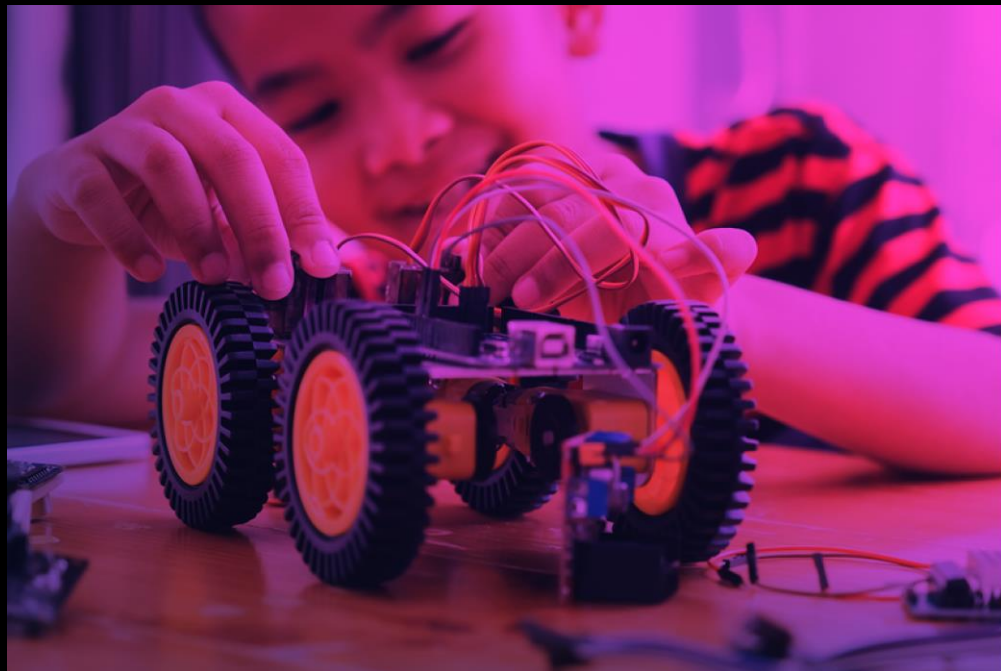


# Bridging the Gap between System and Component Design for Vehicle Electrification using Model Based Systems Engineering (MBSE)

Date : 17-18 May 2022



# Agenda

- Introduction
- Challenges in Electric Vehicle development
- Bridging the gaps through MBSE
- How MBSE helped
- TCS Enablers for MBSE

# Introduction

# Speaker Introduction

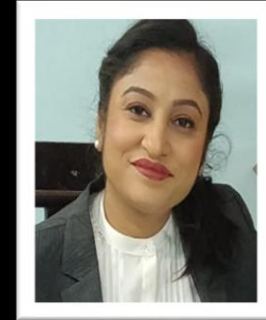


**Yutika Patwardhan**

**Tata Consultancy Services  
IoT & Digital Engineering**

**Head of Centre of Excellence for FuSa, MBSE, Auto  
Electronics**

- 20 +Years in Automotive Embedded Systems- (EV, ADAS, Body Electronics)
- INCOSE CAB representative for TCS
- SME-Functional safety, Functional Safety L2 Certified by TUV SUD
- Technical manager for BMS software, Project lead for modeling and simulation( E/E features)
- Tools Expertise – MBSE tool chains, SysML tools, Safety Analysis tool chain, Requirement Management, ALM tool chains



**Neha Surjekar**

**Tata Consultancy Services  
IoT & Digital Engineering**

**MBSE - Solution Lead, Auto Electronics Centre of Excellence**

- 12 + Years experience in Automotive Embedded Systems
- Experience in MBSE (UML, SysML), ADAS, Body domain
- Member INCOSE, INCOSE India Chapter
- Tools Expertise - MBSE tool chains, SysML tools, Requirement Management, ALM tool chains
- Key member in deploying MBSE practices across various accounts
- Certified Scrum Master

# TCS Automotive Experience Summary



- USA
- UK
- India
- South Korea
- Brazil
- Europe
- China
- Japan



**11,000+**  
Engineers



Working in  
**15+** Countries

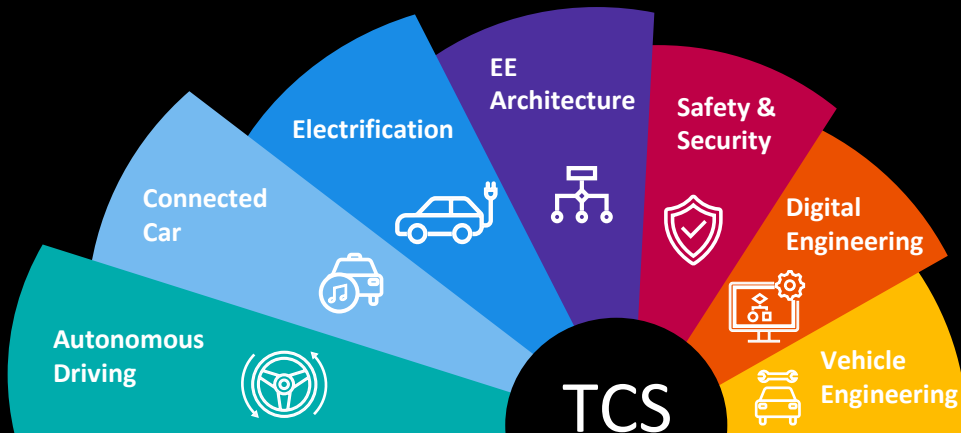


Spread across  
**50+** Customers

**7000+**  
Electrical & Electronics Engineers

**4000+**  
Vehicle & Powertrain Engineers

*TCS recognized as a  
Leader in ACES Automotive Engineering Services  
by Everest Group*



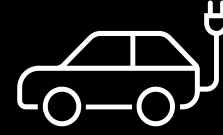
# TCS Automotive Electrical & Electronics Portfolio



Autonomous Driving



Connected & Infotainment



Electrification

Domains



Base Platform  
OS, AUTOSAR



Diagnostics



Cybersecurity



Functional  
Safety



Systems  
Engineering



Hypervisor



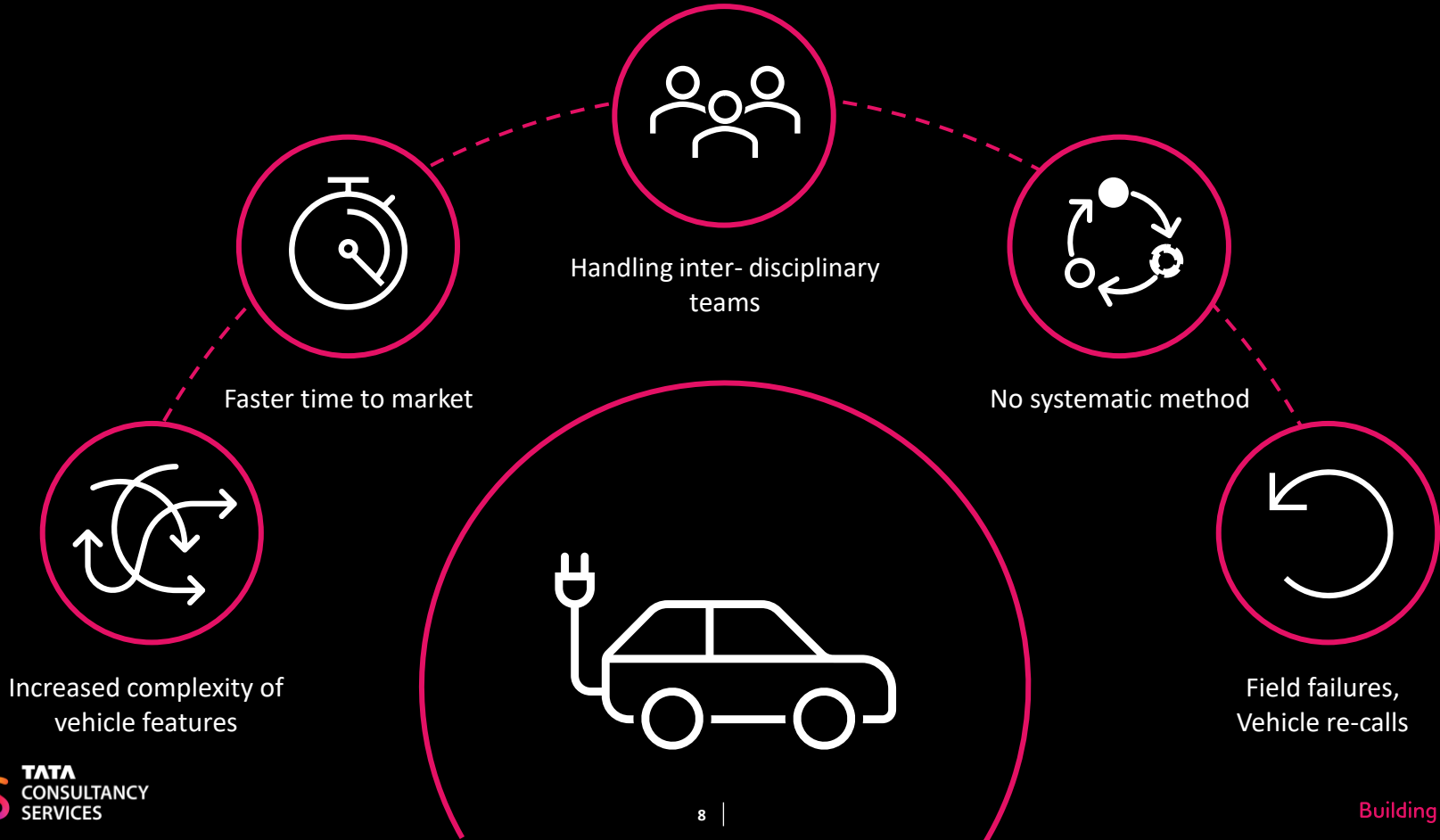
Bootloader & FOTA



EE Architecture Platform

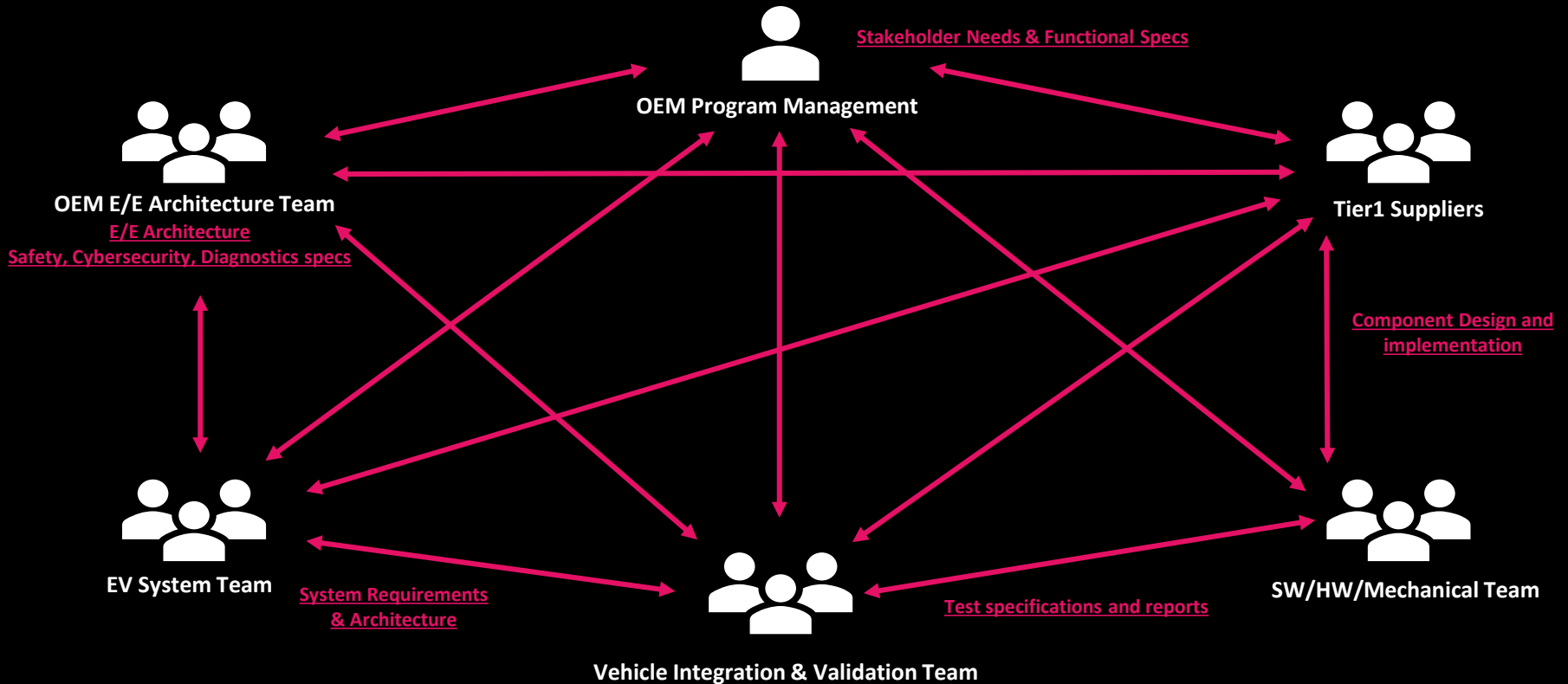
# Challenges in Electric Vehicle Development

