

# SIMULATION OF TORSIONAL VIBRATION RESPONSE OF ENGINE GENSET DRIVELINE FOR SHORT CIRCUIT EVENT

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**NEW POWER**



**ENGINE**



**POWER SYSTEMS**

# Team Introduction



**Sachin S Kulkarni**

Dynamic Analysis-Technical Specialist

Cummins Technical Center India,  
Gandhi Bhavan Rd, Dahanukar Colony,  
Kothrud, Pune

Around 11 years of professional experience in engine Dynamics and powertrain design and analysis.  
Crankshaft and hydrodynamic bearing design expert at Cummins India  
Multidisciplinary optimization  
Torsional analysis

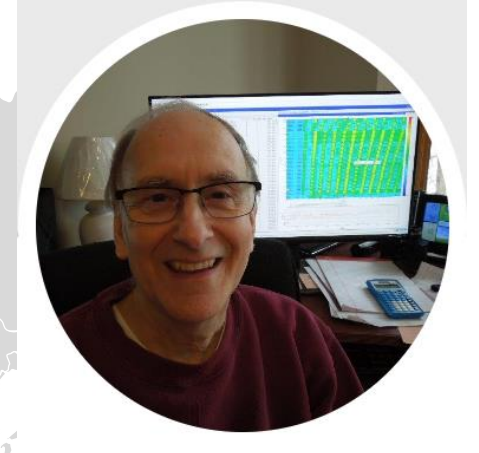


**Bibhu Mahanta**

Dynamic Analysis-Technical Advisor

Cummins Corporate R&T  
Cummins Tech Center, 1900 McKinley Ave, US, IN

Around 17 years of professional experience in engine Dynamics and powertrain design and analysis.  
Global torsional functional area leader  
Leading advanced Simulation capability development  
Global component owner for Vibration Dampers

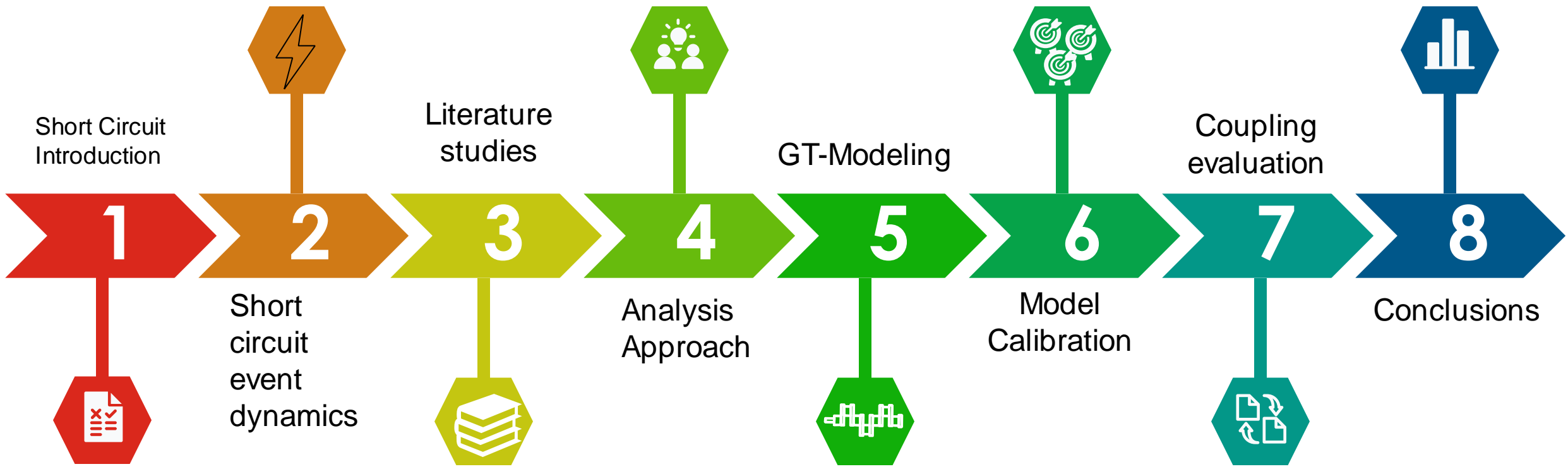


**Steve Seidlitz**

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Around 50 years of professional experience at Cummins  
Global genset testing leader



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- What is a short circuit event
- Types of Short Circuit events
- Short Circuit test at Cummins

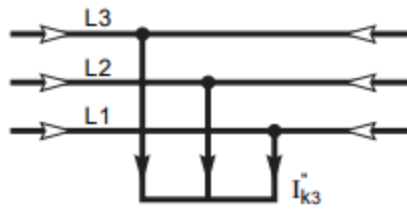
# Introduction

What is short circuit event ?

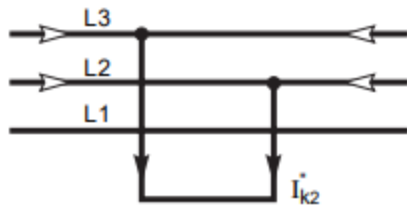
→ Any / all phases of electrical current if connects to ground or each other, and there is sudden surge of current such event is called as a short circuit event.

- Characteristics of Short circuit event
  - Duration (self extinguishing, transient and steady state )
  - Origin ( mechanical break in a conductor, accidental contact between two conductor via a foreign body, Insulation breakdown )
  - Phase to earth
  - Phase to phase
  - Three phase
- Consequences of short Circuits
  - Damage to insulation
  - Fire and danger to life
  - High electrodynamic forces & danger to mechanical components

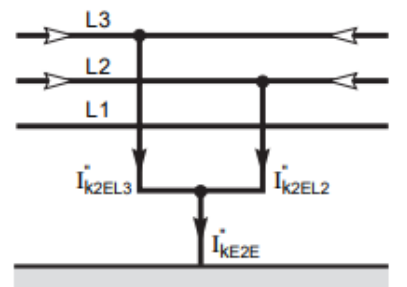
# Types of short circuit events (IEC60909)



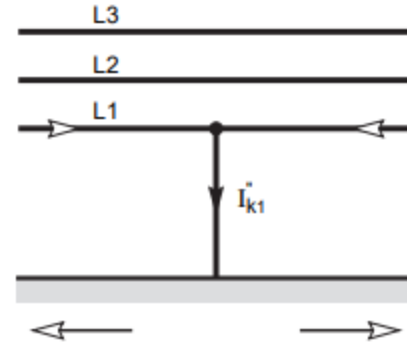
- Three phase short circuit (less than 5%)



- Two phase short circuit (5-10%)



- Three phase short circuit to ground (less than 5%)



- Phase to earth (80 % of faults)

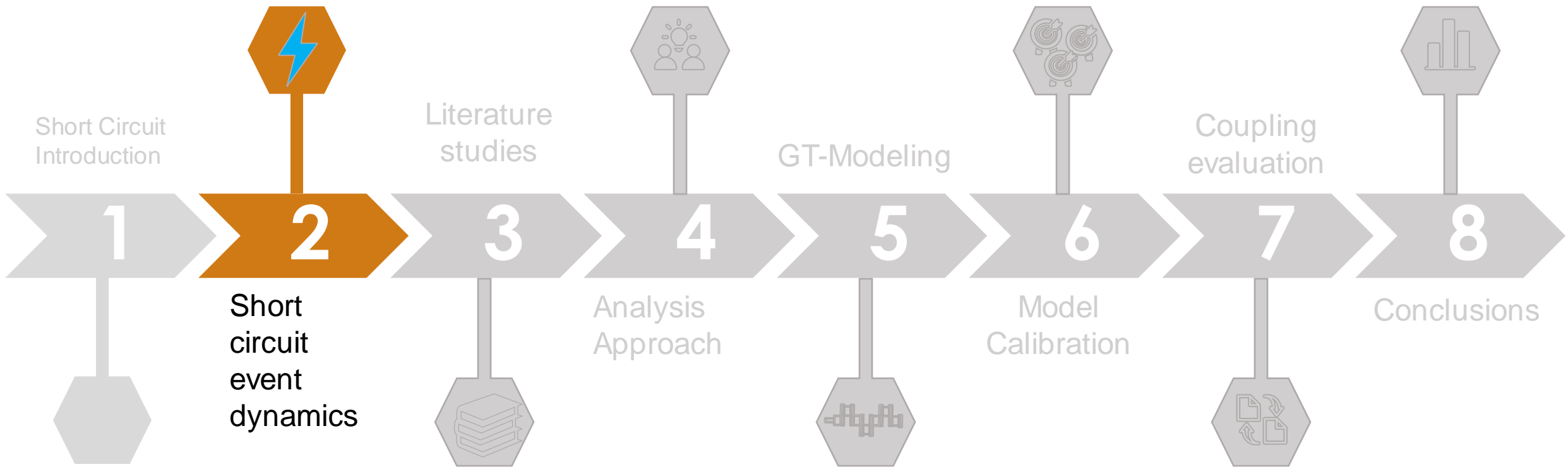
- These are major types of short circuit events that occurs statistically worldwide.
- Among of these the one which produces highest electrical current is 2 phase short circuit

# Induced Short circuit test at Cummins

- 50 Hz Krypton / Short Circuit Testing – Vibration @ Fridley
- HSK78G PA2-4G & MVI804X2
- w/ Reich AC-10.2D.SN.F2K.21.350 Torsional Coupling

This generator set was subjected to IEC 60034-1 Section 9.9, IEC 60909 short circuit testing per ESW-21. This gave us the opportunity to collect strain, linear, and torsional data during short circuit testing. Testing was focused on short circuit testing; not our standard DP-0001 tests.





