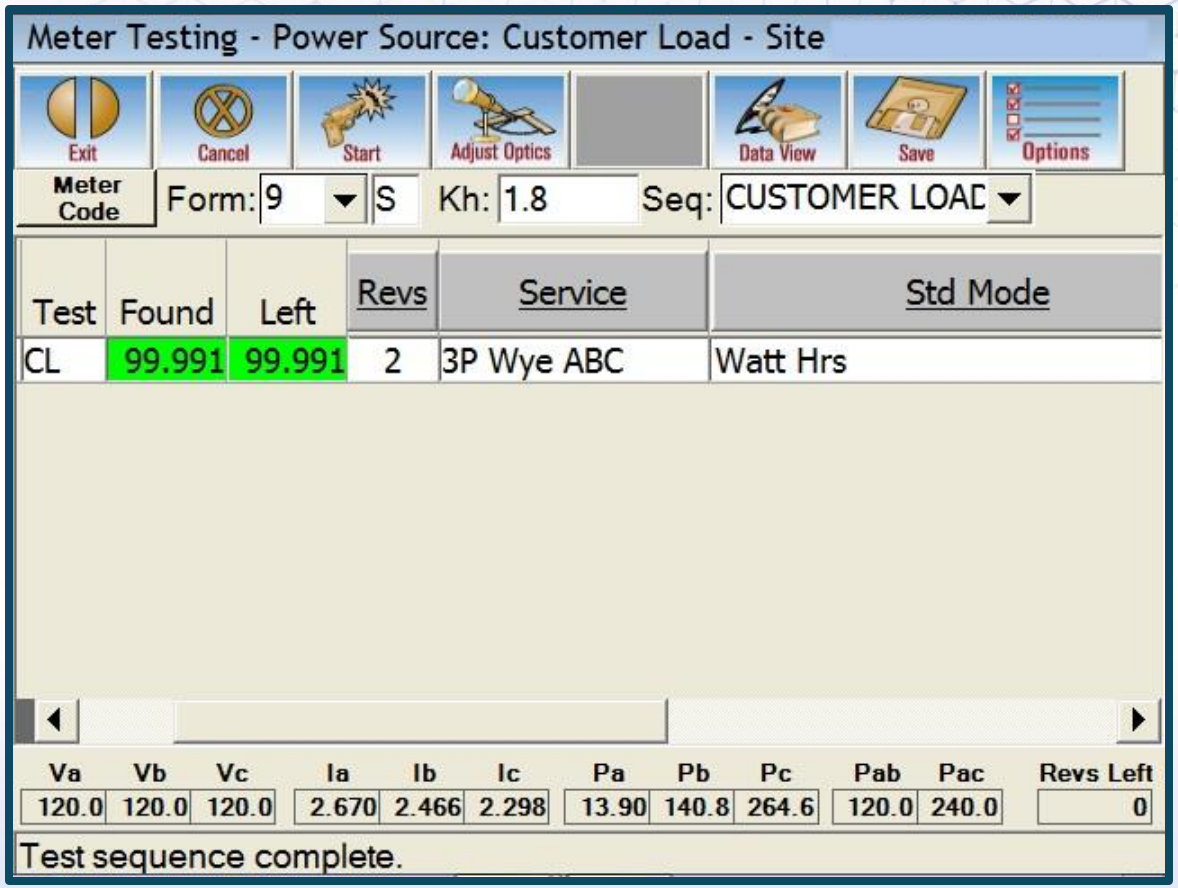




Customer Load Testing

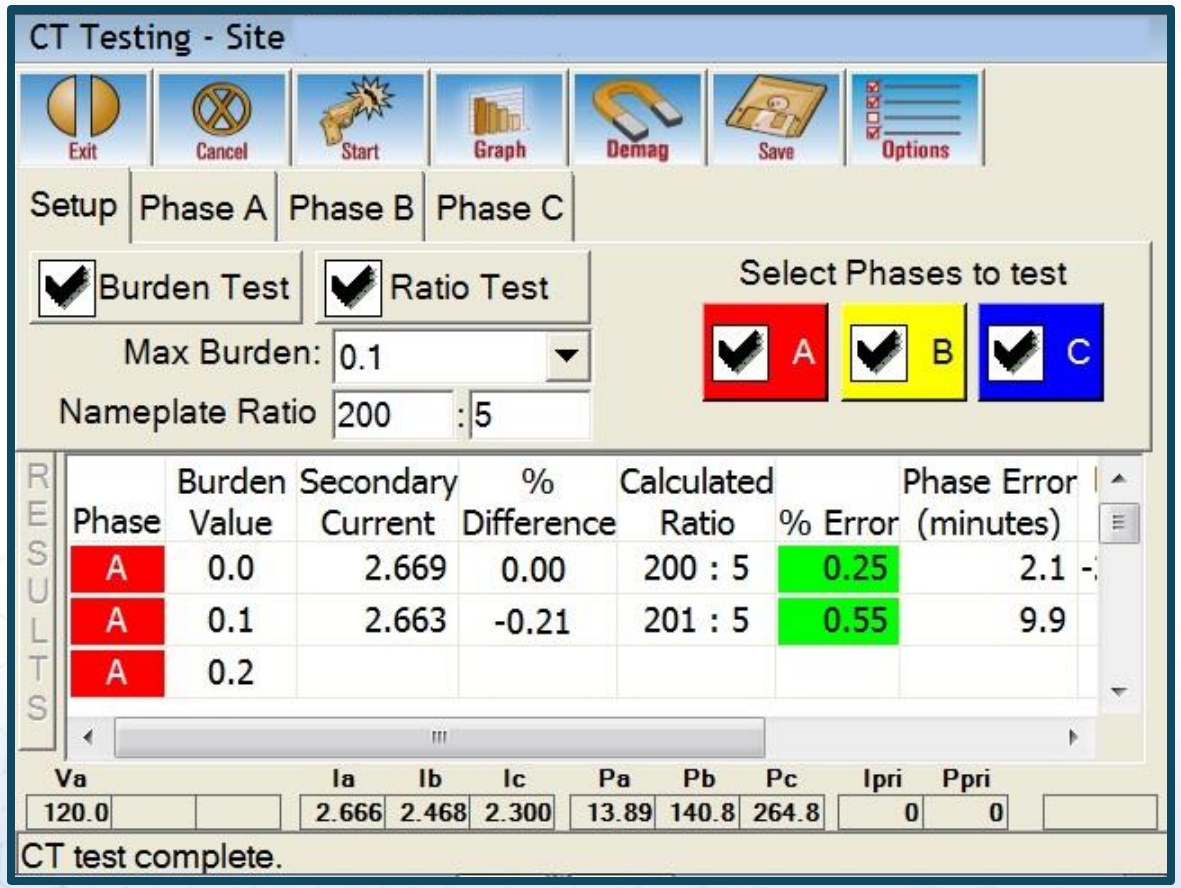
Vector and Customer Load Meter Test

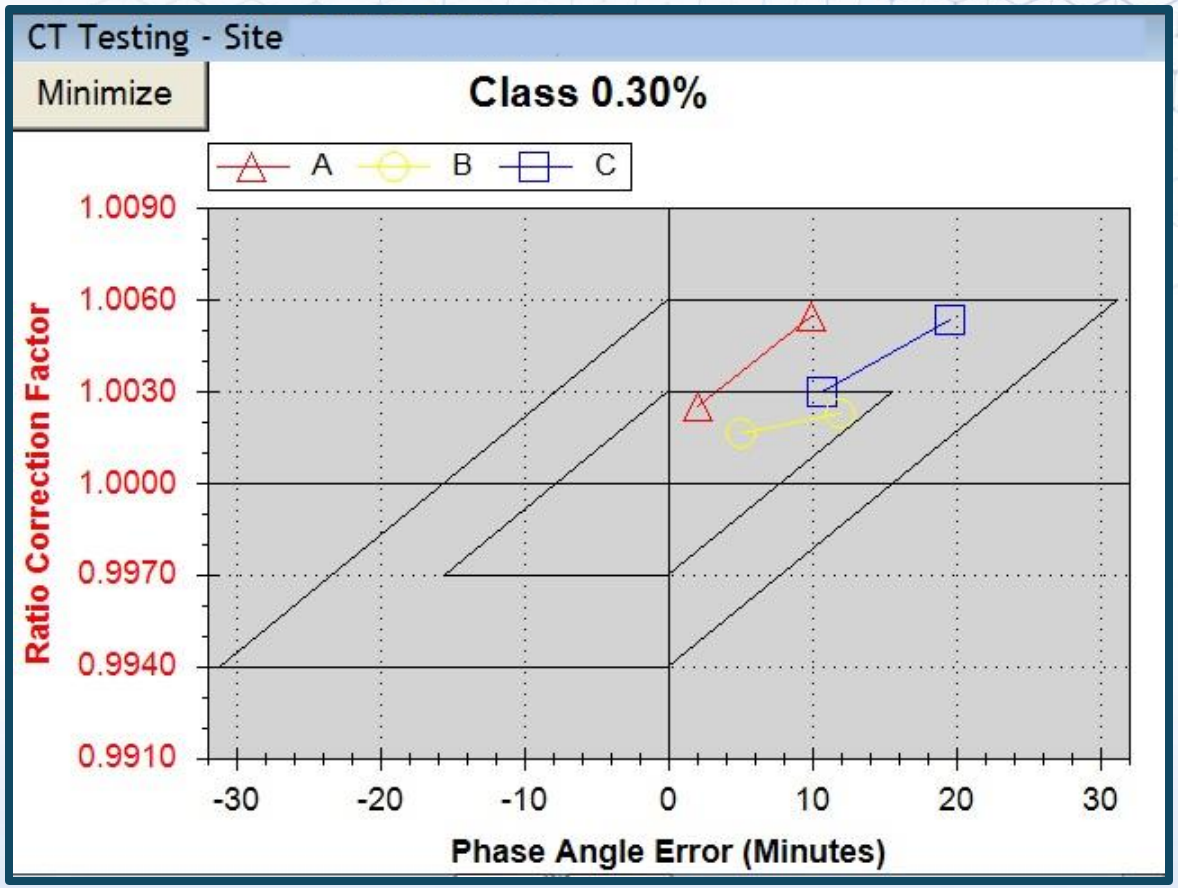




Customer Load Testing

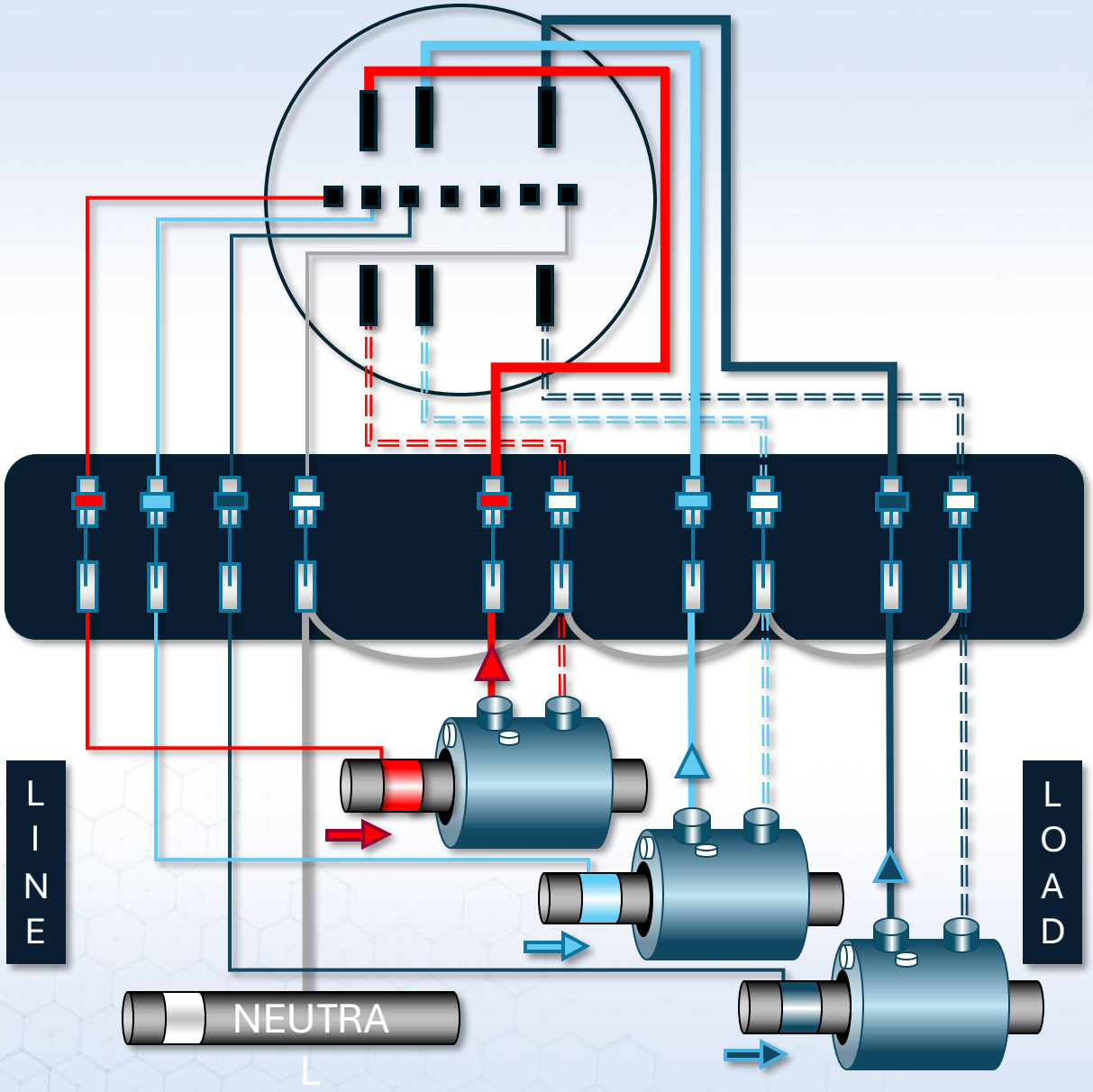
CT Ratio with Added Burden





Test Switch Connections

Phantom Load Testing

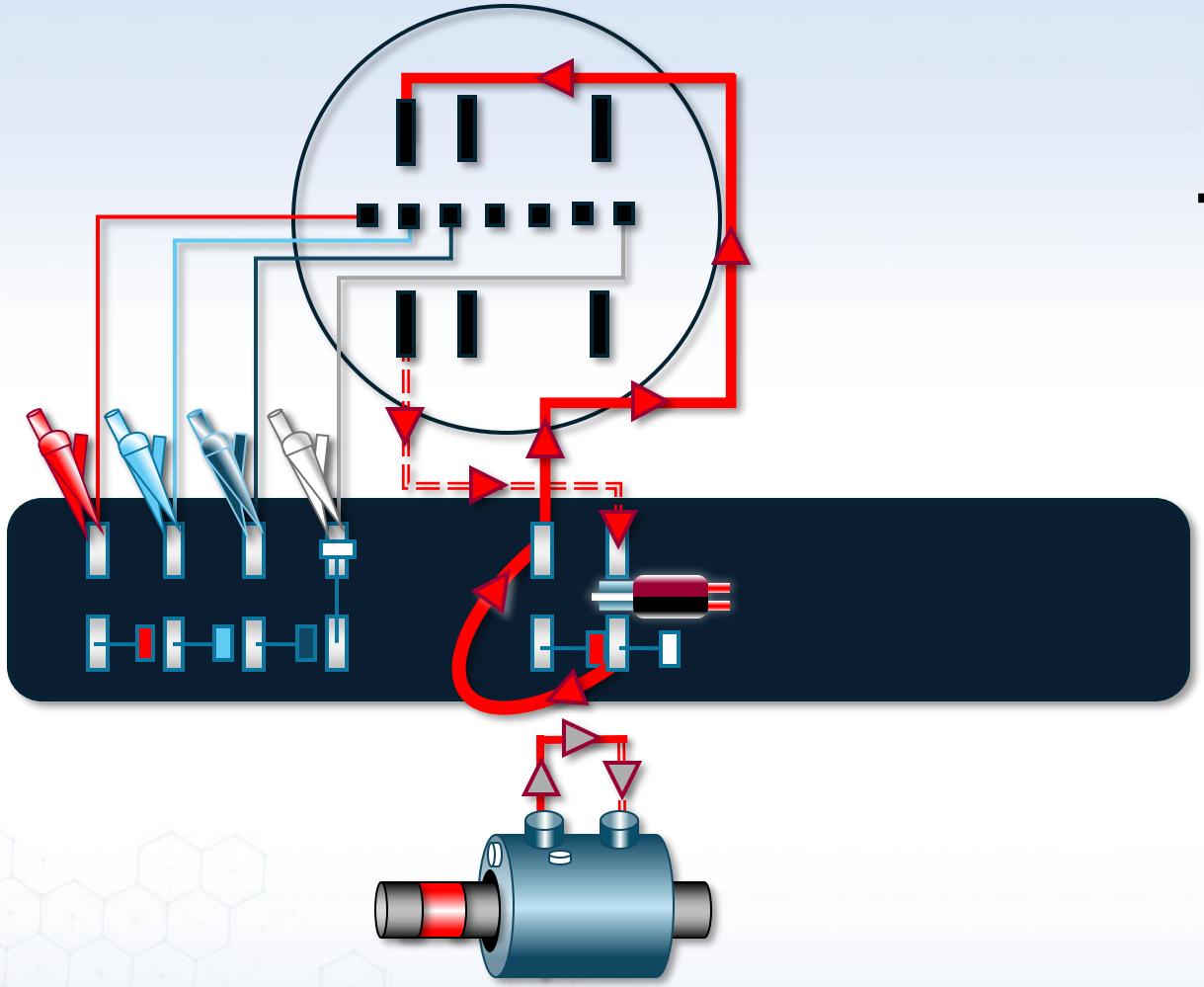


Phantom Load Testing

Phantom Load Meter Testing

- ANSI FL, PF, LL
- Sinusoidal Voltage, Current
- New ANSI Harmonics
- Full 4 Quadrant Testing
- Element Testing
- Wh, VARh, VAh, A^2h, etc.
- Testing through Test Switch Uses Installed Wiring and Connections (Billing)

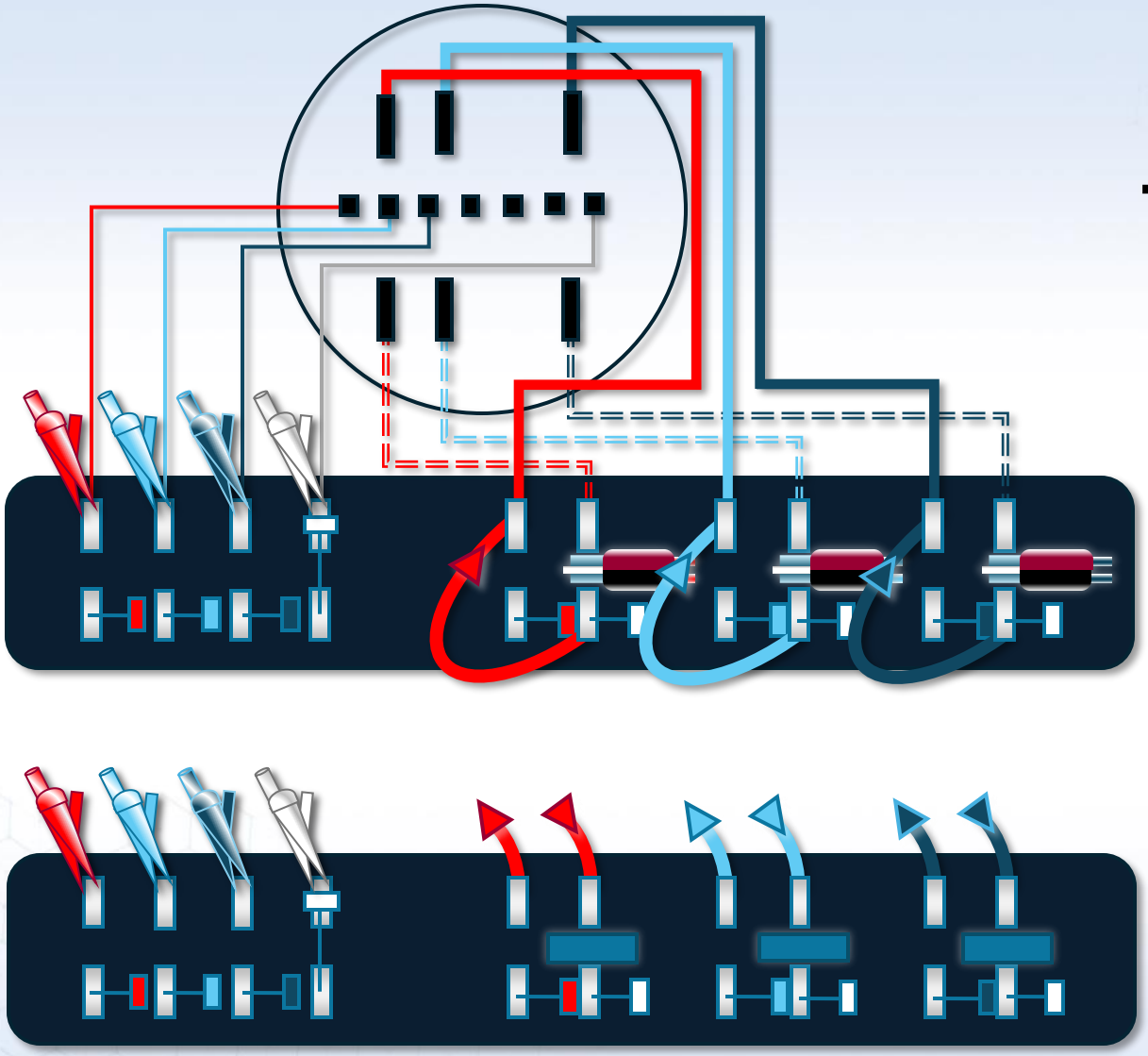
Phantom Load Testing



Applicable for True Three Phase Voltage and Current Source Only!

