Implementation and Case Study of High Performance/Low Cost Motor HILS using JMAG-RT

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Abstract :
Many of the designers of control systems have been forced to resolve conflicting issues between “High quality and Complex System” and “Shorten Development Time” and they believe that “Model Based Development (MBD)” is a powerful approach to solve these problems, which is often applied in the field of control system development. In many case studies this development approach seems to apply universal but in order to success in MBD, we need to solve the following two points.

In this presentation, we introduce a couple of solution for motor designers and developers to solve these problems by using an accurate Motor-HIL simulator achieved by combination between JMAG-RT and NI's COTS products and automated control parameter tuning by combination with optimization tools.

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JMAG-RTを使用した
高性能・低コストMotor-HILSの実現とその応用事例

Implementation and Case Study of High Performance/Low Cost Motor HILS using JMAG-RT

National Instruments
Shusaku Hayakawa

STEP1
- Using JMAG-RT for high performance HILS

STEP2
- Automating adaptation of controlled parameter

What is National Instruments (NI)?

- Corporate Headquarters Austin, Texas USA
- Global Operations Offices in 40 countries (Japan: 3 offices)
- Employees 5,500 (In-house engineers 3,500)
- Net Sales $820 million (estimated earnings 2010)
- Business Domain Worldwide leader in PCbased measurement and control devices

Support development from design to production in a single environment

Strong growth: Double-digit growth since being established 31 years ago

More than 48,000 offices succeeding worldwide (95% in manufacturing)

More than 80,000 users worldwide

More than 600 alliance partners

What is National Instruments (NI)?

More than 6000 types of PC based measurement and control devices

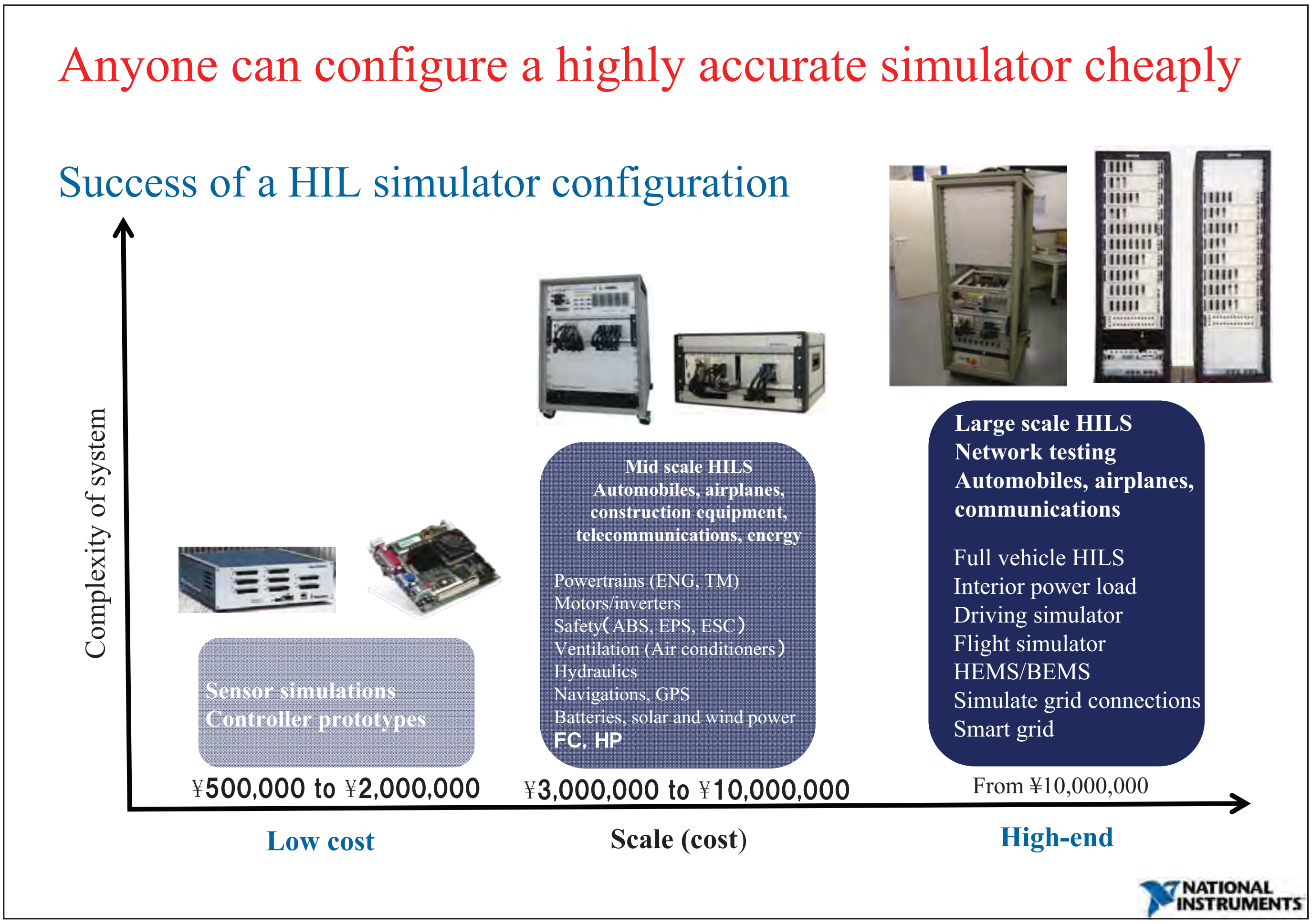
Software for Testing and Measurements

Module type Measurement/Control Hardware

Communication (USB,Serial, CAN) | Multimeter | Oscilloscope | Power supply•SMU | RF signal generater/analyzer

