Economics of Transformer Design

Transformer Concepts & Applications Seminar

Goldsboro , NC

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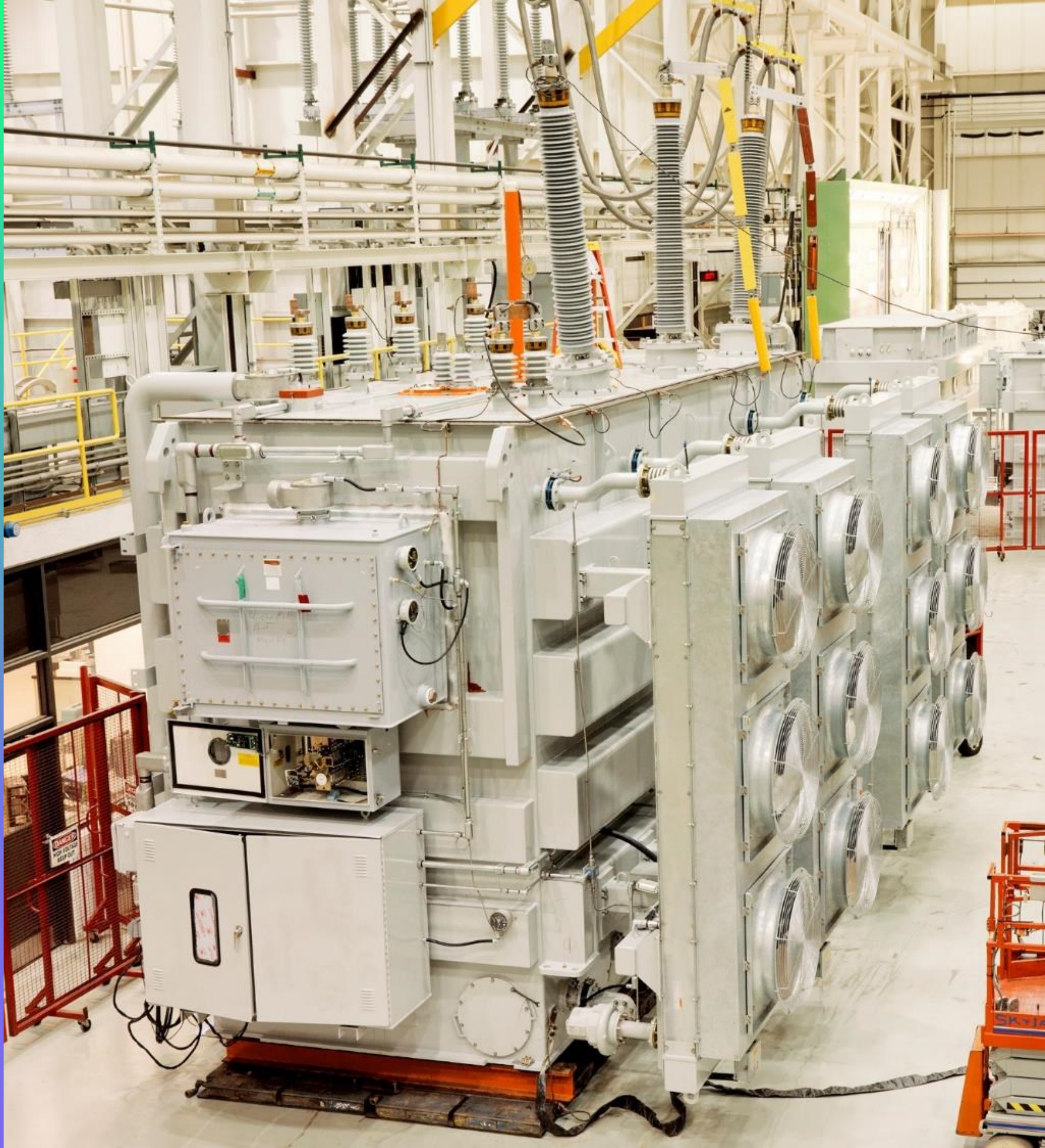
Dharam Vir
Vice President of Engineering

Dharam started with Prolec GE Waukesha in 2004 and is currently responsible for engineering at both the Goldsboro and Waukesha facilities. During his 40+ years in the transformer industry, he has held positions in engineering, testing, production and plant operations. His design experience ranges from development of power transformers up to 765kV, shunt reactors and HVDC transformers. Dharam is an active member of the IEEE Transformers Committee and frequent contributor to industry training programs. He holds a Bachelor of Science Degree in Electrical Engineering from University of Delhi (India), an MS in Electrical Engineering from NIT Bhopal, India and an MBA in Finance and Marketing from Bhopal University, India.



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Overview of Today’s Presentation

- The History of the transformer
- Operation of a transformer
- Economics -Concept of Total Owning Cost (TOC)
- Typical specification parameters
- Design and construction materials
- Impact of Non-standard requirements – Cost /size
- Test requirements – Cost /Size
- Other specific requirements

If you have questions, please stop and ask at ANY time during the presentation.

The History of the Transformer

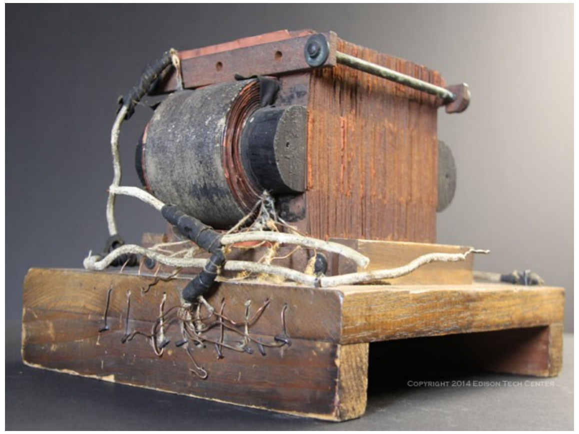
Transformer - a device that transfers electrical energy from one circuit to another circuit using inductively coupled conductors.

In other words by putting two coils of wire close together while not touching,

The magnetic field from the first coil called the primary winding effects the other coil (called the secondary coil).

This effect is called "inductance". Inductance was discovered by Joseph Henry and Michael Faraday in 1831.

The History of the Transformer



- Ottó Bláthy, Miksa Déri, Károly Zipernowsky of the Austro-Hungarian Empire First designed and used the transformer in both experimental, and commercial systems.
- Later on Lucien Gaulard, Sebstian Ferranti, and William Stanley perfected the design
- The property of induction was discovered in the 1830's but it wasn't until 1886 that William Stanley, working for Westinghouse built the first reliable commercial transformer.
- His work was built upon some rudimentary designs by the Ganz Company in Hungary (ZBD Transformer 1878), and Lucien Gaulard and John Dixon Gibbs in England.

Market Dynamics & Outlook

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Key Market Drivers

The U.S. is undergoing a significant energy transition driven by decarbonization efforts and digitalization:

- Infrastructure Investment and Jobs Act (IIJA) & Inflation Reduction Act (IRA) funds continue to bolster the US energy transition.

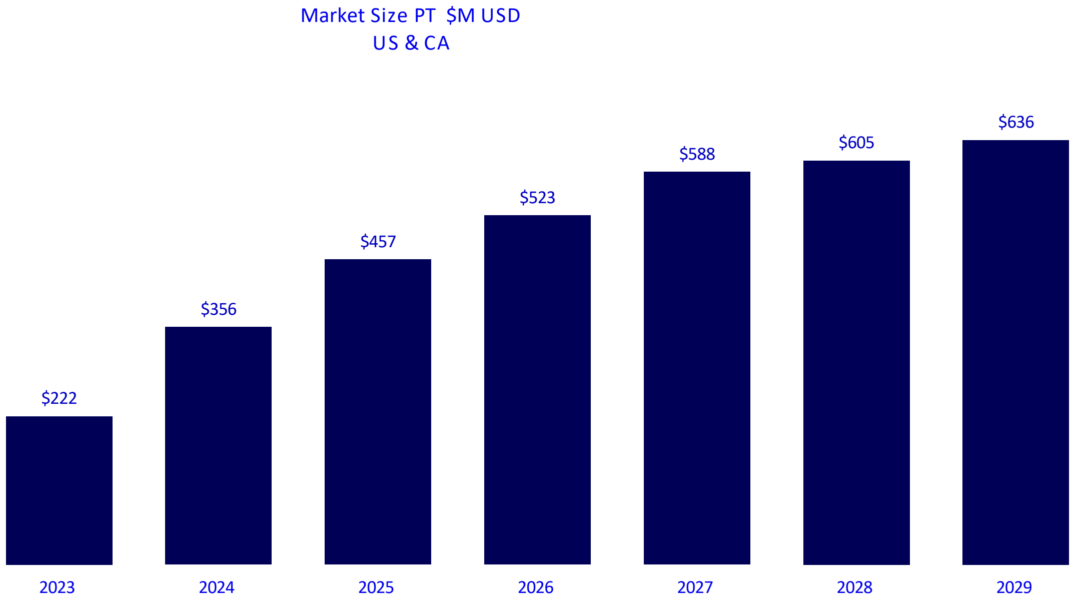
- Renewables growth continues in solar, wind, and battery storage
  - The percentage of renewable generation will jump from 22% in 2022 to 23% in 2023 and 25% in 2024, while nuclear power's share will hold at 19%.
  - Due to inflationary pressures the US offshore wind power capacity under contract dropped 18% in the third quarter of this year.
- Grid interconnects expected to drive increases in transmission investment
  - US Utilities need $80 - $100bn in transmission investment to meet IRA goals.
  - US Merchant Transmission developers have found success by sidestepping one of the most difficult challenges. In lieu of any effective joint interregional planning, merchant companies are filling the void with individual power suppliers that subscribe to the line's transmission capacity.

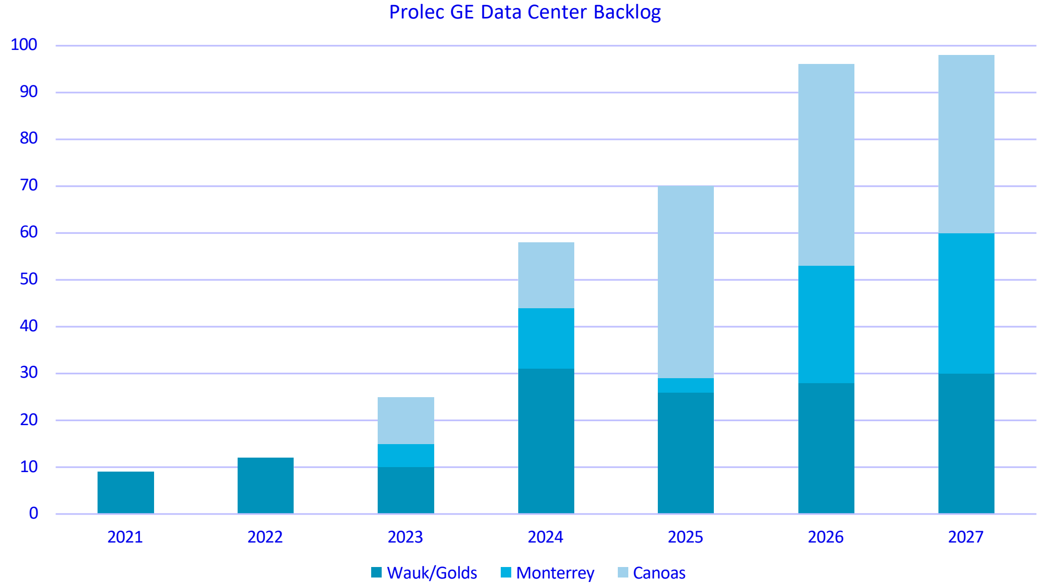
- Data center expansion due to increase in digitalization (AI and Cloud-based storage)
  - US has the largest datacenter market in the world, Electric utilities that serve it point to it a "growth machine“.
- Asset aging and replacement
  - Most of the U.S. electric grid was built in the 1960s and 1970s
  - In addition to investments being made in support of growth and expansion it is estimated US utilities are investing a combined $20-$25bn per year in support of aging infrastructure and assets.

- Record demand is rapidly consuming capacity and pushing lead times for power transformers out 3 to 4 years or more.

- Supply chain constraints related to labor and material availability is requiring order timing at a minimum of 52 weeks prior to shipment.

Data Center Market





- Estimated CAGR of 19% from 2023-2029 for power transformer demand for data centers in US & Canada
- Driven by rapid surge in AI development from tech firms such as Amazon, Apple, Google, Meta and Microsoft
- Prolec GE's data center backlog is growing at a CAGR of 49% from 2021-2027
  - Significant increases from Canoas beginning in 2025 and from Monterrey in 2026
- Continuing trend of growing MVA ratings, which further stresses LP/EHV capacity

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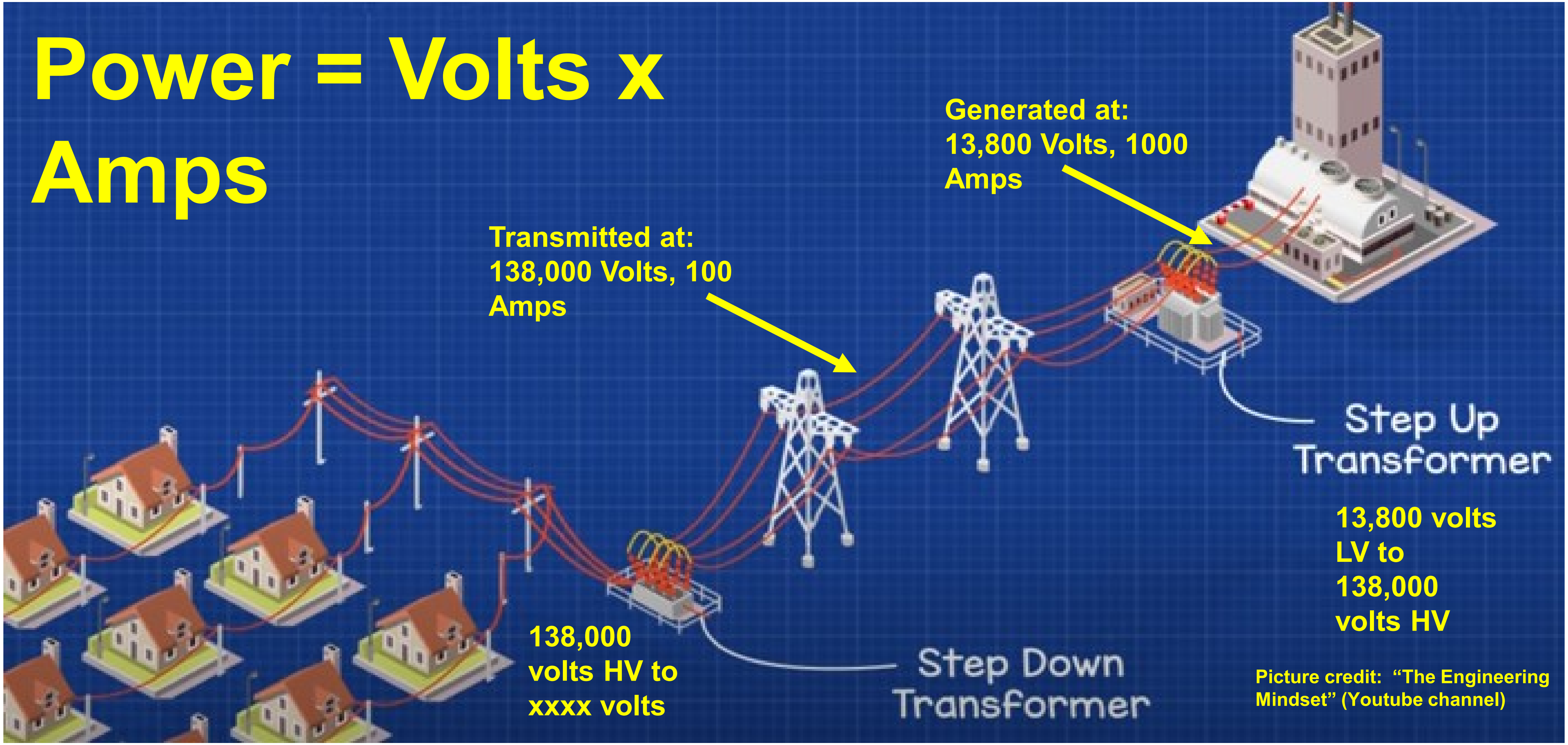
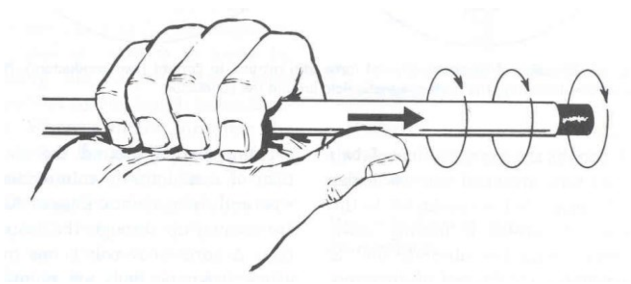
Step-by-Step Operation of a Transformer

