Electrical Design Process

Transformer Concepts & Applications Seminar

Goldsboro, NC

September 17-19, 2024

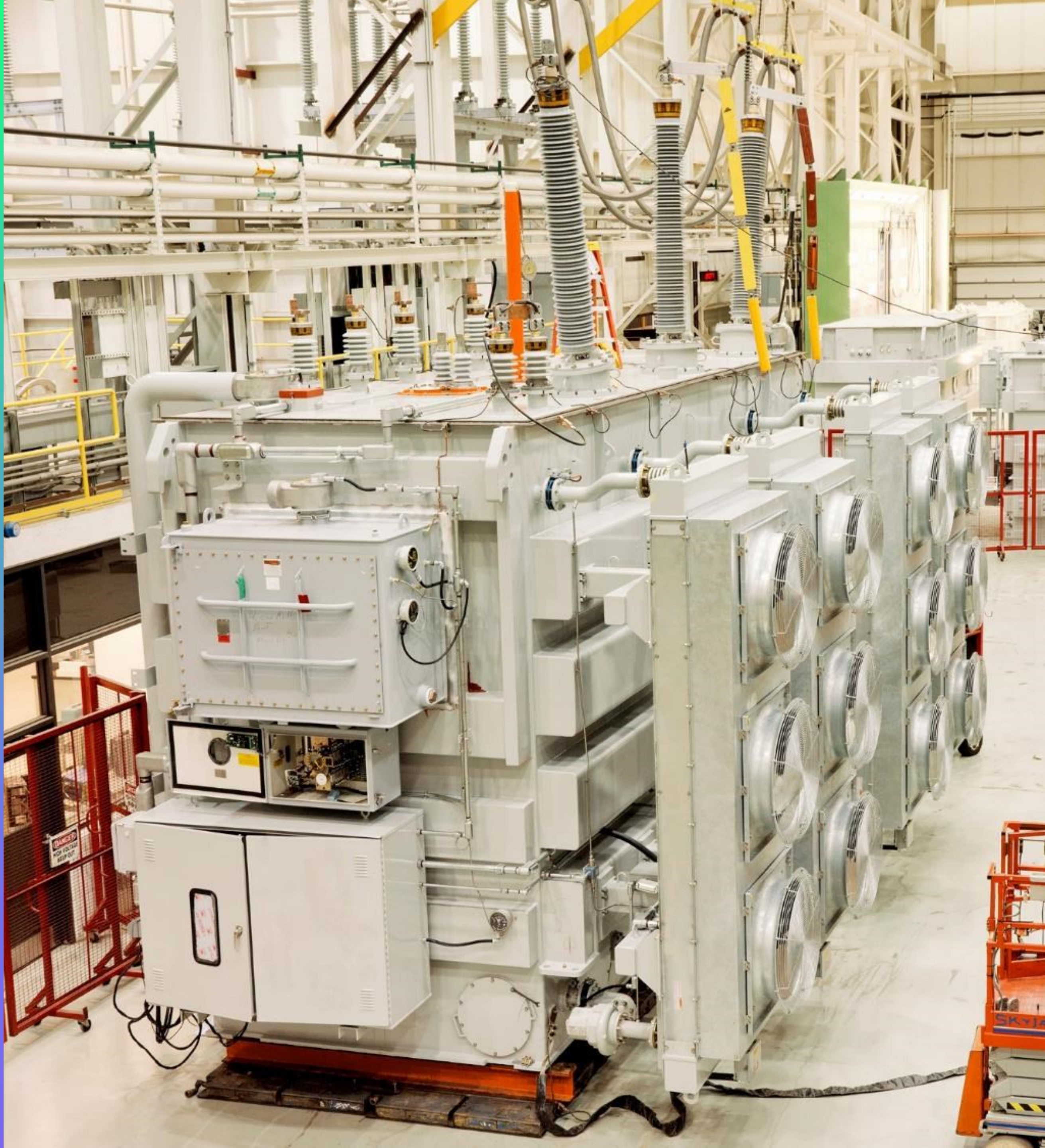
waukesha
a prolec ge company

Matthew Lutze

Associate Electrical Design Engineer

Matthew joined Prolec-GE Waukesha in January 2024 after graduating from East Carolina University. He works in the Goldsboro facility and has quoted and designed transformers up to 230kV and 60 MVA.