# Automotive Trend - Vehicle Electrification – Challenges





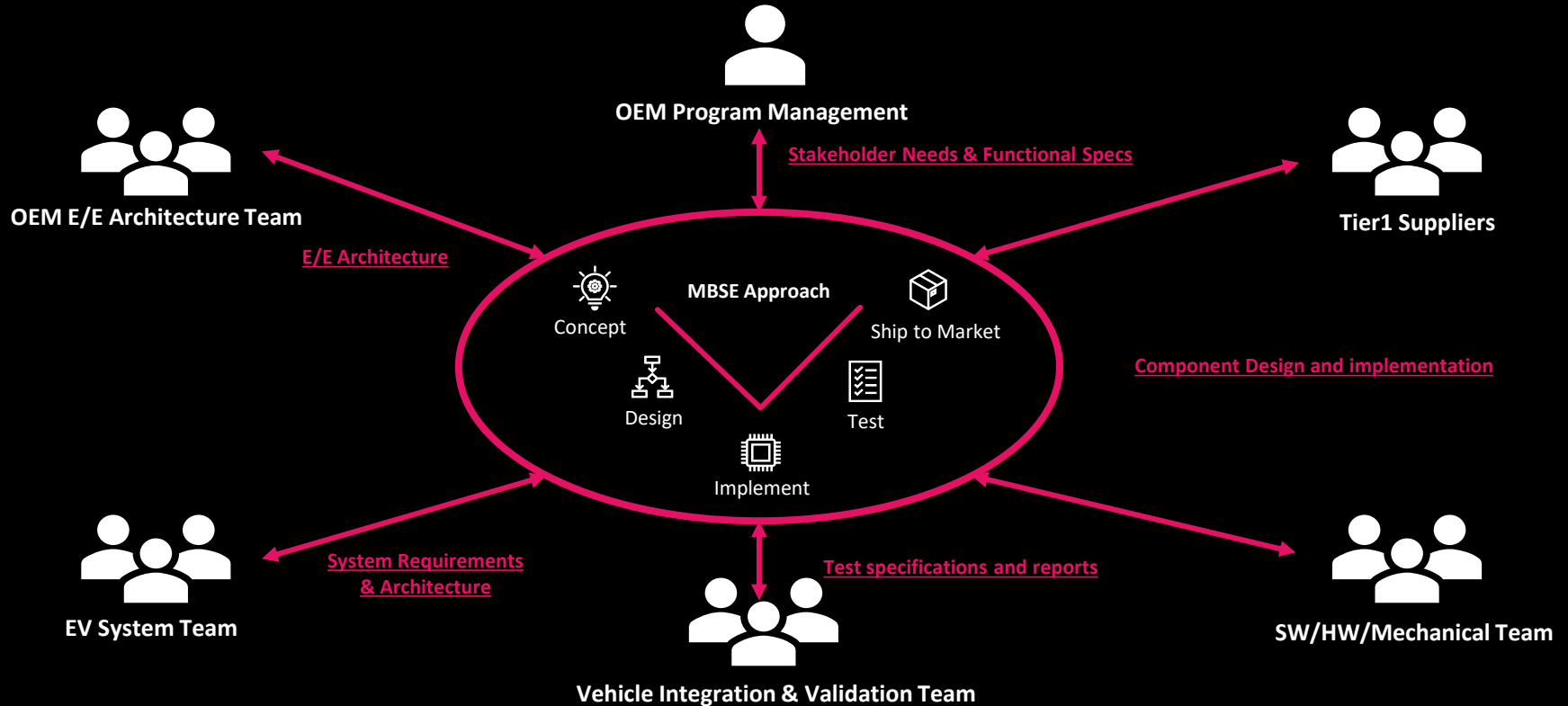
# Traditional Vehicle Electrification Development



Complex system design and development need complicated cross-functional interaction

# Bridging the Gaps through MBSE

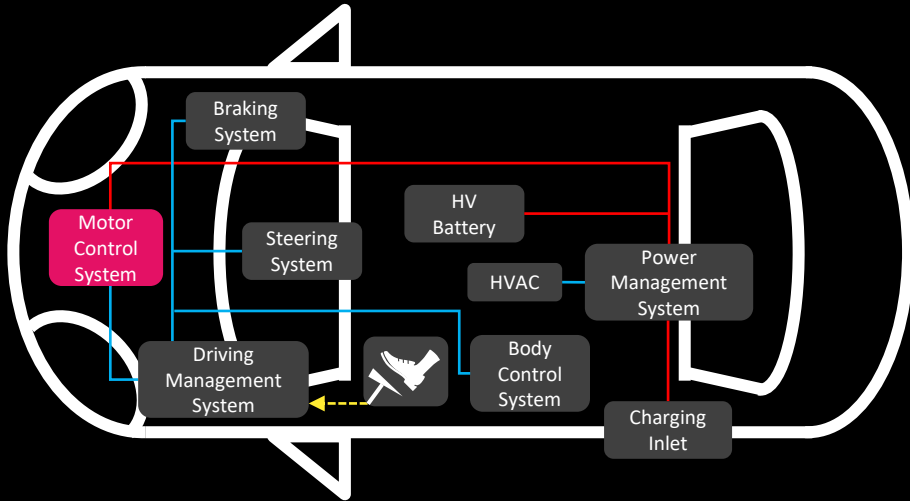
# Adaption of MBSE for Vehicle Electrification Development



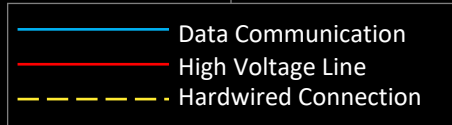
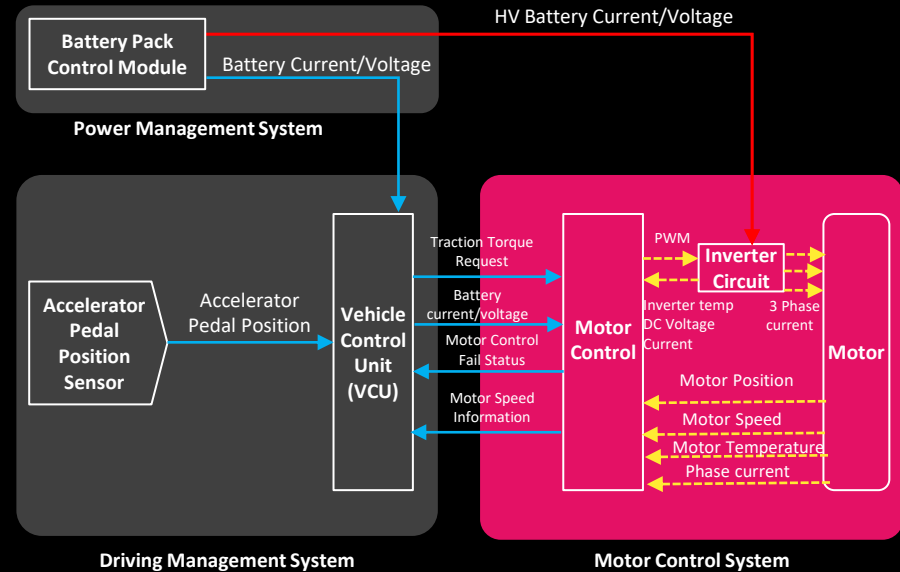
System Engineering aims to ensure, the pieces work together to achieve the objective of the whole

# Motor Control System Development using MBSE

## Vehicle Context



## System Context \*



\* High level Representation of Motor torque control, not an exhaustive architecture

# MBSE applied to Motor Control System Development

System

### Authoring System Requirements

Authoring System requirements

Derive System requirements combined with Stakeholder requirements, functional models, technical, reliability, critical performance measures

### System Architecture & Req Allocation

System Architecture & Requirement Allocation

### Sys Req to Architecture Traceability

System Req to System Architecture traceability

Establish and maintain traceability between System Requirements and System Architecture elements

### System Verification

System Verification

### End – End Traceability

Traceability

End to End traceability can be maintained: System -> Sub System -> Software and component requirements

Sub-system

### Authoring Sub Sys Requirements

Sub System requirements Authoring

Derive Sub system requirements from System requirements. Requirement entry guidelines help to author quality requirements

### Defining Interfaces

Defining Interfaces

### Sub Sys Architecture & Req Allocation

Sub System Architecture & Requirement Allocation

### Sub Sys Req to Arch traceability

Sub System Requirement to Architecture Traceability

Component

### Component Requirements

Component Requirements

### Authoring Software Requirements

Software Requirements

### SW Architecture & Req Allocation

Software Architecture

### Software Design & Implementation

Software Design and Implementation

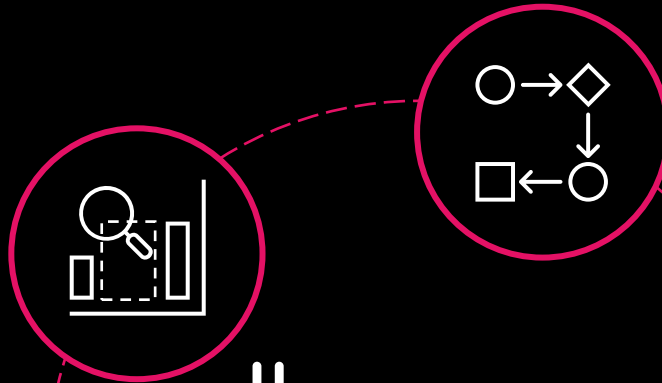
### Stakeholder Views

Stakeholder views

## How MBSE helped

# Benefits

Gaps between System and Component design Identified before implementation

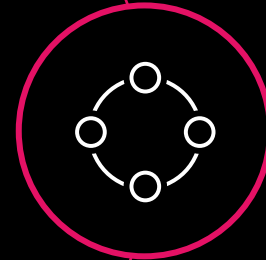
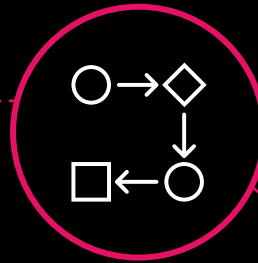


Seamless traceability:

EV Propulsion system requirements

Motor Control sub- system requirements

Motor, Motor control ECU detailed requirements, design



Stakeholder views for OEM System team, TCS team, Suppliers

Reduction in time taken for adapting MBSE



Classified and Precise Information exchange between OEM Team, TCS team, Suppliers

TCS in MBSE



# TCS in MBSE



**8+** Customer Engagements



**INCOSE** Working Group Contributor



**10+** years of SysML Cross-industry Experience



System Requirement Decomposition & Maturation



System Architecture & Design



Simulation of System Functional behavior



Integration of System Engineering & Functional Safety



Expertise in Multiple Tools & Tool Chain Integration



ADAS



Body - Chassis



Infotainment



Powertrain




Electrification

# Thank you

Contact : [IoT.De@tcs.com](mailto:IoT.De@tcs.com)

# Authoring System requirements



 Toolbox used -  
Simulink Requirements

Index	ID	Summary	Type	Implemented	TypeOfReq
Motor control System Requirements_System_V1					
1	EV_1	Motor Control System functionality	Container		System
1.1	Sys_1.1	Produce required torque	Functional		System
1.2	Sys_1.2	Communication with DMS	Functional		System
1.3	Sys_1.3	Communication with PMS	Functional		System
1.4	Sys_1.4	Regenerative braking	Functional		System
1.5	Sys_1.5	Perform Diagnostics	Functional		System
1.6	Sys_1.6	Feedback to driving management system	Functional		System
2	EV_2	Driving Management System functionality	Functional		System
3	EV_3	Power Management System functionality	Functional		System
Motor control System Requirements_SubSystem_V1					
Motor control System Requirements_Software_V1					

Requirement: Sys\_1.1

Details

**Properties**

Type: Functional

Index: 1.1

Custom ID: Sys\_1.1

Summary: Produce required torque

Description Rationale

Motor Control System shall produce required torque as per driver request.

Keywords:

Revision information:

Custom Attributes

Links

Derives:

- [Sub\\_Sys\\_1.1.1 Actual Torque Estimation](#)
- [Sub\\_Sys\\_1.1.2 Sensor Validity](#)

Specify System requirements consistent with Stakeholder requirements, functional boundaries, functions, constraints, critical performance measures

# System Architecture & Requirement Allocation



Toolbox used - System Composer

Identify system elements, interaction between them to satisfy the system requirements.

TATA CONSULTANCY SERVICES

21 | Building on belief

Toolbox used - System Composer

Establish "implements" relationship between architectural elements and requirements

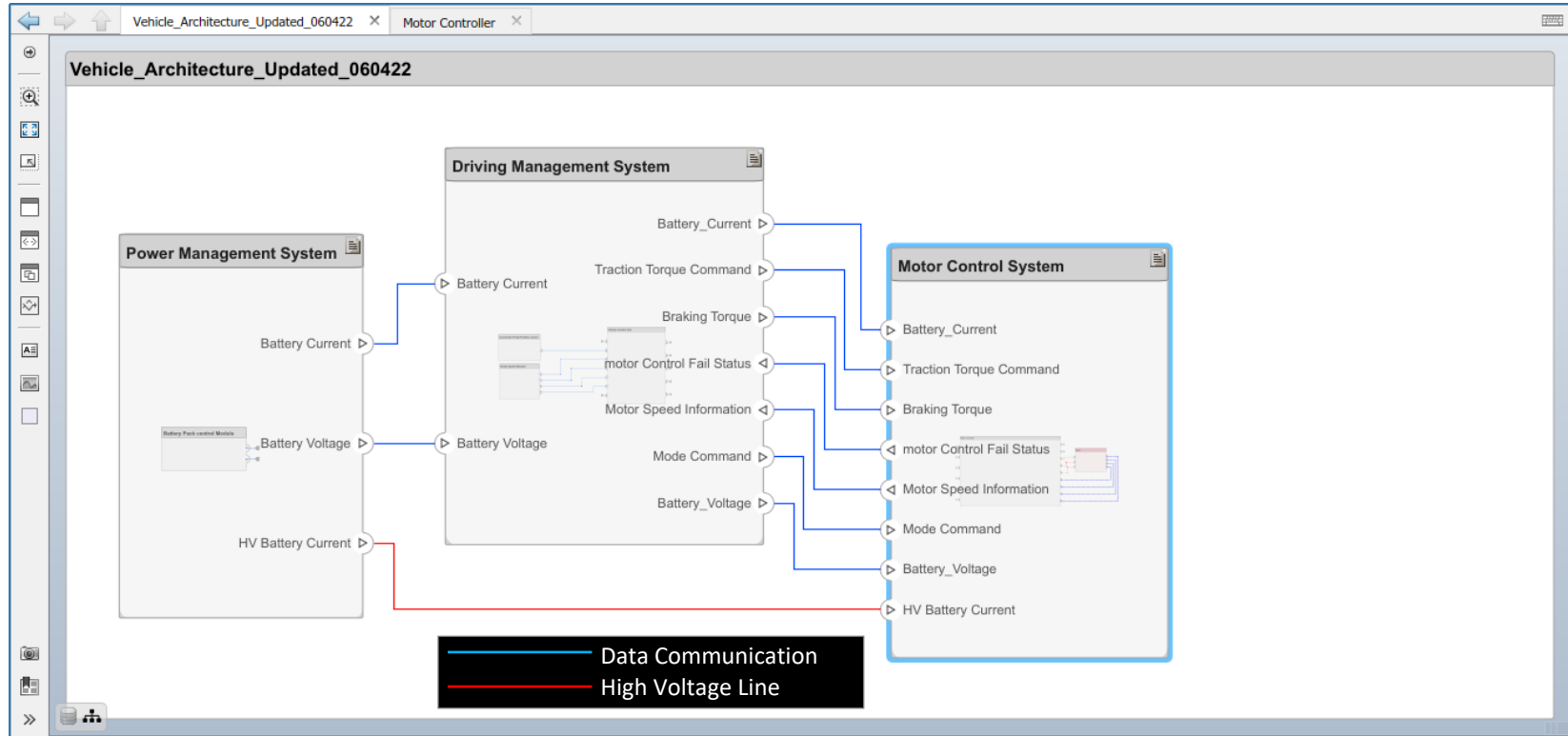
Requirements - Vehicle\_Architecture\_Updated\_060422

View: Requirements

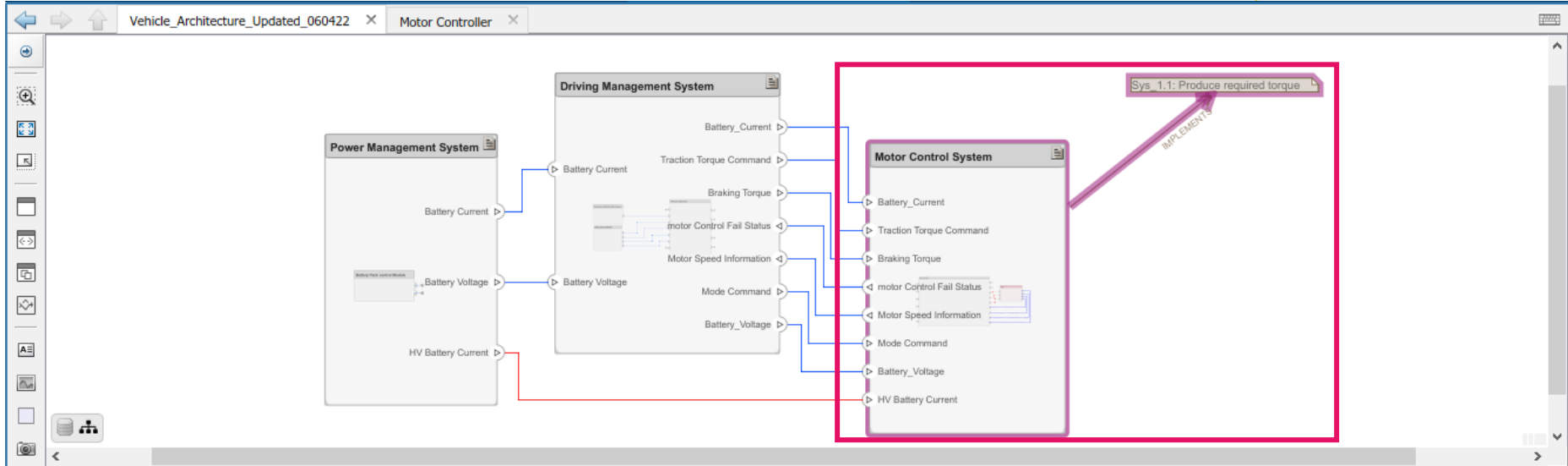
Index	ID	Summary
1	EV_1	Motor Control System functionality
1.1	Sys_1.1	Produce required torque
1.2	Sys_1.2	Communication with DMS
1.3	Sys_1.3	Communication with PMS

TATA CONSULTANCY SERVICES

22 | Building on belief



Identify system elements, interaction between them to satisfy the system requirements.



Requirements - Vehicle\_Architecture\_Updated\_060422

View: Requirements

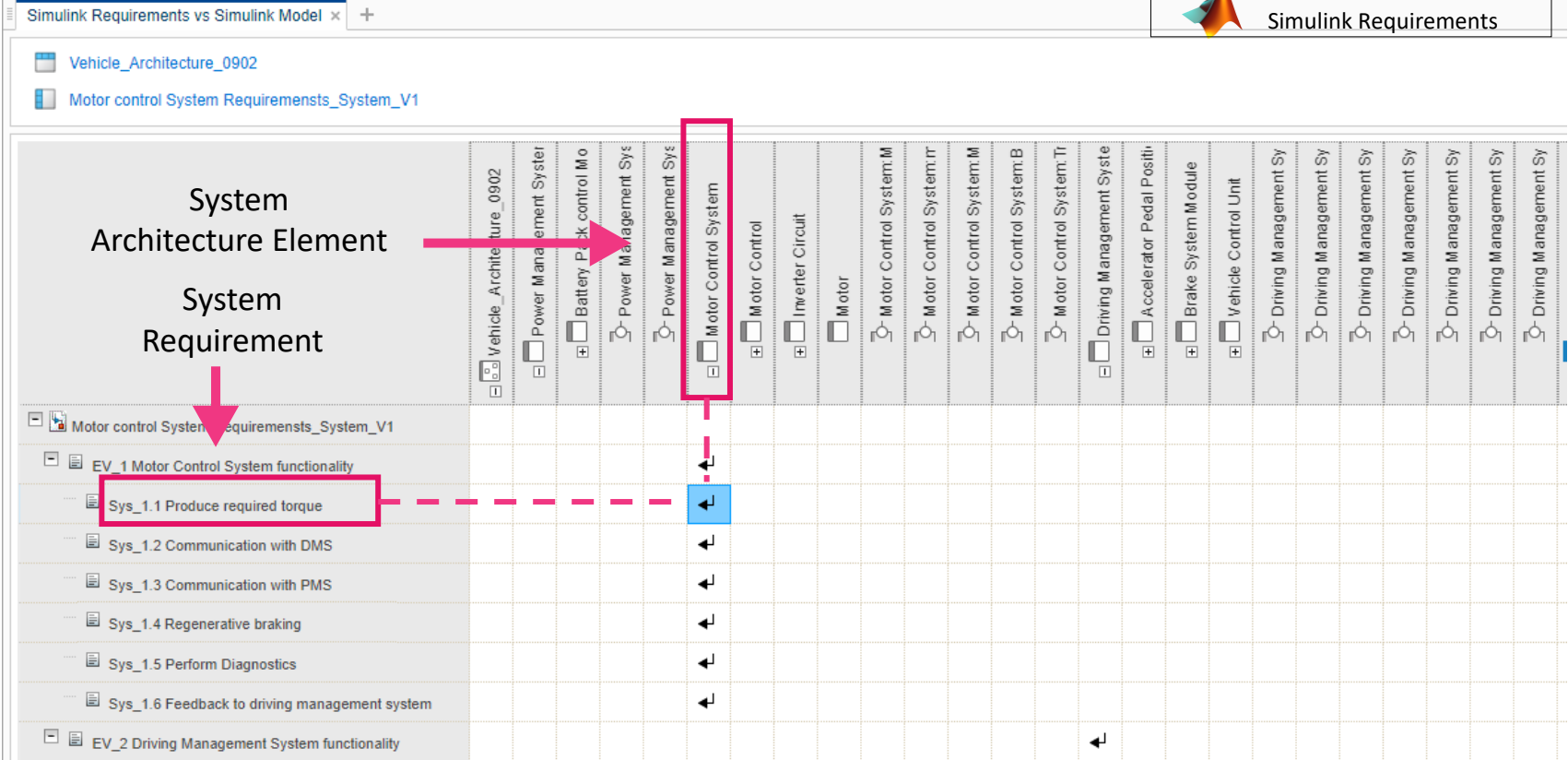
Index	ID	Summary
Motor control System Requirements_System_V1		
1	EV_1	Motor Control System functionality
1.1	Sys_1.1	Produce required torque
1.2	Sys_1.2	Communication with DMS
1.3	Sys_1.3	Communication with PMS