Basic Power Transmission

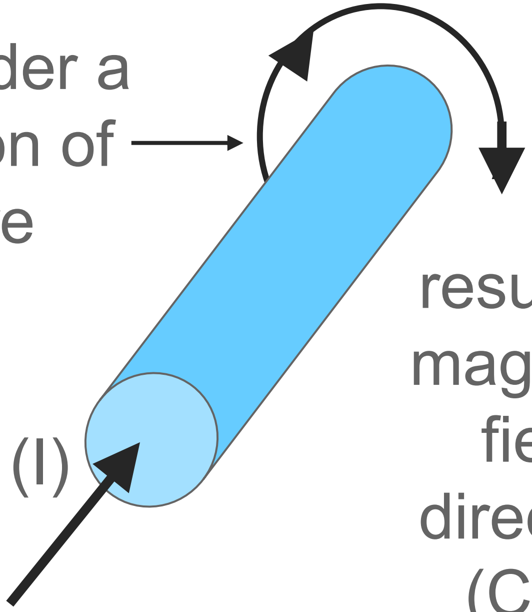


Current & Magnetic Field Relationships



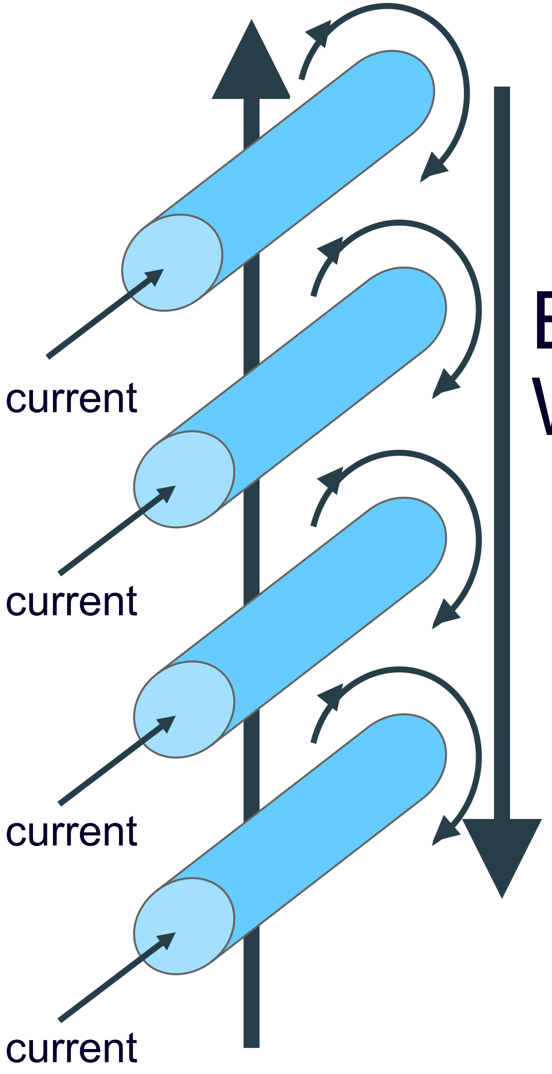
Right hand rule

Consider a section of wire



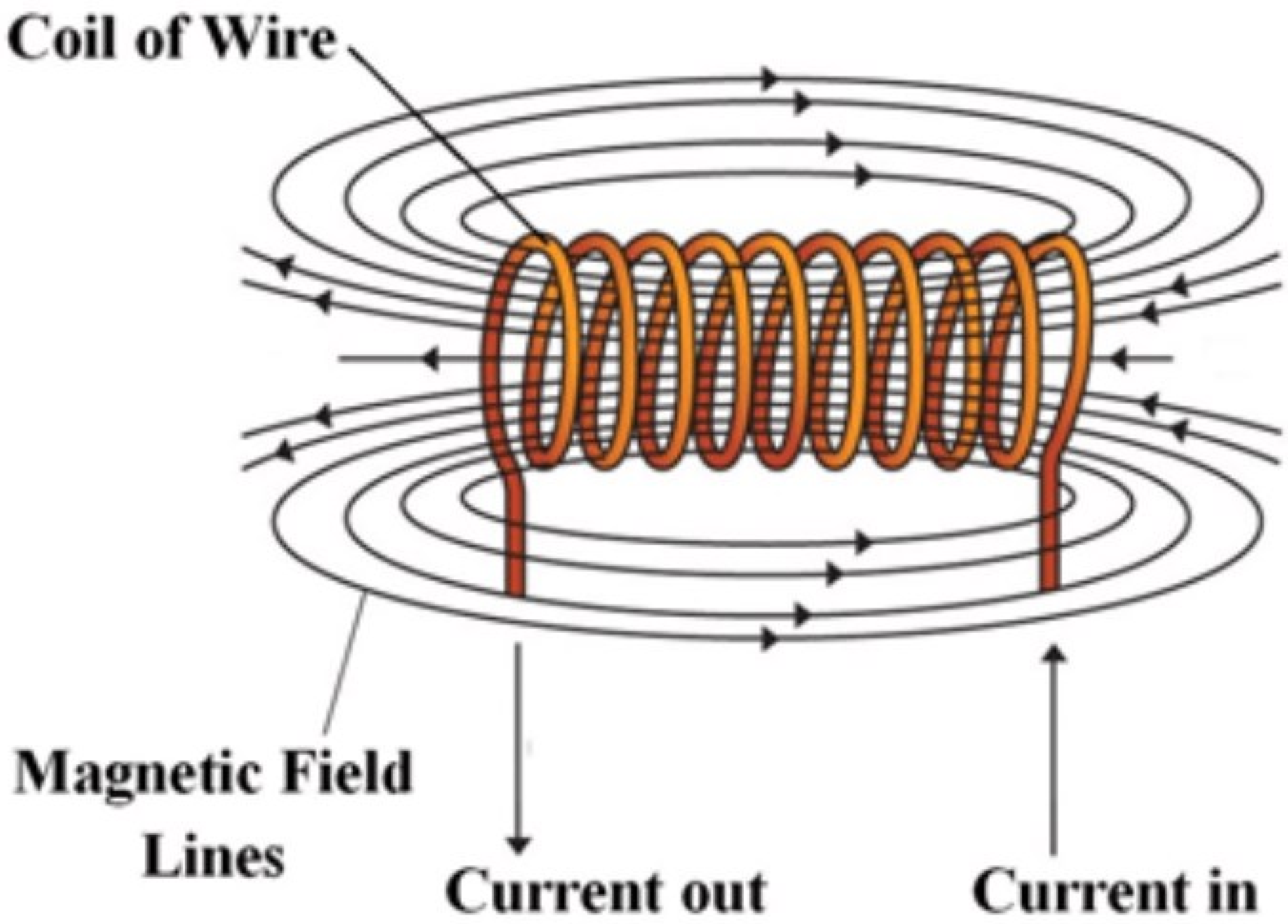
Current Flow (I)

resulting magnetic field direction (CW)



Effect of Many Wires Together

Effect of putting the wire into a coil



Picture credit: www.researchgate.net

AC vs DC effects on secondary circuit

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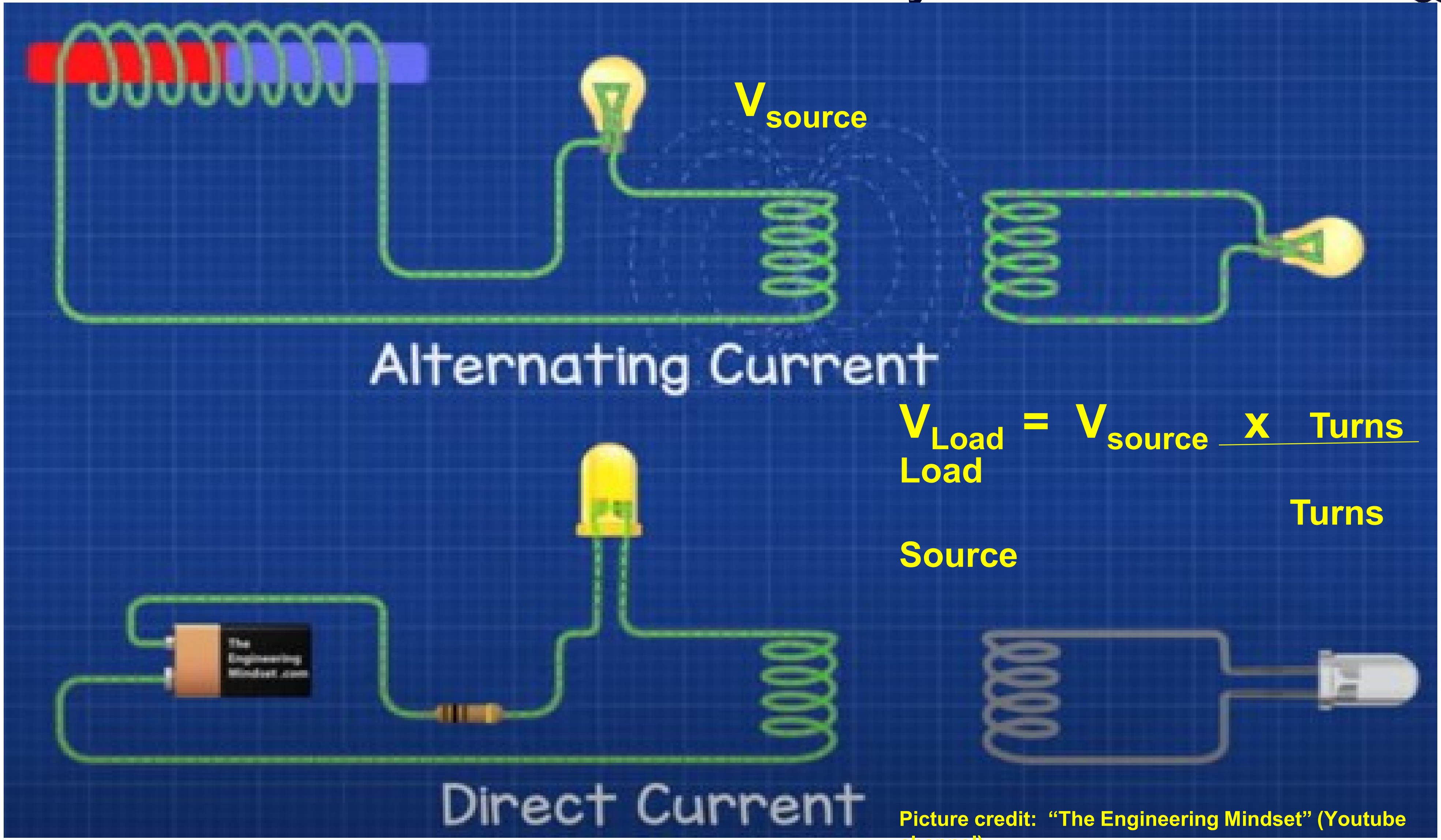


V_{source}

$V_{Load} = V_{source} \times \frac{Turns_{Load}}{Turns_{Source}}$

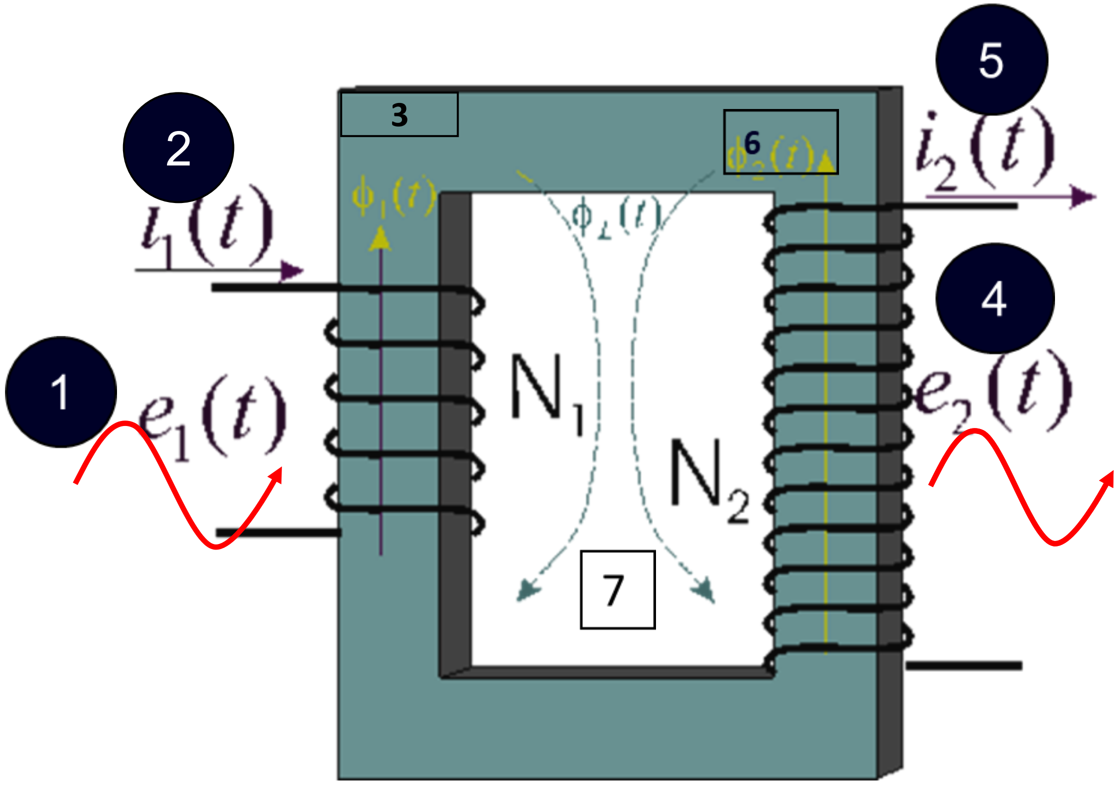
Picture credit: “The Engineering Mindset” (Youtube channel)

Textbook Transformer (step-by-step

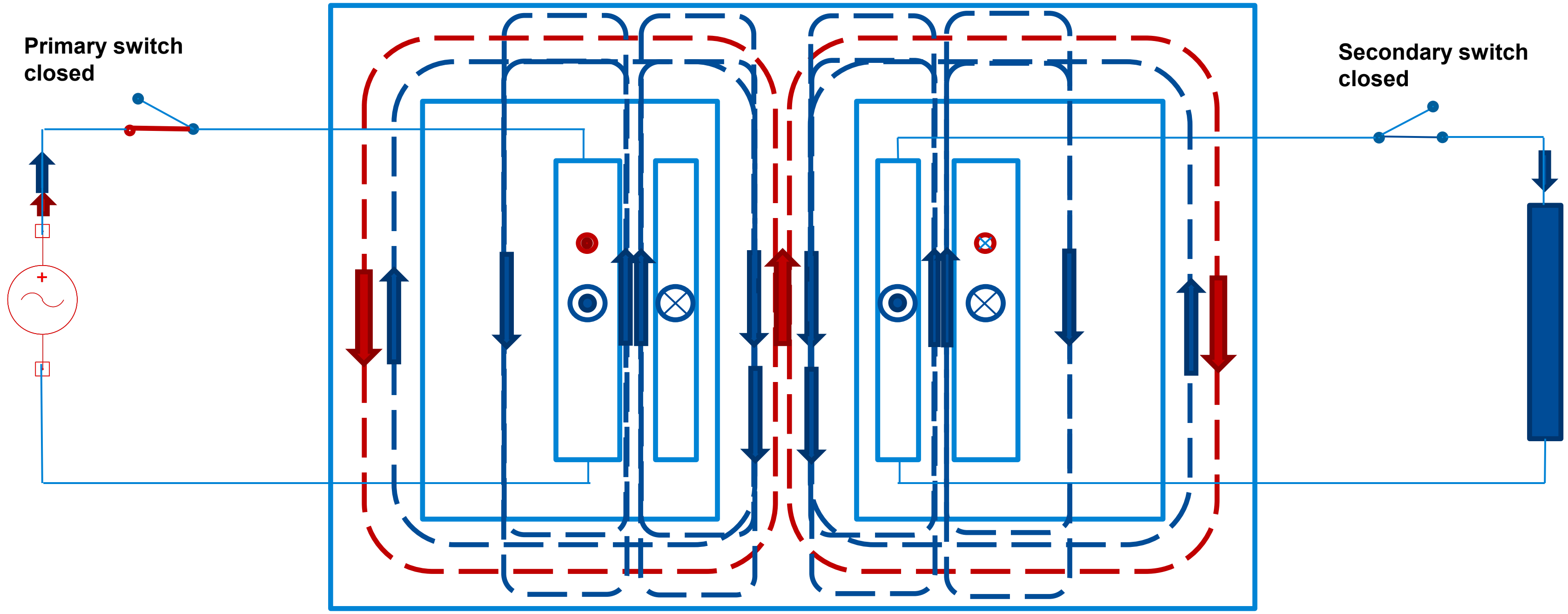
- Faraday's law of Electromagnetic Induction

$$E = -N\frac{d\Phi}{dt} \text{ volts}$$

- Right hand Rule –Relation between magnetic field and current
- Lenz's law states that the direction of the current induced in a conductor by a changing magnetic field is such that the <u>magnetic field</u> created by the induced <u>current</u> opposes the initial changing magnetic field which produced it.



