Motor Drive Dynamic System Model

Thermal Transient, Electronics, Controls

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Summary

A Dynamic (Time Domain) Simplorer Model of a Motor Drive:

- Electrical System Model
  - Power Circuit
  - Motor
  - Controls
- Transient Thermal Model
- Simulation Results

Purpose:

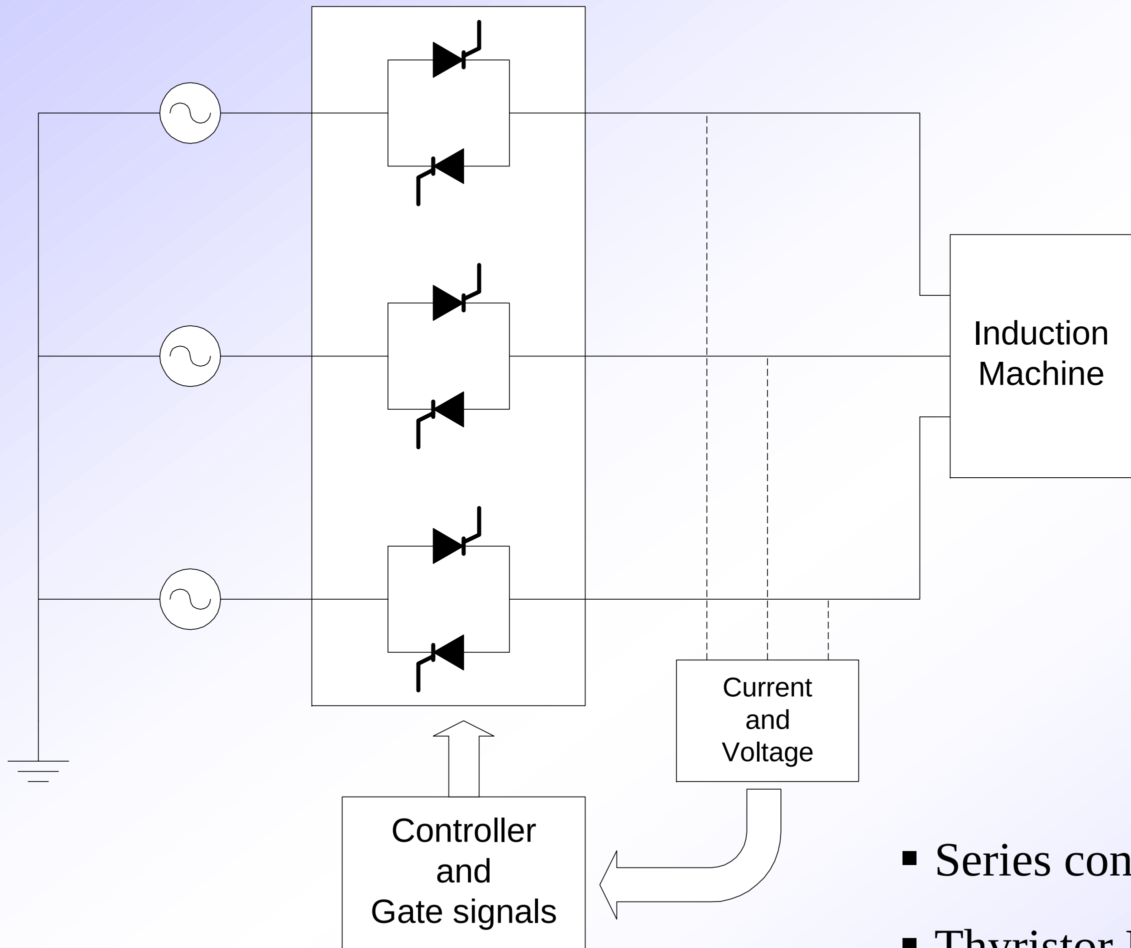
- Simulate Transient Thermal Performance
- Determine Transient Ratings for the Motor Drive

Electrical System Model

- Power Circuit Diagram
- Motor Model
- Control Model
- Verification

Power Circuit Diagram

Soft Start is a Reduced Voltage method of Starting Induction Machines



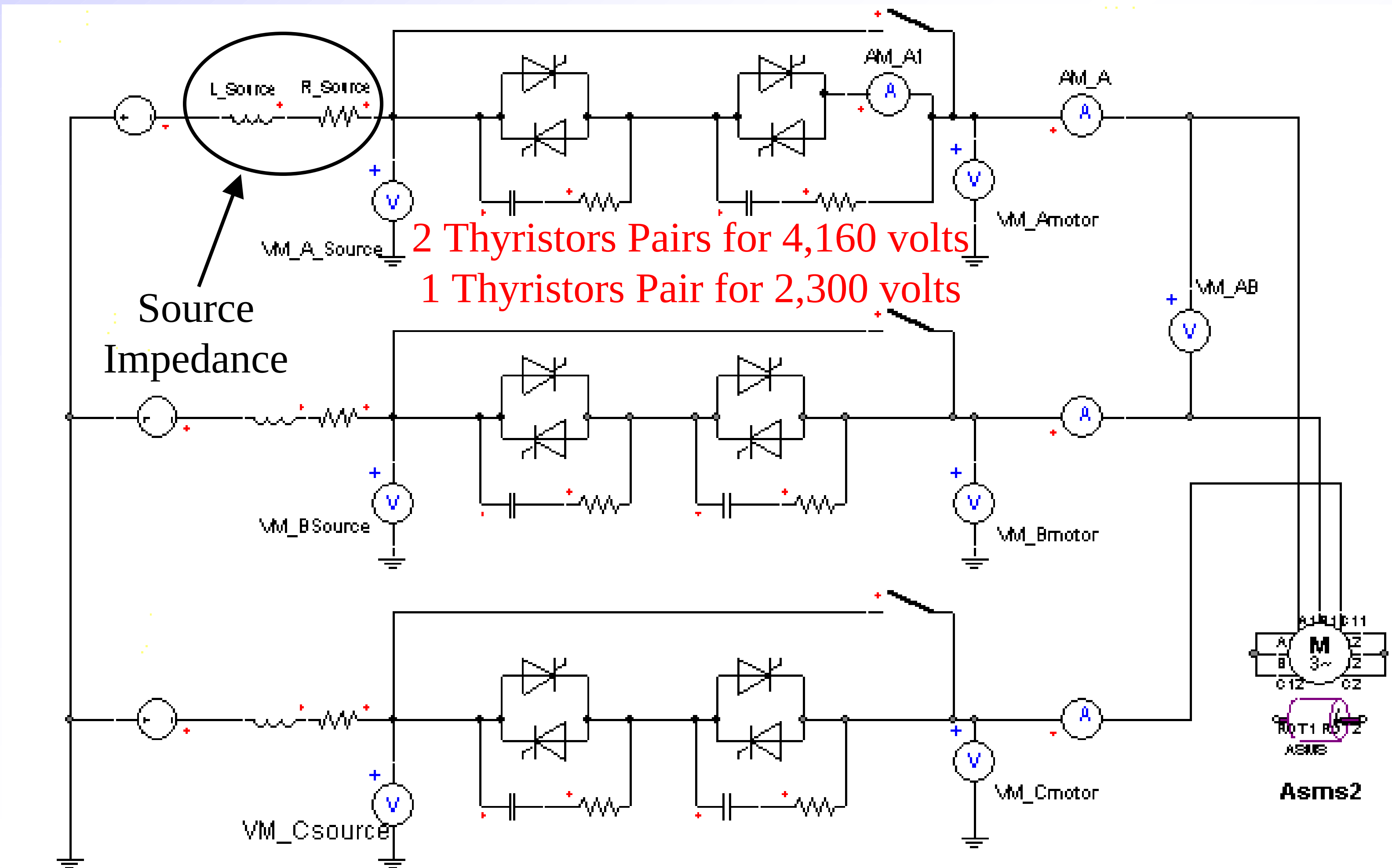
- Series connected back-to-back Thyristors
- Thyristor Pairs are Fired based on Current Zero
- The Firing Angle Profile is User Defined

Overall Power Circuit

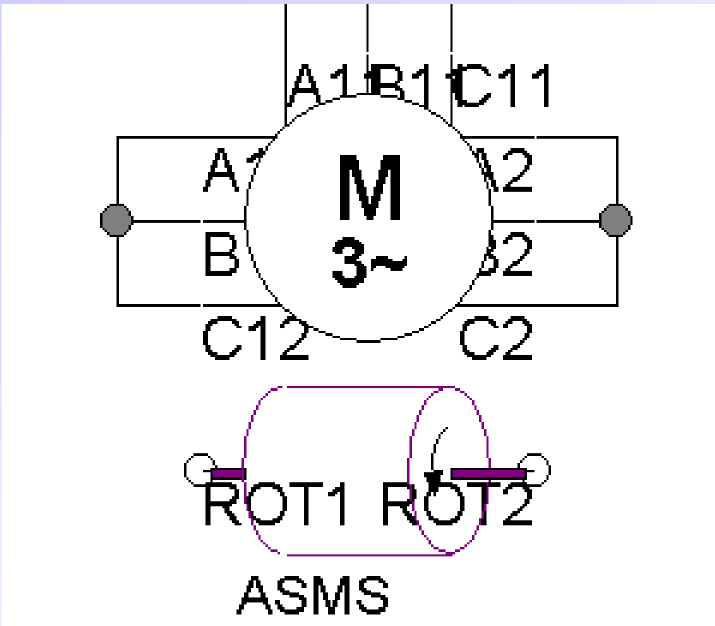
Bypass Contactor

Closes after the Motor is up to Speed

(Sensed by Thyristor Voltage, which typically Drops below Line Voltage)