# Dynamics of Short Circuit event

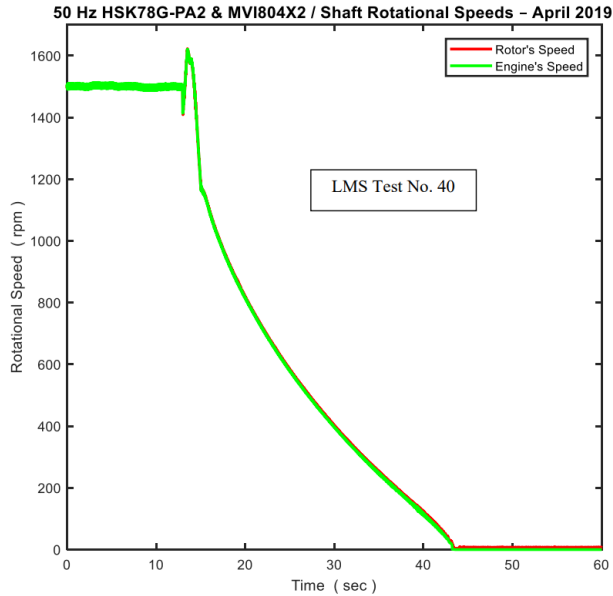


Fig3a: Time vs Speed

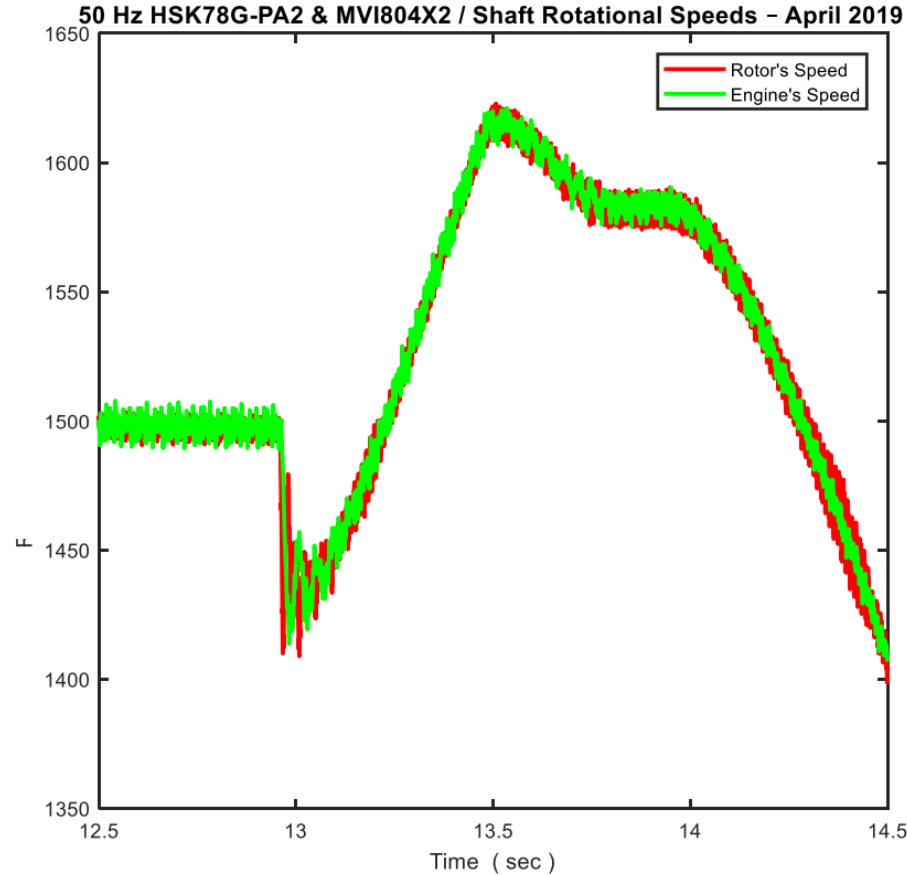


Fig3b : Time vs speed

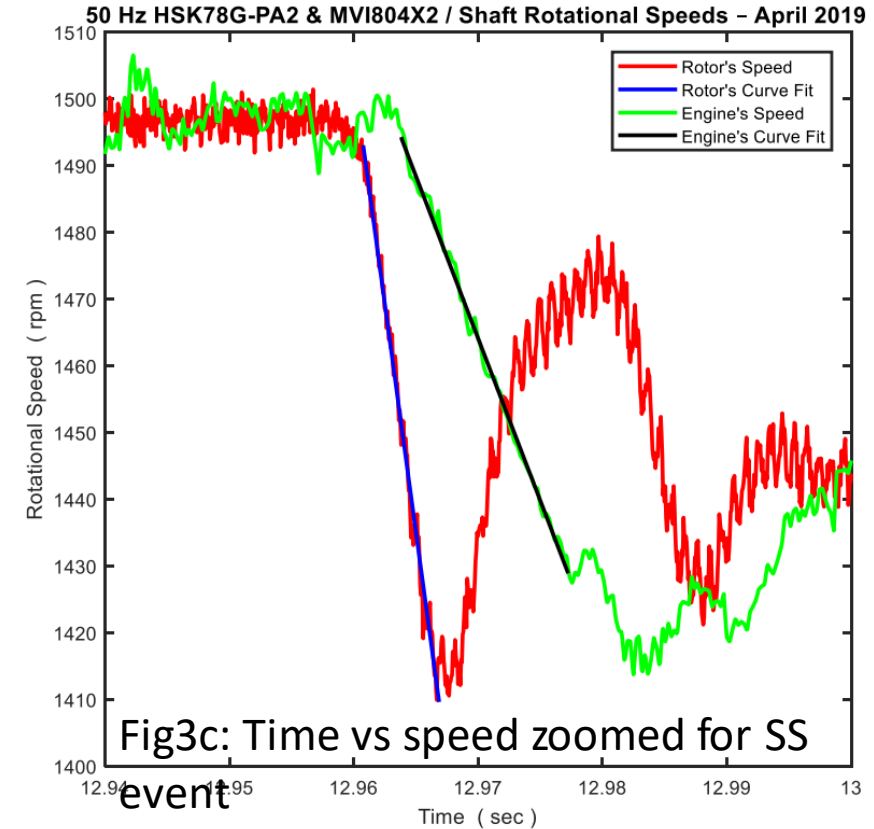
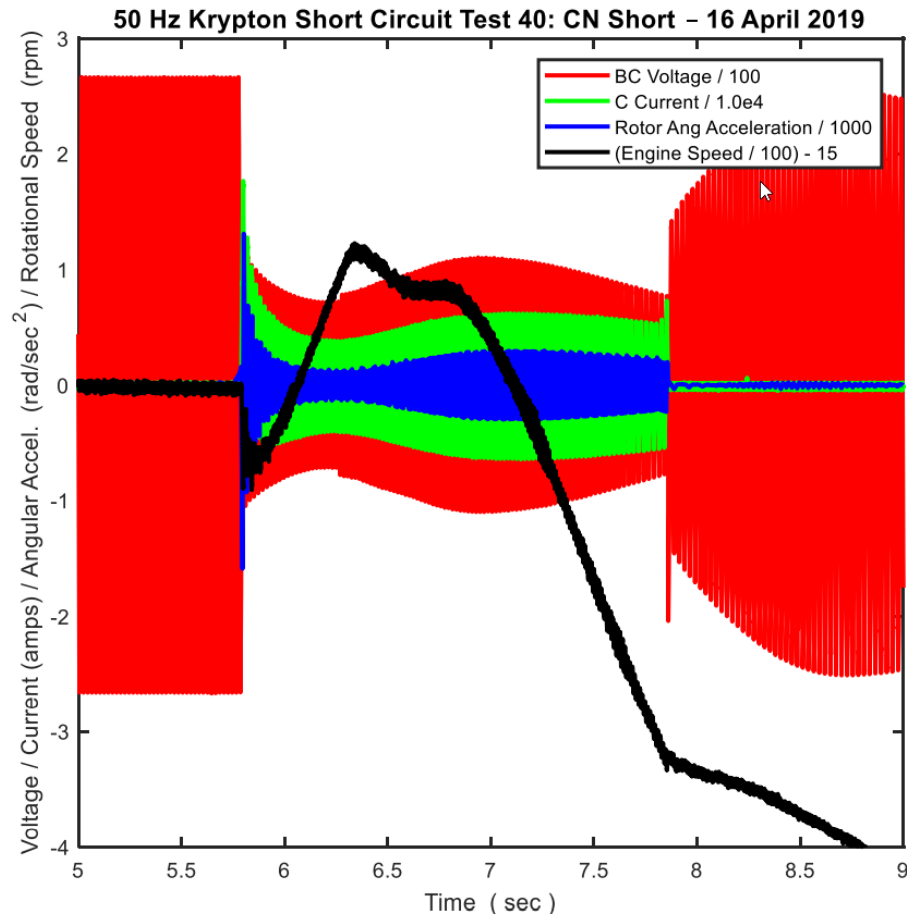
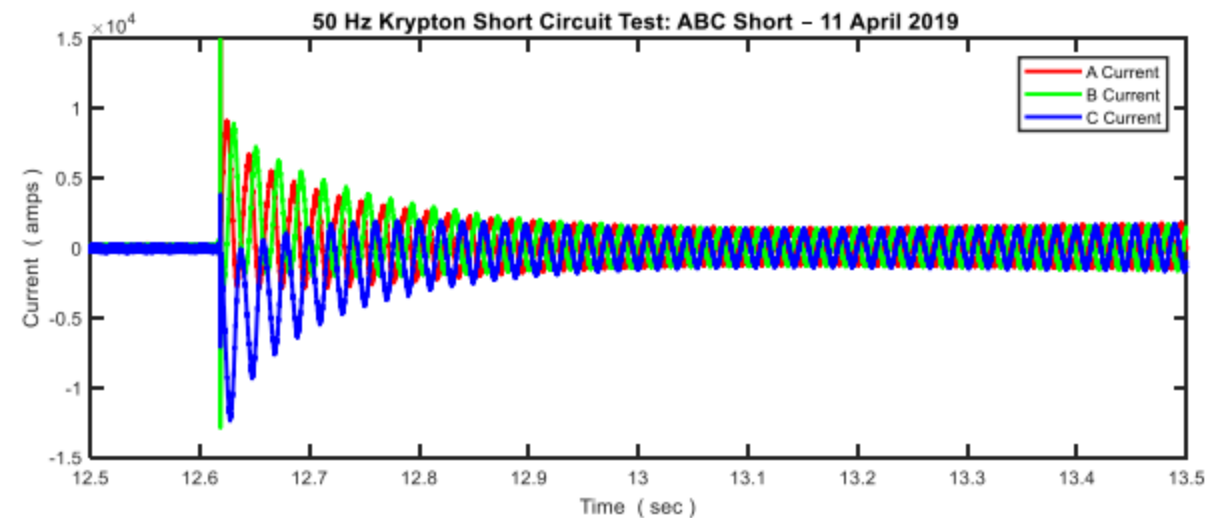