Transformer Operation step-by step



EMF Equation of a Transformer

Applied voltage $v_1 = N_1 \frac{\mathrm{d}\phi}{\mathrm{d}t}$

Induced emf $e_1 = -N \frac{\mathrm{d}\Phi}{\mathrm{d}t}$ volts

As the applied voltage is sinusoidal

$$v_1 = v_{1\mathrm{m}\ \mathrm{Sin}\ 2\pi f t}$$

$$\phi = \phi_m \,\mathrm{Sin}\, 2\pi f t$$

$$\frac{\mathrm{d}\Phi}{\mathrm{d}t} = \phi_m \cos 2\pi f t \; X 2\pi f$$

$$e1 = -N_1 \phi_m \cos 2\pi f t \; X 2\pi f$$

RMS value of Induced emf

$$E_1 = \frac{2\pi}{\sqrt{2}} f\, N_1 \phi m$$

$$E_1 = 4.44 f\, N_1 \phi m$$

V/T =4.44 f B A

Concept of Total Owing Cost (TOC)

Loss Evaluation

User Parameters

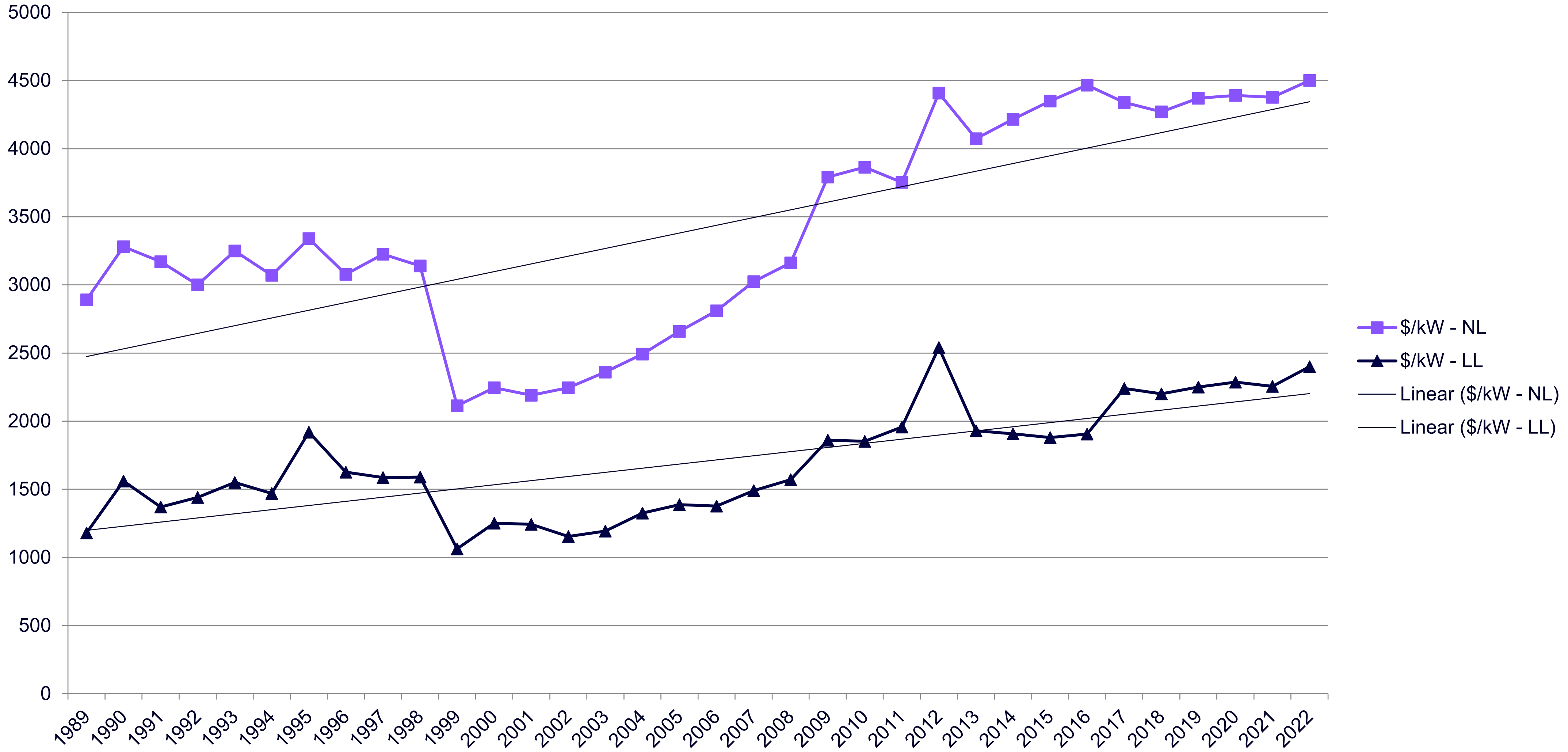
- $/KW No Load Loss at 100% Excitation
- $/KW Load Loss at 100% Self Cooled KVA
- $/KW Auxiliary Losses per Forced Cooled Stage

Loss Evaluation

Manufacturers Guarantee Values

- Selling Price
- No Load Loss at 100% Excitation
- Load Loss at 100% Self Cooled Rating
- Auxiliary Losses per Stage of Forced Cooling

Loss Evaluation Trend



Transformer Design Parameters

Optimum Design – A Balance

- Cost of variable items
- Oil, conductor, steel
- Cost of constant items
- Bushings, gauges, CT's
- Cost of losses
- Cost of manufacturing
- ***Customer Satisfaction***

Optimization of a Design

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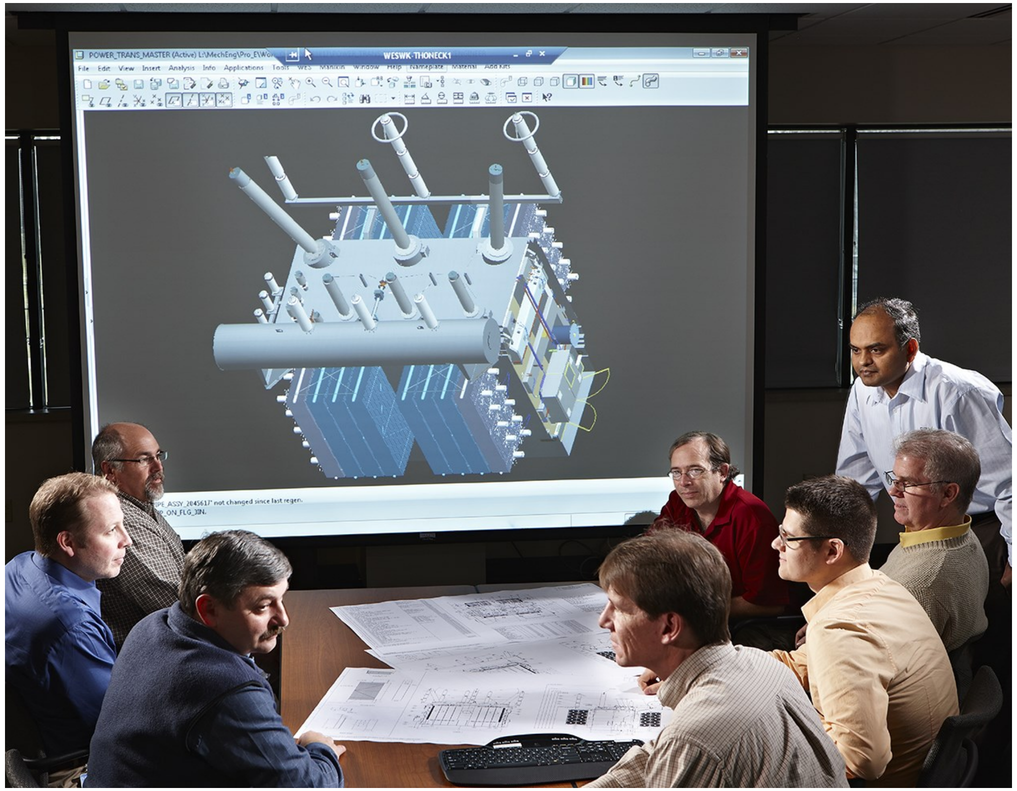
- Determine the ranges of the major characteristics
- Basic transformer requirements (voltage, KVA, impedance, temperature rises and sound level)
- Computer programs
- Best transformer design the application



20 MVA 132/13.8 KV – Evaluation

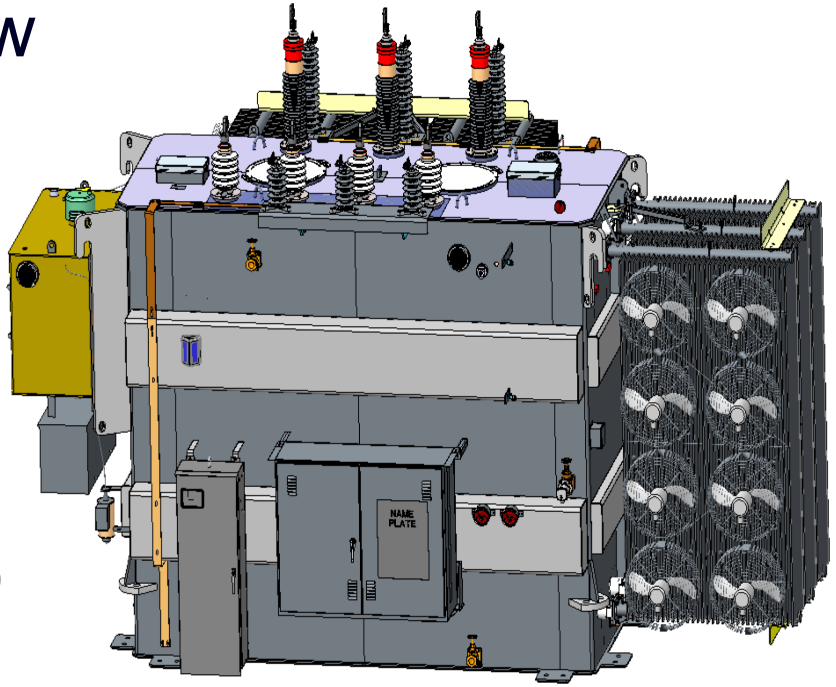
Load Loss $2000/kw, No Load Loss $3000/kw

Vendor A

- Price: $500,000
- No load loss: 20 kw
- Load loss+Aux Loss: 100kw
- Loss Evaluation: BASE
- TOC: $500,000

Vendor B

- Price: $475,000
- No load loss: 23 kw
- Load +Aux Loss: 110 kw
- Loss Evaluation: $29,000
- TOC: $504,000

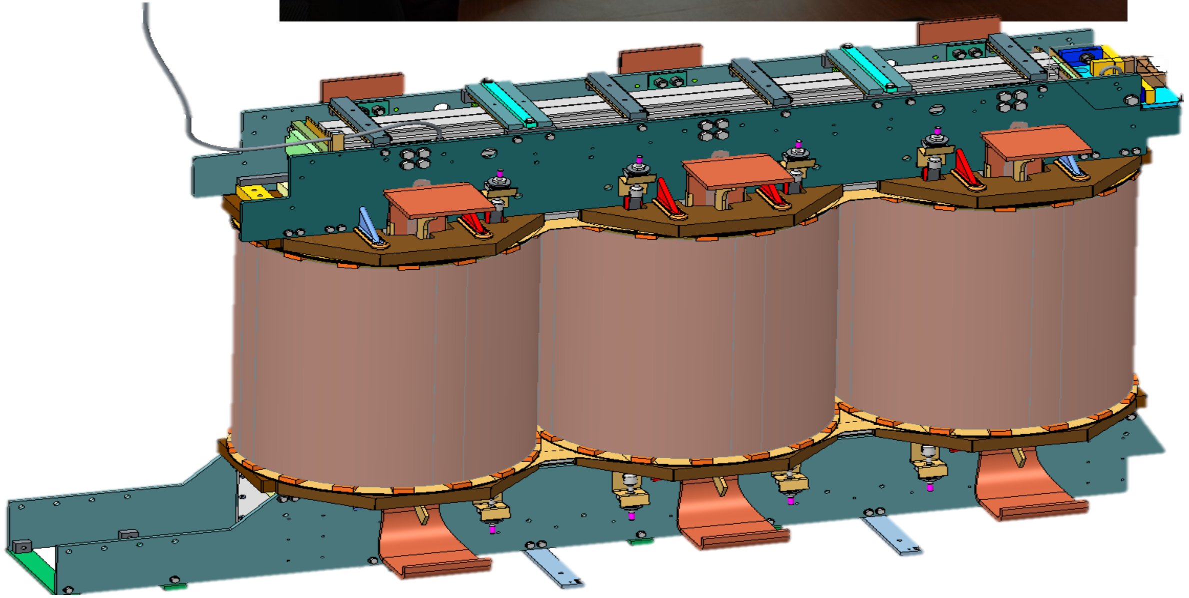


Transformer Design Parameters

High Load Loss Evaluation

- Larger Core Diameter
- Higher Flux Density
- Fewer Turns
- Squatty Windings
- Larger Magnet Wire
- Lower Current Density

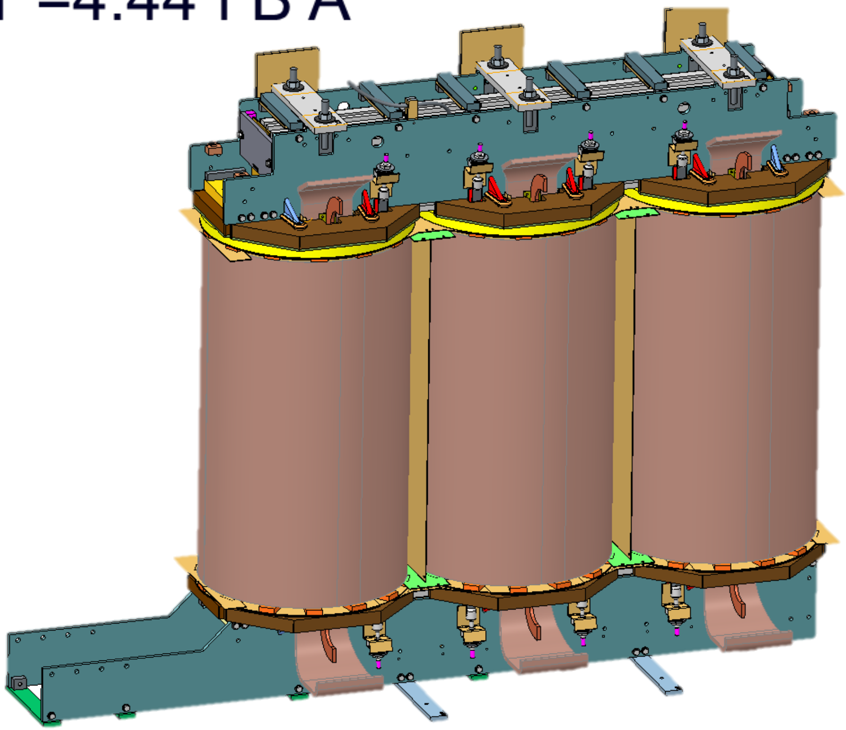
V/T =4.44 f B A

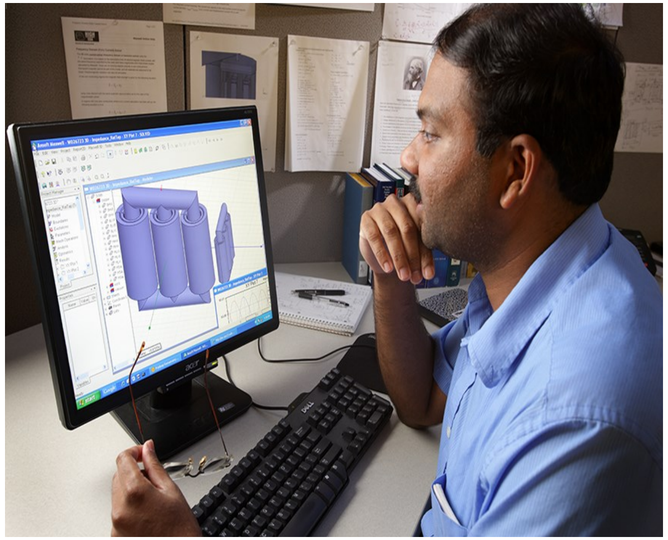


Transformer Design Parameters

High No-Load Loss Evaluation / Low Sound

- Smaller core diameters
- Lower flux density   V/T =4.44 f B A
- More Turns
- Tall, thin windings
- Smaller magnet wire
- Higher current density





Transformer Design Parameters

Lightest Weight, No Loss Evaluation

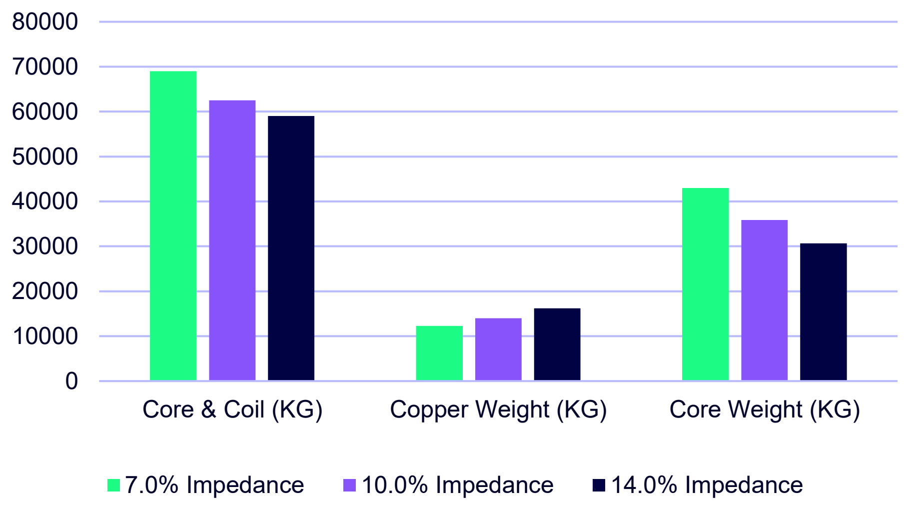
- Small core diameter
- higher flux density
- Fewer turns
- Tall skinny windings
- Small magnet wire
- higher current density
- Higher losses, more cooling
- Higher noise

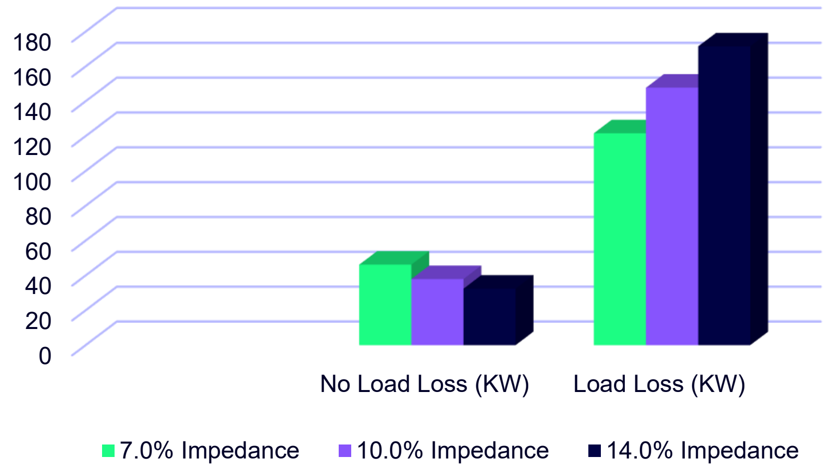
$V/T = 4.44\ f\ B\ A$

Customer

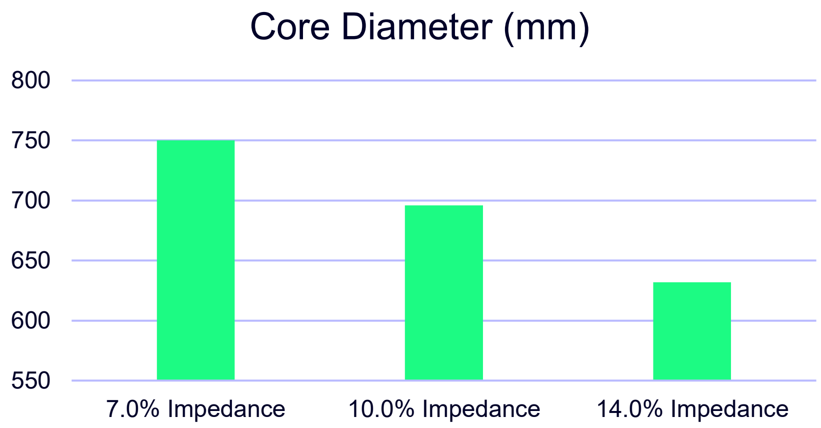
"I want the lowest price!! OKAY?!"

