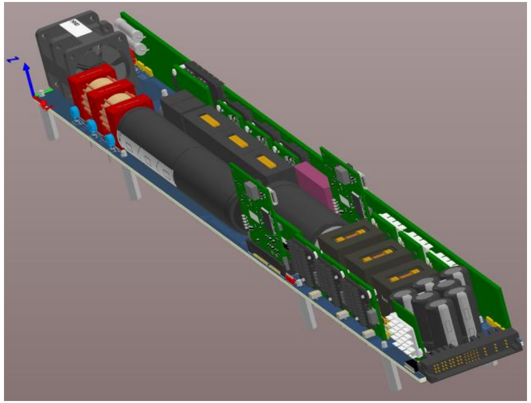
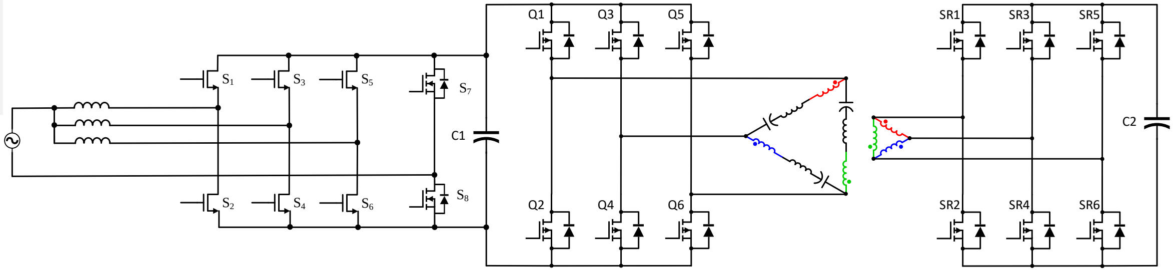
PMP23547 8 kW AI Server PSU

Features

- Peak Efficiency 97.5 % with fan
- Δ-Δ Connected 3 Phase LLC
    - 200 kHz – 1.5 MHz
    - Reduced resonant tank currents
    - In/output current cancellation
- 3 Phase Totem Pole PFC
    - ZVS across line and load
    - 70 kHz – 1.2 MHz
- Available Q2 2025
- 700 mm x 68.5 mm x 32 mm



Parameter	Specification
AC Input voltage	180 V to 305 V
Output voltage	48 V
Output Power	8 kW
Switching frequency	70 kHz – 1.2 MHz
Topology	TCM Totem Pole PFC 3 Phase LLC
Key Enabling ICs	LMG3527R030 LMG3100R017 TMS320F280039C TMS320F28P550SJ



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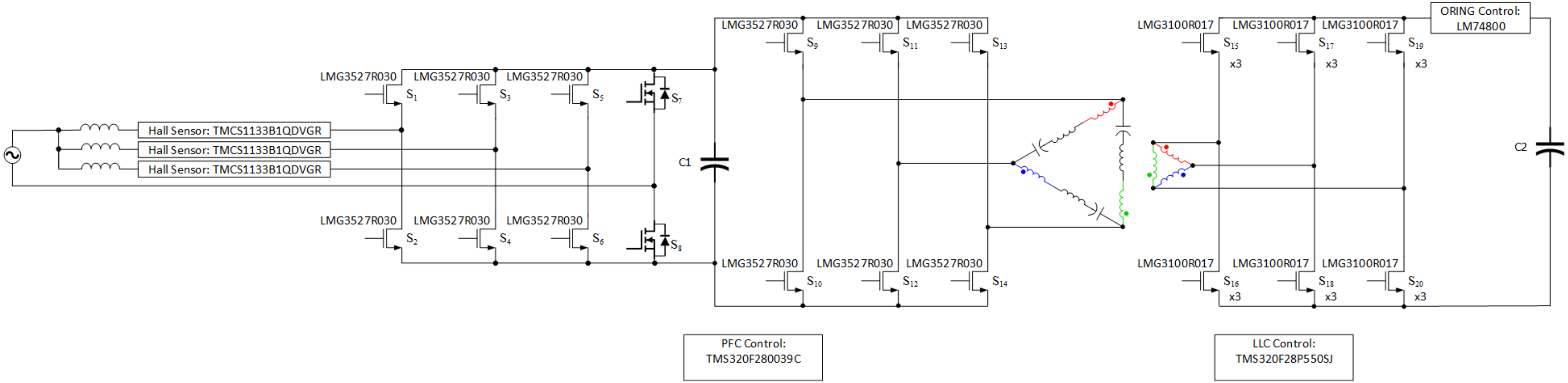
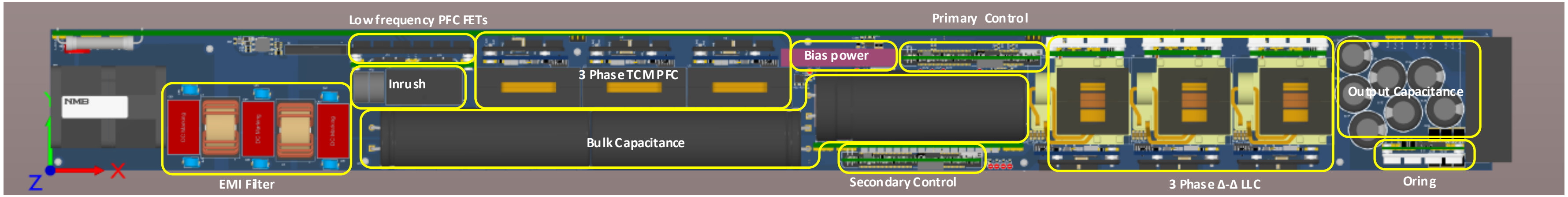
Key TI Parts



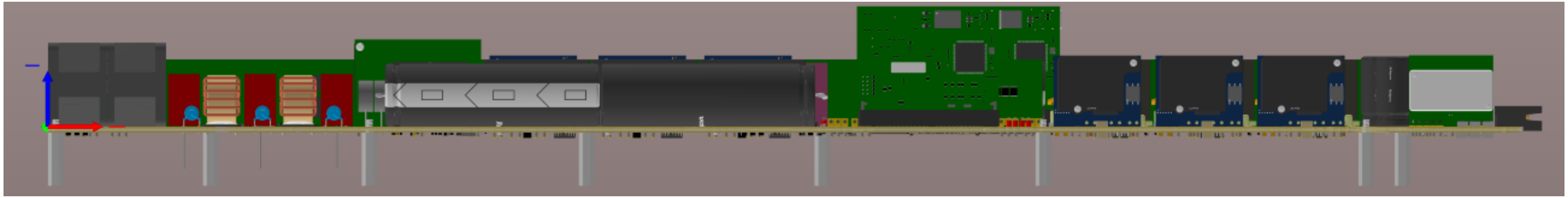
LMG3527R030
S1
LMG3527R030
S3
LMG3527R030
S5
S7
Hall Sensor: TMCS1133B1QDVGR
Hall Sensor: TMCS1133B1QDVGR
Hall Sensor: TMCS1133B1QDVGR
LMG3527R030
S2
LMG3527R030
S4
LMG3527R030
S6
S8
C1
LMG3527R030
S9
LMG3527R030
S11
LMG3527R030
S13
LMG3527R030
S10
LMG3527R030
S12
LMG3527R030
S14
LMG3100R017
S15
x3
LMG3100R017
S17
x3
LMG3100R017
S19
x3
ORING Control:
LM74800
C2
LMG3100R017
S16
x3
LMG3100R017
S18
x3
LMG3100R017
S20
x3
PFC Control:
TMS320F280039C
LLC Control:
TMS320F28P550SJ

Top view

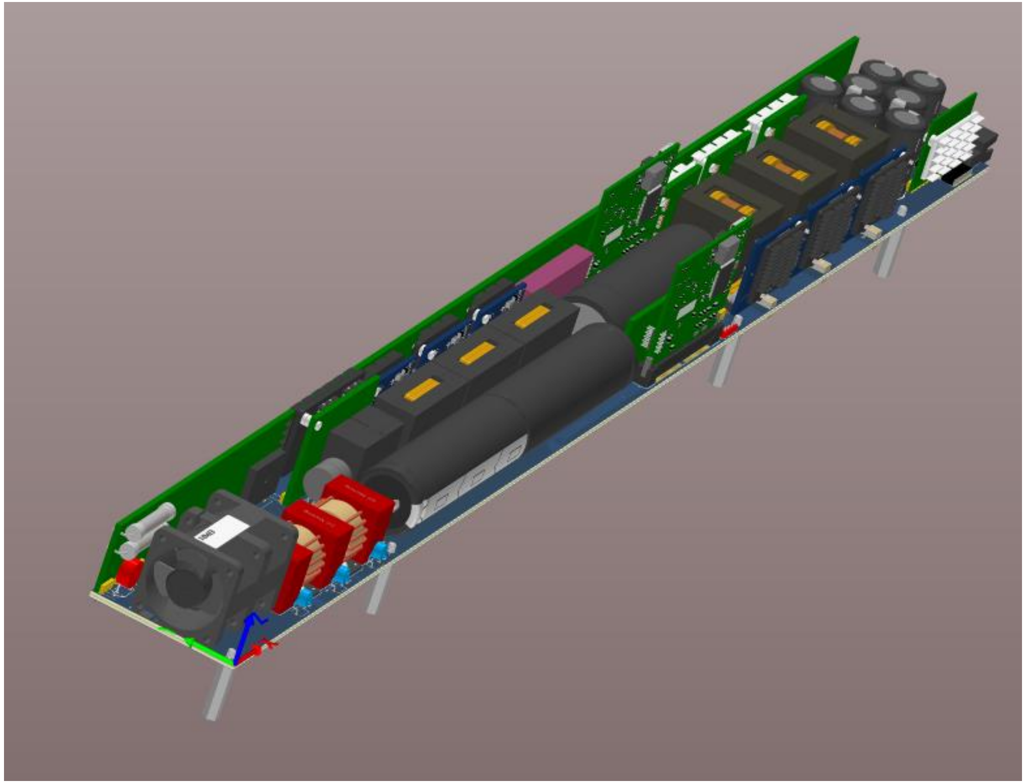


Low frequency PFC FETs
Primary Control
Bias power
Inrush
3 Phase TCM PFC
Output Capacitance
Bulk Capacitance
EMI Filter
Secondary Control
3 Phase Δ-Δ LLC
Oring

Side view



Isometric view



Worst Case Power Losses – Calculated at 180 V_{rms}

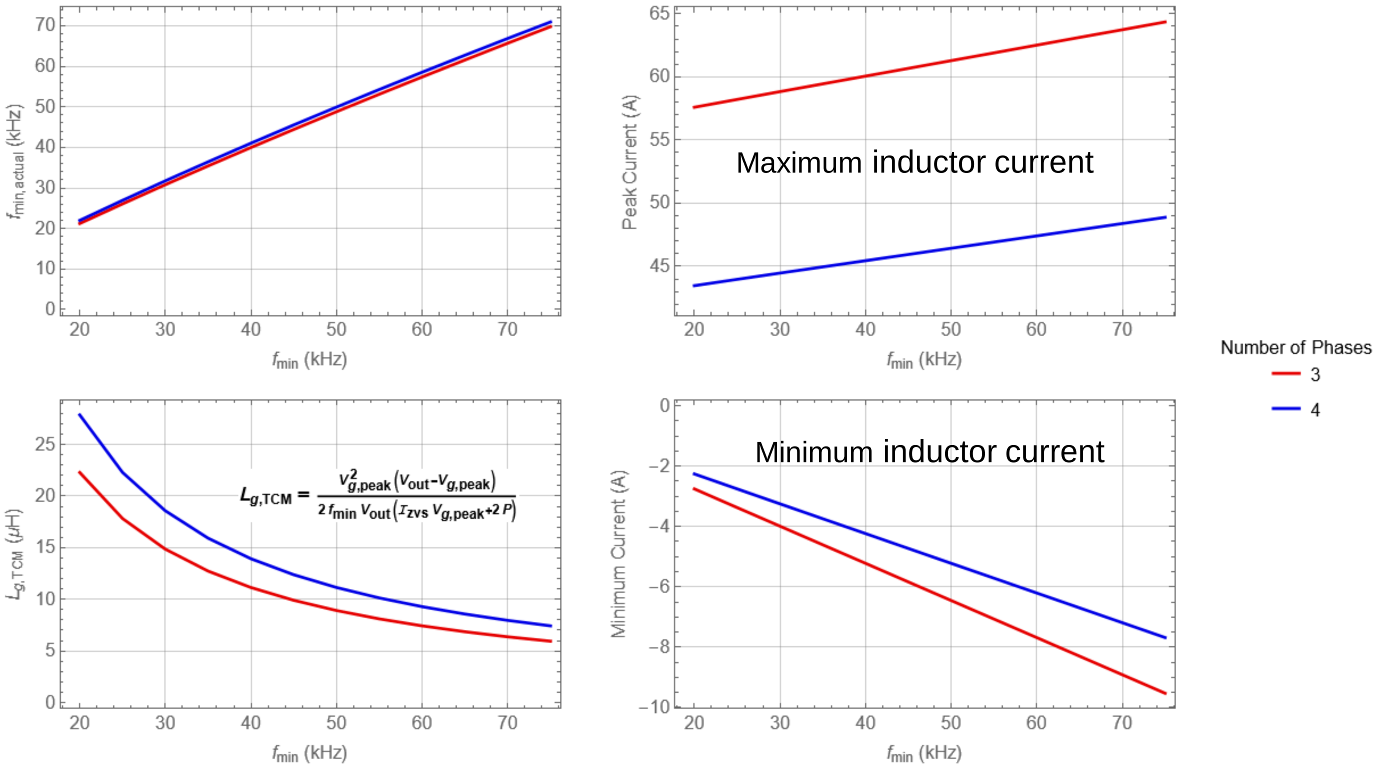
Efficiency:					95.1%
Element	**Loss (W)**	**n**	**Devices per Card**	**Loss per Card**	**Total Loss (W)**
LLC,xfmr,each	10.01	3			30.03
LLC,pri,fet,each	6.19	6	2	12.38	37.14
LLC,sec,fet,each	4.68	18	6	28.10	84.31
LLC,cin,each	0.00	3			0.00
LLC,cout,each	0.00	7			0.00
LLC,cres,each	0.52	12			6.29
LLC,bias	2.29	1			2.29
LLC,oring,each	1.82	4	4	7.29	7.29
PFC,GaN,fet,each	10.56	6	2	21.12	63.36
PFC,LF,fet,each	6.49	4	4	25.95	25.95
PFC,ind,each	7.24	3			21.72
PFC,cbulk,1,each	6.85	2			13.70
PFC,cbulk,2,each	9.11	1			9.11
PFC,cmc,each	7.92	2			15.84
Fan	80.00	1			80.00
PFC bias	2.00	1			2.00
Bias loss	9.37	1			9.37
Relay	5.99	1			5.99
Total					**414.38**