Fig3c: Time vs speed zoomed for SS event

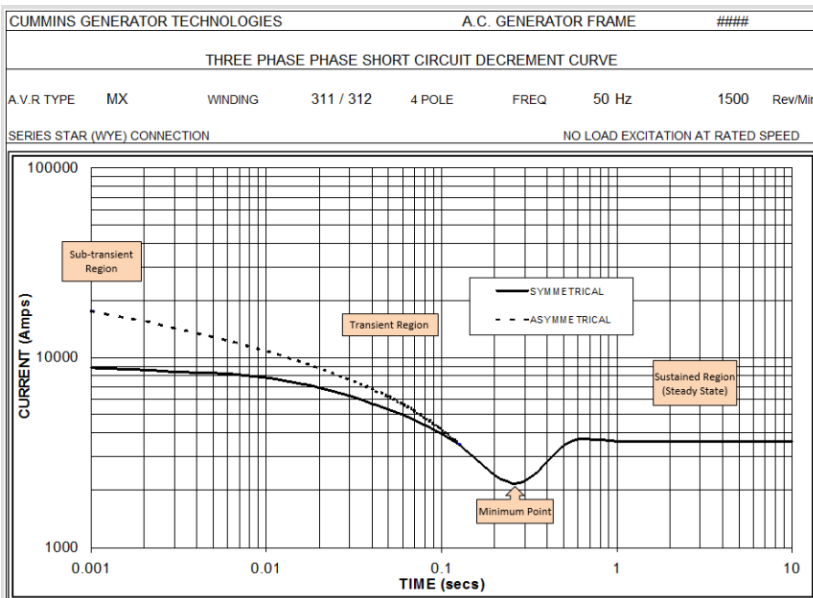
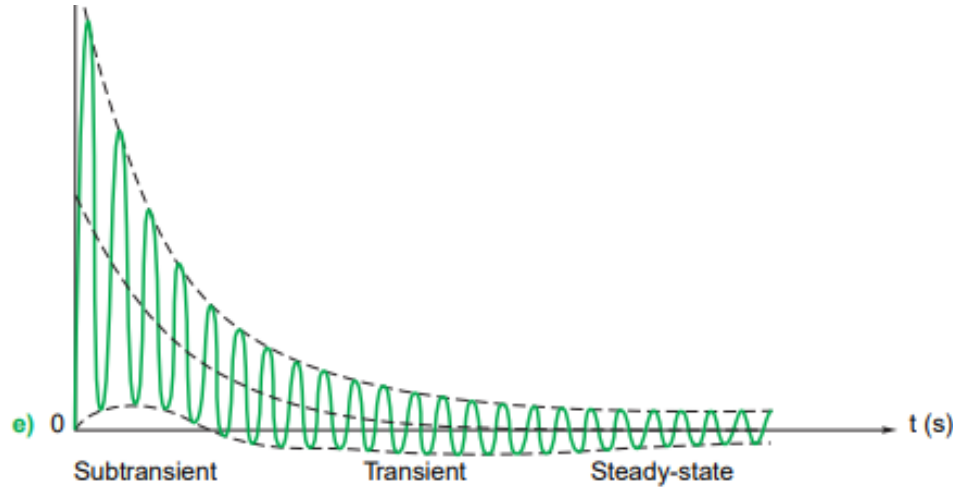
# Dynamics of short circuit event



- The rotor current as you can see increasing drastically after the short circuit event.
- Also the Rotor angular acceleration is very high at the start of SS event.

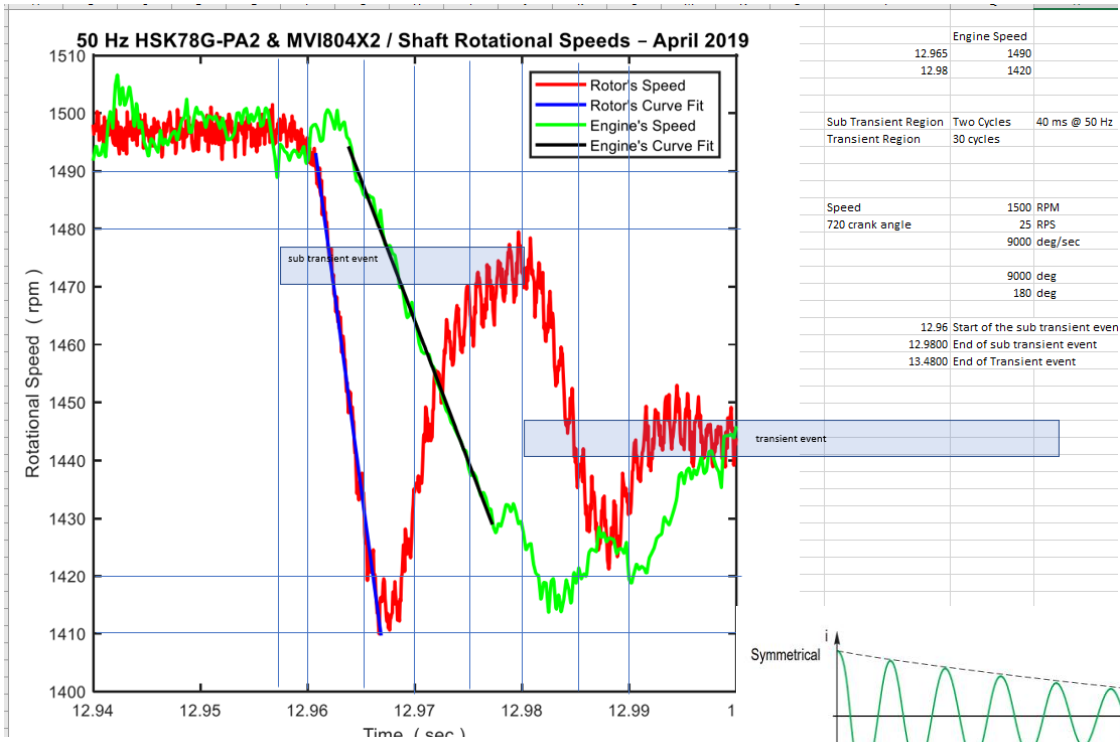


# Dynamics of SS event



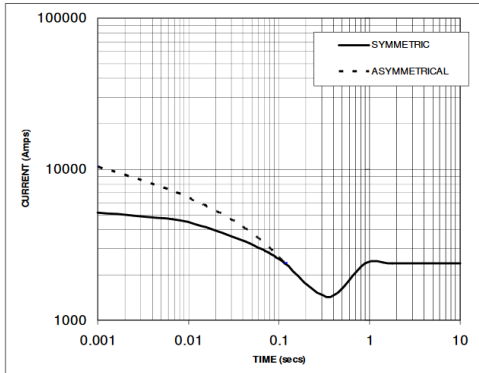
- The sub-transient time period is typically no more than two cycles (40ms @ 50Hz).
- The time from the sub transient region onwards, to the convergence of the symmetrical and asymmetrical curves and on to the point after which the fault current begins to increase, is referred to as the transient region.
- Steady state region : With regard to the sustained region level of fault current, this region is often referred to as the steady state or synchronous region. With the current level in this region being multiples of rated output current, the alternator is clearly operating under a condition of forced excitation;

# Dynamics of SS event



Three Phase Short Circuit Decrement Curve  
No- Load Excitation at Rated Speed

Based on series star (wye) connection



NOTE 1  
THE FOLLOWING MULTIPLICATION FACTORS SHOULD BE USED TO ADJUST THE VALUES FROM CURVES BETWEEN THE 0.001 SECONDS AND THE MINIMUM CURRENT POINT IN RESPECT OF NOMINAL OPERATING VOLTAGE

VOLTAGE	FACTOR
3300V	X 1.00

THE SUSTAINED CURRENT VALUE IS CONSTANT IRRESPECTIVE OF VOLTAGE LEVEL

NOTE 2  
THE FOLLOWING MULTIPLICATION FACTORS SHOULD BE USED TO CONVERT THE VALUES CALCULATED IN ACCORDANCE WITH NOTE 1 TO THOSE APPLICABLE TO THE VARIOUS TYPES OF SHORT CIRCUIT

	3 PHASE	2 PHASE L-L	1 PHASE L-N
INSTANTANEOUS	X 1.0	X 0.87	X 1.30
MINIMUM	X 1.0	X 1.80	X 3.20
SUSTAINED	X 1.0	X 1.50	X 2.50
MAX SUSTAINED DURATION	10 SEC	5 SEC	2 SEC

ALL OTHER TIMES ARE UNCHANGED

SUSTAINED SHORT CIRCUIT = 2381 Amps

## SHORT CIRCUIT DECREMENT CURVES

An example of a typical Three Phase Short Circuit Decrement Curve is shown in Figure 1.