waukesha
a prolec ge company

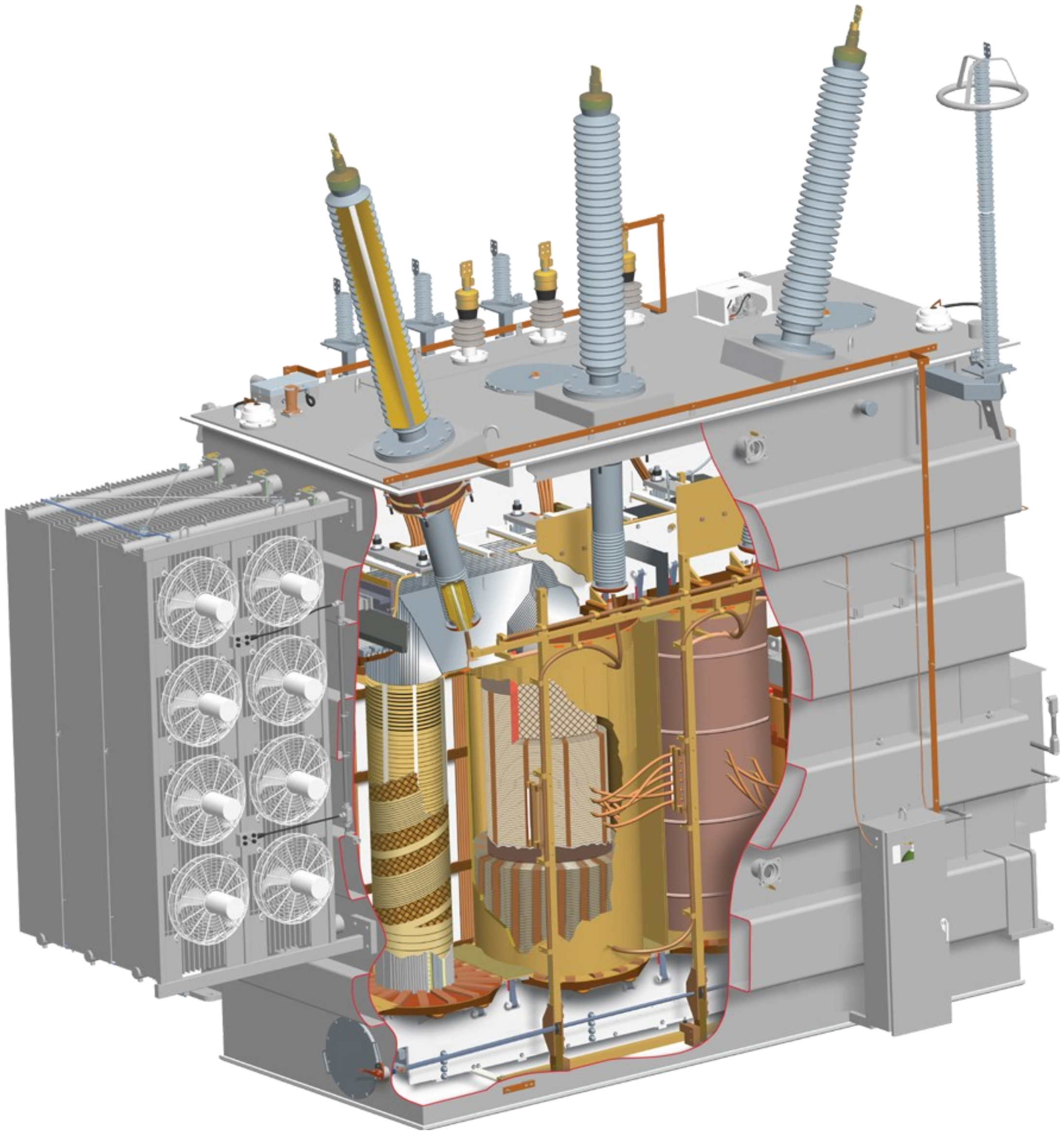


Agenda

- Bid design process
- Parameters affecting bid design
- Final design process
- Design parameters

Transformer Cutaway View

waukesha
a prolec ge company



waukesha
a prolec ge company

Bid Design Process

Bid Design Parameters

waukesha
a prolec ge company

Customer Specification

Normal operation – MVA rating, voltage ratio, connection LTC/DETC, % impedance, parallel operation, sound levels

Application – GSU, SAT, UAT Phase Shifting, Multiple Windings, Zig-Zag, Series / Parallel

Transformer Controls & online Monitoring

Loss evaluation, Existing size and weight restrictions shipping by rail/road

Short circuit, overloading, over fluxing, seismic conditions, Geomagnetic induced Current (GIC) Unusual Service Conditions

Type of cooling – Temp rises, Top oil, Average winding, Hot spot - winding and core. DGA limits

Dielectric Requirements BILs-LI, SI, induced voltage, applied voltage

Parameters Affecting Bid Design

- Loss evaluation affects the selection of flux density for core and selection of current density for windings
- % impedance affects core and coil dimensions, leakage flux distribution, short circuit stresses and regulation
- % impedance depends on the following:
  - Winding dimensions
  - Voltage per turn
  - Frequency
  - Transformer rating

Parameters Affecting Bid Design (cont.)

- Basic insulation levels (BIL) affect the clearance between windings, phase-to-phase clearances, winding end clearances and tank clearances
- Over-excitation requirements affect selection of flux density, size
  and weight of core
- Taps purpose, type, range and location affect core and winding design
- Dimension and shipping weight limitations affect core dimensions, flux density and current density

Parameters Affecting Bid Design (cont.)

- Sound level affects the type of core construction, flux density, type of cooling fans
- Temperature rise and type of cooling affects the quantity of radiators and fans
- Overload requirement may increase the quantity of radiators, quantity of fans and winding conductor area
- Parallel operation with existing transformers affects placement of windings on core

Parameters Affecting Bid Design (cont.)

- No load loss = (along grain core weight * watt/lb + across grain weight * watt/lb)* correction factor, where: watt/lb. ~ flux density, core grade and correction factor ~ core dimensions and type of core construction

