



MODEL BASED DESIGN AND INTEGRATION TESTING OF OIL & GAS DRILLING TOOLS

MATLAB EXPO, June 26th, Munich

MOTIVATION & APPROACH

CASE STUDY

WRAP UP

COMPANY INFORMATION

We invent smarter ways to bring energy to the world

We are BHGE

Only BHGE has a fullstream capability: the portfolio, the technology, and the people to radically transform the industry and deliver unparalleled improvement in industrial yield for our customers.

120+

COUNTRIES

64K+

EMPLOYEES

\$22B*

COMBINED 2017 REVENUE

\$600M+*

COMBINED 2017 R&D SPEND



FULLSTREAM

Upstream

Evaluation

Drilling

Completion

Production & optimization

Midstream

Pipeline & storage

LNG

Downstream

Refinery

Petrochemical & fertilizer

Industrial power & processing

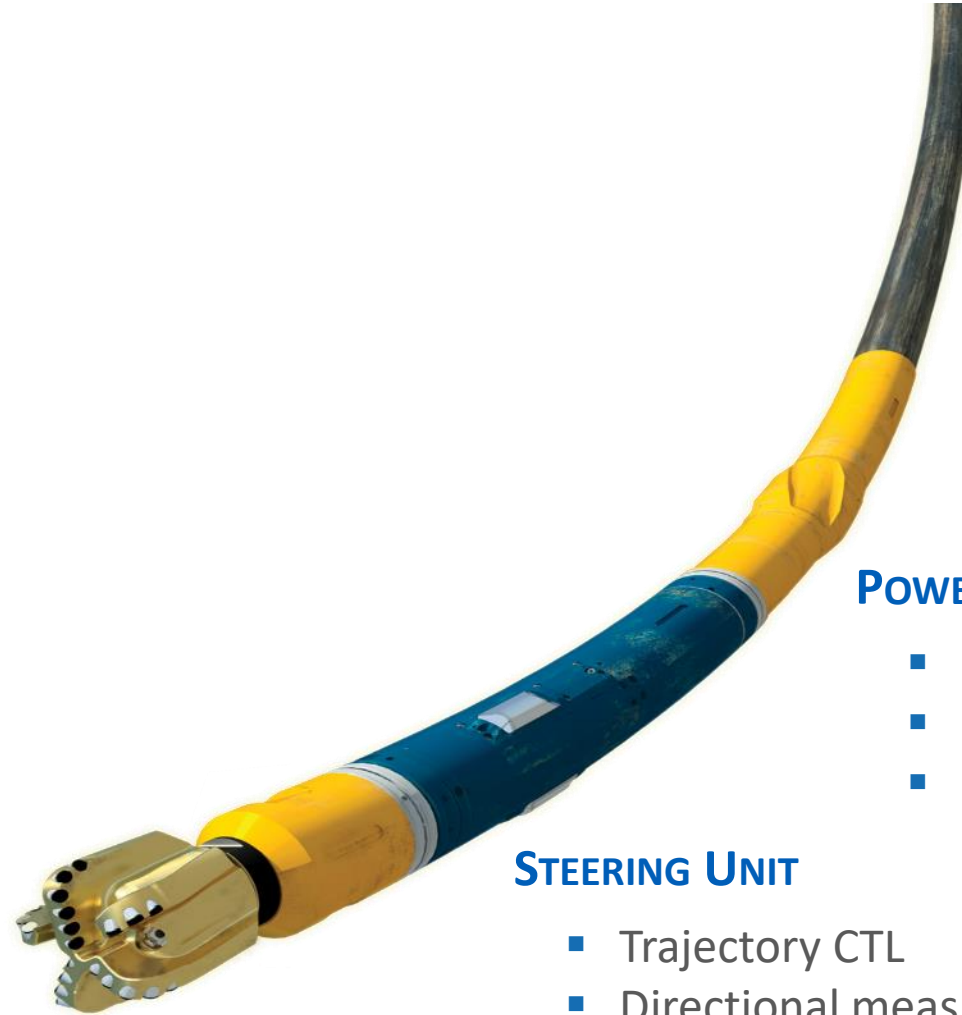
DRILLING AND EVALUATION

FUNCTIONS

- Logic driven systems
- Control systems
- Signal processing

ENVIRONMENT

- Depth: 10 km
- Pressure: 2000 bar
- Temperature: 175 °C



LOGGING WHILE DRILLING

- Formation evaluation

POWER & COM UNIT

- Generator CTL
- Pulser CTL
- Communication (≤ 40 bit/s)

STEERING UNIT

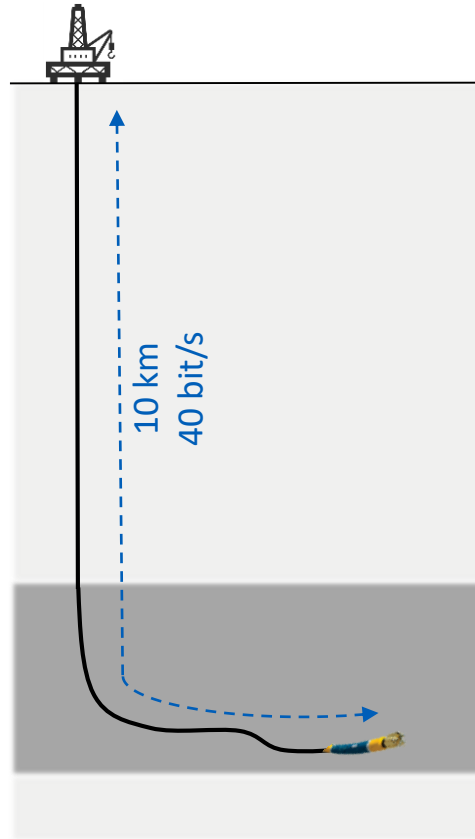
- Trajectory CTL
- Directional measurements