Impact of Change In Impedance





Impedance (%)	7.0	10.0	14.0
Capacity (MVA)	60/80/100/112	60/80/100/112	60/80/100/112
HV KV	230	230	230
LV KV	34.5	34.5	34.5
Vector Group	Dyn1	Dyn1	Dyn1



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Typical Specification Parameters

Requirements by Specification

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Performance Specification-R1

Quotation No: 70003912 **Item No:** 000010 **Project Name:** 168/224/280_345-115-14.4 LTC AUTO - NEUTRAL END

AUTOTRANSFORMER RATINGS

		Cooling Class	HV Volts		XV Volts		YV Volts		ZV (TV) Volts	
Phase	3		345,000	- -	115,000	- -	- -	- -	14,400	- -
Frequency	60		GrdY	- -	GrdY	- -	- -	- -	Delta - Loaded	
Temp Rise °C	65	ONAN	168.00	- -	168.00	- -	- -	- -	45.00	- -
Insulating	Oil	ONAF	224.00	- -	224.00	- -	- -	- -	60.00	- -
		ONAF	280.00	- -	280.00	- -	- -	- -	75.00	- -

ADDITIONAL TAP VOLTAGES

Terminal	Style	Taps or KV	Capacity
HV	DETC	+ 2 / - 2 @ 2.500 %	FULL
H0X0	On Tank LTC	+16 / -16 @ 0.625 %	REDUCED

PERCENT IMPEDANCE VOLTS

%	Windings	At MVA
6.00	H-X	168.0
- -	H-Y	- -
- -	X-Y	- -

AUXILIARY LOSSES AND SOUND LEVEL

MVA	Class	Cooling	Sound Level dB
168.00	ONAN	- -	78
224.00	ONAF	9,200	80
280.00	ONAF	18,500	81

The above v... equipment (heaters, control devices, etc.) losses of 2,000 watts

INSULATION LEVELS (KV)

Terminal Winding Bushing

HV, H0, XV, XV, YV, YV, ZV, ZV

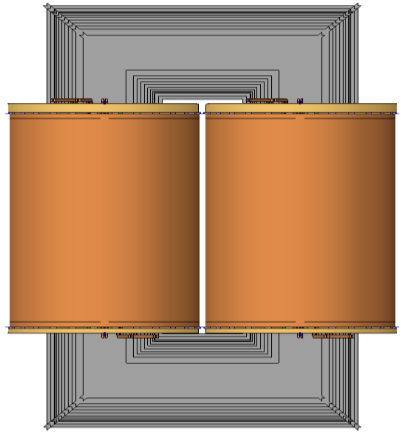
PERFORMANCE BASED ON A LOADING OF

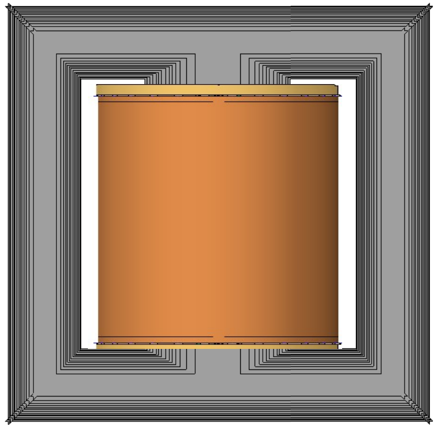
0.8 3.83

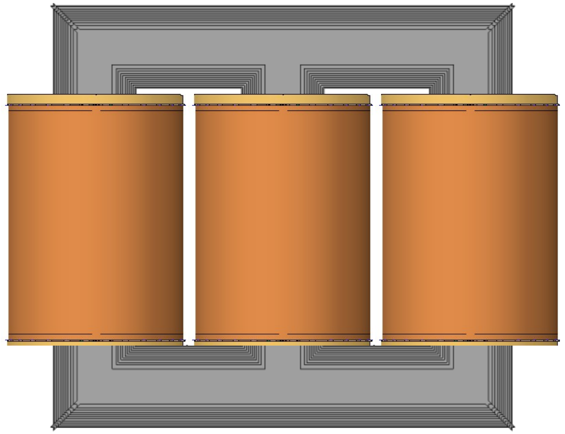
Class	Cooling	Sound Level dB
ONAN	- -	78
ONAF	9,200	80
ONAF	18,500	81

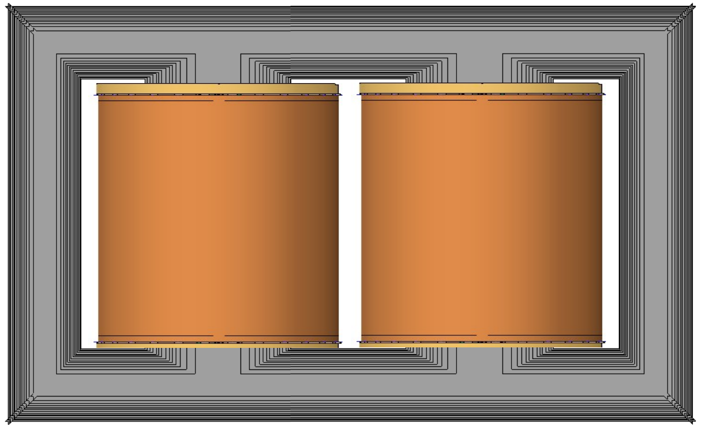
Design and Construction Materials

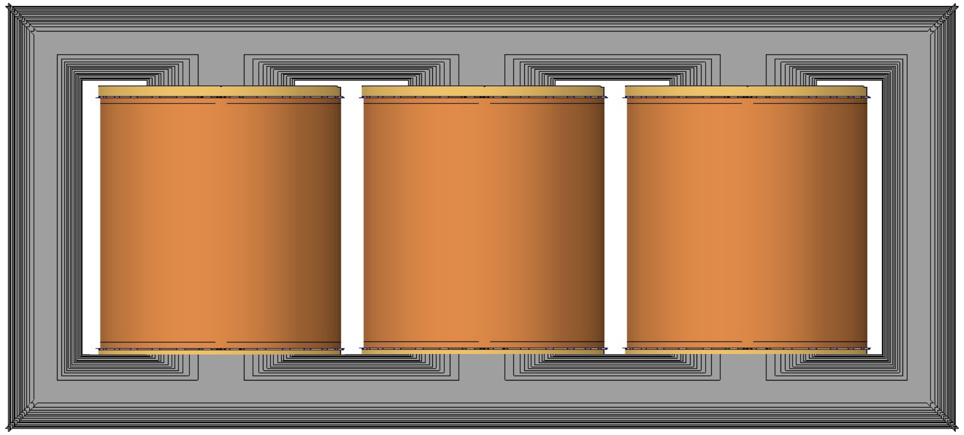
Different types of Core Construction


Single Phase, 2-Limb Core form


Single Phase, 3-Limb Core form


Three Phase, 3-Limb Core form

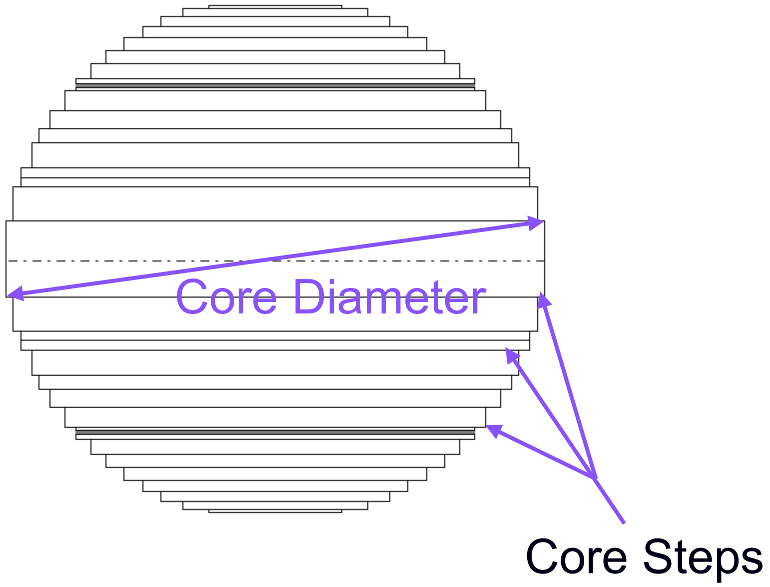

Single Phase, 4-Limb Core form

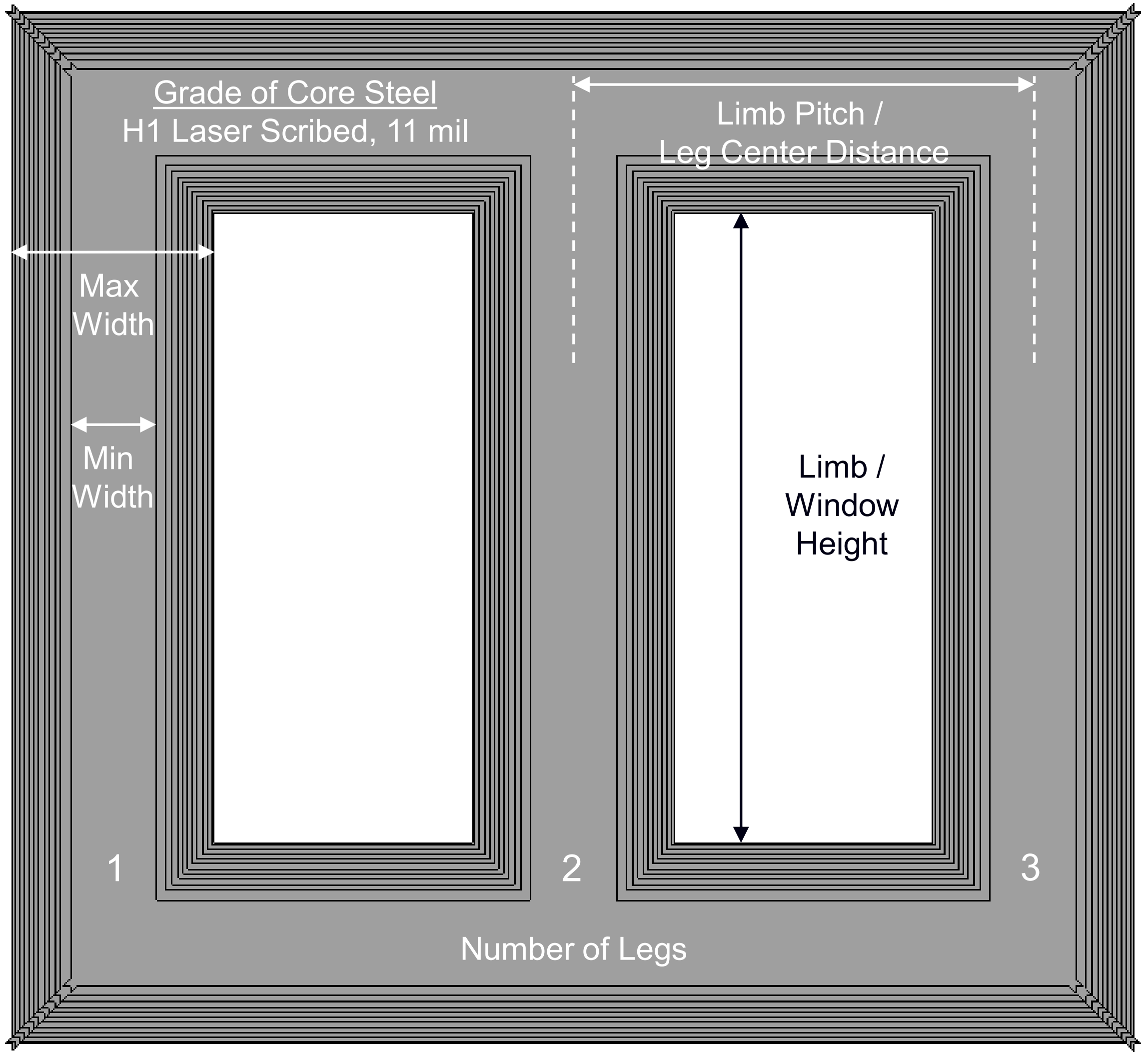

Three Phase, 5-Limb Core Form

Core Design Considerations

- Flux Density
- No Load Loss
- Sound
- Excitation Current
- Temperature Rise
- Internal
- Outer Packet

- Tie Plate
- Clamps
- Tie Plate
- Lifting + Clamping Stress
- Short Circuit Stress





Types of Windings

Layer/Barrel

- Regulating (RV) and Tertiary windings (TV)

Screw (Helical)

- LV, Series (Booster) transformer

Continuous Disc

HV, LV, Series (Booster)

These winding types may use magnet wire or CTC

Layer Type Winding

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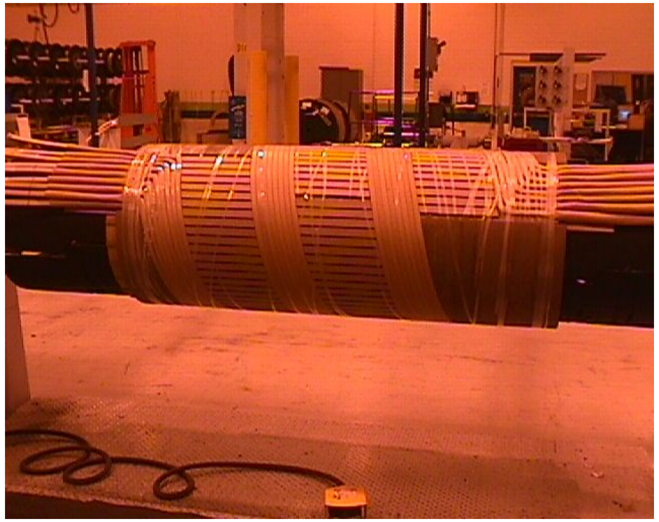
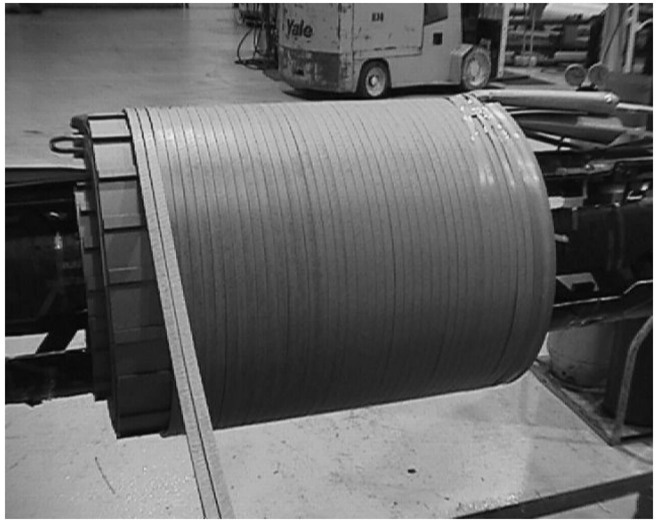
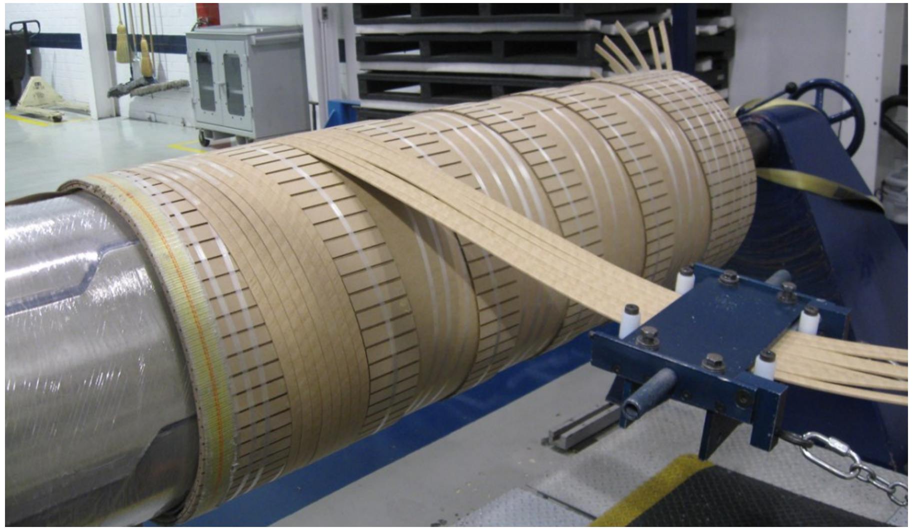
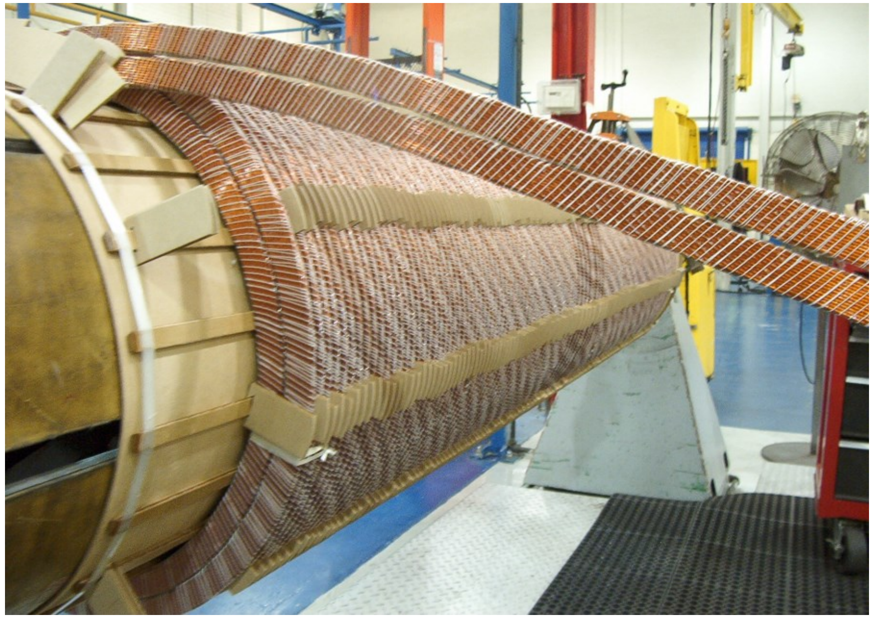
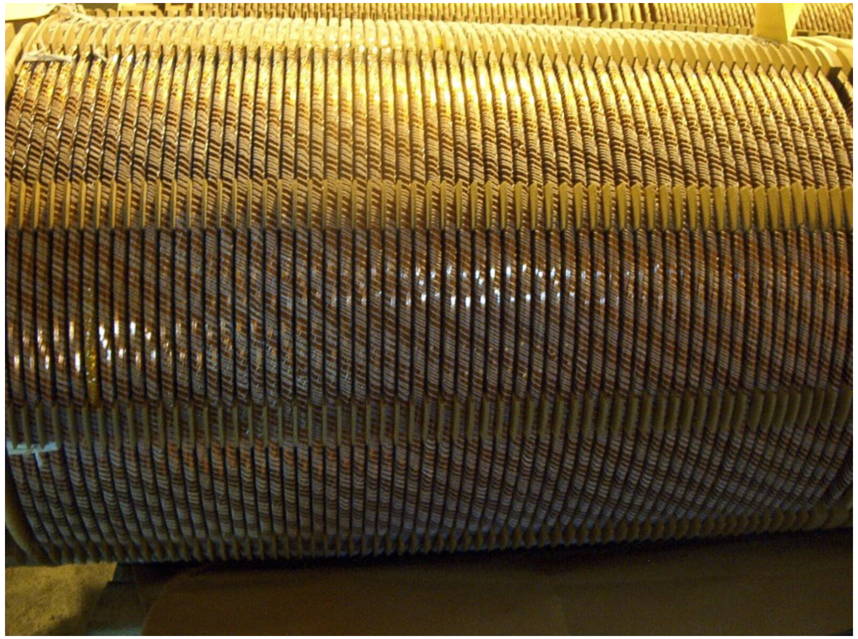
SLL / Layer / Barrel