Phantom Load Meter Testing

- Open Voltage Blades on Test Switch
- Engage Current Shunts on Test Switch and DO NOT RE-ENGAGE
- Open Current Returns on Test Switch
- Insert Duckbills
- Install Current Jumpers



Phantom Load Testing

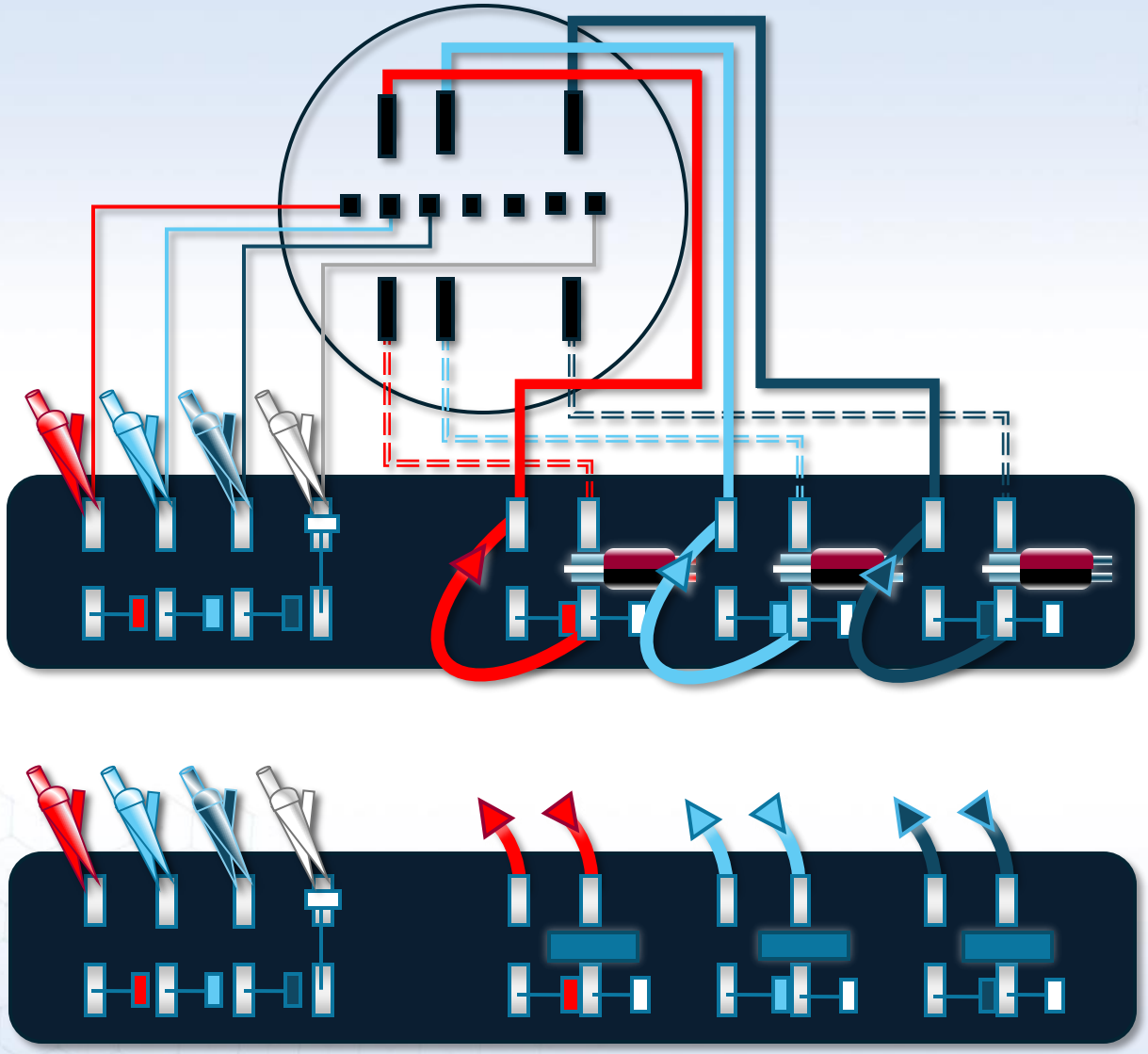
Phantom Load Meter Testing

- Open Voltage Blades
- Engage Current Shunts
- Open Returns
- Insert Duckbills
- Install Current Jumpers

  -Or

  Use Isolators and Source Directly to Top of Switch

Phantom Load Testing



Meter Testing - Power Source: RW-31 - Site

Exit | Cancel | Start | Adjust Optics | Creep | Data View | Save | Options

Meter Code | Form: 9 | S | Kh: 1.8 | Seq: 9S FL PF LL Wh

Test	Found	Volts	Amps	Phase Angle	Revs	Service	
FL	99.983	120.0	2.5	0.0	5	3P Wye ABC	Watt Hrs
PF	99.979	120.0	2.5	60.0	2	3P Wye ABC	Watt Hrs
LL	99.996	120.0	0.25	0.0	1	3P Wye ABC	Watt Hrs

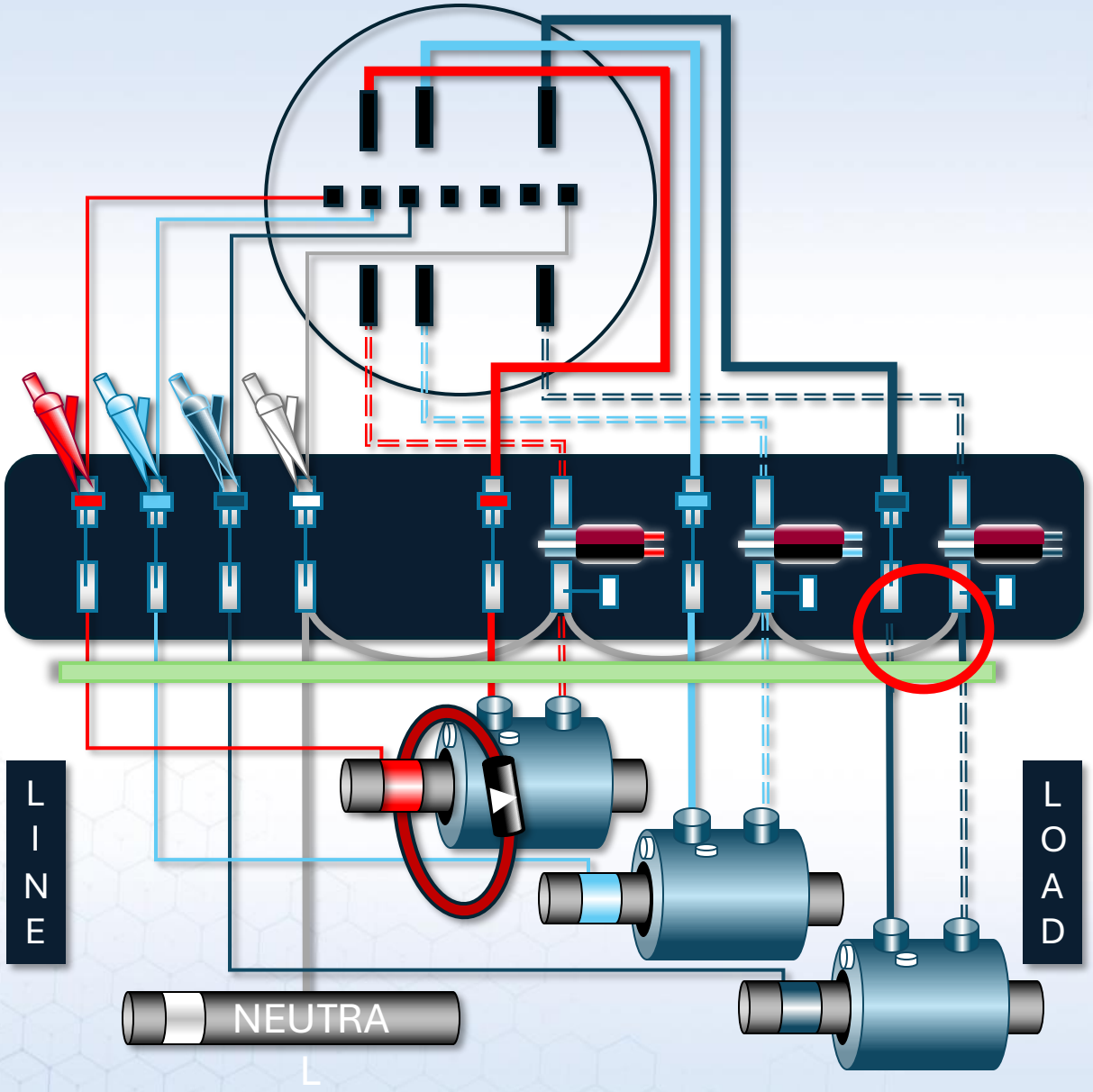
Va	Vb	Vc	Ia	Ib	Ic	Pa	Pb	Pc	Pab	Pac	Revs Left

Test sequence complete.

Revenue Loss Examples

Industrial Account
$15,000 Monthly
$180,000 Yearly
9S 3P4WY

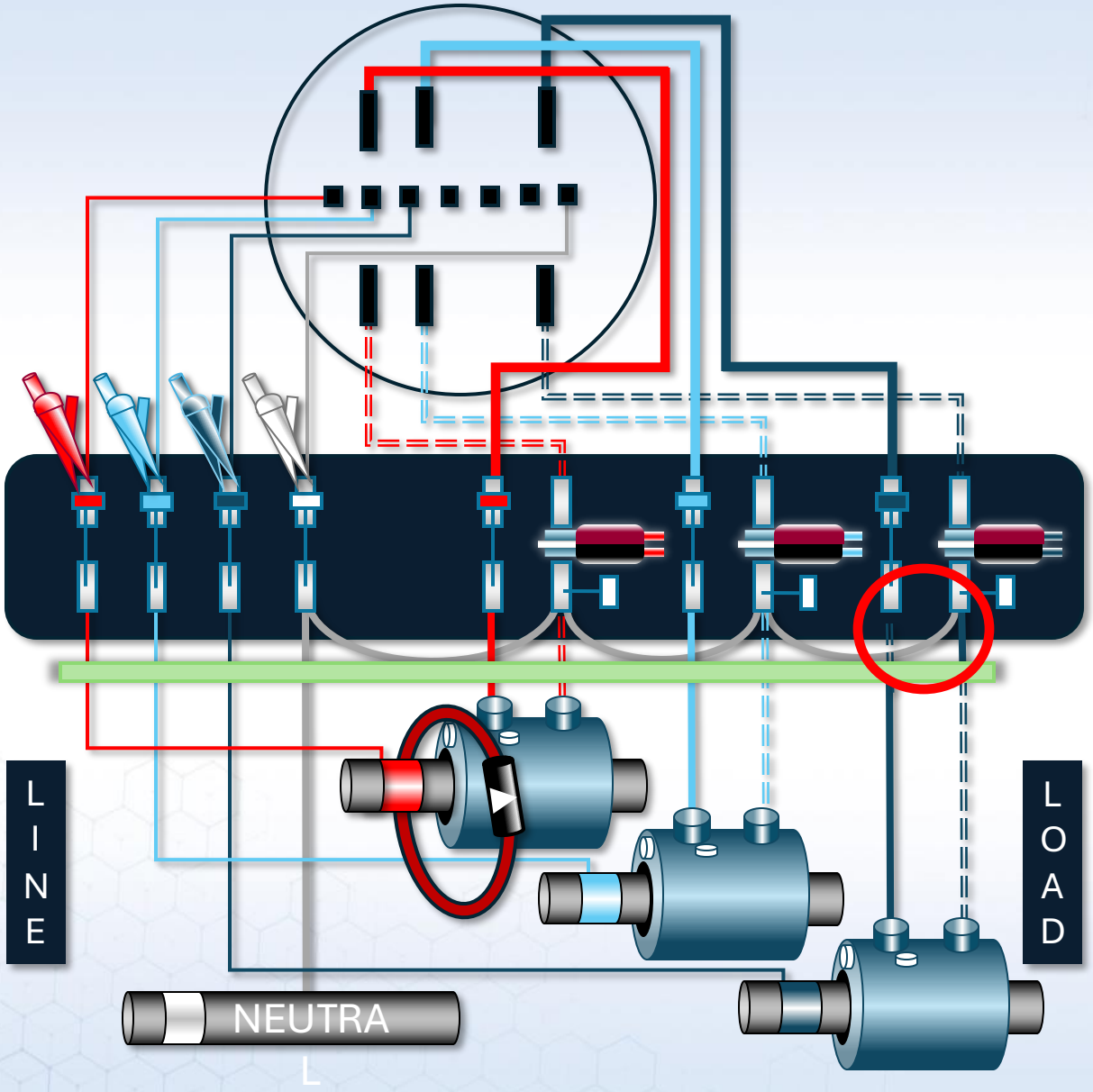
Examples of Possible Errors and Actual Revenue Loss



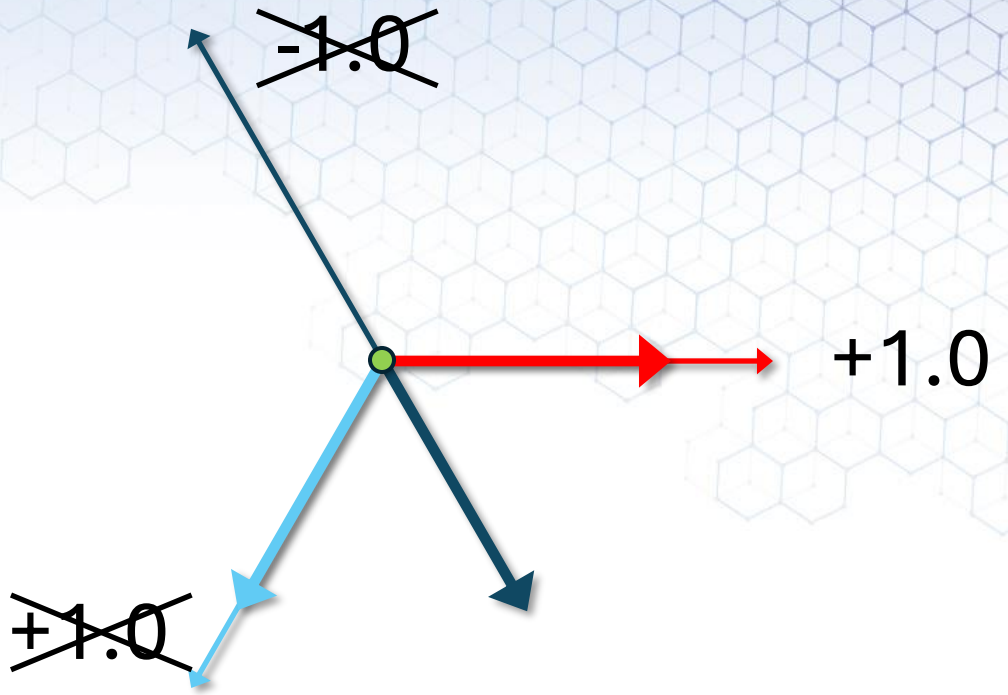
What is the Problem?

Phase C Secondary Current Wiring on Bottom of Test Switch

How Do We Estimate Loss?

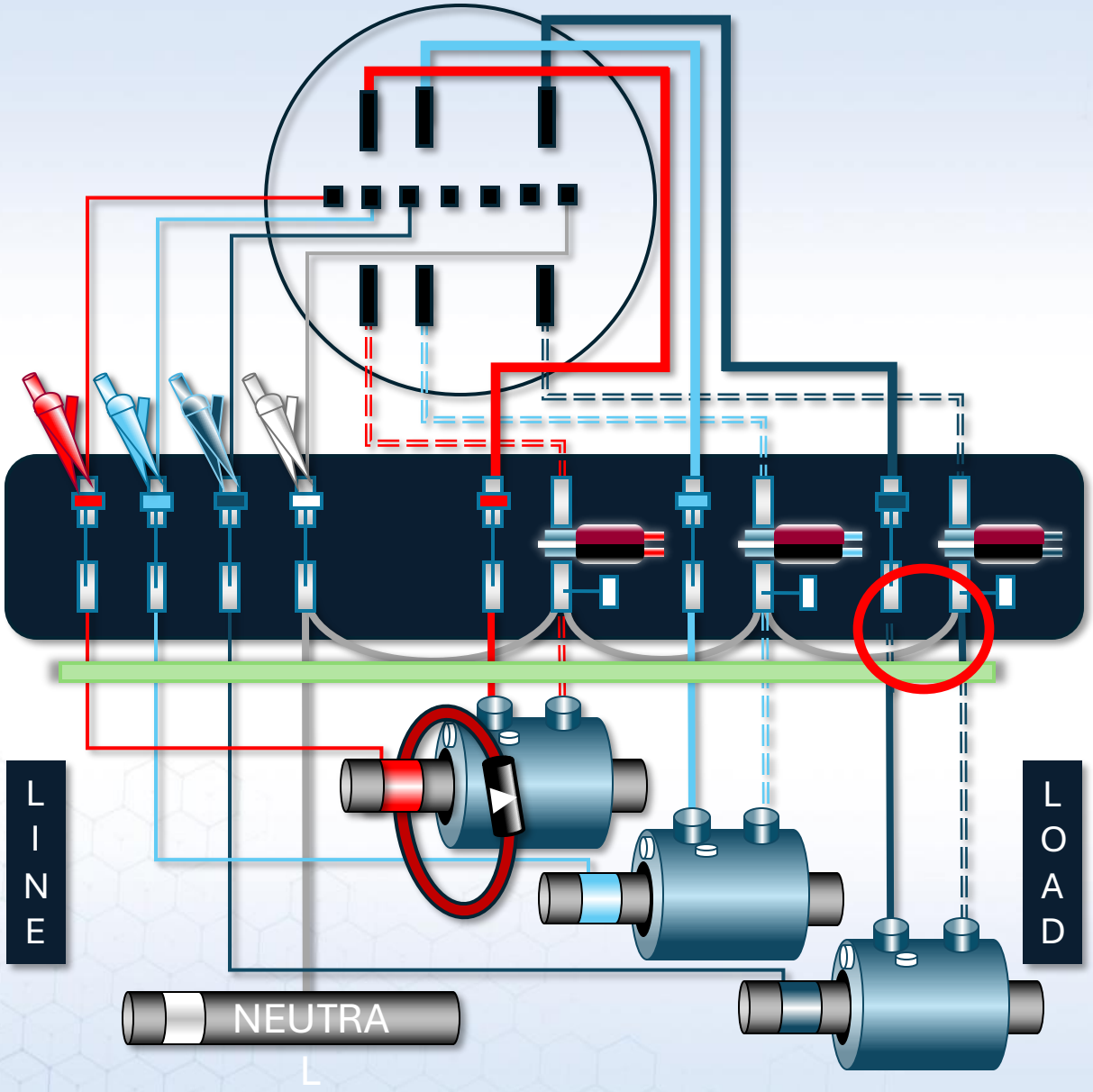


What PF Does the Meter See?



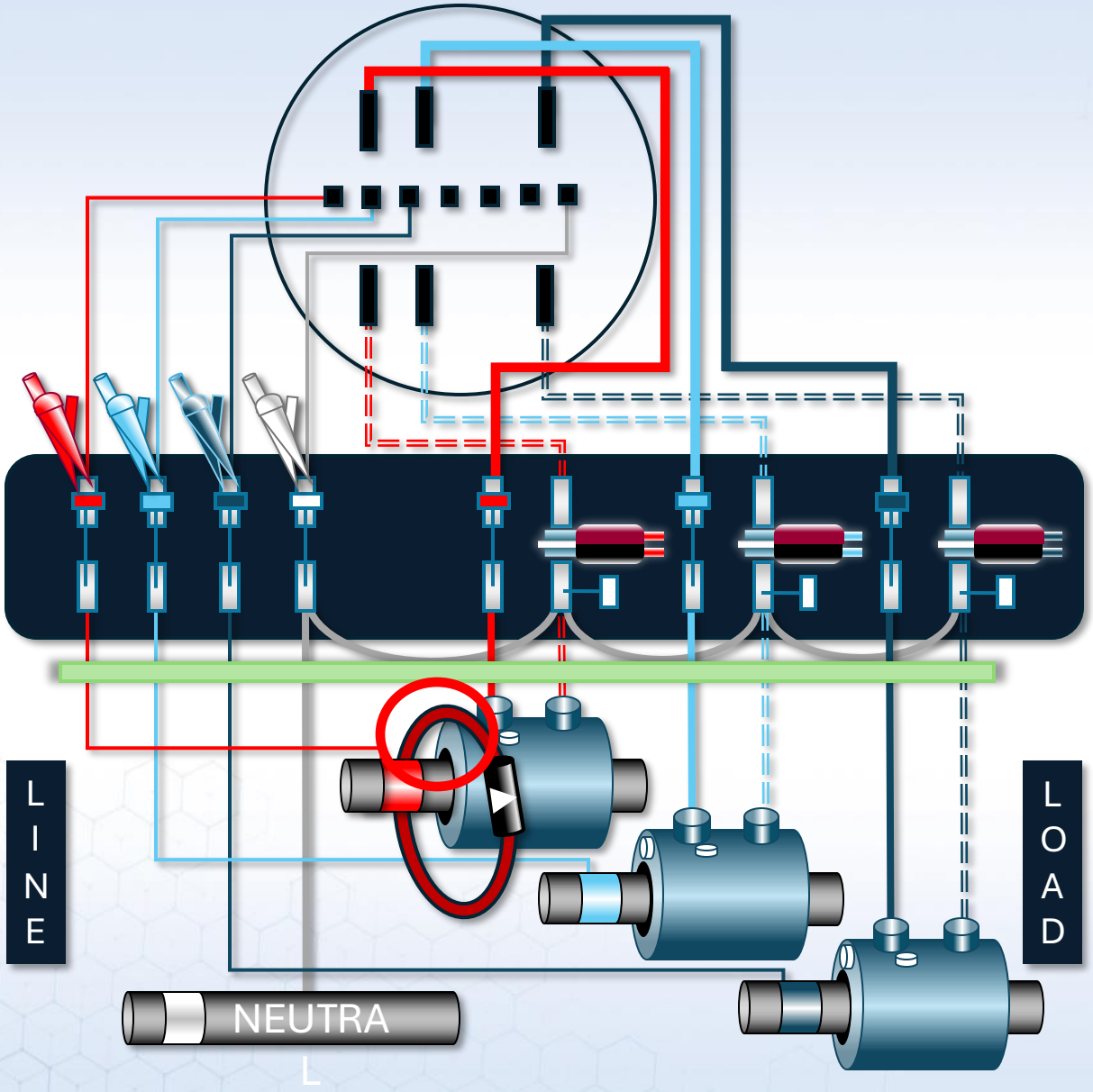
Equates to 2/3 LOSS

- $120k Yearly Loss



How can you find the error?

- ✓ Vector Diagram
- X Customer Load Meter Test
- X Phantom Load Meter Test
- X • Through Test Switch
- X • Remove Meter from Socket
- ✓ CT Ratio Test
- X CT Burden Test

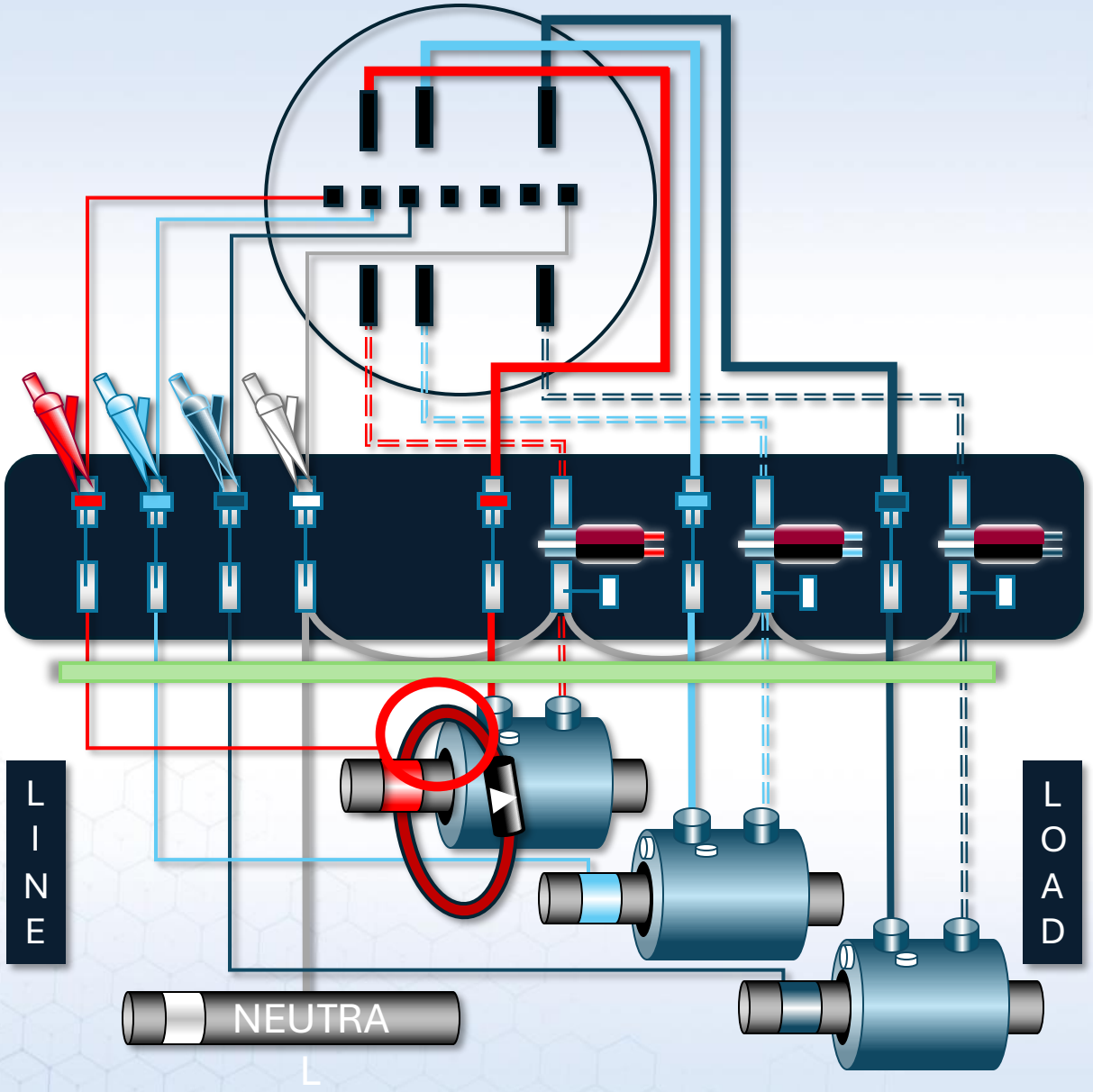


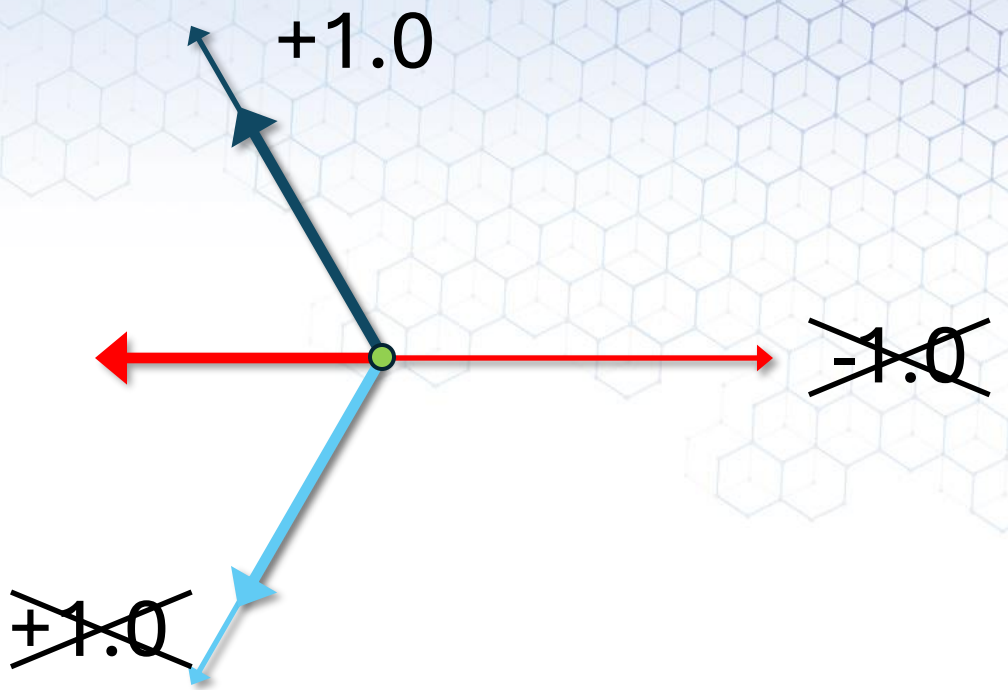
What is the Problem?