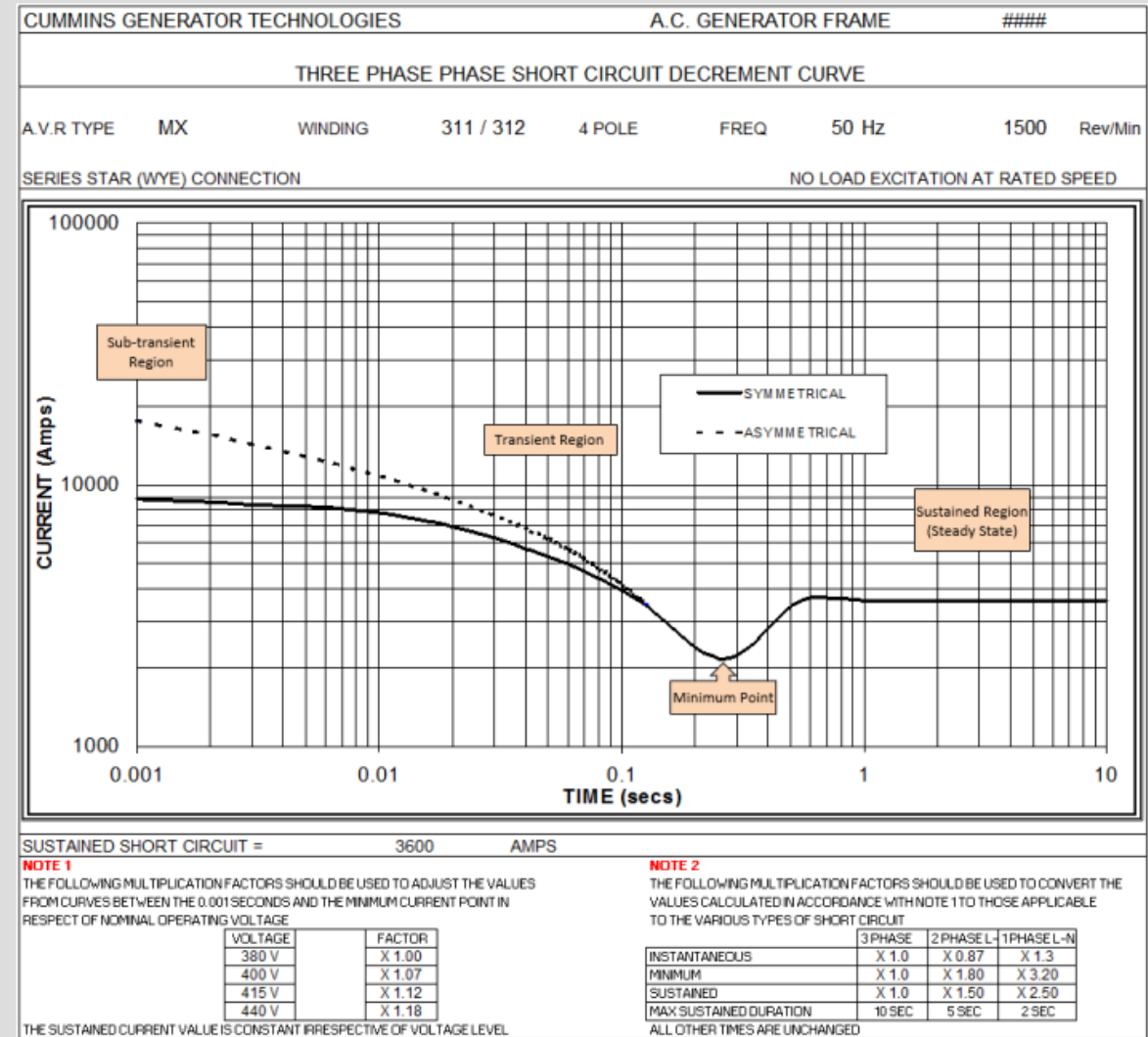
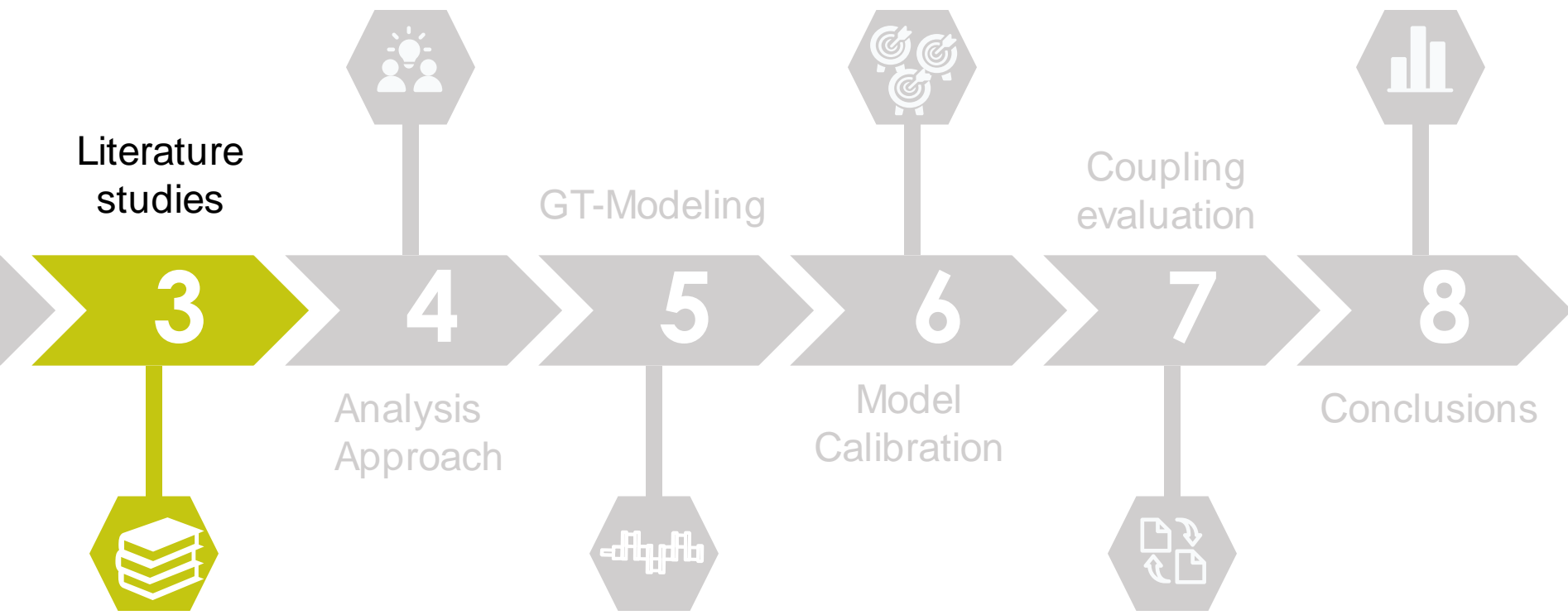


Figure 1 Typical Three Phase Short Circuit Decrement Curve

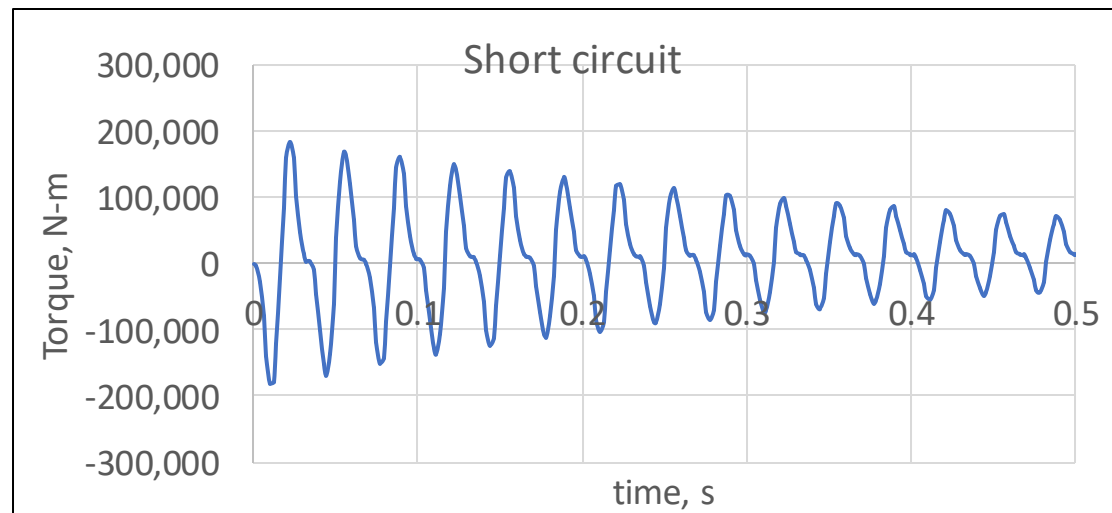


# Literature survey [3]

- The transient torsional vibration behavior of a turbine generator system under short circuit excitation

$$\frac{T_t}{T_n} = 10 \times e^{\frac{-t}{0.4}} \times \sin(\omega t) - 5 \times e^{\frac{-t}{0.4}} \times \sin(2\omega t) - \left(1 - e^{\frac{-t}{0.15}}\right)$$

Where  $T_t$  = Transient torque;  $\omega$  is frequency of current,  $T_n$  is nominal torque.