Standard Computer Technology（Windows, MAC, Linux, RT, built-in）

PCI•PCI Express•USB/Ethernet standard | PXI•PXI Express Standard | RT, FPGA/DSP, Single-board


Anyone can configure a highly accurate simulator cheaply
Success of a HIL simulator configuration
Complexity of system
Sensor simulations
Controller prototypes
¥500,000 to ¥2,000,000
Low cost
Mid scale HILS
Automobiles, airplanes, construction equipment, telecommunications, energy
Powertrains (ENG, TM)
Motors/inverters
Safety(ABS, EPS, ESC)
Ventilation (Air conditioners)
Hydraulics
Navigations, GPS
Batteries, solar and wind power
FC, HP
¥3,000,000 to ¥10,000,000
Scale (cost)
Large scale HILS
Network testing
Automobiles, airplanes, communications
Full vehicle HILS
Interior power load
Driving simulator
Flight simulator
HEMS/BEMS
Simulate grid connections
Smart grid
From ¥10,000,000
High-end
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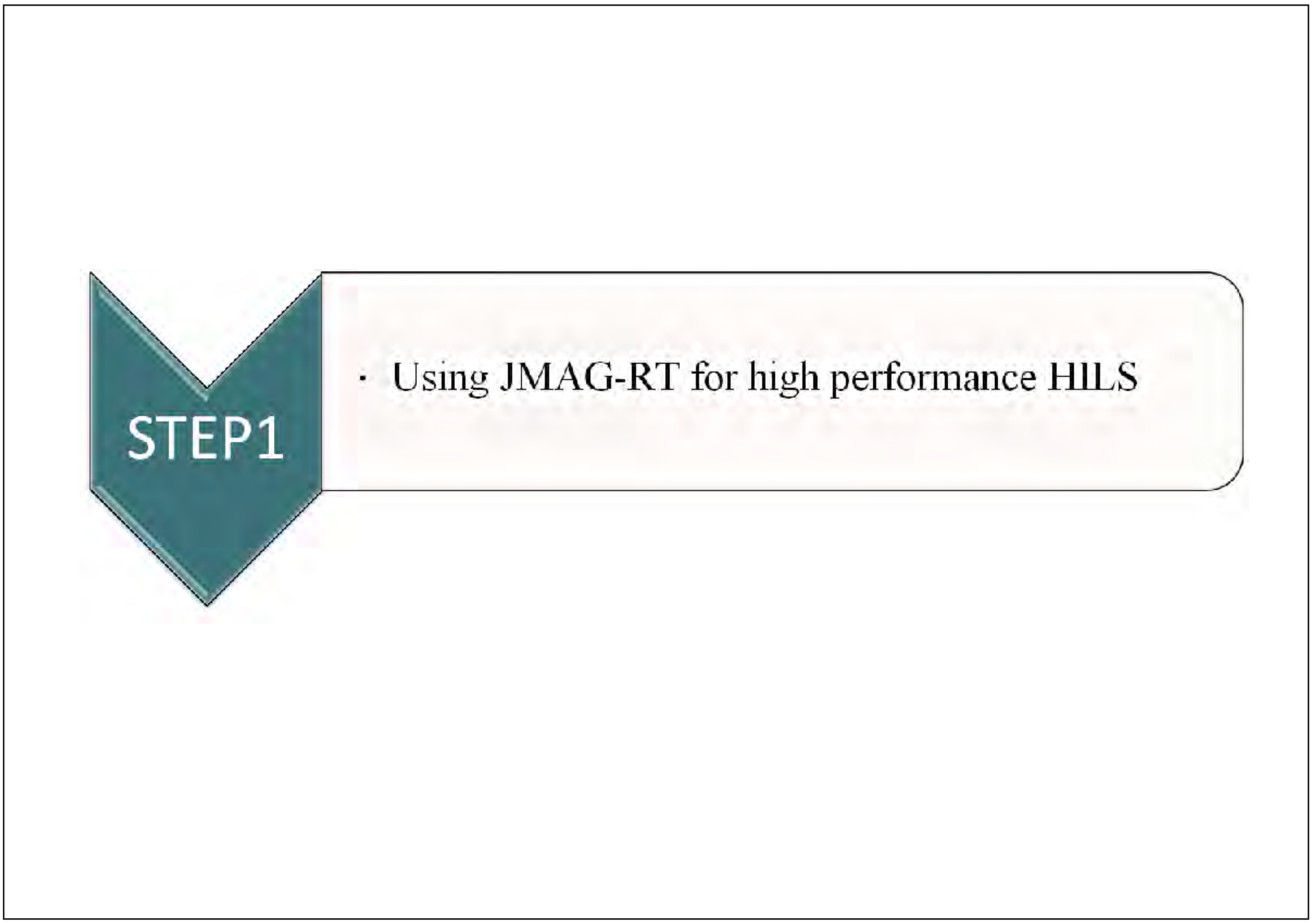
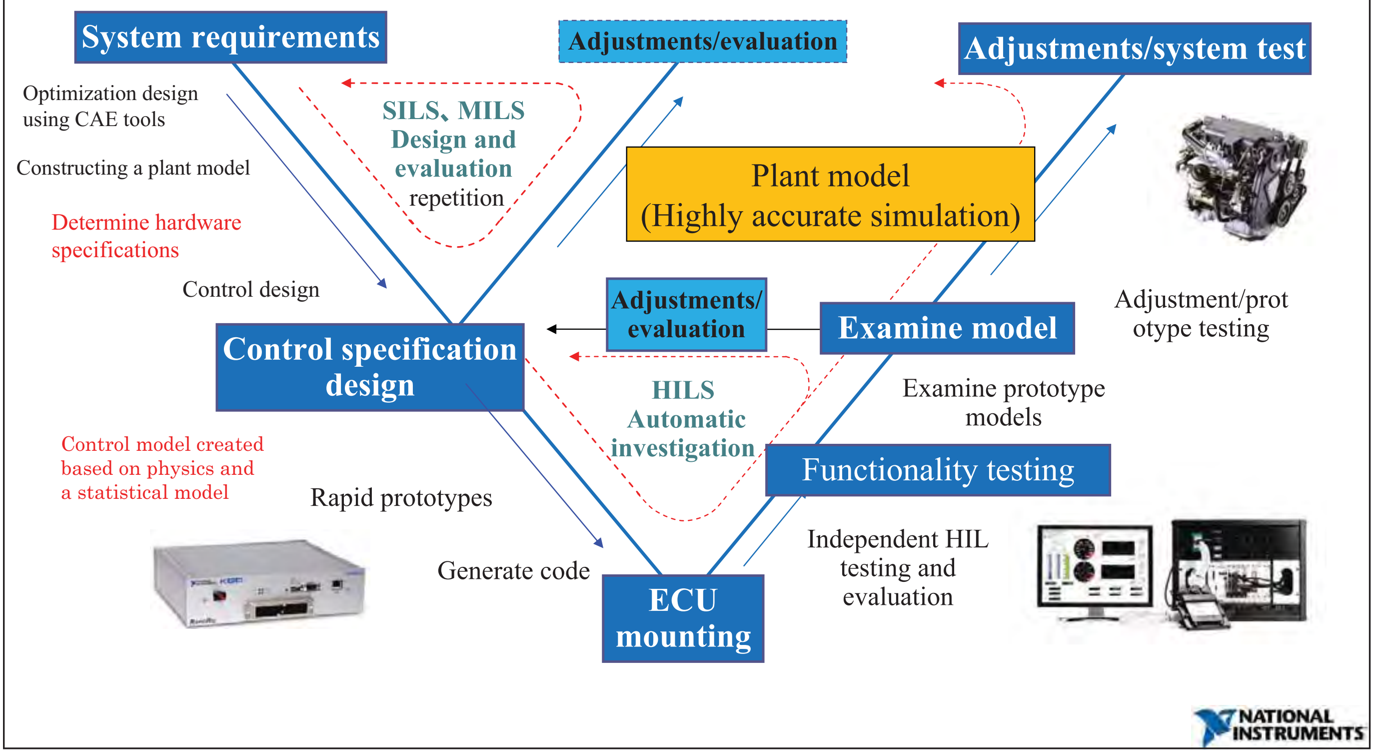
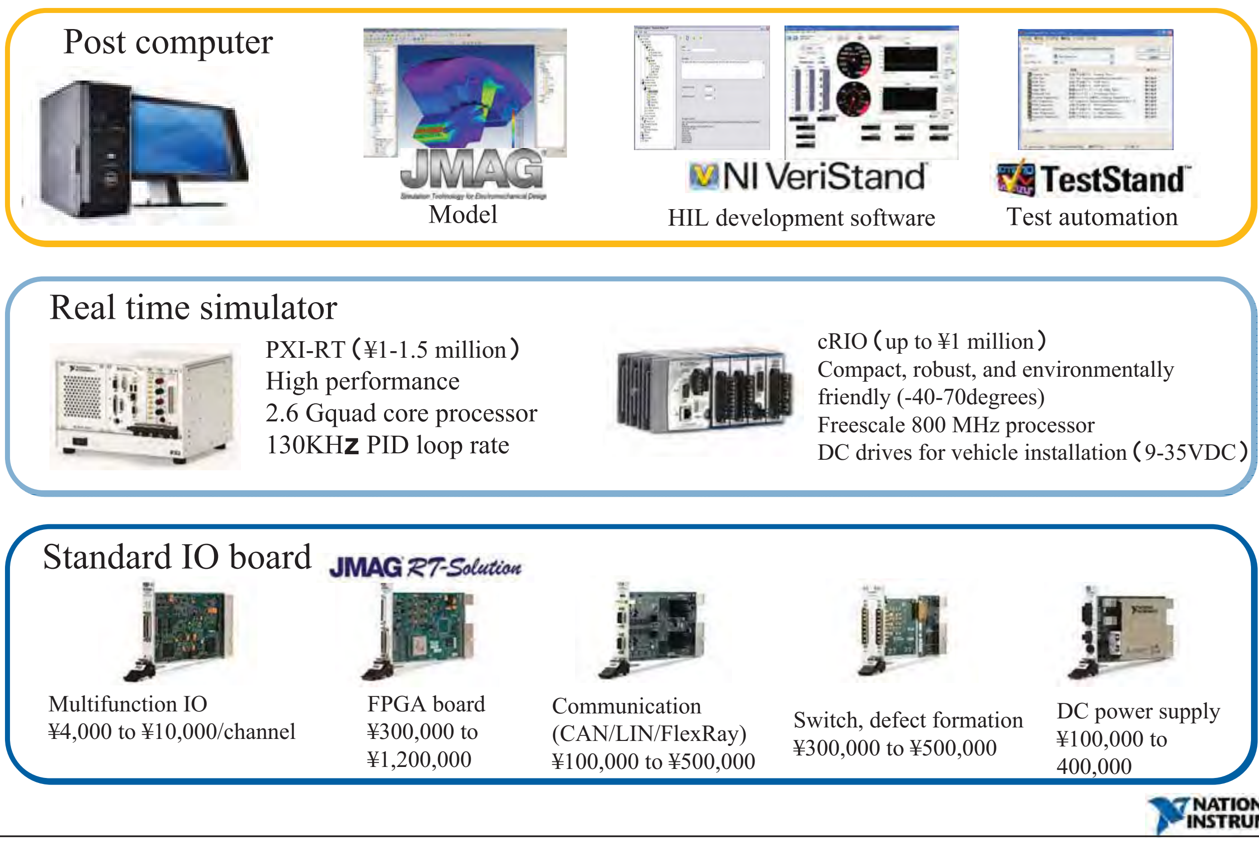