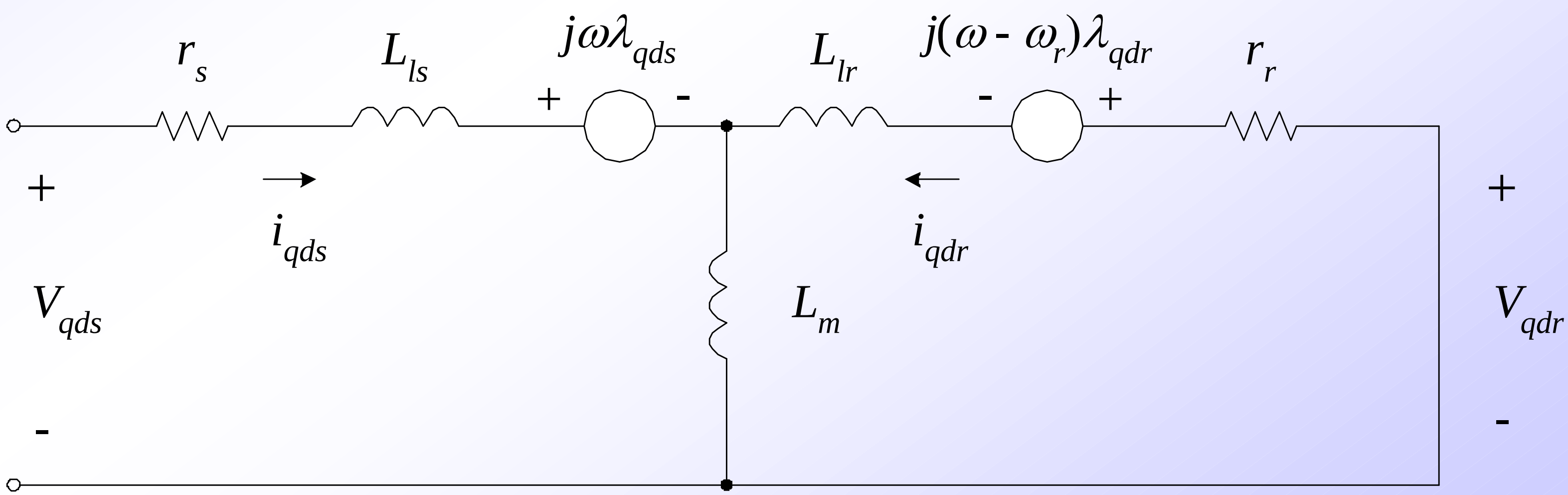
Induction Motor Model



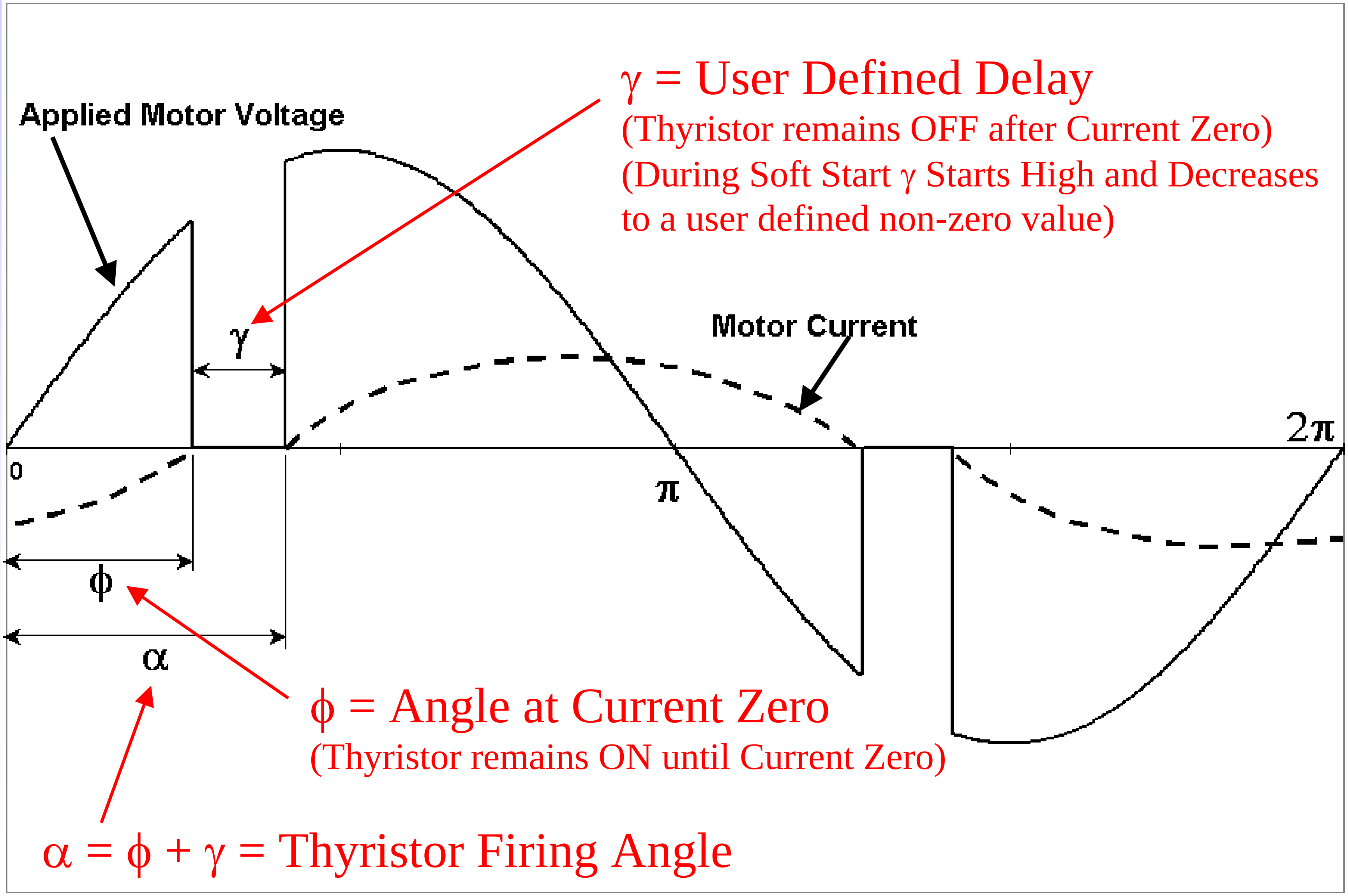
1000 hp, 4160 V, 60 Hz, 4-pole Motor Parameters

$r_s = 0.348\ \Omega$ $r_r = 0.348\ \Omega$ $L_{ls} = 4.613$ mH

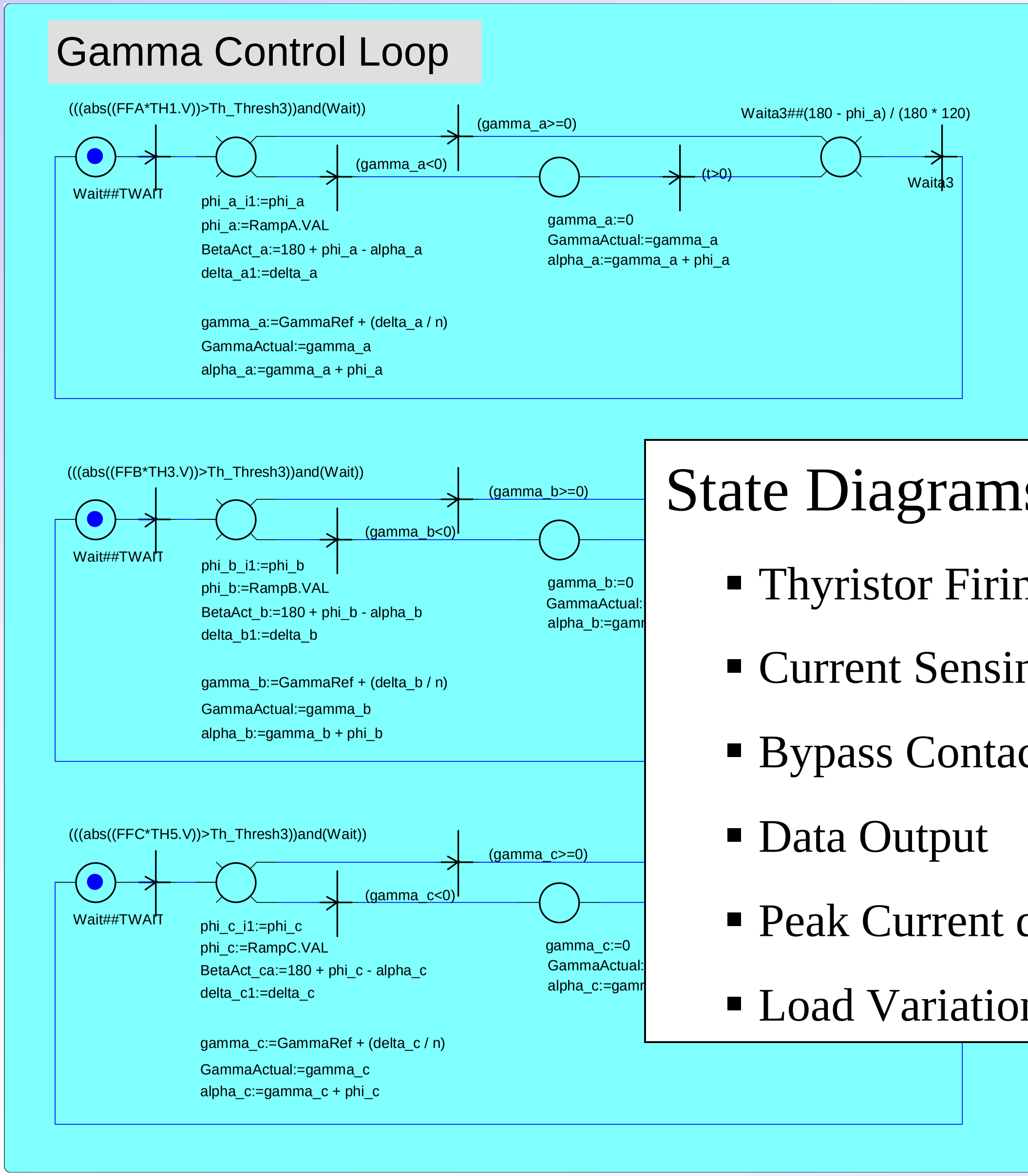
$L_{lr} = 4.613$ mH $L_m = 246$ mH $J = 31.4$ kg-m²