PFC Inductor Selection

- The target inductance value is selected based on the lowest desired operating frequency.
- $L_{g,TCM} = \frac{V_{g,peak}^2 \cdot (V_{out} - V_{g,peak})}{2 \cdot f_{min} \cdot V_{out} \cdot (I_{zvs} \cdot V_{g,peak} + 2 \cdot P)}$
  - $V_{g,peak}$ is the peak line voltage at the maximum AC RMS voltage
  - V_{out} is the PFC output voltage
  - f_{min} is the minimum desired operating frequency
  - I_{zvs} is the required negative current for ZVS
  - P is the maximum output power

PFC Inductance and Frequency

This plot shows compares the actual operating frequency as predicted from the governing differential equations to the equation below.



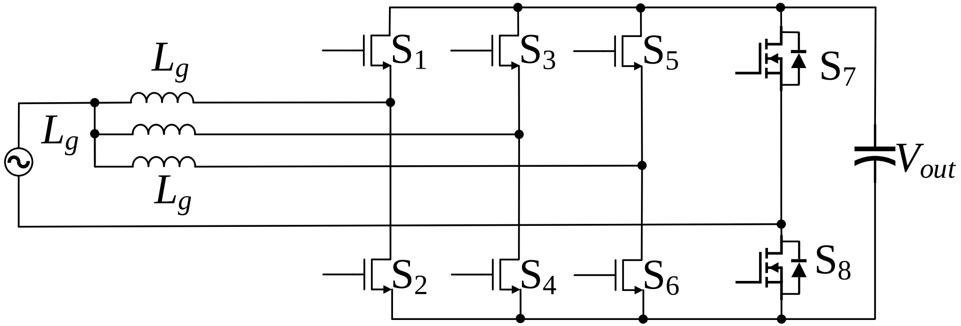
Final inductance considerations

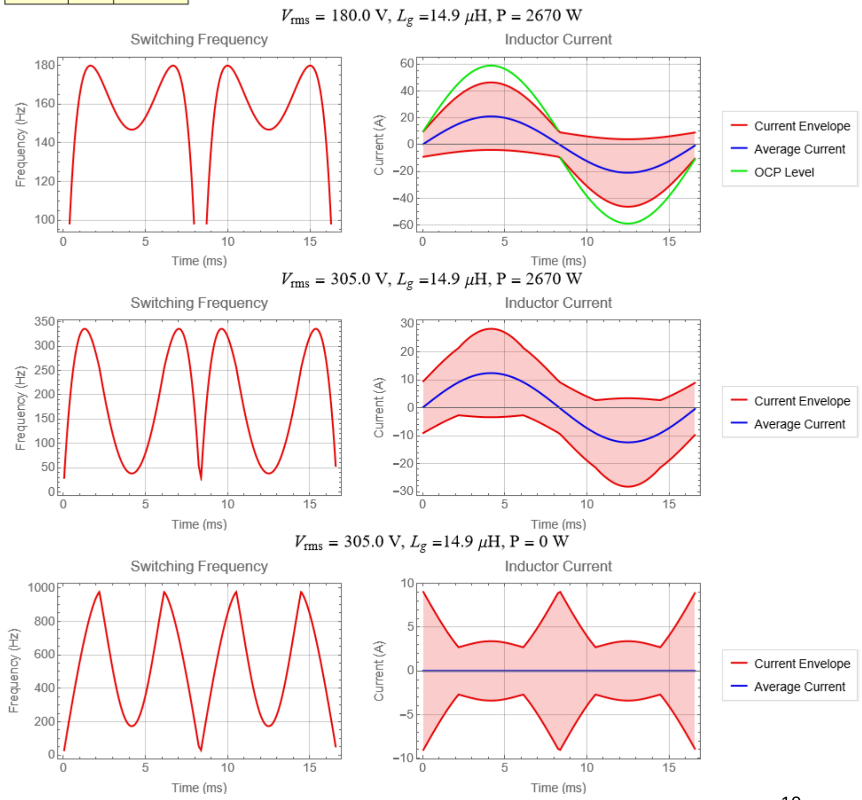
- 3 phases was chosen over 4 in order to simplify the control and minimize the overall solution volume.
- f_{min} = 30-35 kHz was chosen in order to minimize the peak inductor current.
- The resulting target inductance chosen was ~15 μH

PFC Inductor Requirements

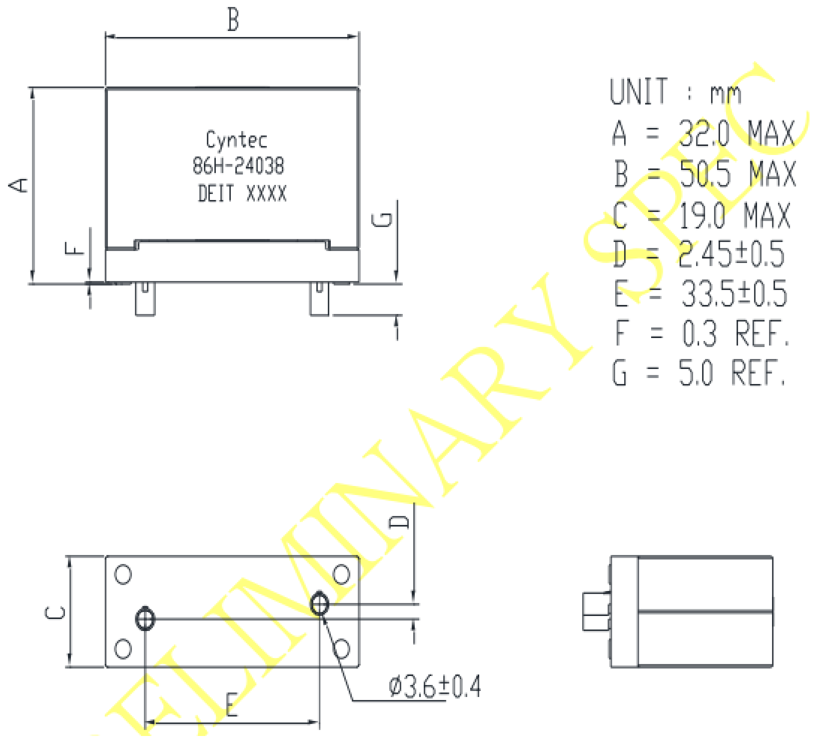
Power	V_{rms}	$I_{L,rms}$
2670.	180.	21.482
2670.	305.	13.3883
0	305.	4.56875

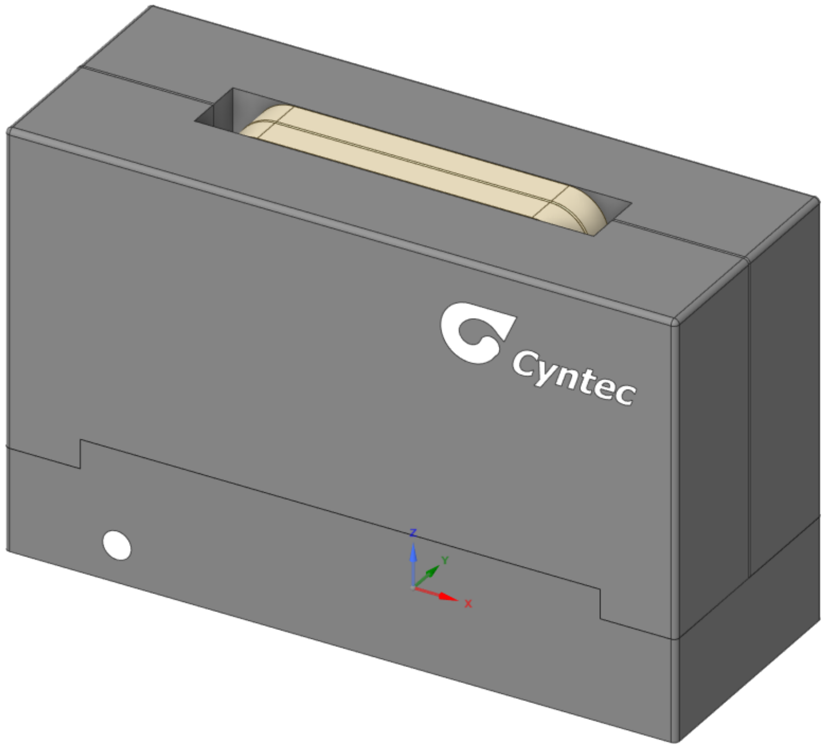
- The top set of plots shows the maximum peak to peak current in steady state (red), the average current (blue) and the peak inductor current during a surge event (green).
- The additional 2 cases have lower current levels but they illustrate the range of frequencies that the inductor will be subjected to.





PFC Inductor

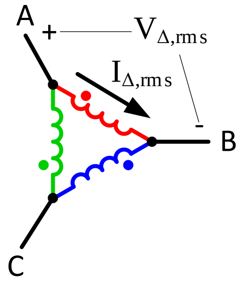




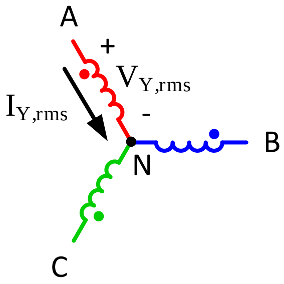
3 Phase Basics

- Sine wave conversions for Δ–Y conversions assuming balanced loading.
  - $\frac{V_{\Delta,rms}}{V_{Y,rms}} = \sqrt{3}$
  - $\frac{I_{\Delta,rms}}{I_{Y,rms}} = \frac{1}{\sqrt{3}}$
  - $\frac{z_{\Delta}}{z_{Y}} = 3$
- Δ–Δ architecture is chosen due to the reduced RMS currents flowing in the resonant tank.
- First harmonic load resistance approximations for 3 phase LLC topologies assuming balanced loading.
  - $R_{eq,\Delta} = \frac{18 \cdot V_{out}}{\pi^2 \cdot I_{out}}$
  - $R_{eq,Y} = \frac{6 \cdot V_{out}}{\pi^2 \cdot I_{out}}$