Establish “implements” relationship between architectural elements and requirements

# System Req to System Architecture traceability



Toolbox used -  
Simulink Requirements



Establish and maintain traceability between System Requirements and System Architecture elements

# Traceability



Motor control System Requirements - V1

Motor control System Requirements - SubSystem\_V1

System Requirement

Sub-System Requirement

Toolbox used - Simulink Requirements

Building on belief

25

Detailed description: This screenshot shows a hierarchical tree view of requirements. The 'System Requirement' level is expanded to show 'Motor control System Requirements - V1'. Underneath, the 'Sub-System Requirement' level is expanded to show 'Motor control System Requirements - SubSystem\_V1'. A red box highlights 'Sub\_Sys\_1.1.4 Actuated Torque Production', which is linked to a requirement 'Sys\_1.1 Produce required torque' at the system level. A red arrow points from the system requirement to the sub-system requirement. The TCS logo is in the bottom left.

Motor control System Requirements - SubSystem\_V1

Motor control System Requirements - Software\_V1

Sub-System Requirement

Software Requirement

Toolbox used - Simulink Requirements

Building on belief

26


Detailed description: This screenshot shows a hierarchical tree view of requirements. The 'Sub-System Requirement' level is expanded to show 'Motor control System Requirements - Software\_V1'. Underneath, the 'Software Requirement' level is expanded to show 'Software\_1.1.4.4 Generate stator dq voltage', which is linked to a requirement 'Sub\_Sys\_1.1.4 Actuated Torque Production' at the sub-system level. A red box highlights the software requirement, and a red arrow points from the sub-system requirement to the software requirement. The TCS logo is in the bottom left.

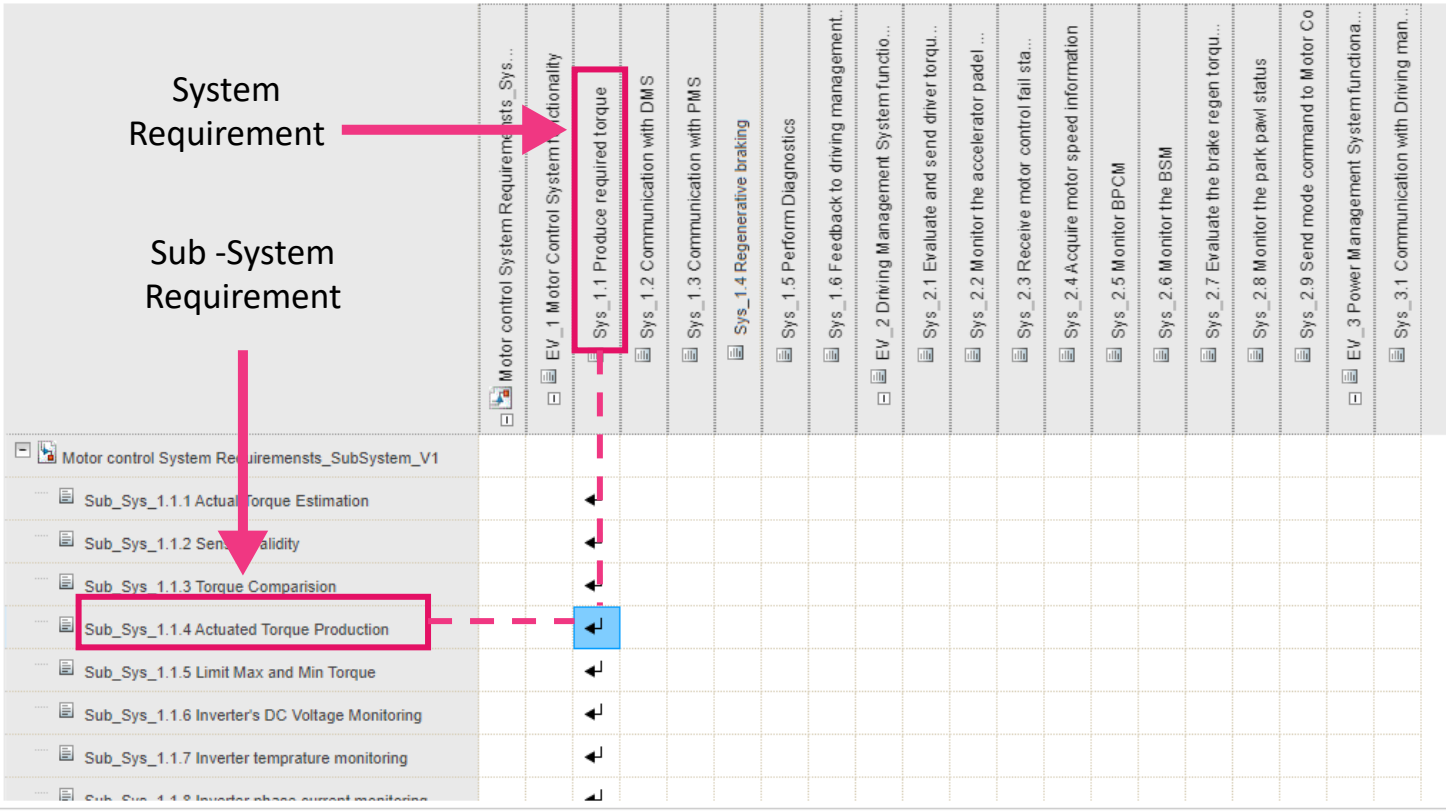
End to End traceability can be maintained. System<->Sub System<-> Software and component requirements






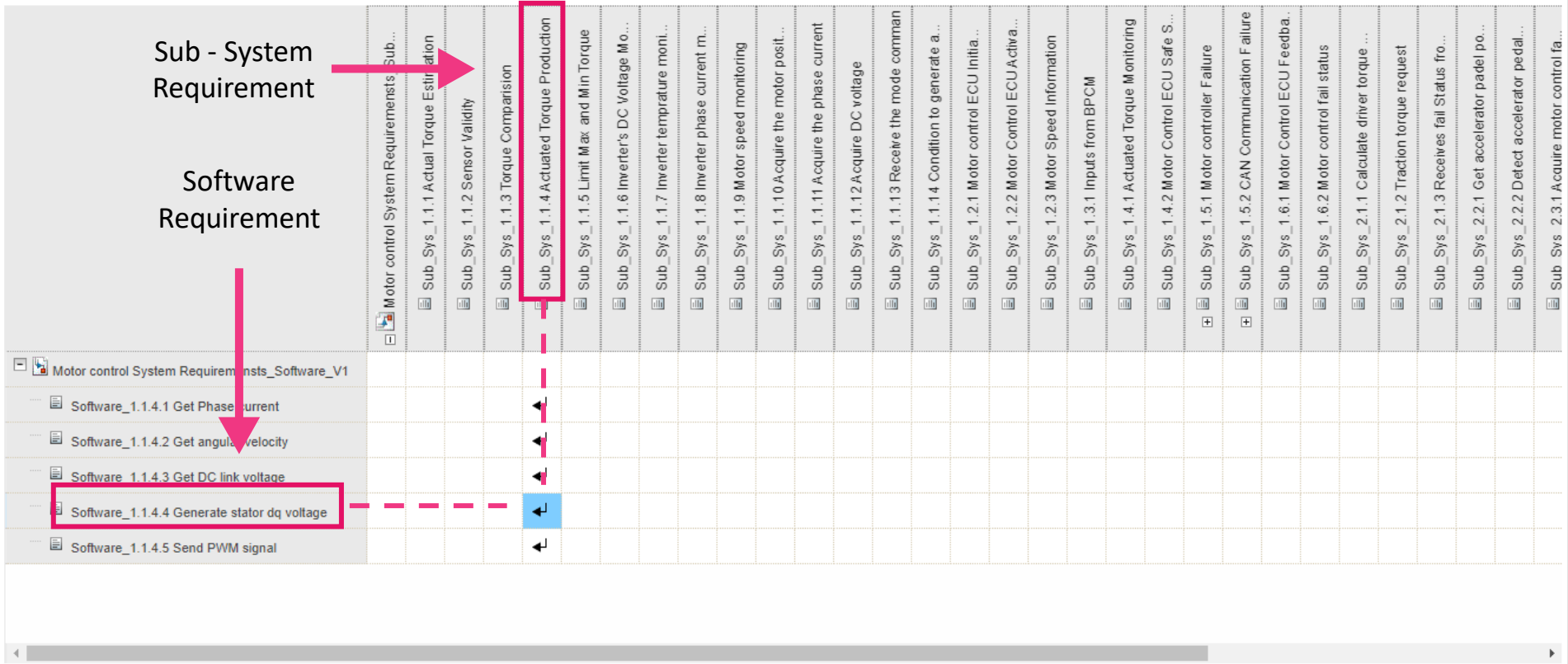
- Motor control System Requirements\_System\_V1
- Motor control System Requirements\_SubSystem\_V1

 Toolbox used -  
Simulink Requirements





 **Toolbox used -  
Simulink Requirements**



# Sub System requirements Authoring



Toolbox used -  
Simulink Requirements

The screenshot displays the Simulink Requirements tool interface. On the left, a table lists various requirements under the 'Motor control System Requirements' hierarchy. Requirement 'Sub\_Sys\_1.1.4' is highlighted with a red box. On the right, a detailed view for 'Requirement: Sub\_Sys\_1.1.4' is shown, including its type (Functional), index (4), custom ID (Sub\_Sys\_1.1.4), and summary (Actuated Torque Production). The description field contains the text: 'Motor Control ECU shall generate equivalent PWM signal based on commanded torque and feedback motor parameters(Speed position, feedback current and voltage)'. Below the description, there are sections for 'Keywords', 'Revision information', 'Custom Attributes', and 'Links', which includes 'Derived from' and 'Derives'.