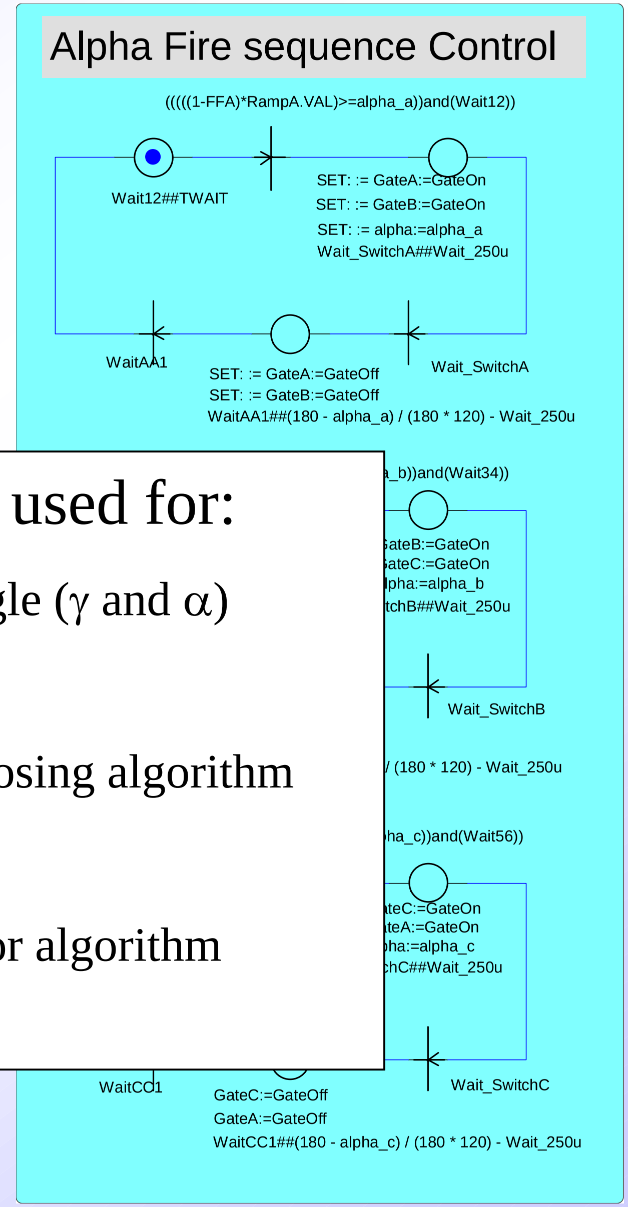


Firing Angle Control



Control Algorithms - State Diagrams

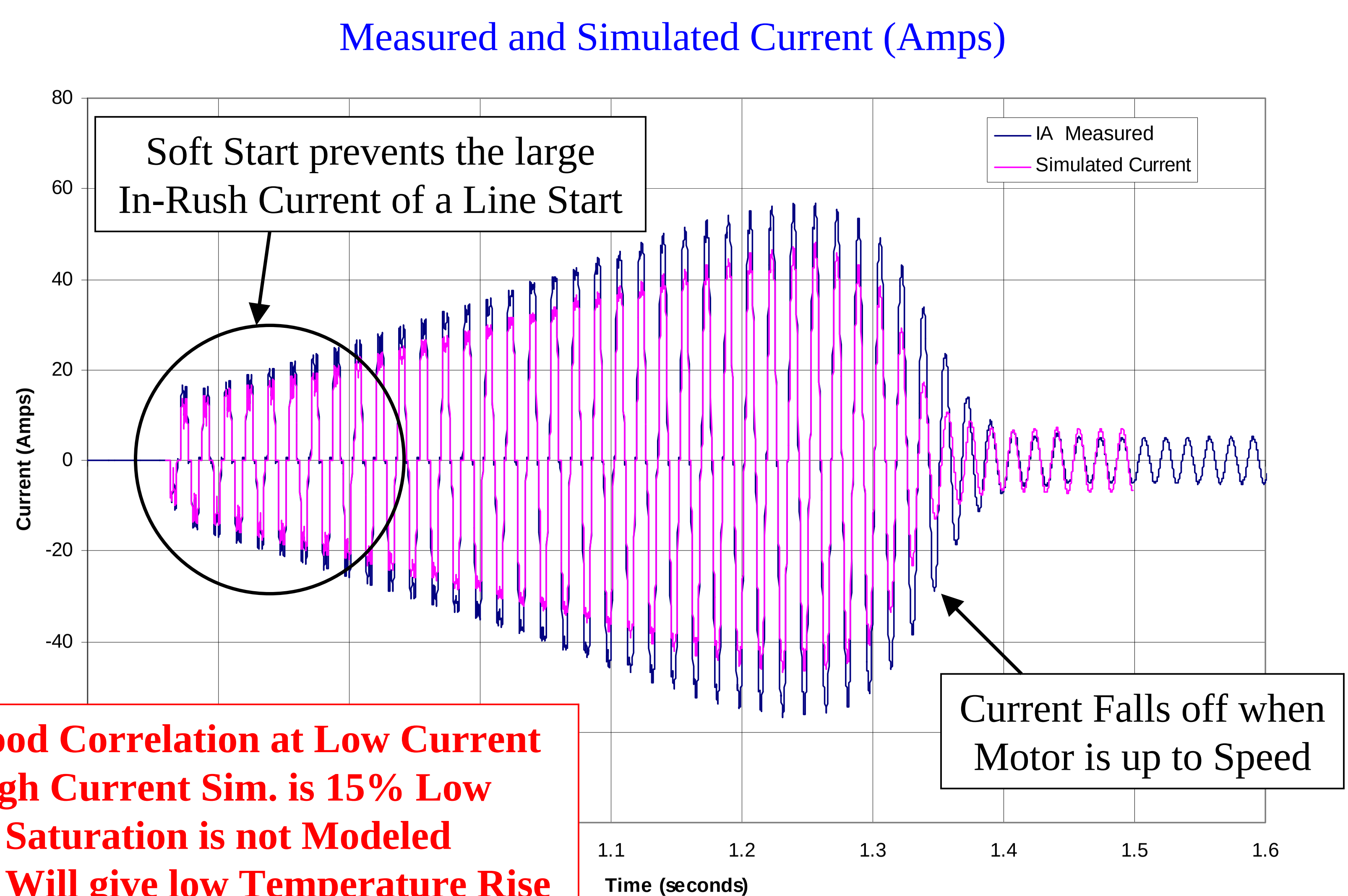




State Diagrams are used for:

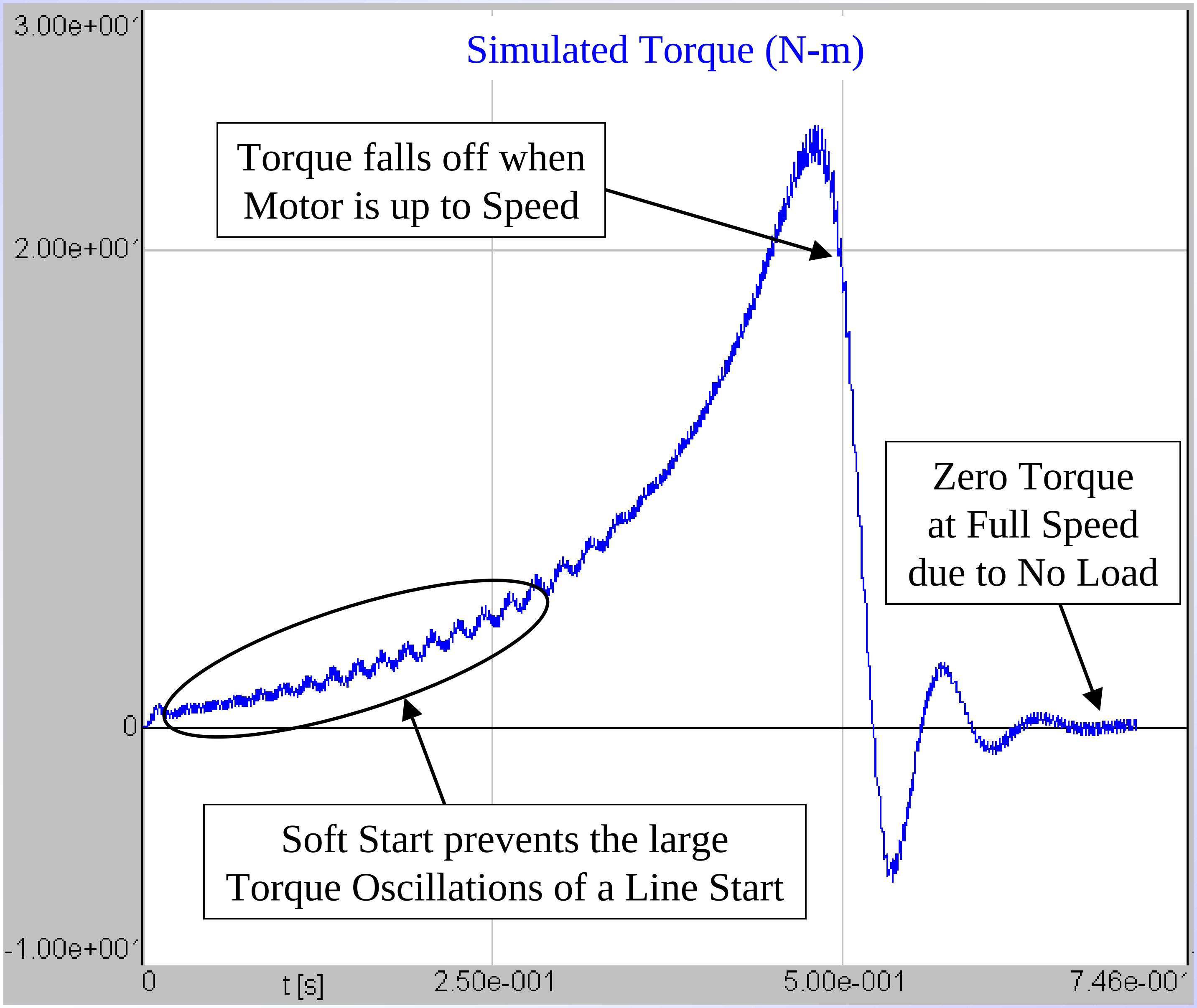
- Thyristor Firing Angle (γ and α)
- Current Sensing
- Bypass Contactor closing algorithm
- Data Output
- Peak Current detector algorithm
- Load Variations

Results - 5 Horsepower Motor (No Load)



- **Good Correlation at Low Current**
- **High Current Sim. is 15% Low**
  - **Saturation is not Modeled**
  - **Will give low Temperature Rise**

Results - 5 Horsepower Motor (No Load)



Transient Thermal Model

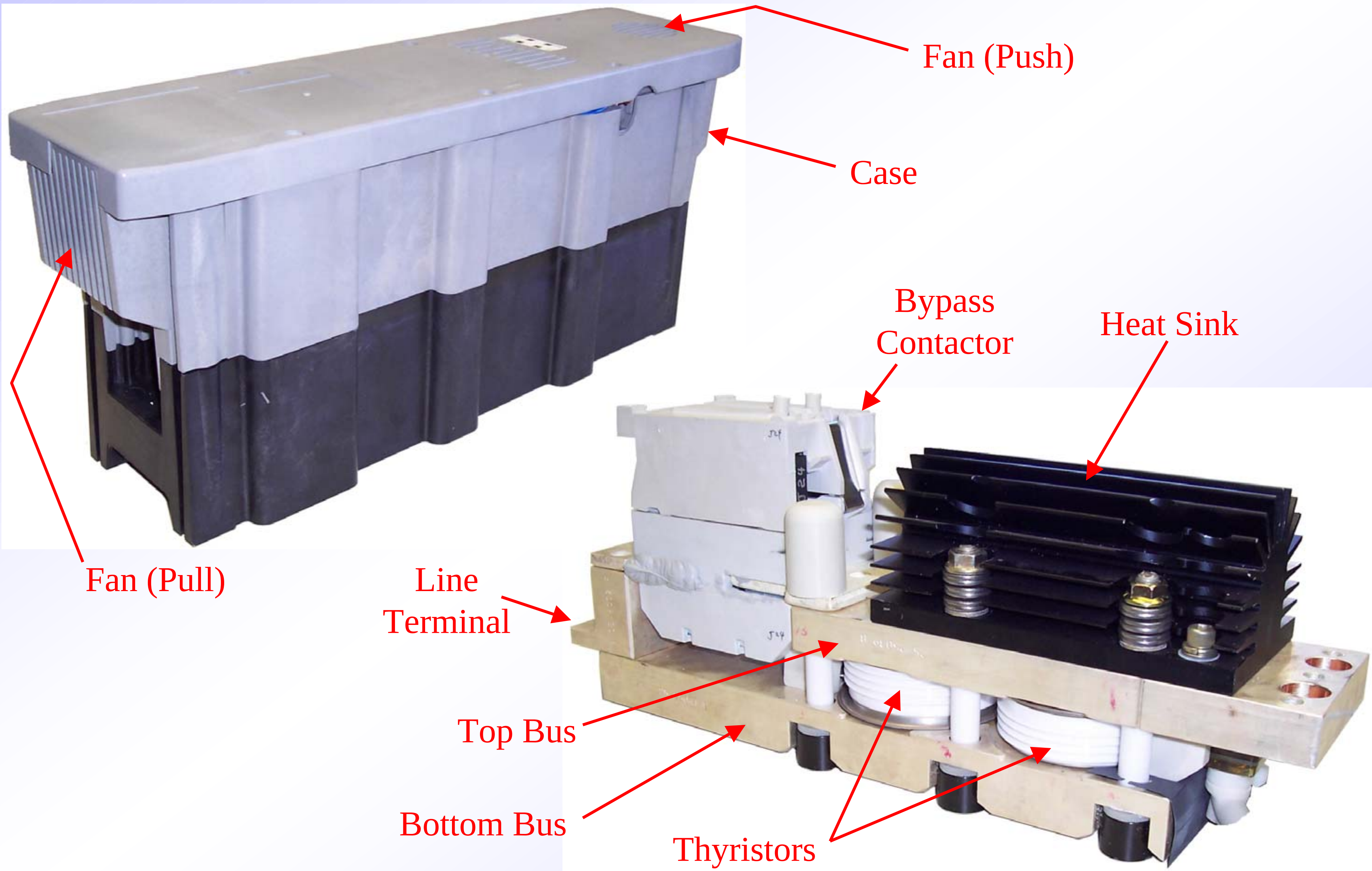
- Electrical Analogy for Heat Transfer
  - Thermal Resistance
  - Thermal Capacitance

- Thermal Resistance - Heat Transfer
  - Conduction
  - Contact Interface
  - Convection
  - Radiation
  - Air Flow