MOTIVATION

SYSTEM LEVEL TEST OF OIL AND GAS DRILLING TOOLS

LIMITED ACCESS

- Deep black hole
- No diagnostic plug
- Mud pulse telemetry



EXPENSIVE

- Time consuming
- Offshore rig
½...1 Mio. \$/day

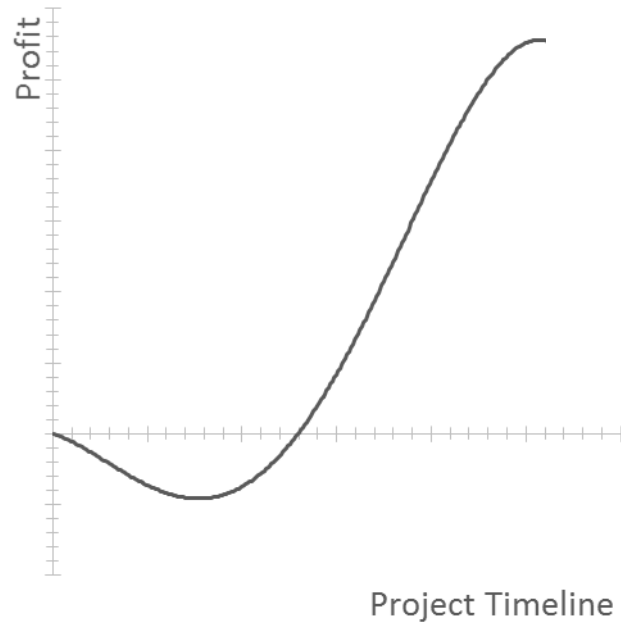
LIMITED POSSIBILITIES

- Error insertion

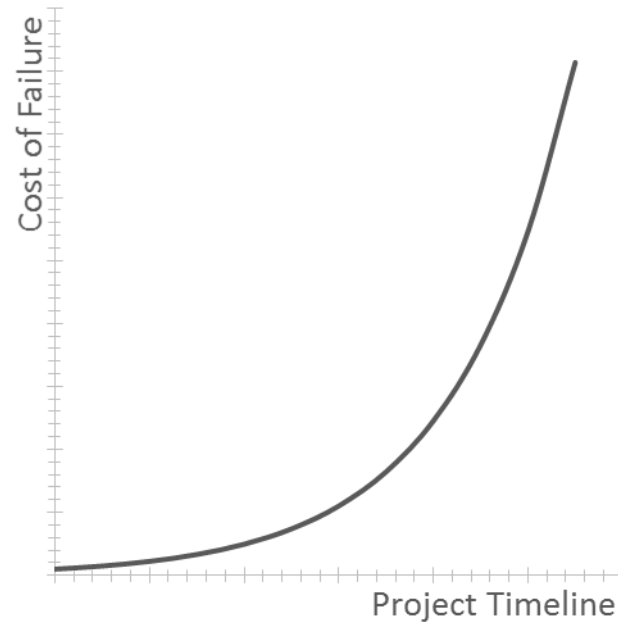


MOTIVATION

TIME TO MARKET



COST OF FAILURE

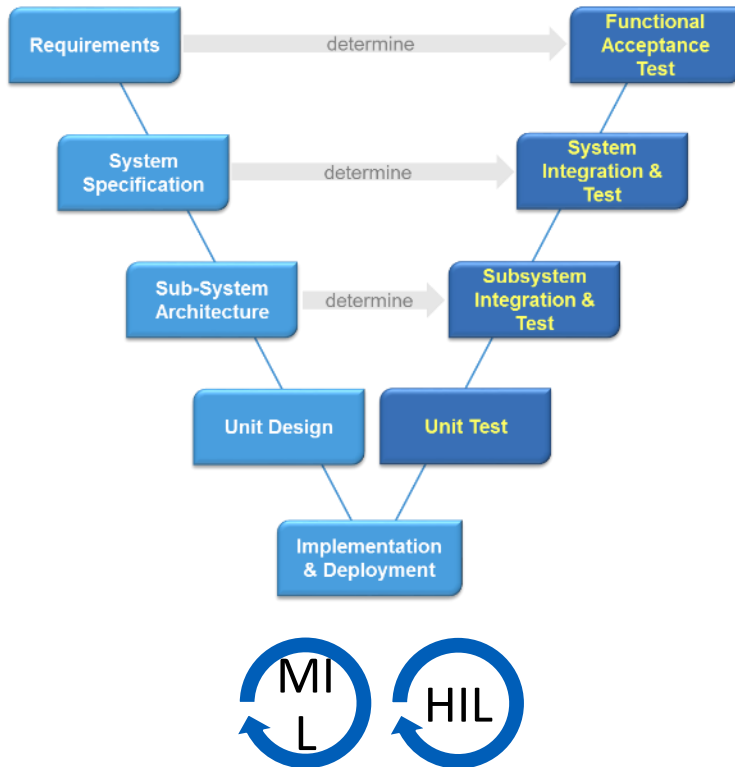


COMPANY REPUTATION

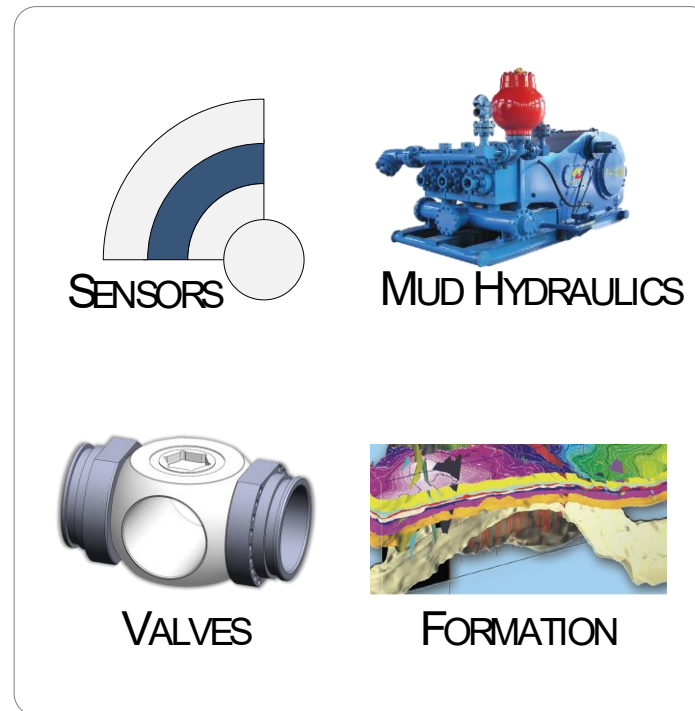


APPROACH

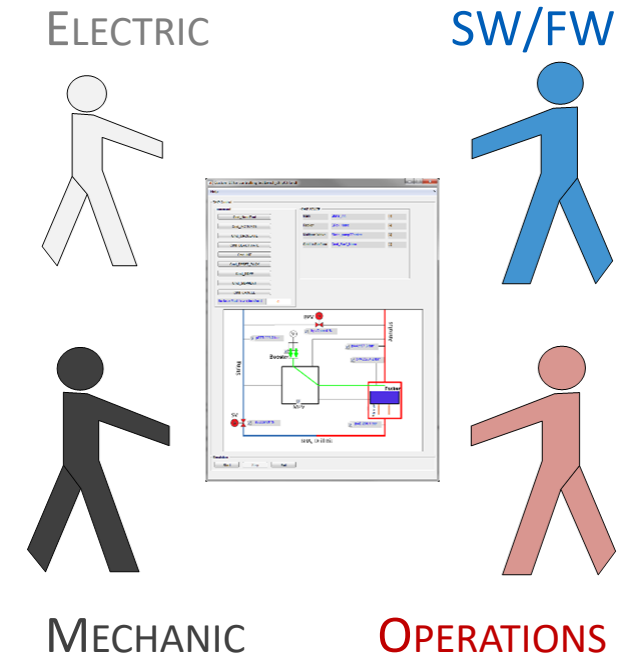
INTEGRATE AND TEST EARLY



MODEL WHAT YOU DON'T HAVE



INVOLVE „ALL“ DISCIPLINES



CASE STUDY - DOWNHOLE ISOLATION PACKER

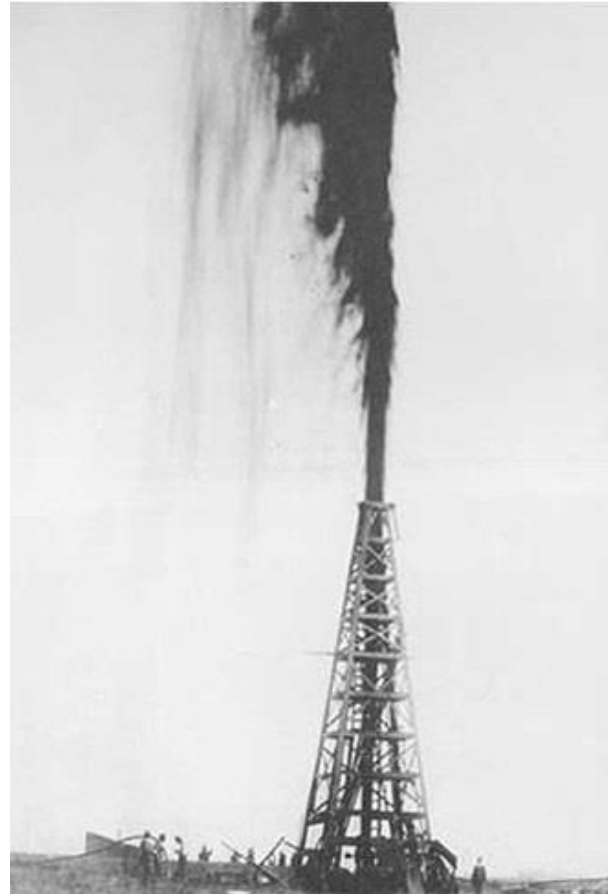
Introduction

Integration Testing on System Level

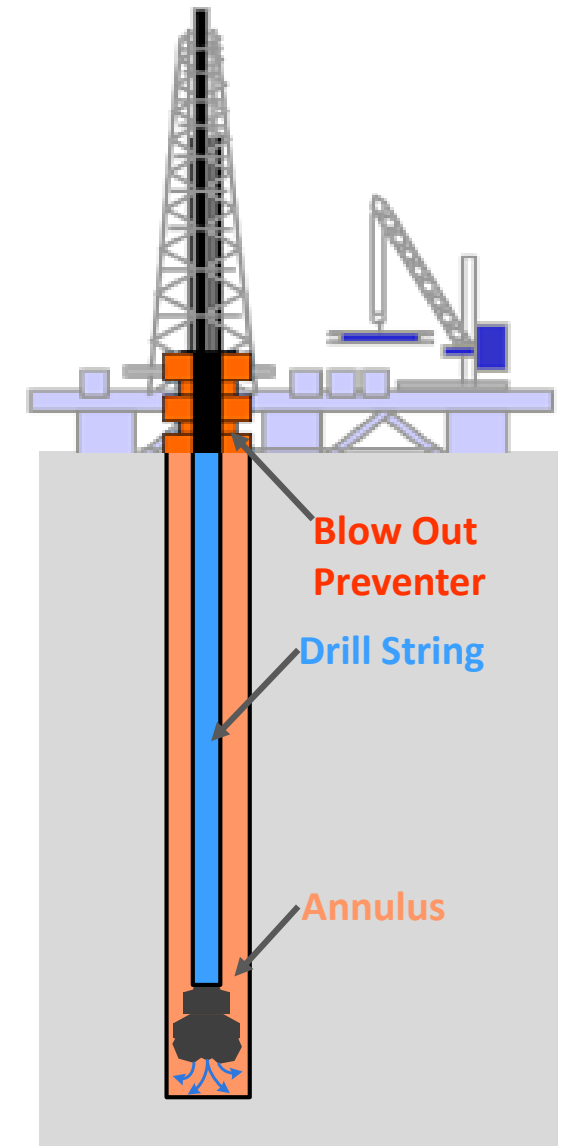
DOWNHOLE ISOLATION PACKER

SCOPE

- Mitigate risk related to fluid influx
- Isolate or reduce a kick
- Restore well stability



Lucas Gusher, Spindletop, Texas, 1901
[John Trost, American Petroleum Institute]



DOWNHOLE ISOLATION PACKER

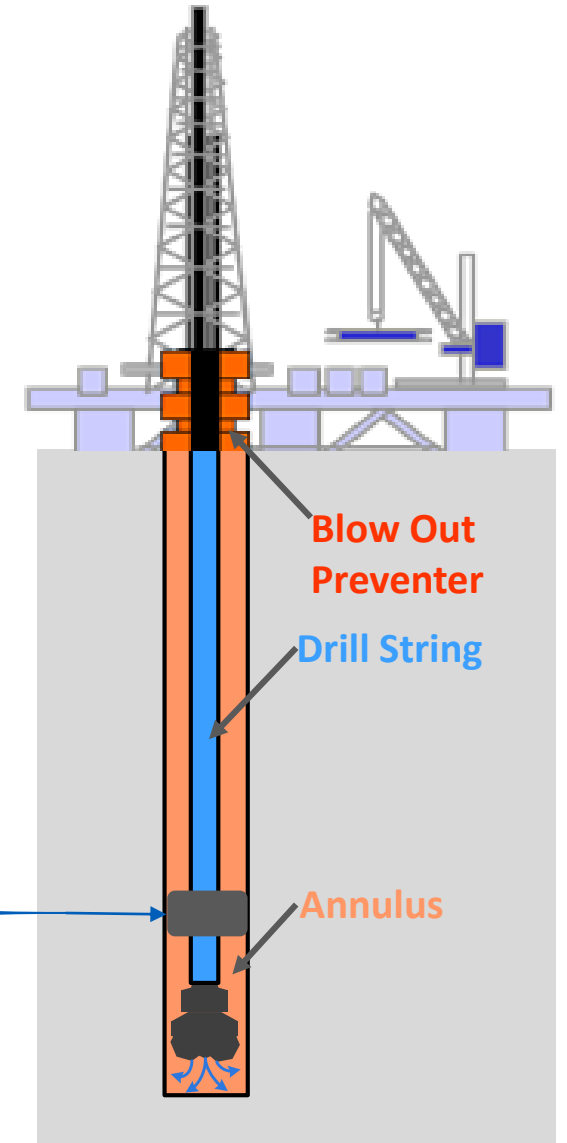
SCOPE

- Mitigate risk related to fluid influx
- Isolate or reduce a kick
- Restore well stability