STEP1
・ Using JMAG-RT for high performance HILS

Objectives of Model Based Design（MBD）

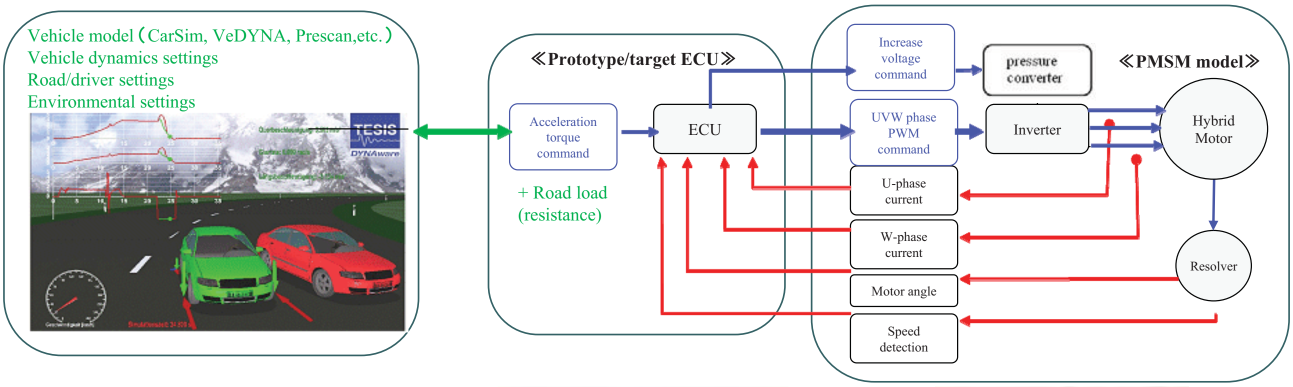
Implementation of development flow without redevelopment