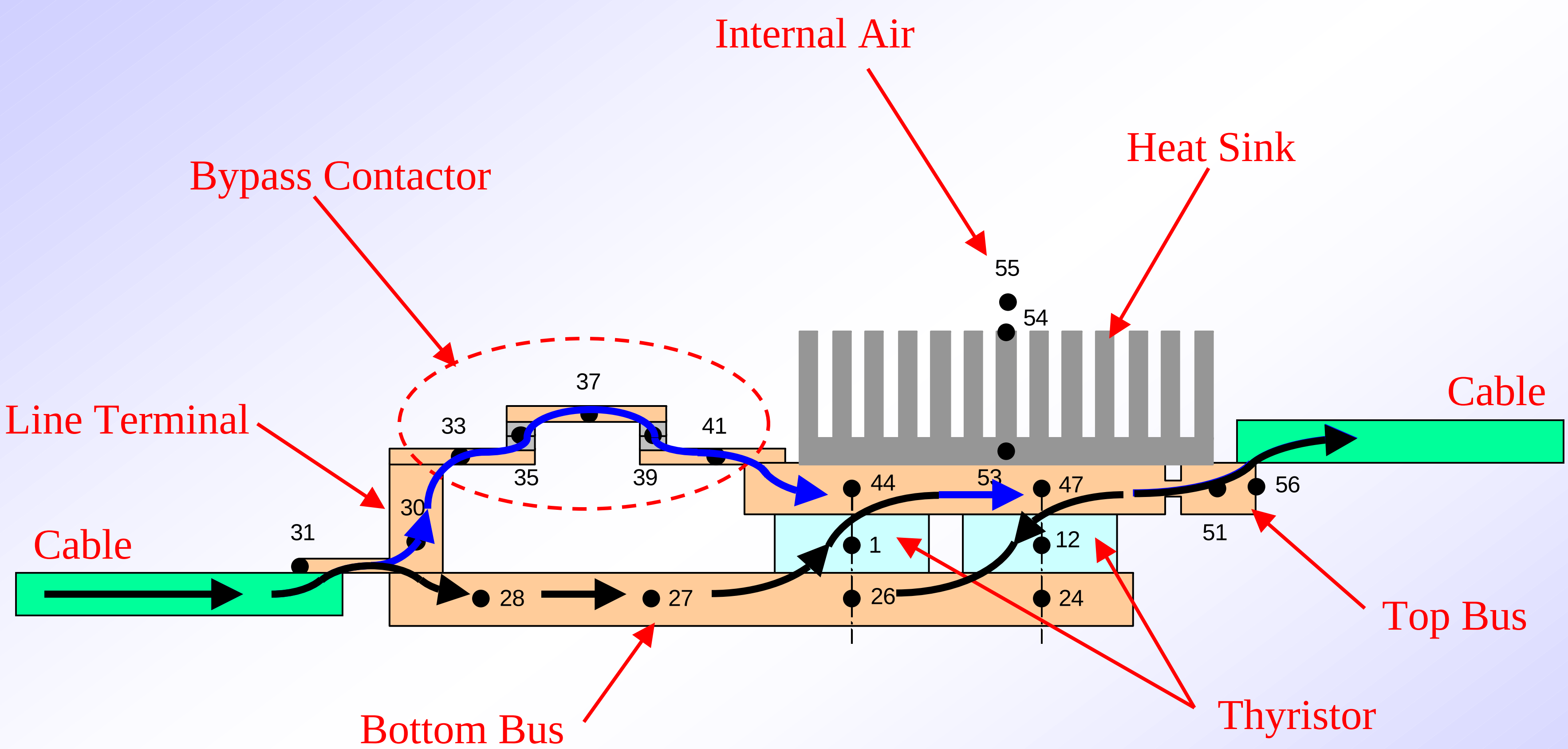
- Thyristor - Transient Thermal Model

- Overall Motor Drive - Transient Thermal Model

Soft Starter (one pole)

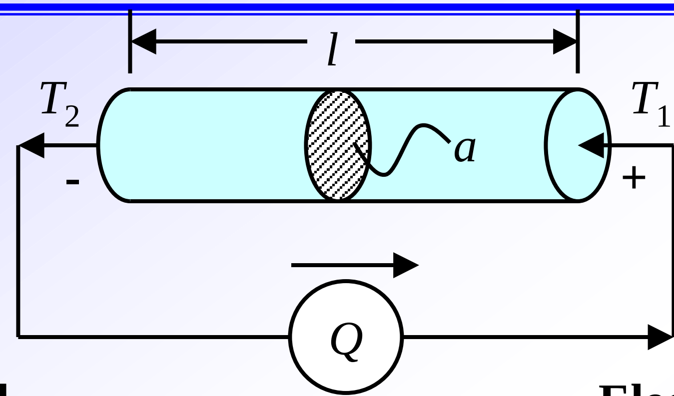


Physical Schematic for Thermal Model



Configuration		Soft Start	Full Speed
• Bypass Contactor	=	Open	Closed
• Current through	=	Thyristors	Bypass Contactor

Thermal Model - Electrical Analogy



	Thermal	**Electrical**
Ohm's Law:	$\Delta T = Q\, R_k$	$\Delta V = I\, R_e$
Conduction Resistance:	$R_k = \dfrac{\Delta T}{Q} = \dfrac{l}{k\, a}$	$R_e = \dfrac{\Delta V}{I} = \dfrac{l}{\sigma\, a}$
Capacitance:	$Q = C_T \dfrac{dT}{dt}$	$I = C_e \dfrac{dV}{dt}$

Equivalent Terminologies:

Thermal	Electrical
ΔT = Temperature Drop (°C)	ΔV = Voltage Drop (volt)
Q = $I^2 R_e$ = Heat Source (watt)	I = Current Source (amp)
R_k = Resistance (°C/w)	R_e = Resistance (ohm)
C_T = $m\, c_p$ = Capacitance (J/°C)	C_e = Capacitance (farad)
k = Conductivity (w/m-°C)	σ = Conductivity (1/ohm-m)
m = Mass (kg)	
c_p = Specific Heat (J/kg-°C)	

Thermal Resistance

Contact Interface:

$R_S = \frac{1}{2 k r_s}$ Solid Contact Spot

$R_V = \frac{l_V}{k_V a_V}$ Voids between Surfaces

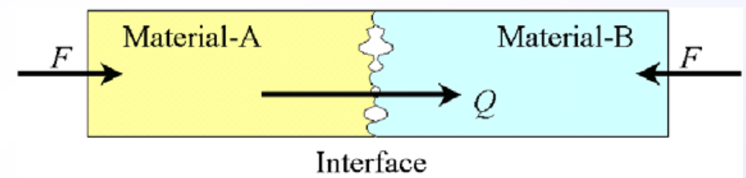
$R_I = \frac{1}{1/R_S + 1/R_V}$ Total

$r_s = \sqrt{\frac{F}{\pi g H}}$ Radius of Contact Spot

F = Force (N)

H = Hardness (kg/mm^2)

g = gravity (9.8 m/s^2)



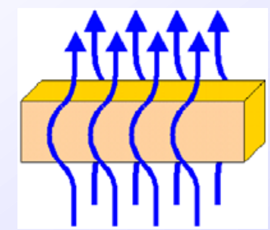
Convection:

$R_c = \frac{1}{h_c a}$

Typical Convection Heat Transfer Coefficient

$h_c = 5$ w/m^2 °C … Natural Convection for Air

$h_c = 12$ w/m^2 °C … Forced Convection For Air

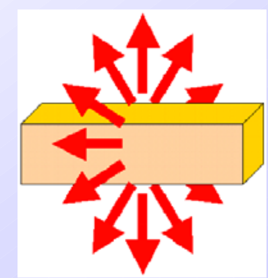


Radiation:

$R_r = \frac{1}{h_r a}$

Typical Radiation Heat Transfer Coefficient

$h_r = 6$ w/m^2 °C … for Electronic Systems



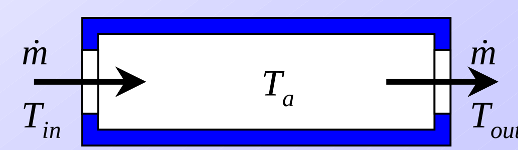
Air Flow:

$R_a = \frac{1}{2 \dot{m} c_p}$

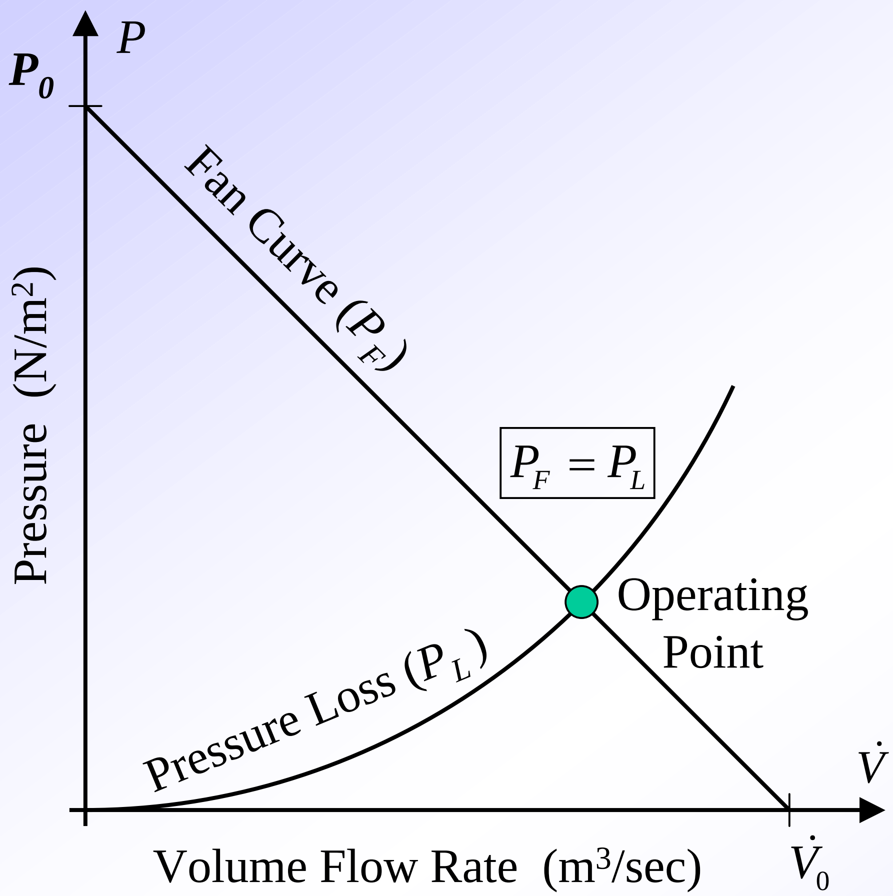
$\Delta T_a = Q R_a$ … Ave. Temperature Rise of Air Flow