TOP LEVEL REQUIREMENTS

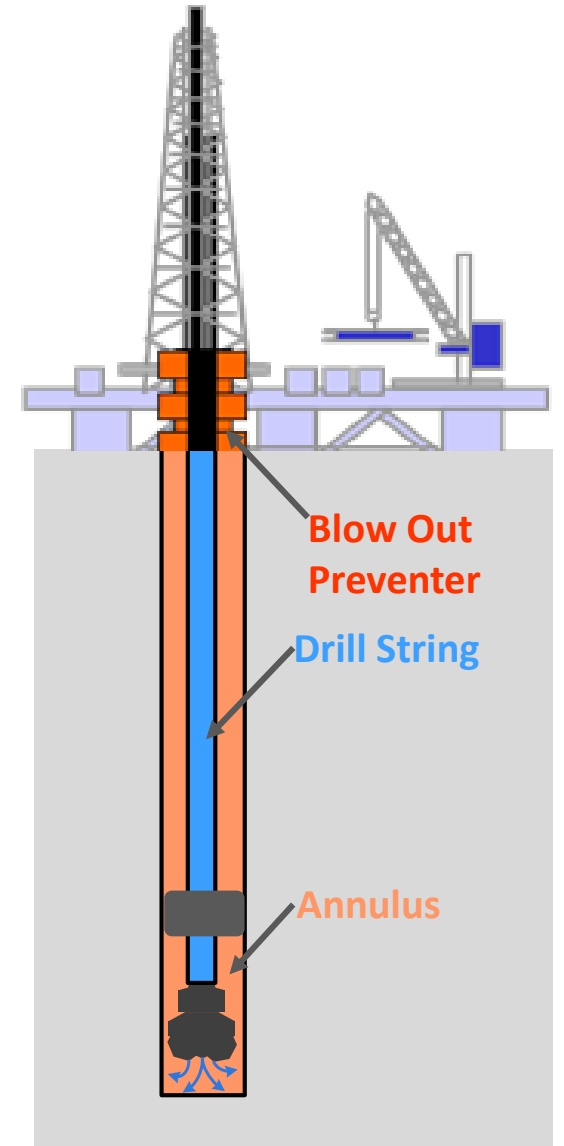
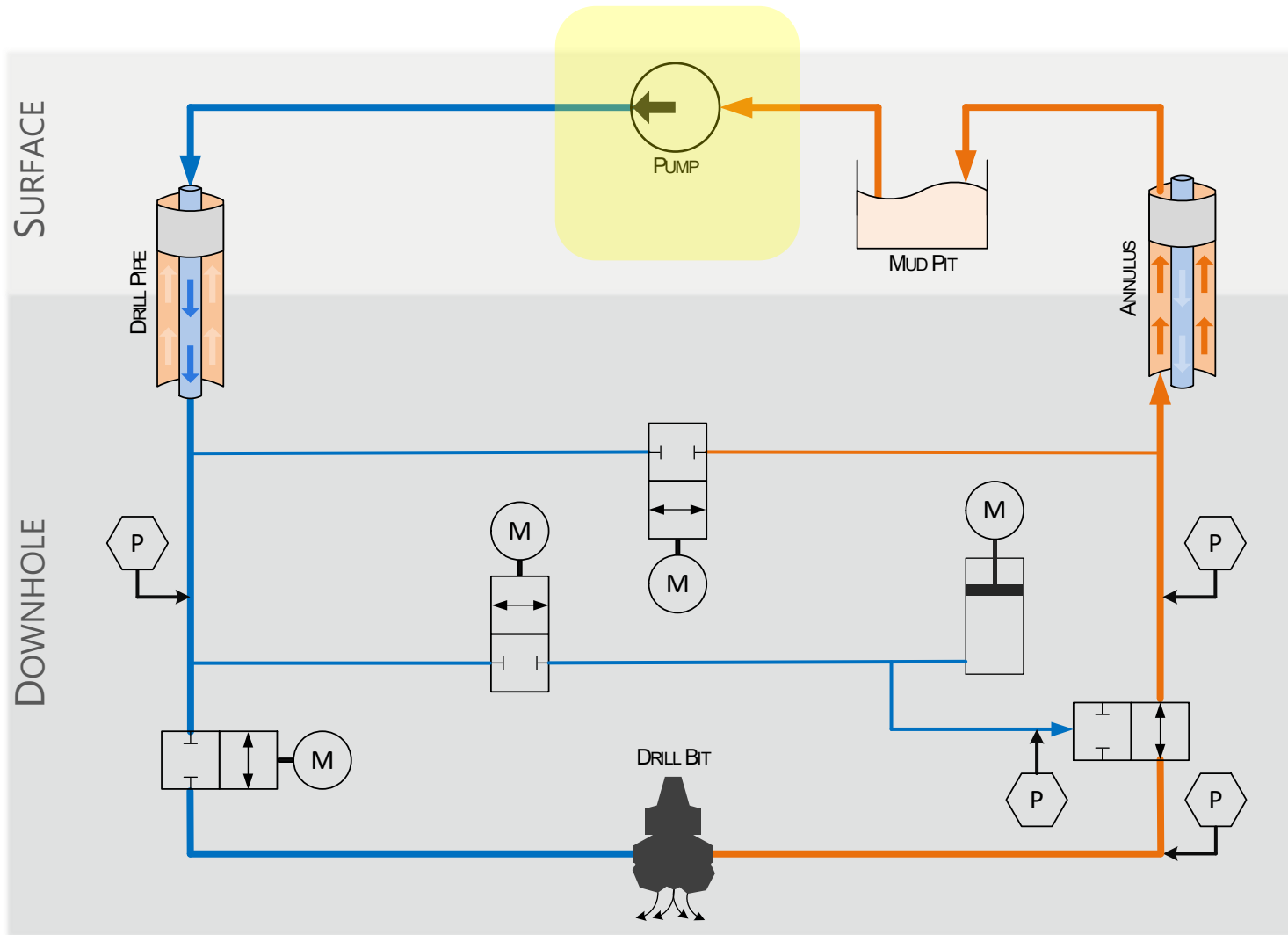
- Shut-in the drill string
- Shut-in the annulus
- Circulation through bypass

PACKER ELEMENT

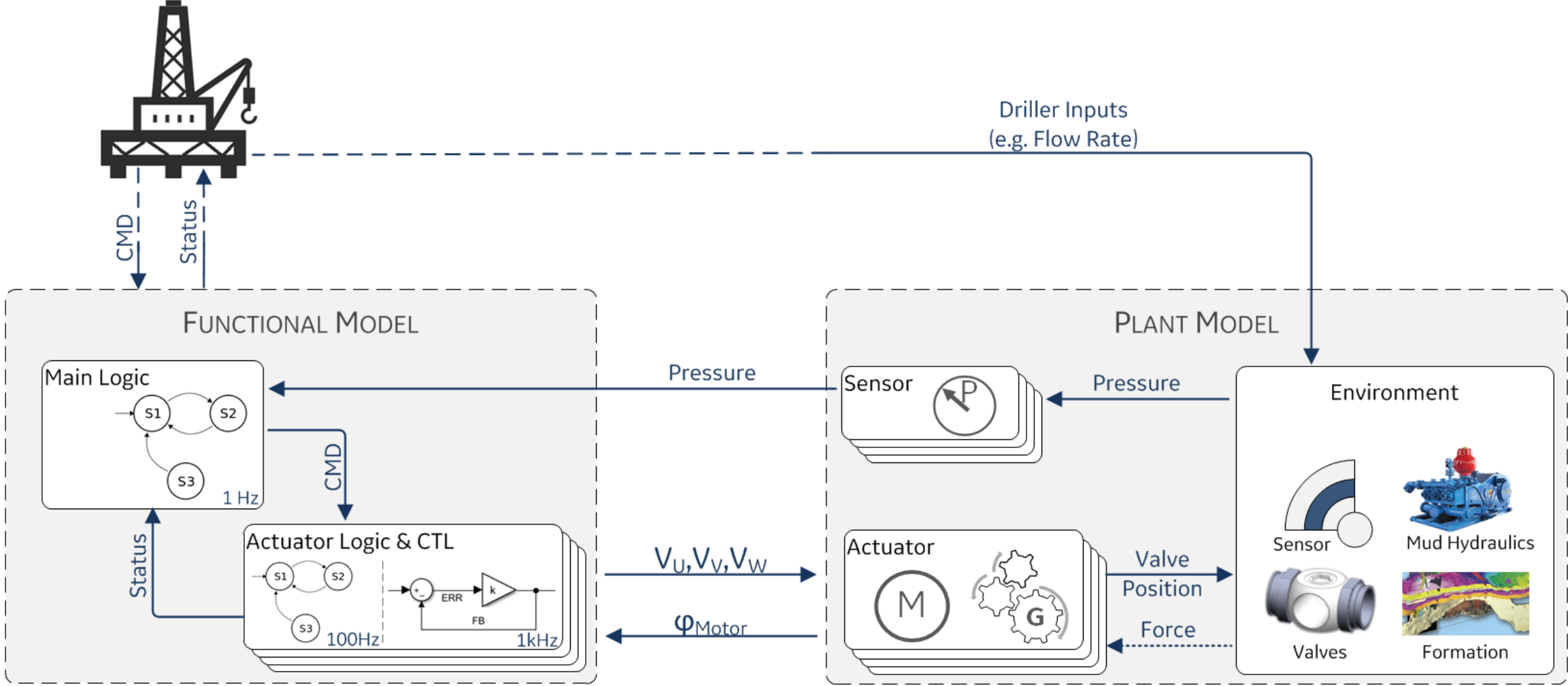


Completion Packer Element
[Baker Hughes, a GE Company]

PLANT OVERVIEW



SYSTEM OVERVIEW

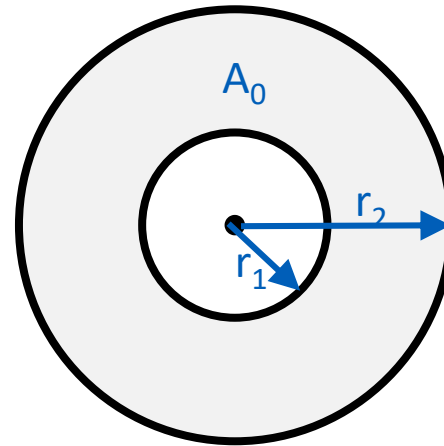
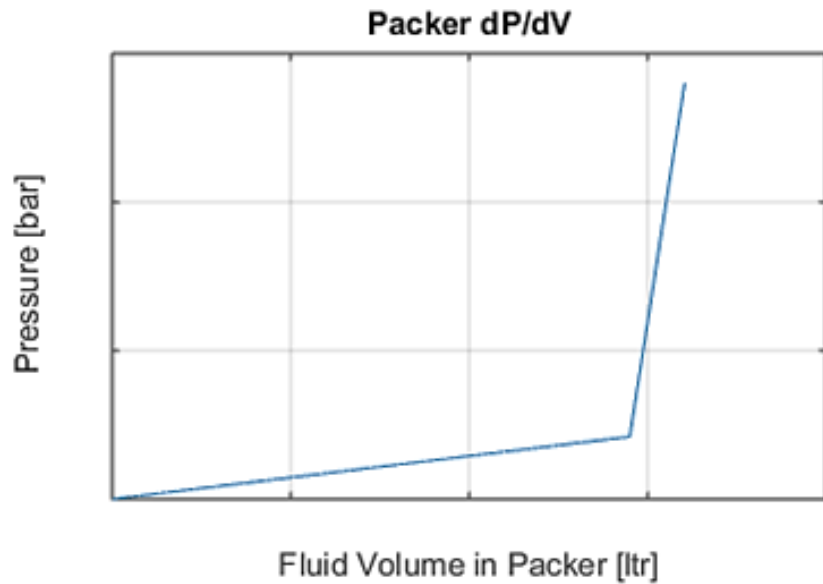