Phase A Primary Current Polarity Wiring Error

What is the Estimated Loss?

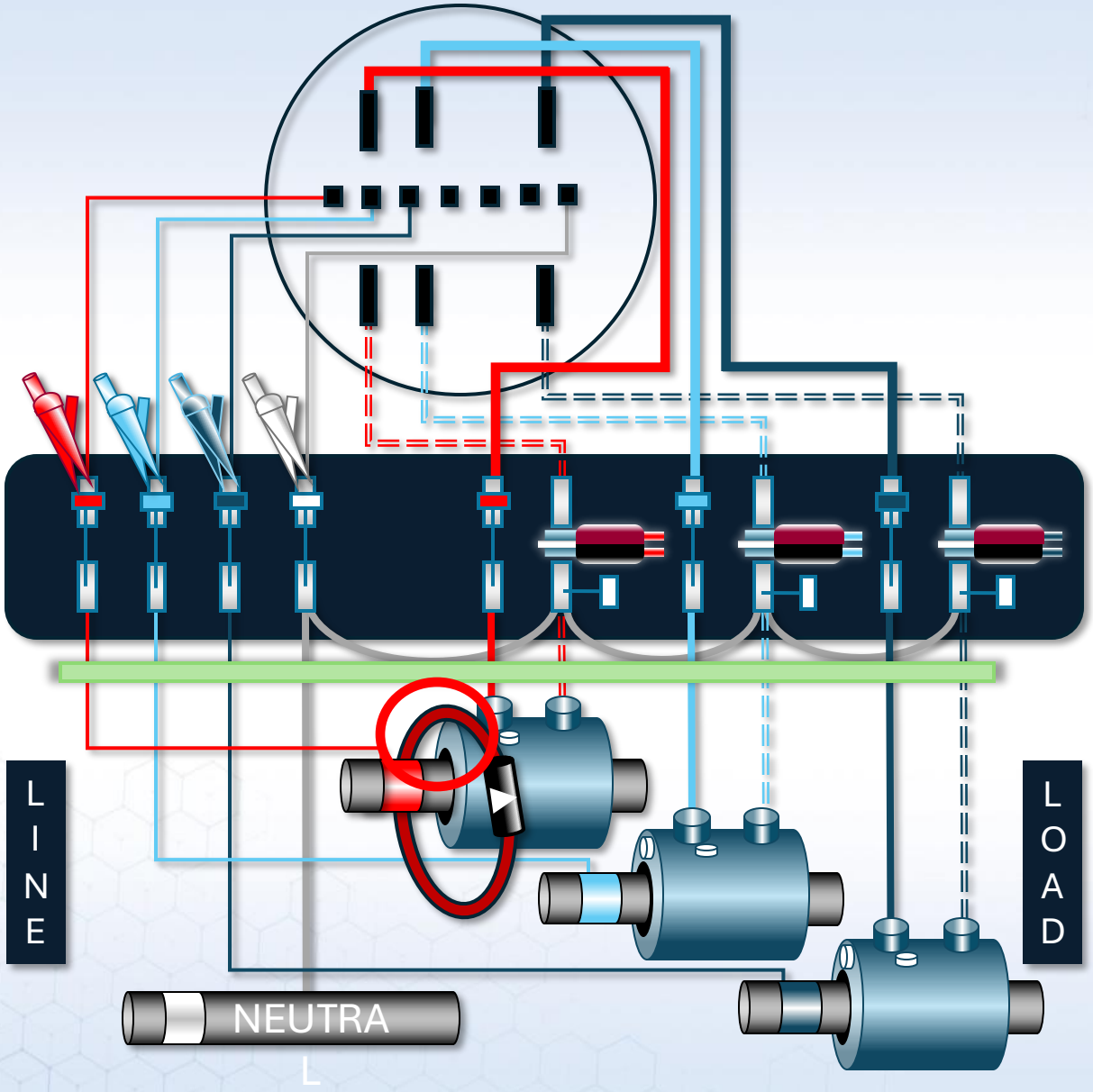
What PF Does the Meter See?





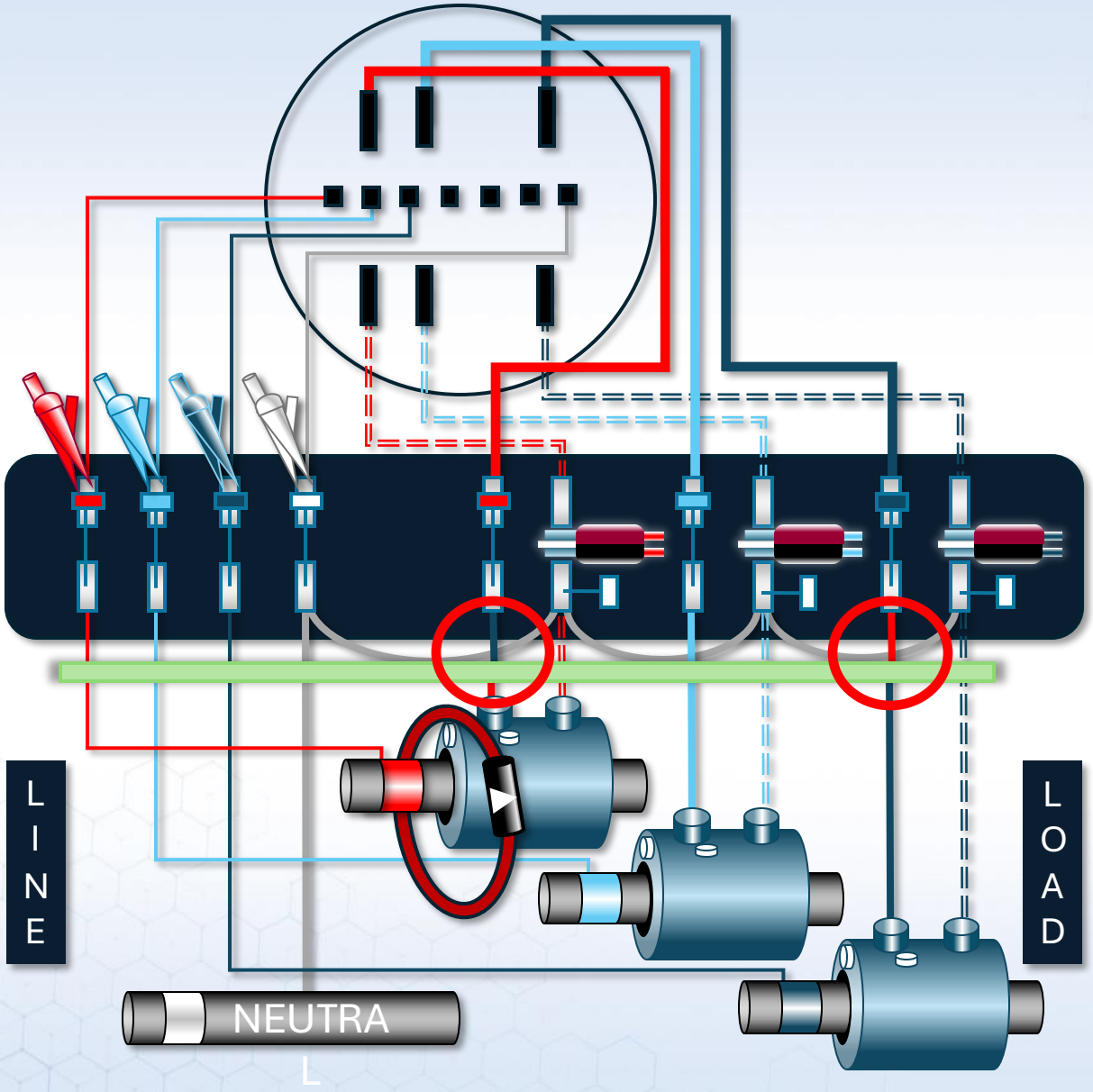
Equates to 2/3 LOSS

- $120k Yearly Loss



How can you find the error?

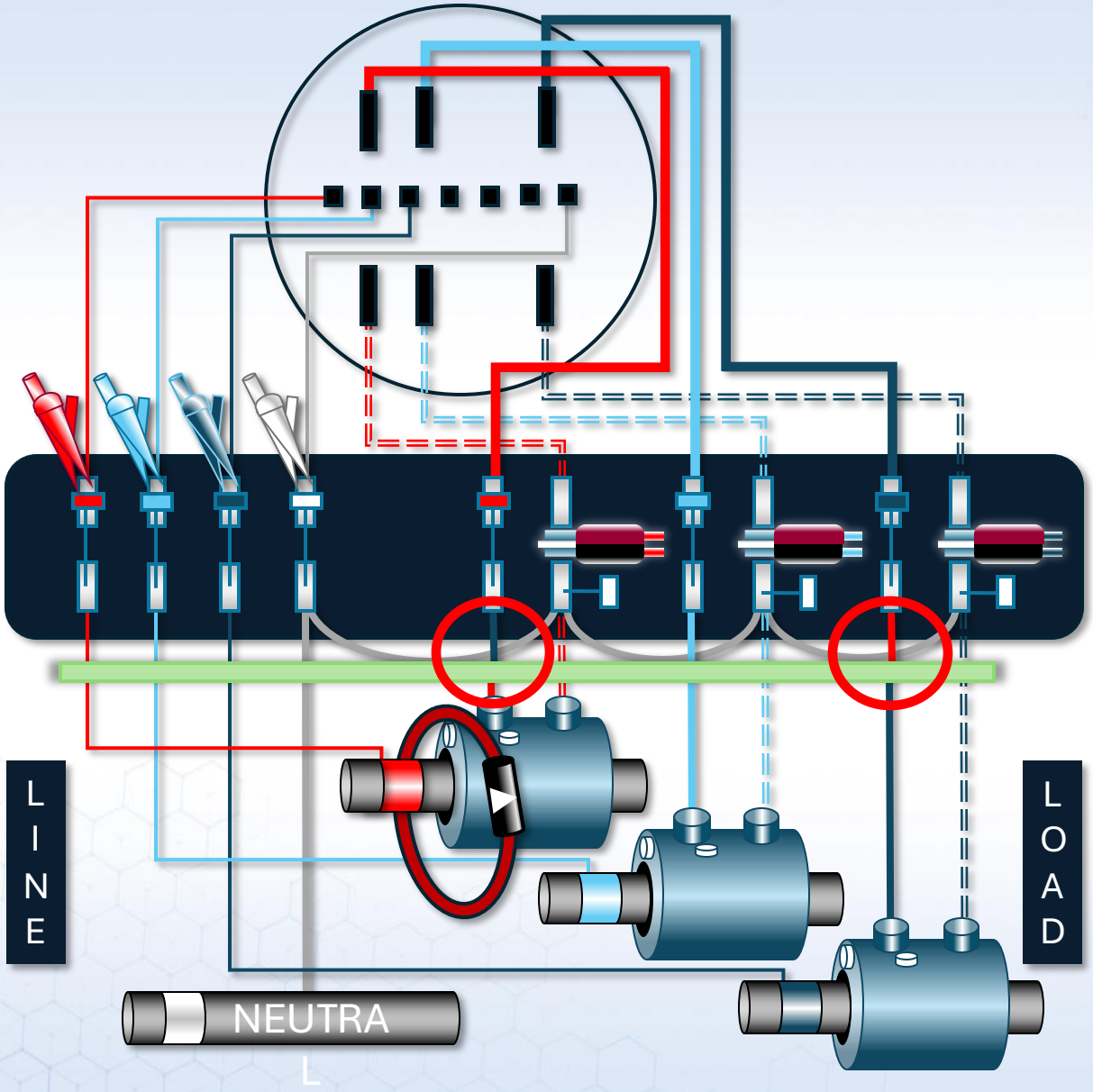
- ✓ Vector Diagram
  Customer Load Meter Test
  Phantom Load Meter Test
  - Through Test Switch
  - Remove Meter from Socket
- ✓ CT Ratio Test
  CT Burden Test



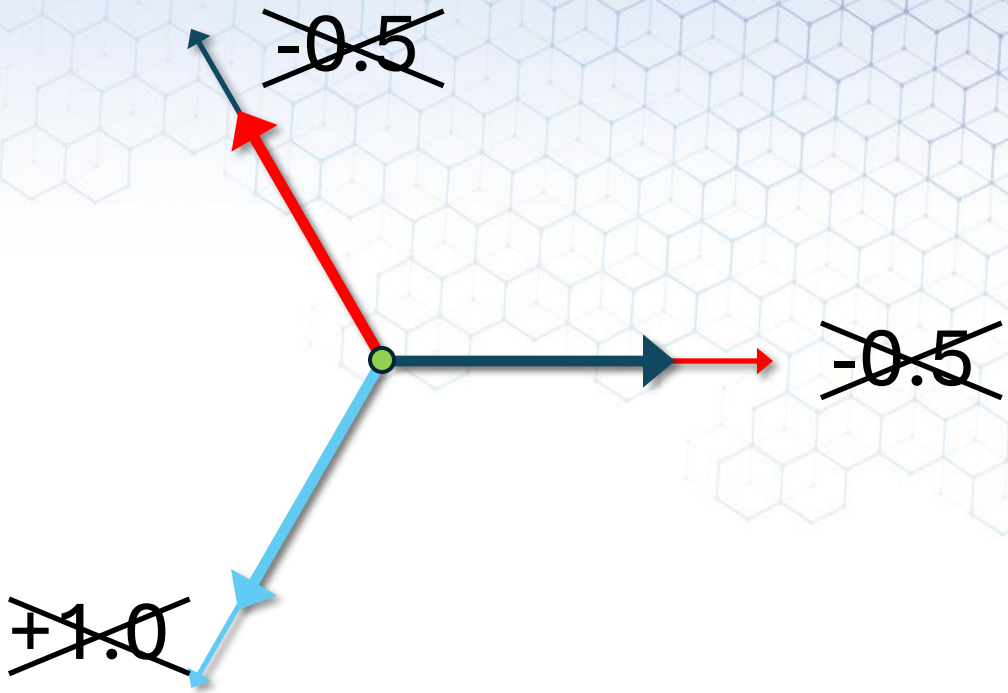
What is the Problem?

Phase A & C Cross Phase Wiring Error at Bottom of Test Switch

What is the Estimated Loss?

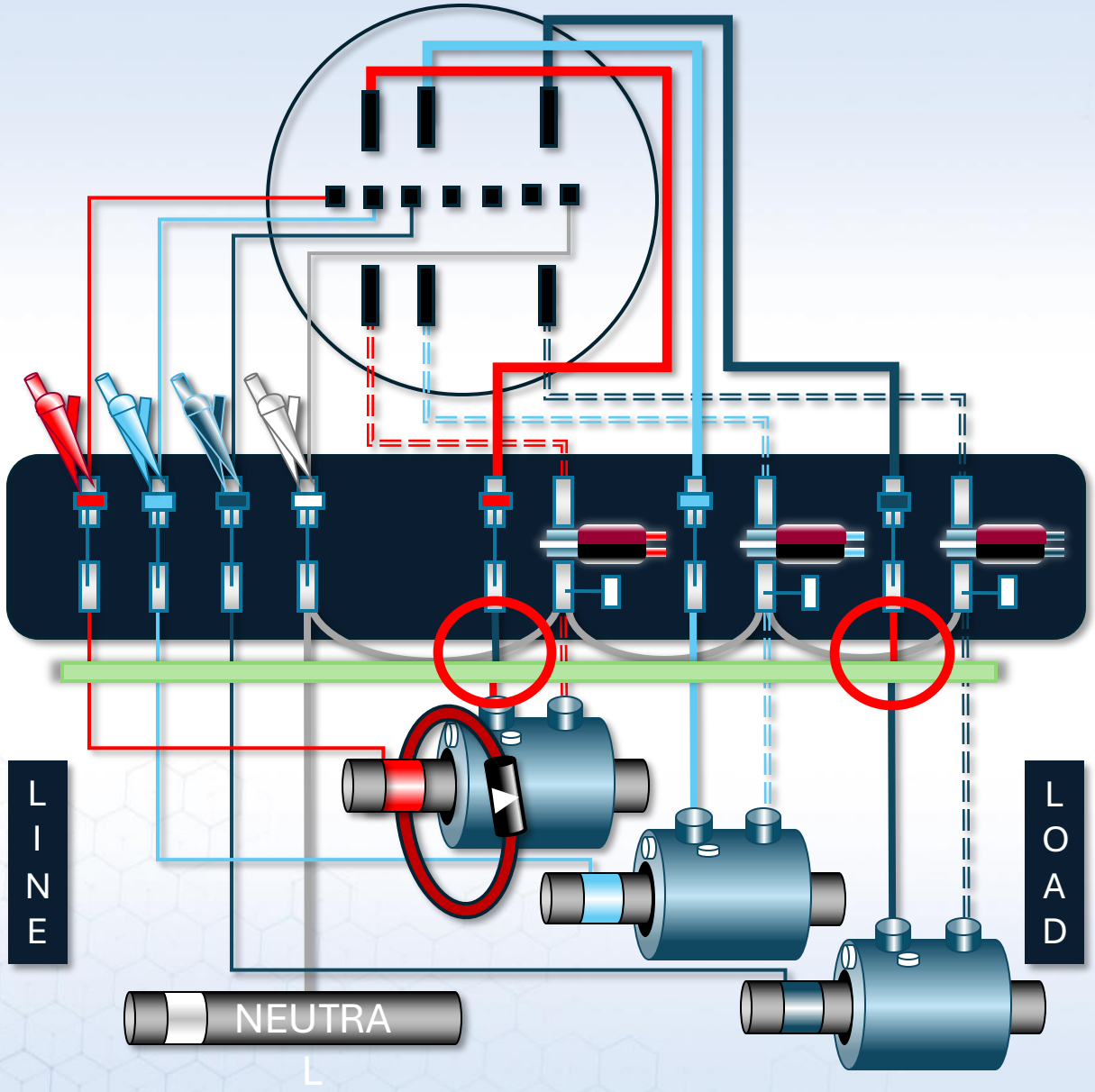


What PF Does the Meter See?



Equates to Total LOSS

- $180k Yearly Loss

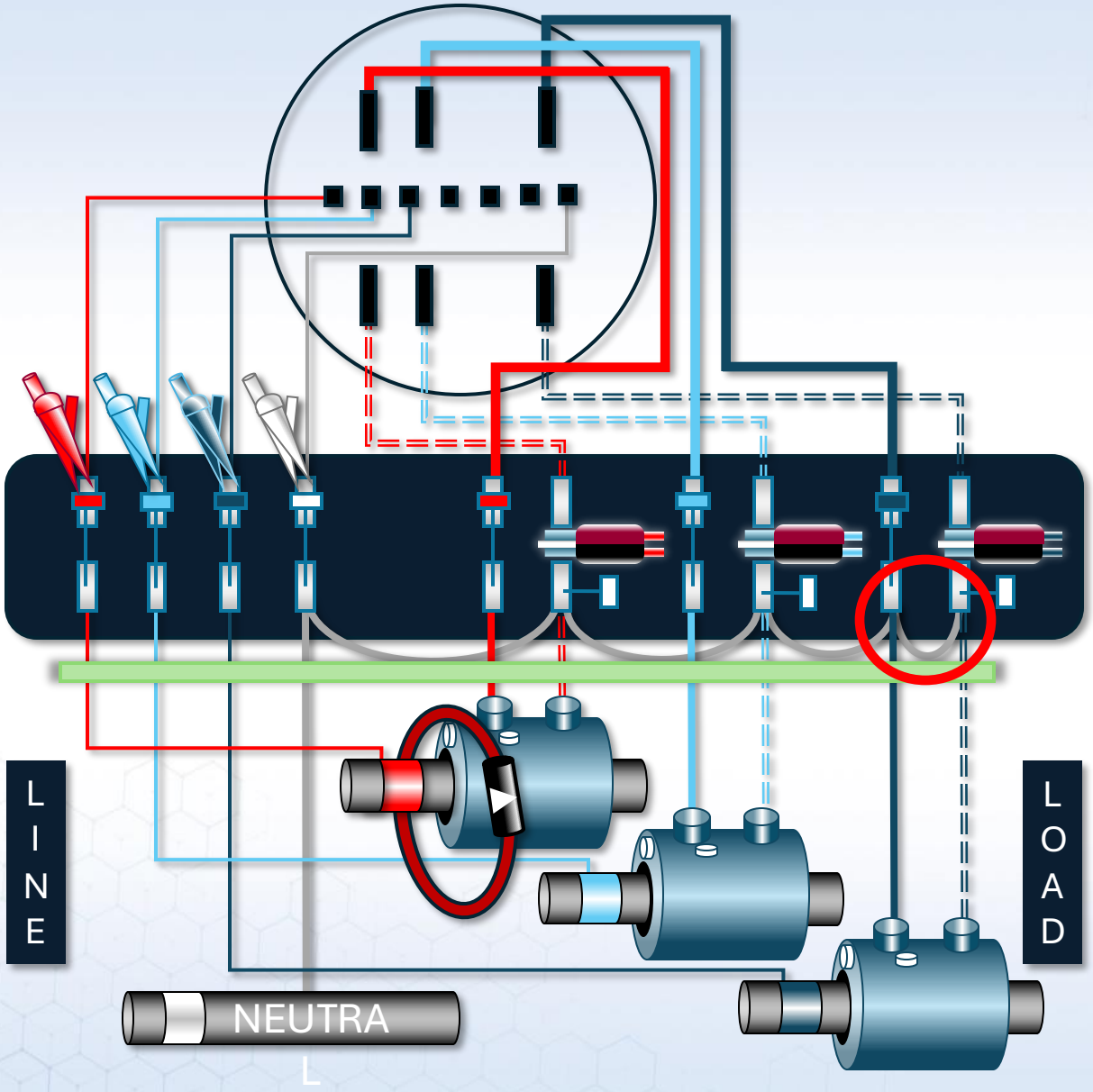


How can you find the error?