Basic configuration required for MBD



Motor(PMSM)-HILS configuration



Post PC
User interface

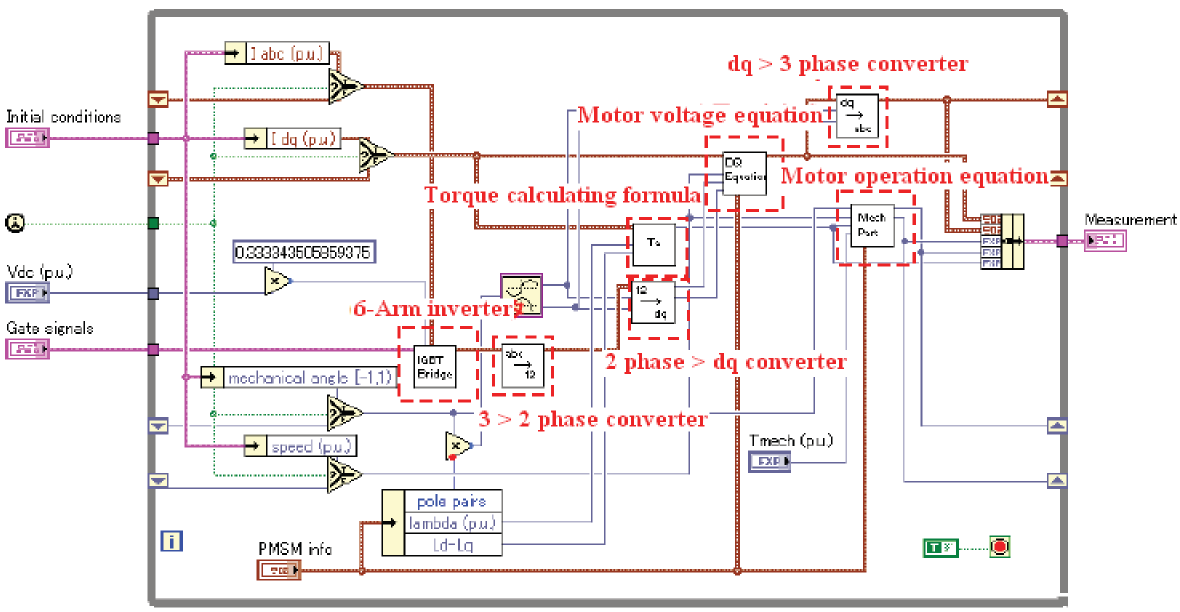
Target ECU

Real time simulator
Hardware IO

Operate at a maximum of 1 μS（1 MHz）

Motor (PMSM) model

LabVIEW-FPGA module



Permanent Magnet Synchronous Motor (PMSM) Equations

Park transformation equations

$$v_d = \frac{2}{3}[v_a \cos\theta + v_b \cos(\theta - \frac{2\pi}{3}) + v_c \cos(\theta - \frac{4\pi}{3})]$$

$$v_q = \frac{2}{3}[-v_a \sin\theta - v_b \sin s(\theta - \frac{2\pi}{3}) - v_c \sin(\theta - \frac{4\pi}{3})]$$

D-Q axis electric circuit equations

$$v_d = R_s i_d + L_d \frac{d}{dt} i_d - L_q \omega_e \frac{d}{dt} i_q$$

$$v_q = R_s i_q + L_q \frac{d}{dt} i_q + L_d \omega_e \frac{d}{dt} i_d + \omega_e \lambda_{PM}$$

Torque equations

$$T_e = \frac{3}{2} P[\lambda_{PM} i_q + (L_d - L_q) i_d i_q]$$

$$T_e = T_L + K_f \omega_m + J \frac{d}{dt} \omega_m$$

Inverse Park transformation equations

$$i_a = i_d \cos\theta - i_q \sin\theta$$

$$i_b = i_d \cos(\theta - \frac{2\pi}{3}) - i_q \sin(\theta - \frac{2\pi}{3})$$

$$i_c = i_d \cos(\theta - \frac{4\pi}{3}) - i_q \sin(\theta - \frac{4\pi}{3})$$

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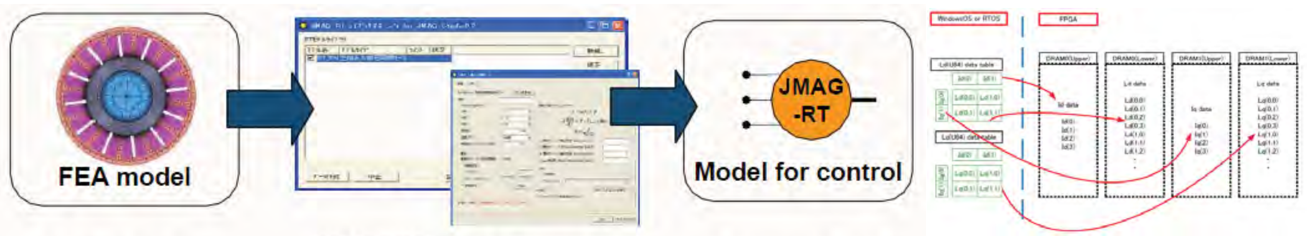
Linking to JMAG
Realizing highly accurate Motor-HILS

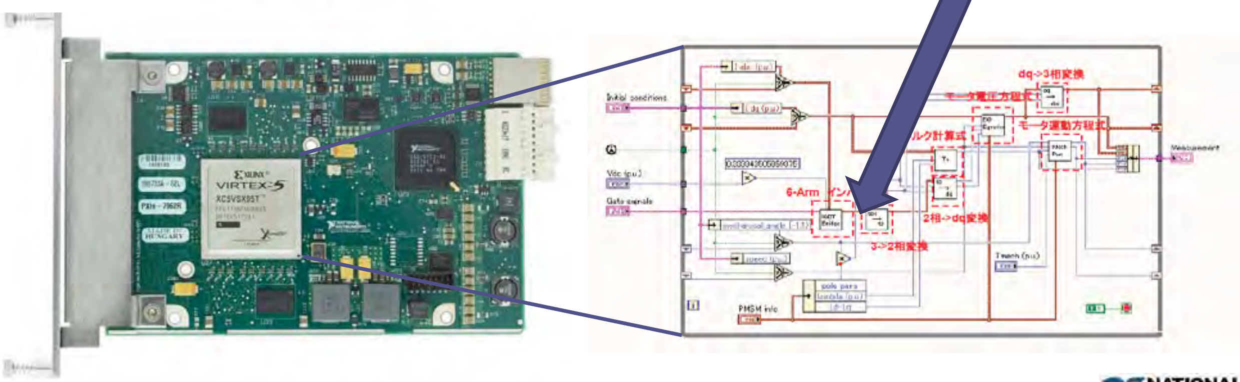


FEA Model (JMAG)

JMAG-RT manager (Magnetic field analysis is created when a JMAG-RT model is created)