Index	ID	Summary	Type	Implemented	TypeOfReq
> Motor control System Requirements_System_V1					
> Motor control System Requirements_SubSystem_V1					
1	Sub_Sys_1.1.1	Actual Torque Estimation	Functional	Implemented	Sub System
2	Sub_Sys_1.1.2	Sensor Validity	Functional	Implemented	Sub System
3	Sub_Sys_1.1.3	Torque Comparison	Functional	Implemented	Sub System
4	Sub_Sys_1.1.4	Actuated Torque Production	Functional	Implemented	Sub System
5	Sub_Sys_1.1.5	Limit Max and Min Torque	Functional	Implemented	Sub System
6	Sub_Sys_1.1.6	Inverter's DC Voltage Monitoring	Functional	Implemented	Sub System
7	Sub_Sys_1.1.7	Inverter temperature monitoring	Functional	Implemented	Sub System
8	Sub_Sys_1.1.8	Inverter phase current monitoring	Functional	Implemented	Sub System
9	Sub_Sys_1.1.9	Motor speed monitoring	Functional	Implemented	Sub System
10	Sub_Sys_1.1.10	Acquire the motor position	Functional	Implemented	Sub System
11	Sub_Sys_1.1.11	Acquire the phase current	Functional	Implemented	Sub System
12	Sub_Sys_1.1.12	Acquire DC voltage	Functional	Implemented	Sub System
13	Sub_Sys_1.1.13	Receive the mode command	Functional	Implemented	Sub System
14	Sub_Sys_1.1.14	Condition to generate actuated torque	Functional	Implemented	Sub System
15	Sub_Sys_1.2.1	Motor control ECU Initialization	Functional	Implemented	Sub System
16	Sub_Sys_1.2.2	Motor Control ECU Activation for Torque	Functional	Implemented	Sub System
17	Sub_Sys_1.2.3	Motor Speed Information	Functional	Implemented	Sub System
18	Sub_Sys_1.3.1	Inputs from BPCM	Functional	Implemented	Sub System
19	Sub_Sys_1.4.1	Actuated Torque Monitoring	Functional	Implemented	Sub System
20	Sub_Sys_1.4.2	Motor Control ECU Safe State for Torque Product...	Functional	Implemented	Sub System
> 21	Sub_Sys_1.5.1	Motor controller Failure	Container	Implemented	Sub System
> 21.1	Sub_Sys_1.5.1.1	Sensor Failure	Container	Implemented	Unset
> 21.2	Sub_Sys_1.5.1.2	Motor Control Failure	Container	Implemented	Unset

Derive Sub system requirements from System requirements. Requirement writing guidelines help to author quality requirements

# Defining Interfaces



Toolbox used - System Composer

Interfaces

	Type	Dimensions	Units	Complexity	Minimum	Maximum	De
MotorControl_FailS	boolean	1	NA	real	0	1	Feedback tr
Motor_Position	double	1	Degree	real	0	360	
Motor_Speed	double	1	RPM	real	-1200	1200	

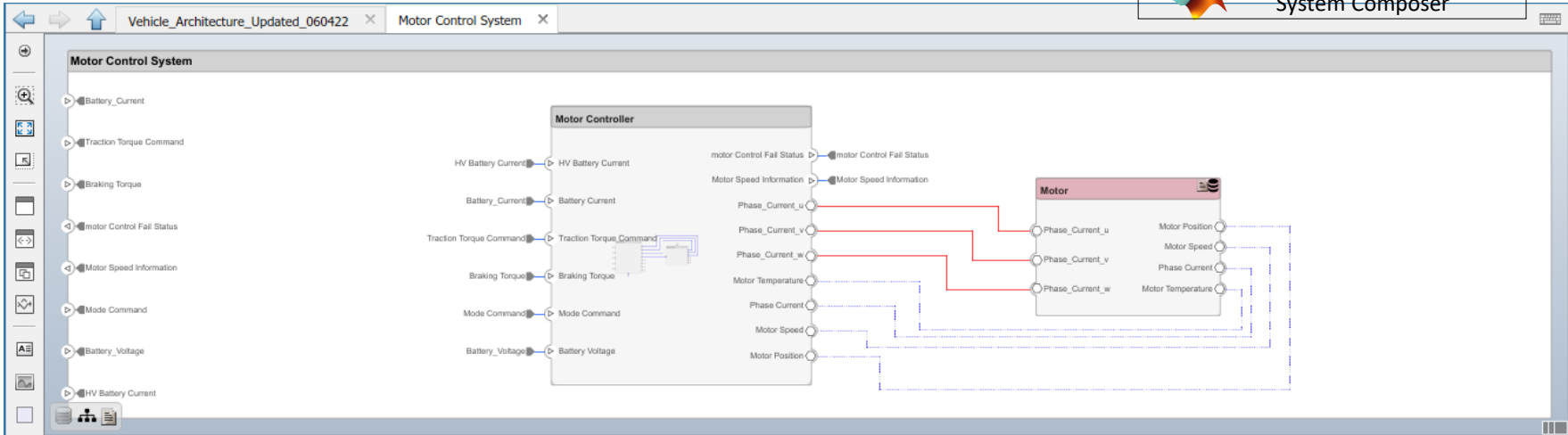
Perform interface definition for defining the required interface and understanding of architecture.

Toolbox used - System Composer

Simulink Bus: DC\_Voltage

Name	DataType	Complexity	Dimensions	Min	Max	Dimensions Mode	Unit	Description
DC_Voltage	double	real	1	0	450	Fixed	volt	

Defined interfaces are represented using data dictionary



Property Inspector

Interfaces

Search Dictionary View

	Type	Dimensions	Units	Complexity	Minimum	Maximum	De
MotorControl_FailS							
elem0	boolean	1	NA	real	0	1	Feedback fr
Motor_Position							
elem0	double	1	Degree	real	0	360	
Motor_Speed							
Motor_Speed	double	1	RPM	real	-1200	1200	

Perform interface definition for defining the required interface and understanding of architecture.



Contents of: ...LevelDD.sidd' (and below)

Column View: Dictionary Objects [Show Details](#) [15 object\(s\)](#)

Name	Status	Value	DataType	Dimensions
MotorControl_FailStatus	Mod			
Battery_Current				
Battery_Voltage				
Mode_Command				
Motor_Speed_Info				
RegReq_Or_Braking_Trq				
Traction_Trq_Command				
DC_Current				
Phase_Current				
Motor_Temperature				
DC_Voltage				
Inverter_Temperature				
Motor_Position	Mod			
Motor_Speed				
PWM				

Contents | Search Results

### Simulink.Bus: DC\_Voltage

Launch Bus Editor

Design | Code Generation

Bus elements

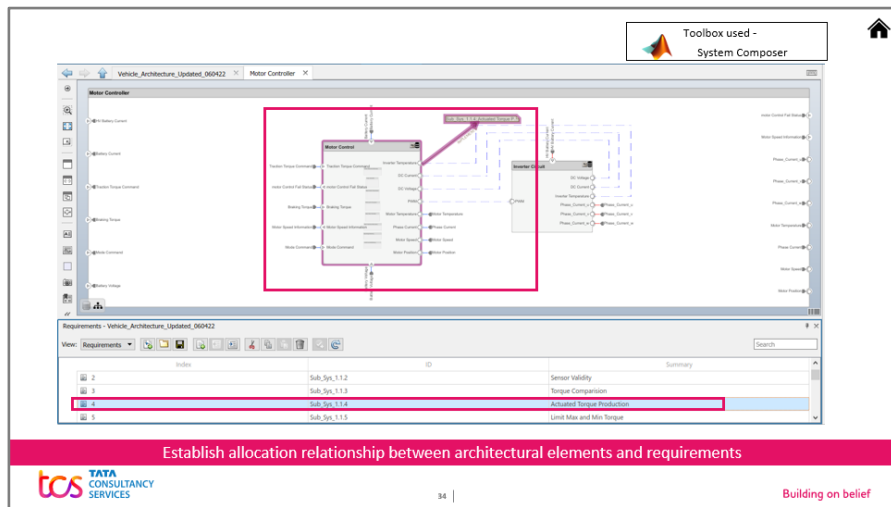
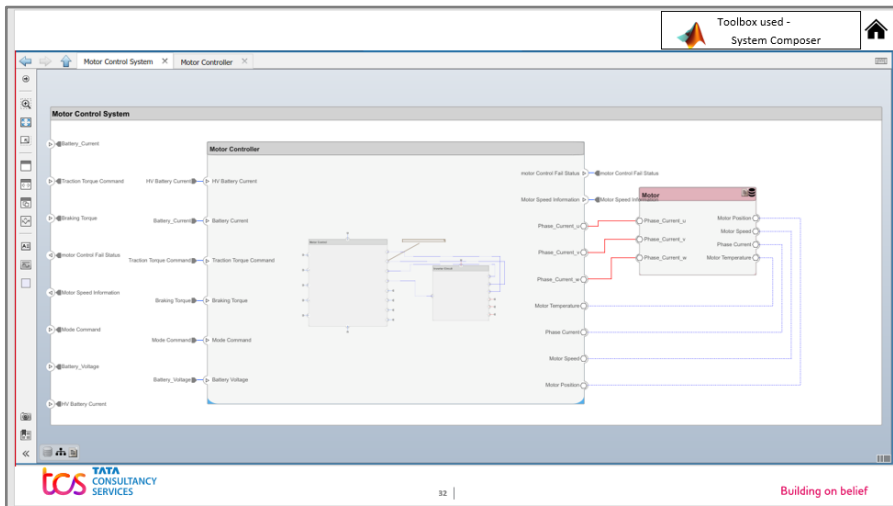
Name	DataType	Complexity	Dimensions	Min	Max	Dimensions Mode	Unit	Description
DC_Voltage	double	real	1	0	450	Fixed	volt	

Description:

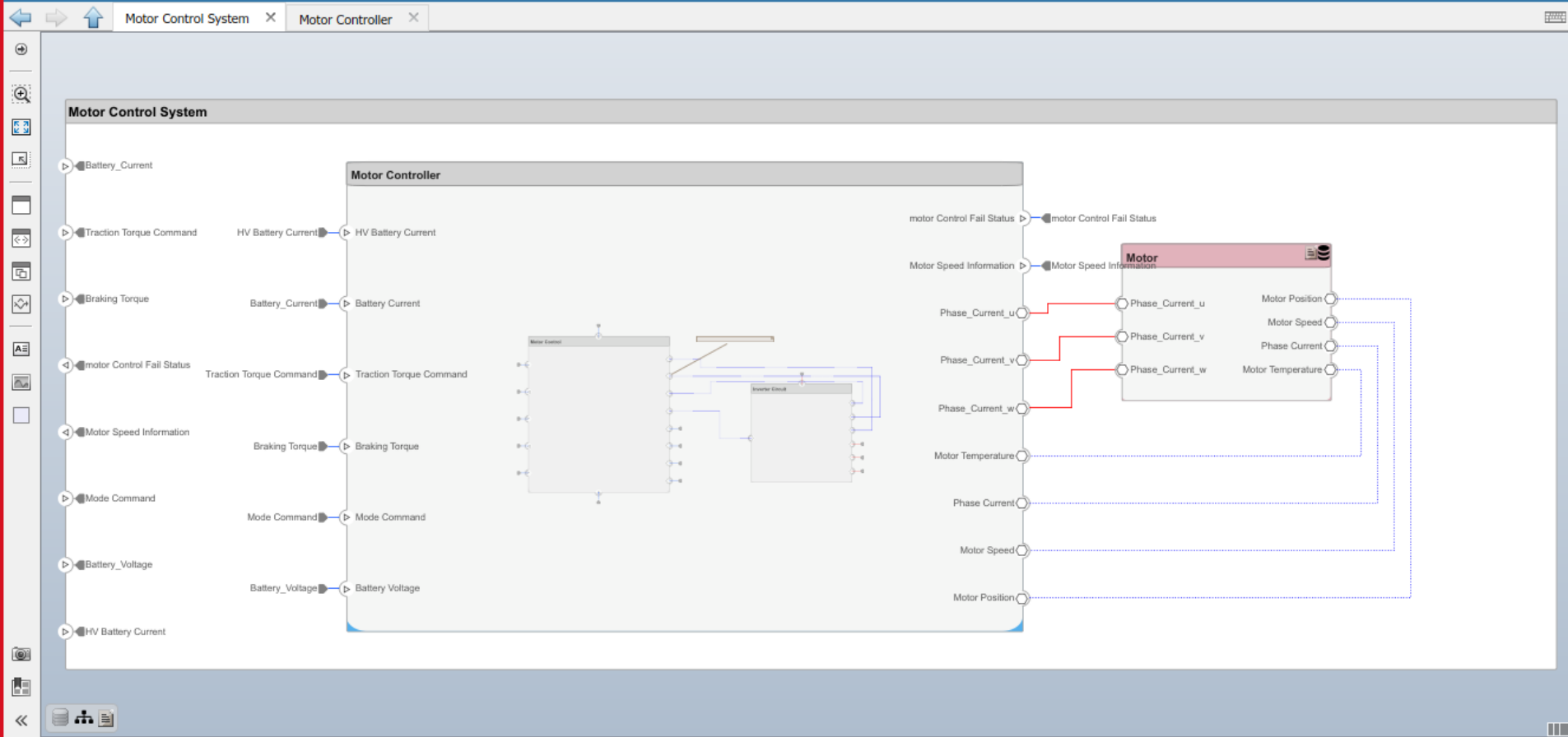
Revert | Help | Apply

Defined interfaces are represented using data dictionary

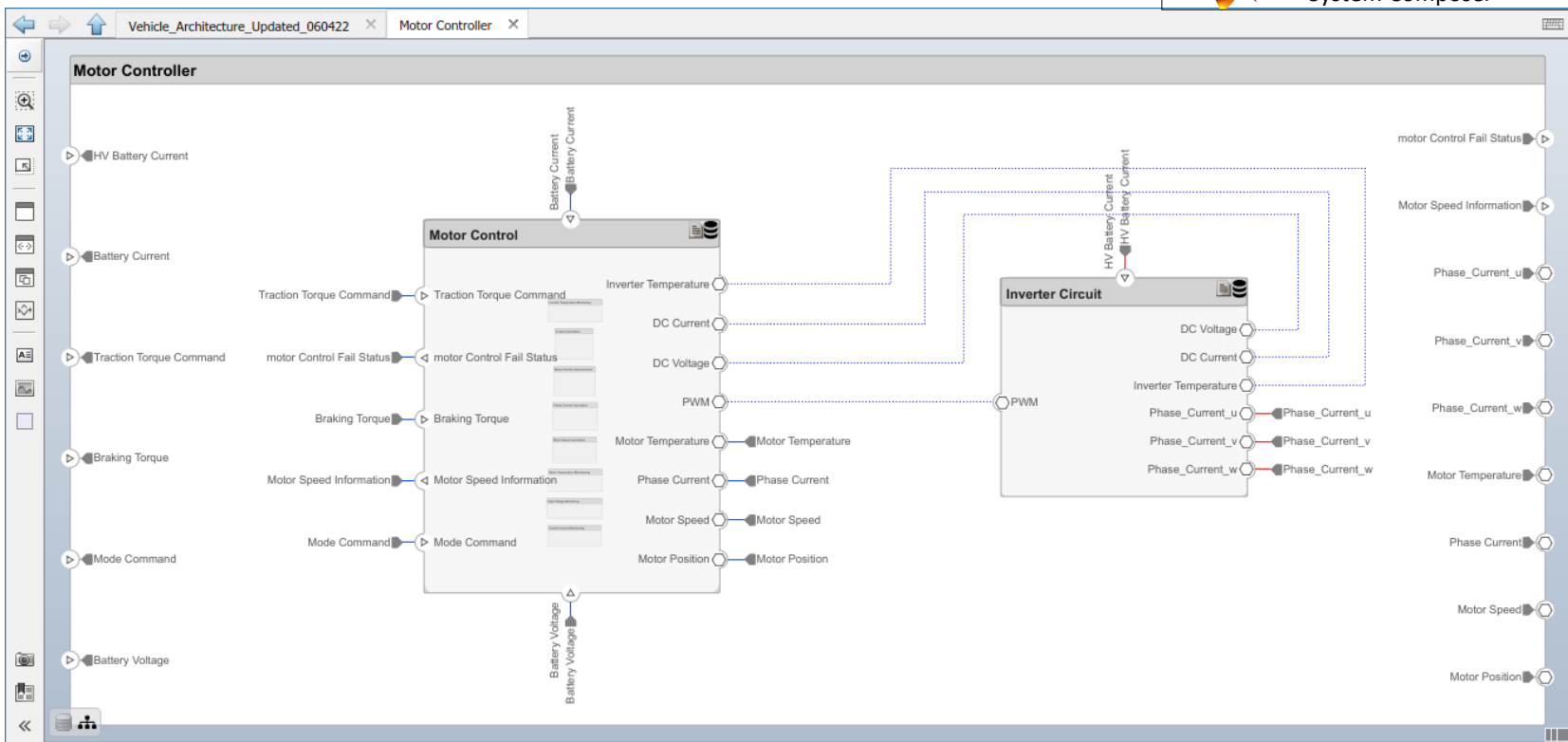
# Sub System Architecture & Requirement Allocation



Establish allocation relationship between architectural elements and requirements










The screenshot displays the System Composer interface for a vehicle architecture. The main workspace shows a 'Motor Controller' block and an 'Inverter Circuit' block. A pink box highlights a specific allocation relationship between 'Sub\_Sys\_1.1.4 / Actuated Torque Pk' and 'Actuated Torque Production'. Below the workspace, a 'Requirements' table is visible, with the row for 'Sub\_Sys\_1.1.4' and 'Actuated Torque Production' highlighted in pink.

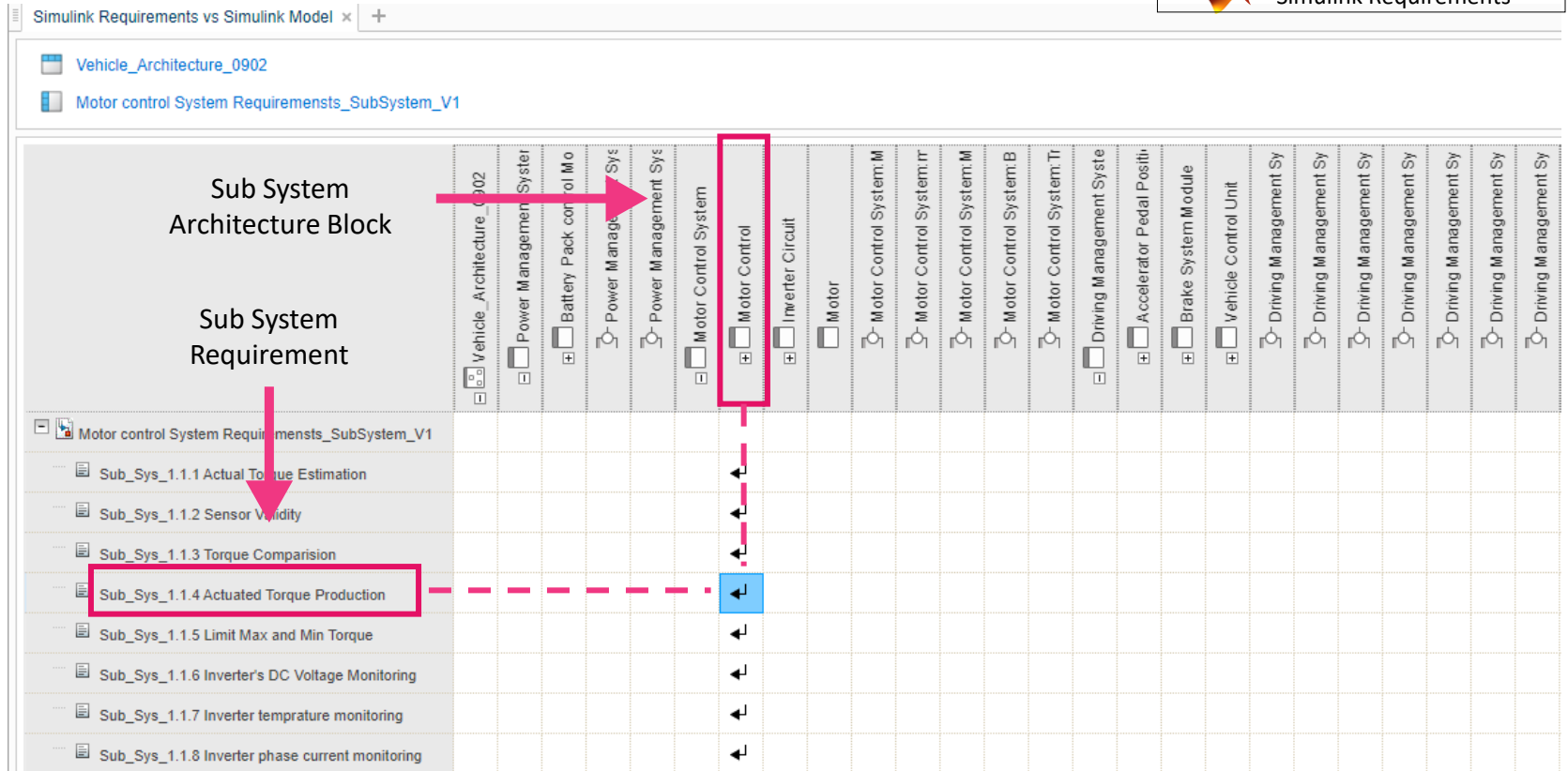
Index	ID	Summary
2	Sub_Sys_1.1.2	Sensor Validity
3	Sub_Sys_1.1.3	Torque Comparison
4	Sub_Sys_1.1.4	Actuated Torque Production
5	Sub_Sys_1.1.5	Limit Max and Min Torque

Establish allocation relationship between architectural elements and requirements

# Sub System Requirement to Architecture Traceability



 Toolbox used -  
Simulink Requirements





# Software Requirements



Toolbox used -  
Simulink Requirements



Index	ID	Summary	Type	Implemented	TypeOfReq
> Motor control System Requiremensts_System_V1					
> Motor control System Requiremensts_SubSystem_V1					
✓ Motor control System Requiremensts_Software_V1					
1	Software_1.1.4.1	Get Phase current	Functional		Software
2	Software_1.1.4.2	Get angular velocity	Functional		Software
3	Software_1.1.4.3	Get DC link voltage	Functional		Software
4	Software_1.1.4.4	Generate stator dq voltage	Functional		Software
5	Software_1.1.4.5	Send PWM signal	Functional		Software

Requirement: Software\_1.1.4.4

Details

Type: Functional

Index: 4

Custom ID: Software\_1.1.4.4

Summary: Generate stator dq voltage

Description

Rationale

rial 10 B I U

Current control module shall generate stator dq voltage based on torque request, phase current, angular velocity and DC voltage.