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Analysis Approach

- Intent of the overall exercise
- What we want to achieve of this

analysis

GT-Modeling

Coupling evaluation

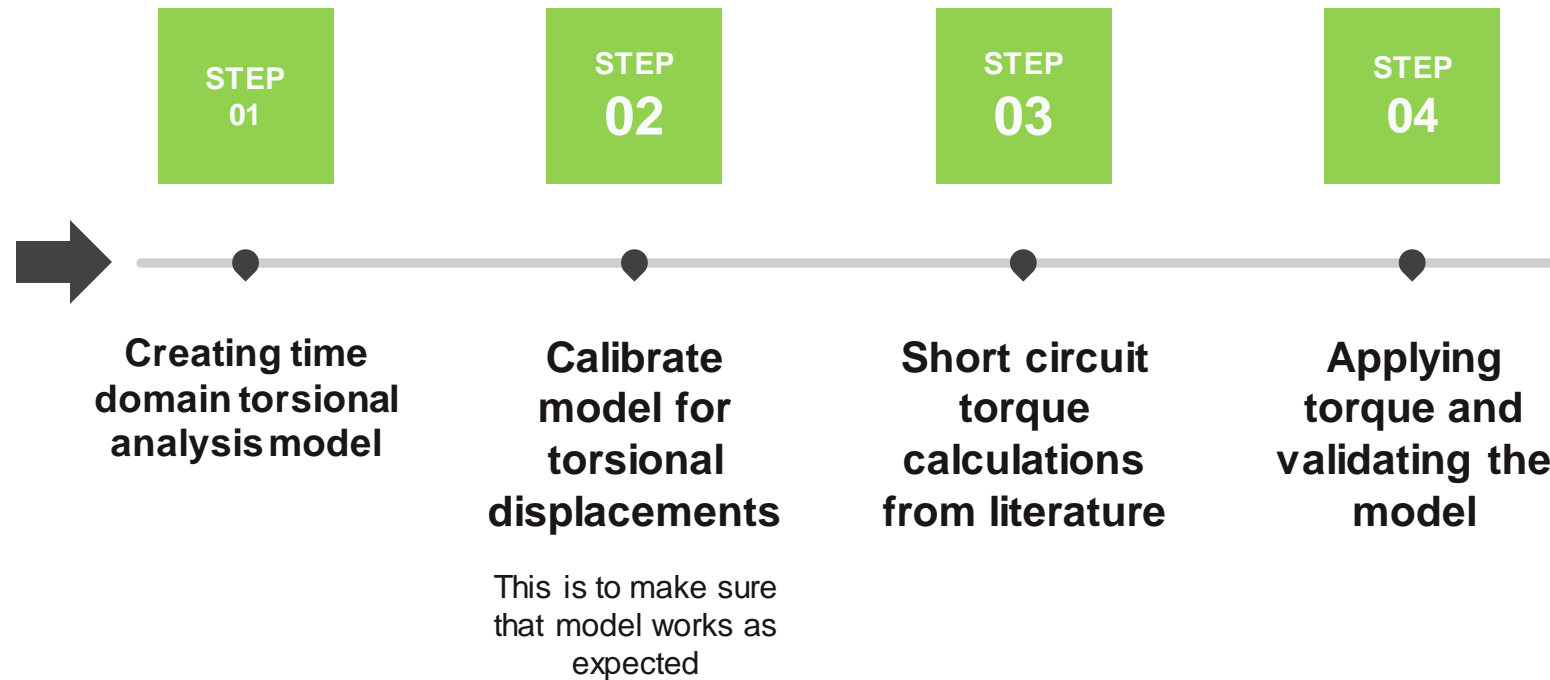
Model Calibration

Conclusions



# Analysis approach and model building

- 1. Dynamic torsional model
- 2. Understanding the nature of short circuit event.



GT-Modeling

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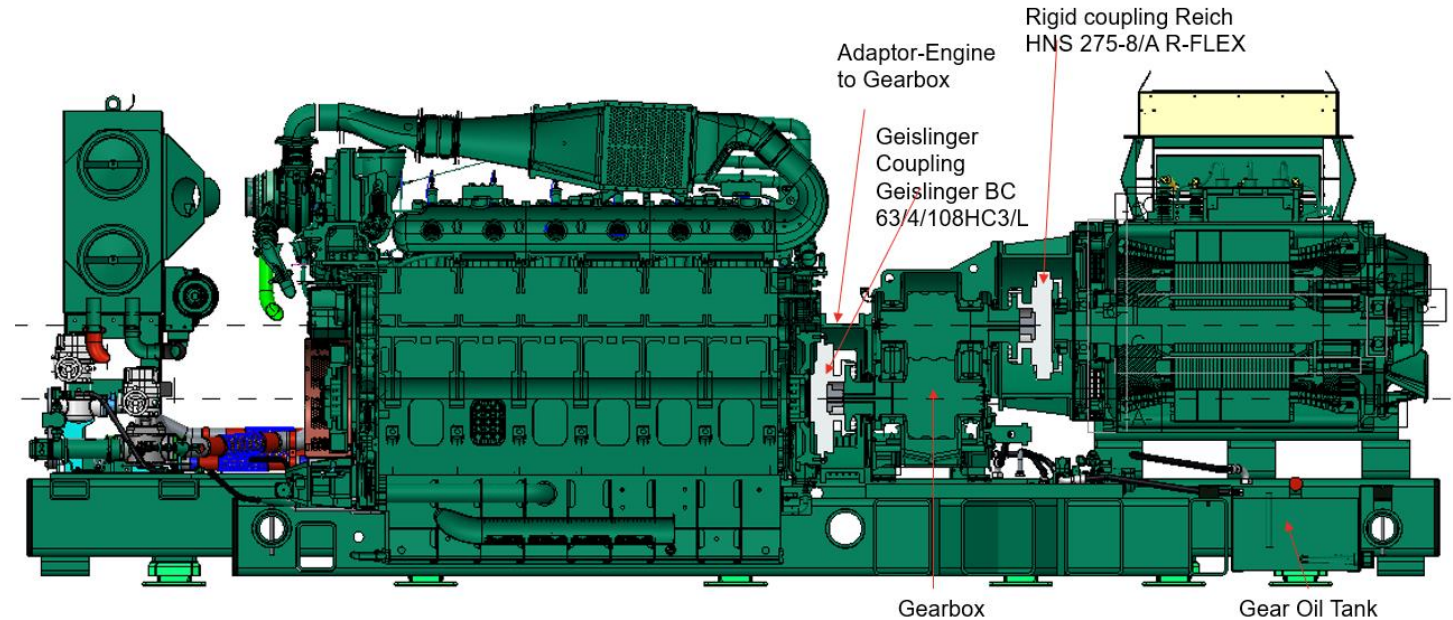
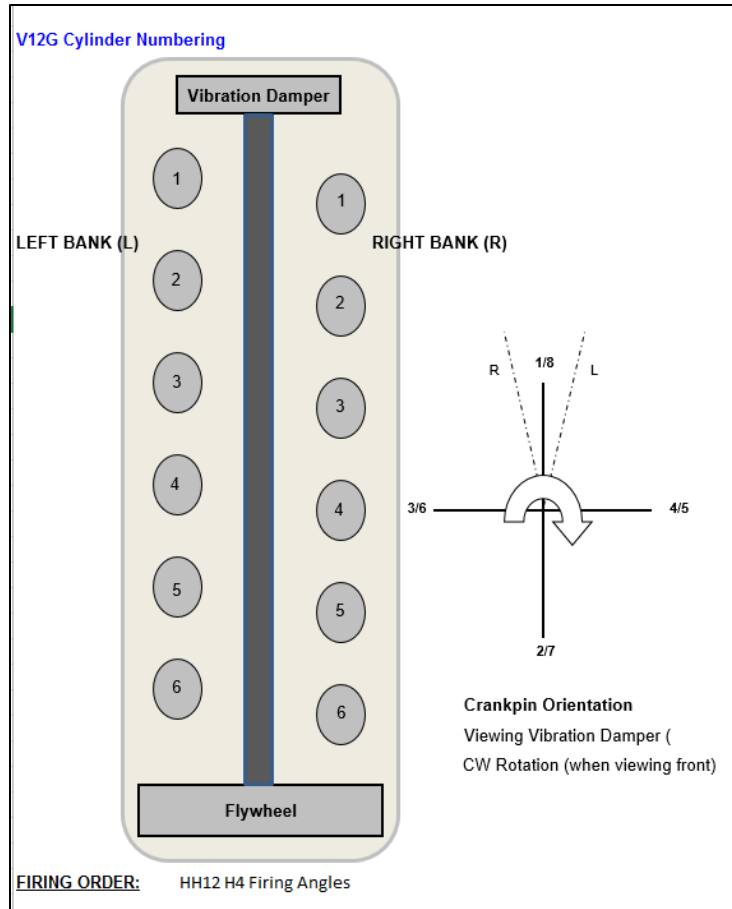