Behaviour model (JMAG-RT)

Transfer Map data (RRT file) to DRAM in FPGA



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Realizing highly accurate Motor-HILS

<Model calculation parameters>

- Rated voltage （V）
- Rated current （A）
- Standard speed （rpm）
- d-axis inductance （H）
- q-axis inductance （H）
- Back EMF（Vrms/rpm）
- Armature winding resistance (Ω)
- Inertia moment (kg • m2)
- Friction coefficient
- Number of poles
- Double angle resolver
- External load torque （Nm）

Linking to JMAG
Realizing highly accurate Motor-HILS

<HILS operating mode>

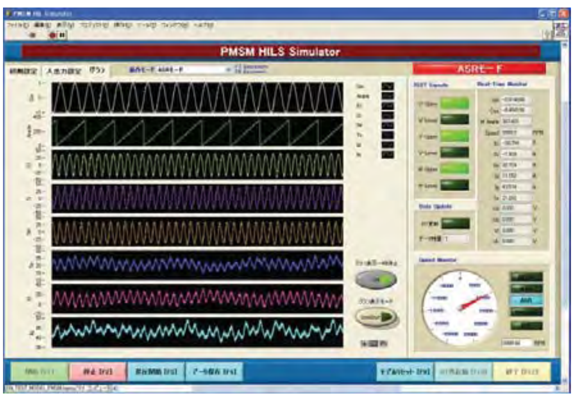
- Constant torque operating mode（Nm）
- Constant speed operating mode（rpm）
- Programing pattern mode (speed /昇圧)

<Specialized Features>

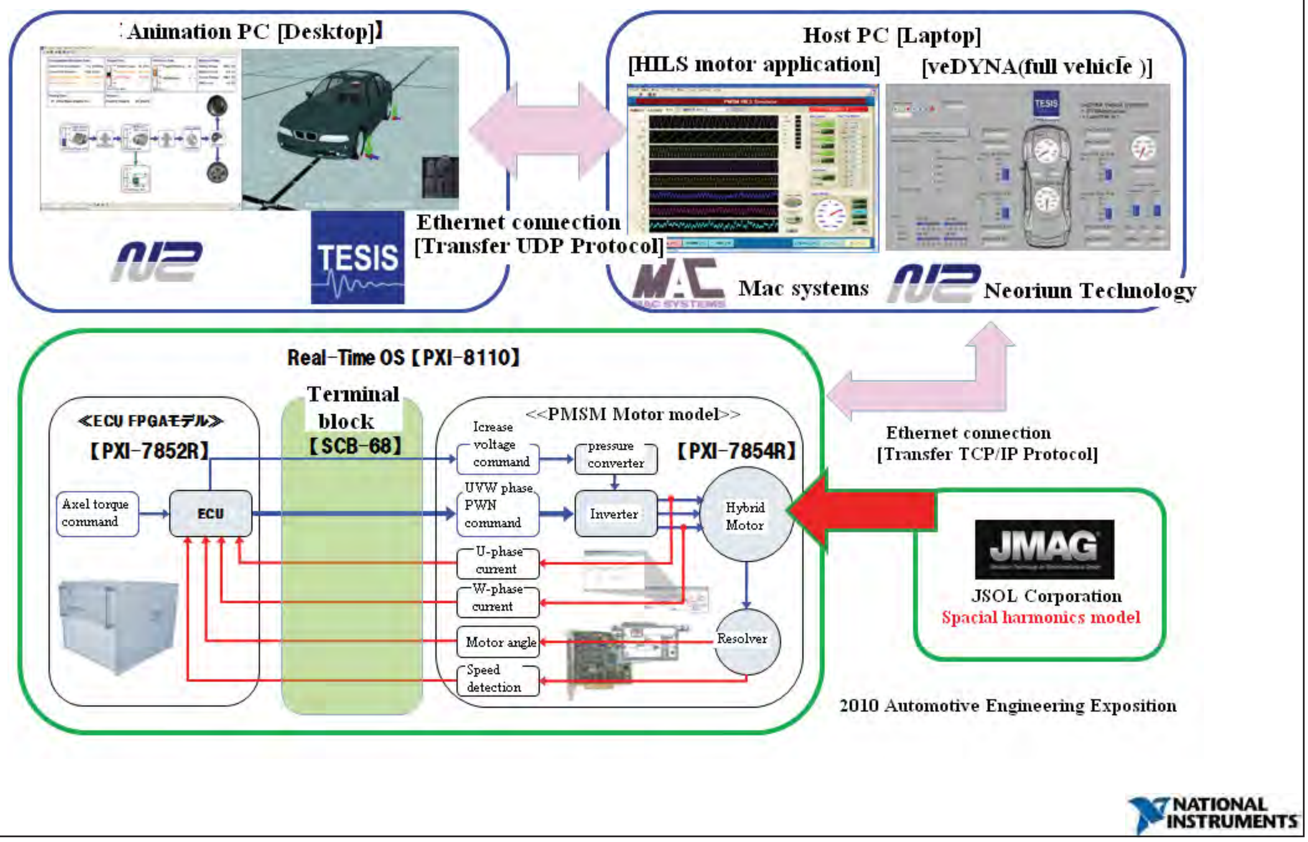
- Synchronization process to external systems
- Wide range of motor tests
- Joining vehicle models (full vehicle)