ENVIRONMENT MODEL

PACKER ELEMENT (SIMSCAPE FLUIDS)



Completion Packer Element
[Baker Hughes, a GE Company]



$$A_0 = \pi(r_2^2 - r_1^2)$$

$$V_{Packer} = \pi r_1^2 l_{Packer} \rightarrow r_1 = \sqrt{\frac{V_{Packer}}{\pi l_{Packer}}}$$

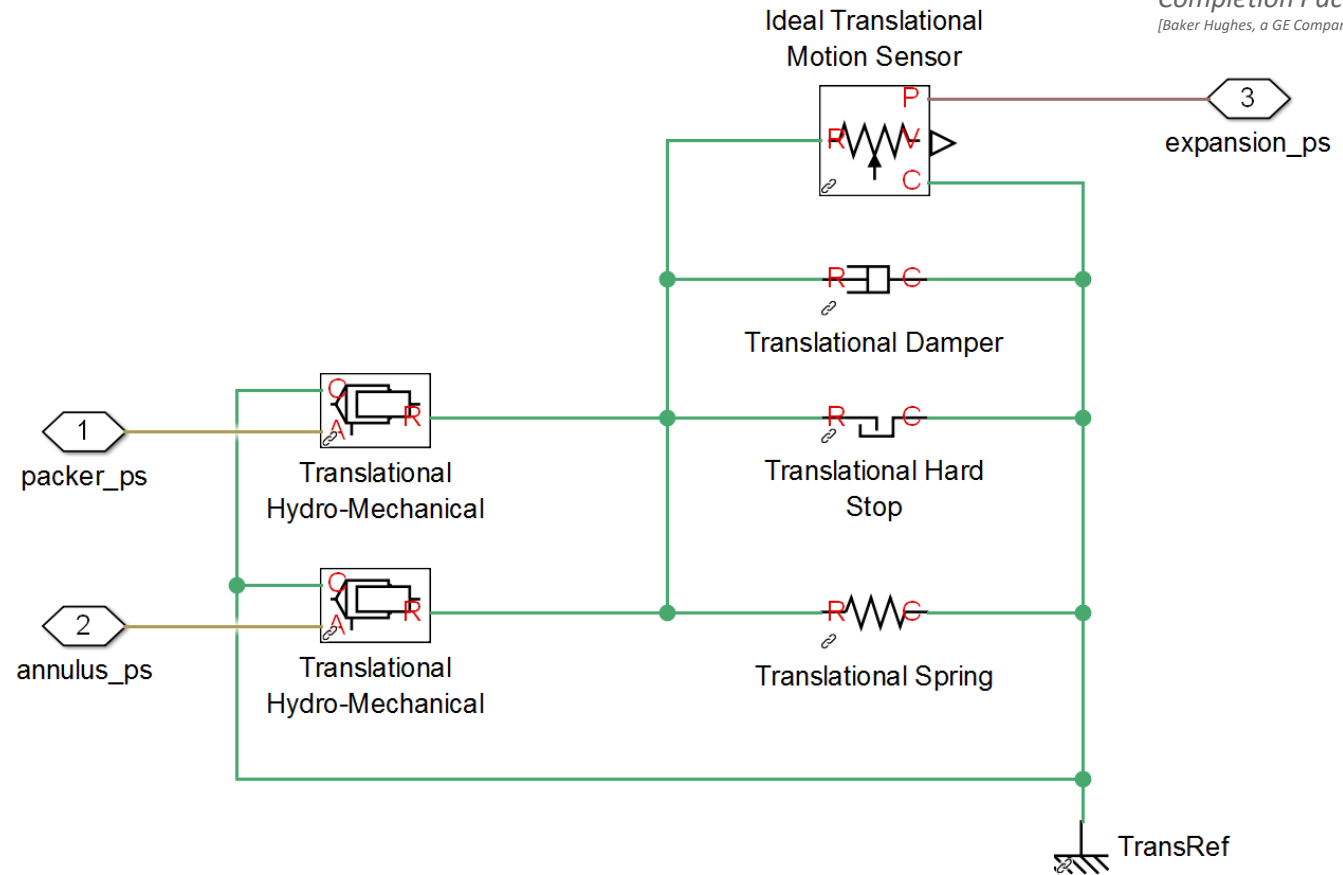
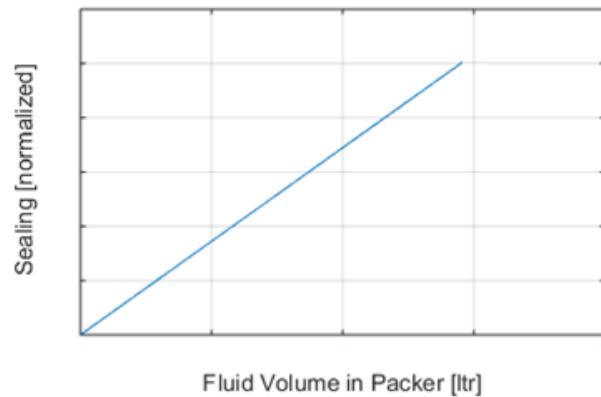
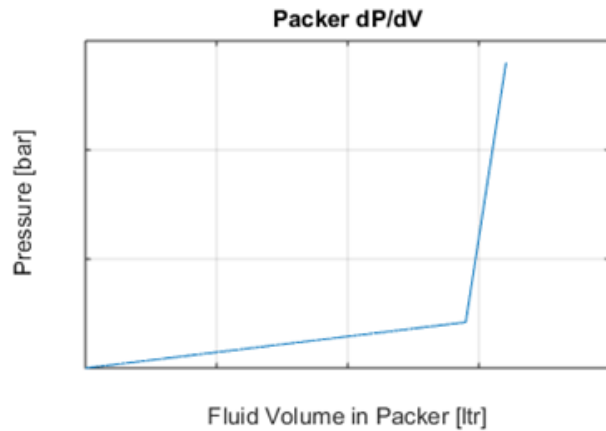
$$A_0 = \pi r_2^2 - \frac{V_{Packer}}{l_{Packer}}$$

ENVIRONMENT MODEL

PACKER ELEMENT (SIMSCAPE FLUIDS)



Completion Packer Element
[Baker Hughes, a GE Company]