- ✓ Vector Diagram
- ✓ Customer Load Meter Test

  Phantom Load Meter Test
  - Through Test Switch
  - Remove Meter from Socket
- ✓ CT Ratio Test

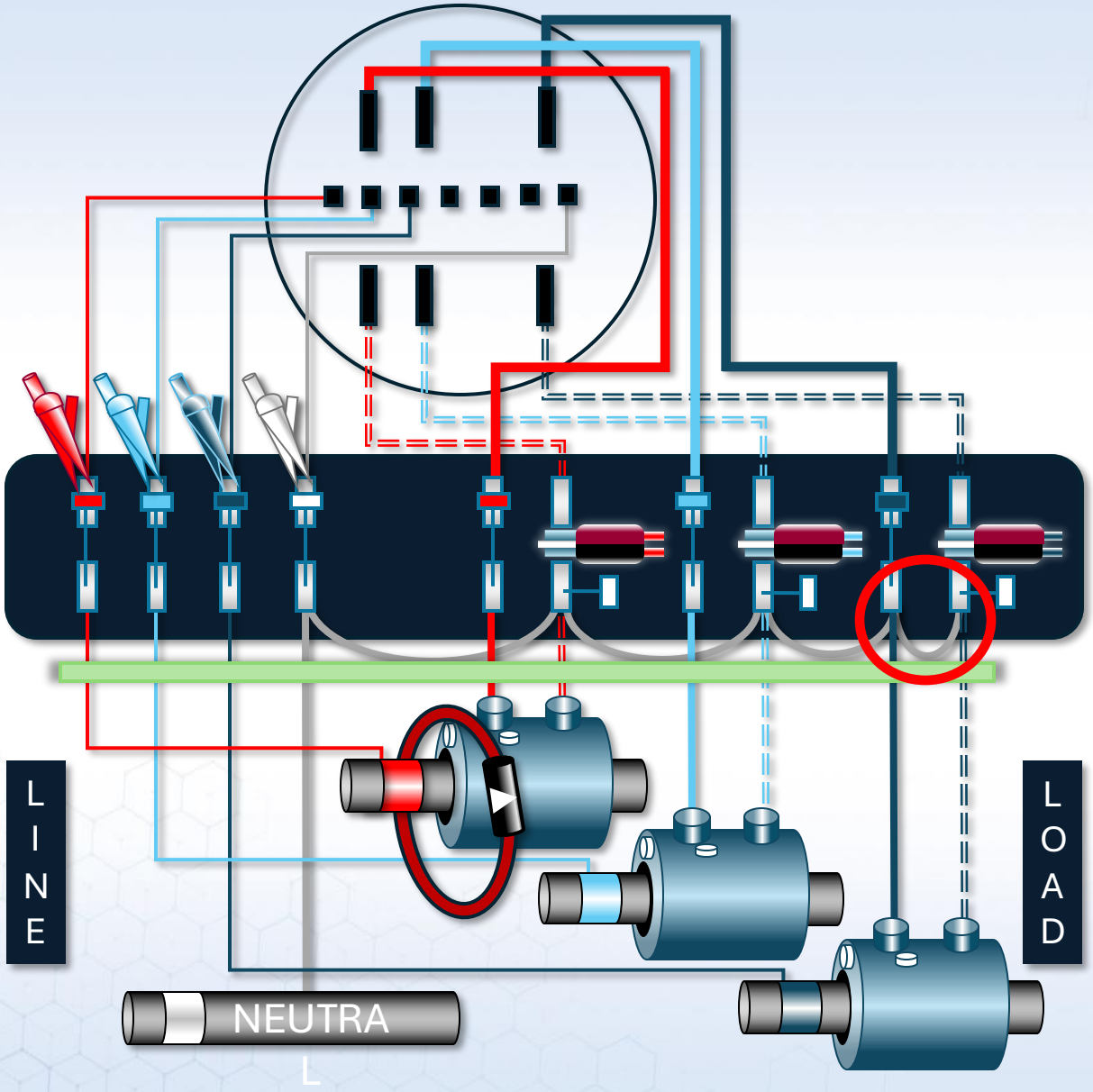
  CT Burden Test



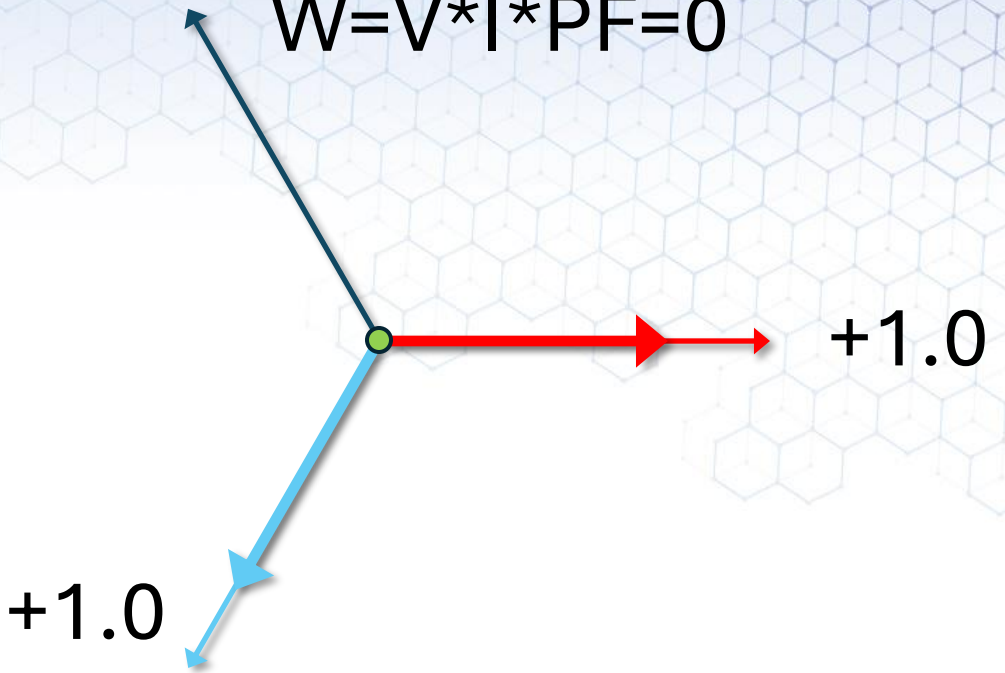
What is the Problem?

Phase C Secondary Current Polarity Tied to Neutral at Bottom of Test Switch

What is the Estimated Loss?

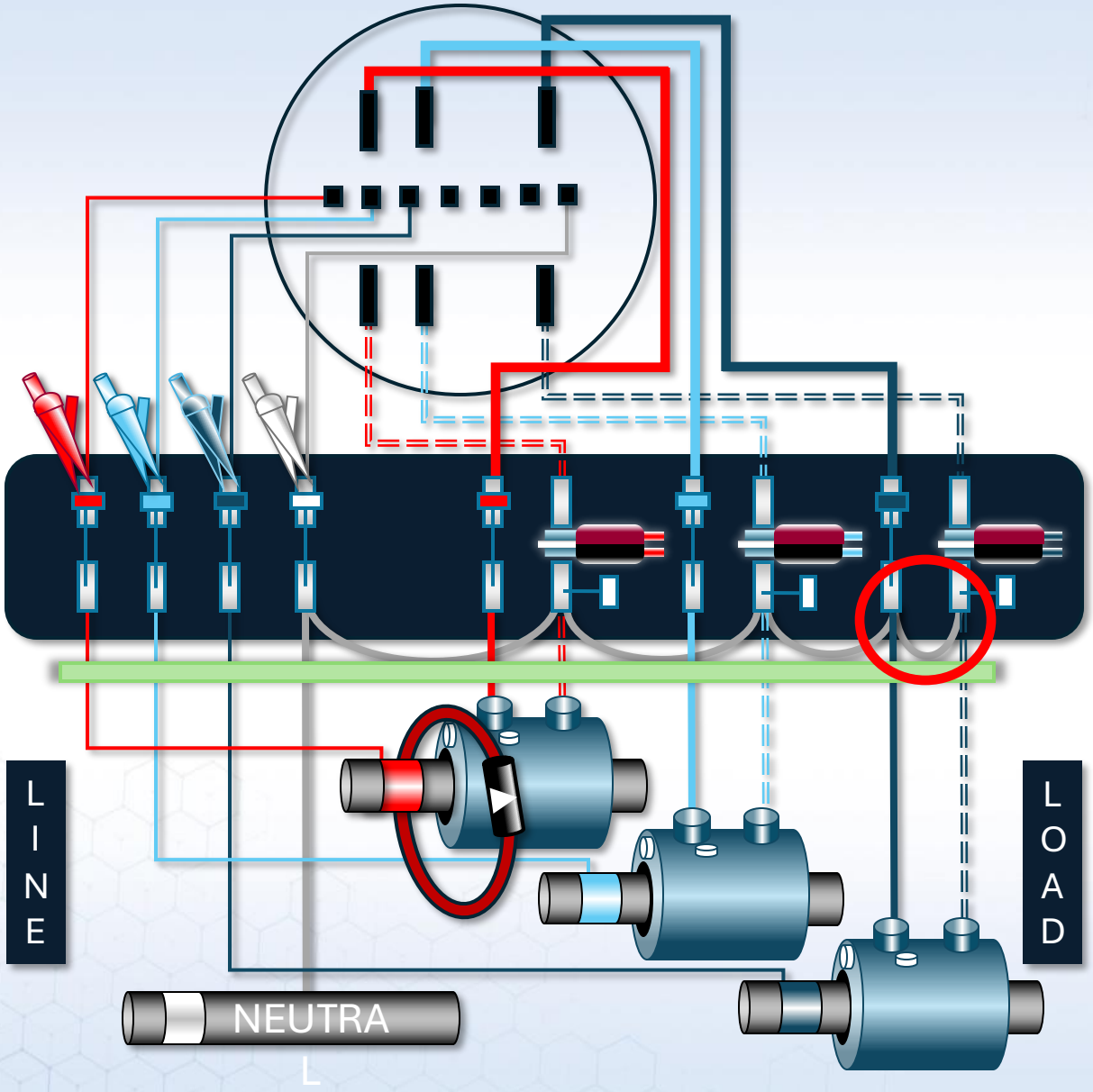


What Does the Meter See?



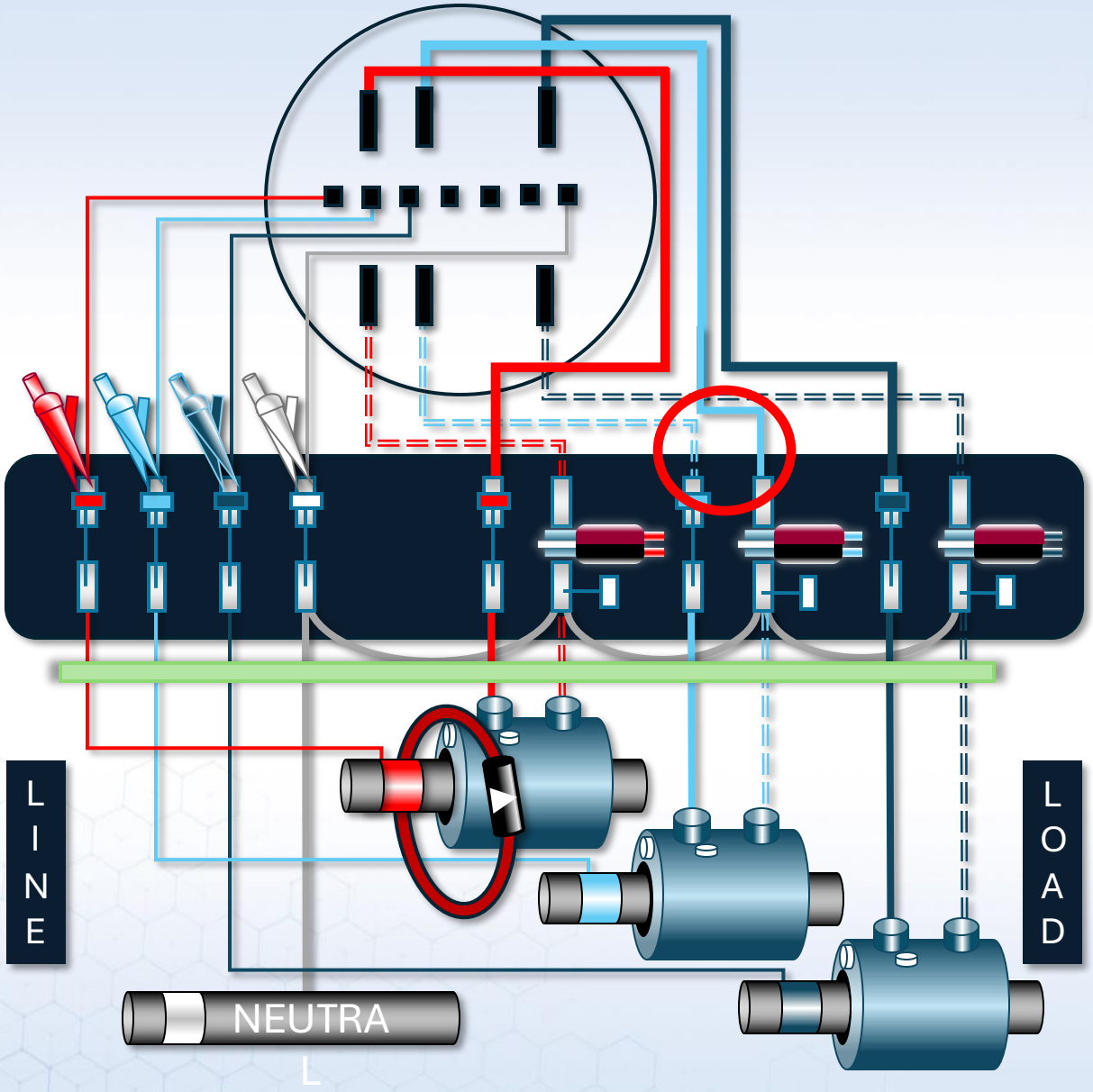
Equates to 1/3 LOSS

- $60k Yearly Loss



How can you find the error?

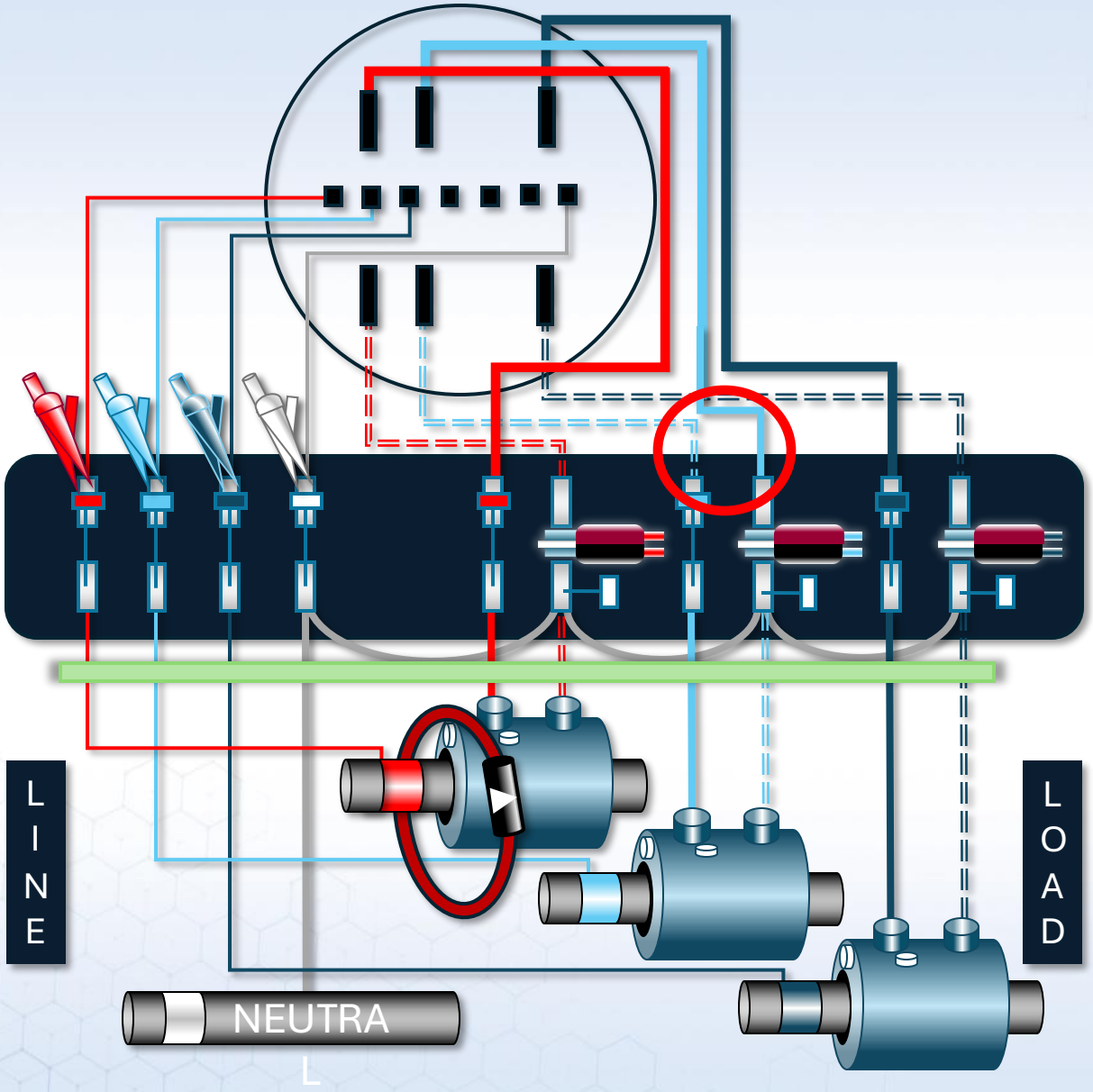
- ✓ Vector Diagram
  Customer Load Meter Test
  Phantom Load Meter Test
  - Through Test Switch
  - Remove Meter from Socket
- ✓ CT Ratio Test
  CT Burden Test



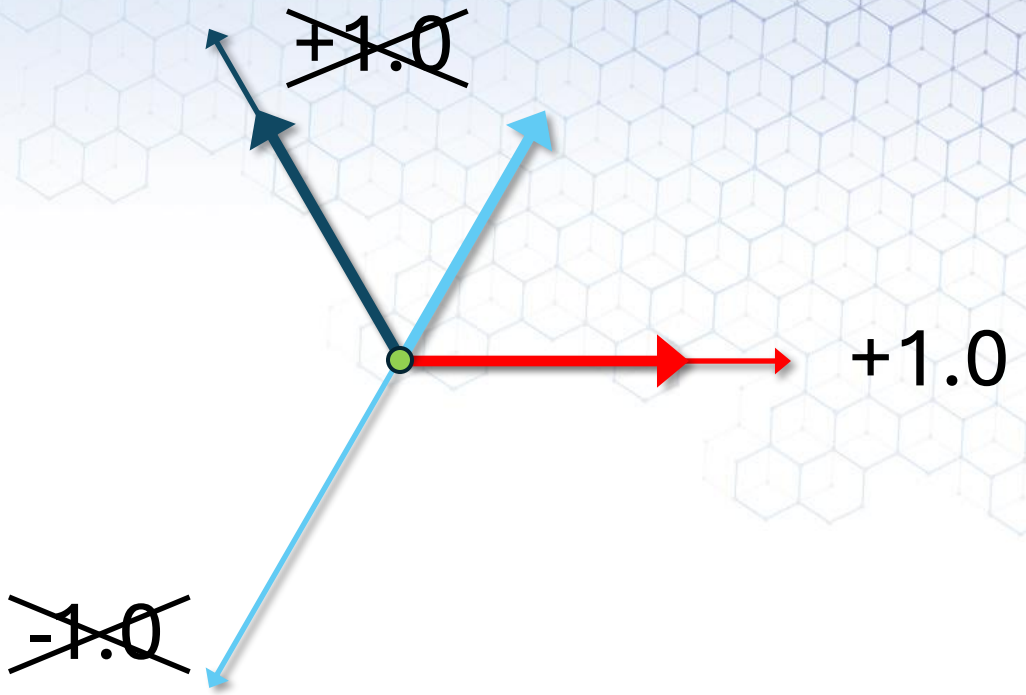
What is the Problem?

Phase B Current Polarity Wiring Error at Top of Test Switch

What is the Estimated Loss?

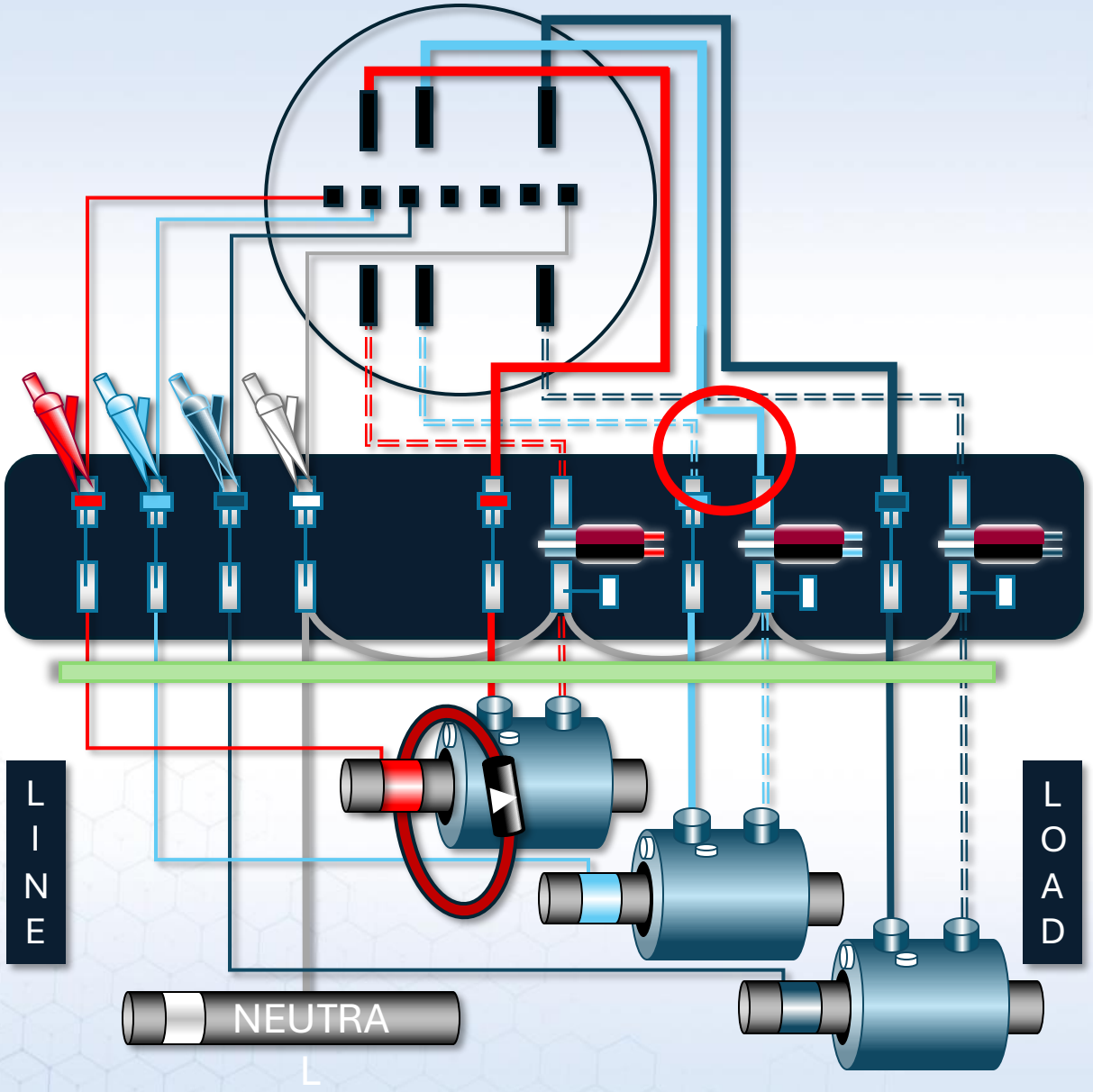


What PF Does the Meter See?