- How the GT model was built
- PID controller

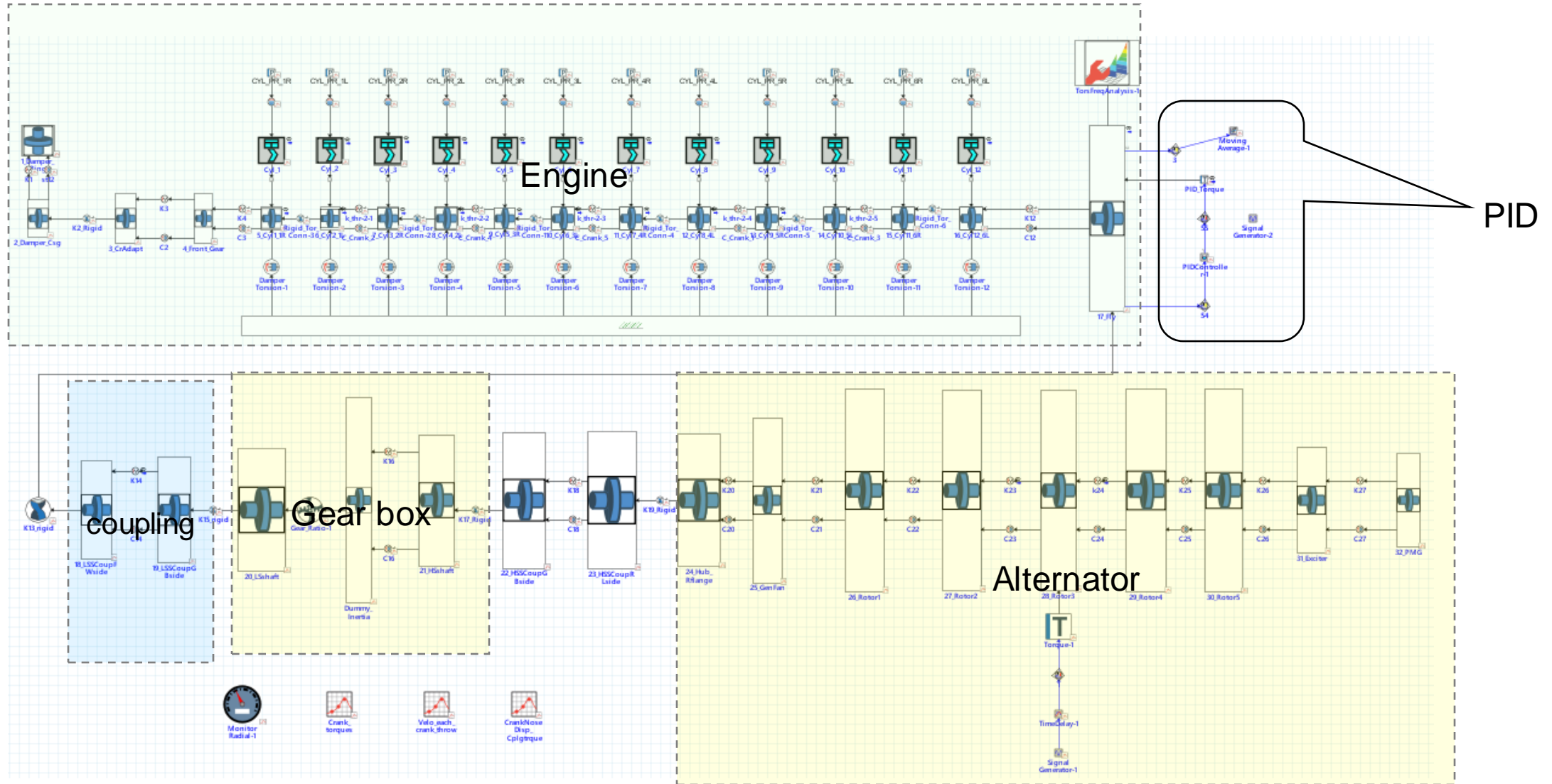
# Problem statement

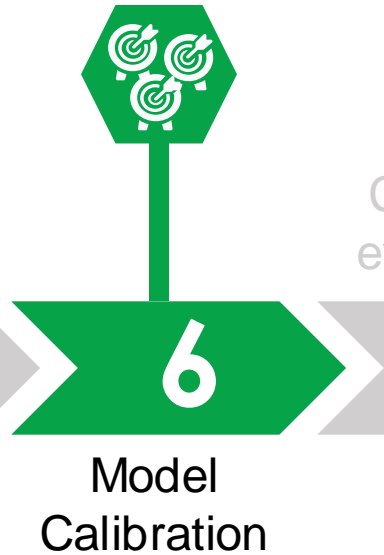
- Build a GT torsional model (time domain) to steady state at desired RPM. This we want to achieve without speed boundary conditions.
- So, we will use a PID controller at the flywheel which would try to give an opposite torque as of the total engine torque to the flywheel so that overall system achieves a steady state.
- For our problem the system is a HSK78 engine with P80R2 alternator, this driveline has a torsional coupling, a step-up gear box and alternator at the other end.

# Engine and driveline details



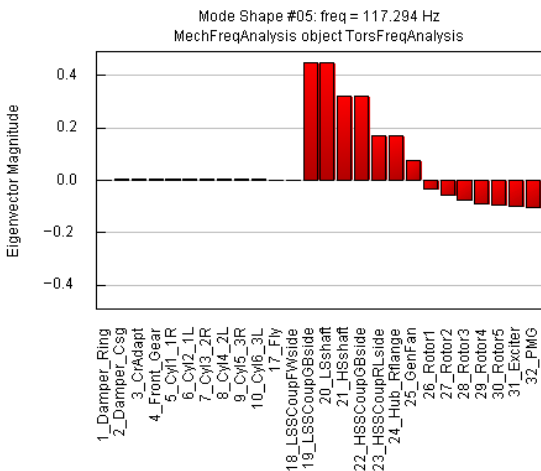
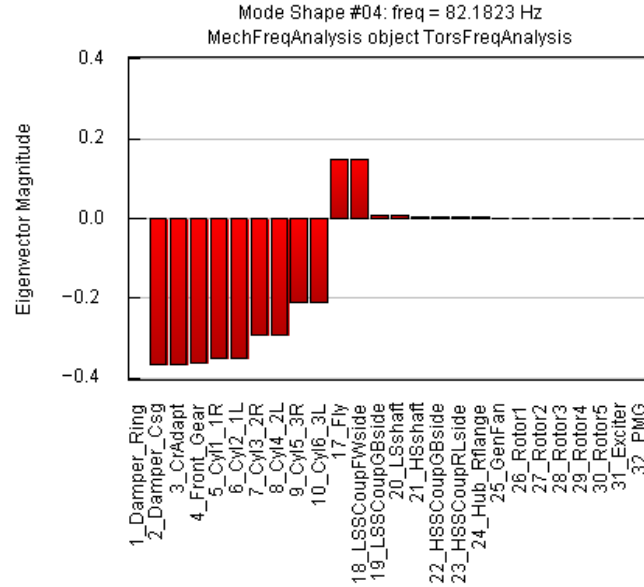
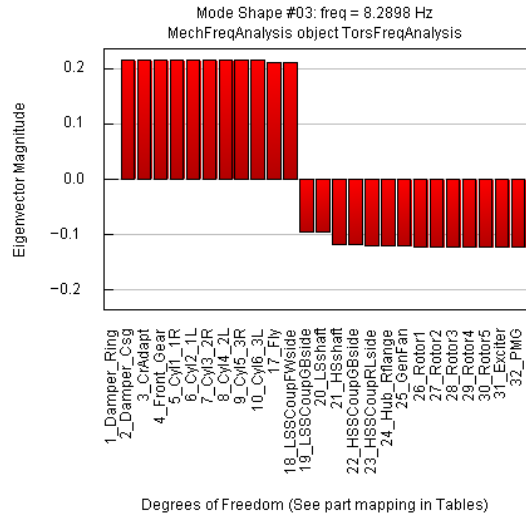
# GT Model Details



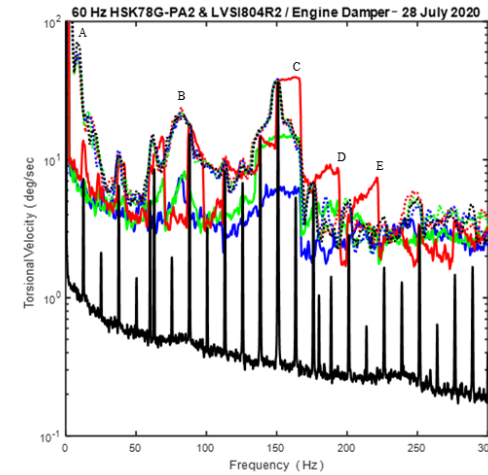


- Steps for model validation
- How the calibration was carried out

# Natural frequency calibration



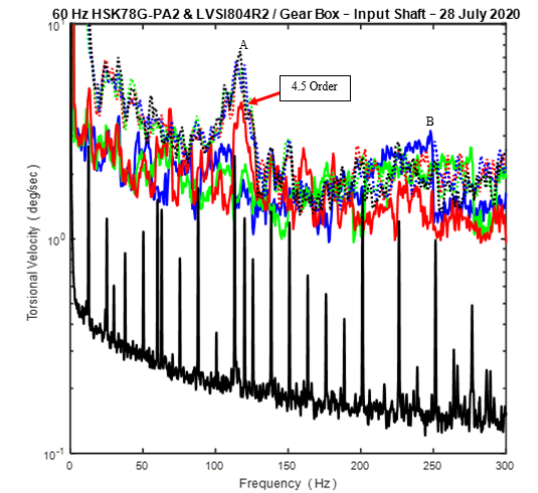
Engine Torsionals @ Damper  
The dotted lines are the start/stop tests.



Peak	Frequency (Hz)	Angular Velocity (deg/sec)	Alternating Displacement (+/- deg)	Exciting Order	Engine Speed of Peak (rpm)
A	8	70.75	1.4075	6.0	80
B	82	23.81	0.0462	6.0	820
C	165	38.96	0.0376	6.0	1650
D	193	8.74	0.0072	7.0	1654
E	221	7.44	0.0054	8.0	1658

Gear Box Torsionals @ Input Shaft  
The dotted lines are the start/stop tests.

Per the start/stops, we think the 117 Hz resonant excitation is gear mesh frequency.