Helical Winding with two CTCs

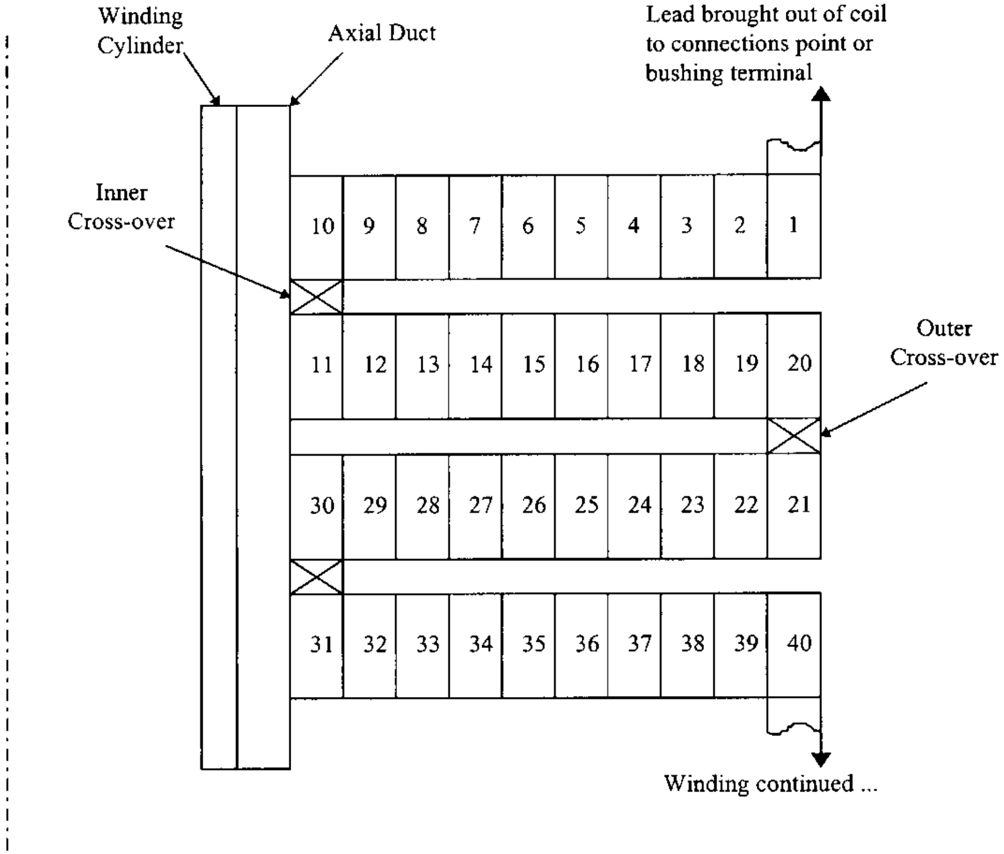




Continuous Disk Winding

Inner cross-over

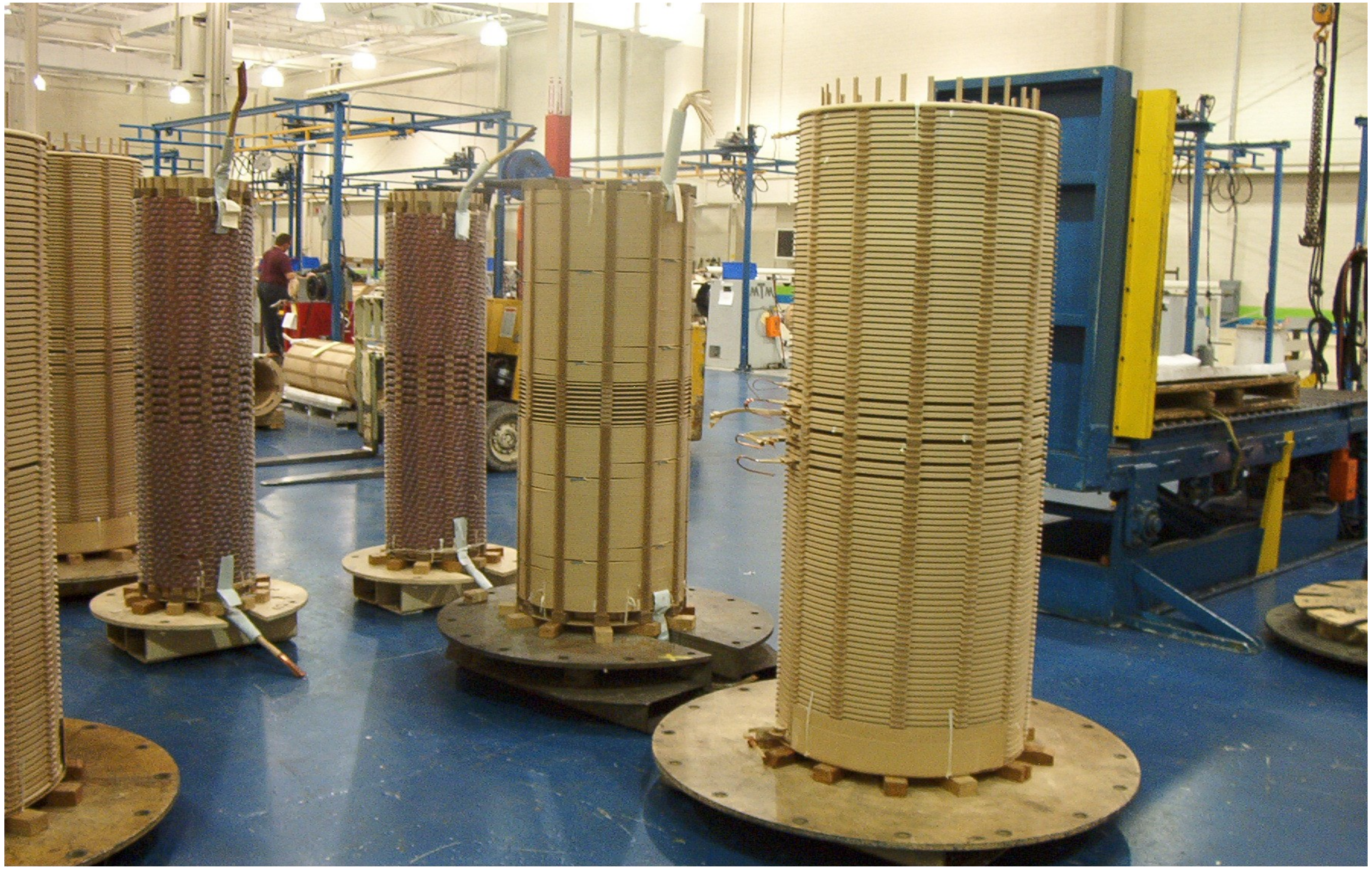
Outer cross-over



Disc Winding with Magnet Wires

Set of Windings

Set of Windings for a given Transformer



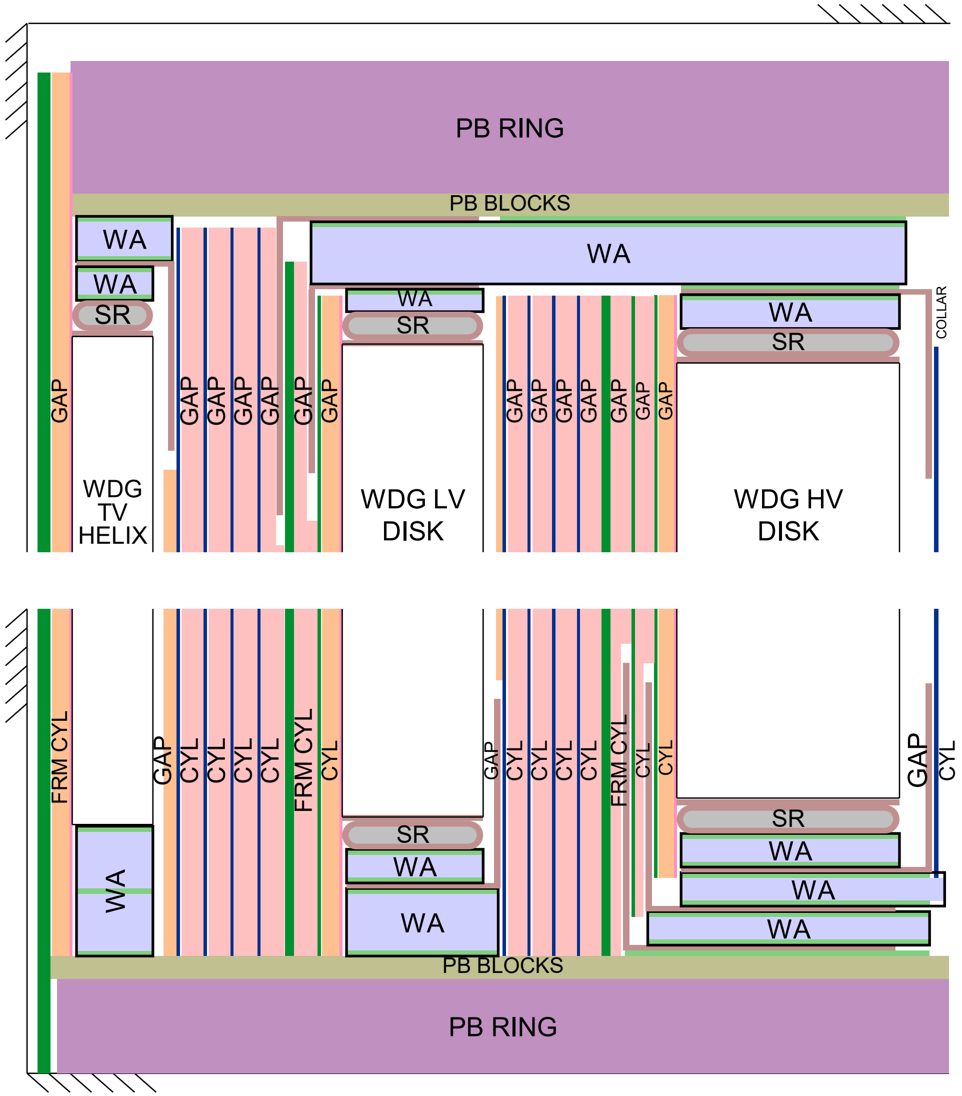
Insulation Materials

Major Insulation

Insulation of windings to ground, core, other windings within the phase and to other phases

Materials

- Pressboard (cellulose)
  - High density (TIV) – cylinders
  - Medium density (Hi-Val) – collars
  - Layered TIV (TX2) – rings, washers
- Nomex – for higher temperatures
- Laminated Wood – rings
- Kraft Paper (cellulose) – leads
- Copaco (cotton based paper) – leads
- Resin/epoxy materials – on metal parts



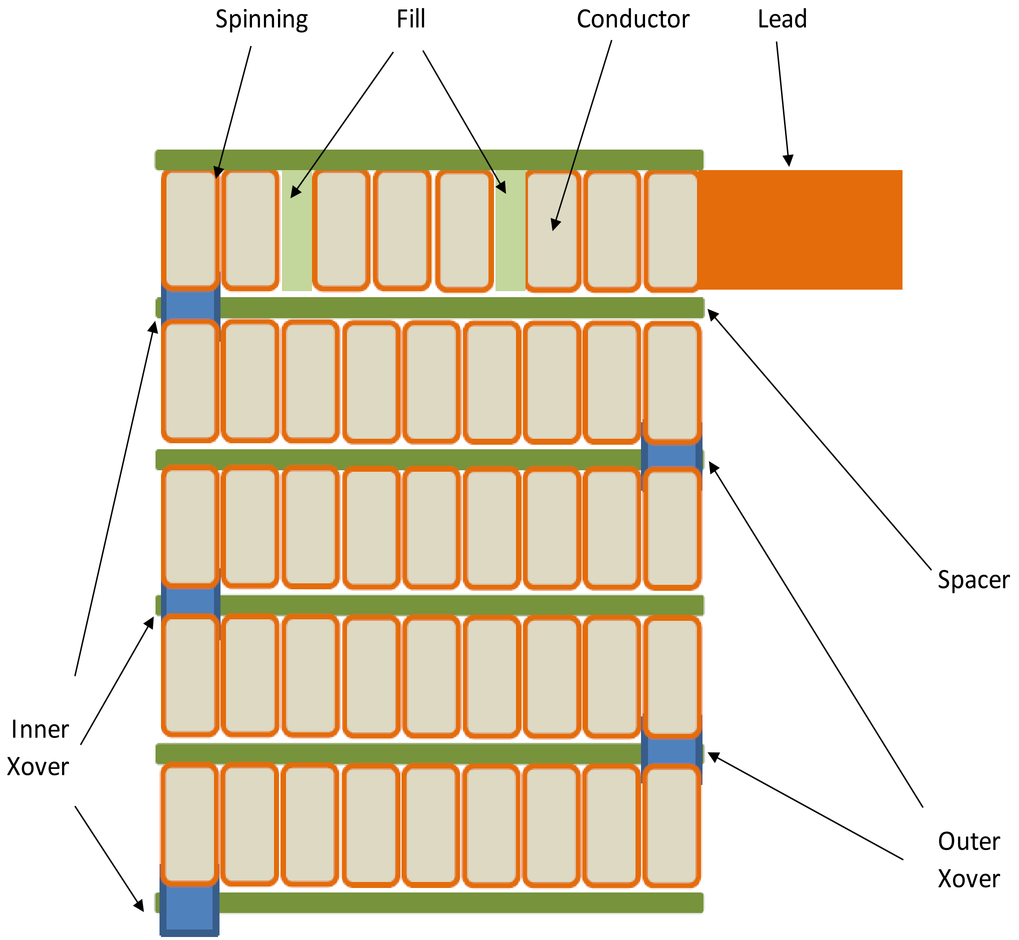
Insulation Materials

Minor Insulation

Insulation between different parts of one winding – between turns, stands of conductors, discs or layers

Materials

- Kraft Paper – conductor insulation/spinning
- Nomex – spinning, spacers
- Formvar – conductor insulation
- Epoxy (CTC) – conductor insulation
- Copaco (cotton based paper) – leads
- Pressboard
  - High density (TIV) – spacers
  - Medium density (Hi-Val) – collars, etc.
  - Layered TIV (TX2) – structural parts



Insulation Materials

Insulating Fluids
- Mineral Oil
- Natural Ester

Advantages of Natural Ester
- Slows aging of cellulose (equiv. to roughly 10 ˚C lower winding rise)
- Higher Flashpoint (330˚C vs 140˚C)
- Environmental advantage/containment

Drawbacks
- Cost
- Higher viscosity
- Solidifies below -20˚C

Other Materials

Lead Insulation
- Kraft Paper
- Copaco
- Nomex
- Pressboard

Lead Supports
- Maple
- Laminated Wood
- TX2

Bushings, Insulators
- Resin/epoxy materials
- Porcelain

Impact of Non-standard requirements

Price Per MVA Concept.

In view of the variations from spec to spec and all design parameters, cost per MVA becomes a complex equation.

Example

20 mva , 138/13.8kv 6% impedance , 550 BIL and

20 mva 138/13.8 kv 10 % impedance and 650 BIL

will have different cost/price , losses .

Therefore the first price of the transformer is based on MVA AND BIL and cost adders are needed for different characteristics.