Δ Connection



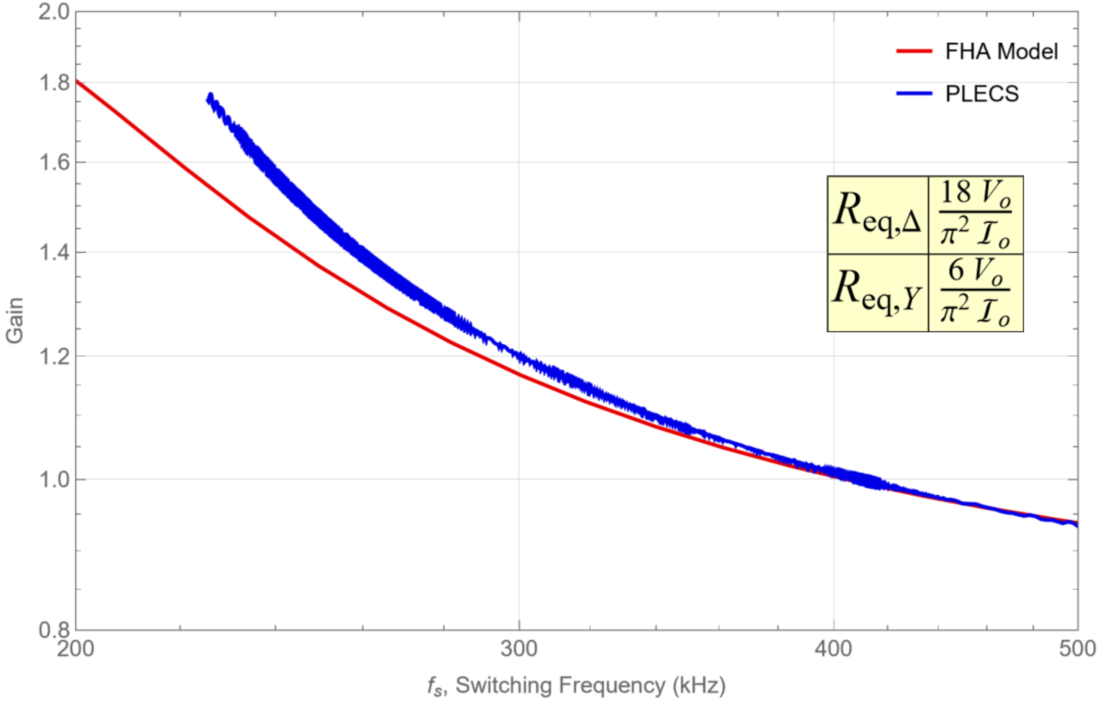
Y Connection



FHA Model Verification (8 kW)

f_r = 500 kHz
L_m/L_r = 8
n_p/n_s = 10

1st Harmonic Gain Plot: $\frac{V_{in,norm}}{V_{o,norm}} \frac{(s L_m) \| R_e}{(s L_m) \| R_e + s L_r + \frac{1}{s C_r}} \frac{n_s}{n_p}$

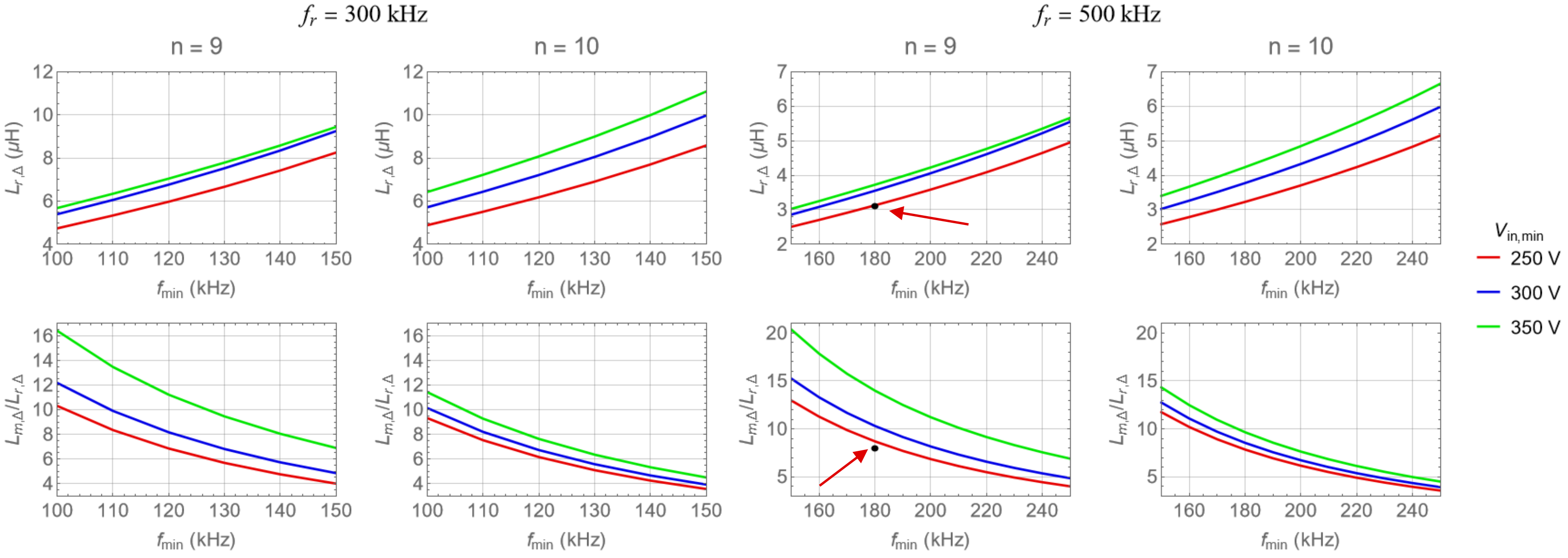


$R_{eq,\Delta}$	$\frac{18 V_o}{\pi^2 I_o}$
$R_{eq,Y}$	$\frac{6 V_o}{\pi^2 I_o}$

Valid for Δ-Δ and Y-Y transformer connections.

LLC Tank Considerations

- f_r = 500 kHz, chosen to minimize tank component size
- n = 9 chosen to minimize C_{bulk} required for hold up.
- Equivalent performance n = 10 requires larger inductance values.



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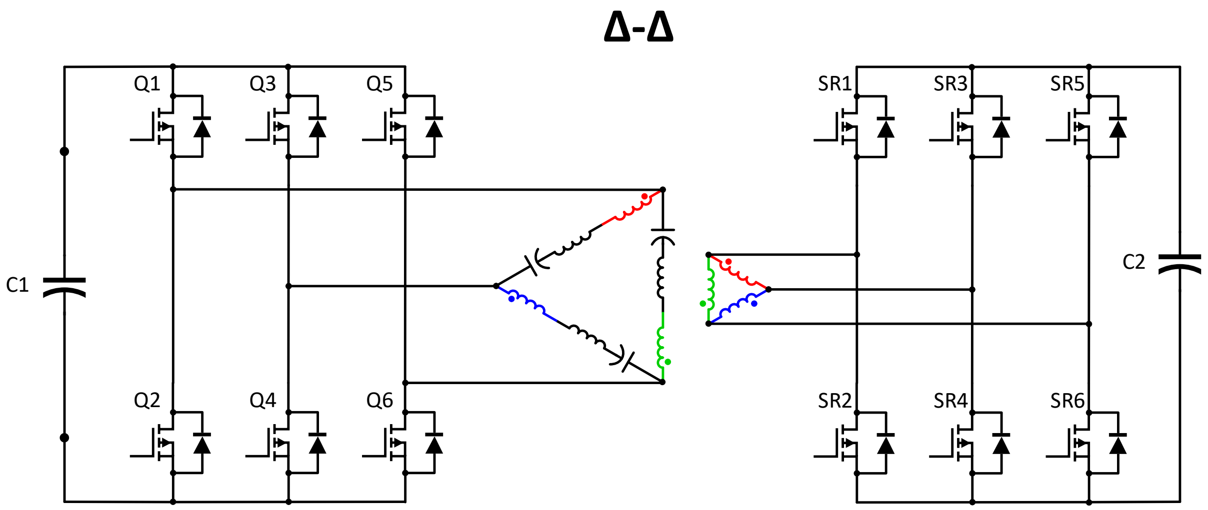
3 Phase LLC Tank Design



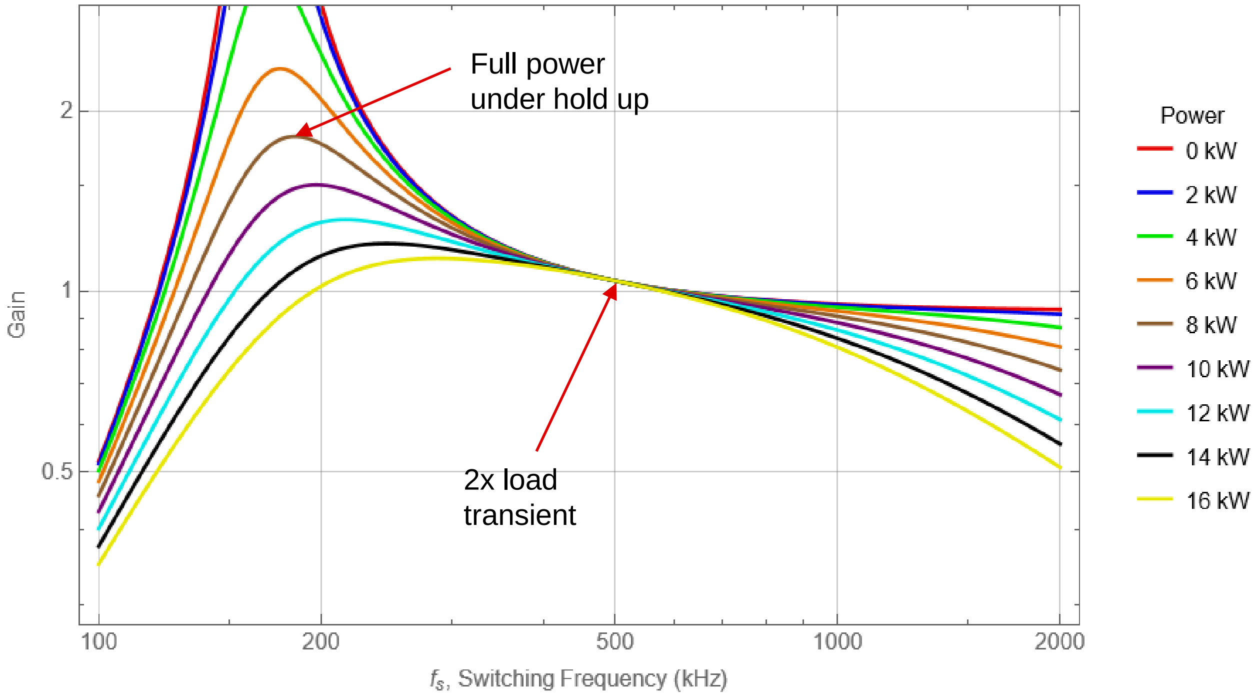
- $L_r = 3.1\ \mu H$
- $L_m = 24.8\ \mu H$
- $C_r = 32.7\ nF$
- $n_p/n_s = 9$
- $L_m/L_r = 8$
- $f_r = 500\ kHz$

FHA Gain Plot

Sufficient gain for:

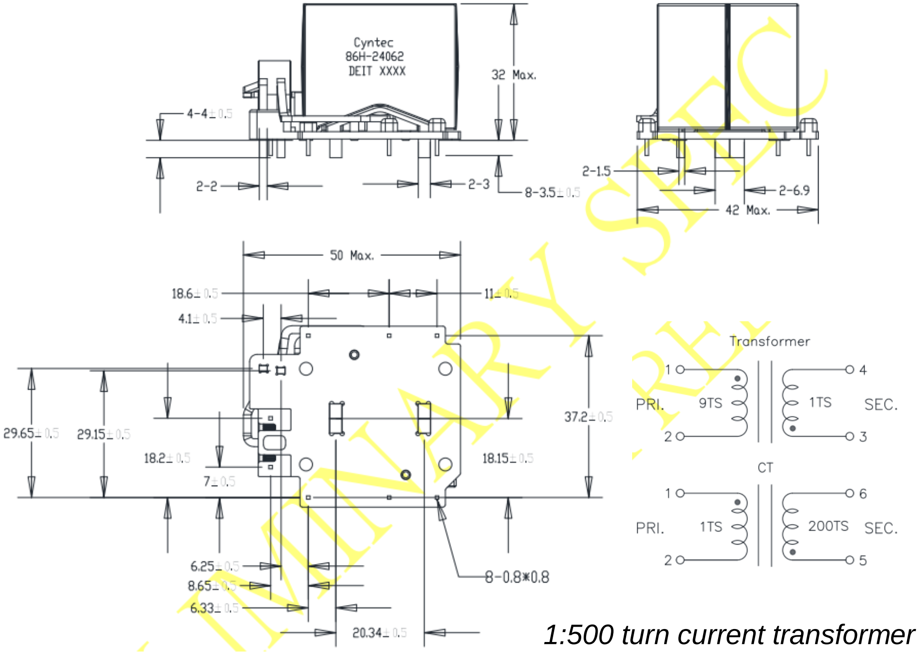
- full power operation under hold up conditions.
- 2x transient load conditions.