$\dot{m}$ = Air Mass Flow Rate (kg/s)

c_p = Specific Heat of Air



Air Flow



Fan Curve:

$$P_F = P_0 - \frac{P_0}{\dot{V}_0}\dot{V} = P_0 - \frac{P_0}{\dot{m}_0}\dot{m}$$

Pressure Loss across Vents and Turns:

$$P_L = C_L \frac{\rho u^2}{2} = C_L \frac{\dot{m}^2}{2\rho A^2} = \frac{\dot{m}^2}{2} \sum \frac{C_L}{\rho A^2}$$

u = Air Velocity (m/s)

ρ = Air Density (kg/m^3)

$\dot{m}$ = Air Mass Flow Rate (kg/s)

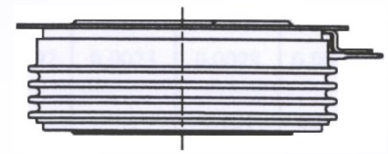
A = Air Path Cross Sectional Area (m^2)

C_L = Loss Coefficient

Sudden Contraction:	$C_L = 0.5$
Sudden Expansion:	$C_L = 1.0$
90° Turn:	$C_L = 1.5$

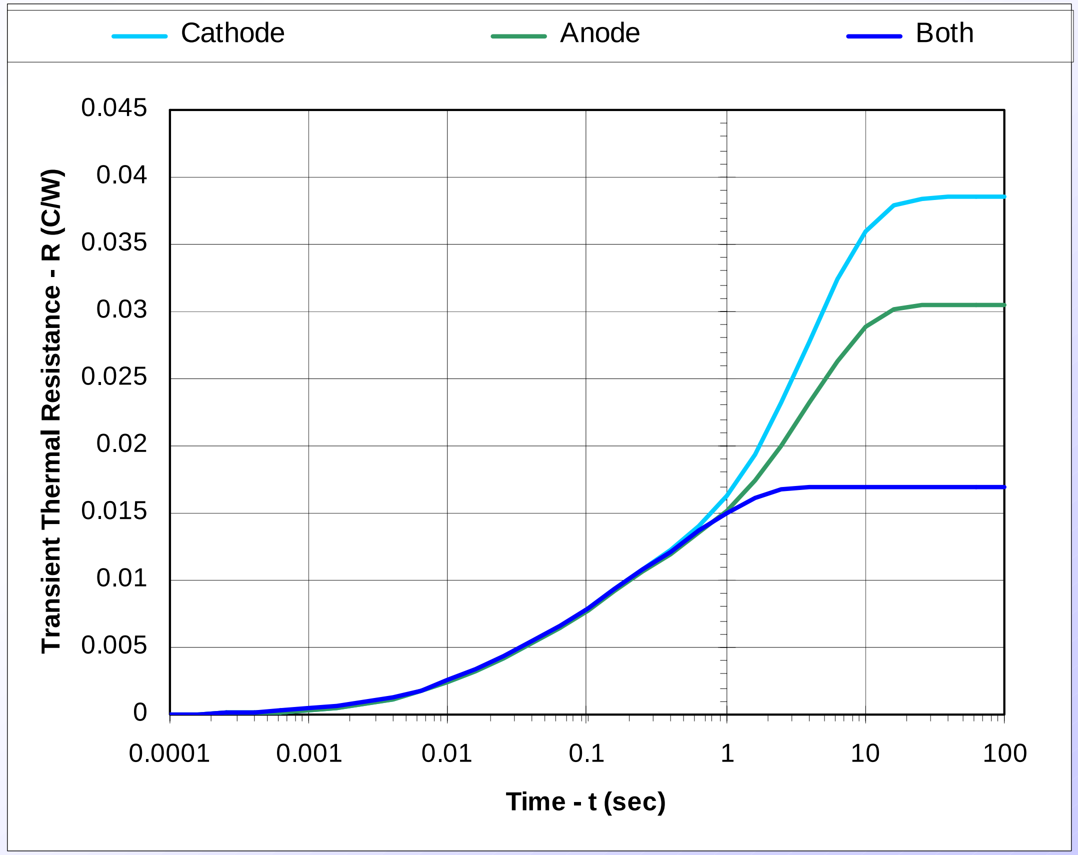
Thyristor - Data Sheet

		Values from the T-501N data sheet				
Both Sides		1	2	3	4	5
Ri	C/w	0.00033	0.00272	0.00304	0.00243	0.00848
TCi	s	0.0019	0.0134	0.062	0.132	0.676
Anode Side		1	2	3	4	5
Ri	C/w	0.0192	0.0023	0.0028	0.00366	0.00254
TCi	s	4.13	0.4	0.154	0.0607	0.0101
Cathode Side		1	2	3	4	5
Ri	C/w	0.0281	0.00106	0.00487	0.00237	0.0021
TCi	s	4.13	0.45	0.126	0.0374	0.0091



$$R = \sum_{i=1}^{5} R_i \left(1 - e^{-t/TC_i}\right)$$

Transient Thermal Resistance



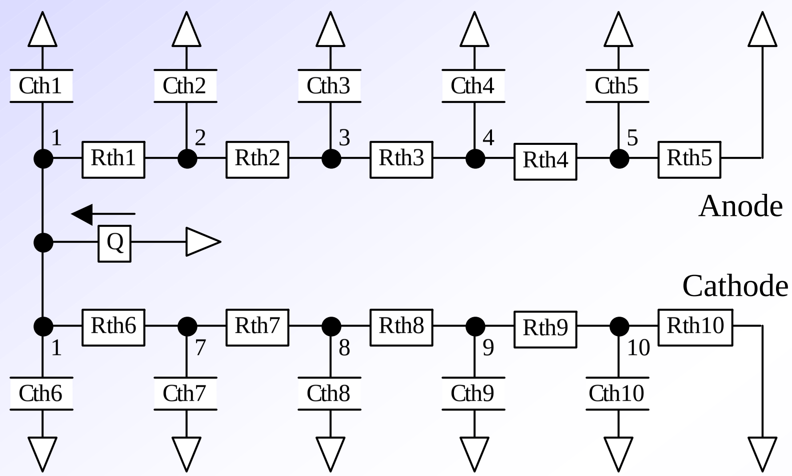
Valid only when the Thyristor is continuously "ON".

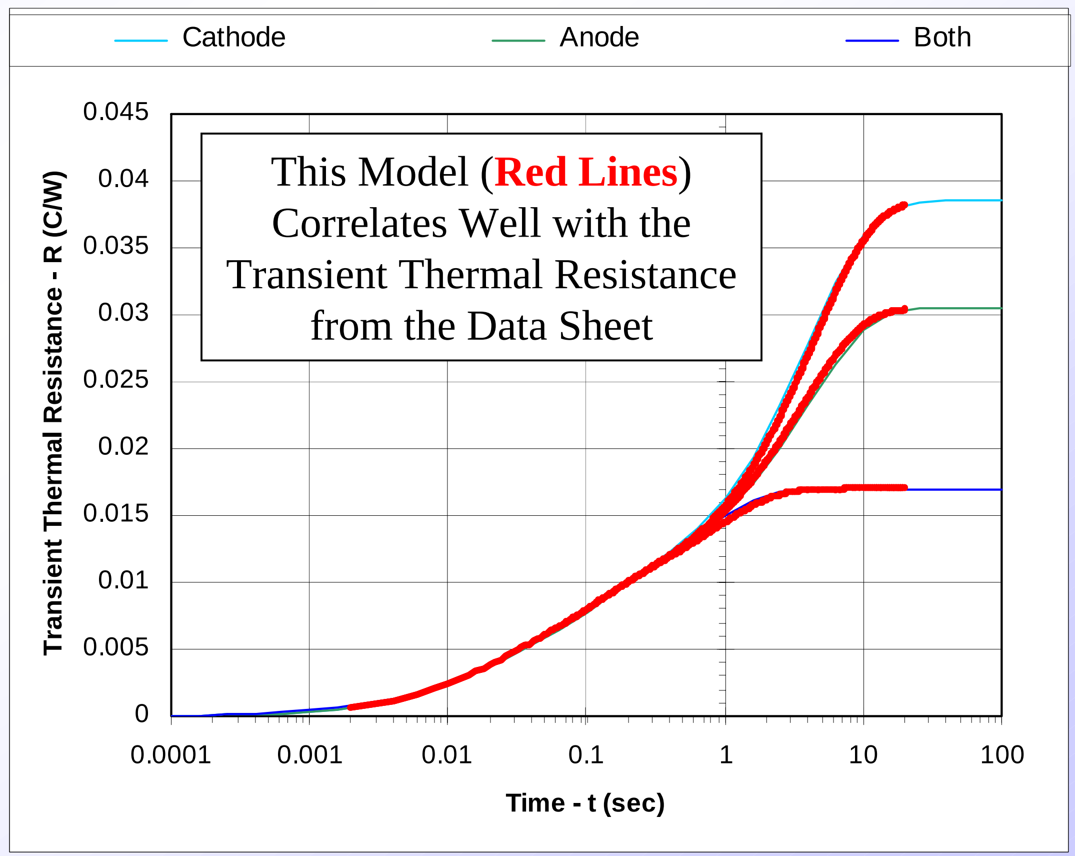
NOT Valid when the Thyristor is switched "ON" and "OFF" repeatedly.