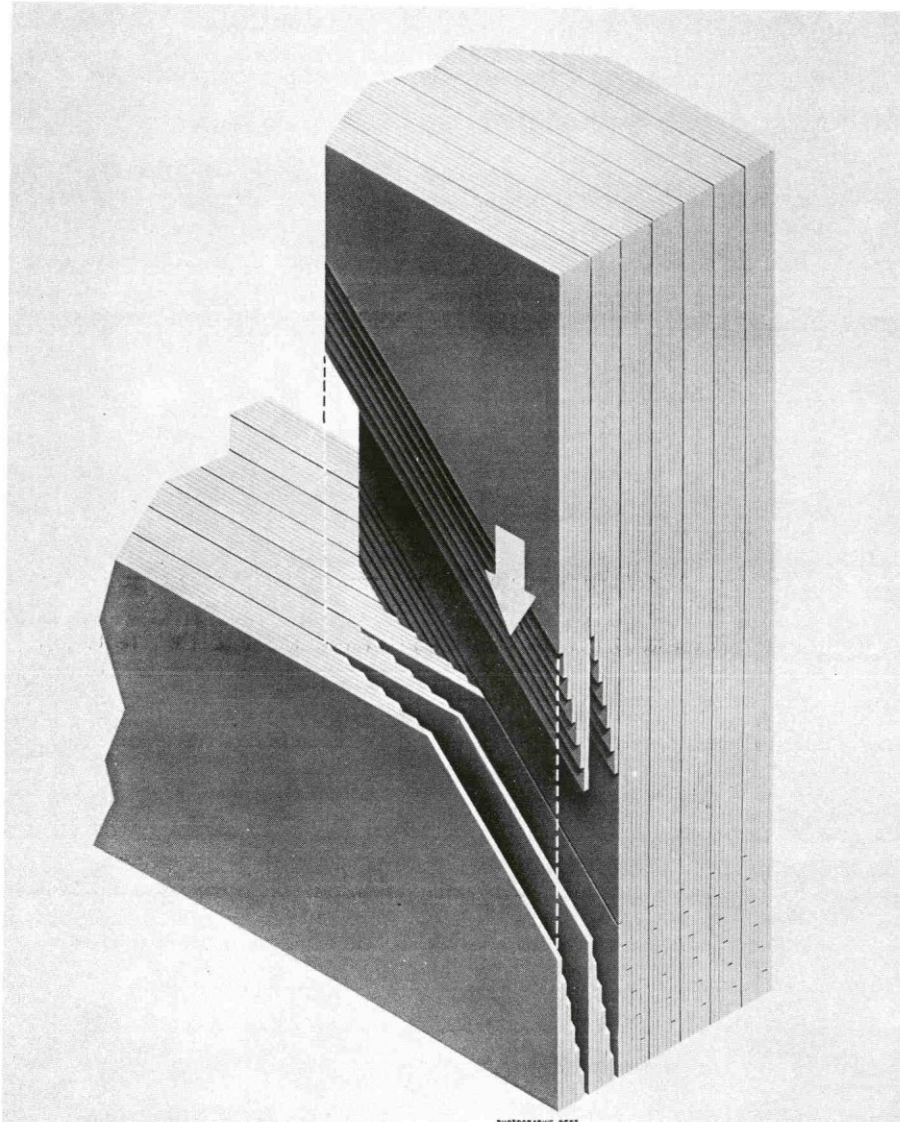
No-load loss at 20°C = loss at T°C*(1+ (T-20)*Kt),
where, Kt = 0.00065 for grain oriented steel

- Load loss depends on winding dimensions, number of turns, current density, conductor type and frequency

Load Loss = I^2R loss + Eddy loss + Stray loss

I^2R depends on the number of turns, winding dimensions,
area of copper conductor

Step Lap Joint



Bid Design Steps

First and Final Consideration:

Optimize the Total Owning Cost = Selling Price + Cost of Losses

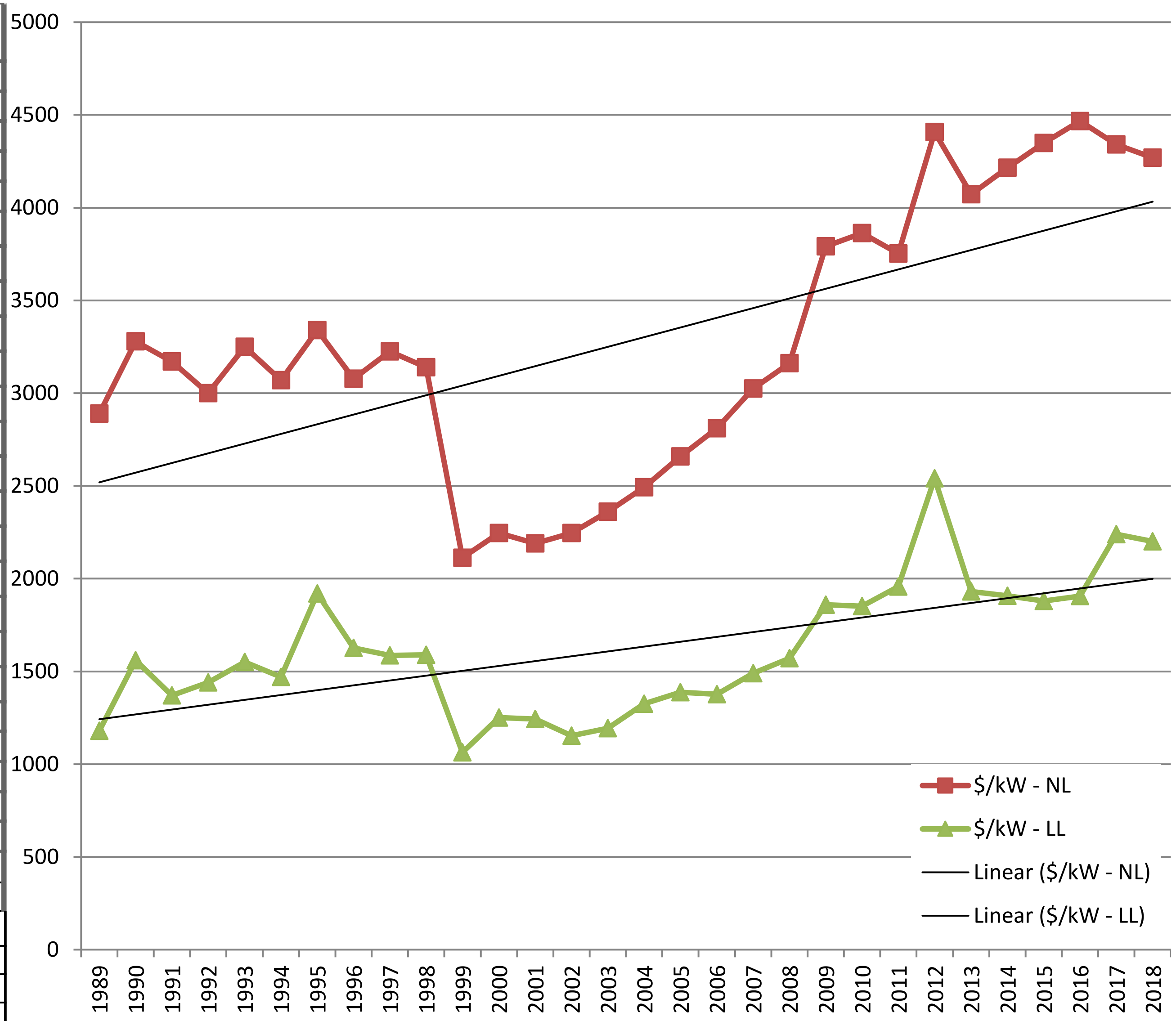
Considerations

- Summarize design parameters
- Finalize winding arrangement
  - Standard winding arrangement:
    Core – TV – TAP – LV – HV
- Select clearances between windings, winding to yoke, phase to phase and winding to tank
- Select type of core construction
  - Mitered or Step-lap core
- Select grade of core steel and winding material (CTC/Mag Wire)
- Input limits for winding current density, flux density, core overall dimensions (maintaining shipping limits)