1st Harmonic Gain Plot: $\frac{V_{in,norm}}{V_{o,norm}} \; \frac{(s L_m)\|R_e}{(s L_m)\|R_e + s L_r + \frac{1}{s C_r}} \; \frac{n_s}{n_p}$

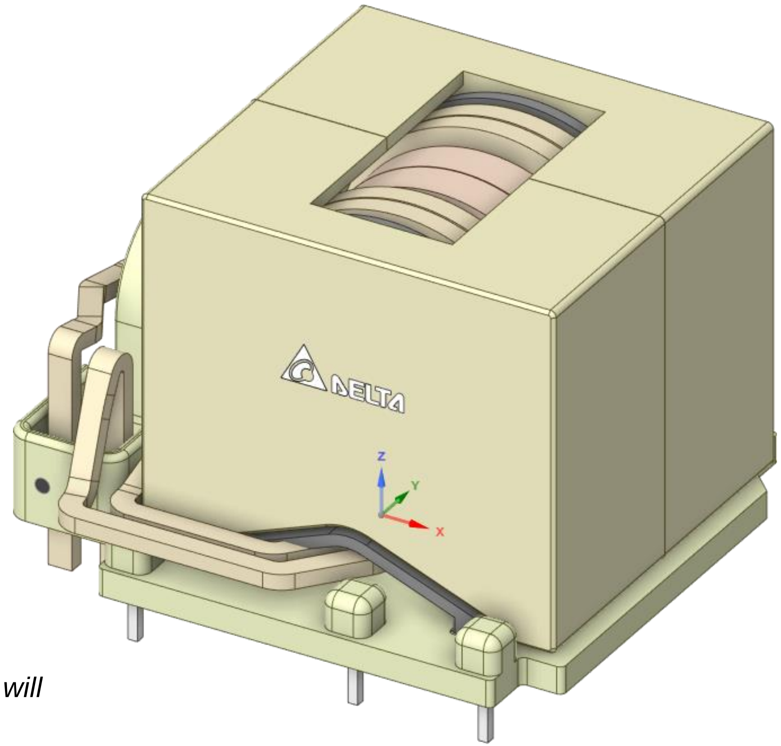


$L_{r,\Delta}$	3.1×10^{-6}
$L_{m,\Delta}$	24.8×10^{-6}
$C_{r,\Delta}$	32.6843×10^{-9}
L_r	1.03333×10^{-6}
L_m	8.26667×10^{-6}
C_r	98.0528×10^{-9}
f_r	$500.\times10^{3}$
n_p	9.
n_s	1.
R_e	14.1817
V_o	48.
I_o	166.667
P_o	$8.\times10^{3}$
$V_{o,\text{norm}}$	48.
$V_{\text{in,norm}}$	450.
$R_{\text{eq},\Delta}$	525.249×10^{-3}
$R_{\text{eq},Y}$	175.083×10^{-3}

Transformer with integrated current sense



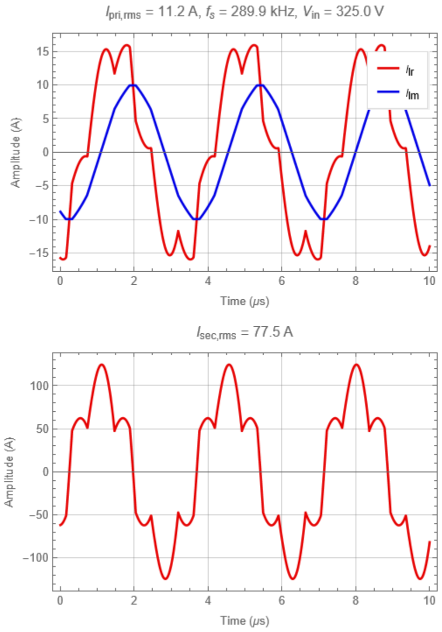
1:500 turn current transformer will also be evaluated.



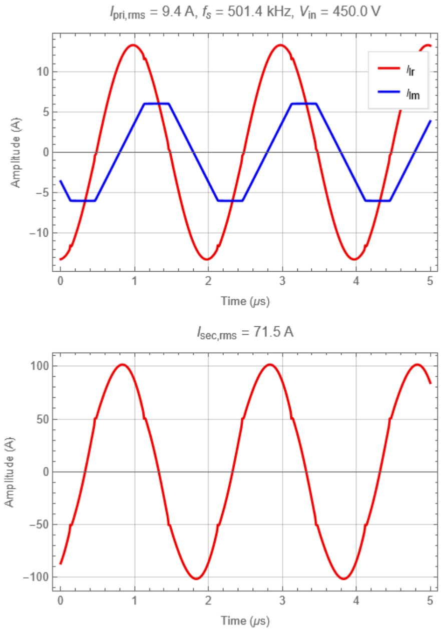
Operating Waveforms

- Inductor
  - $L_r = 3.1\ \mu H$
- Transformer
  - $L_m = 24.8\ \mu H$
  - Turns ratio: n_p:n_s = 9:1

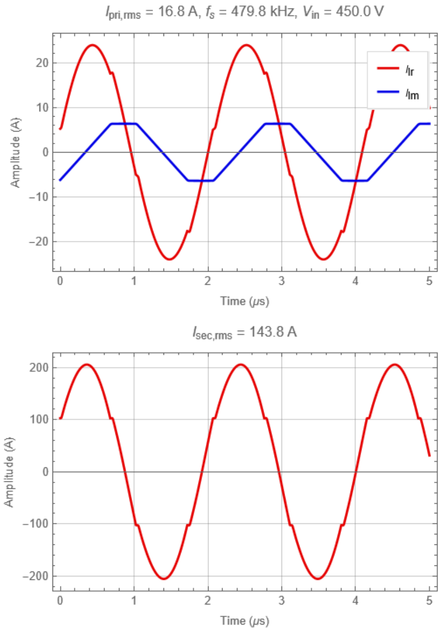
AC line drop out (20 ms)



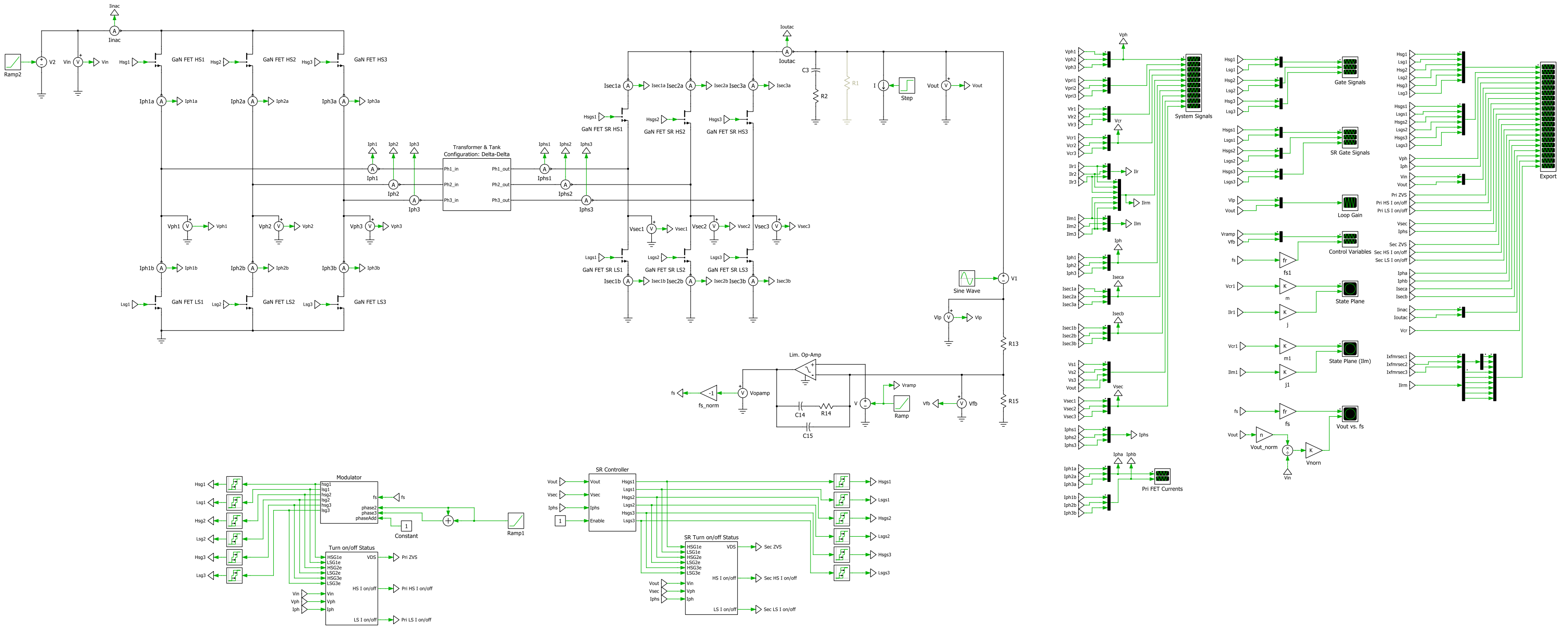
Maximum steady state operating



Low duty cycle transient. Do not consider for thermal impact.



PLECS Model



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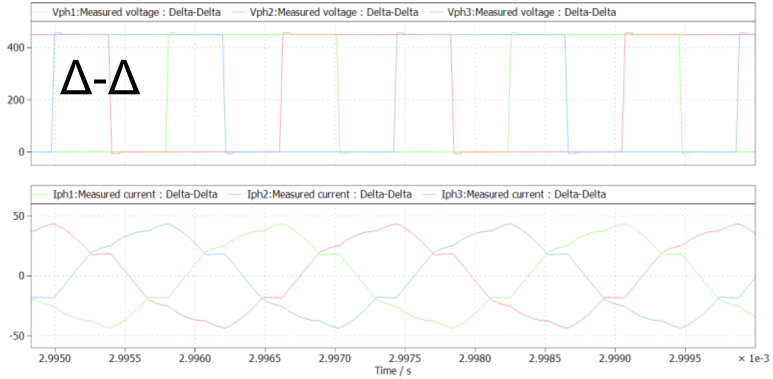
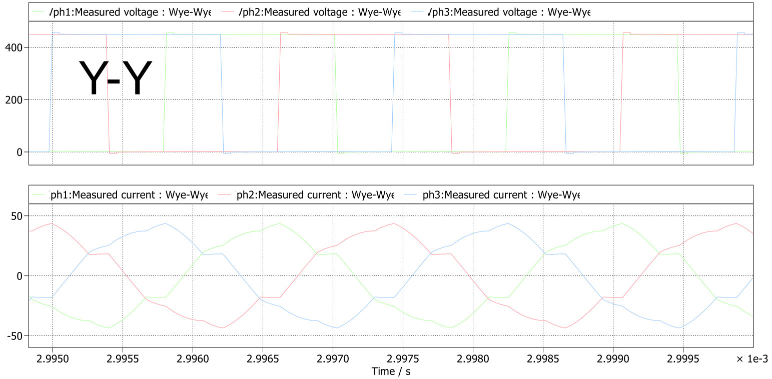
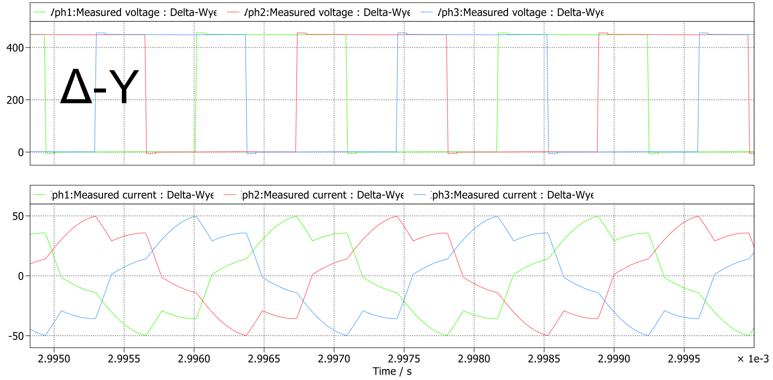
Back up

ZVS behavior 16 kW







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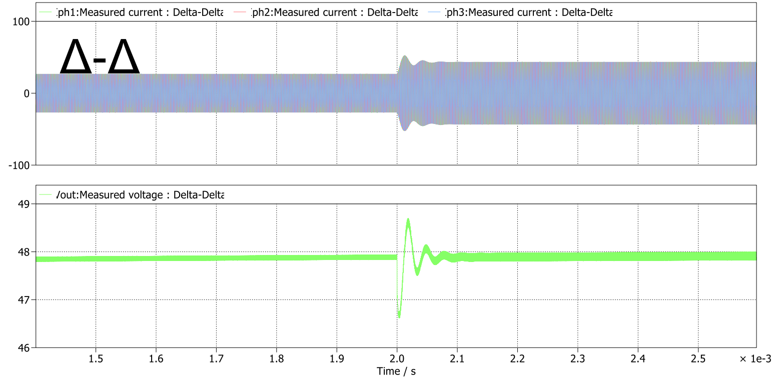
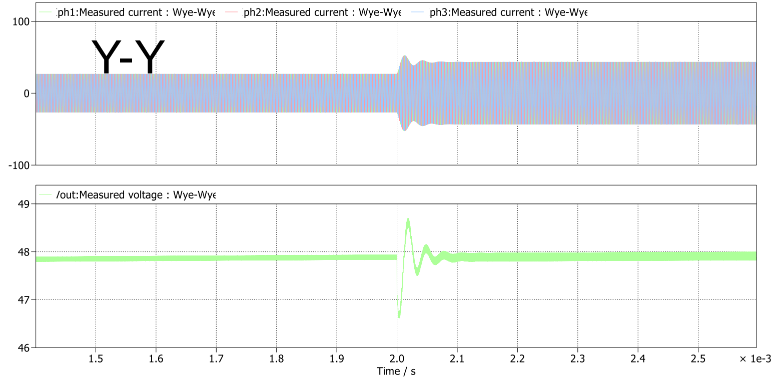
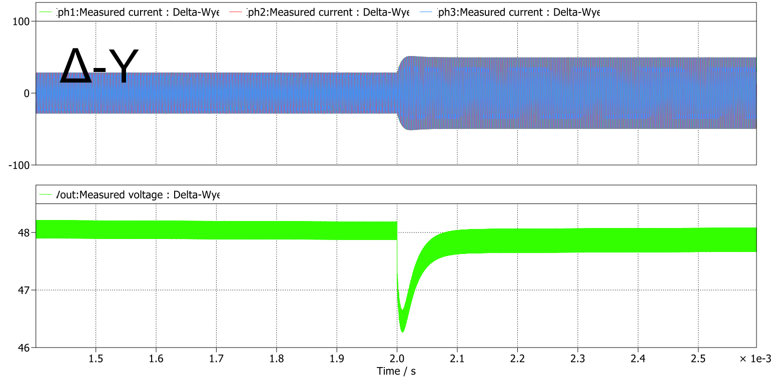
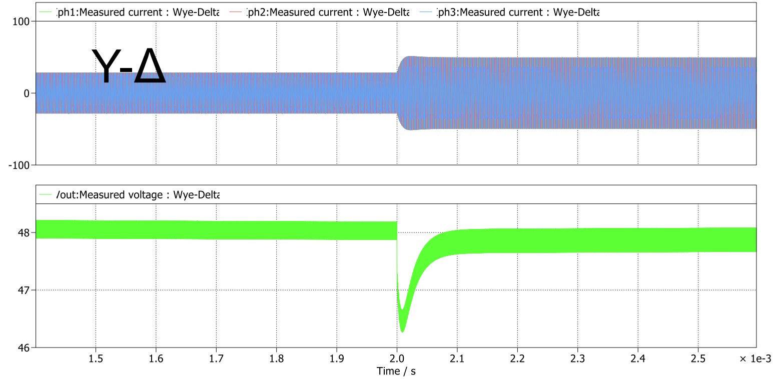
Load Transient