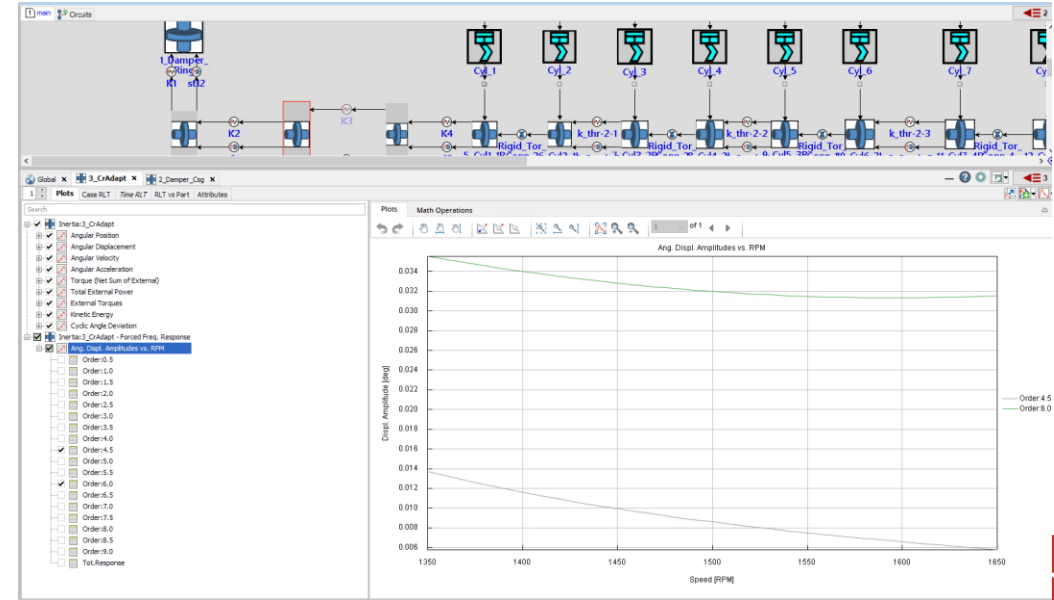
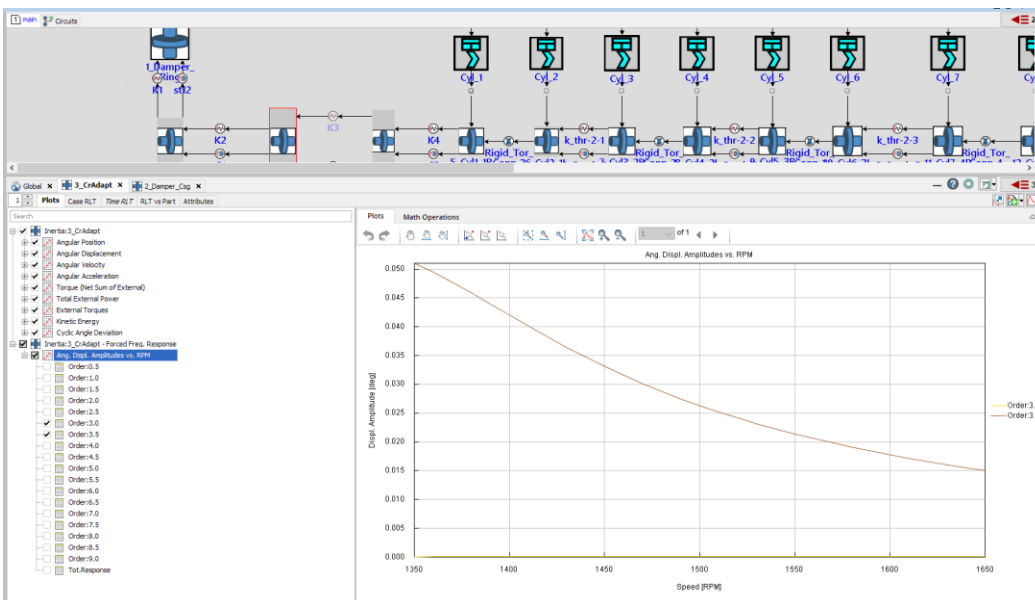
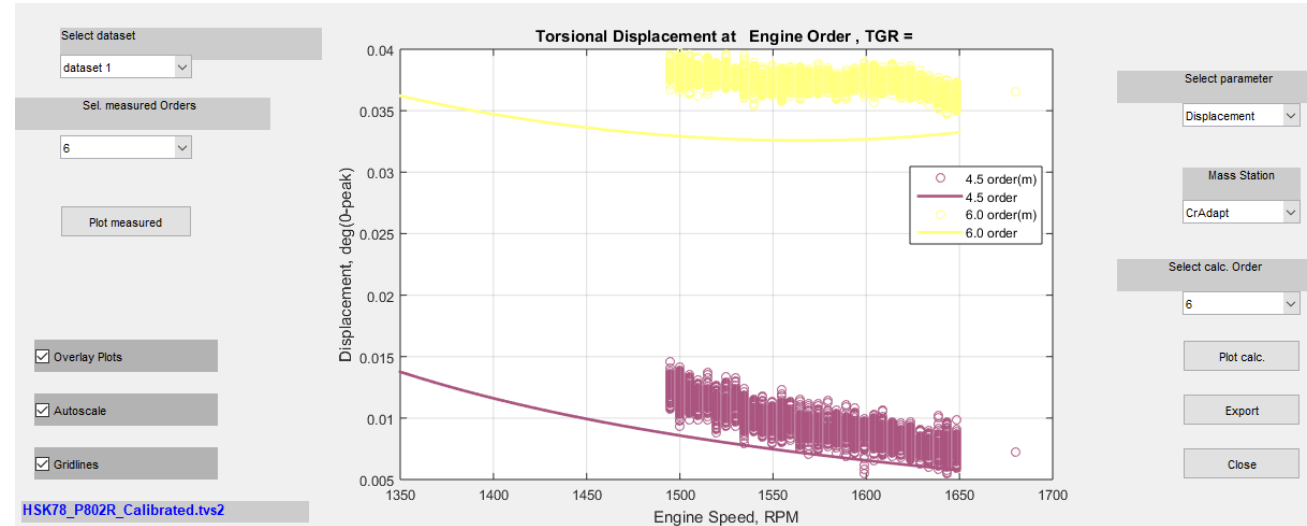
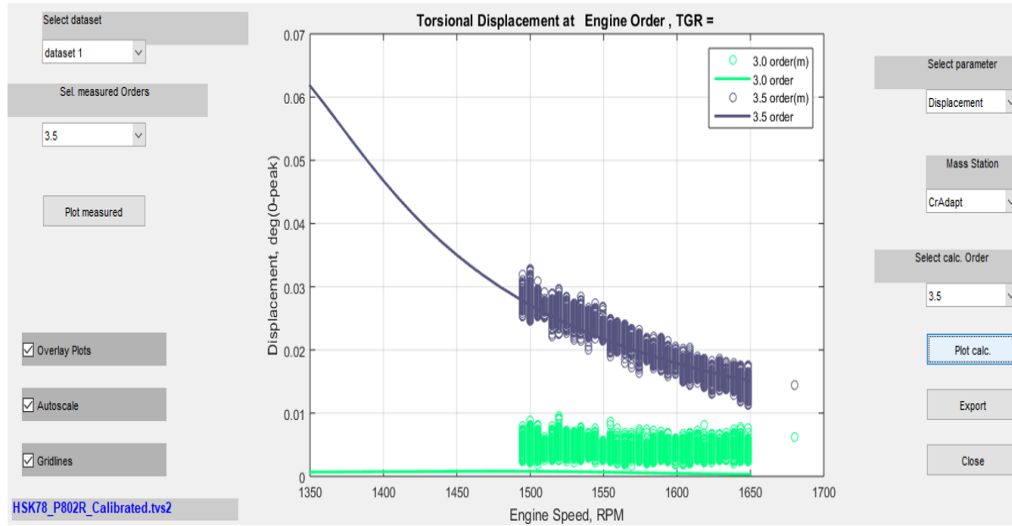


Peak	Frequency (Hz)	Angular Velocity (deg/sec)	Alternating Displacement (+/- deg)	Exciting Order	Engine Speed of Peak (rpm)
A	117	7.477	0.0102	68.0	103
B	248	3.172	0.0020	9.0	1653

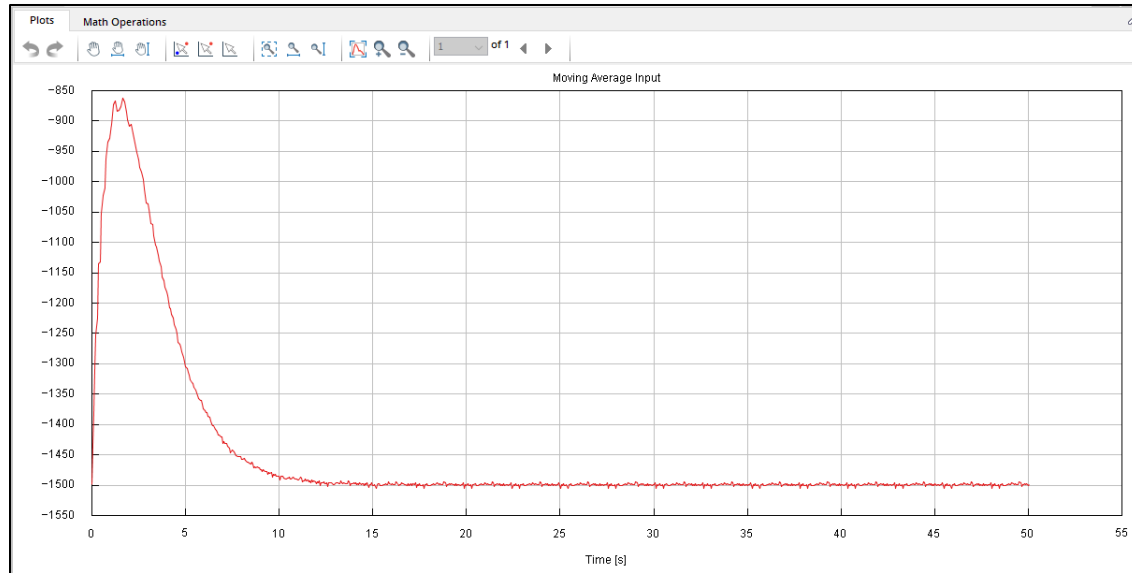
The GT Suite model predicts the coupling mode at 8.29 Hz, first engine mode at 81.75 Hz and generator mode at 117.32 Hz which is well matching with torsional test prediction of 8Hz, 82Hz and 117Hz respectively.