Input to the Optimizer Program

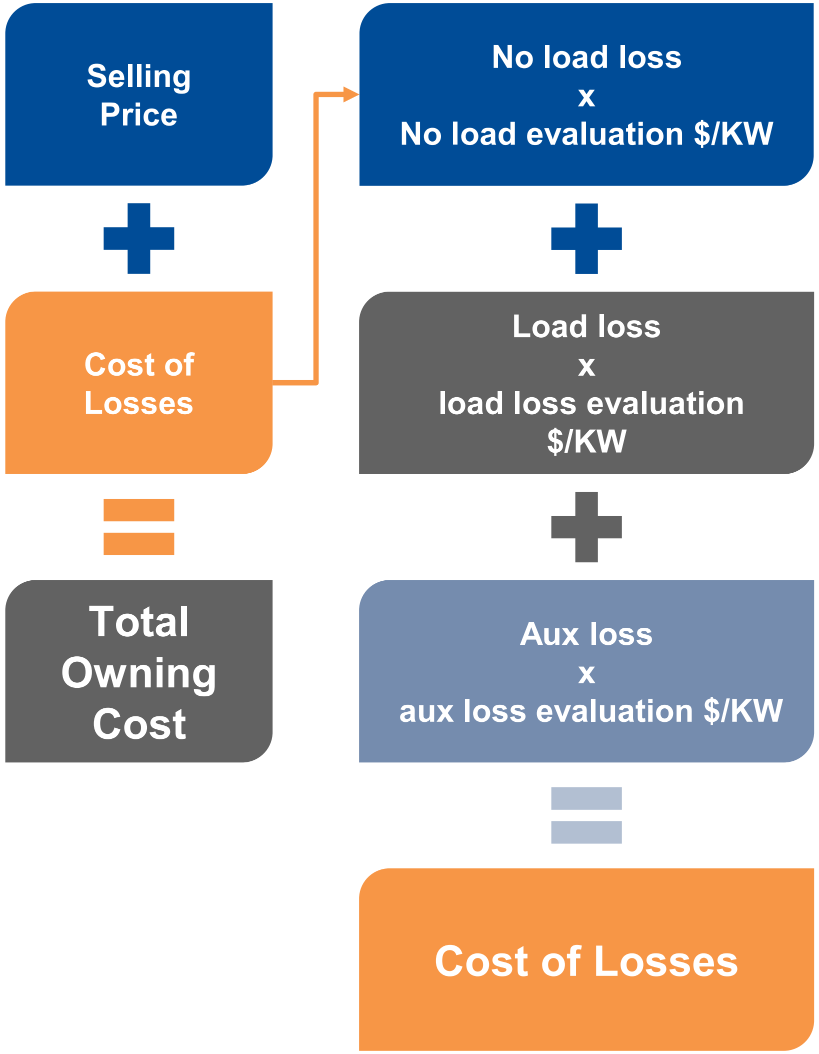
Customer-Specified Loss Evaluation Trend

Year	$/kW - NL	$/kW - LL
1989	2890	1180
1990	3280	1560
1991	3170	1370
1992	3000	1440
1993	3250	1550
1994	3070	1470
1995	3340	1920
1996	3078	1626
1997	3225	1587
1998	3140	1590
1999	2113	1063
2000	2245	1251
2001	2190	1243
2002	2245	1153
2003	2360	1194
2004	2492	1325
2005	2659	1388
2006	2810	1377
2007	3025	1490
2008	3162	1571
2009	3792	1860
2010	3863	1852
2011	3752	1957
2012	4408	2540
2013	4073	1930
2014	4215	1907
2015	4349	1880
2016	4467	1906
2017	4340	2240
2018	4270	2200



Bid Design Steps

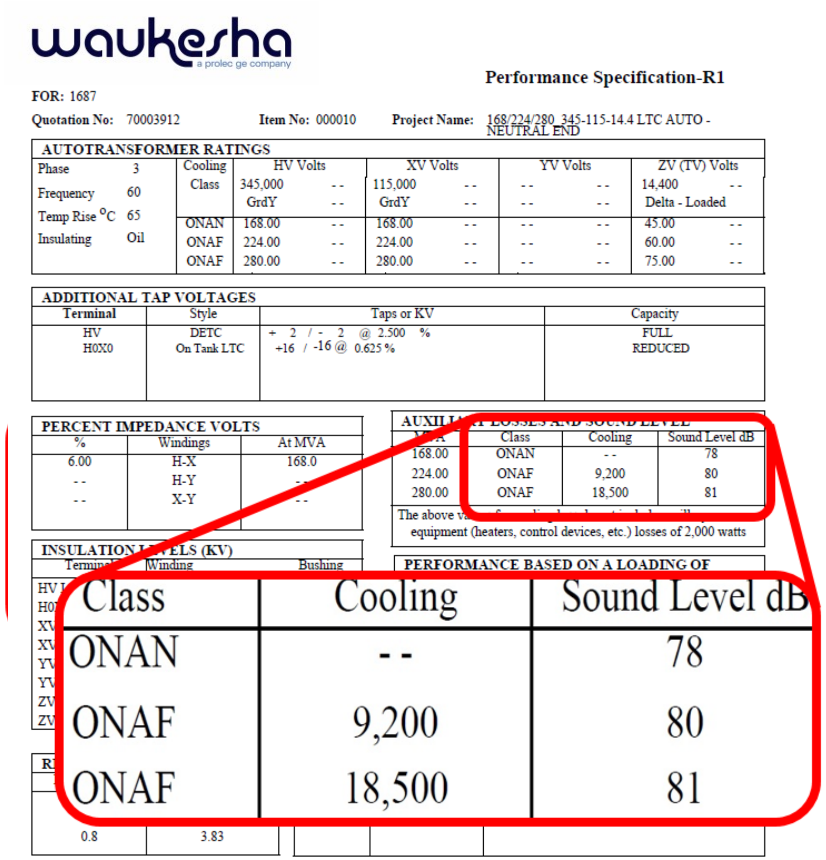
- Bid optimizer software computes different designs based on loss evaluation and meeting performance parameters as per specification
- Computation considers
  - Flux Density, Core Dimensions
  - Winding Dimensions, Current Density
  - Dielectric, Short Circuit and Thermal
  - Overall Size and Weight Restrictions
- Evaluate various design options
- Select the optimum feasible design meeting customer and design requirements with lowest total owning cost