V_{in} = 450 V
V_{out} = 48 V
P_{out} = 8 kW → 16 kW

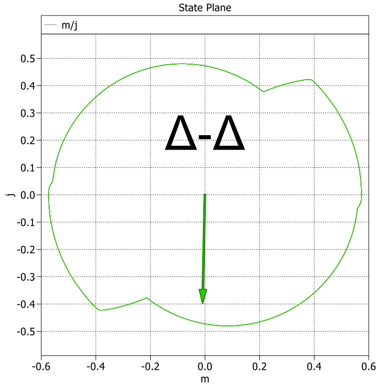


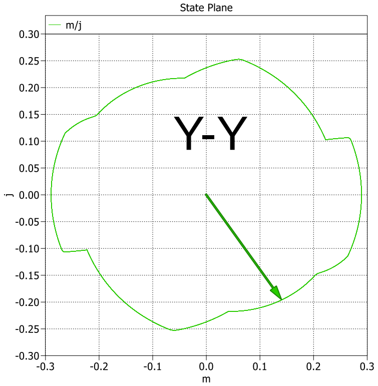


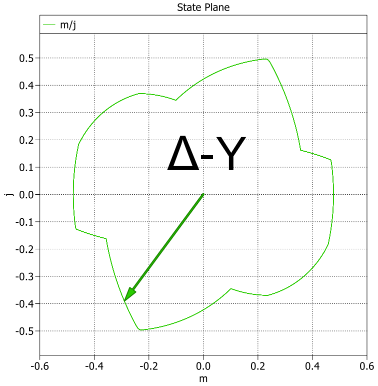


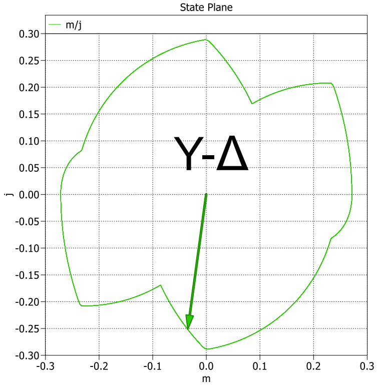


State Plane – 16 kW

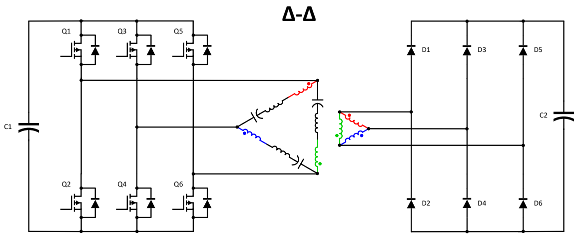




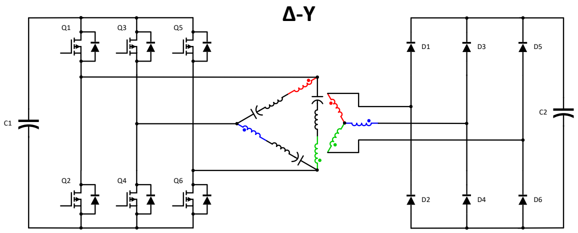




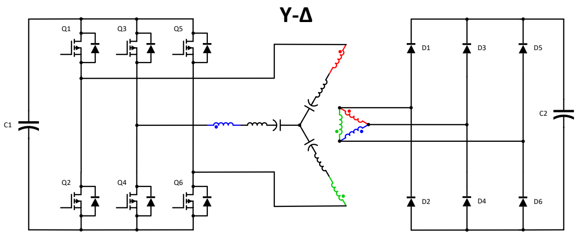
Resonance – Switch States



Delta-Delta & Wye-Wye



Delta-Wye



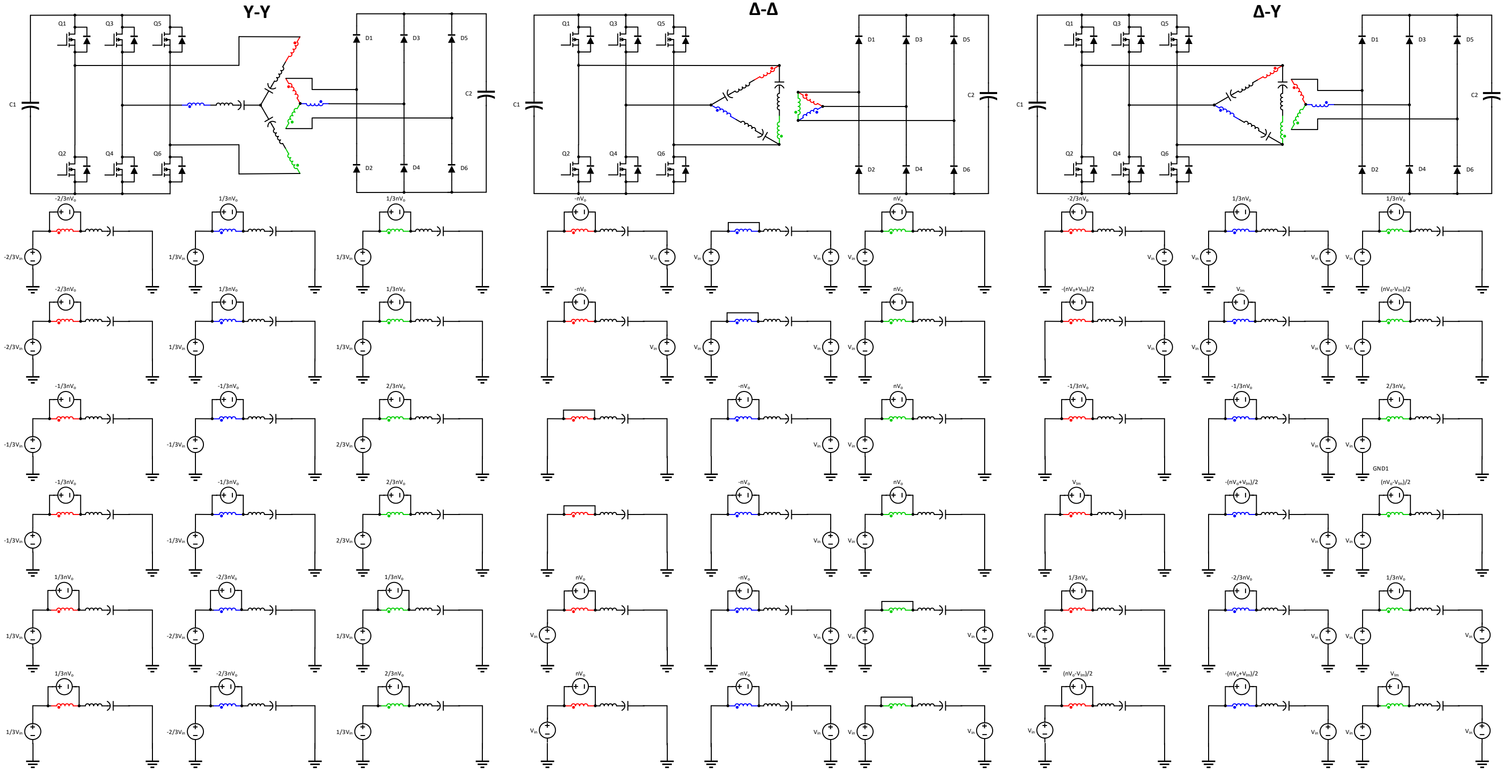
Wye-Delta

Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q6	D1	D4	D6
Q1	Q4	Q6	D1	D4	D6
Q1	Q3	Q6	D1	D3	D6
Q1	Q3	Q6	D1	D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q5	D2	D3	D5
Q2	Q3	Q5	D2	D3	D5
Q2	Q4	Q5	D2	D4	D5
Q2	Q4	Q5	D2	D4	D5

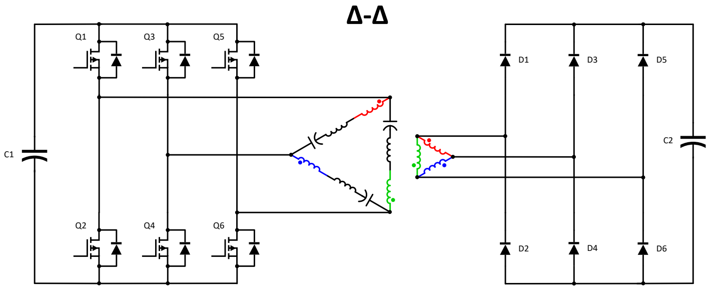
Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q5	D1	D4	
Q1	Q4	Q6	D1	D4	D6
Q1	Q4	Q6	D1		D6
Q1	Q3	Q6	D1	D3	D6
Q1	Q3	Q6		D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q6	D2	D3	
Q2	Q3	Q5	D2	D3	D5
Q2	Q3	Q5	D2		D5
Q2	Q4	Q5	D2	D4	D5
Q2	Q4	Q5		D4	D5

Q1	Q4	Q5	D2	D4	D5
Q1	Q4	Q5		D4	D5
Q1	Q4	Q6	D1	D4	D5
Q1	Q4	Q6	D1	D4	
Q1	Q3	Q6	D1	D4	D6
Q1	Q3	Q6	D1		D6
Q2	Q3	Q6	D1	D3	D6
Q2	Q3	Q6		D3	D6
Q2	Q3	Q5	D2	D3	D6
Q2	Q3	Q5	D2	D3	
Q2	Q4	Q5	D2	D3	D5
Q2	Q4	Q5	D2		D5

Resonance – Positive ½ Cycle States



Δ-Δ States



Below Resonance

Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q5	D1	D4	
Q1	Q4	Q6	D1	D4	D6
Q1	Q4	Q6	D1		D6
Q1	Q3	Q6	D1	D3	D6
Q1	Q3	Q6		D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q6	D2	D3	
Q2	Q3	Q5	D2	D3	D5
Q2	Q3	Q5	D2		D5
Q2	Q4	Q5	D2	D4	D5
Q2	Q4	Q5		D4	D5

Resonance

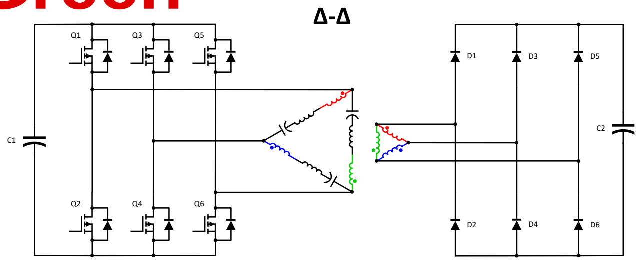
Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q6	D1	D4	D6
Q1	Q4	Q6	D1	D4	D6
Q1	Q3	Q6	D1	D3	D6
Q1	Q3	Q6	D1	D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q5	D2	D3	D5
Q2	Q3	Q5	D2	D3	D5
Q2	Q4	Q5	D2	D4	D5
Q2	Q4	Q5	D2	D4	D5