First price comprises of $P = S \times MVA^{X} + K\ BIL^{Y}$

a) BASE PRICE
b) ADDITION FOR BIL
c) Other parameters per list below
d) TOTAL PRICE

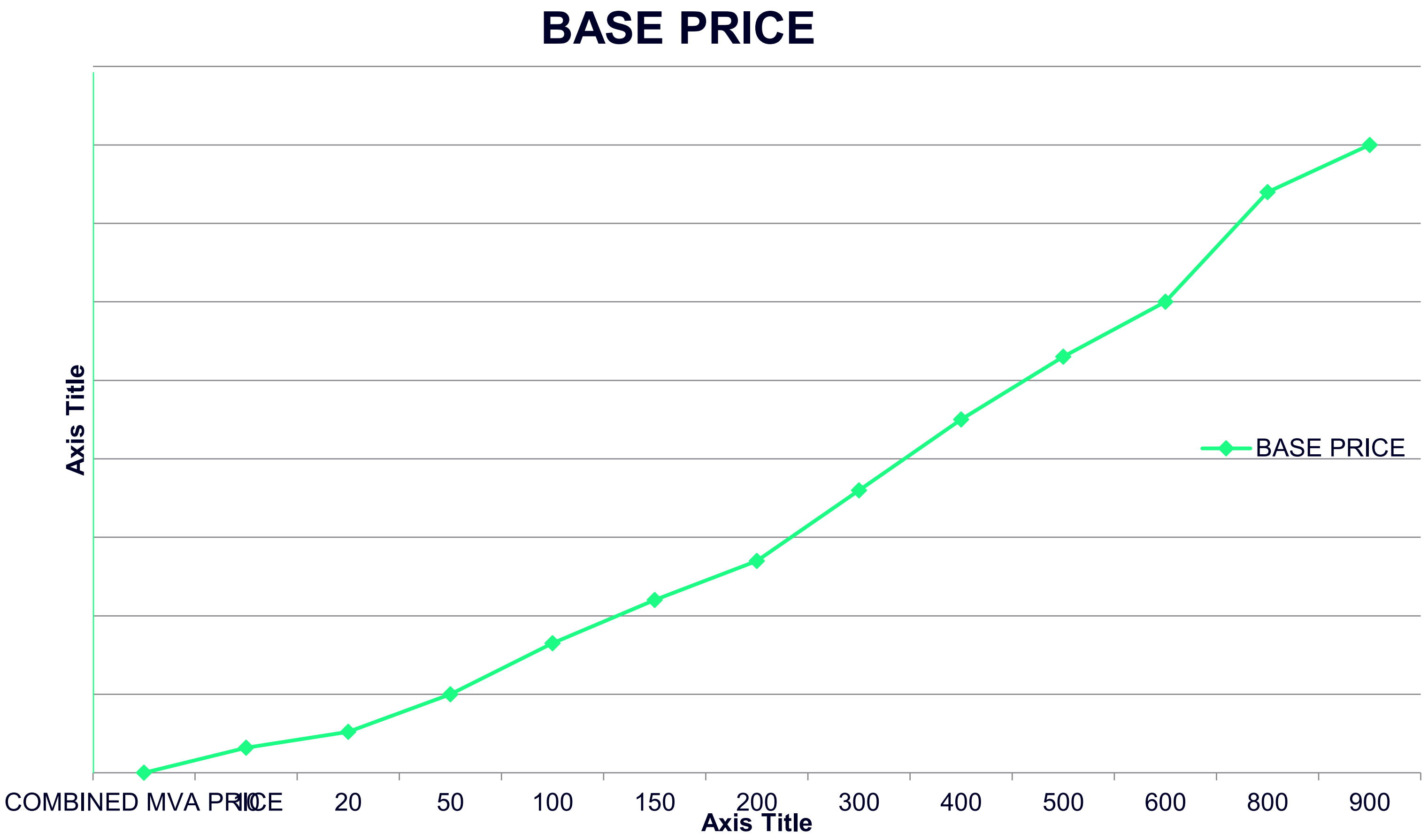
Parameters –Cost

a) Loss evaluation rates
b) Operating voltage , 138 kv delta vs 230 kv delta or Y
c) LTC type and cost, RMVI OR II ,In tank, tap range
d) Change in DETC or LTC range
e) Impedance ..high or low
f) Auto transformer co ratio (co ratio is used to calculate equivalent 2 winding rating for an auto transformer)
   (220-132)/220=0.4
g) Change in temperature rise 55 Deg C vs 65 Deg C
h) Reduced sound level
i) Special dielectric tests impacting the clearances
j) Over excitation requirements , effects core size
k) Reduced PD levels
l) Reduced DGA Limits
m) Axially stacked windings
n) Unit AUX TR/ station AUX TR

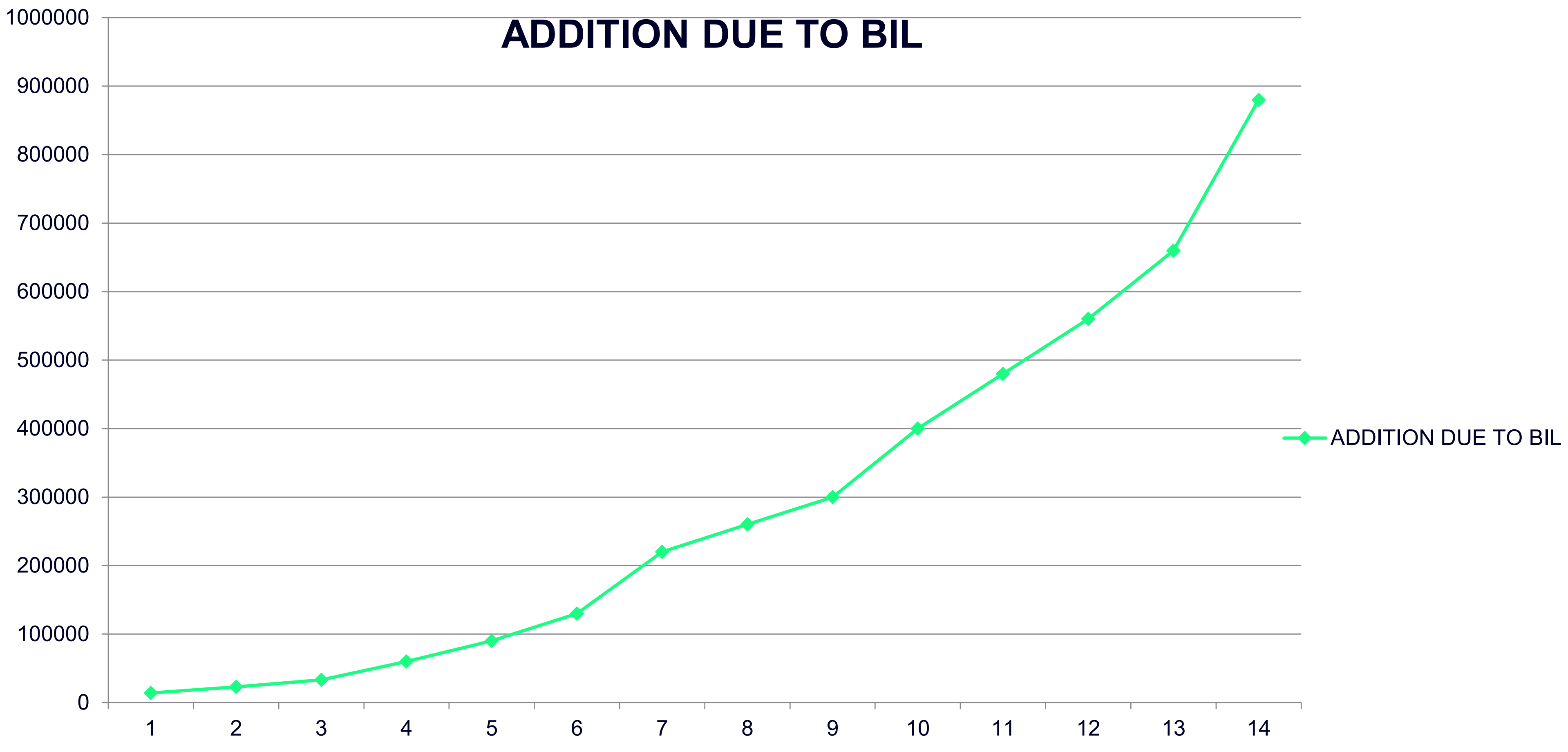
Parameters –Cost

o)No. of windings , if more than 3
p)Double layer RV windings
q)Unit with or series transformer
r)Cooling , ODAF, Overload , three winding loss
s)Tertiary ..loaded vs stabilizing mva . losses
t)Terminal boards cost /labor
v)Special controls additions – Monitoring equipment
v)Bushings high voltage , high currents
w)Altitude
x)Short circuit requirements
y)Special current density/ flux density requirements
z)Application – Furnace , wind , wind solar , SCV , STATCOM
a) GIC Requirement
b) Reverse flow power
c) ANY OTHER REQUIREMENTS
Paint thickness , CTs accuracy specific make of accessories , control box

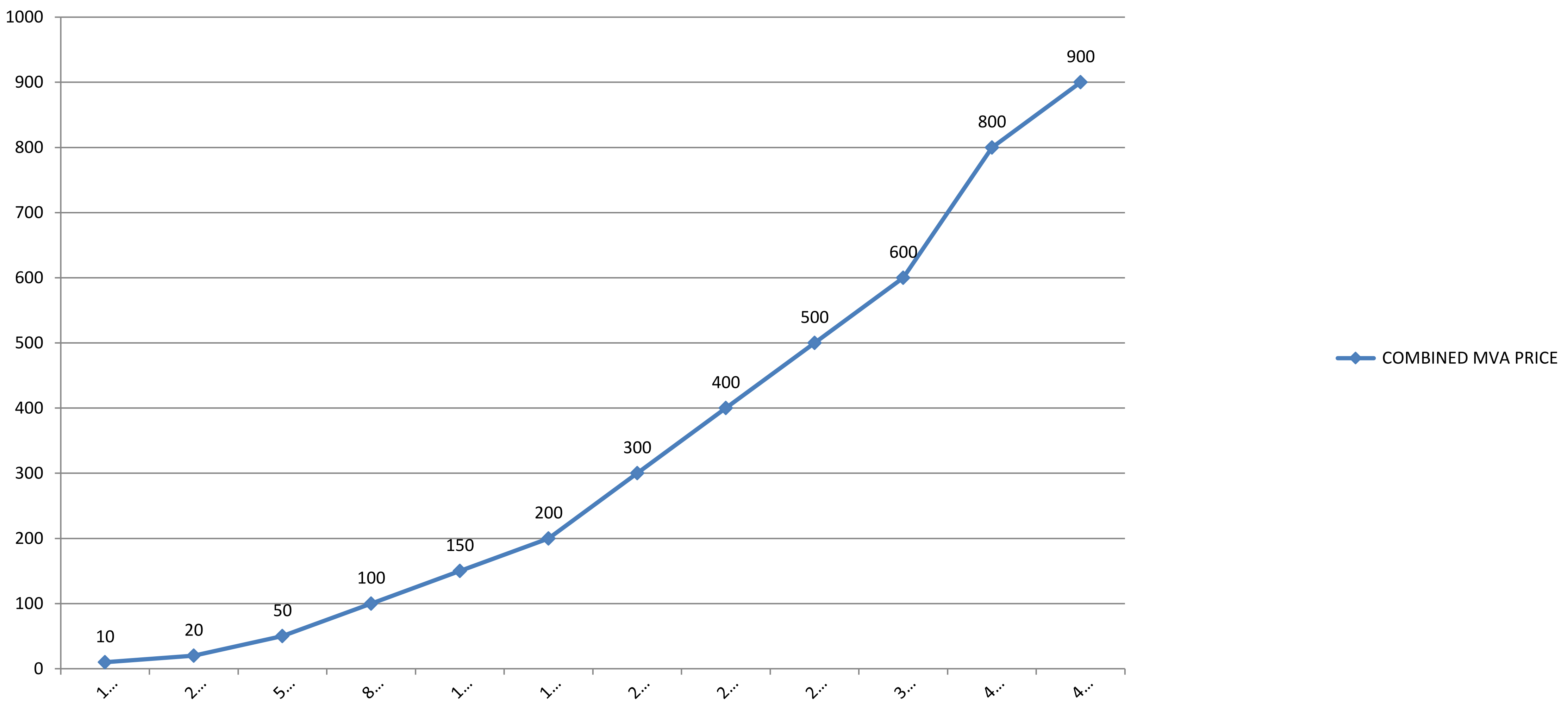
Base MVA Chart



Addition due to BIL change



Combined MVA+BIL



Requirements by Specification

- Type of core / Core Material
- Conductor Material Type
- Winding Type
- Sound Level
- Load Noise
- Special Loading
- Special %IZ
- Multiple Voltage Windings
- Stabilizing Windings
- Special Duty LTC
- GSU /Over fluxing
- Impact (High current for short duration) loading
- GIC

Requirements by Specification

Conductor Material

- Copper
- Aluminum
- Designer to Specify – Unless Critical

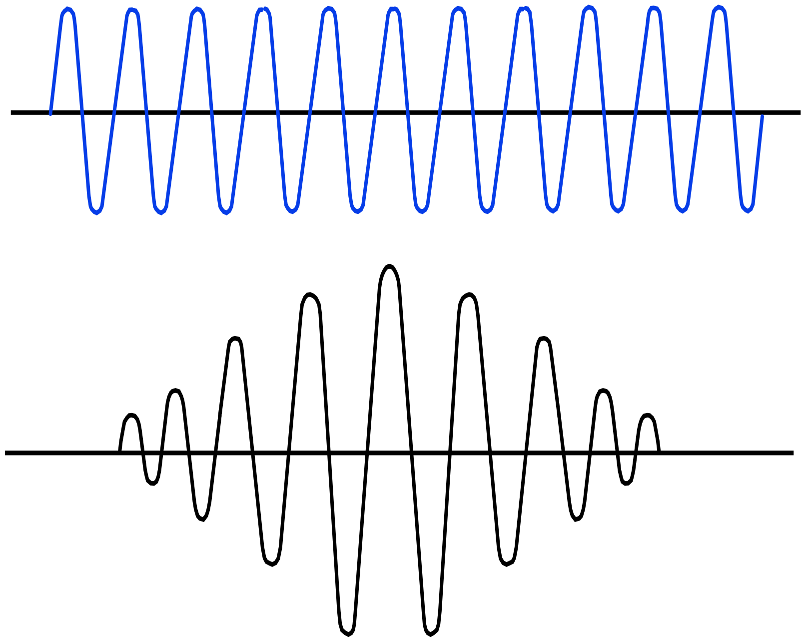
Core– High grade H0

Requirements by Specification

Winding Type

- Distribution Class Rectangular < 2500 KVA
- Power Class Circular Disc > 10,000 KVA
- Application Driven for In Between KVA

Requirements by Specification



Sound Level Requirements

- Standard per NEMA TRI
- $3/Watt or Higher
  No Load Evaluation May Achieve 5-10 db-A Lower (Flux Density)
- Additional Reduction for Increased Price
- Load Noise

Requirements by Specification

Special Loading

- Summer/Winter Ambient Temperature Profiles
- Max Top Oil Temp
- Max Hot Spot Temp
- Max Loss of Life
- Higher Current Rating Components

Requirements by Specification

Special Loading

TO CONTROL	VARY THE DESIGN PARAMETER
• Average oil temperature rise over ambient	• Amount of coolers (radiators, fans, and pumps) and Thermal time constant of the unit
• Winding gradient	• Current densities in winding conductors and cooling surface within the winding
• Hot spot gradient	• Current densities in winding conductors and distribution of stray losses

Requirements by Specification

Special Loading

Harmonics

- Higher than Normal (<0.05 per unit)
- User must specify entire harmonic profile
- Affects temperature rise, eddy and stray losses
- Larger “equivalent” KVA

Requirements by Specification

Impedance

Standard %IZ

- Most Economical Design
- BIL and LTC Dependent
- HV-LV Winding Clearance
- LTC Leads

Requirements by Specification

Impedance

Tertiary % IZ vs. Fault Current

- May lead to less economical design Special % IZ

Lower Impedance

- Minimize Regulation
- Match existing unit
- Causes higher short circuit currents
- Increases cost - more strength needed

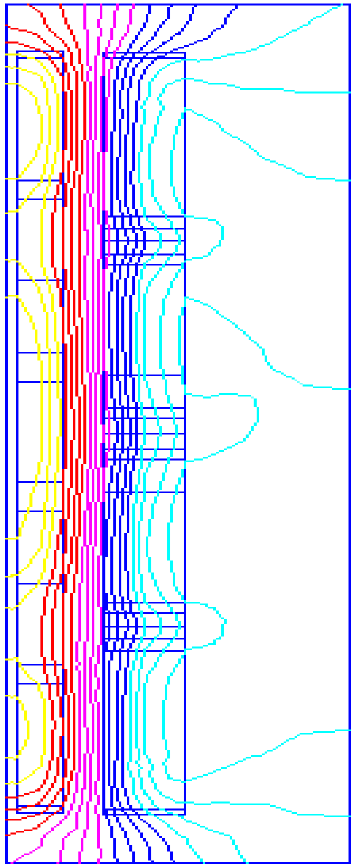
Requirements by Specification

Impedance

Special % IZ

Higher Impedance

- Limits fault current
- Higher regulation for poor power factor
- Higher stray losses
- Possible over-heating due to leakage flux related stray losses, can raise price of unit



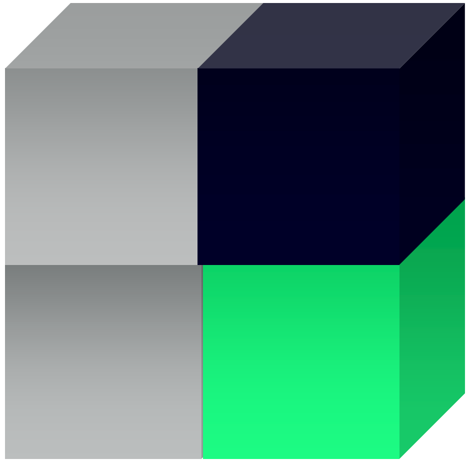
Leakage flux
stray losses

Requirements by Specification

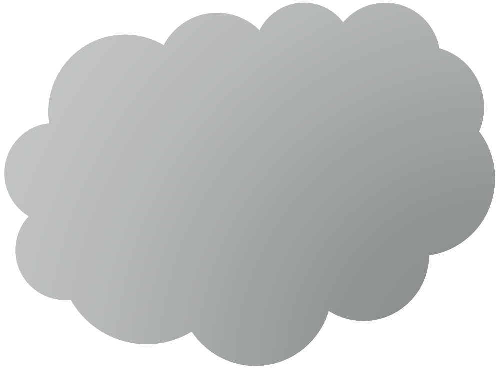
Multiple Voltage Windings

- Future system upgrades
- System spare for different voltages
- Even multiple - cost effective design
- Uneven multiple - can cause problems