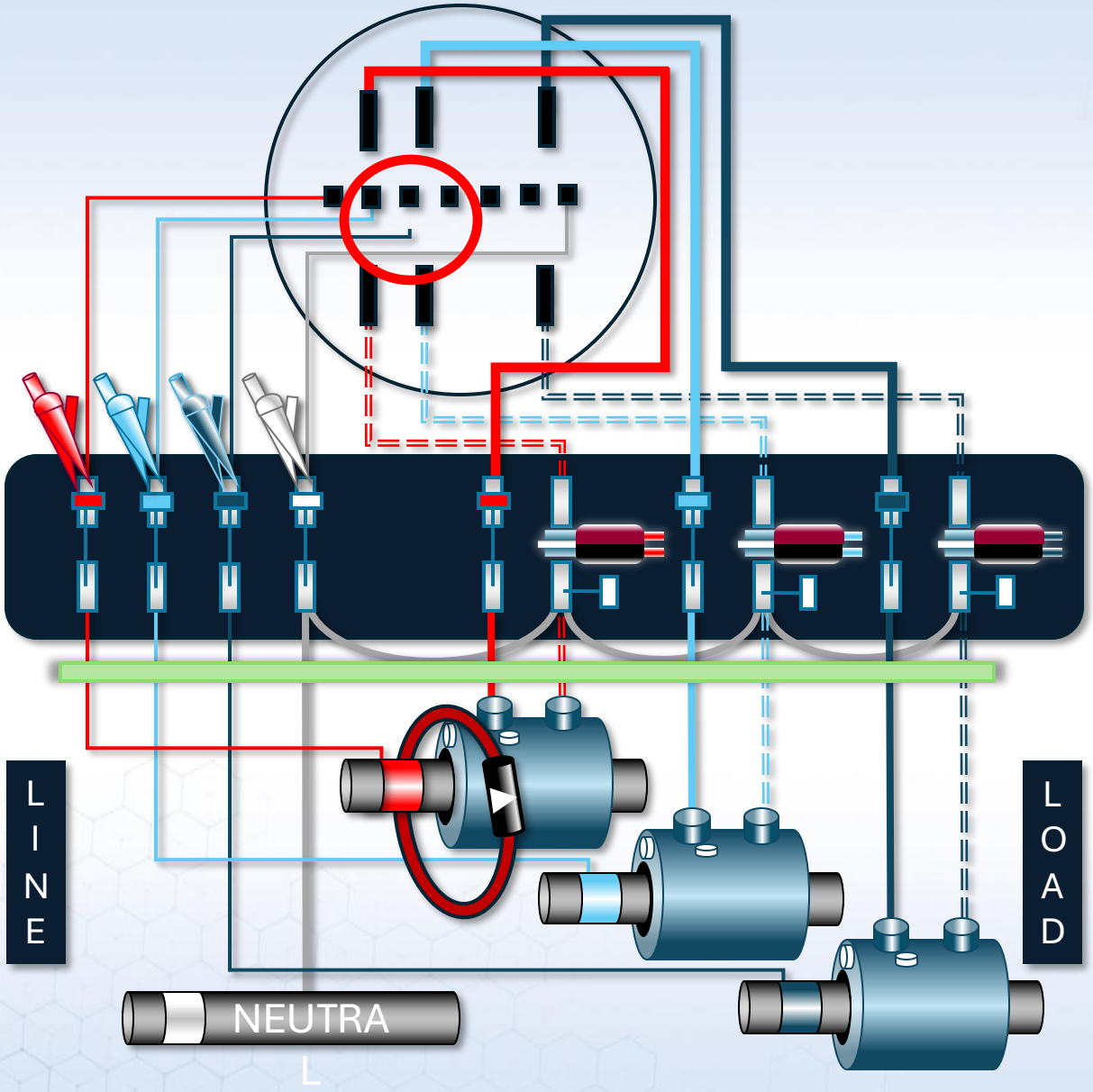
Equates to 2/3 LOSS

- $120k Yearly Loss



How can you find the error?

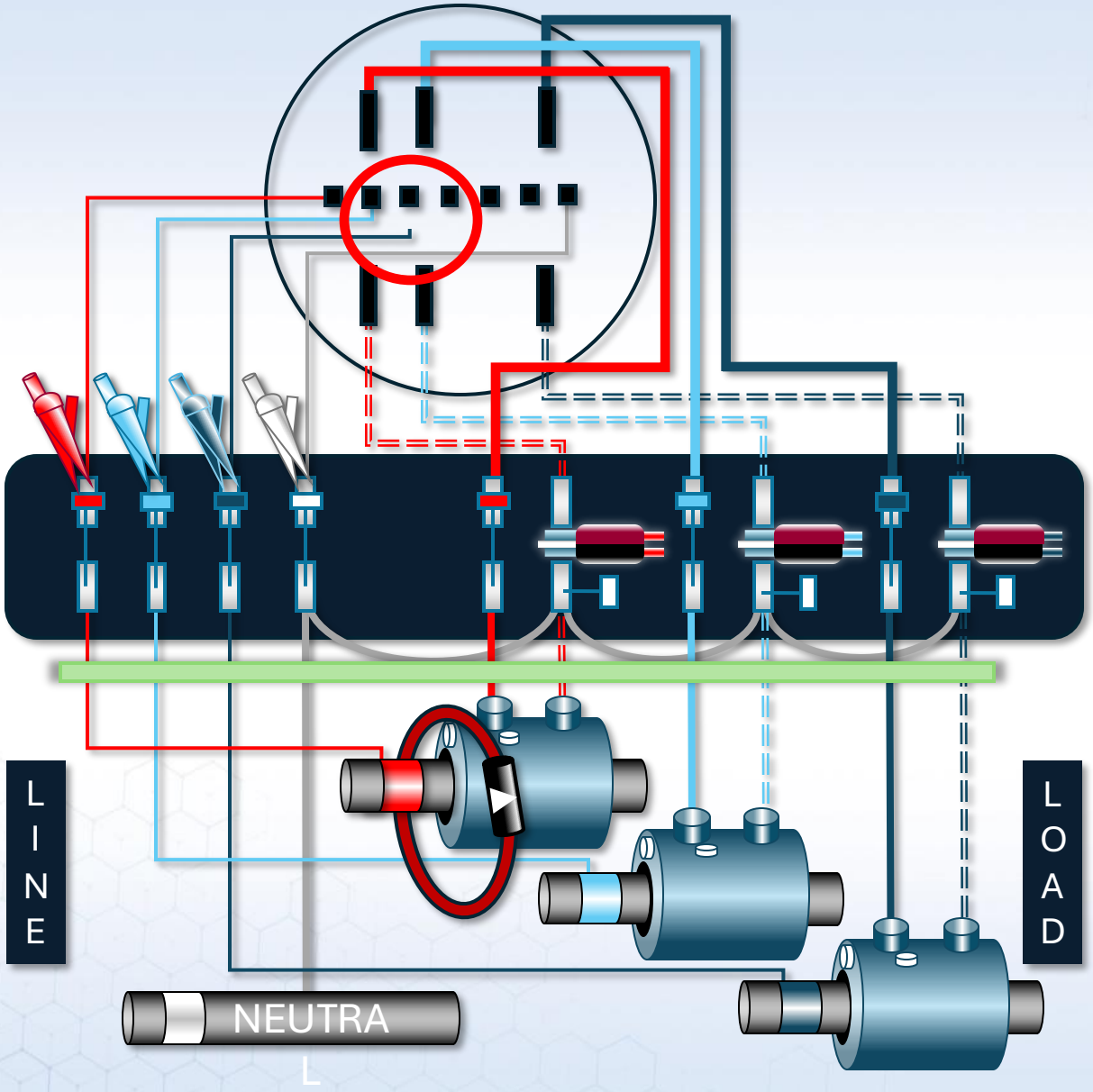
- Vector Diagram
- ✓ Customer Load Meter Test
- ✓ Phantom Load Meter Test
- ✓
  - Through Test Switch
  - Remove Meter from Socket
- CT Ratio Test
- CT Burden Test



What is the Problem?

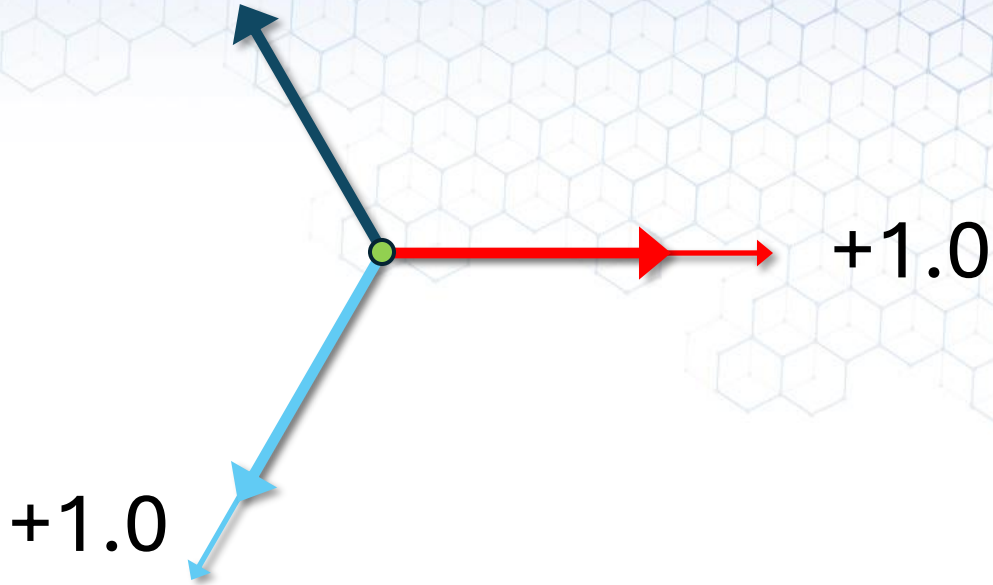
Phase C Voltage not Connected at Socket (or insulation not stripped correctly)

What is the Estimated Loss?



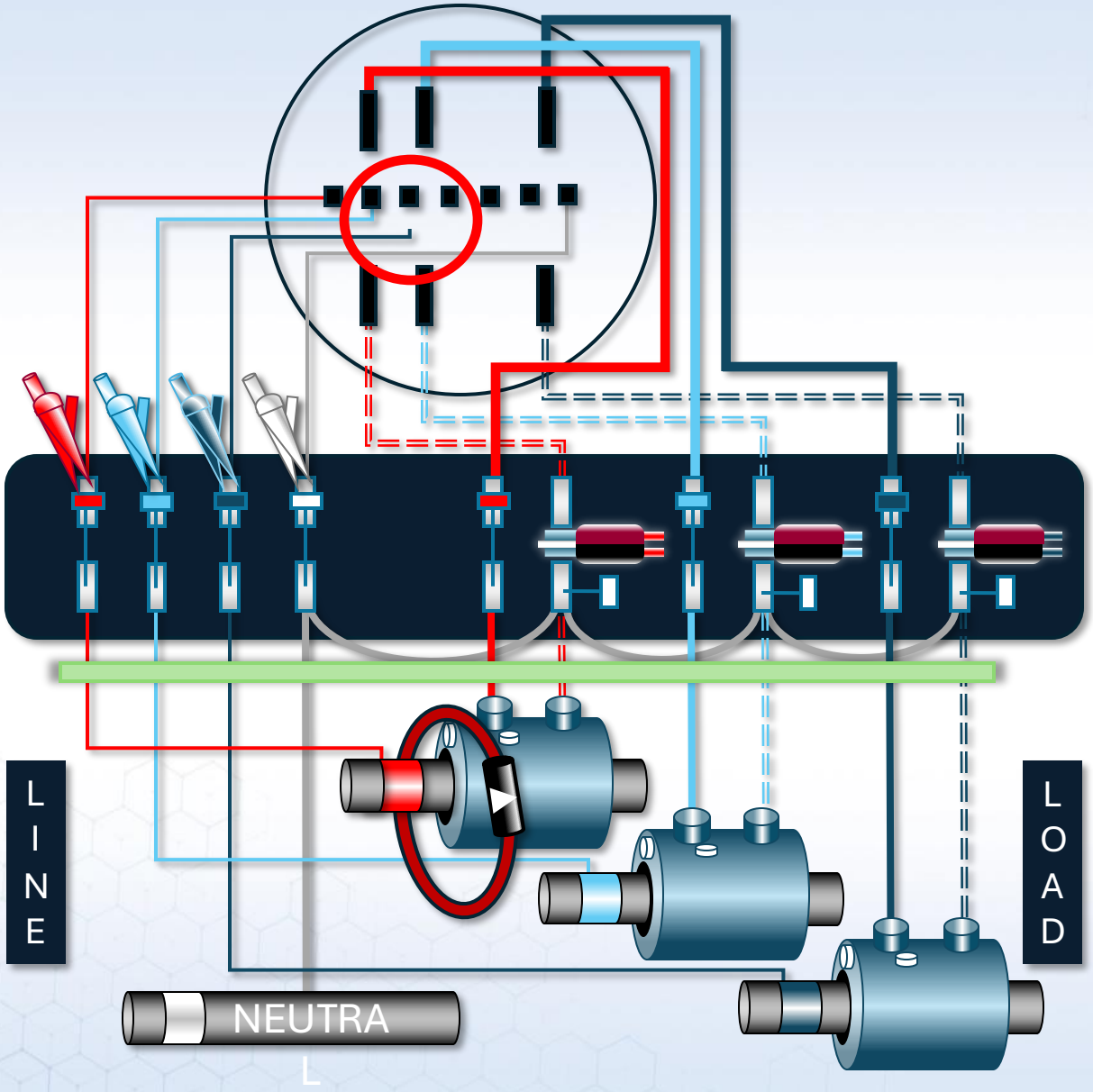
What Does the Meter See?

$$W=V*I*PF=0$$



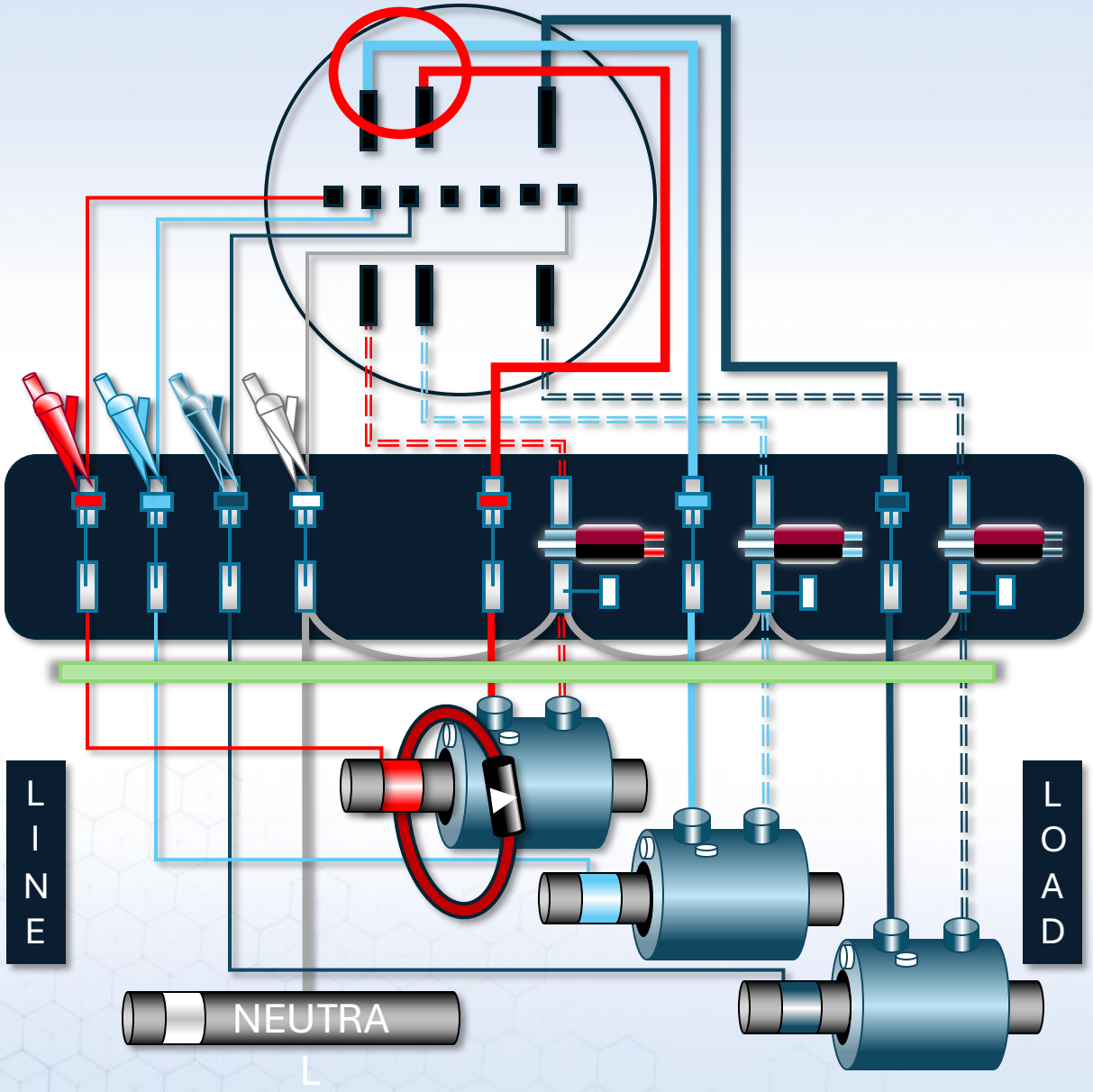
Equates to 1/3 LOSS

- $60k Yearly Loss



How can you find the error?

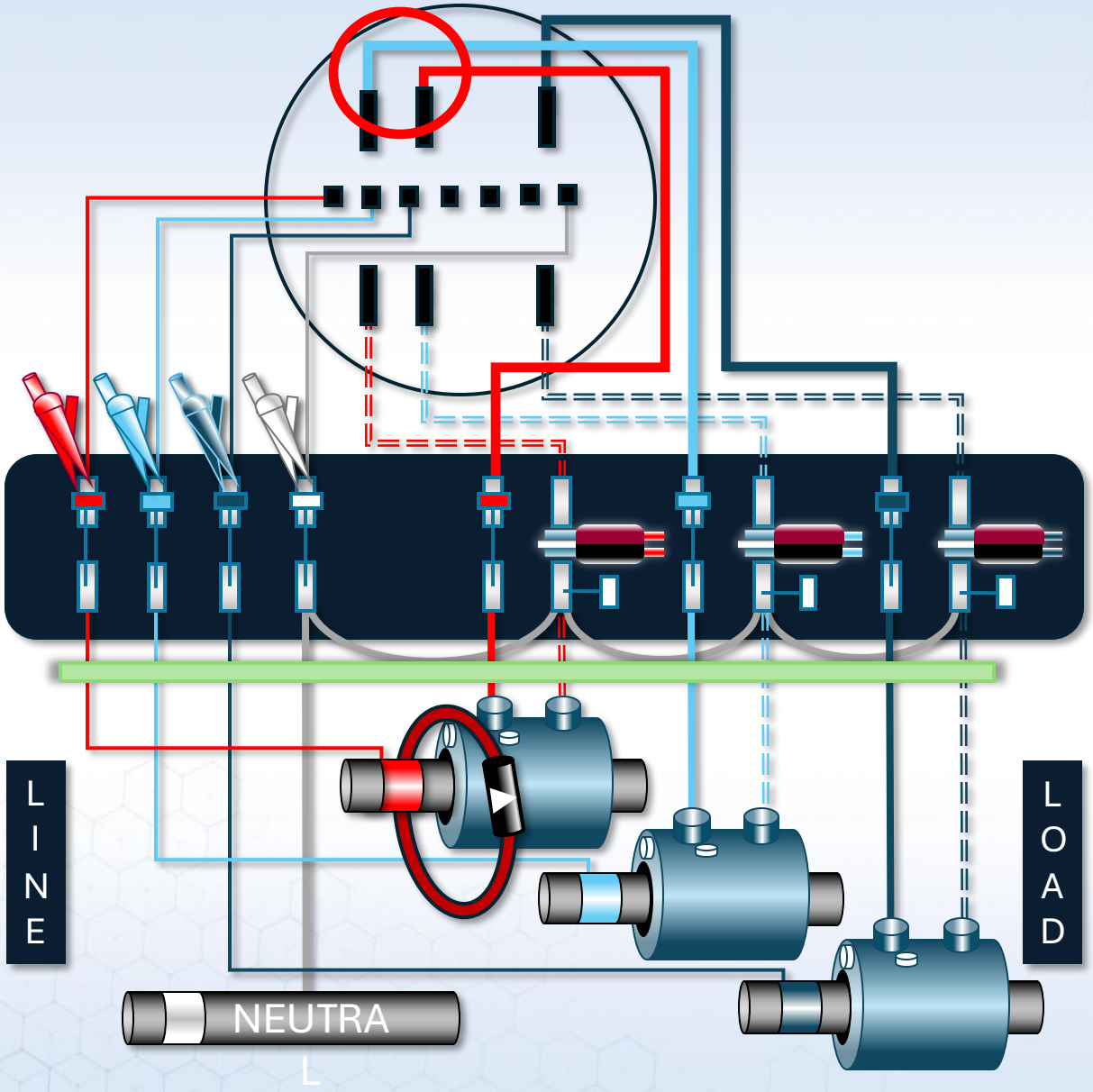
- Vector Diagram
- ✓ Customer Load Meter Test
- Phantom Load Meter Test
- ✓
  - Through Test Switch
  - Remove Meter from Socket
- CT Ratio Test
- CT Burden Test



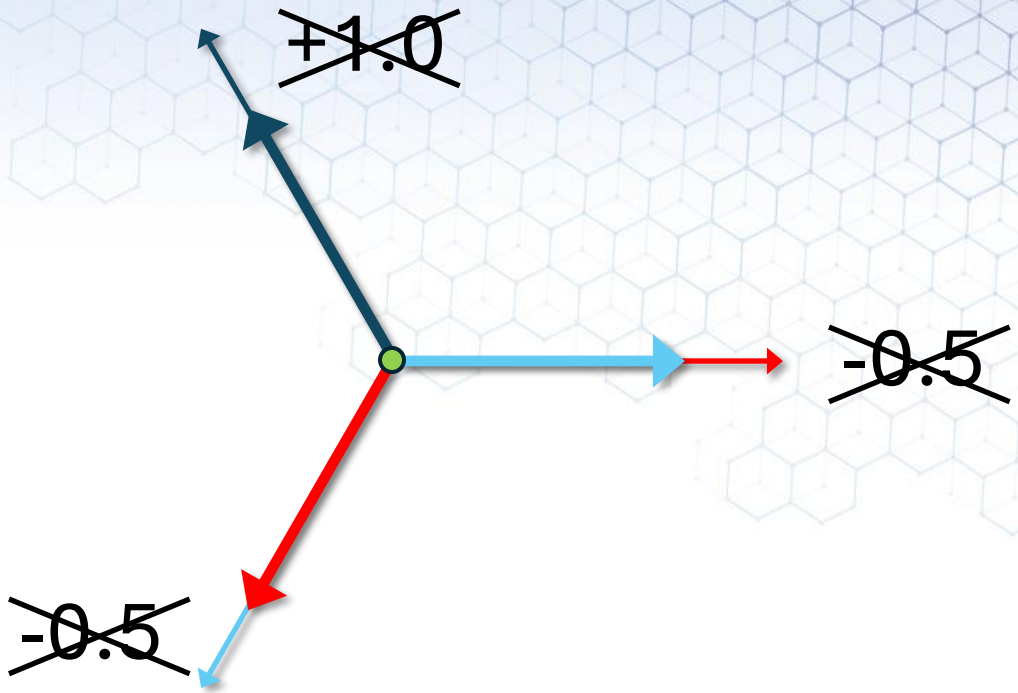
What is the Problem?