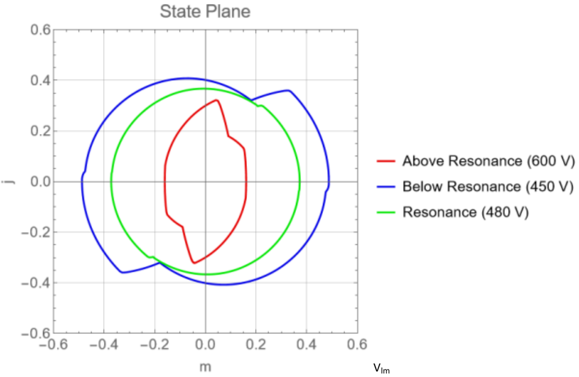
Above Resonance

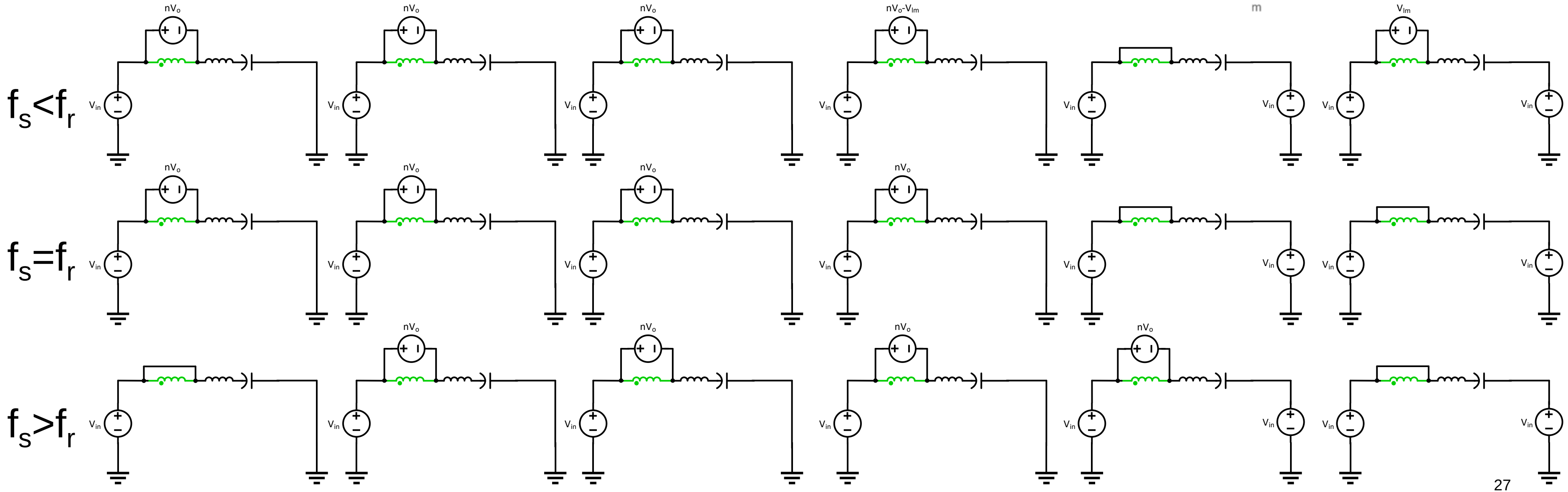
Q1	Q4	Q5	D2	D4	D5
Q1	Q4	Q5	D1	D4	D5
Q1	Q4	Q6	D1	D4	D5
Q1	Q4	Q6	D1	D4	D6
Q1	Q3	Q6	D1	D4	D6
Q1	Q3	Q6	D1	D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q6	D2	D3	D6
Q2	Q3	Q5	D2	D3	D6
Q2	Q3	Q5	D2	D3	D5
Q2	Q4	Q5	D2	D3	D5
Q2	Q4	Q5	D2	D4	D5

Phase States – Green

$v_{lm,1}(t)$	$\frac{1}{2}\left(\frac{t(I_{lr,0}-I_{lb,0})}{C_r} - V_{cb,0} + V_{cr,0}\right)$
$v_{lm,2}(t)$	$\frac{1}{2}\left(\frac{t(I_{lg,0}-I_{lr,0})}{C_r} + V_{cg,0} - V_{cr,0}\right)$
$v_{lm,3}(t)$	$\frac{1}{2}\left(\frac{t(I_{lb,0}-I_{lg,0})}{C_r} + V_{cb,0} - V_{cg,0}\right)$



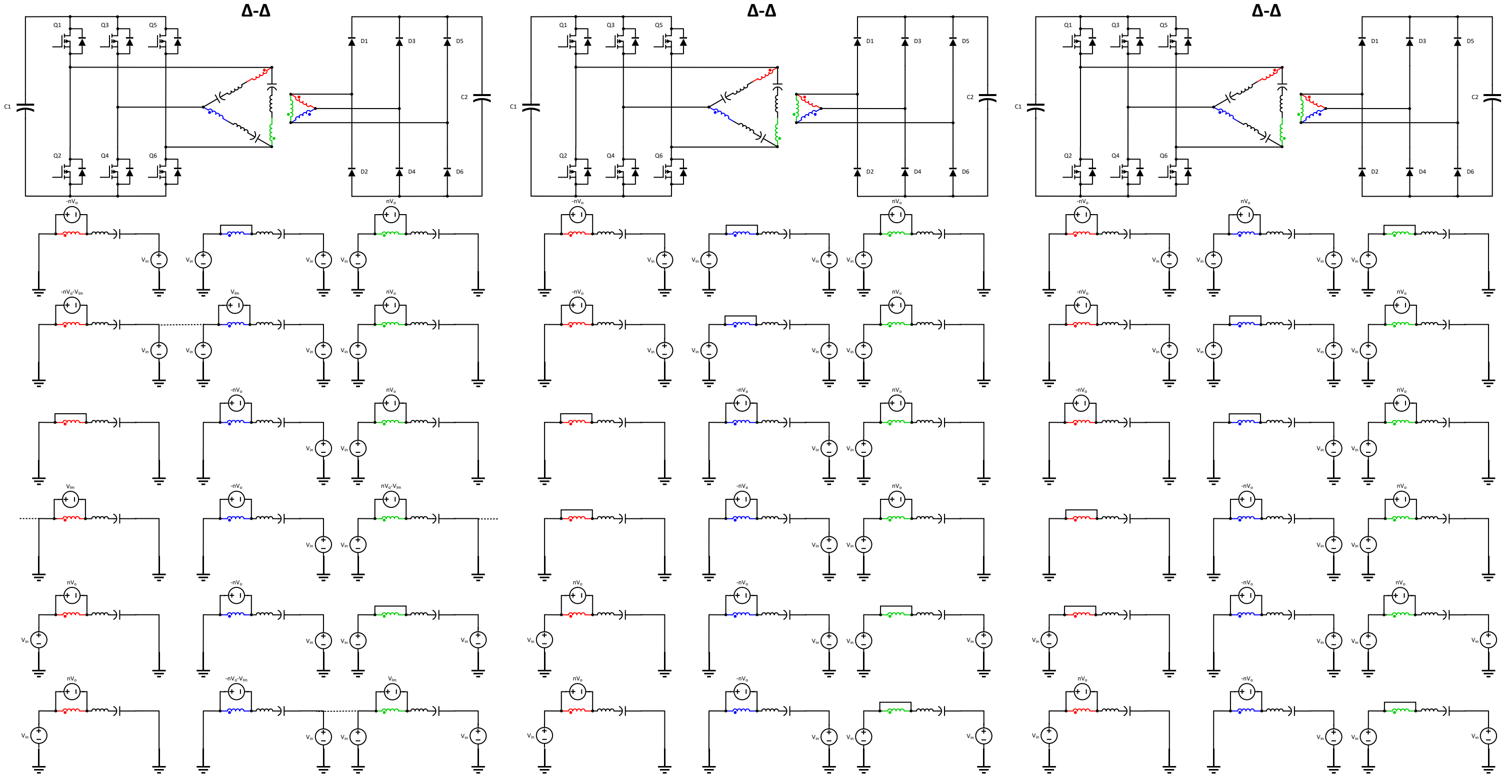




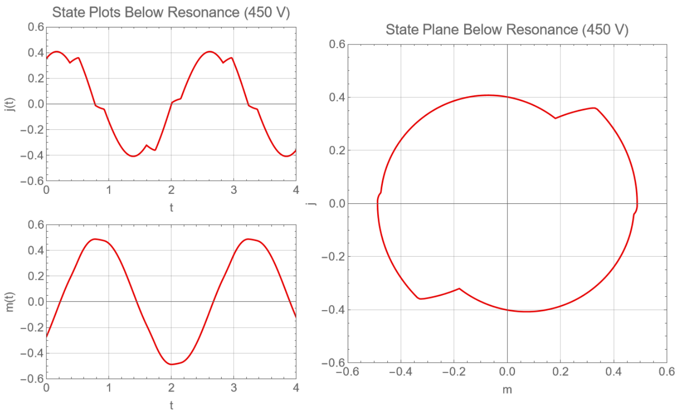
Δ-Δ States

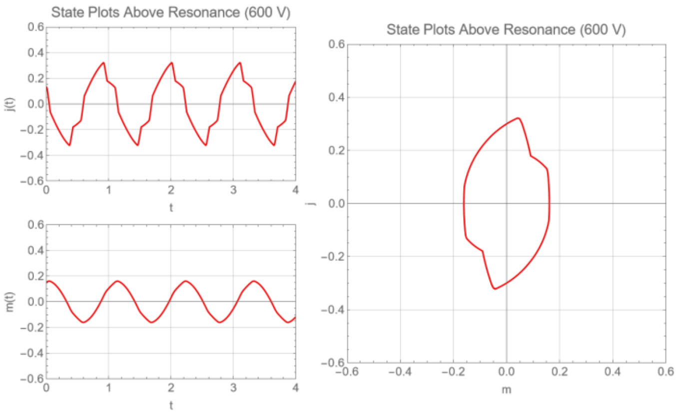
$v_{\mathrm{lm},1}(t)$	$\frac{1}{2}\left(\frac{t\left(I_{\mathrm{lr},0}-I_{\mathrm{lb},0}\right)}{C_r}-V_{\mathrm{cb},0}+V_{\mathrm{cr},0}\right)$
$v_{\mathrm{lm},2}(t)$	$\frac{1}{2}\left(\frac{t\left(I_{\mathrm{lg},0}-I_{\mathrm{lr},0}\right)}{C_r}+V_{\mathrm{cg},0}-V_{\mathrm{cr},0}\right)$
$v_{\mathrm{lm},3}(t)$	$\frac{1}{2}\left(\frac{t\left(I_{\mathrm{lb},0}-I_{\mathrm{lg},0}\right)}{C_r}+V_{\mathrm{cb},0}-V_{\mathrm{cg},0}\right)$

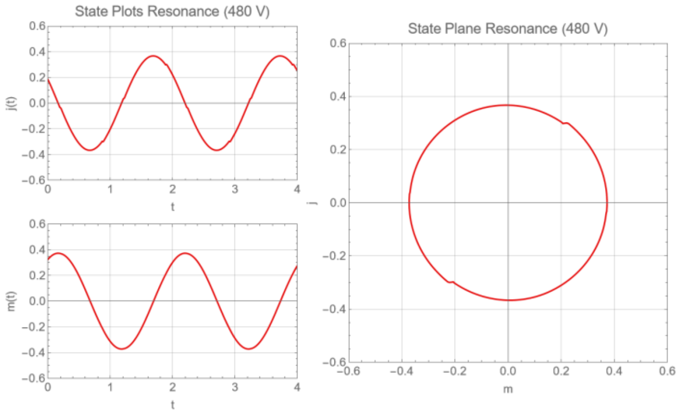
Below Resonance | Resonance | Above Resonance



State Plane Plots





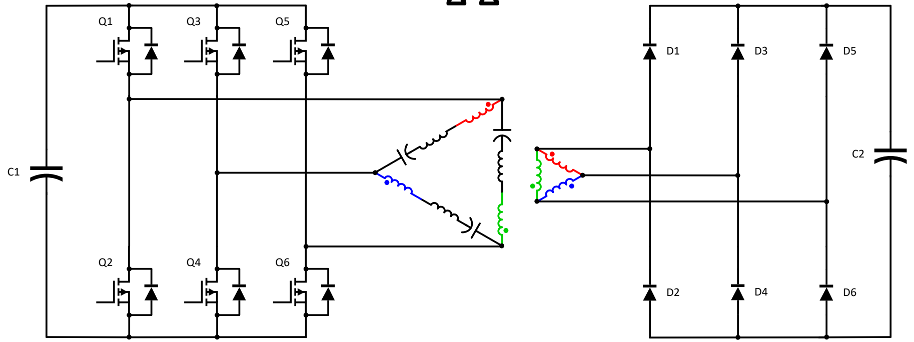


3 Phase LLC

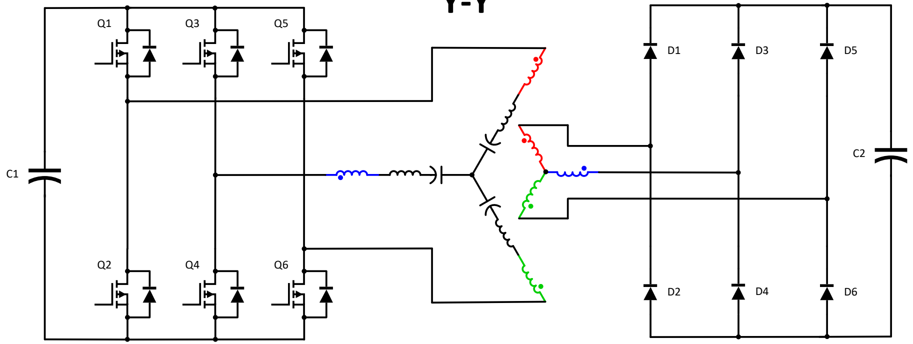
Δ-Δ & Y-Y behave the same and
Δ-Y & Y-Δ behave the same but these pairs behave different.