Bid design is the launch point for the final design (after receipt of PO).

Bid Design Output – Performance Specification

waukesha
a prolec ge company



waukesha
a prolec ge company

Performance Specification-R1

FOR: 1687

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

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

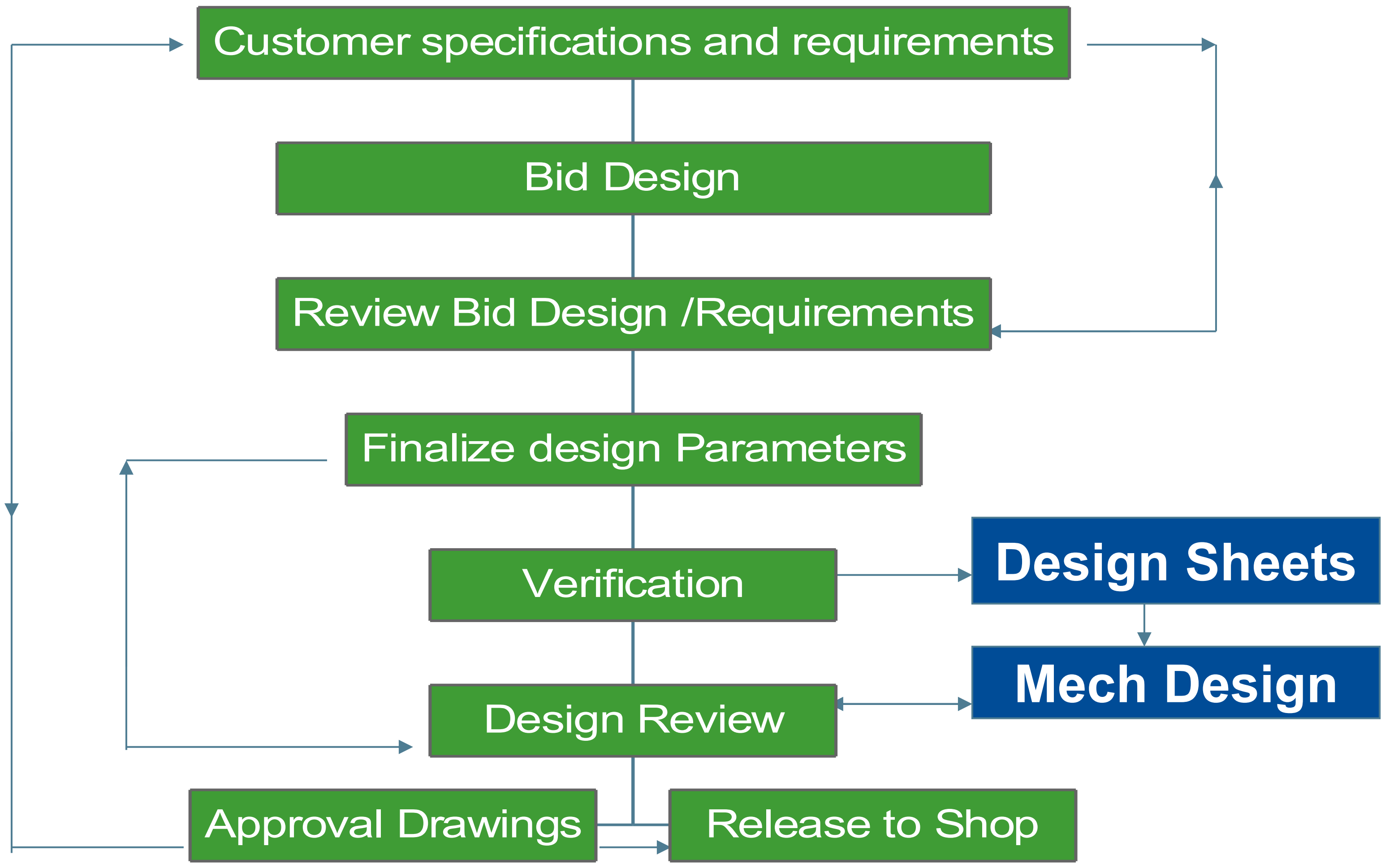
Non-Standard Bid Designs

- Dual High Voltage, Dual Low Voltage, DETC on HV and LTC on LV
- Dual Low Voltage with RMVs on both LVs and DETC on HV
- Non-integer Low and High Voltage
- Autotransformer with co-ratio less than 0.4
- Autotransformer with Line end LTC >350 KV BIL
- Re-connectable any non integer Ratio for LV or HV
- Re-connectable with HV> 900 KV BIL
- Double LV stack Design with unequal voltage or MVA