Thyristor - Thermal Model

		R-C Network - for the T501N - - Input Values				
Anode Side		**1**	**2**	**3**	**4**	**5**
Rth	C/w	**0.0015**	**0.004**	**0.005**	**0.01**	**0.01**
Cth	J/C	**1.28**	**0.2**	**0.3**	**10**	**60**
TCth	s	0.0019	0.0008	0.0015	0.1000	0.6000
Cathode Side		**6**	**7**	**8**	**9**	**10**
Rth	C/w	**0.0015**	**0.004**	**0.005**	**0.013**	**0.015**
Cth	J/C	**1.28**	**0.2**	**0.3**	**5**	**60**
TCth	s	0.0019	0.0008	0.0015	0.0650	0.9000

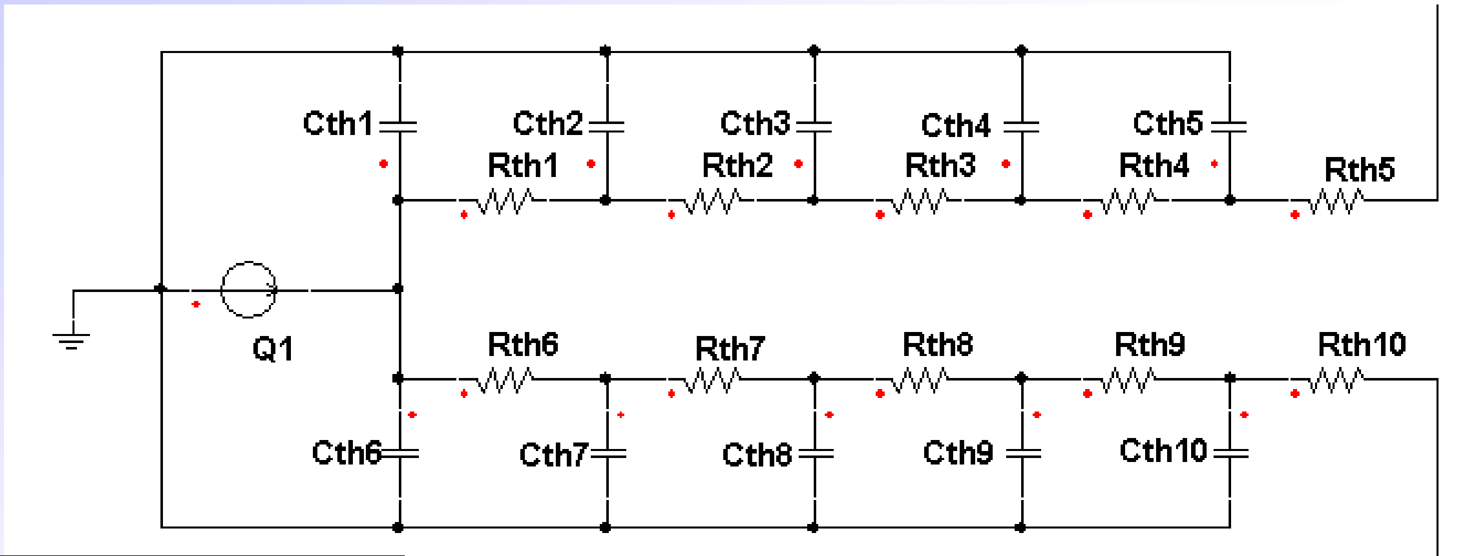
Thermal Resistance and Capacitance Model





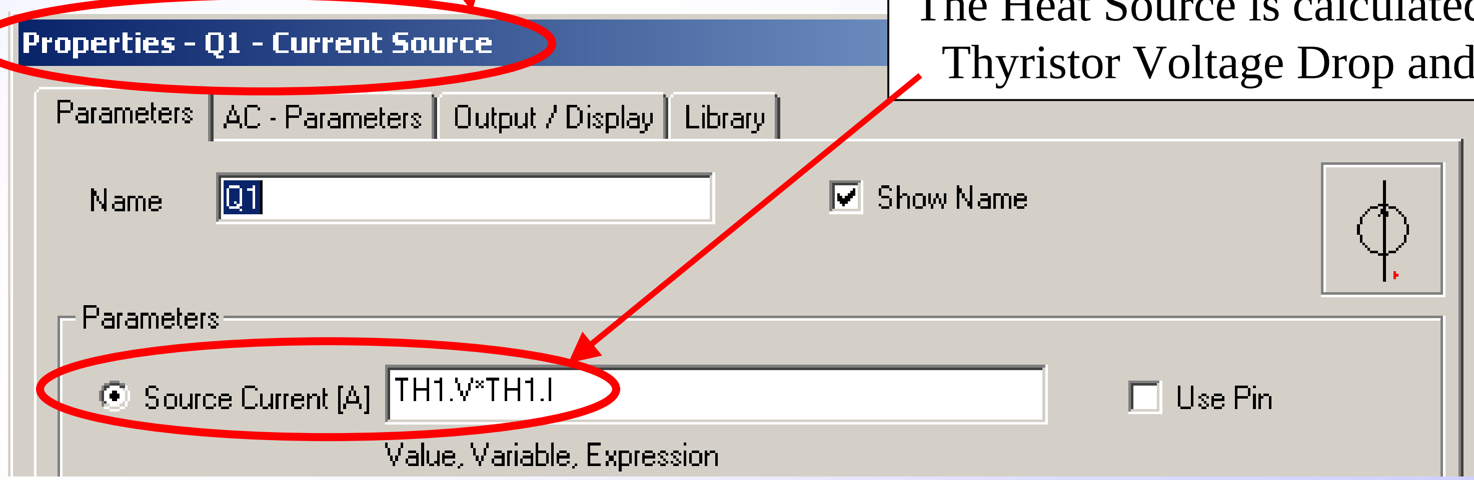
Valid for All Conditions including "ON / OFF" switching.