- $V_\Delta = \sqrt{3} \cdot V_Y$
- $I_\Delta = \frac{I_Y}{\sqrt{3}}$
- $Z_\Delta = 3 \cdot Z_Y$

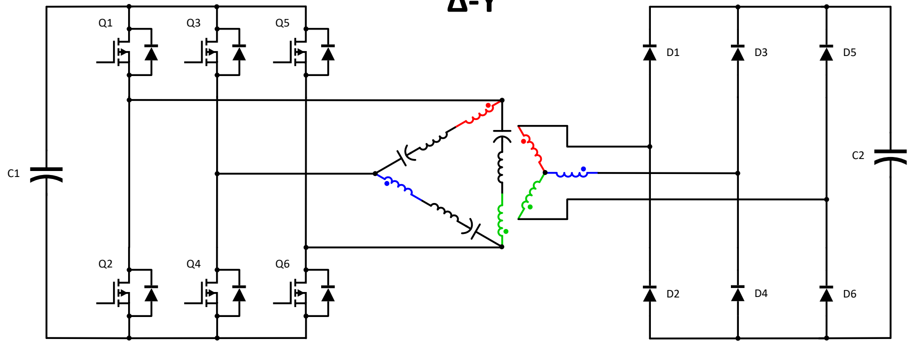
Δ-Δ



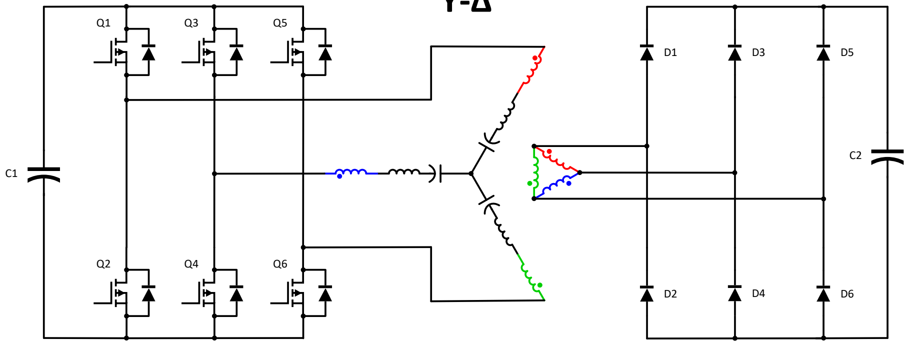
Y-Y



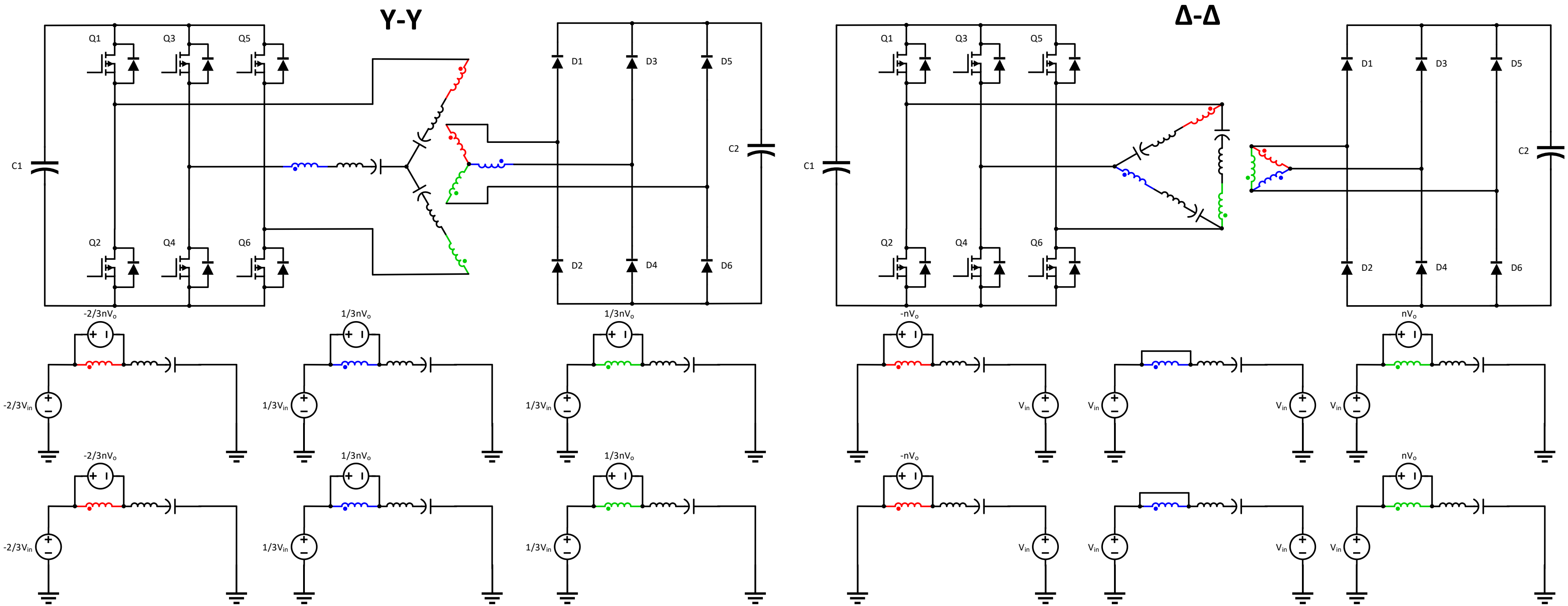
Δ-Y



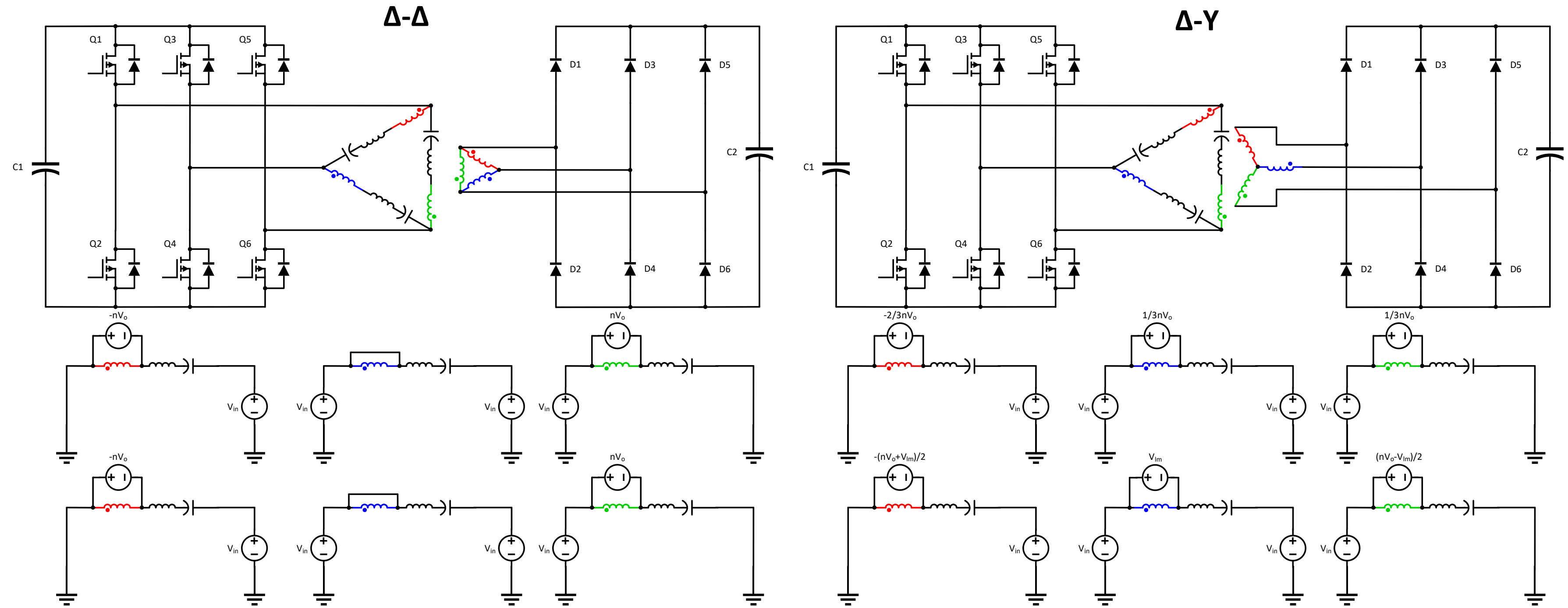
Y-Δ



Y-Y vs. Δ-Δ States



Δ-Δ vs. Δ-Y States



Below Resonant Magnetizing Voltage Solutions

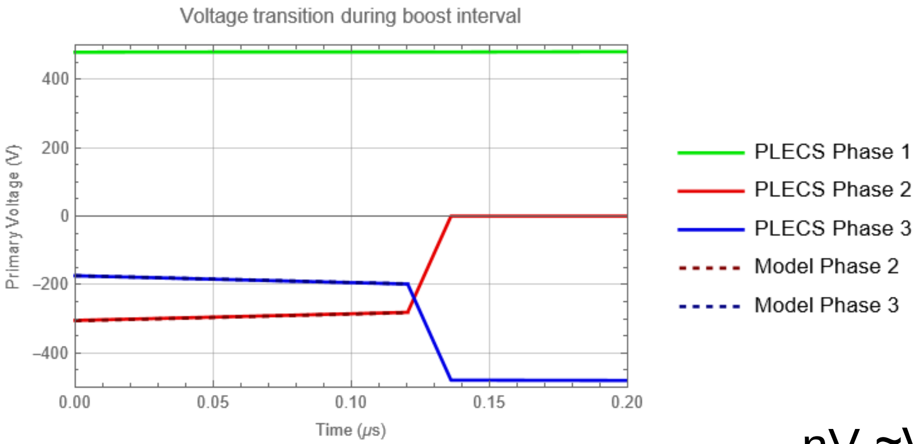
	Tank Voltages		Magnetizing Voltages	
	Interval 1			
	Tank Voltages		**Magnetizing Voltages**	
	$-v_{\text{lm}}(t)$	$-V_{\text{in}} + v_{\text{lm}}(t) + n\,V_o$	$v_{\text{lm}}(t)$	$-v_{\text{lm}}(t) - n\,V_o$
Exact	$\frac{L_m\,(v_{\text{cb}}(t)-v_{\text{cr}}(t)-V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$	$\frac{L_m\,(-v_{\text{cb}}(t)+v_{\text{cr}}(t)-V_{\text{in}}+n\,V_o)+L_r\,(n\,V_o-2\,V_{\text{in}})}{2\,(L_m+L_r)}$	$\frac{L_m\,(-v_{\text{cb}}(t)+v_{\text{cr}}(t)+V_{\text{in}}-n\,V_o)-n\,L_r\,V_o}{2\,(L_m+L_r)}$	$-\frac{L_m\,(-v_{\text{cb}}(t)+v_{\text{cr}}(t)+V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$
$L_m/L_r \approx \infty$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cr}}(t) - V_{\text{in}} + n\,V_o)$	$\frac{1}{2}\,(-v_{\text{cb}}(t) + v_{\text{cr}}(t) - V_{\text{in}} + n\,V_o)$	$\frac{1}{2}\,(-v_{\text{cb}}(t) + v_{\text{cr}}(t) + V_{\text{in}} - n\,V_o)$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cr}}(t) - V_{\text{in}} - n\,V_o)$
$nV_o \approx V_{in}$ $L_m/L_r \approx \infty$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cr}}(t))$	$\frac{1}{2}\,(v_{\text{cr}}(t) - v_{\text{cb}}(t))$	$\frac{1}{2}\,(v_{\text{cr}}(t) - v_{\text{cb}}(t))$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cr}}(t) - 2\,n\,V_o)$
	Interval 2			
	Tank Voltages		**Magnetizing Voltages**	
	$-v_{\text{lm}}(t)$	$V_{\text{in}} + v_{\text{lm}}(t) - n\,V_o$	$v_{\text{lm}}(t)$	$n\,V_o - v_{\text{lm}}(t)$
Exact	$-\frac{L_m\,(v_{\text{cg}}(t)-v_{\text{cr}}(t)-V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$	$\frac{L_m\,(v_{\text{cg}}(t)-v_{\text{cr}}(t)+V_{\text{in}}-n\,V_o)+L_r\,(2\,V_{\text{in}}-n\,V_o)}{2\,(L_m+L_r)}$	$\frac{L_m\,(v_{\text{cg}}(t)-v_{\text{cr}}(t)-V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$	$\frac{L_m\,(-v_{\text{cg}}(t)+v_{\text{cr}}(t)+V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$
$L_m/L_r \approx \infty$	$\frac{1}{2}\,(-v_{\text{cg}}(t) + v_{\text{cr}}(t) + V_{\text{in}} - n\,V_o)$	$\frac{1}{2}\,(v_{\text{cg}}(t) - v_{\text{cr}}(t) + V_{\text{in}} - n\,V_o)$	$\frac{1}{2}\,(v_{\text{cg}}(t) - v_{\text{cr}}(t) - V_{\text{in}} + n\,V_o)$	$\frac{1}{2}\,(-v_{\text{cg}}(t) + v_{\text{cr}}(t) + V_{\text{in}} + n\,V_o)$
$nV_o \approx V_{in}$ $L_m/L_r \approx \infty$	$\frac{1}{2}\,(v_{\text{cr}}(t) - v_{\text{cg}}(t))$	$\frac{1}{2}\,(v_{\text{cg}}(t) - v_{\text{cr}}(t))$	$\frac{1}{2}\,(v_{\text{cg}}(t) - v_{\text{cr}}(t))$	$\frac{1}{2}\,(-v_{\text{cg}}(t) + v_{\text{cr}}(t) + 2\,n\,V_o)$
	Interval 3			
	Tank Voltages		**Magnetizing Voltages**	
	$-v_{\text{lm}}(t)$	$-V_{\text{in}} + v_{\text{lm}}(t) + n\,V_o$	$v_{\text{lm}}(t)$	$-v_{\text{lm}}(t) - n\,V_o$
Exact	$\frac{L_m\,(-v_{\text{cb}}(t)+v_{\text{cg}}(t)-V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$	$\frac{L_m\,(v_{\text{cb}}(t)-v_{\text{cg}}(t)-V_{\text{in}}+n\,V_o)+L_r\,(n\,V_o-2\,V_{\text{in}})}{2\,(L_m+L_r)}$	$\frac{L_m\,(v_{\text{cb}}(t)-v_{\text{cg}}(t)+V_{\text{in}}-n\,V_o)-n\,L_r\,V_o}{2\,(L_m+L_r)}$	$-\frac{L_m\,(v_{\text{cb}}(t)-v_{\text{cg}}(t)+V_{\text{in}}+n\,V_o)+n\,L_r\,V_o}{2\,(L_m+L_r)}$
$L_m/L_r \approx \infty$	$\frac{1}{2}\,(-v_{\text{cb}}(t) + v_{\text{cg}}(t) - V_{\text{in}} + n\,V_o)$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cg}}(t) - V_{\text{in}} + n\,V_o)$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cg}}(t) + V_{\text{in}} - n\,V_o)$	$\frac{1}{2}\,(-v_{\text{cb}}(t) + v_{\text{cg}}(t) - V_{\text{in}} - n\,V_o)$
$nV_o \approx V_{in}$ $L_m/L_r \approx \infty$	$\frac{1}{2}\,(v_{\text{cg}}(t) - v_{\text{cb}}(t))$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cg}}(t))$	$\frac{1}{2}\,(v_{\text{cb}}(t) - v_{\text{cg}}(t))$	$\frac{1}{2}\,(-v_{\text{cb}}(t) + v_{\text{cg}}(t) - 2\,n\,V_o)$