Phase A & B Current Swap at Meter Socket (maybe pre-wired)

What is the Estimated Loss?

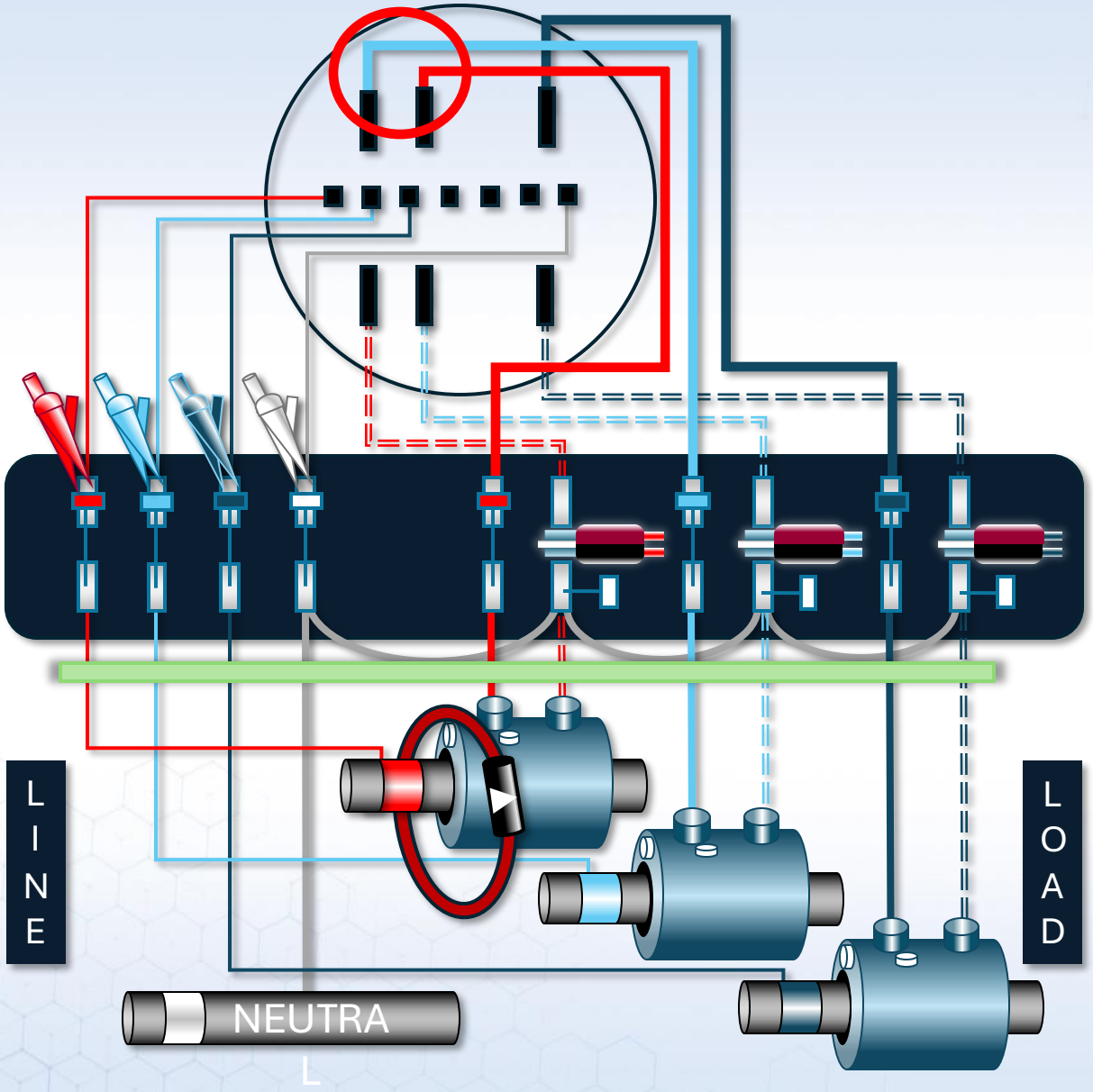


What PF Does the Meter See?



Equates to Total LOSS

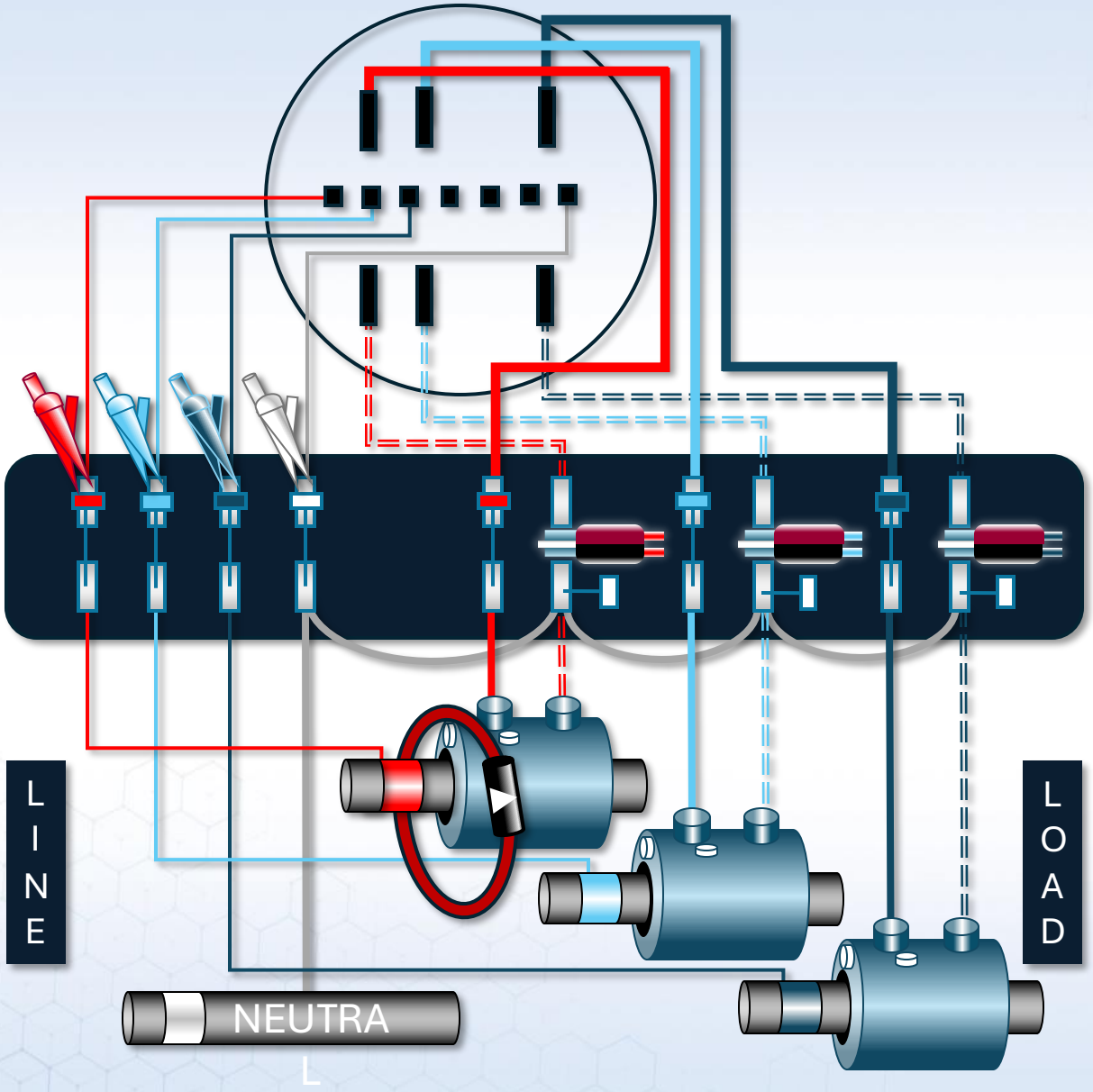
- $180k Yearly Loss



How can you find the error?

- ✓ Vector Diagram
- ✓ Customer Load Meter Test
- ✓ Phantom Load Meter Test
- ✓
  - Through Test Switch
  - Remove Meter from Socket
- ✓ CT Ratio Test

CT Burden Test



What is the Problem?

$15,000 Loss per Year

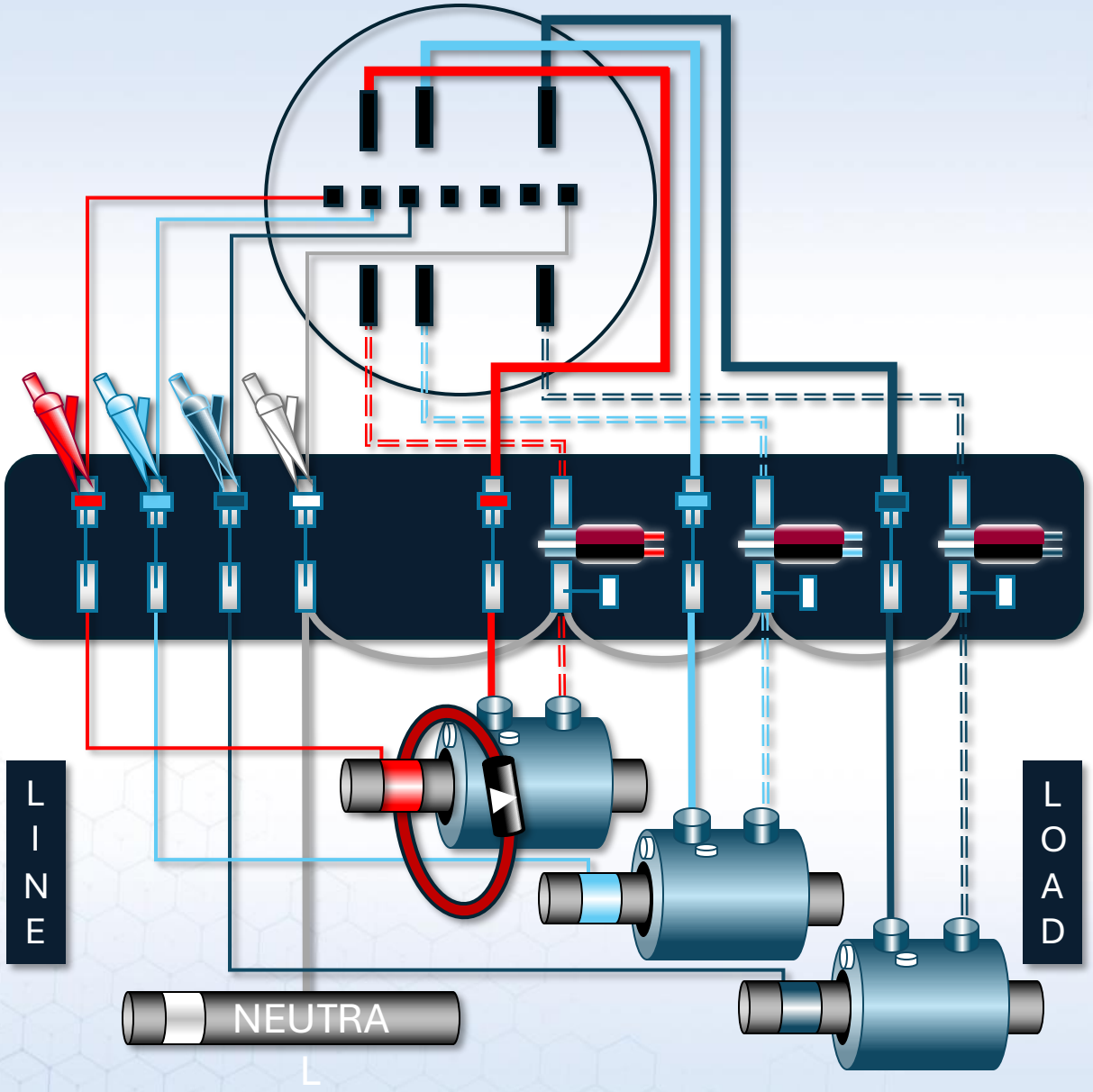
Customer Load Meter Test

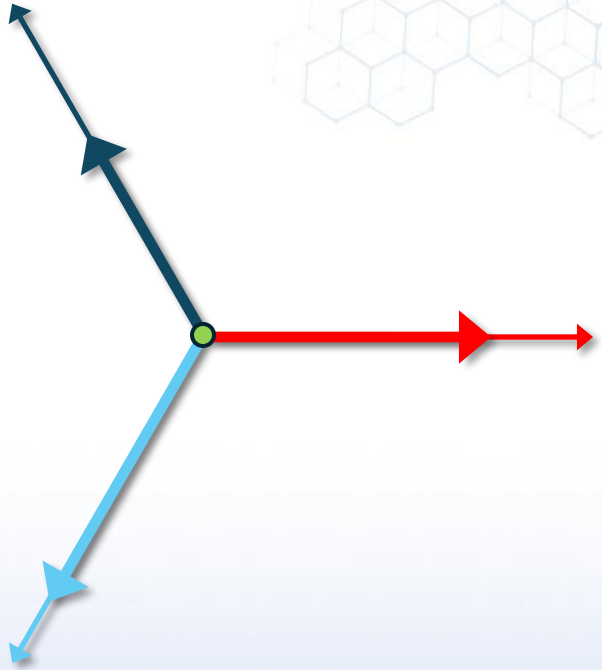
- 100%

Phantom Load Meter Test

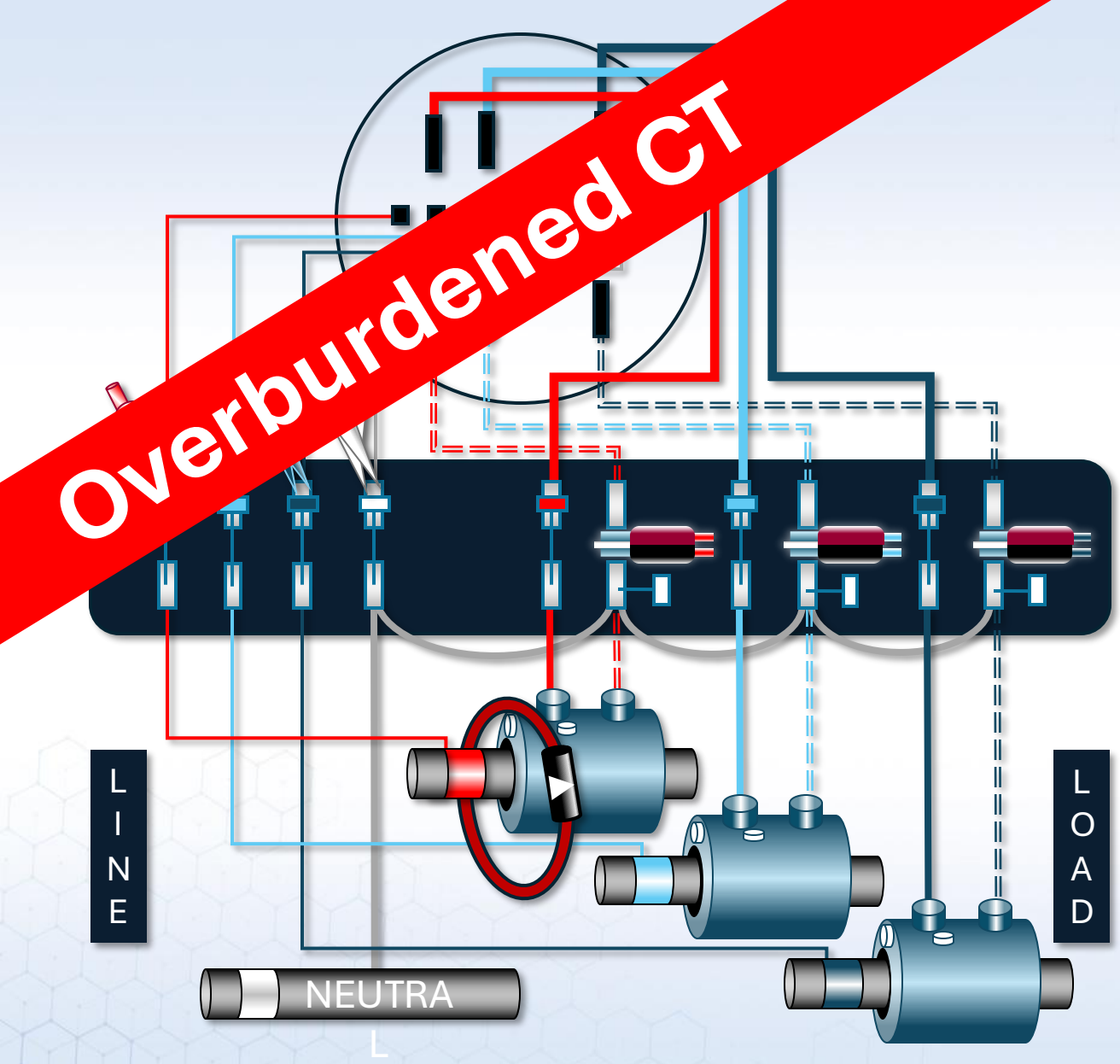
- 100%

$15,000 Loss per Year





Ia 1.5A
Ib 1.6A
Ic 1.2A



$15,000 Loss per Year

CT Ratio Test

Phase A

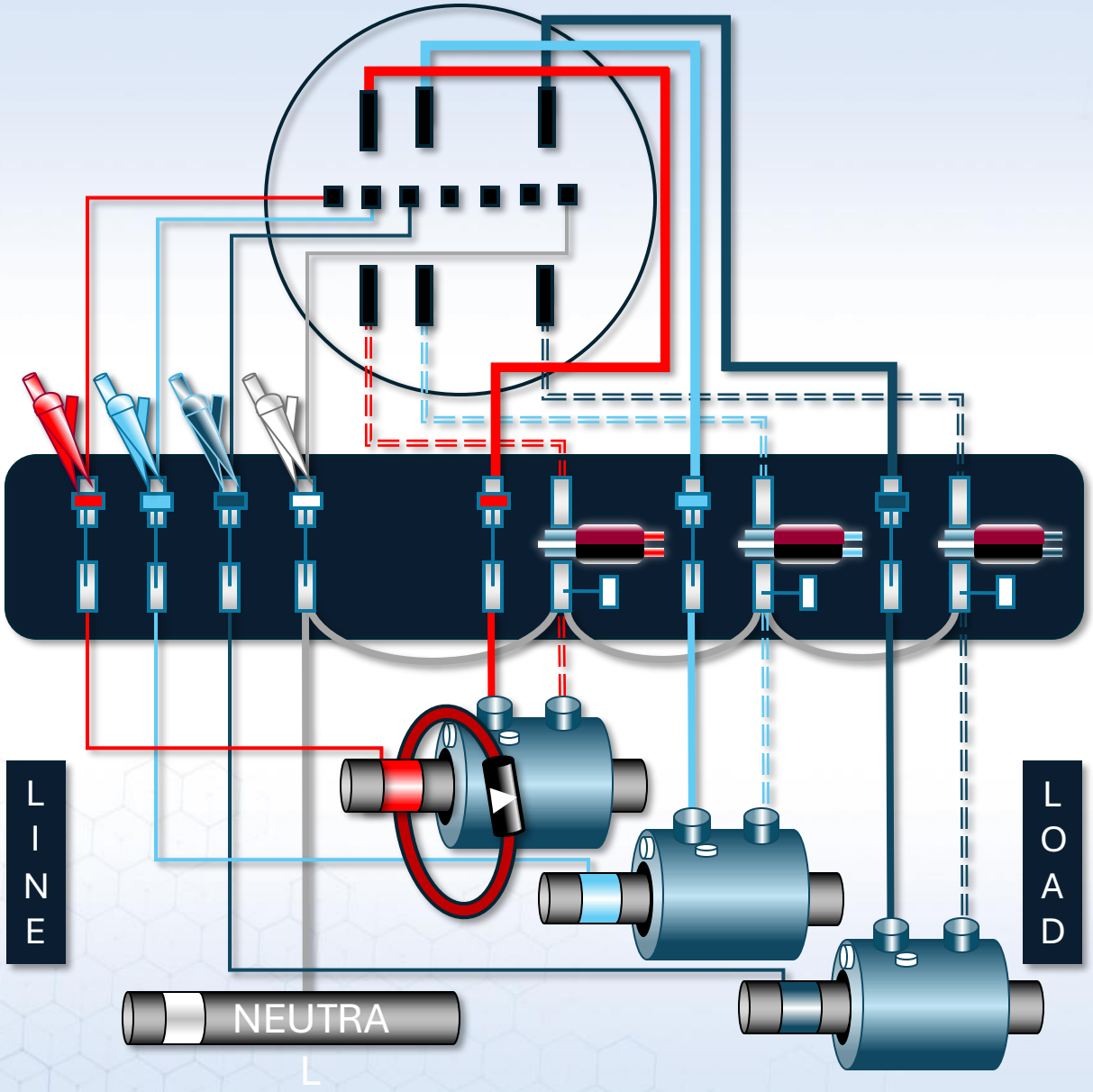
- 240A(p) 1.5A(s) 800:5

Phase B

- 256A(p) 1.6A(s) 800:5

Phase C

- 256A(p) 1.2A(s) 1067:5



What is the Problem?