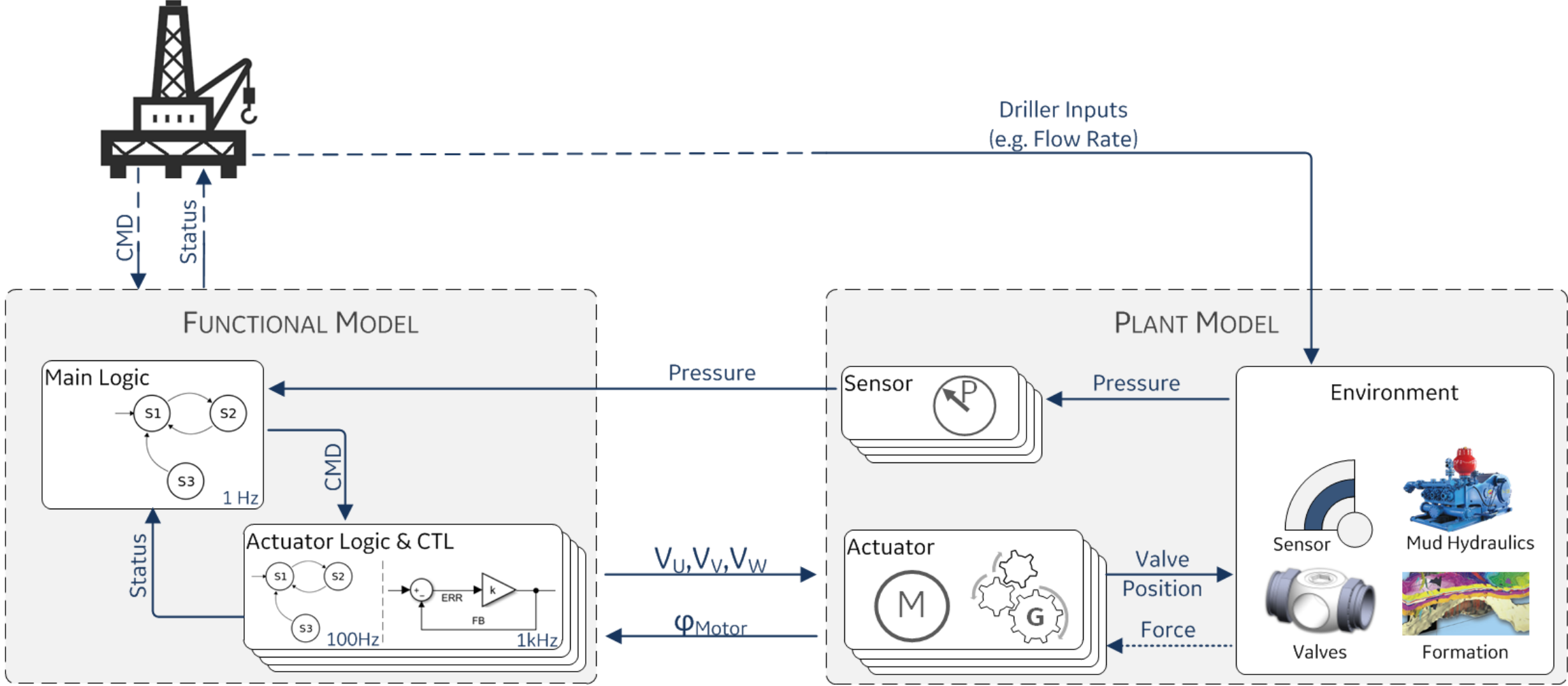


CASE STUDY - DOWNHOLE ISOLATION PACKER

Introduction

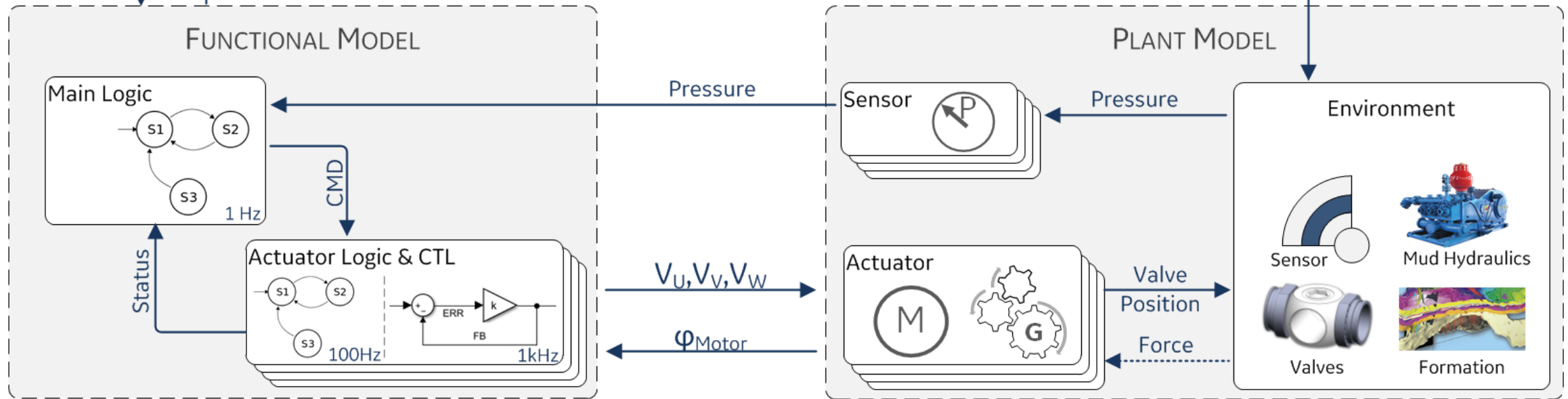
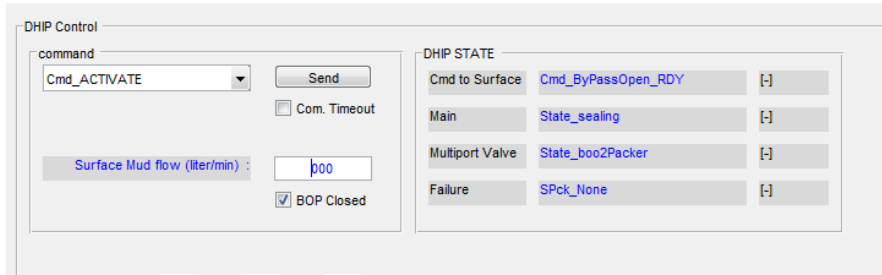
System Level Testing

SYSTEM LEVEL TESTING



USER ACCEPTANCE TEST

HMI



USER ACCEPTANCE TEST

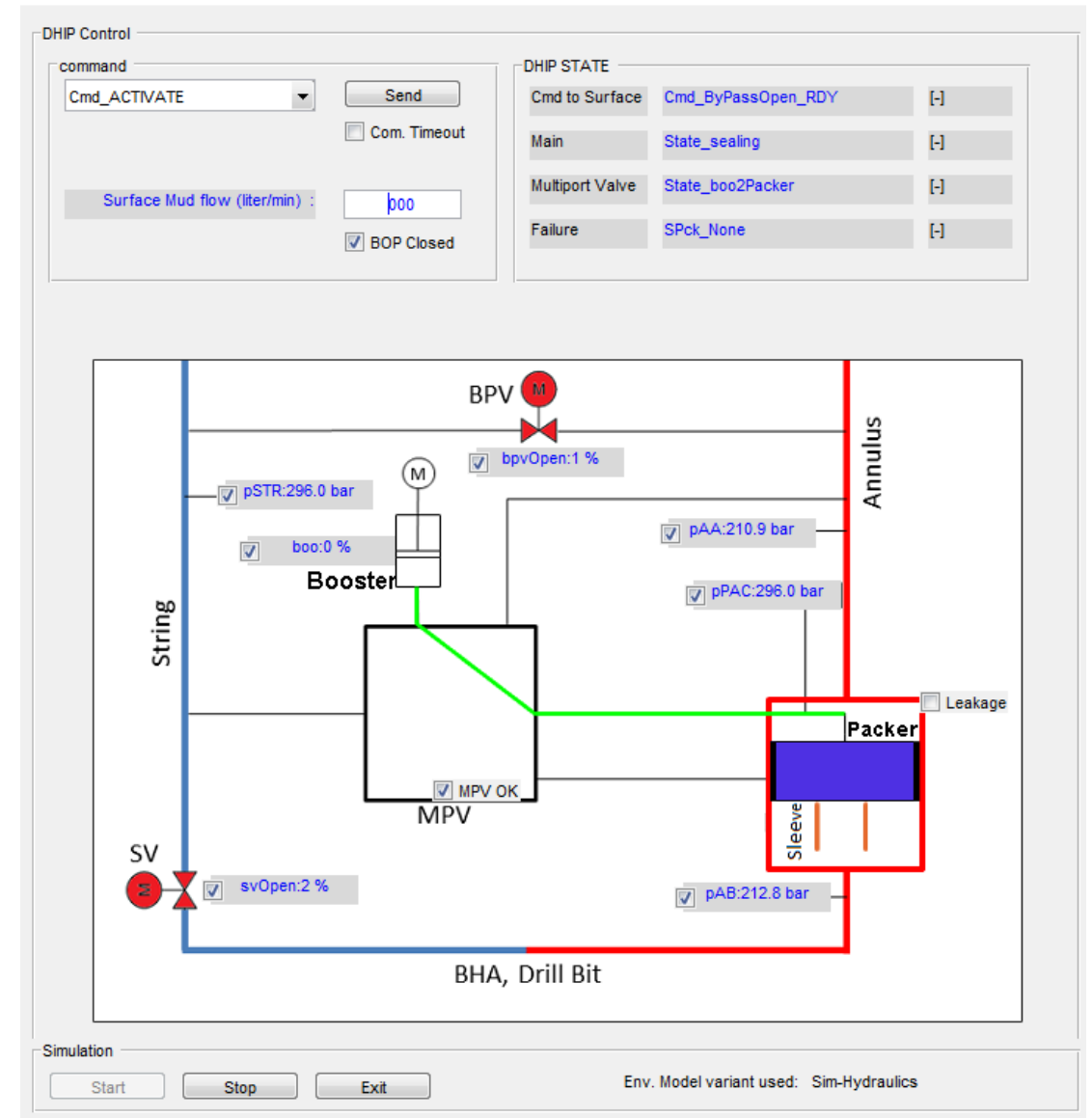
HMI

INPUT:

- Operator CMD → Functional Model
- Drilling parameters → Environment
- Error insertion

OUTPUT:

- Tool status
- FSM state
- Plant status

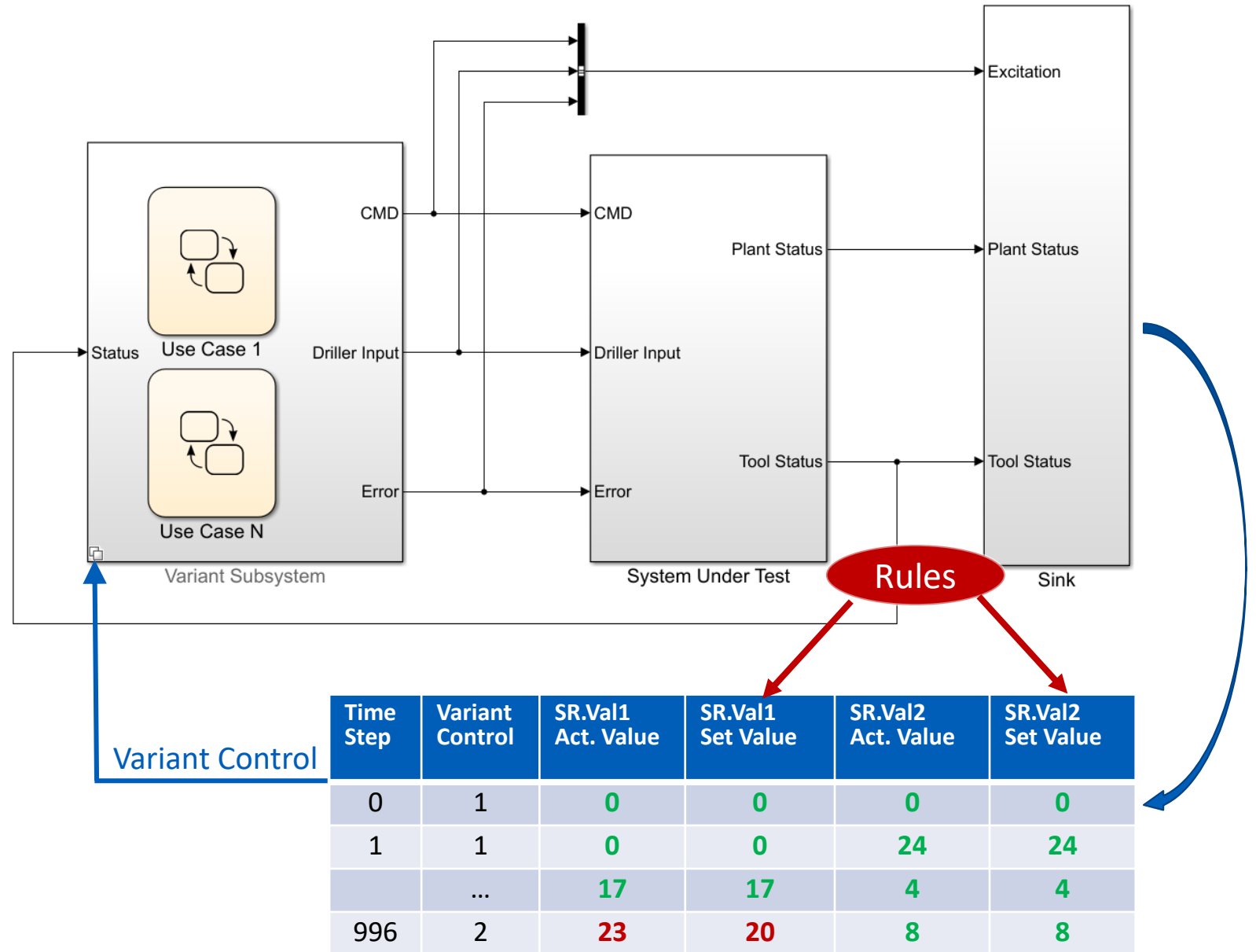


SYSTEM LEVEL MIL

APPROACH

ACTUAL =? SET VALUE

- Size of Set Value list
- **Creation of set values**
 - **Based on Rules**



SYSTEM LEVEL MIL

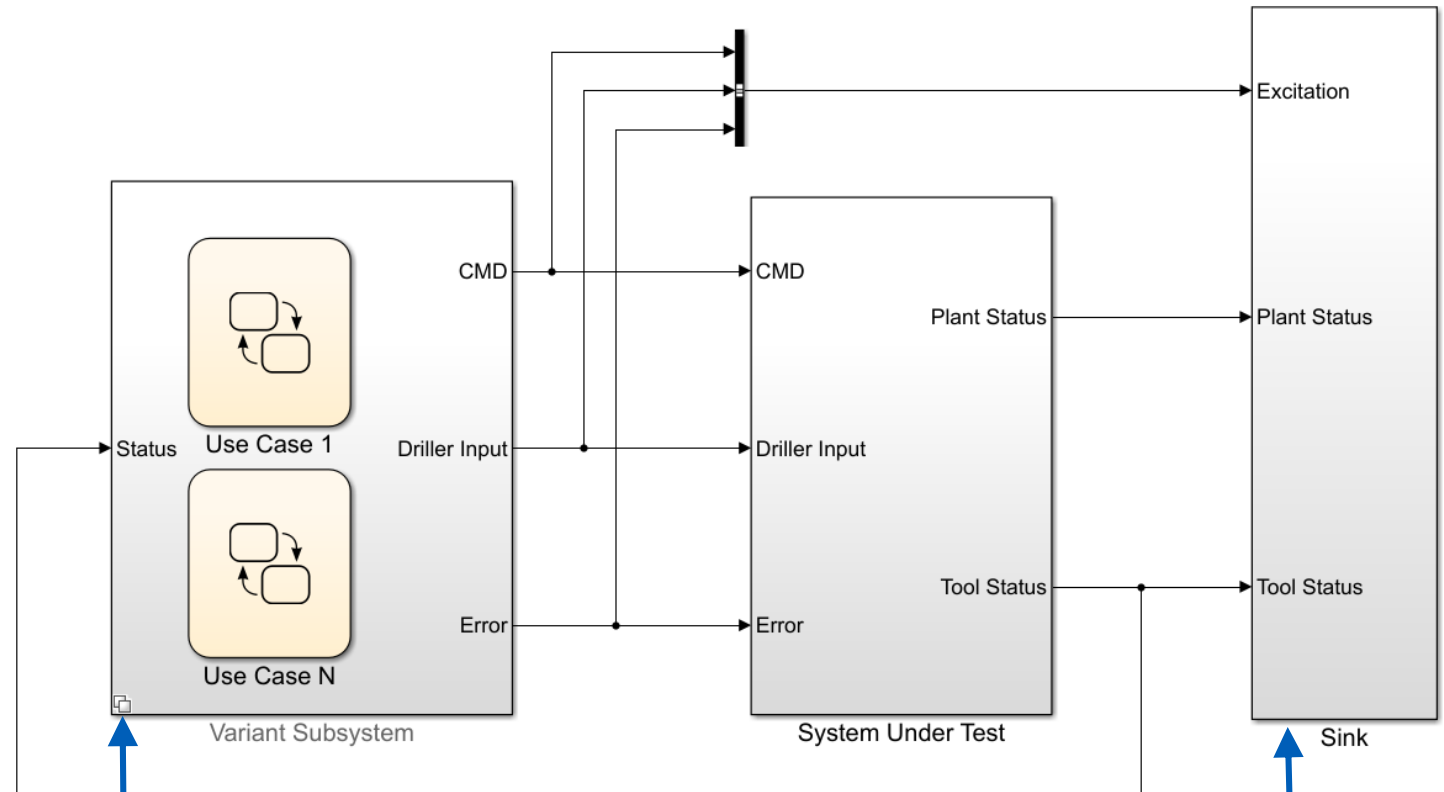
APPROACH

ACTUAL =? SET VALUE

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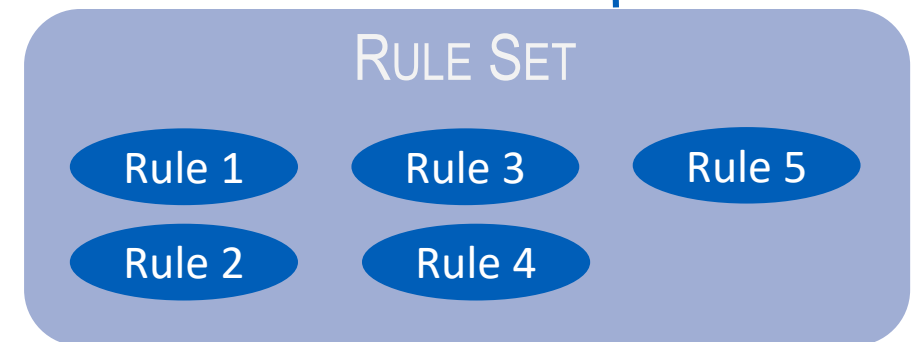
RULE CHECK

- ✓ Intuitive
- Rules derived from requirements
- **Knowing when you are done**

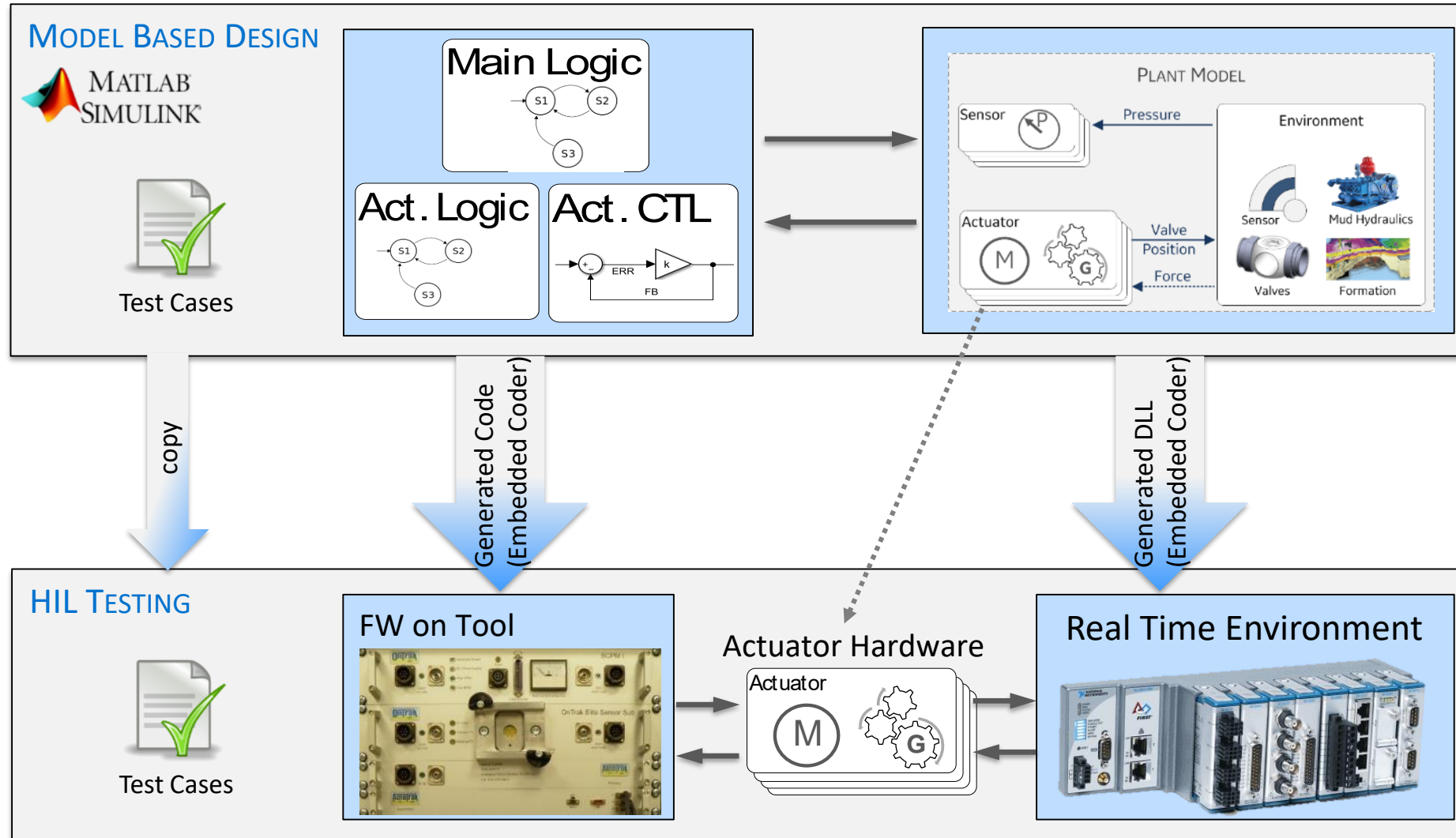


Variant Control

| Time Step | Variant Control |
|-----------|-----------------|
| 0 | 1 |
| 1 | 1 |
| | ... |
| 996 | 2 |