<Other features>

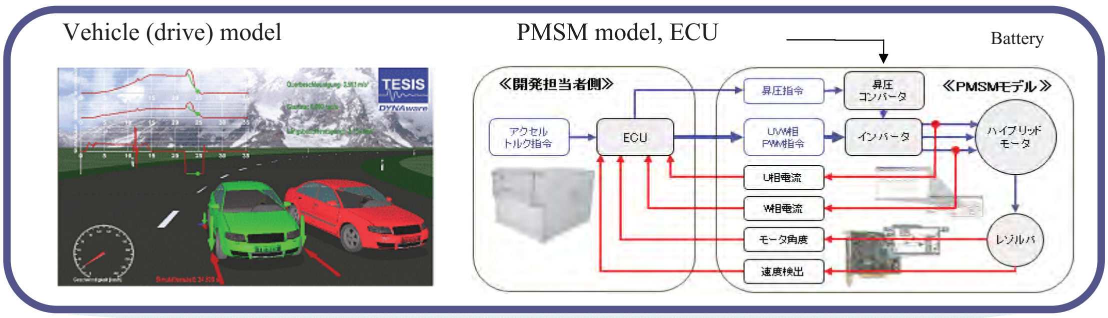
- Comprehensive settings for output signals
- IGBT inverse logic features
- Resolver inverse output features
- Smoothing feature when transitioning operations
- Create real-time graphs
- Features for saving model data (differentiation, averaging)



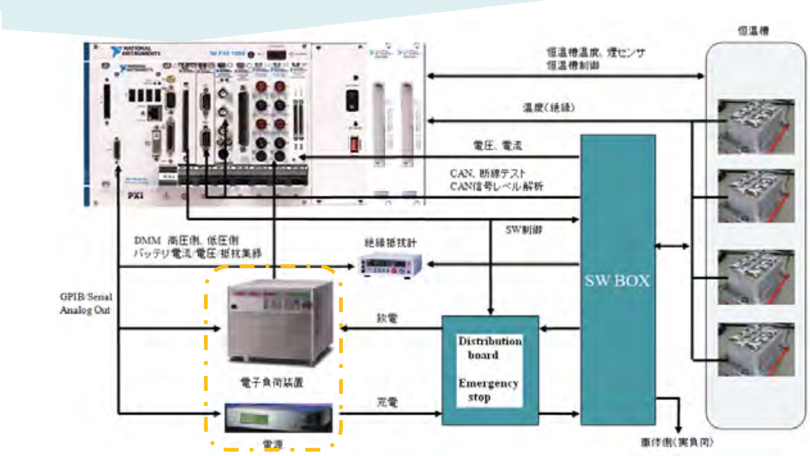
Example Full Vehicle HILS Including Motor Models



Example: Full Vehicle EV HILS for Battery

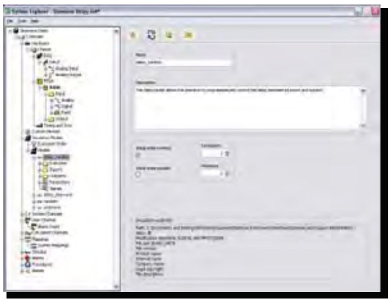


Drive HEV motors under dynamic loads, and then enter the power consumption waveform of the motor (up to 1MH z) using the discharge and charge equipment. For recharge systems that have rapid response (external analog command support), a response speed from the actual battery to the discharger (output) and charger (regeneration) can be performed with a response speed of 100 KH z or higher. （Switching from output to regeneration is performed based on a command from ECU. ）
Furthermore, more realistic battery testing can be achieved by using a constant temperature reservoir, leaning device, and excitation device.



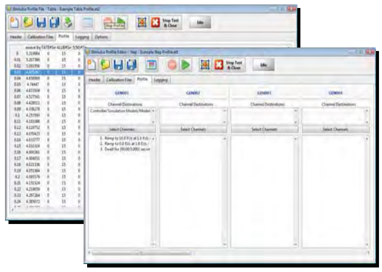
Future
Linking to HILS operation sof

NI VeriStand
Real-Time Testing and Simulation Software



System Explorer
Importing JMAGmodels
IO connections to hardware

WorkSpace
Users interface
Parameter settings



Test Profile Editor
Execute test profiles
Data logging

1. Open plateform

- Links using multiple model languages such as **JMAG**、Simulink®、MATRIXx、TESIS DYNAware、GT-POWER、MapleSim、SimulationX、SCADE、AMESim、VI **Grade**、CarSim、C++, etc.
- Easier links for universal PCI platforms, third-party products, and **various IO** （over 6000types）
- Fully customizable screens（including GUI）and features

2. Low cost

- Development license: ¥700,000
- Run time license: ¥70,000
- Trail version: 1 to 3 months (free)