Even =

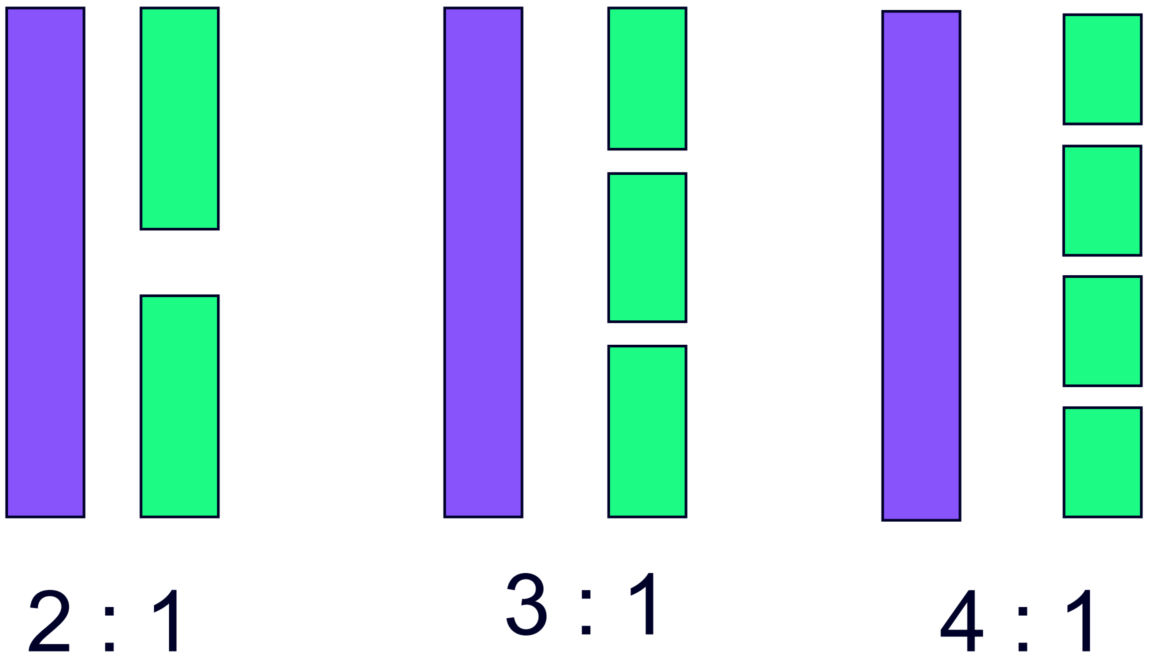


Uneven =



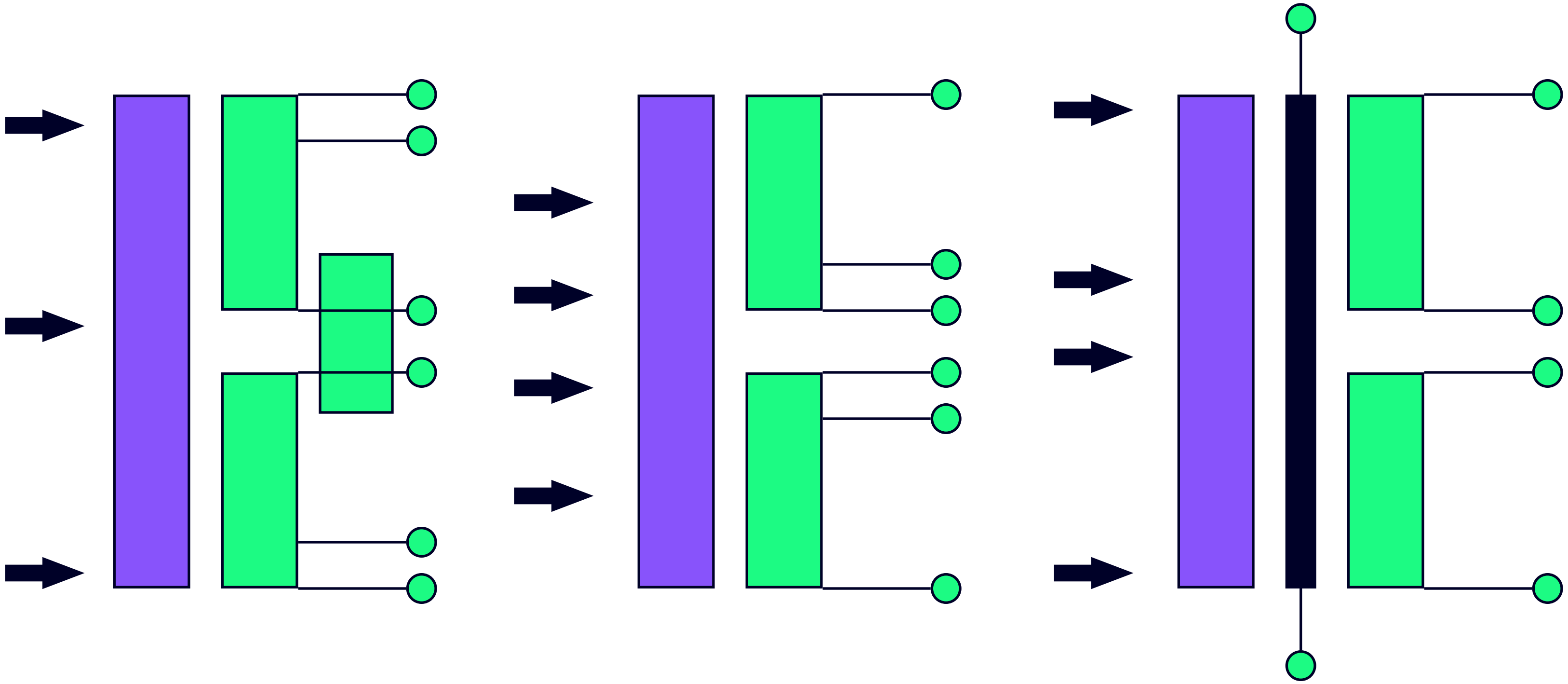
Multiple Voltage Windings

- Evens Ratio, Good Ampere-Turn Balance
- Minimum Short-Circuit Forces
- Minimum Stray Loss Problems



Multiple Voltage Windings

- Uneven Ratio, Bad Ampere-Turn Balance
- Large Short-Circuit Forces
- Potential Stray Loss Problems



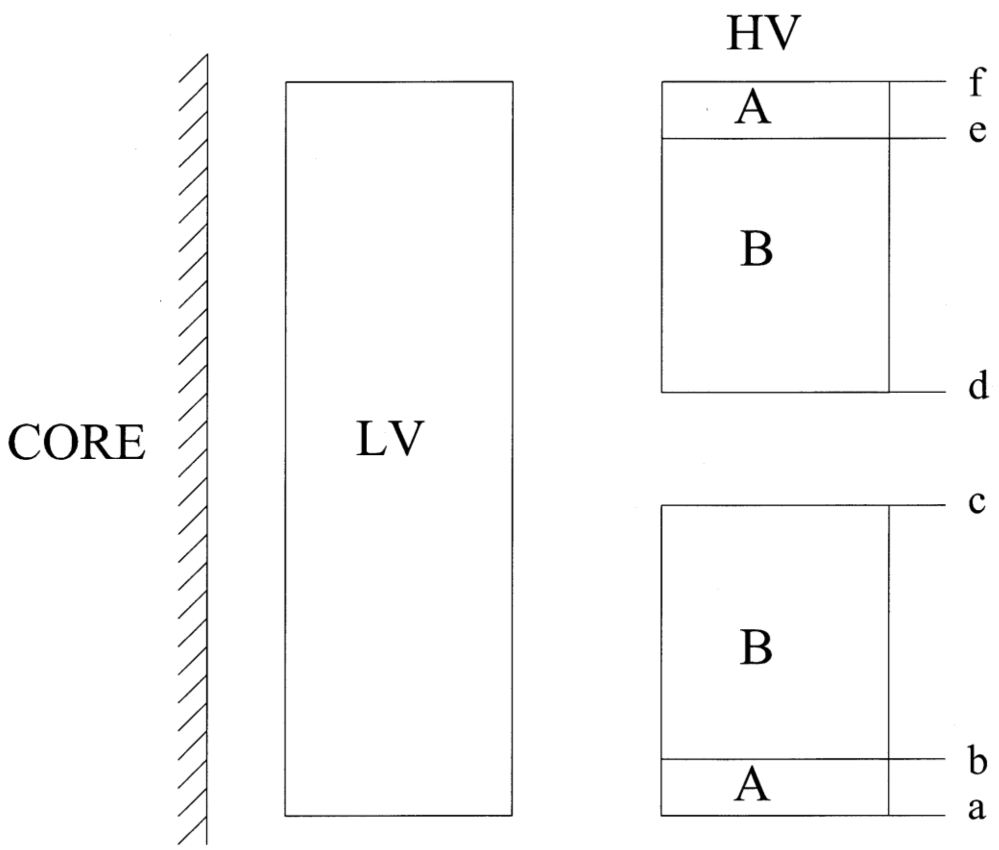
Requirements by Specification

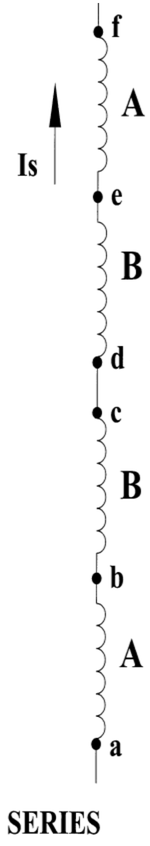
Uneven Multiple Concerns

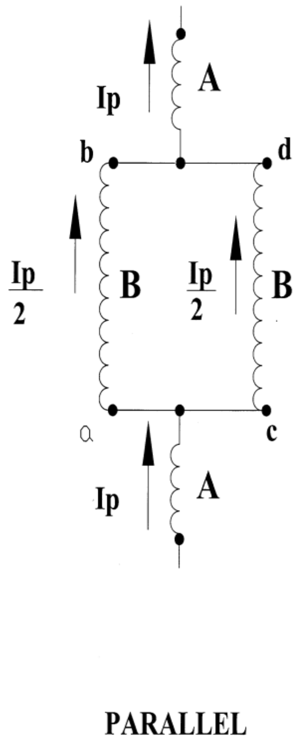
- Short circuit forces
- Stray losses
- Winding stresses
- Complicated switches or terminal boards
- Specify when economically justified

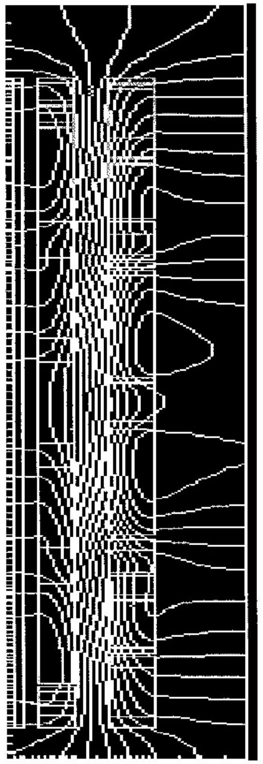
Requirements by Specification

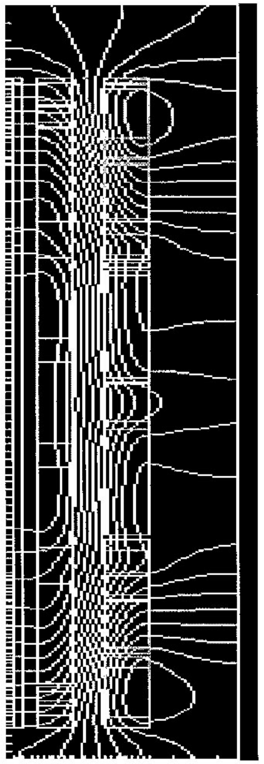
Multiple Voltage Windings





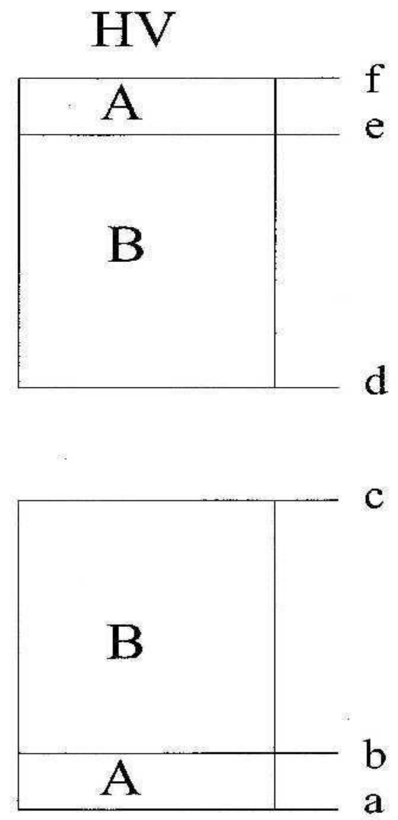


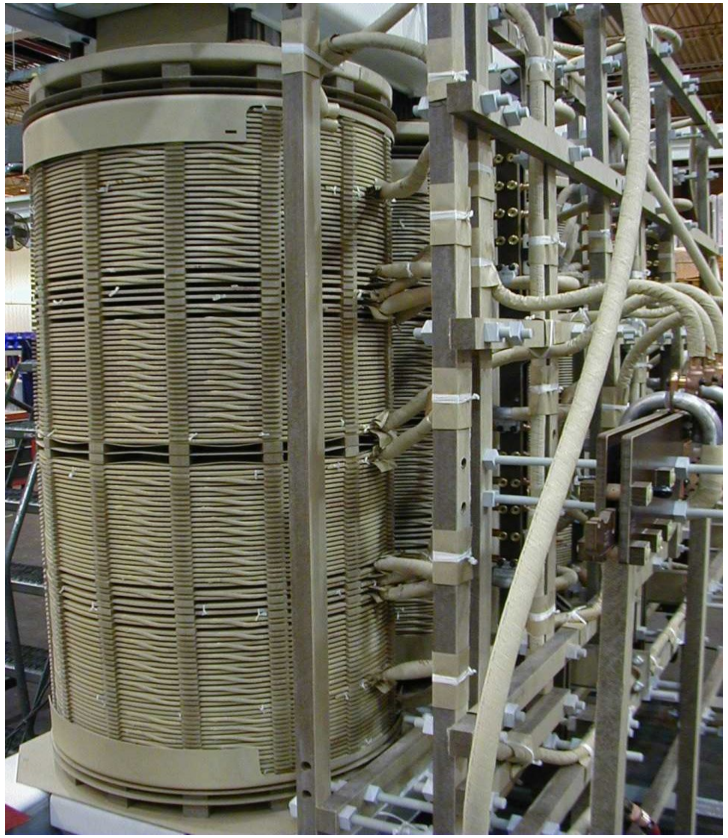

Series


Parallel

Requirements by Specification

Multiple Voltage Windings





Requirements by Specification

Stabilizing Winding

- Delta connected in Y-Y transformers and Y-connected auto's
- Long term practice
- Taken for granted as necessary
- Defined in ANSI C.57.80

Requirements by Specification

Stabilizing Winding

As Defined in IEEE/ANSI C57.12.80

- To stabilize the neutral point of the fundamental frequency voltages
- To minimize third-harmonic voltage and the resultant effects on the system
- To mitigate telephone influence due to third-harmonic currents and voltages
- To minimize the residual direct-current magnetomotive force on the core
- To decrease the zero-sequence impedance of transformers with Y-connected windings

Requirements by Specification

Stabilizing Winding

Per B.A. Cogbill paper “Are Stabilizing Windings Necessary in all Y- Connected Transformers?” (1959)

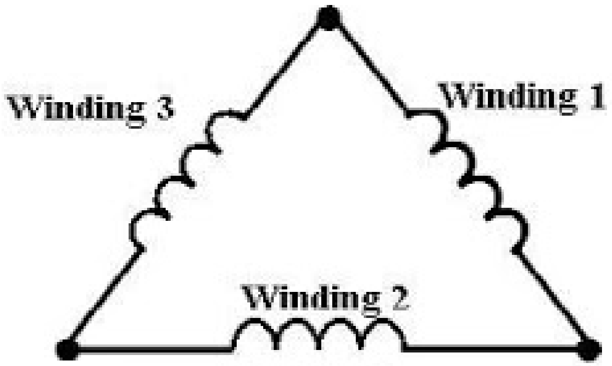
- Not needed in many cases when 3-legged cores are used.
- Questionable need with other core design

General Requirements

What are the differences?

Stabilizing Winding

- Not intended to be loaded
- Considered to be "buried"
- May have no external bushings
- Sometimes has temporary bushings for testing purposes
- Sometimes has one to two external bushings for grounding/testing purposes

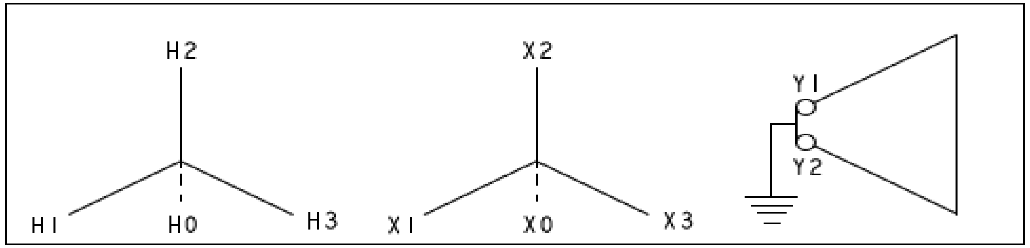


Tertiary Winding

- Intended to be loaded or provide station-service loading
- Also functions as a stabilizing winding (same benefits)
- Thermal, loading and impedance considerations required
- Higher short-circuit considerations - exposure to external faults

General Requirements

Tertiary and Stabilizing Windings (C57.158)



- Main Effects of Having a Stabilizing Winding
  - Reduce the Zero-Sequence impedance
  - Control generation and flow of 3rd harmonic voltages and currents
- **Benefits of Eliminating a Stabilizing Winding**
  - Lower transformer losses
  - Smaller footprint and transformer size
  - Reduce the number of components exposed to SC Currents
- **Potential Reasons for Omitting a Stabilizing Winding**
  - Today the loads on transmission lines are much closer to being balanced
  - Telephone interference is less prevalent due to better grounding circuits and metallic returns and fiber optic communication
  - Modern relaying equipment can better calculate the various components of voltages and currents

General Requirements

Tertiary and Stabilizing Windings (C57.158)

What Exactly is Unstable?