SYSTEM LEVEL HIL



SYSTEM LEVEL HIL

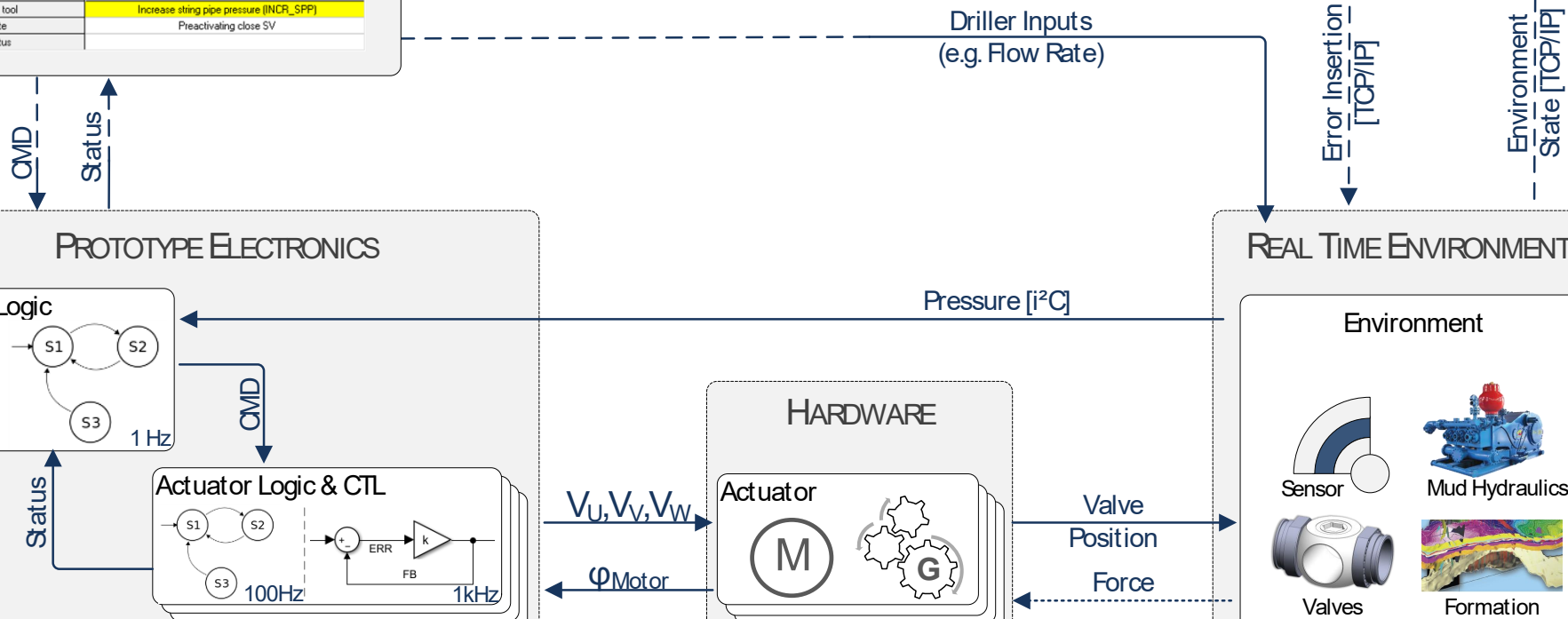
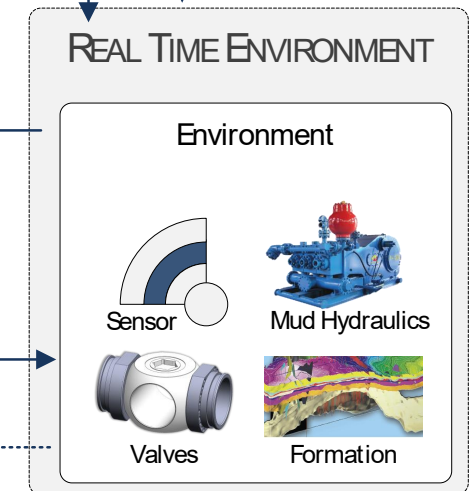
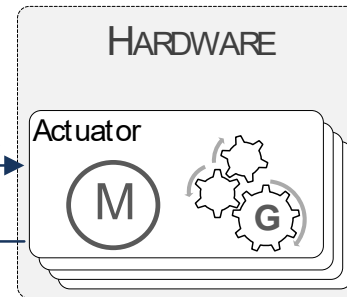
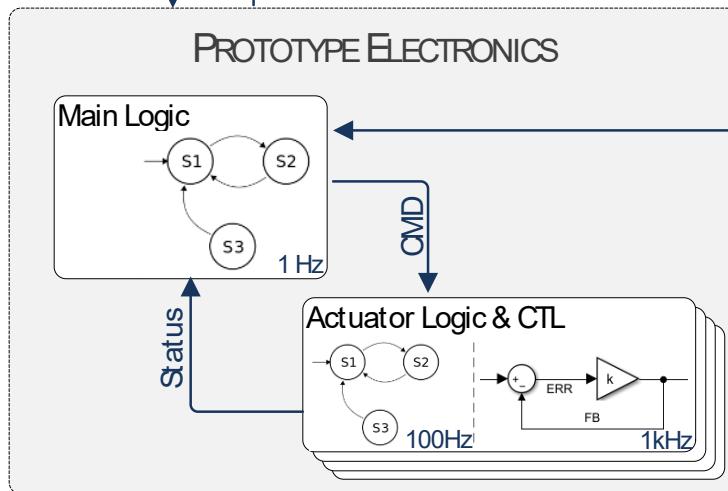
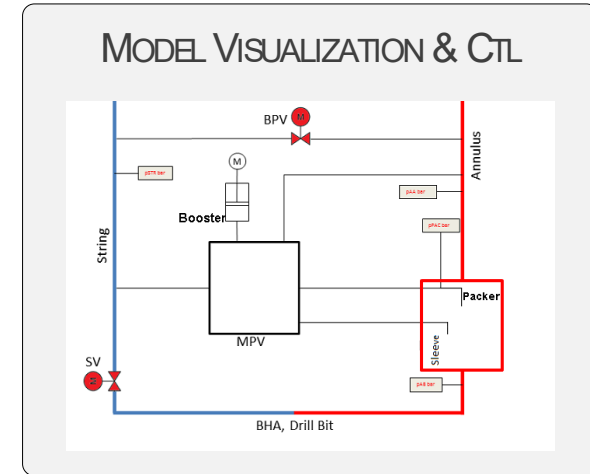
SURFACE SOFTWARE

| | Pressure [bar] | Temp. [°C] | Node Status |
|-----------------------------|----------------|------------|-------------|
| Sensor inside string | 197.3 | 0.0 | ● ● ● ● |
| Sensor inside packer | 197.3 | 0.0 | ● ● ● ● |
| Sensor annulus above packer | 197.3 | 0.0 | ● ● ● ● |
| Sensor annulus below packer | 197.3 | 0.0 | ● ● ● ● |

| | State | Node Status |
|--------------------------|---|-------------|
| Actuator bypass valve | Closed | ● ● ● ● |
| Actuator string valve | Closing | ● ● ● ● |
| Actuator multiport valve | String connected with protection sleeve | ● ● ● ● |
| Booster pump | Ready to pump | ● ● ● ● |

| | Cap. [Ah] | Mode | Node Status |
|---------------------|-----------|------|-------------|
| Smart Battery Sub 2 | -1.0 | ??? | ● ● ● ● |

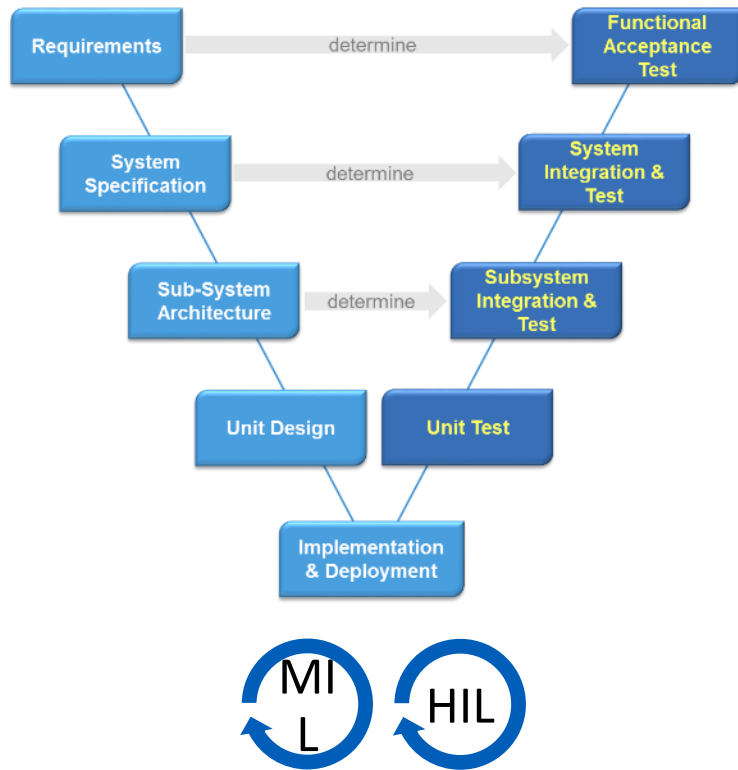
| Text/State | |
|-----------------------|--|
| Instruction from tool | Increase string pipe pressure (INCR_SFP) |
| Main Logic State | Preactivating close SV |
| Main Logic Status | |