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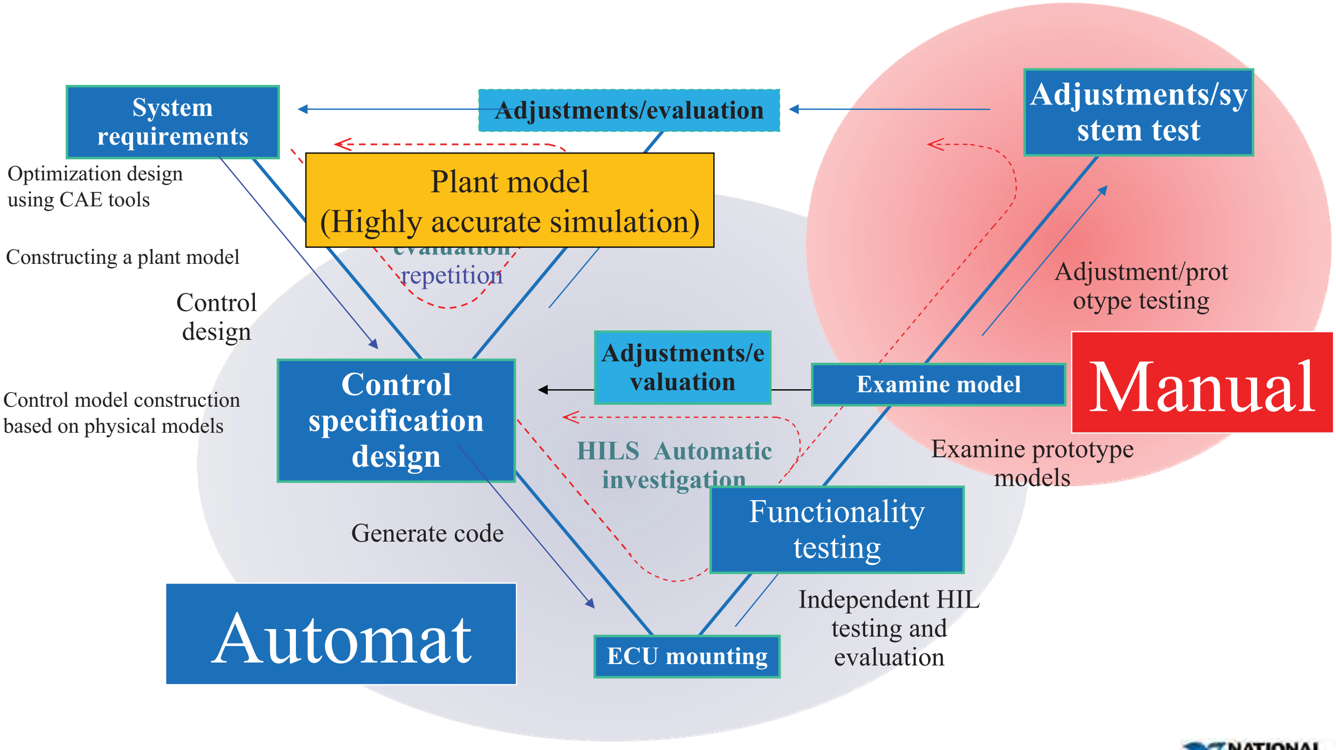
STEP2

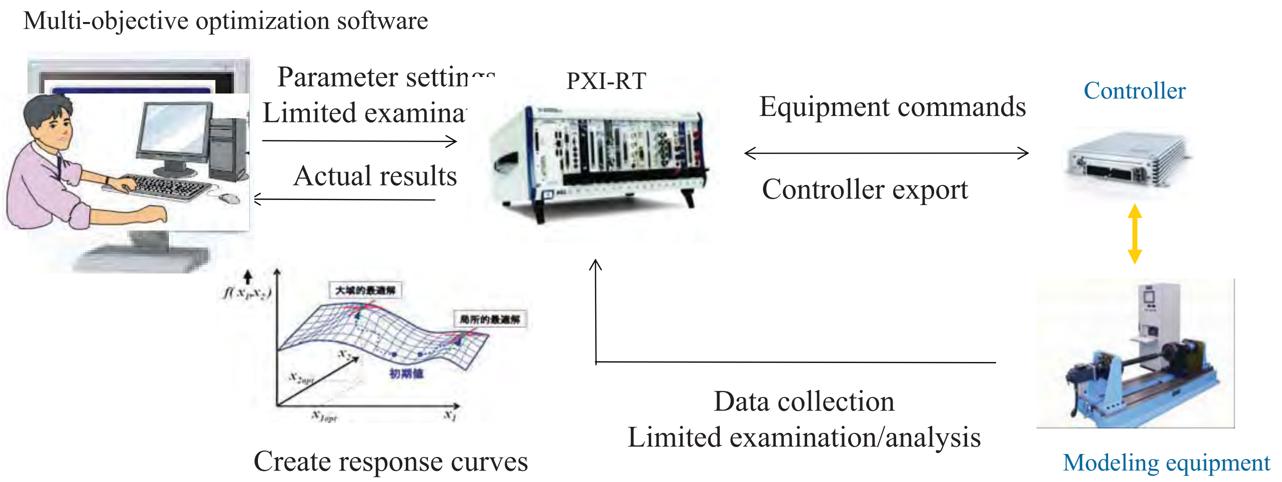
- Automating adaptation of controlled parameter

Future Challenges of Control System Design



Adaption and efficiency of system tests
Manual to automated

Automated evaluation of optimal solutions using computers



Application Example:
Automating Adaption of Various Motor Parameters using Motor-HILS