Keywords:

Revision information:

Custom Attributes

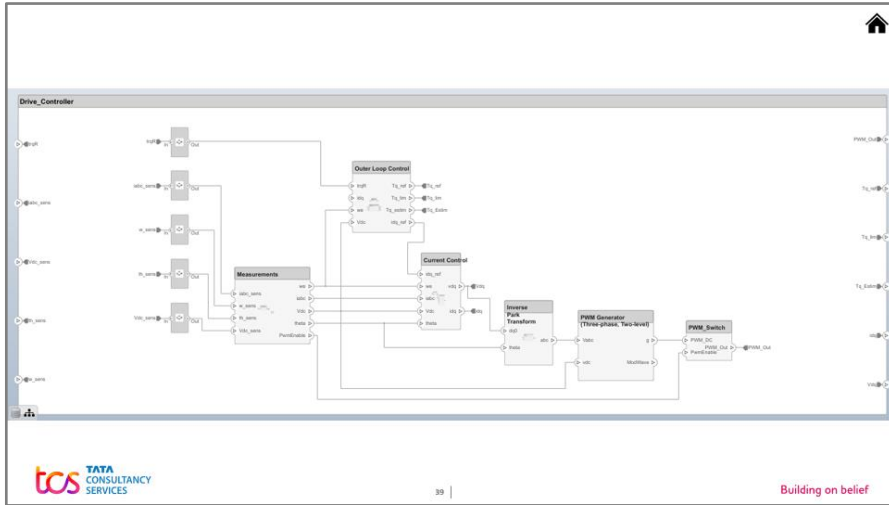
Links

Derived from:

[Sub\\_Sys\\_1.1.4 Actuated Torque Production](#)

Implemented by:

[Drive\\_Controller](#)



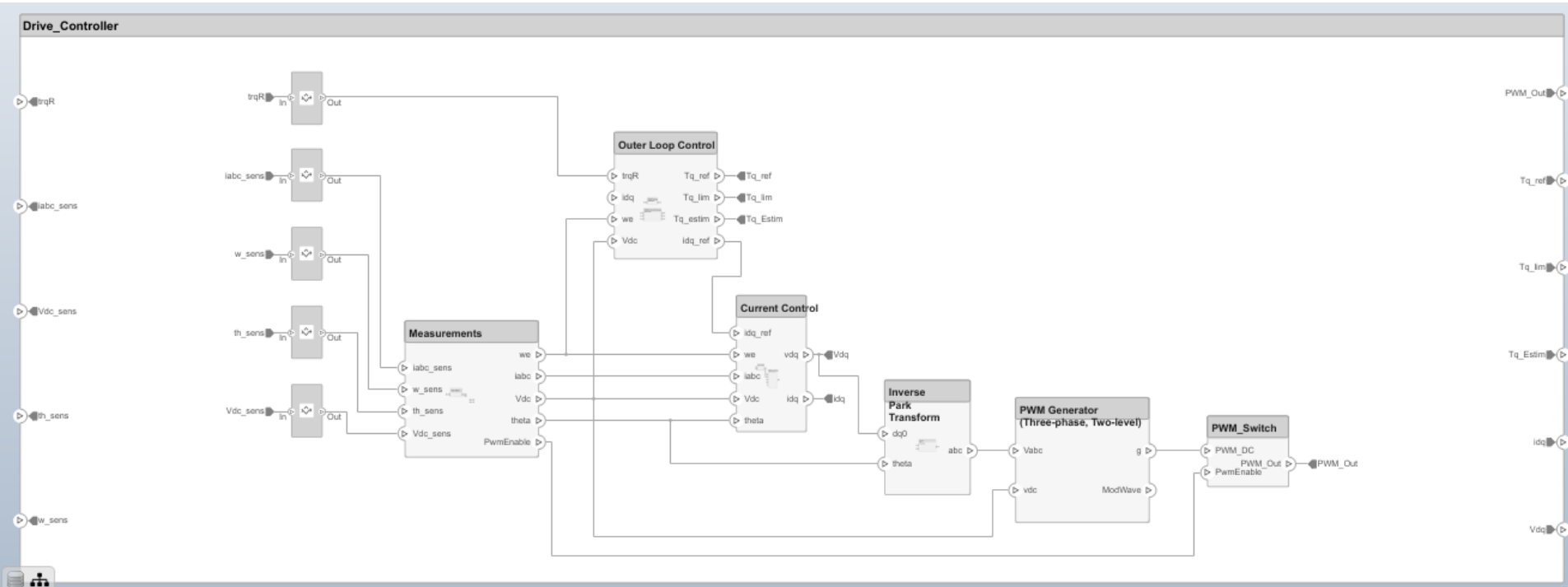
39

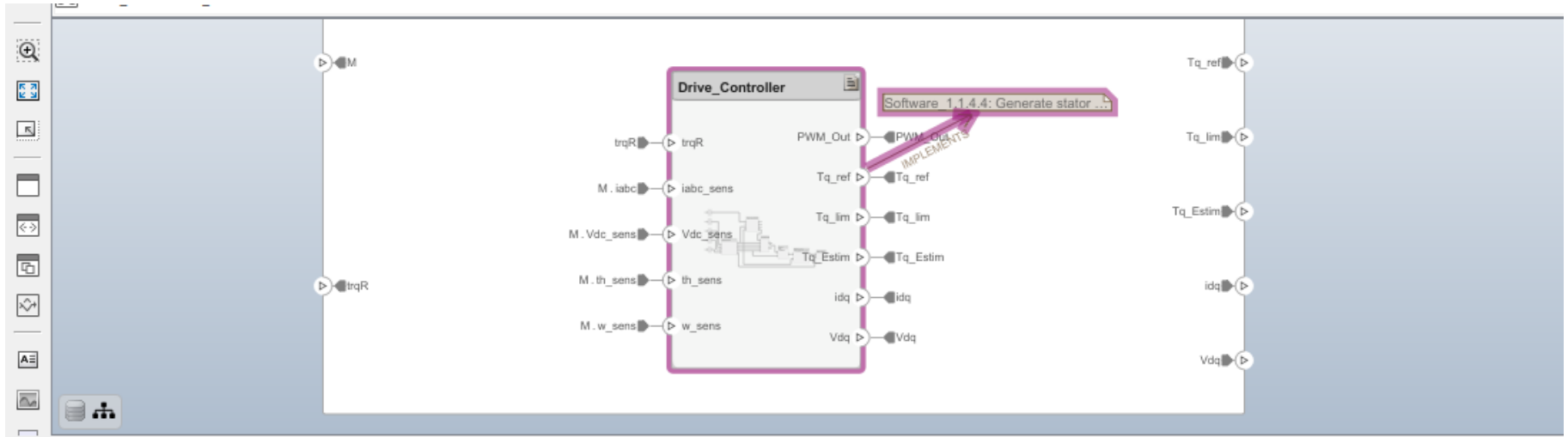
Building on belief

Index	ID	Summary
1	Software_1.1.4.1	Get Phase current
2	Software_1.1.4.2	Get angular velocity
3	Software_1.1.4.3	Get DC link voltage
4	Software_1.1.4.4	Generate stator dq voltage

40

Building on belief





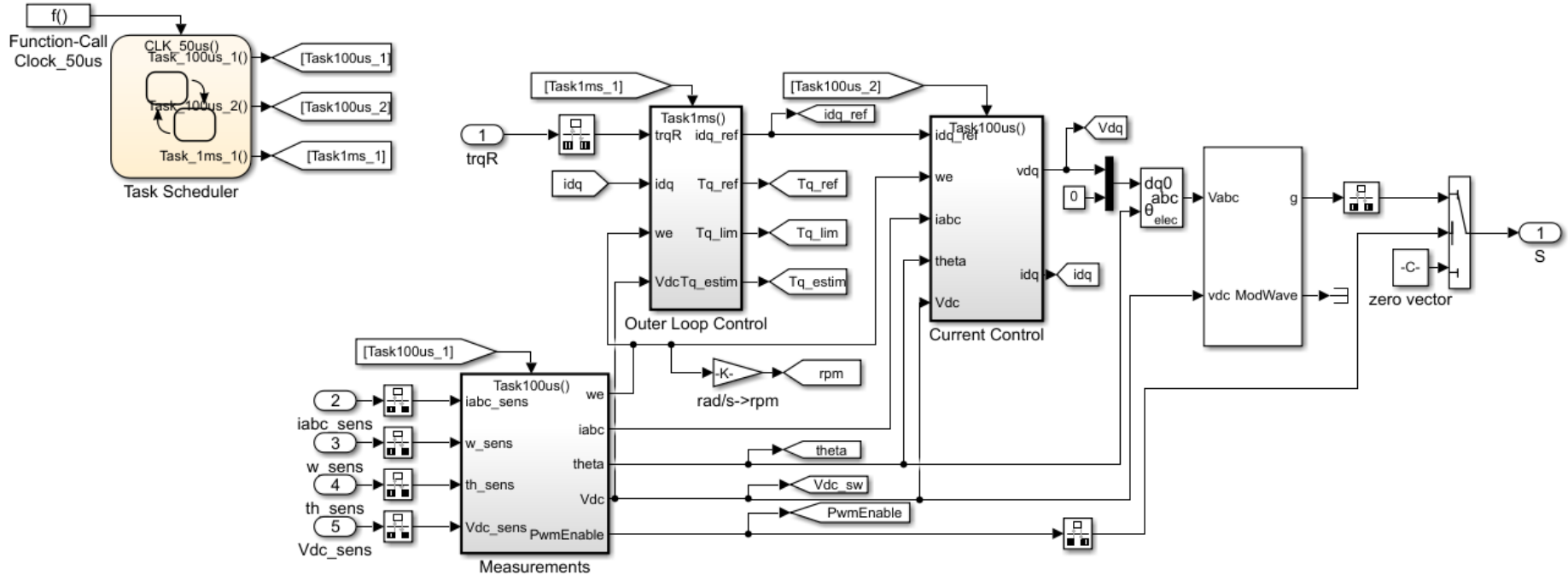
Requirements - Drive\_Controller\_Arch

View: Requirements

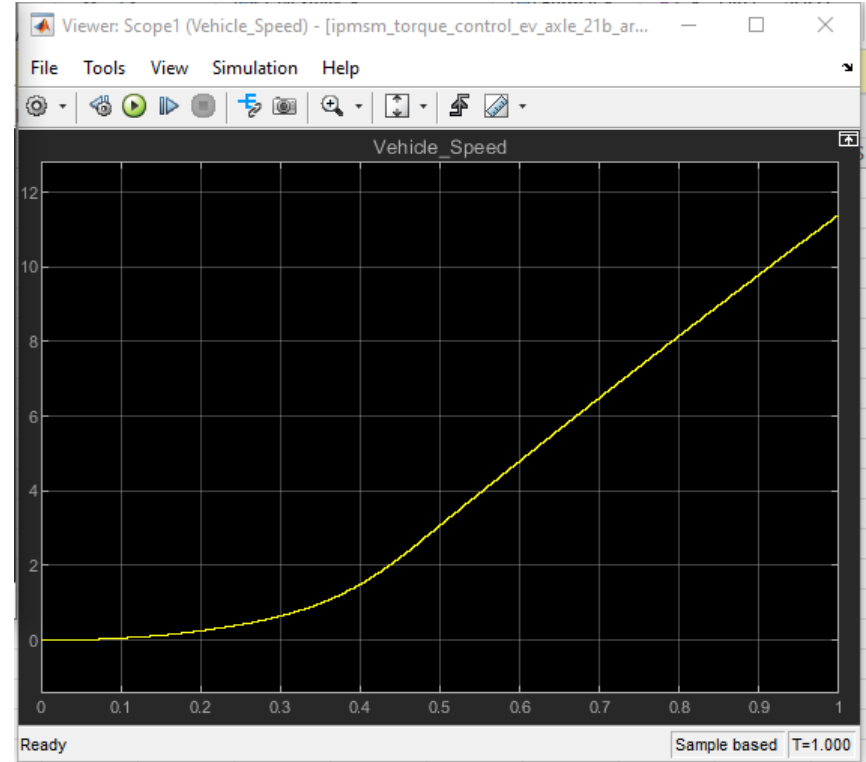
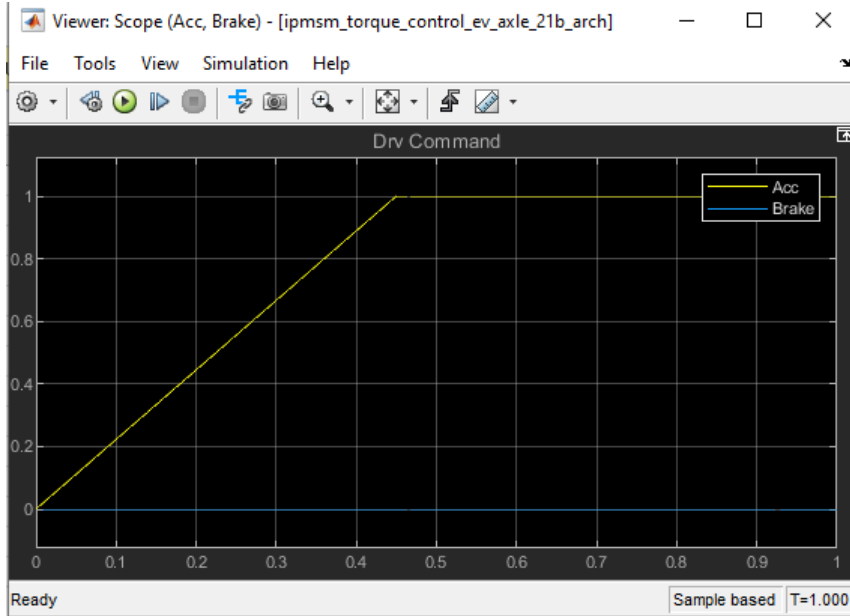
Index	ID	Summary
Motor control System Requirements_Software_V1		
1	Software_1.1.4.1	Get Phase current
2	Software_1.1.4.2	Get angular velocity
3	Software_1.1.4.3	Get DC link voltage
4	Software_1.1.4.4	Generate stator dq voltage
5	Software_1.1.4.5	Generate PWM signal