waukesha
a prolec ge company

Final Design Process

Final Design Steps



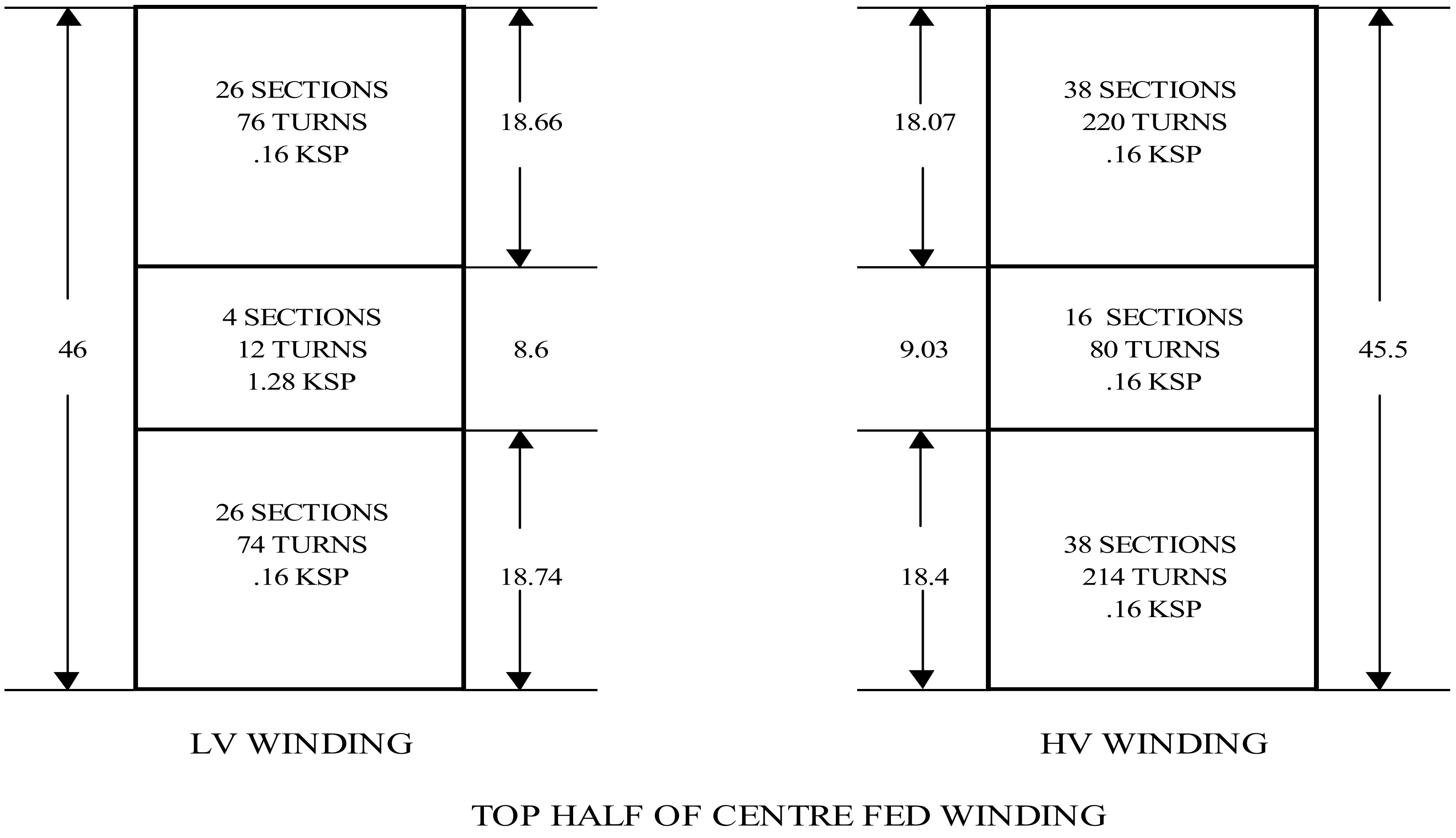
Final Design Steps (cont.)

- Review bid design, customer requirements
- Find a reference design, if available
- Compute the design insulation level for insulation design
- Finalize core diameter, winding turns, type of winding, gap between windings and end clearances
- Check voltage ratio error, change number of turns, if required
- Select number of turns/disk, tap sections, conductor paper, type of conductor, duct between sections/turns

Final Design Steps (cont.)

- Balance ampere-turns in LV windings, in case of de-energized taps in the main HV winding
- Calculate % impedance, core loss, load loss and compare with guaranteed parameters
- Change conductor size and winding height, as required
- Calculate impulse voltage distribution in winding and between gaps
- Finalize wound-in-shield requirement for HV winding