- The phase-to-neutral voltages can become unstable.
- Unstable condition means that the line-to-neutral voltages of the transformer become unsymmetrical with respect to neutral

When Does it Become Unstable?

- Unbalanced line-to-neutral loads are applied to the secondary, load side, and the primary neutral is not directly connected to the neutral of the source (the most general case).
- The third harmonics of the exciting current have a significant magnitude and cannot flow through the primary or secondary windings, consequently inducing third-harmonic voltages in the line-to-neutral voltages of primary and secondary sides of the transformer.

What Else Does the Stabilizing Winding Do?

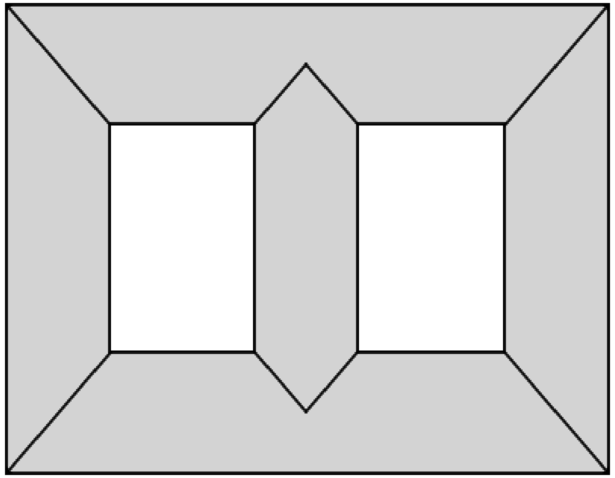
- Carries single-phase circulating currents, also known as zero-sequence currents, or homopolar currents, in terms of power systems analysis techniques.

General Requirements

The Beauty of a Three-Phase, Three-Legged Core

- Three-phase transformers with a three-legged core, without a delta-connected winding, can supply high line-to-ground short-circuit currents, or sustain continuous unbalanced loading at their neutral. This is because of the high reluctance path to zero-sequence flux of their magnetic circuit that reduces its magnitude of the zero-sequence impedance significantly.

  The tank acts like a single turn tertiary.

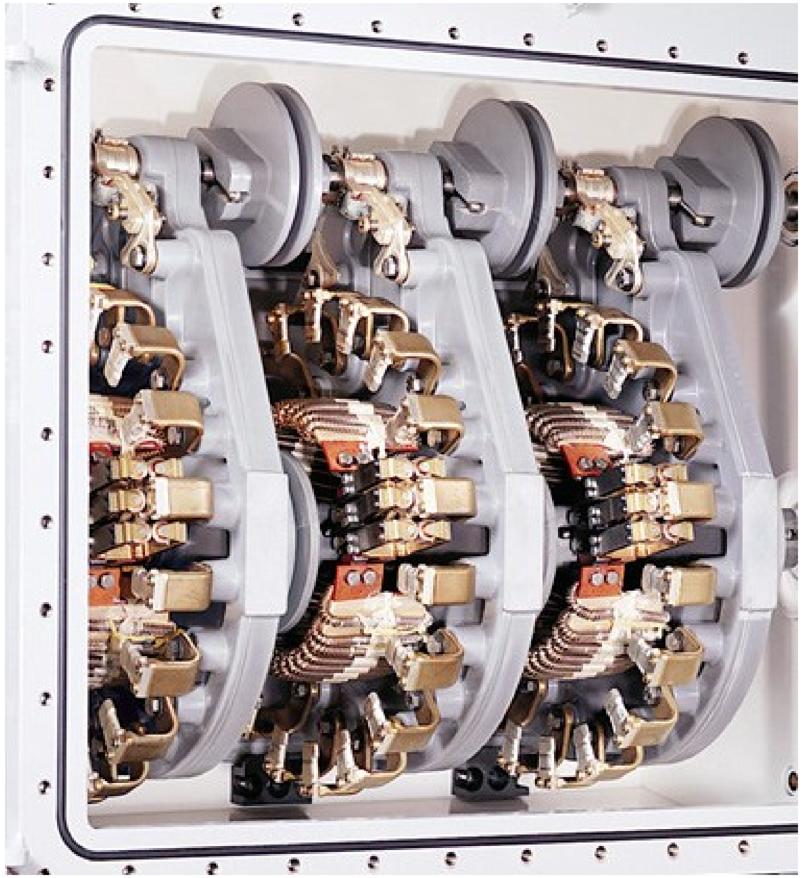


A Word of Caution

- One caution to this application , however, is that the remaining zero-sequence flux closes its path through the tank cover, walls, and bottom, and through the core frames and cross bars, and it can produce severe overheating of these components.

Open-Phase Loading
Long-Duration
Unbalanced Load

Requirements by Specification



Special Duty LTC

“Initiate and complete tap changes during short circuit faults”

- Increases LTC current rating requirement
- Large series transformer
- Extremely low probability

GSU

- Good reference C57.116 Guide
- Wye – Delta for UT
- Delta-Wye for UAT and SST
- Over excitation
- Voltage Regulation considerations
- Breaker Protection

GIC Flow

Factors Influencing the Degree of Risk to the Grid and Equipment:

- Geomagnetic Latitude
- Local Earth Resistivity
- Coastal Effect
  Network Topology
- Design and Specification of Key Equipment
- Storm Duration
- Loading

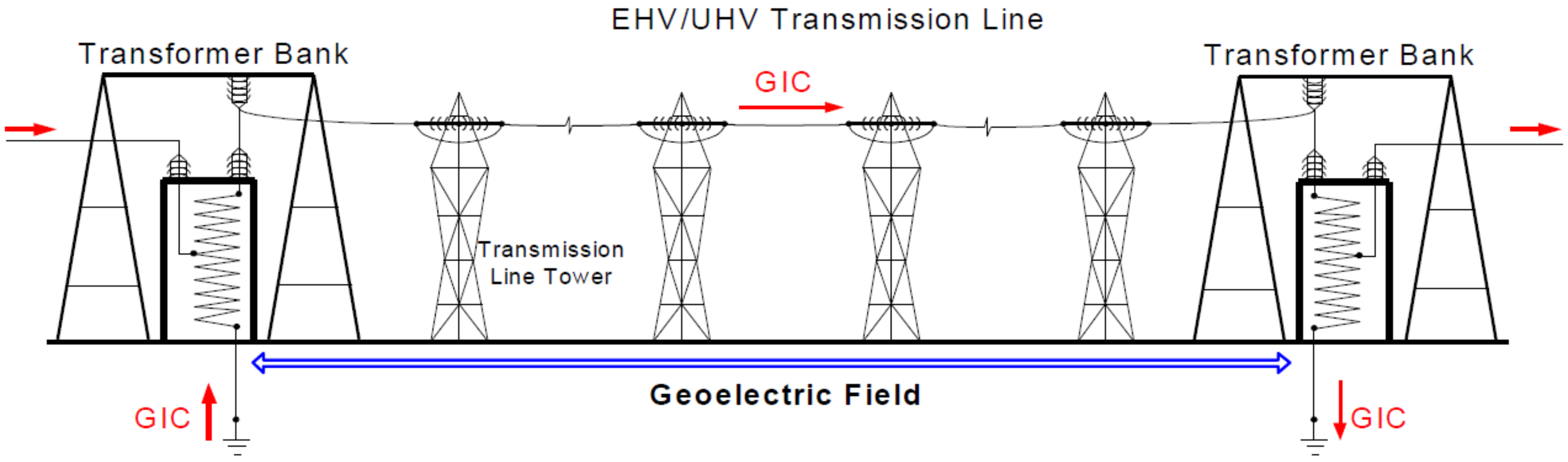
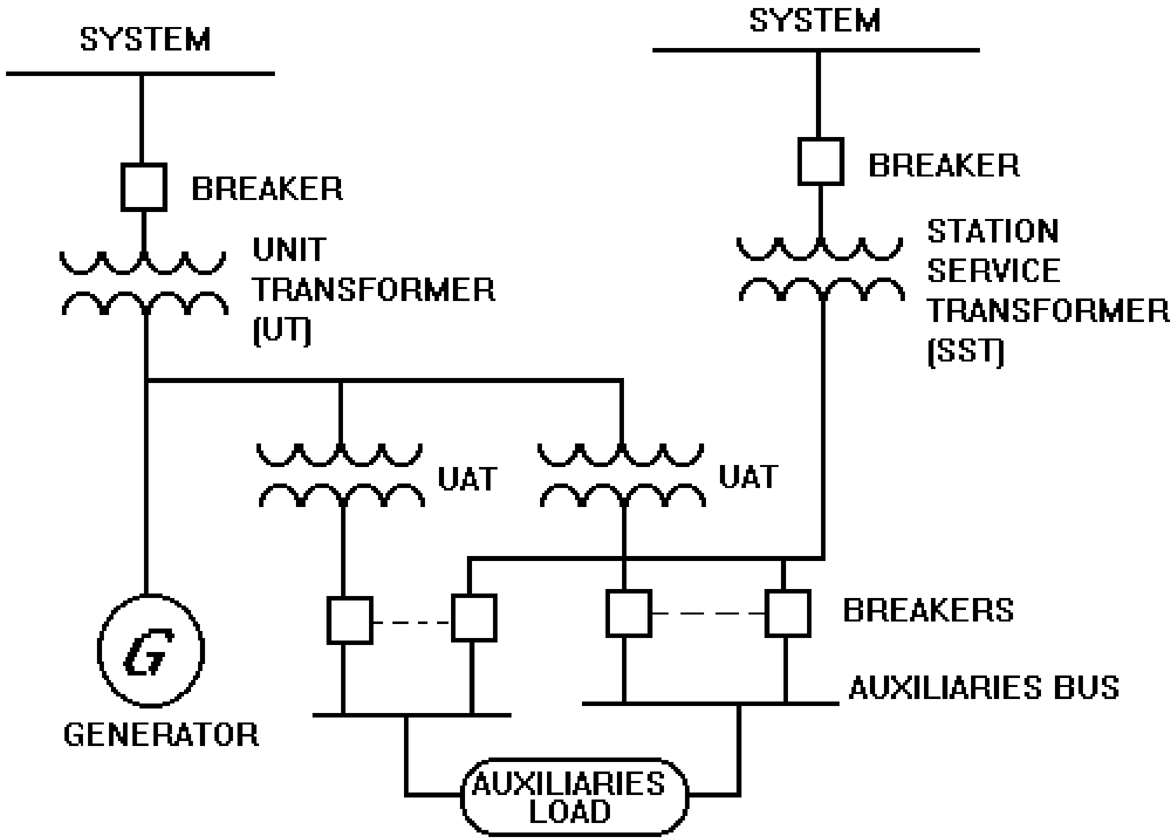


Figure 1—GIC flow in a power network

C57.163-2015 – GIC Guide

Power System One-Line Diagram



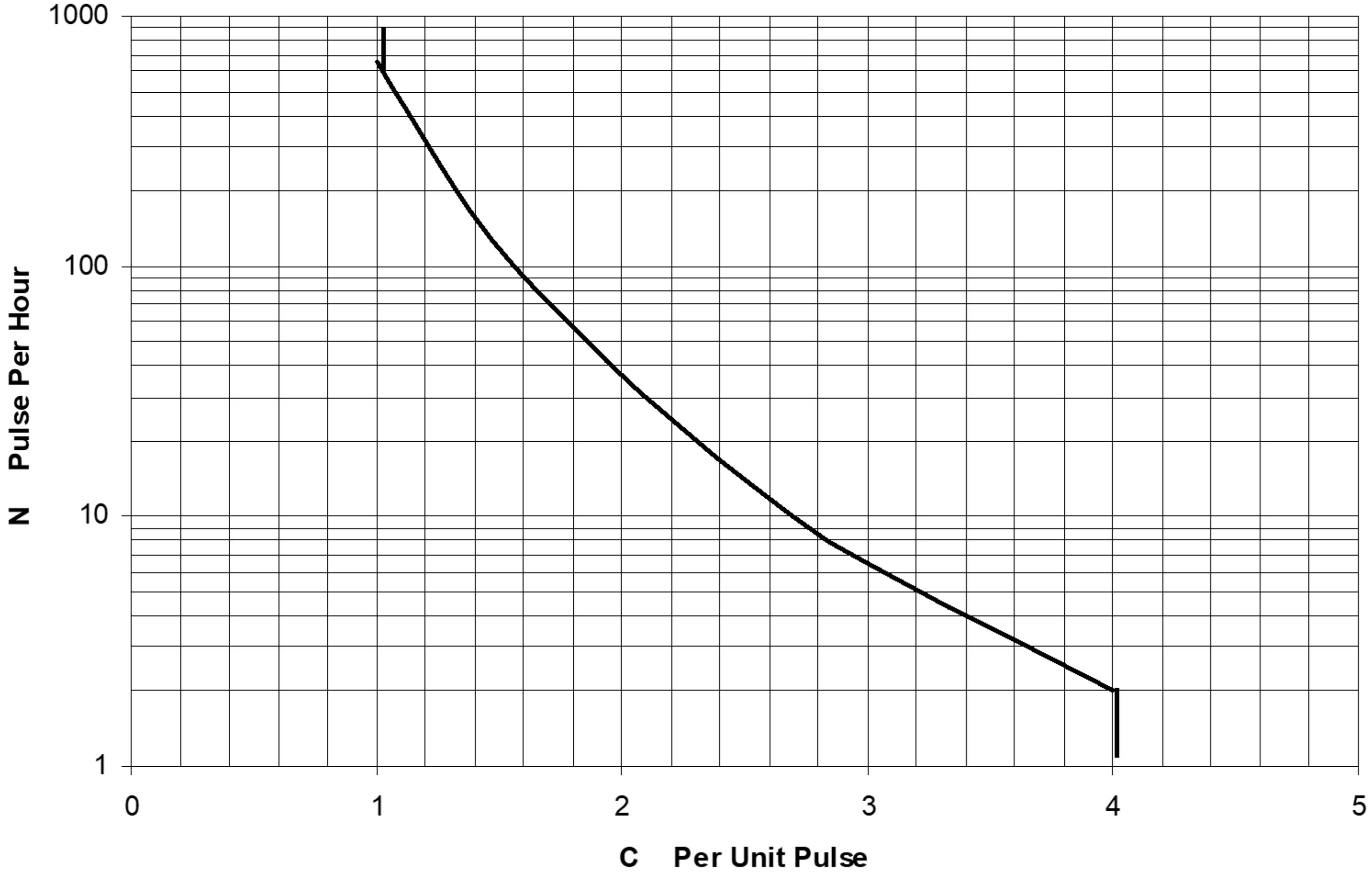
Typical Generating Station Auxiliaries Power System One-Line Diagram

Impact Loading

- Mechanical and Thermal Performance Considerations
- Full Voltage Start
- Reduced Voltage Start
- How many starts per hour?
- “Bumpless Transmission” with Variable Frequency Drives

Impact Loading (high current for short duration)

Transformer MVA > Full Load MVA
Transformer MVA > RMS MVA or
Combined Starting and Load Cycle
Transformer MVA > Starting MVA / C



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Test Requirements

Test Requirements

IEEE Requirements

- Routine - All Units
- Design - Manufacturer Determines
- Other - User Specified

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Test Requirements

Temperature Rise Test

- Time / energy consuming
- Occupies test floor and disrupts normal production cycle

User specific non-standard

- m and n , C57-119
- Use of Fiber optics
- Low DGA
- No load 24 Hours
- Resistance -all taps
- Doble 10 kv –all taps

Other specific requirements

Others …

- Documentation
- Bushing Current Transformers
- Odds and Ends????

Others …

Documentation

- Lots of formats
- CAD files
- Mylar
- Aperture Cards
- Volumes of Prints
- Reduce Costs –
  Order only format and quantity needed

Others

Current Transformers

Be aware of size

- Low ratio, high relay burden means BIG and heavy
- Problems in small units

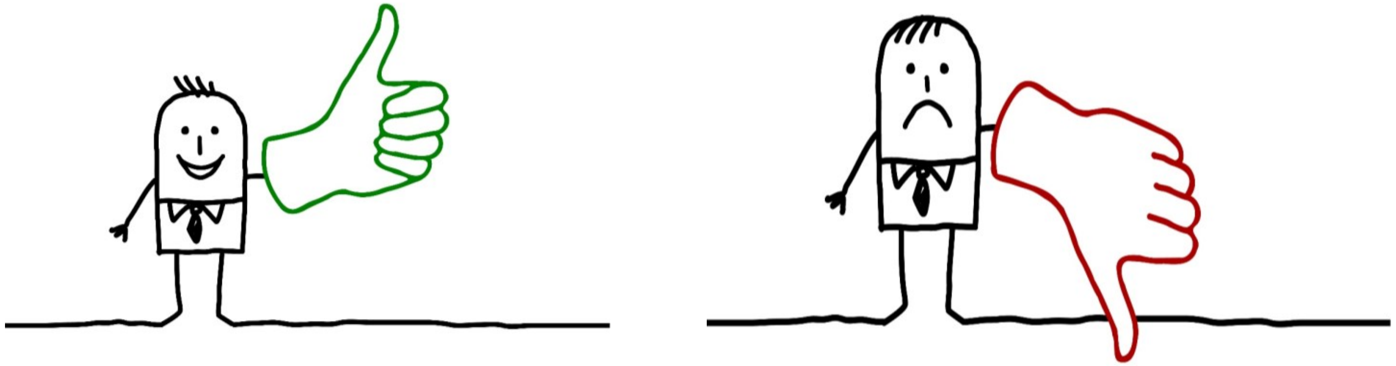
Minimize CT accuracy class when possible

Others

Odds and Ends (Add Cost, Small Value)

- No Brazed Joints
- Maximum Fan Speed
- Gasket versus O-Ring
- 3-Phase Auxiliary Power
- LTC in Segment 1 or 3
- Large No. Fiber Optics
- Very Low DGA
- Very Low PD

- Busbar for Ground Conductor
- Minimum Print Text Size
- Minimum Control Wire Size
- Tap Switch above Coils



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Questions?

Contact

Dharam Vir

Vice President of Engineering

M 262-510-3388

dharam.vir@prolec.energy

Prolec-GE Waukesha, Inc.

400 S. Prairie Avenue

www.waukeshatransformers.com

Waukesha, WI 53186