Below Resonant Magnetizing Voltage Solutions

$nV_o \approx V_{in}$

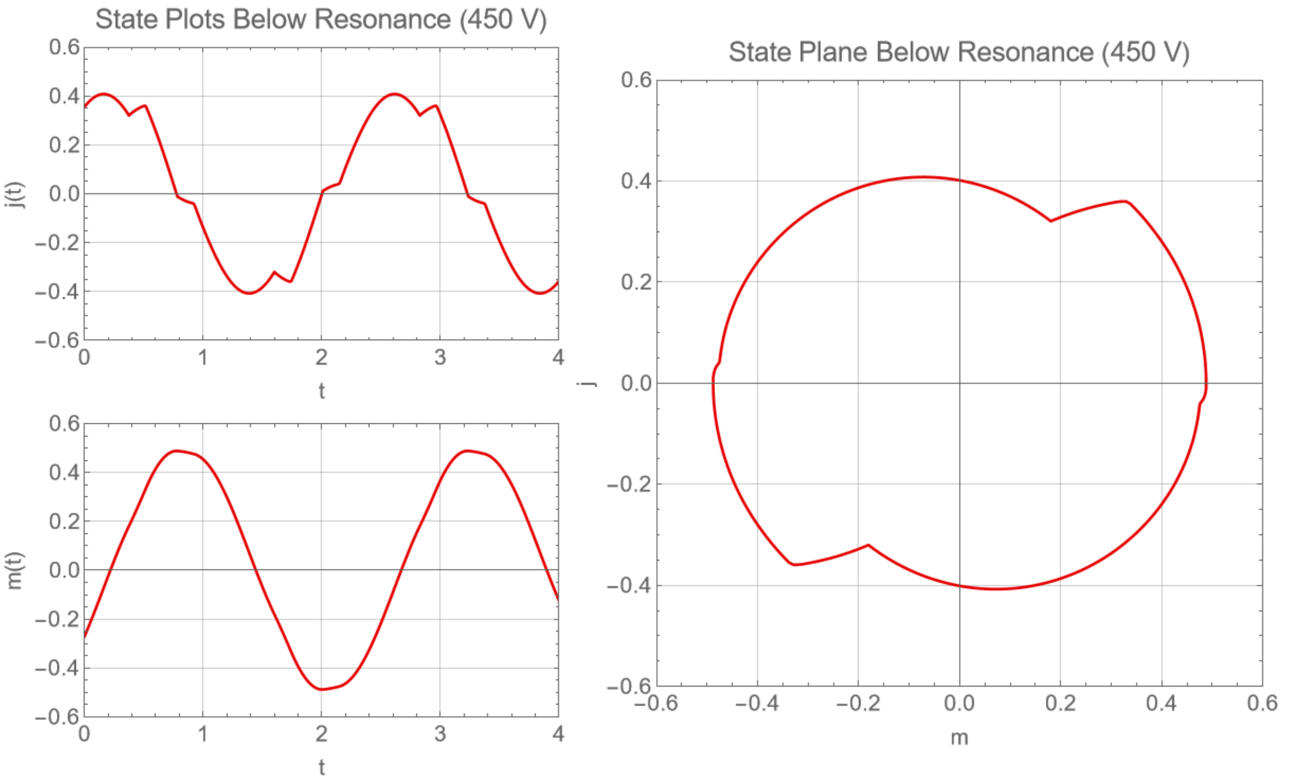
$L_m/L_r \approx \infty$

$v_{lm,1}(t)$	$\frac{1}{2}\left(\frac{t\left(I_{lr,0}-I_{lb,0}\right)}{C_r} - V_{cb,0} + V_{cr,0}\right)$
$v_{lm,2}(t)$	$\frac{1}{2}\left(\frac{t\left(I_{lg,0}-I_{lr,0}\right)}{C_r} + V_{cg,0} - V_{cr,0}\right)$
$v_{lm,3}(t)$	$\frac{1}{2}\left(\frac{t\left(I_{lb,0}-I_{lg,0}\right)}{C_r} + V_{cb,0} - V_{cg,0}\right)$

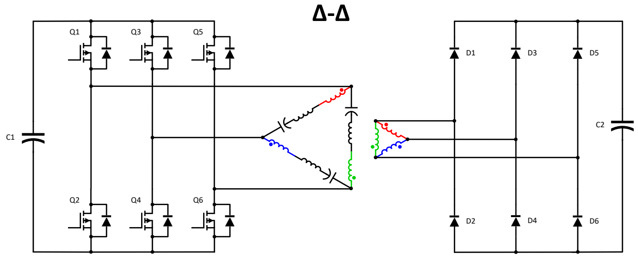


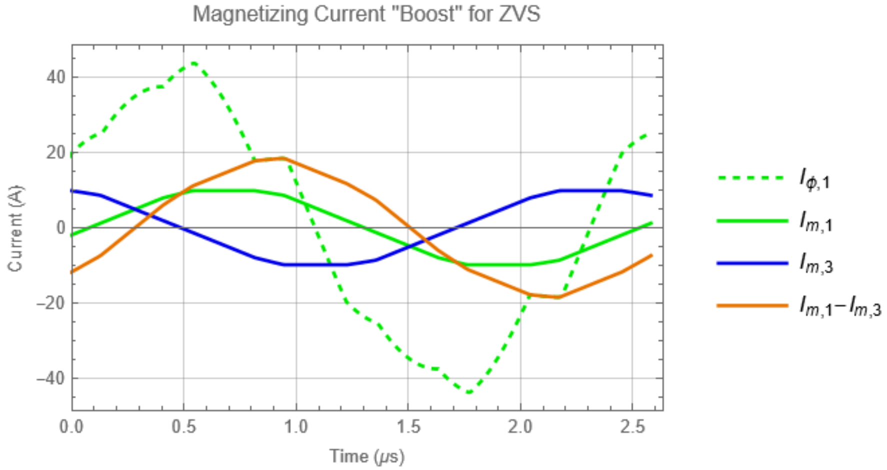
	Exact	$nV_o \approx V_{in}$	$L_m/L_r \approx \infty$	$nV_o \approx V_{in}$, $L_m/L_r \approx \infty$
$v_{lm,1}(t)$	$\frac{1}{2}\left(\frac{L_m\left(\left(V_{cr,0}-V_{cb,0}\right)\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)+V_{in}\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)-nV_o\right)-nL_rV_o}{L_m+L_r}+\frac{L_m\left(I_{lr,0}-I_{lb,0}\right)\sin\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{\sqrt{C_r}\sqrt{L_m+L_r}}\right)$	$\frac{1}{2}\left(\frac{L_m\left(-V_{cb,0}+V_{cr,0}+nV_o\right)\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{L_m+L_r}+\frac{L_m\left(I_{lr,0}-I_{lb,0}\right)\sin\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{\sqrt{C_r(L_m+L_r)}}-nV_o\right)$	$\frac{t\left(I_{lr,0}-I_{lb,0}\right)}{C_r} - V_{cb,0} + V_{cr,0} + V_{in} - nV_o$	$\frac{1}{2}\left(\frac{t\left(I_{lr,0}-I_{lb,0}\right)}{C_r} - V_{cb,0} + V_{cr,0}\right)$
$v_{lm,2}(t)$	$\frac{1}{2}\left(\frac{L_m\left(\left(V_{cg,0}-V_{cr,0}\right)\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)+V_{in}\left(-\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)\right)+nV_o\right)+nL_rV_o}{L_m+L_r}+\frac{L_m\left(I_{lg,0}-I_{lr,0}\right)\sin\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{\sqrt{C_r}\sqrt{L_m+L_r}}\right)$	$\frac{1}{2}\left(-\frac{L_m\left(-V_{cg,0}+V_{cr,0}+nV_o\right)\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{L_m+L_r}+\frac{L_m\left(I_{lg,0}-I_{lr,0}\right)\sin\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{\sqrt{C_r(L_m+L_r)}}+nV_o\right)$	$\frac{t\left(I_{lg,0}-I_{lr,0}\right)}{C_r} + V_{cg,0} - V_{cr,0} - V_{in} + nV_o$	$\frac{1}{2}\left(\frac{t\left(I_{lg,0}-I_{lr,0}\right)}{C_r} + V_{cg,0} - V_{cr,0}\right)$
$v_{lm,3}(t)$	$\frac{1}{2}\left(\frac{L_m\left(\left(V_{cb,0}-V_{cg,0}\right)\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)+V_{in}\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)-nV_o\right)-nL_rV_o}{L_m+L_r}+\frac{L_m\left(I_{lb,0}-I_{lg,0}\right)\sin\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{\sqrt{C_r}\sqrt{L_m+L_r}}\right)$	$\frac{1}{2}\left(\frac{L_m\left(V_{cb,0}-V_{cg,0}+nV_o\right)\cos\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{L_m+L_r}+\frac{L_m\left(I_{lb,0}-I_{lg,0}\right)\sin\left(\frac{t}{\sqrt{C_r(L_m+L_r)}}\right)}{\sqrt{C_r(L_m+L_r)}}-nV_o\right)$	$\frac{t\left(I_{lb,0}-I_{lg,0}\right)}{C_r} + V_{cb,0} - V_{cg,0} + V_{in} - nV_o$	$\frac{1}{2}\left(\frac{t\left(I_{lb,0}-I_{lg,0}\right)}{C_r} + V_{cb,0} - V_{cg,0}\right)$

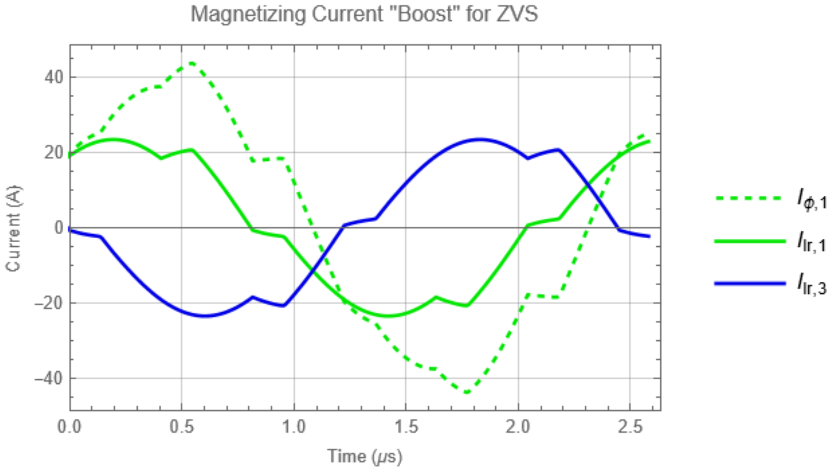
State Plane Below Resonance



ZVS Advantage







Secondary Currents