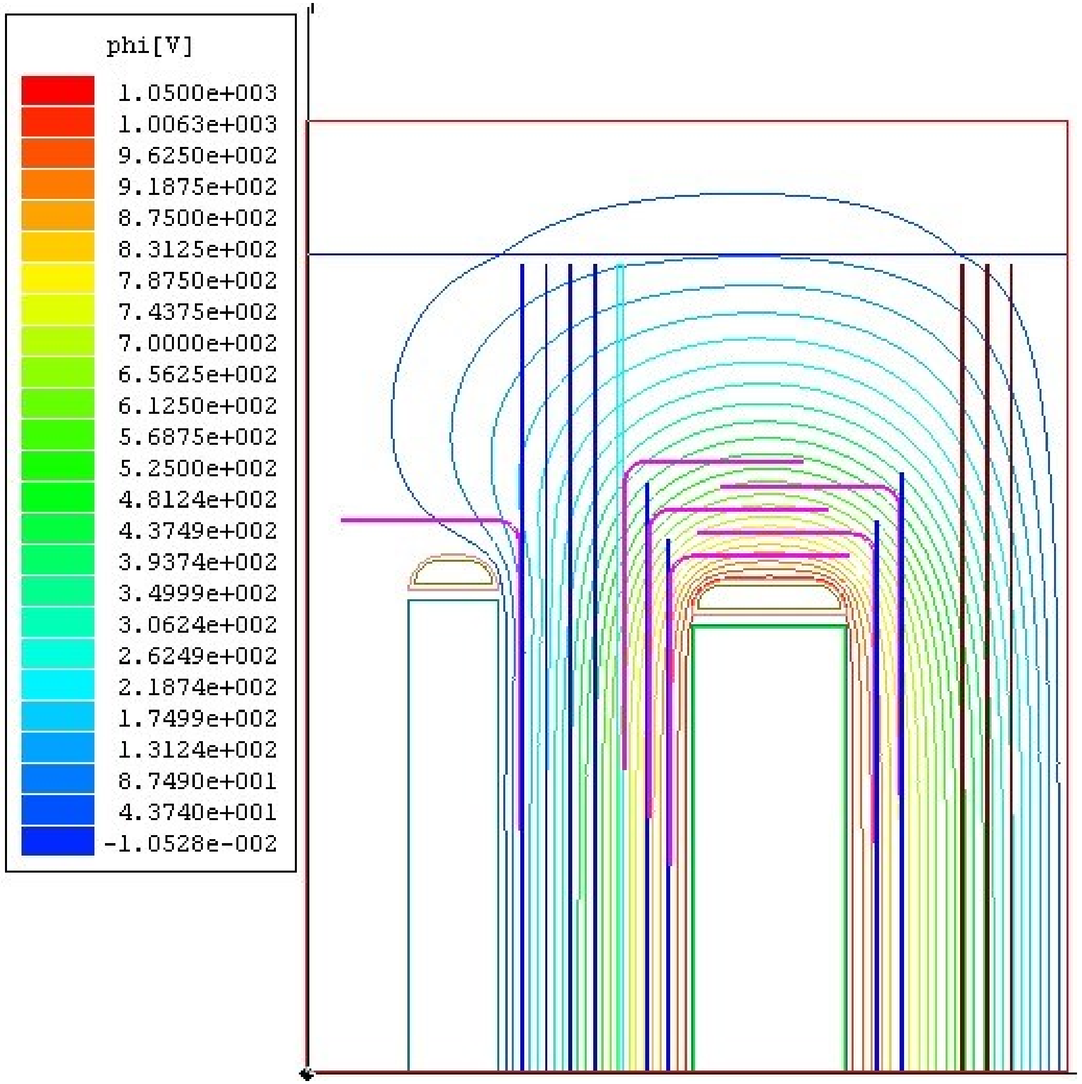
Ampere – Turn Balance



Final Design Steps (cont.)

- Review conductor insulation, gap between windings based on the calculated transient voltages
- Calculate % impedance at rated and tap extremes between windings and compute fault currents
- Perform short-circuit withstand calculations, analyze stresses in windings, key-spacers, end forces; based on results, change winding conductor if required and recalculate the stresses

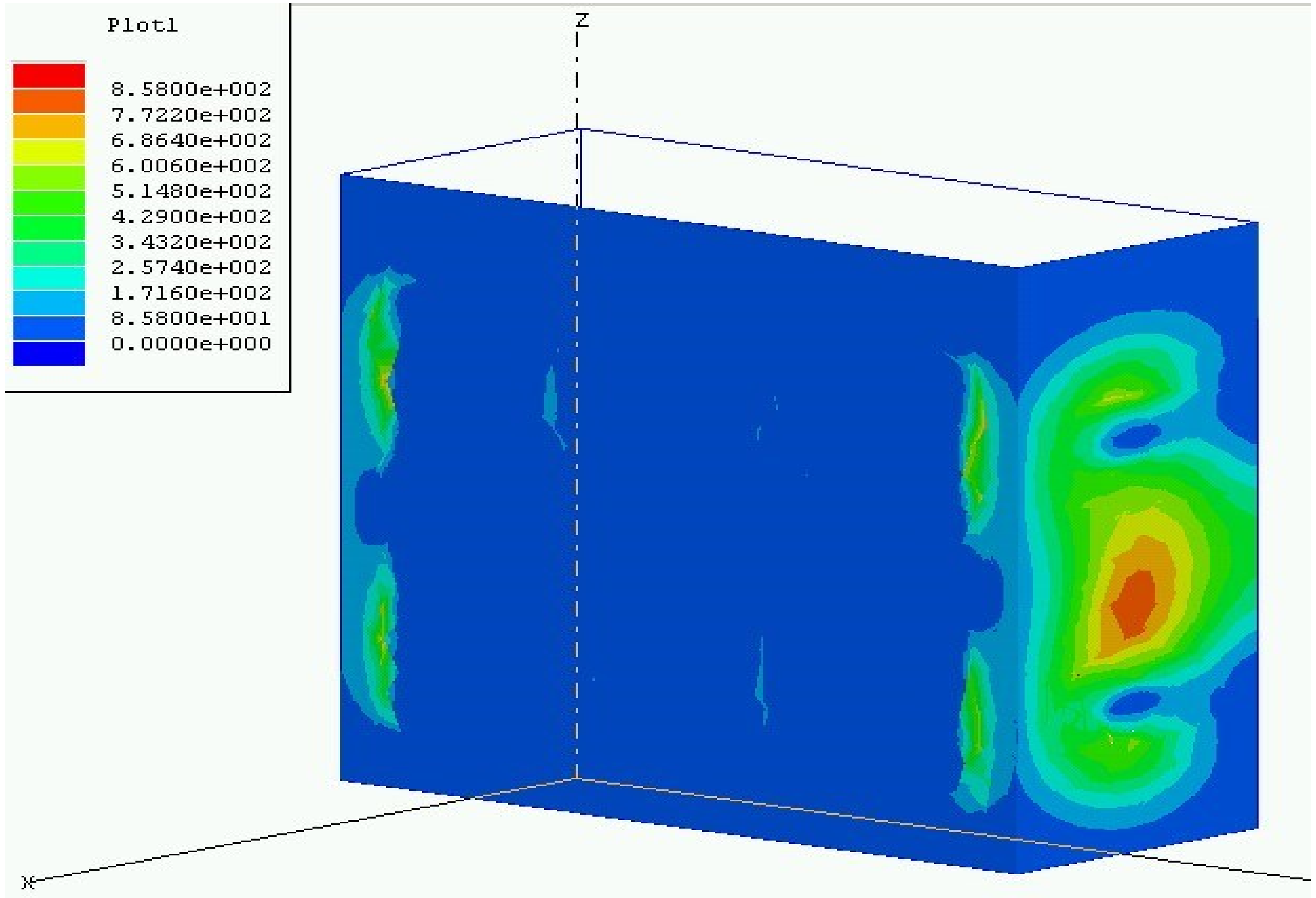
Electrostatic Field Analysis



Final Design Steps (cont.)