Thyristor Thermal Model in Simplorer

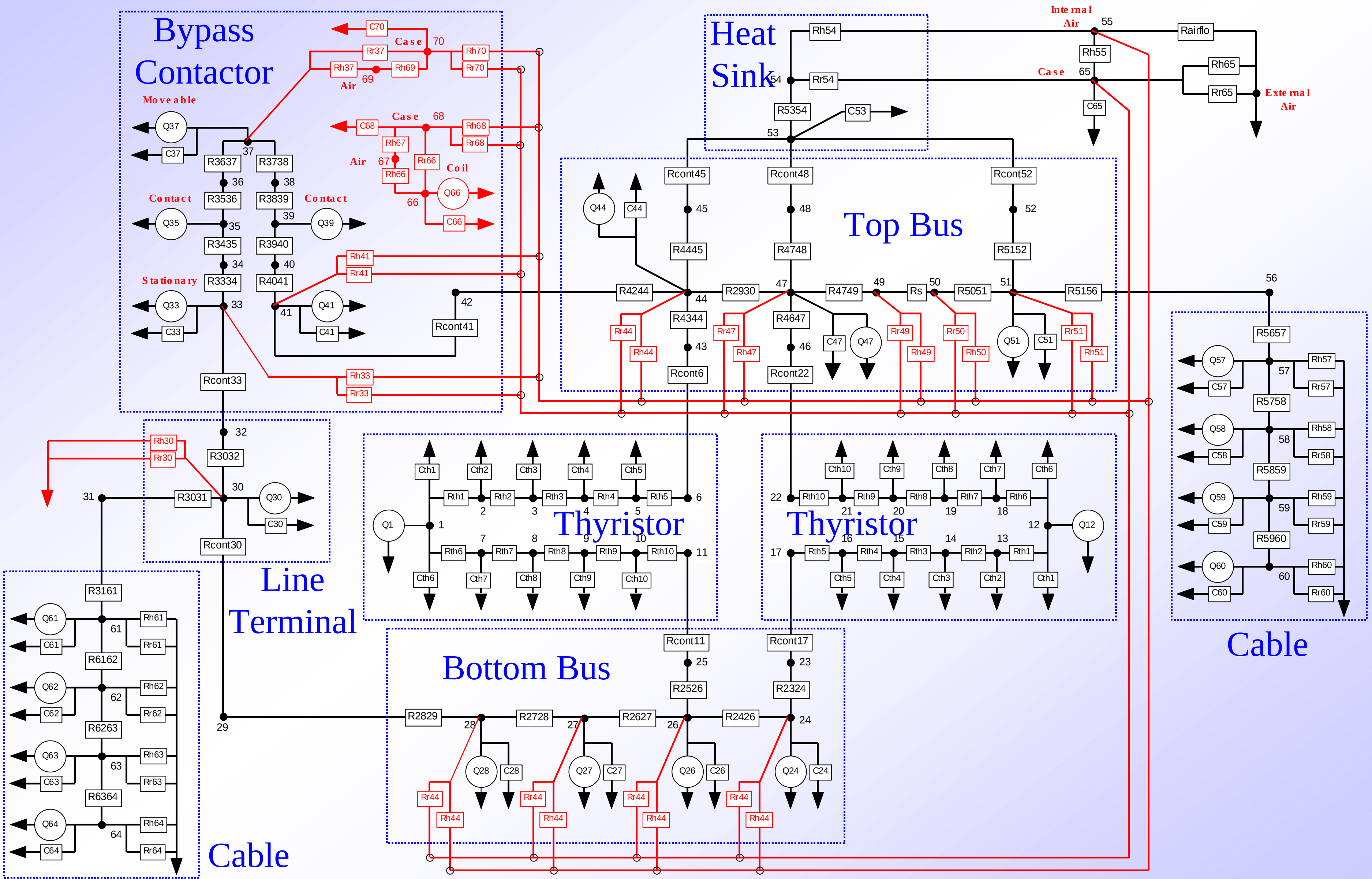


The Thyristor Heat Source is modeled as a Current Source

The Heat Source is calculated from the Thyristor Voltage Drop and Current



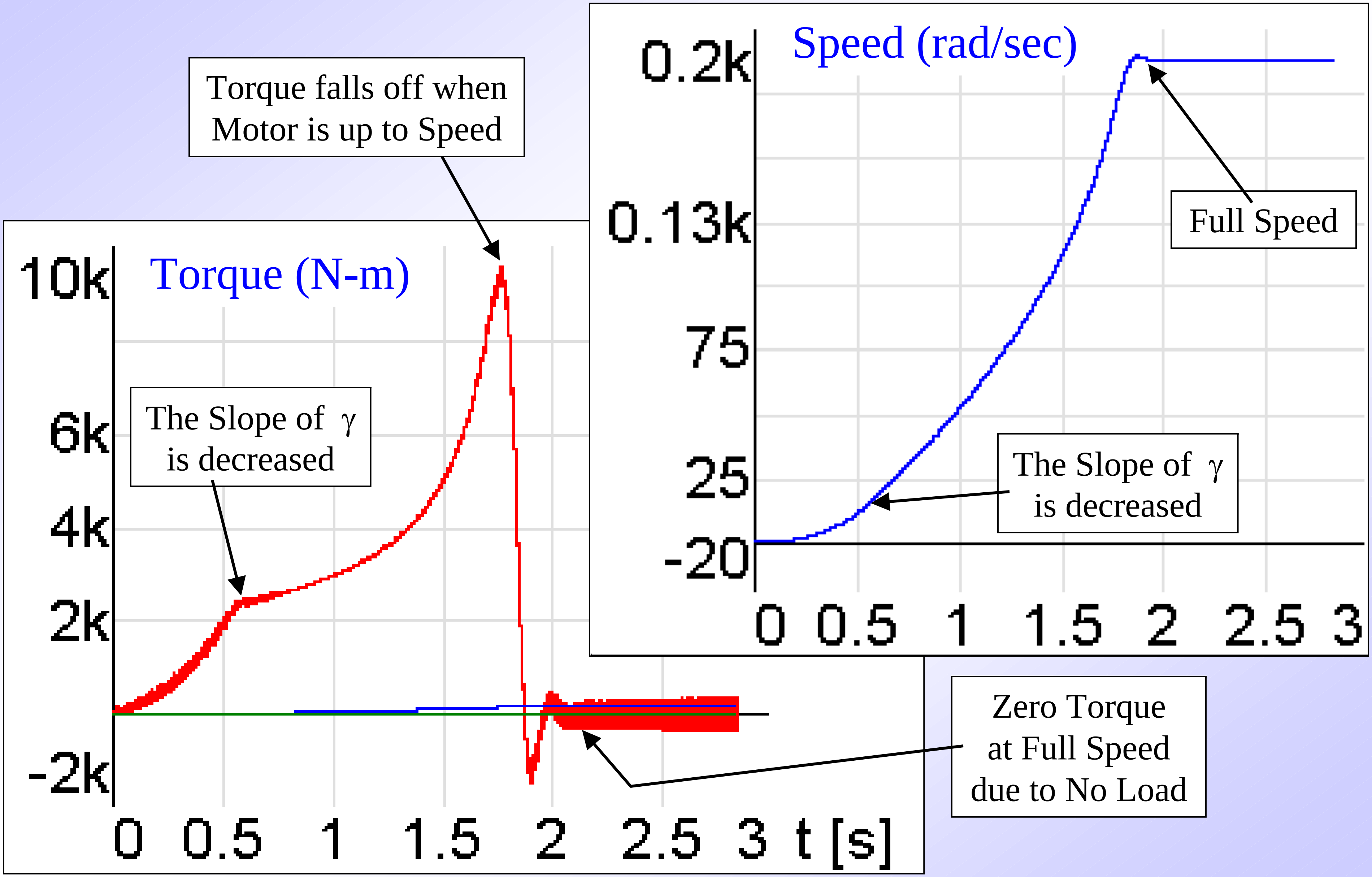
Soft Starter Thermal Model



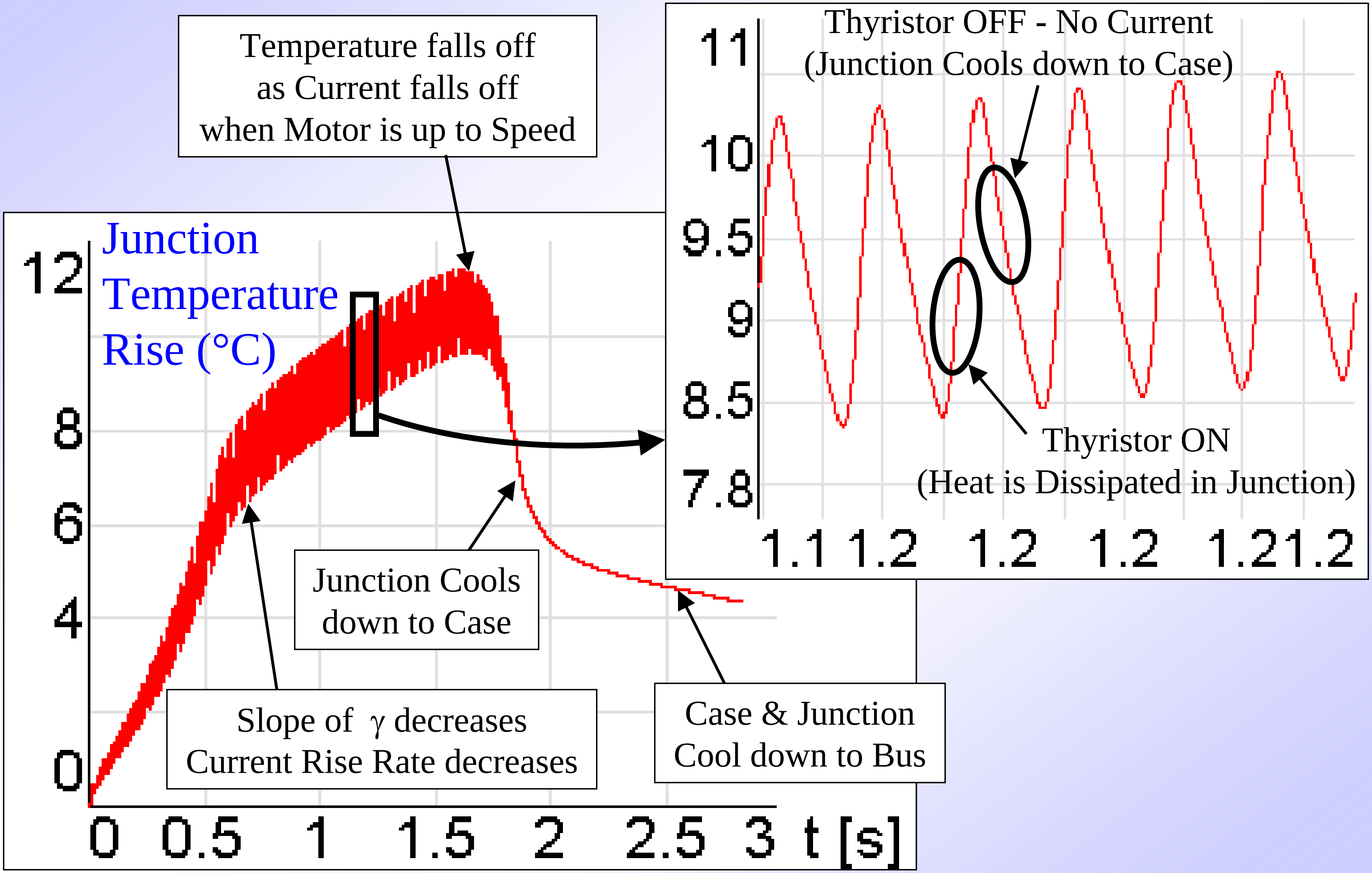
Simulation Results

- Current vs. Time
- Temperature vs. Time

Results - 1,000 Horsepower Motor (No Load)



Results - 1,000 Horsepower Motor (No Load)



Summary & Conclusions

Presented a Simplorer Dynamic Model of a Motor Drive:

- Electrical System Model
  - Power Circuit, Motor, Control
- Transient Thermal Model
  - Electrical Analogy, Thermal Resistance, Thermal Capacitance, Air Flow

Presented Simulation Results:

- Verification of the Electrical System Model
- Simulation Results for a 1000 Horsepower Motor
  - Transient Electrical & Transient Thermal Performance

Future Work:

- Verify the Transient Thermal Model against Tests
- Use this Model to determine the Transient Ratings of the Drive
  - Cycling: Start - Run - Stop …. Start - Run - Stop …. Start - Run - Stop
  - Different Motor & Load Combinations