$58,500 Overbill per Year

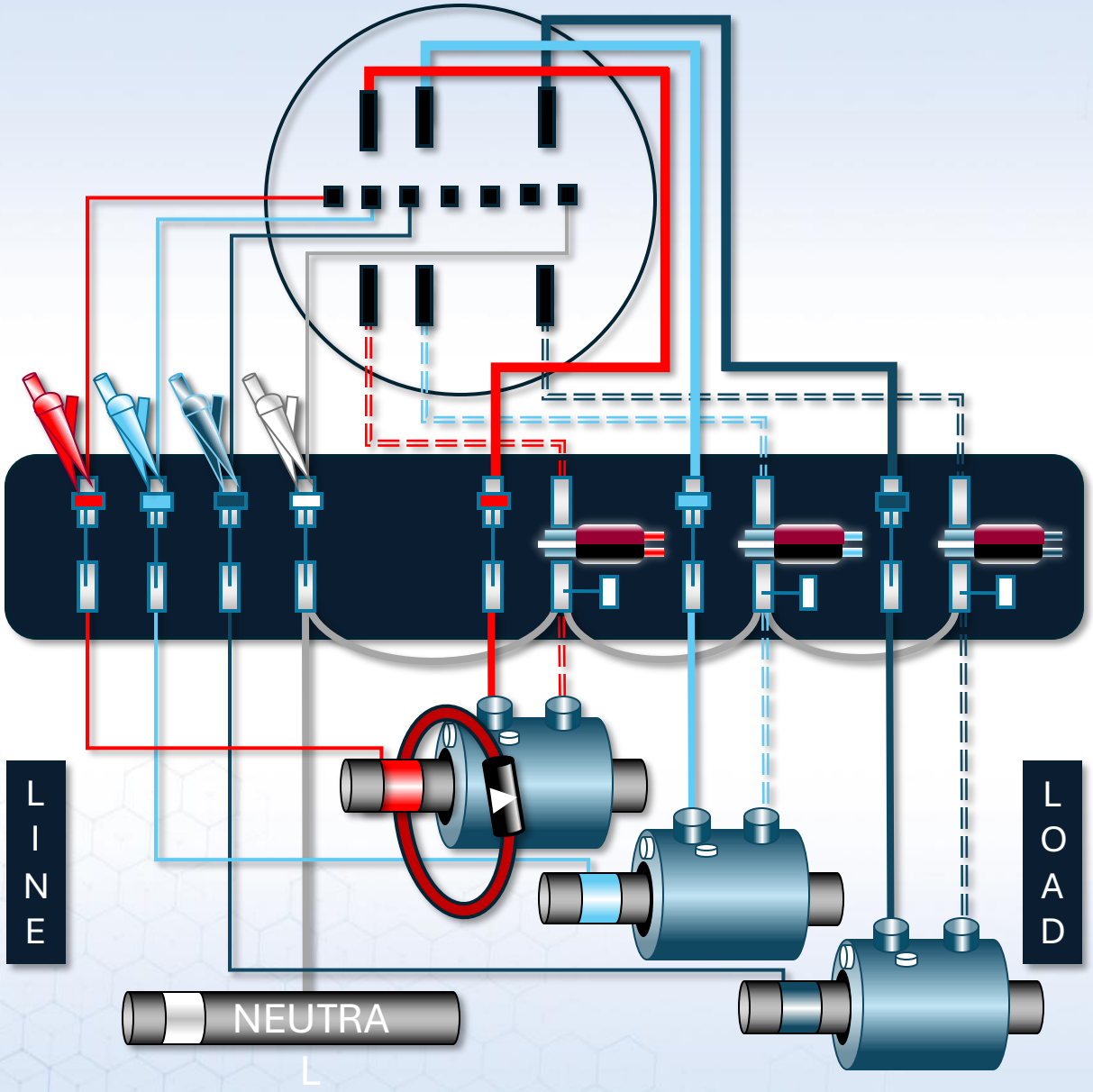
Customer Load Meter Test

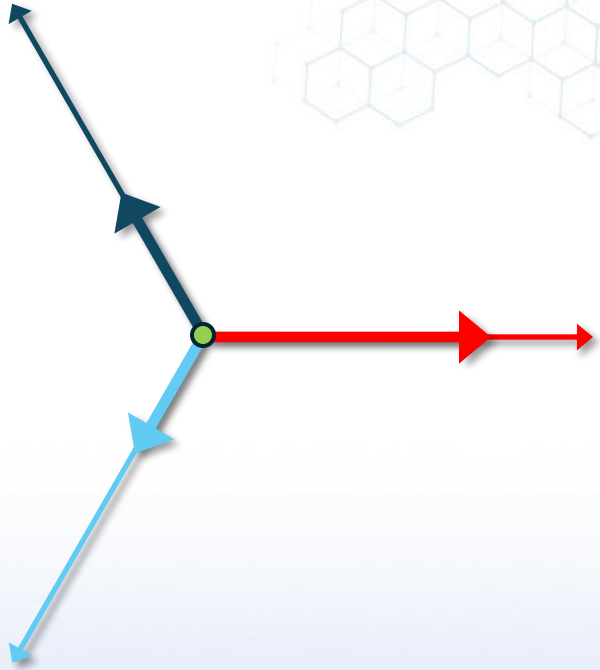
- 100%

Phantom Load Meter Test

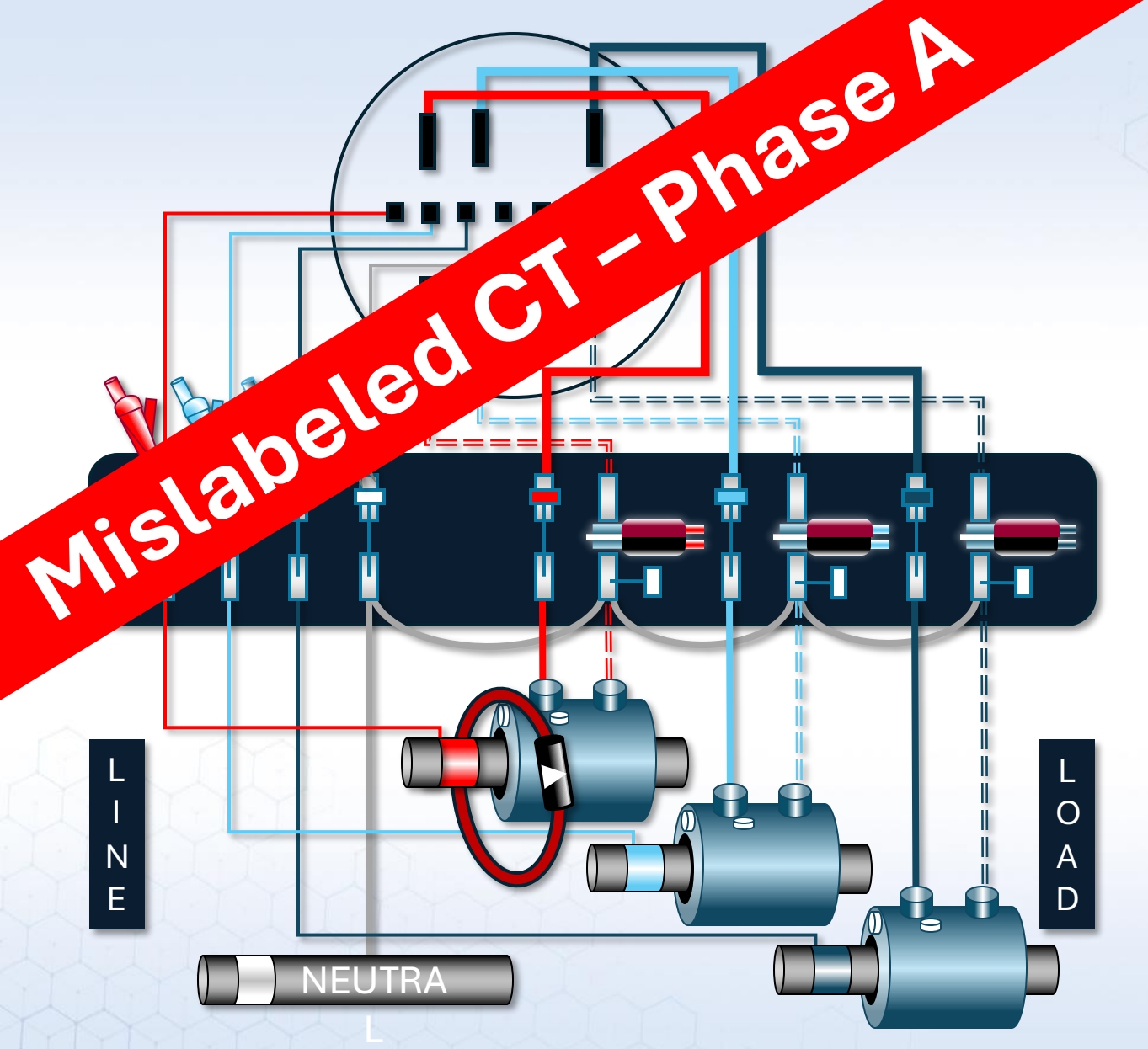
- 100%

$58,500 Overbill per Year





Ia 7.4A
Ib 3.5A
Ic 4.2A



$58,500 Overbill per Year

CT Ratio Test

Phase A

- 592A(p) 7.4A(s) 400:5

Phase B

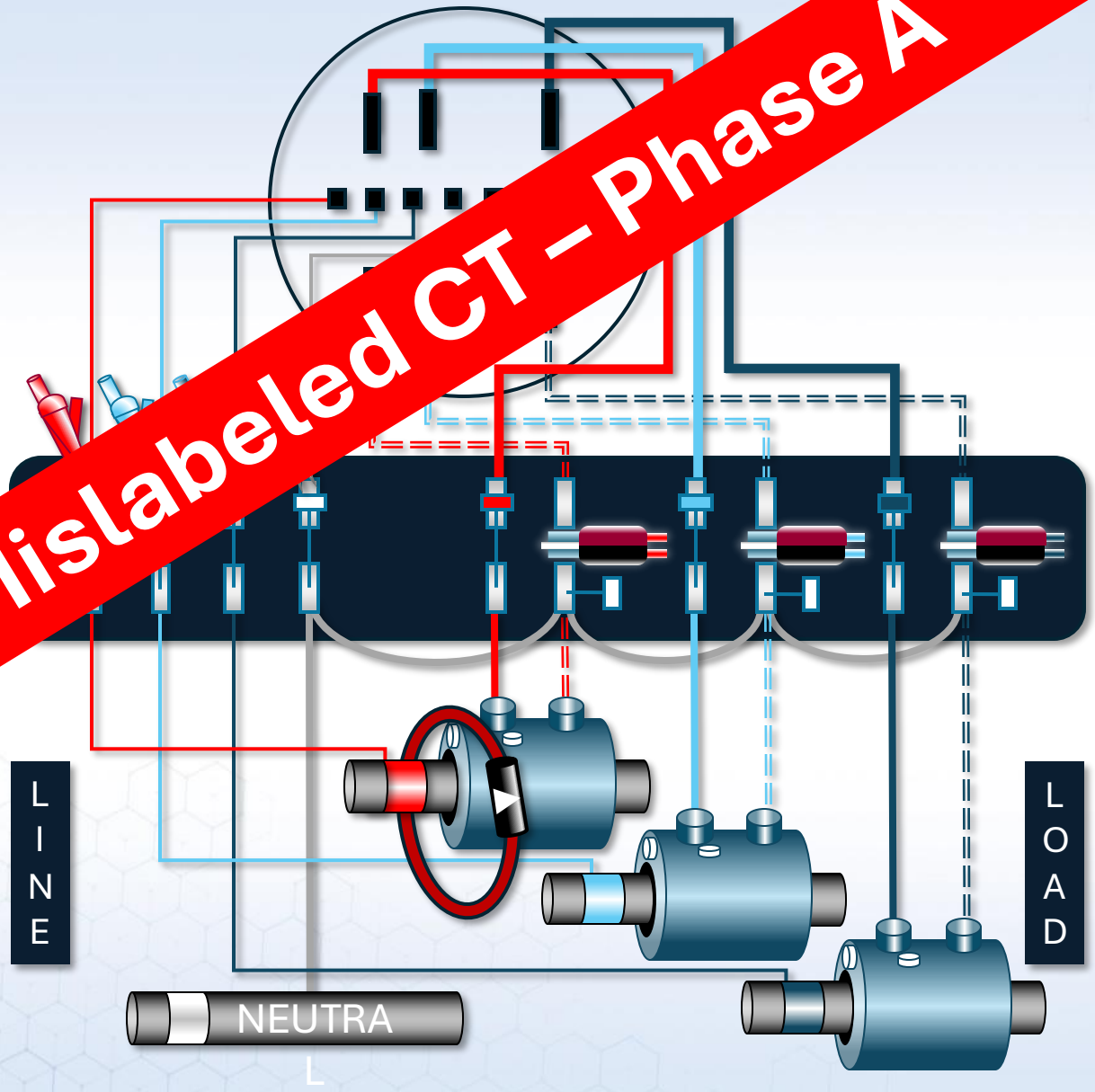
- 560A(p) 3.5A(s) 800:5

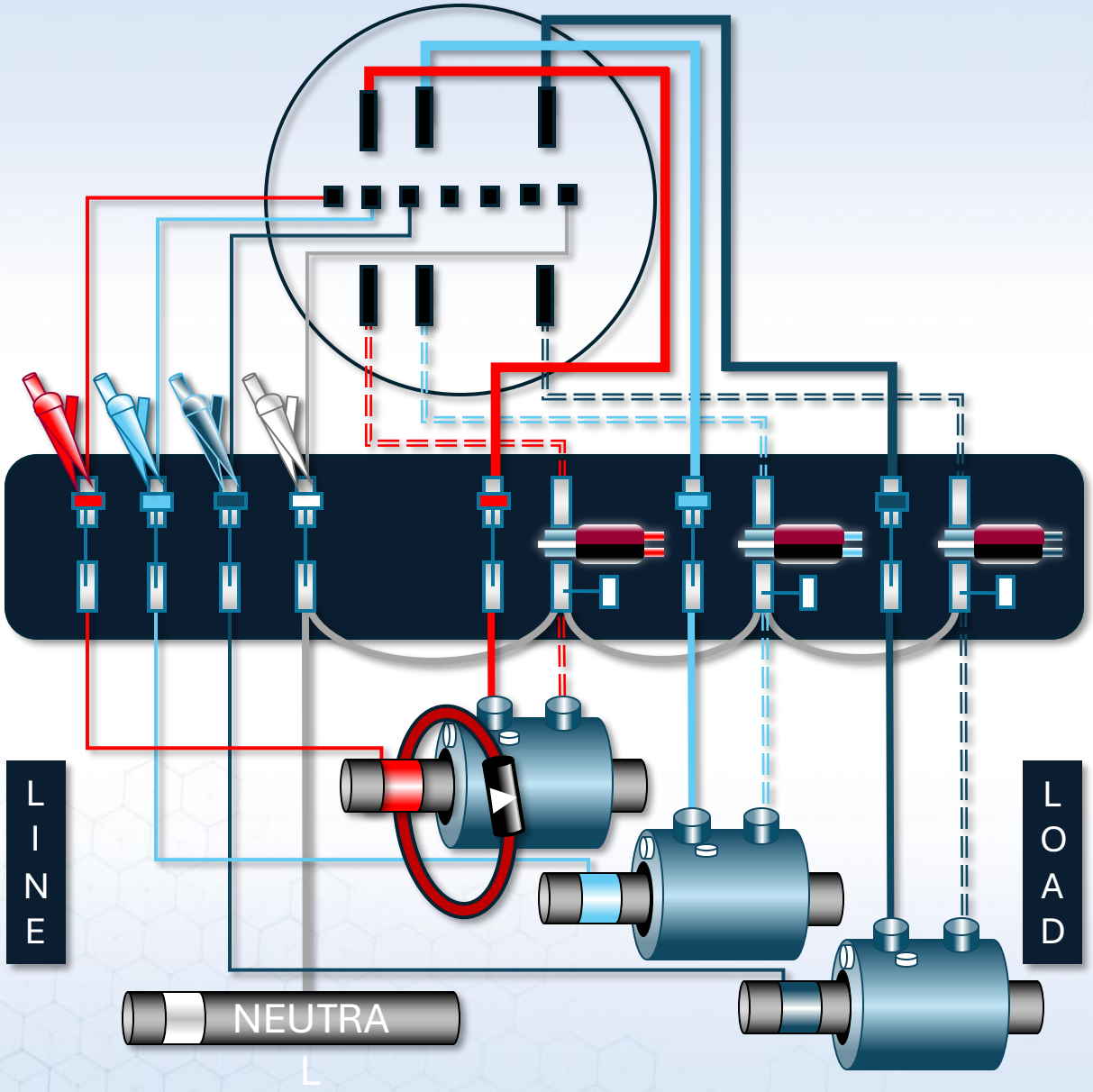
Phase C

- 672A(p) 4.2A(s) 800:5

Mislabeled CT – Phase A

$58,500 Overbill per Year





What is the Problem?