- Recalculate impulse withstand, if required
- Perform leakage flux analysis, calculate tank losses, eddy losses, frame losses
- Calculate temperature rise of clamps and tank
- Increase end clearances and tank clearances, as required
- Calculate flitch plate and outer core temperature rise and split flitch plate/outer core packet, if needed

Leakage Flux Analysis



Final Design Steps (cont.)

- Perform temperature rise calculations and finalize number of radiators, fans to limit the guaranteed top oil rise, average winding rise, hot spot temperature; perform overload temperature rise calculations, if specified
- Prepare detailed design sheets which provide technical information for winding sheets, internal layout, external layout, controls and approval/manufacturing drawings
- Prepare detailed test specification based on ANSI and customer requirements

Design Parameters - 1

- Voltage per turn ~ frequency * core area * flux density
- No. of turns = Phase voltage / voltage per turn
- Voltage ratio V_2 / V_1 = Turns ratio N_2 / N_1
- No load loss = (along grain core weight * watt/lb + across grain weight * watt/lb) * correction factor
- watt/lb. ~ flux density, core grade
- correction factor ~ core dimensions, core construction
- No-load loss at 20°C = No load loss at T°C*(1+ (T-20)*Kt)

  Kt = .00065 for grain oriented steel

Design Parameters - 2

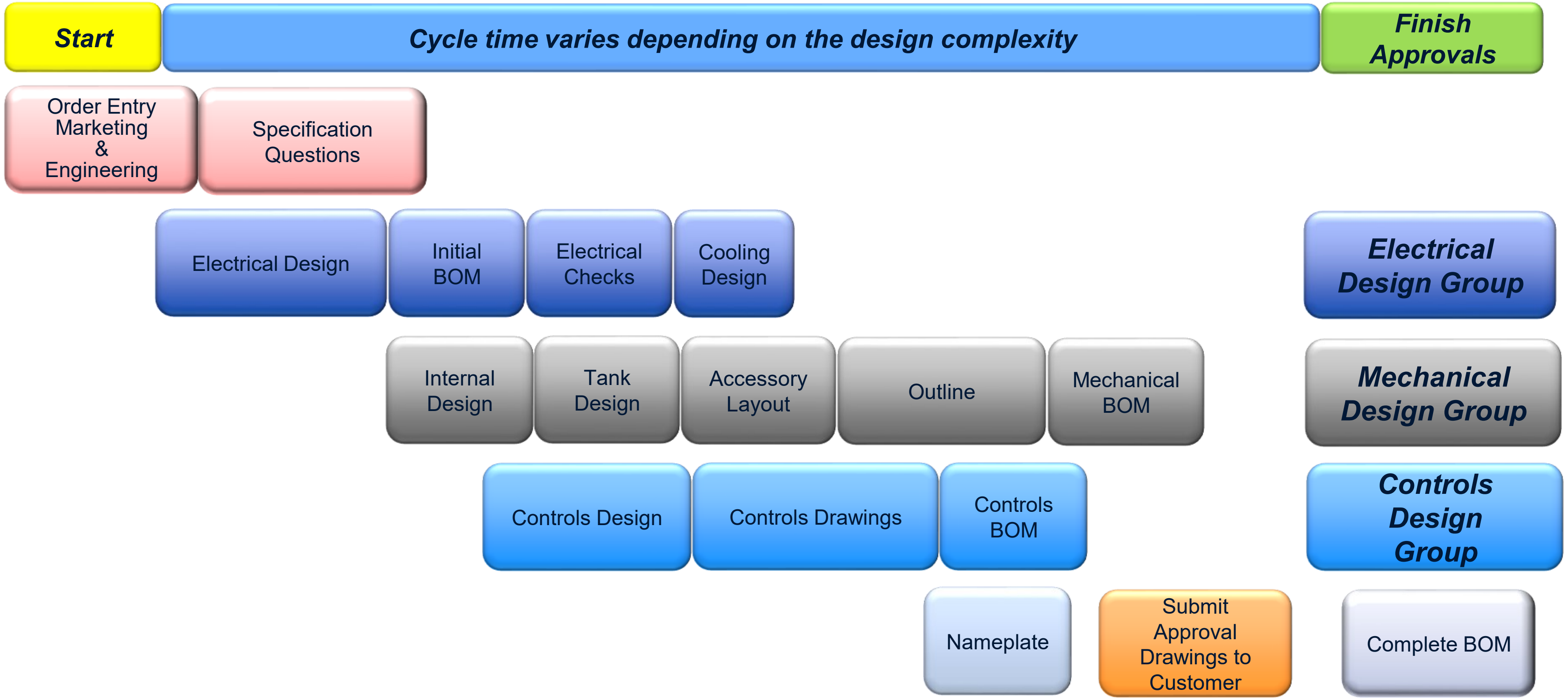
- Load Loss = I^2R loss + Eddy loss + Stray loss
- Eddy losses depend on conductor thickness and width and the leakage flux distribution
- Stray loss ~ % impedance, winding dimensions and tank clearances
- % Impedance ~ (Current*turns*radial winding dimensions) / (axial dimensions * voltage per turn)

Design Parameters - 3

- Sound level ~ flux density, core construction & distance
  $dB_1 = 20 * \log(X_2/X_1) + dB_2$ where, X_2 or X_1 is the distance of point 2 or point 1 from center of transformer
- % Regulation = (%X sinø + %R cosø +((%X cosø -% R sinø)²/200))
  where, cosø = power factor %X = Reactance %R = (Total loss in kW/kVA)*100
- % Efficiency = (1 - Total loss in kW/kVA)*100

Design Process

waukesha
a prolec ge company



Substantial design work is complete with approval package submission.

waukesha
a prolec ge company

Contact

Matthew Lutze
Associate Electrical Design Engineer
Prolec-GE Waukesha, Inc.

Matthew.lutze@prolec.energy

www.waukeshatransformers.com