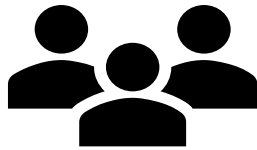
# Software Design and Implementation



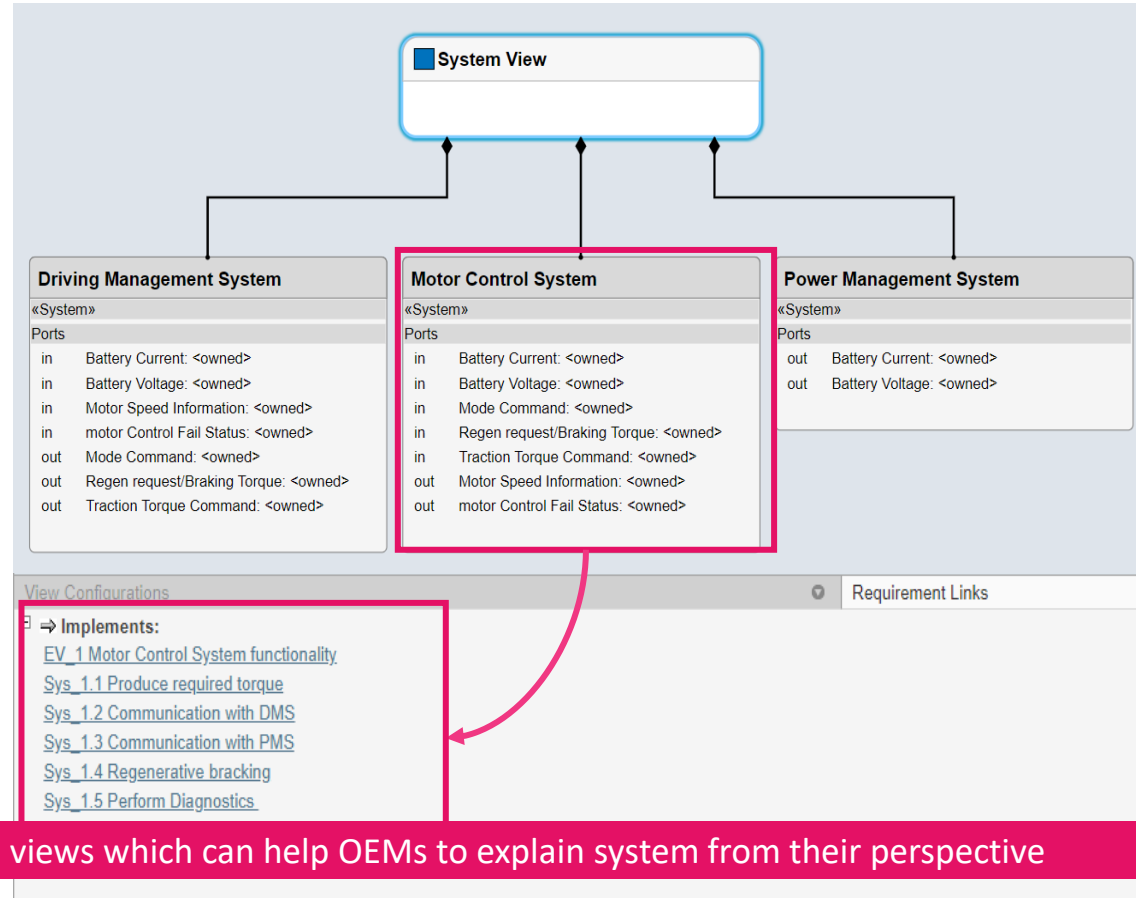
# System Verification



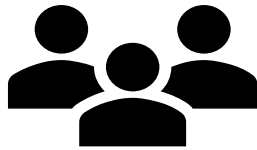




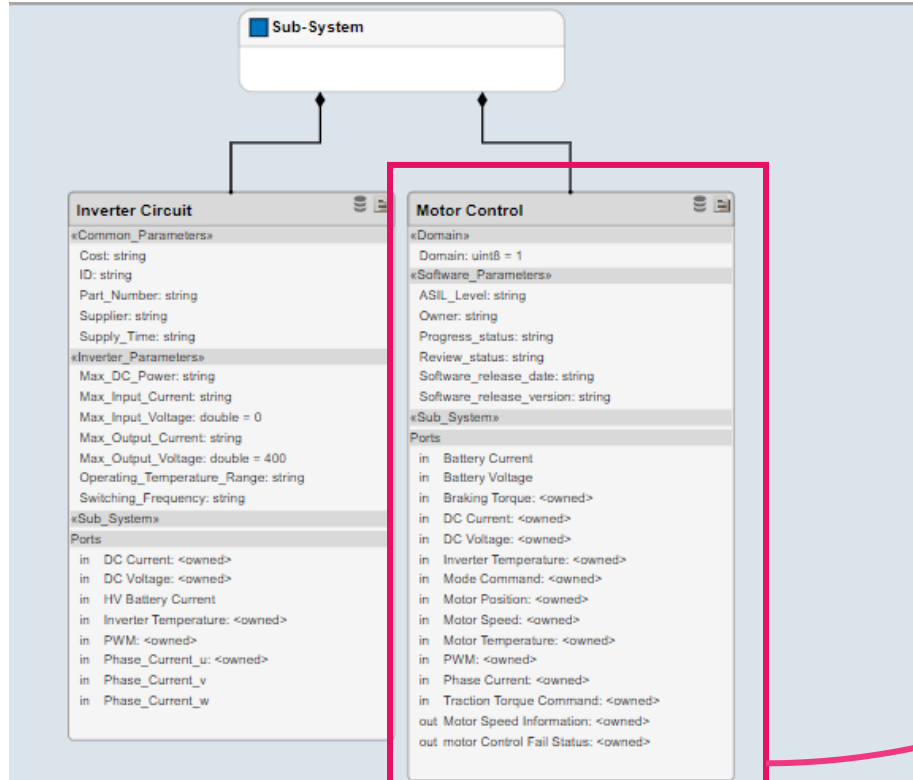
OEM  
Perspective



Apply stereotypes to see the System views which can help OEMs to explain system from their perspective



Tier 1  
Supplier  
Perspective

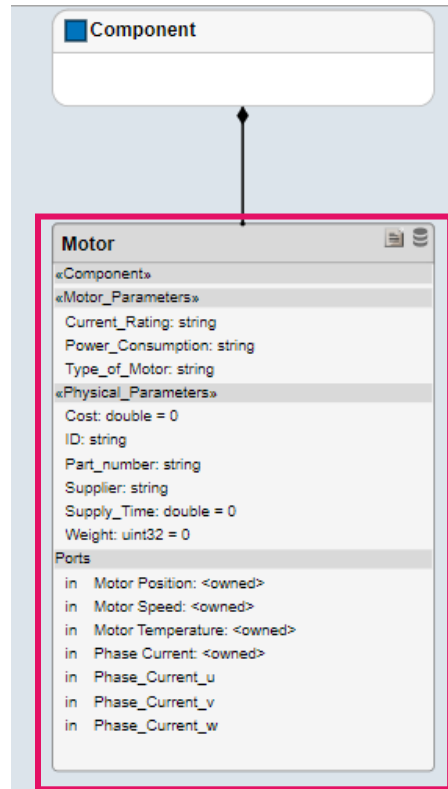


- ⇒ Implements:
- [Sub\\_Sys\\_1.1.1 Actual Torque Estimation](#)
  - [Sub\\_Sys\\_1.1.2 Sensor Validity](#)
  - [Sub\\_Sys\\_1.1.3 Torque Comparison](#)
  - [Sub\\_Sys\\_1.1.4 Actuated Torque Production](#)
  - [Sub\\_Sys\\_1.1.5 Limit Max and Min Torque](#)
  - [Sub\\_Sys\\_1.1.6 Inverter's DC Voltage Monitoring](#)
  - [Sub\\_Sys\\_1.1.7 Inverter temperature monitoring](#)
  - [Sub\\_Sys\\_1.1.8 Inverter phase current monitoring](#)
  - [Sub\\_Sys\\_1.1.9 Motor speed monitoring](#)
  - [Sub\\_Sys\\_1.1.10 Acquire the motor position](#)
  - [Sub\\_Sys\\_1.1.11 Acquire the phase current](#)
  - [Sub\\_Sys\\_1.1.12 Acquire DC voltage](#)
  - [Sub\\_Sys\\_1.1.13 Receive the mode command](#)
  - [Sub\\_Sys\\_1.1.14 Condition to generate actuated torque](#)
  - [Sub\\_Sys\\_1.2.1 Motor control ECU Initialization](#)
  - [Sub\\_Sys\\_1.2.2 Motor Control ECU Activation for Torque](#)
  - [Sub\\_Sys\\_1.2.3 Motor Speed Information](#)
  - [Sub\\_Sys\\_1.3.1 Inputs from BPCM](#)
  - [Sub\\_Sys\\_1.4.1 Actuated Torque Monitoring](#)
  - [Sub\\_Sys\\_1.4.2 Motor Control ECU Safe State for Torque Production](#)
  - [Sub\\_Sys\\_1.5.1 Motor controller Failure](#)
  - [Sub\\_Sys\\_1.5.2 CAN Communication Failure](#)

Generate the sub system view to share precise information with the Tier1 Supplier



## Motor Vendor Perspective



- ⇒ Implements:
- [Component\\_1.1.1 Produce torque](#)
- [Component\\_1.1.3 Torque production range](#)
- [Component\\_1.1.2 Equipped with motor position sensor](#)
- [Component\\_1.1.4 Motor temperature range](#)

Generate the component view to share with the vendors



## 1 Produce torque

**Requirement Type** Functional

**ID** Component\_1.1.1

### Description

Motor shall produce torque based on Phase current provided by Inverter

### Links

Artifact: Vehicle\_Architecture\_0902.slx

Linked Item	Link Type
<input type="checkbox"/> <a href="#">Motor</a>	↔ Implemented by

## 2 Equipped with motor position sensor

**Requirement Type** Functional

**ID** Component\_1.1.2

### Description

Motor shall be equipped with motor position sensor

### Links

Artifact: Vehicle\_Architecture\_0902.slx

Linked Item	Link Type
<input type="checkbox"/> <a href="#">Motor</a>	↔ Implemented by

## 3 Torque production range



Motor  
Specifications

Share the generated component specification along with the requirements with the vendor