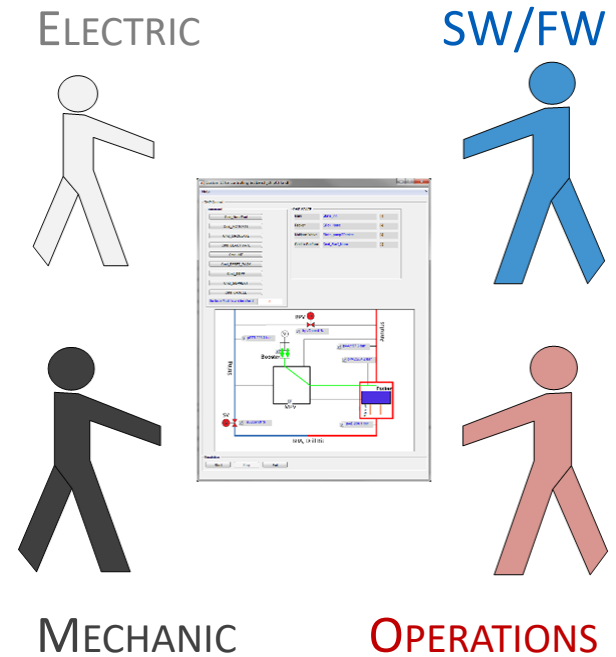
WRAP UP

WRAP UP

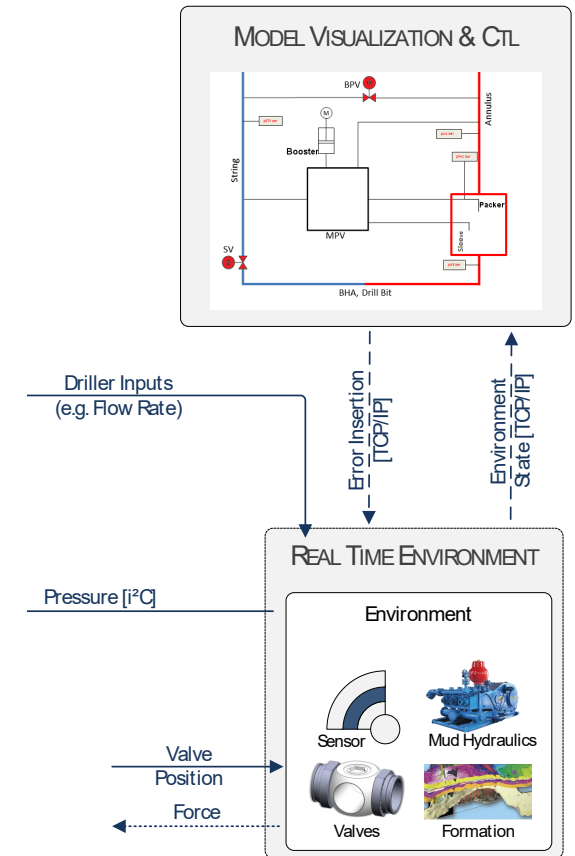
EARLY, FLEXIBLE



COLLABORATION



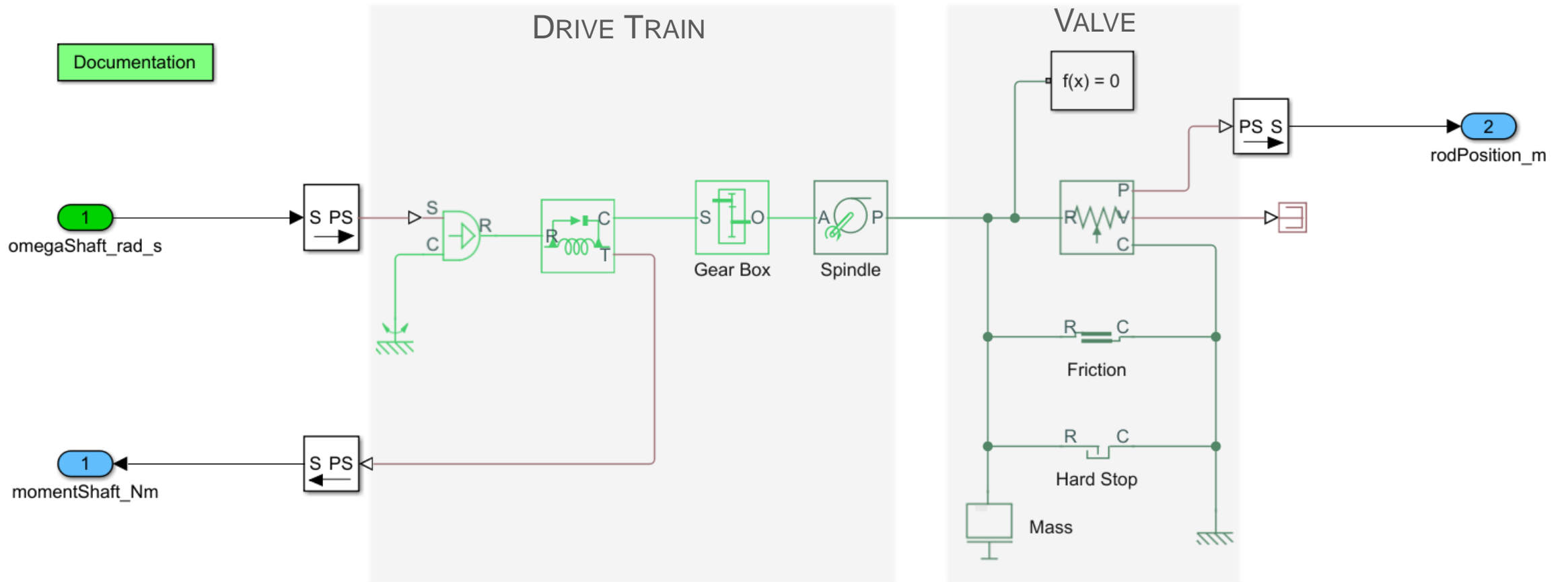
REUSABILITY



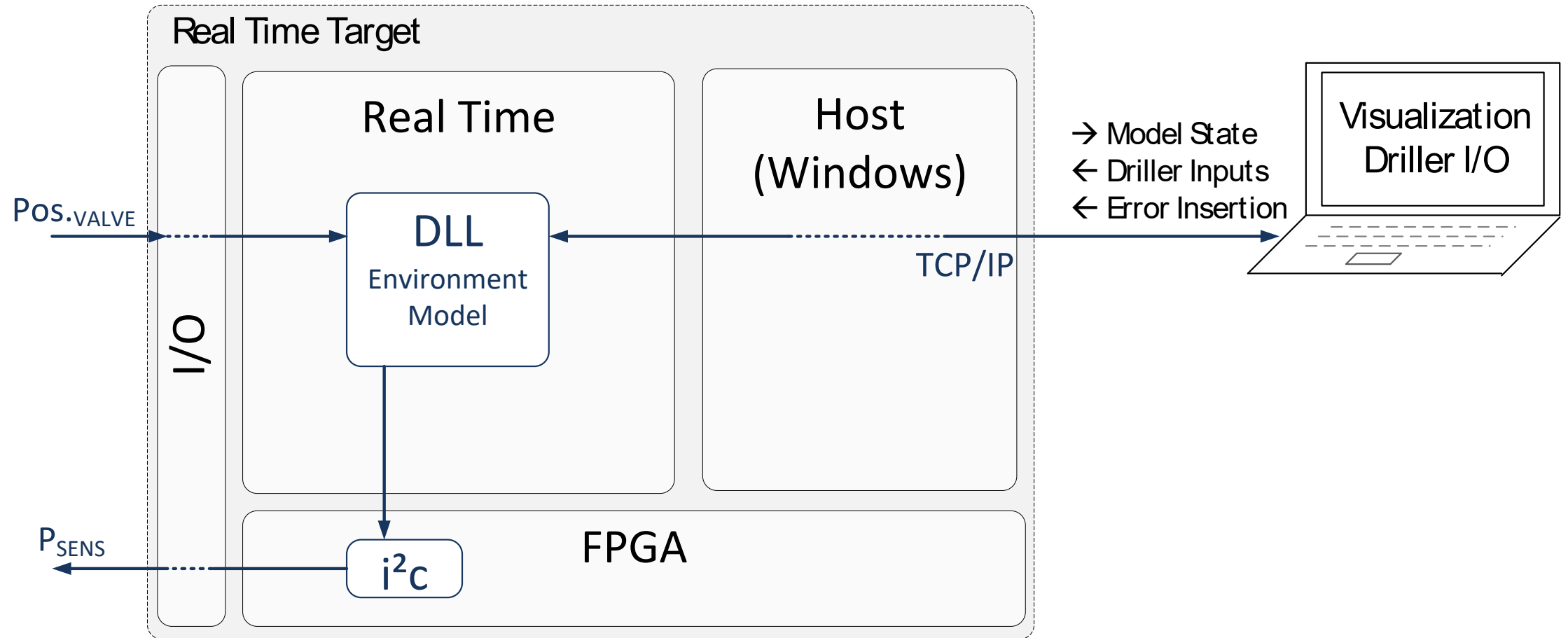
BACKUP SLIDES

ENVIRONMENT MODEL

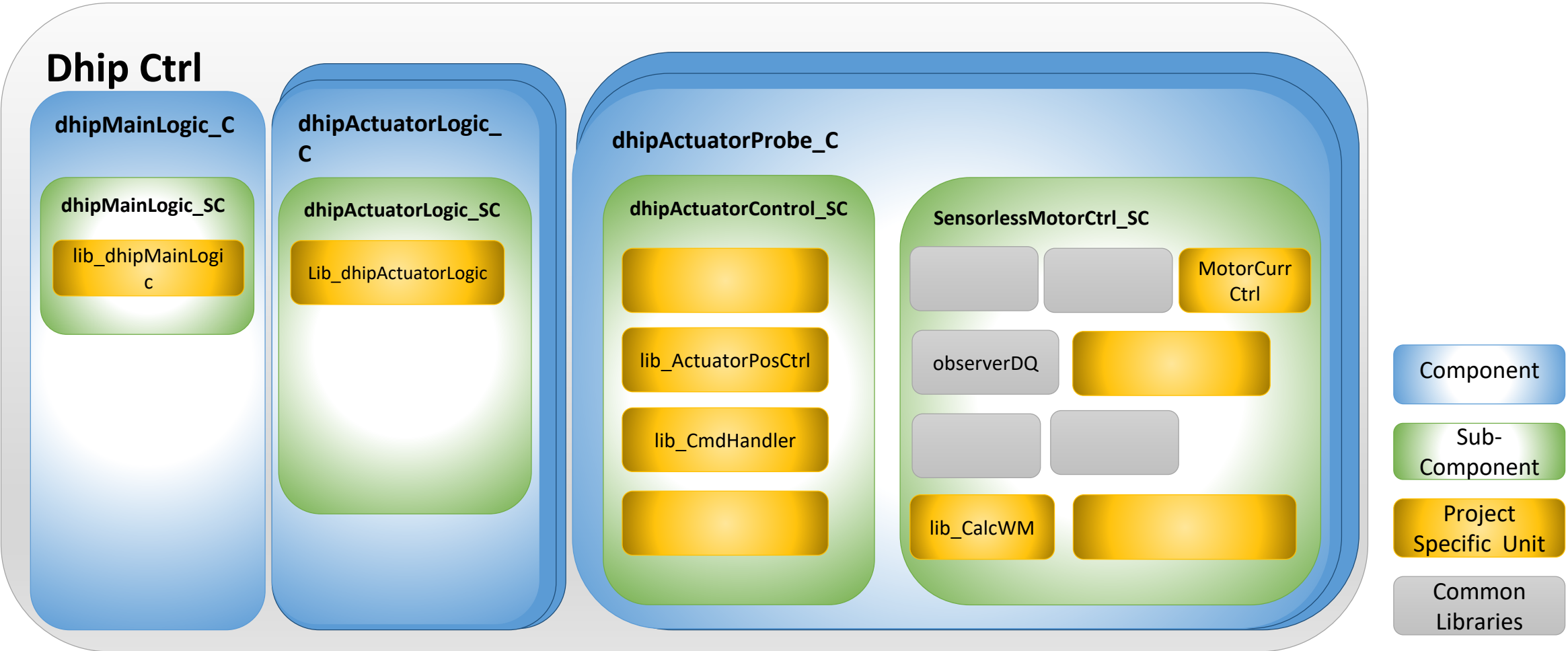
ACTUATOR MECHANICS (PLANT)



CASE STUDY: HIL REAL TIME SETUP



CASE STUDY: FIRMWARE ARCHITECTURE



SYSTEM LEVEL TESTING

UNIT TEST COMPLETED

STATIC:

- V&V Toolbox
- MAAB (subset)
- Custom rule set

DYNAMIC:

- XLS based test cases
- Actual =? set value
- Coverage
- Report generation