# Force response calculations

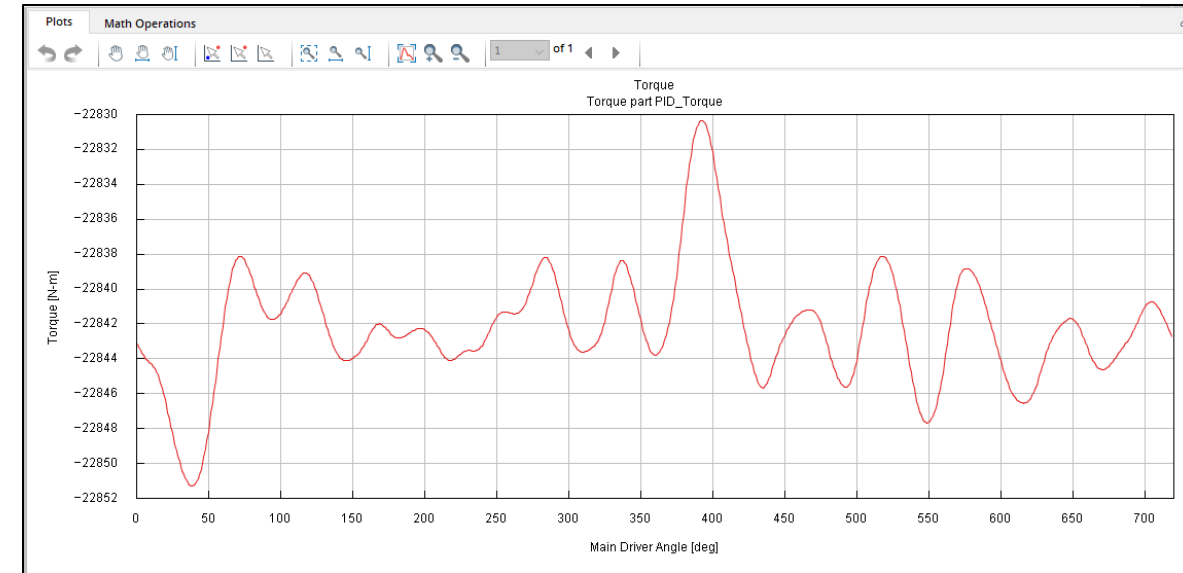
This model was calibrated for the torsional data measured at engine front, crank nose displacements were correlated for all major orders and thus the model validity was confirmed.



# Changes in GT output after using PID controller



Flywheel Speed

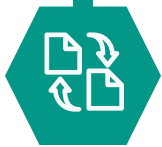


PID Torque applied by PID controller

GT model is ran for 50 seconds so that the overall system achieves the steady state so that we can apply a SS torque. We observed the flywheel speed output as a function of time to observe that.

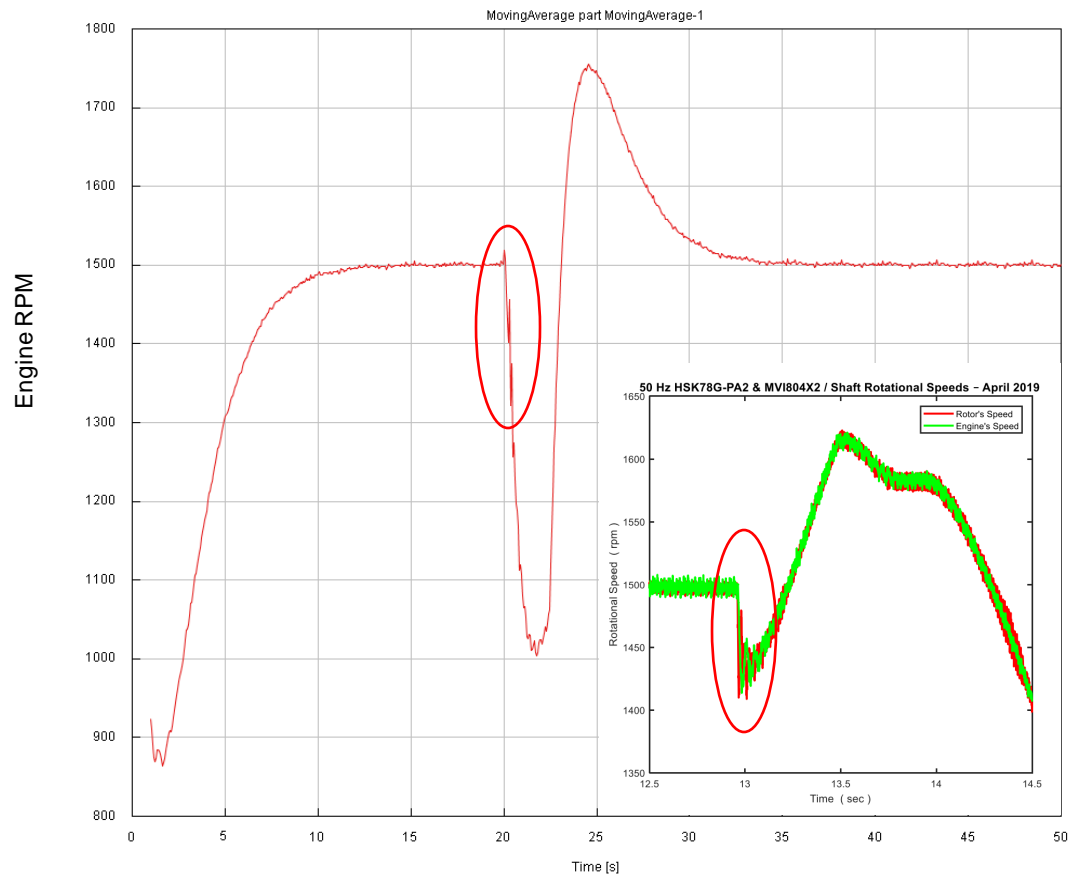
Coupling  
evaluation

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- What is important from coupling perspective ?
- Which section of event to be modeled correctly ?

# After applying Short Circuit torque after steady state condition



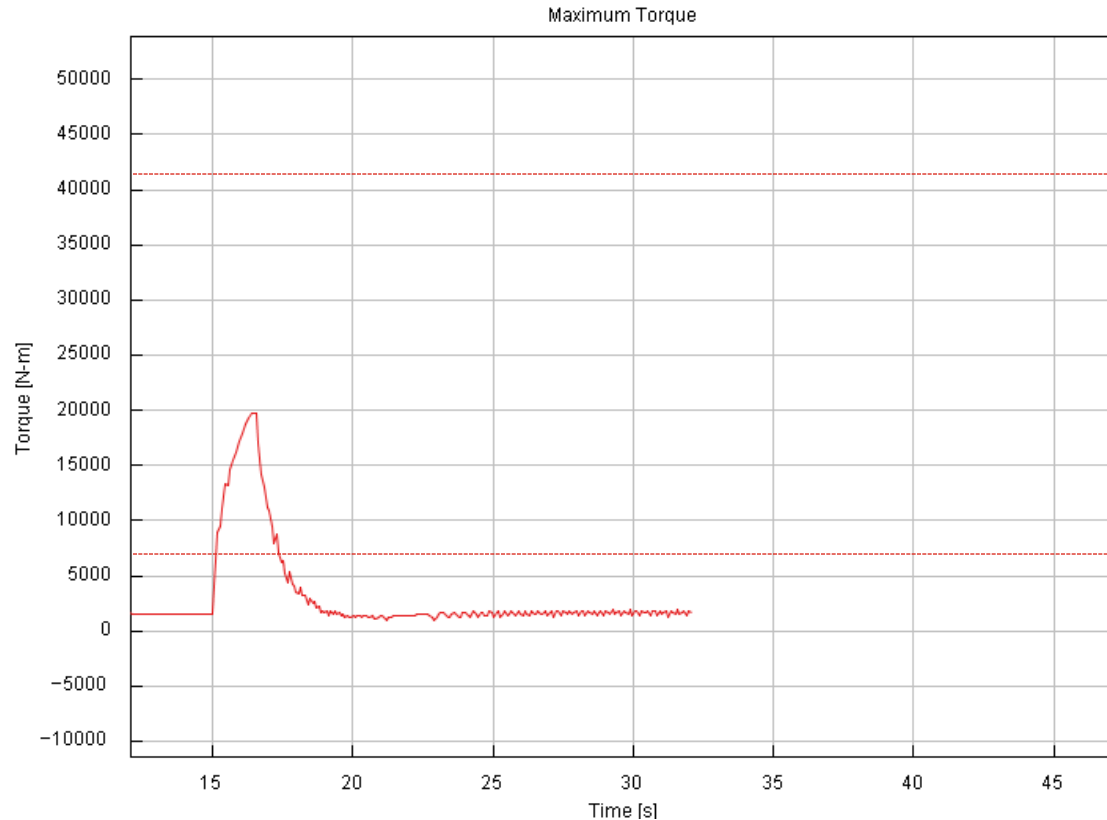
TVSIM model was ran for 15 sec till we achieve a steady state at 1500 RPM and then SS torque was applied.

Due to applied short circuit torque we see a speed drop in the engine mean speed.

After which the speed steadily gets backs to 1500 RPM.

With the given short circuit event parameters, we were not able to achieve good co-relation for the whole event but the deceleration rate was achieved for the short circuit event, and using this model the torque across coupling and heat rate were predicted.

# Transient Torque at torsional coupling



The maximum torque at torsional coupling is around 20kNm much higher than vibratory torque limit of the coupling and this torque remains for around 5 secs.

It is acceptable for the maximum limit of the coupling.

Vib torque limit = 7000 Nm

Max torque limit = 42000 Nm



Conclusions

# CONCLUSIONS

# Conclusions

- Overall torsional modeling and calibration of the model with the test data was completed,
- We were able to calculate the short circuit torque empirically and apply to the GT model which created the short circuit response which was similar to what observed in the test.
- Hence this time domain GT model can now be used for further assessment on the torques at various junctions across the driveline at crankshaft, across the bolted joint etc.
- As next steps we can target to model the overall event better and evaluate the performance of the mechanical components in the driveline.

# REFERENCES.

1. Short-circuit currents in three-phase a.c. systems - Part 4: Examples for the calculation of short-circuit currents [International energy council IEC 60909]
2. India standard; Rotating electrical machines IS/IEC 60034-1:2004
3. TORSIONAL EXCITATION UPON SHORT-CIRCUIT IN INDUCTION MOTORS - IN CONVENTIONAL AND HIGH-SPEED TRAINS – 46<sup>th</sup> Turbomachinery & 33<sup>rd</sup> Pump Symposium Houston, Texas
4. Cummins internal reports on engine testing.

Q+A