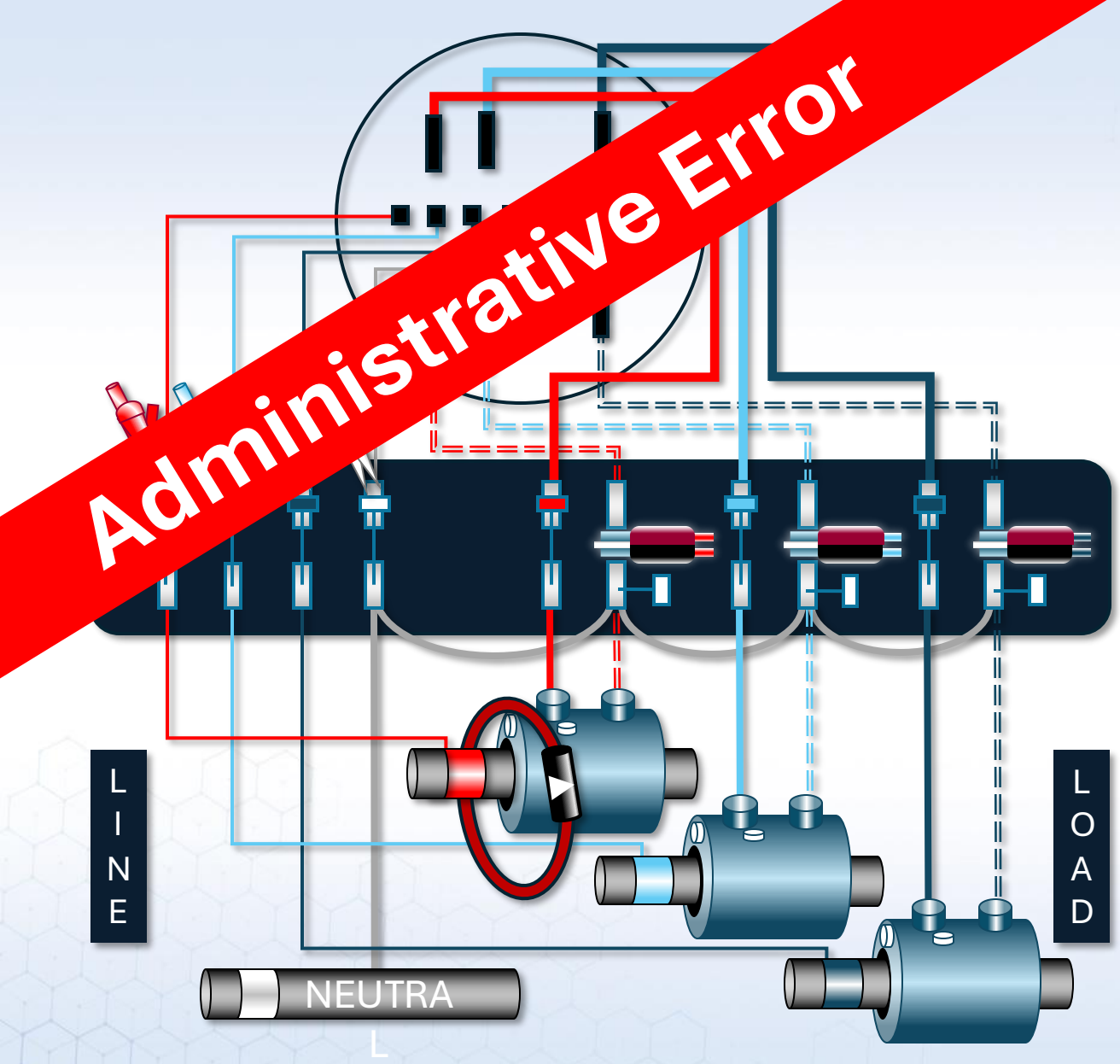
$162,000 Loss per Year

Customer Load Meter Test

- 100%

Phantom Load Meter Test

- 100%



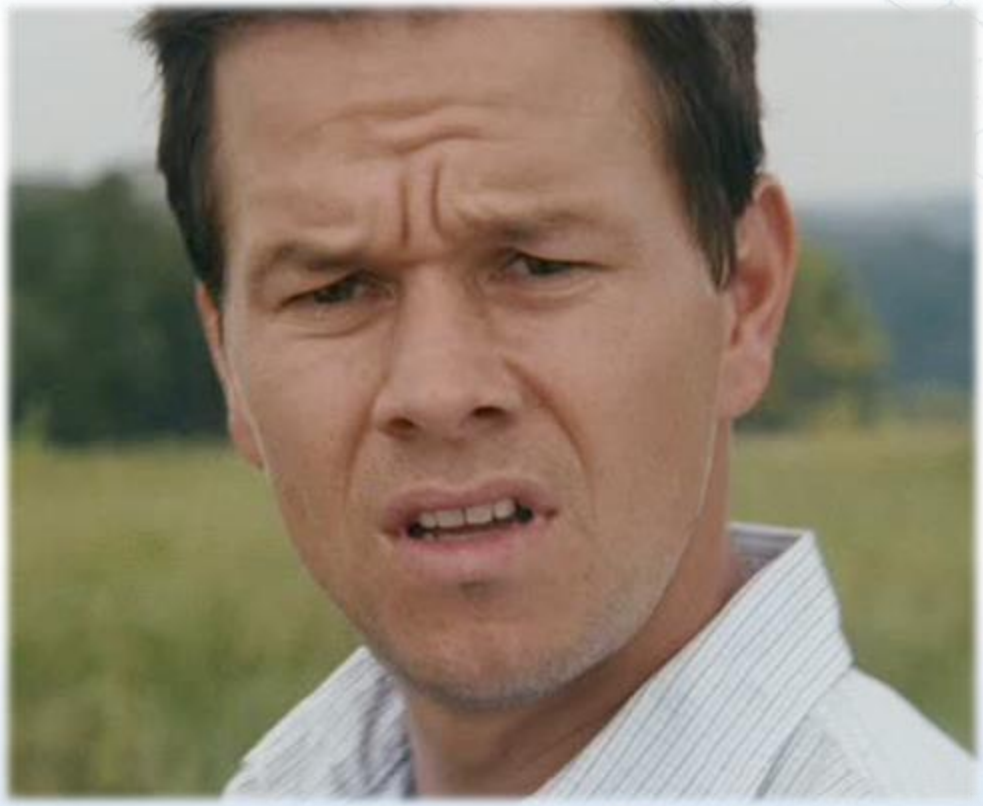
$162,000 Loss per Year

Vector Diagram OK
CT Ratio Test OK
No Signs of Theft

Billing System Multiplier

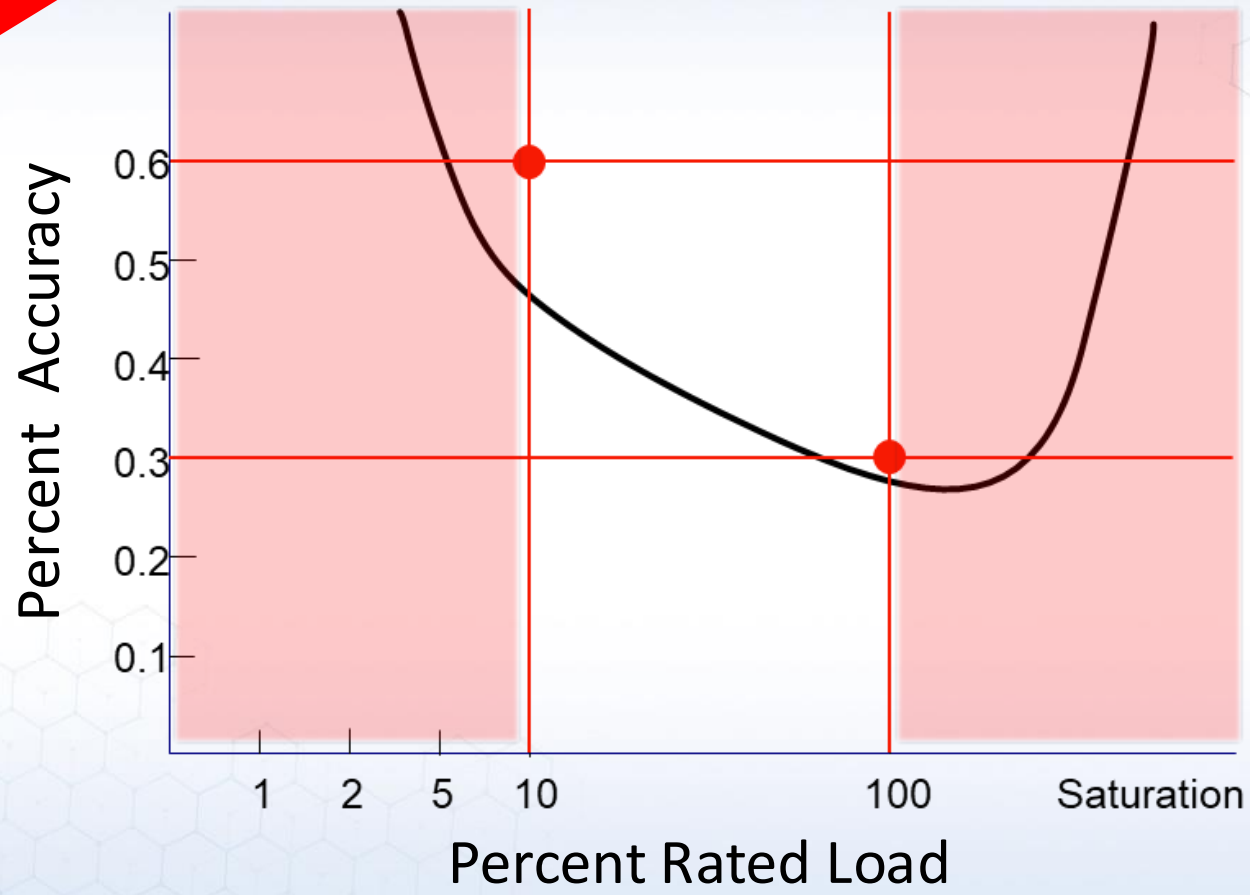
- 16 instead of 160

Errors When There are NO Errors Can Still Cause Revenue Loss



CT Specs - Amplitude & Phase

CT Accuracy Class



0.3% Accuracy Class

RF=1

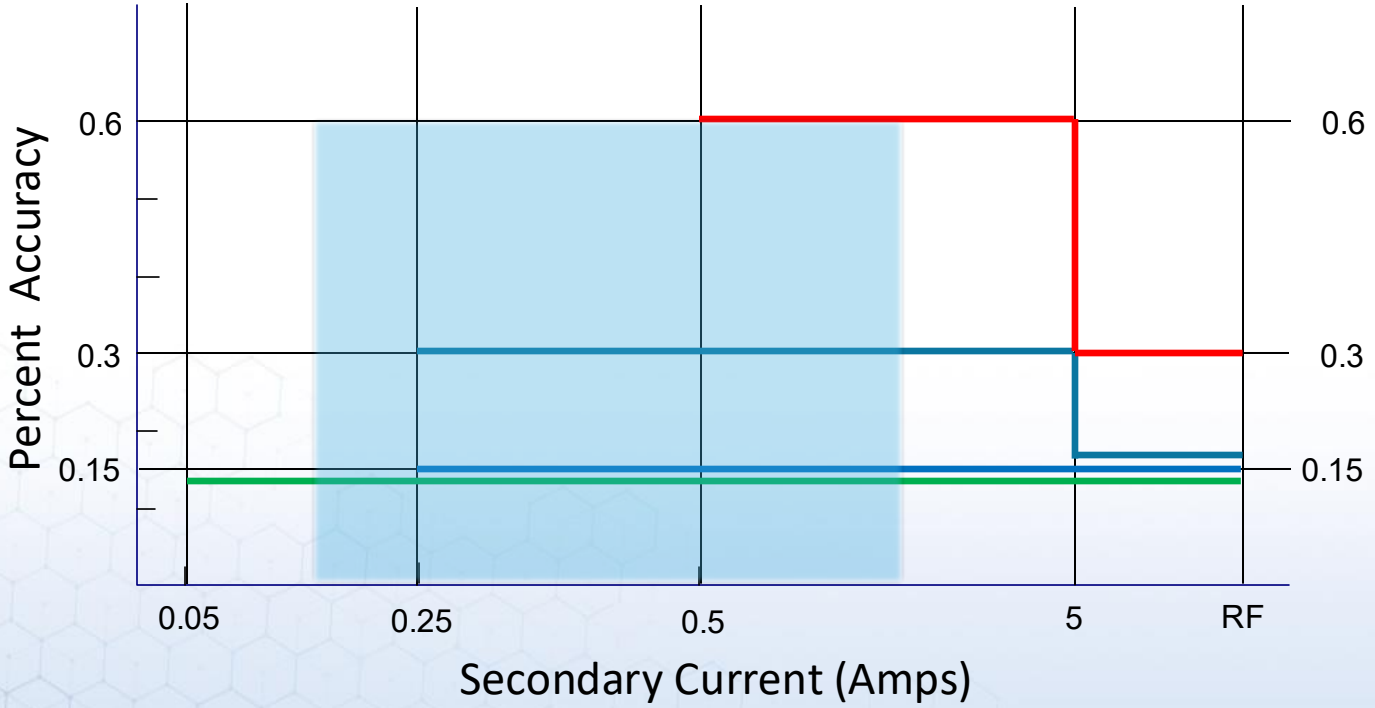
B 1.8

Load Affects Accuracy No Spec Below 10% Saturation on High End

Amplitude

CT Accuracy Class Graph vs Secondary Current

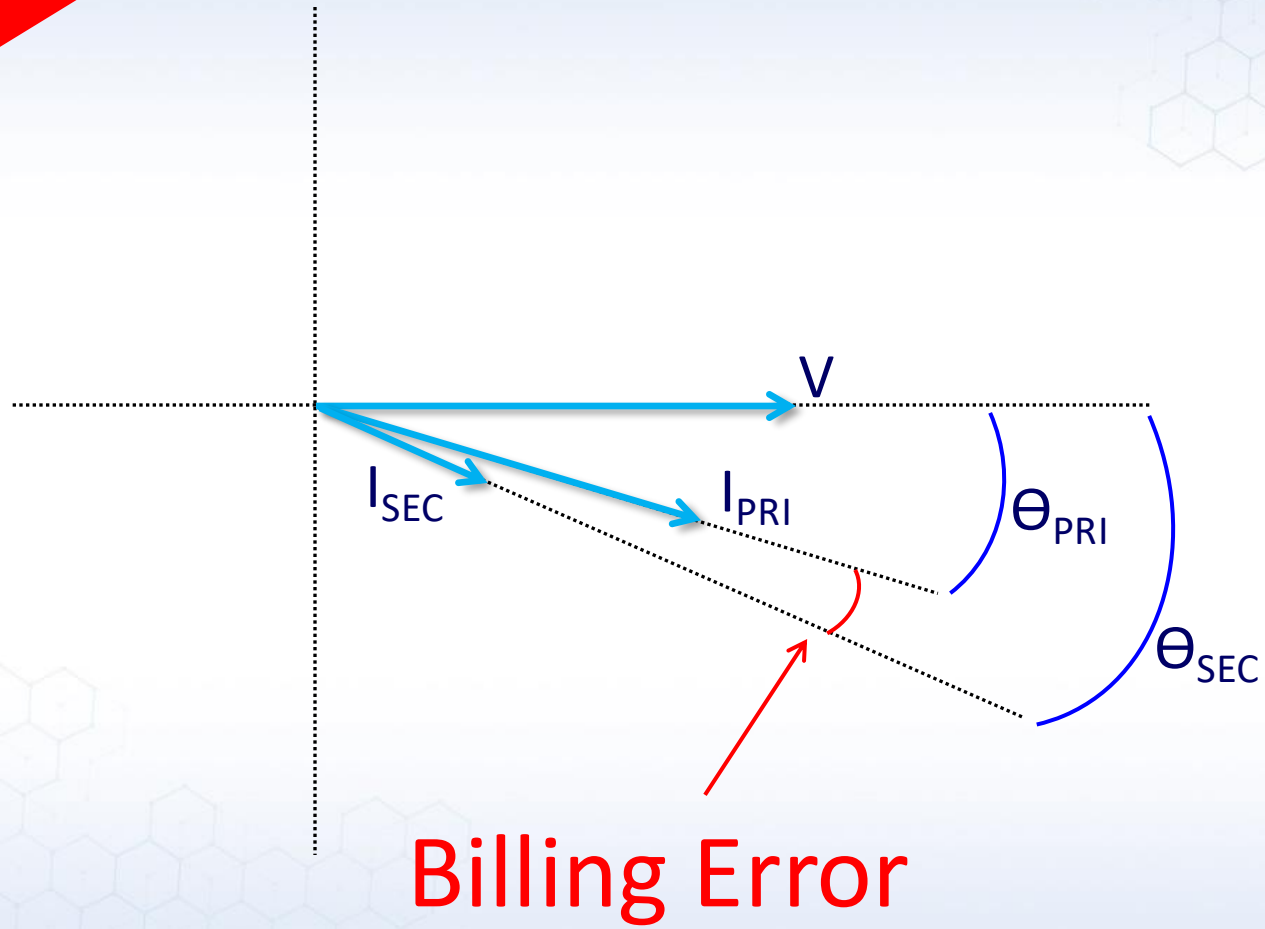
Where do we operate A LOT of the time?



Class 0.3	0.6% - NoSpec
Class 0.15	0.3% - NoSpec
Class 0.15S	0.15% - NoSpec
Class 0.15 Ext	0.15%

Phase

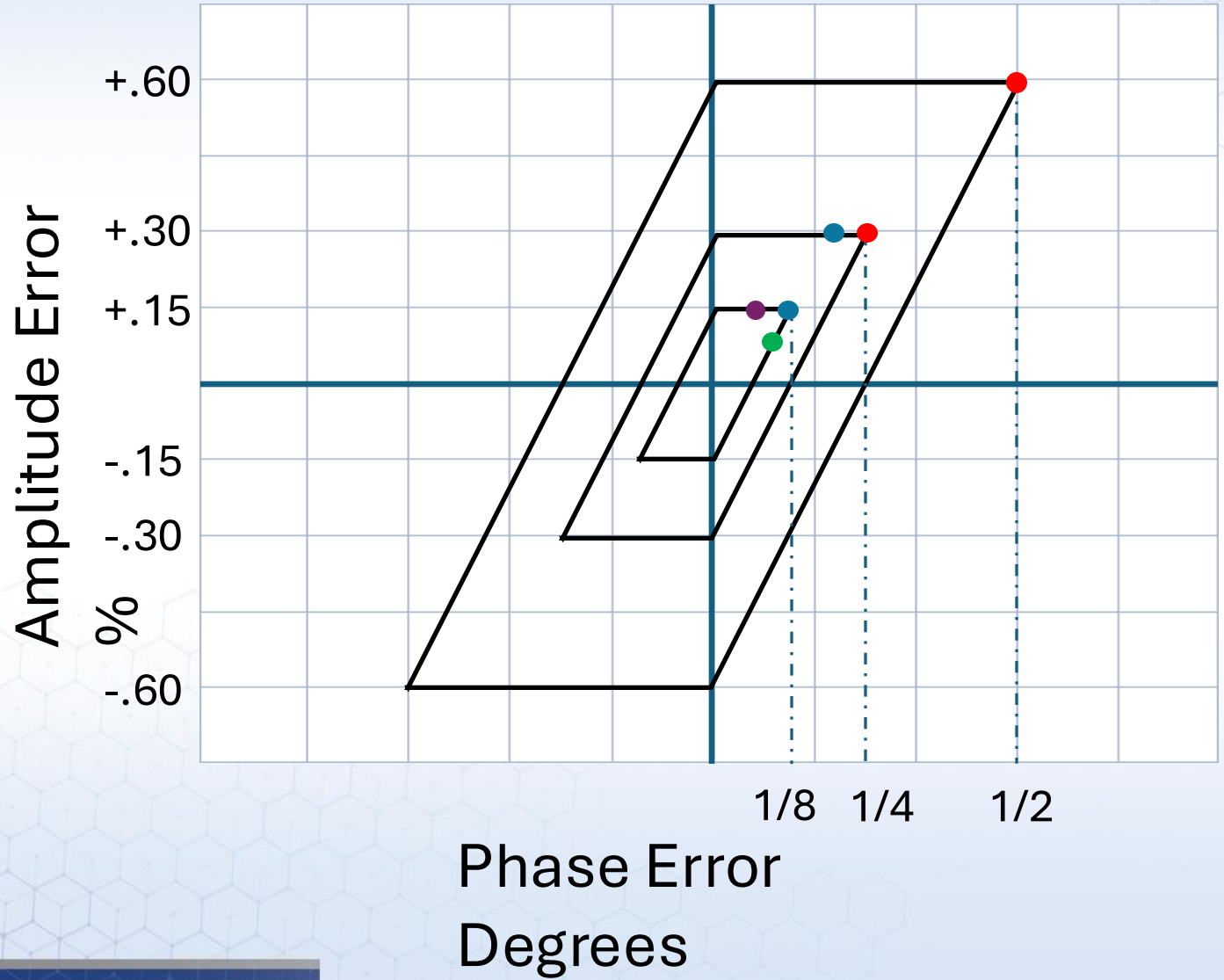
CT Accuracy Class



CT Phase Error

- Angle Between Primary and Sec Current
- IEEE C57.13 Plot Shows Amplitude & Phase

CT Accuracy Class



Class 0.3

- 1/4° RL to RF
- 1/2° 10% RL to RL

Class 0.15

- 1/8° RL to RF
- 1/4° 5% RL to RL

Class 0.15S

- 1/8° 5% RL to RF

Class 0.15 Ext

- 1/8° 1% RL to RF

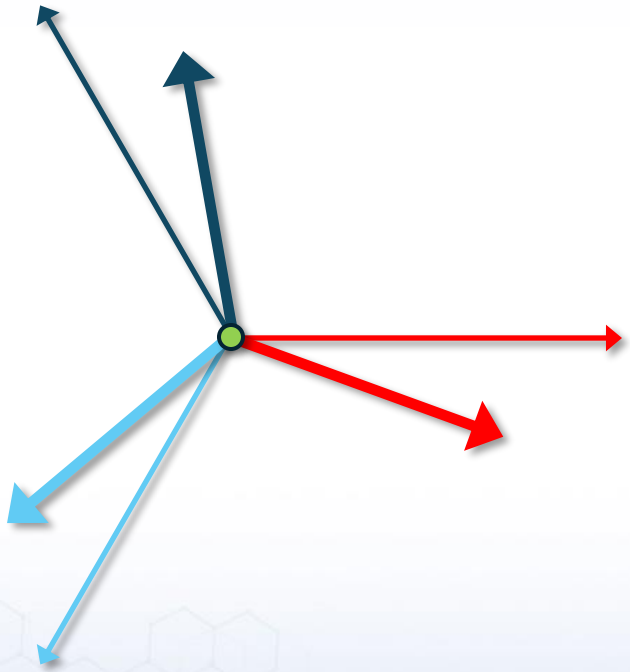
Errors When There are NO Errors Can Still Cause Revenue Loss

What Solutions Can We Utilize?

- Emphasize Sizing CTs Correctly
- Re-Evaluate Installed CTs when Customer Changes
- Use Rating Factors to Our Advantage
- Control Burden (Wire Length, Gauge, Connections)
- Utilize High Accuracy & Extended Range CTs
- Implement Field CT Testing Program

Vectors – Watts, VA, PF

Errors When There are NO Errors Can Still Cause Revenue Loss

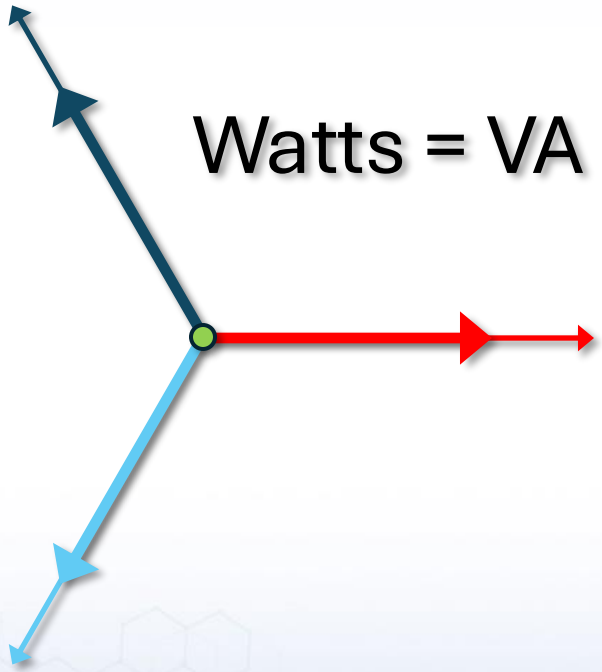


Remember This Question From Earlier?

Could This Very Normal Looking Vector Be the Biggest Cause of Revenue Loss?

It Depends on How You Define “Revenue Loss”.

Errors When There are NO Errors Can Still Cause Revenue Loss



$180k per Year (Watthours)

100% Efficient Resistive Load

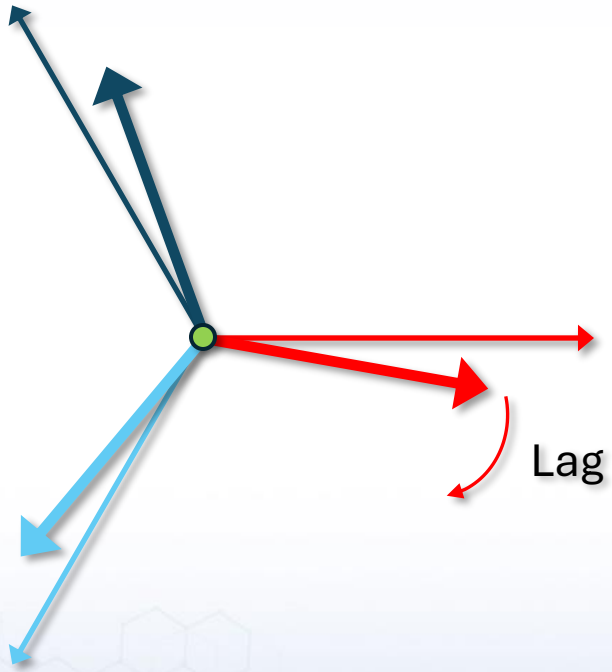
VA=V*I

- Utility Provides
- Customer Consumes

W=V*I*PF

- How Customer is Billed

Errors When There are NO Errors Can Still Cause Revenue Loss



$180k per Year (Watthours)

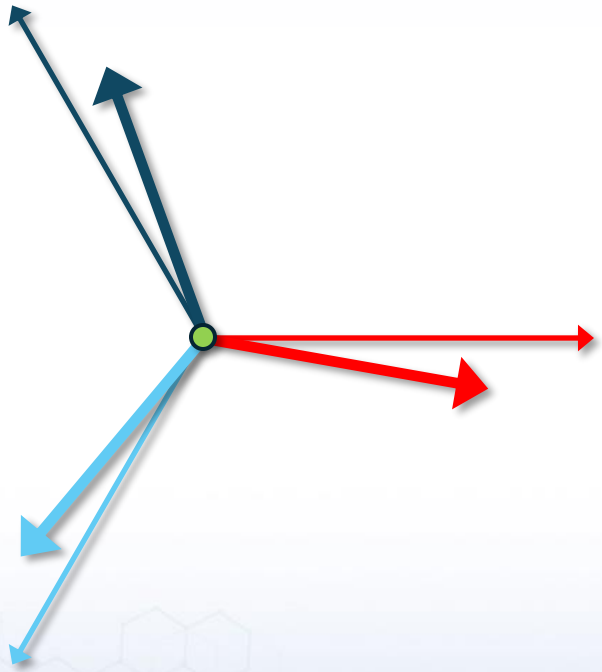
Inductive Load

Current Lagging Voltage by 10°

PF = Cos(10°)

PF = .985

Errors When There are NO Errors Can Still Cause Revenue Loss

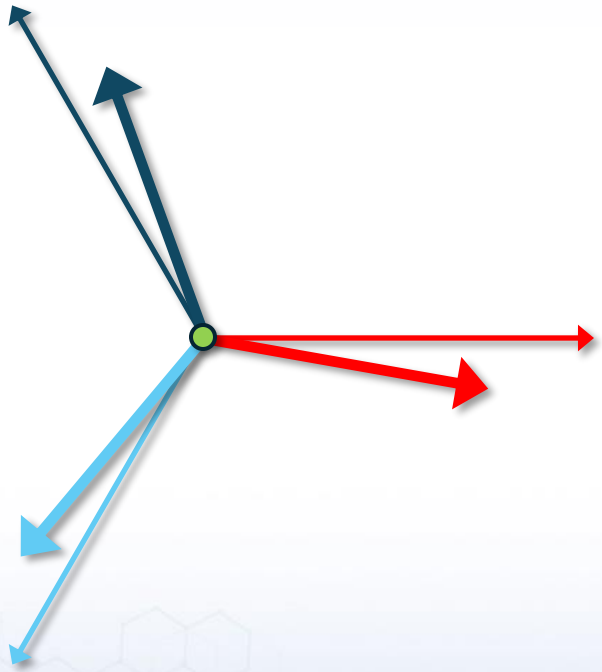


$180k per Year (Watthours)

PF = .985
98.5% Efficient or
1.5% Inefficient

Utility Provides VA (PF = 1)
$182,736 per Year (VAhours)

Errors When There are NO Errors Can Still Cause Revenue Loss



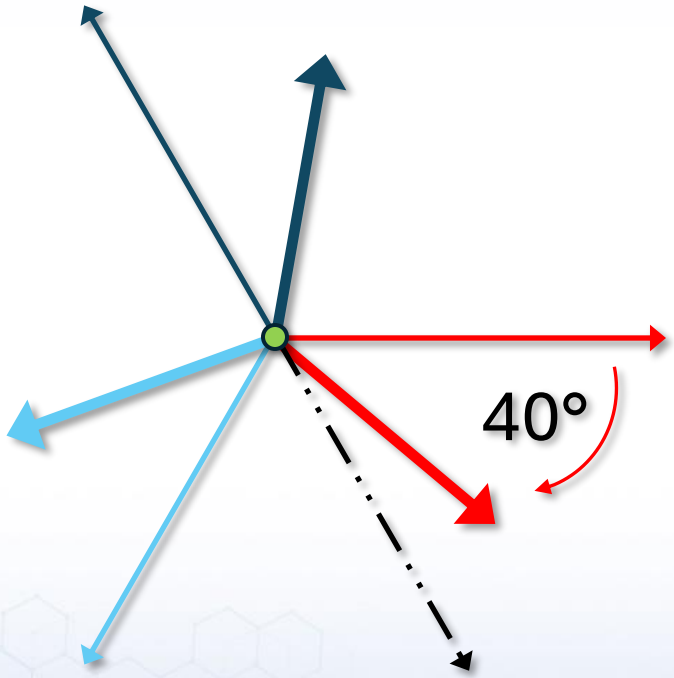
$180k per Year (Watthours)

$182,736 per Year (VAhours)

$2,736 Loss per Year

- Inductive Load
- Lowers Power Factor
- Adds VAR Content

Errors When There are NO Errors Can Still Cause Revenue Loss



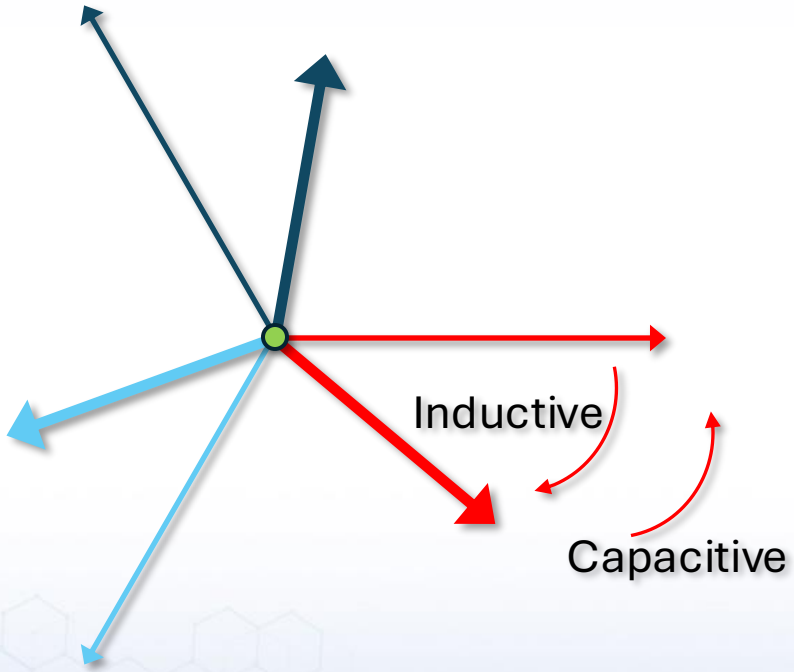
$180k per Year (Watthours)

ANSI C12.20 PF Test is 60° Lag

Power Factor 40° Lag = .766

23.4% Loss
$55k Loss per Year

Errors When There are NO Errors Can Still Cause Revenue Loss



Options for the Utility?

- VAR Penalty
- VARh Billing Instead of Wh

Options for the Customer?

- Capacitor Bank Install
  - Counteracts Inductive Load
  - Improves Power Factor

Transformer Rated Sites

How much revenue is my utility losing through site errors?

80/20 Rule Revenue vs Sites

2-5% Have Error

100% of Sites
Have Power Factor ≠ 1

FUN FACT

$30k Loss per Error

Field Test Equipment
$10k-$50K

QUESTIONS