

# **Real-Time Simulation of a PMSM Drive in Faulty Modes with Validation Against an Actual Drive System**

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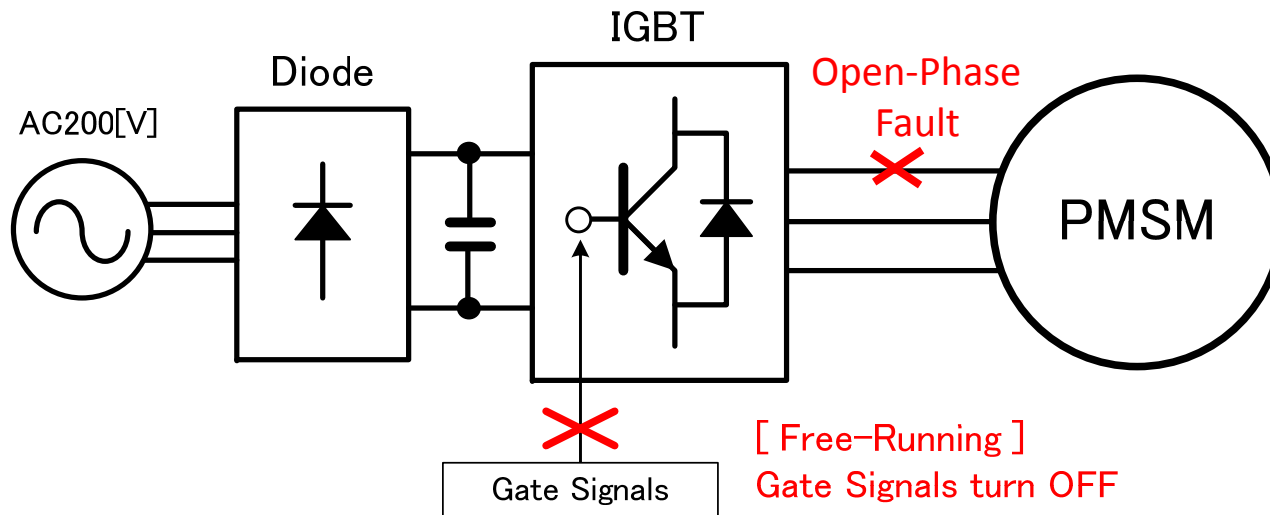
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*Based on a paper originally published in EPE 2009*

# Objective of the work

- Develop a PMSM drive model that is
  - compatible with real-time simulation
  - can support faulty or non-active control modes



# End Application



*Changes for the Better*

This motor drive is used in:

- Machine tool application
- Injection molding machine
- Semi-conductor equipment
- Robots
- Press machine

And especially in:

- Air Conditioning



**Empowering  
Industries**



# End Application

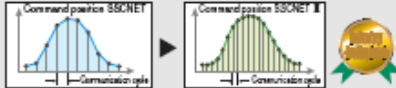
## MELSERVO-J3 The ever-evolving new

## generation servo

### SSCNET III, new high-speed serial bus compatible: MR-J3-B

#### High-speed with high accuracy via optical communication

- Improved system responsiveness!  
The speed of exchanging data between the controller and the servo amplifier has been greatly increased thereby shortening tact time.
- Synchronized control and synchronized starting for advanced interpolation!
- Smooth control using high-speed serial communication with cycle times up to 0.44ms! (Note 1)

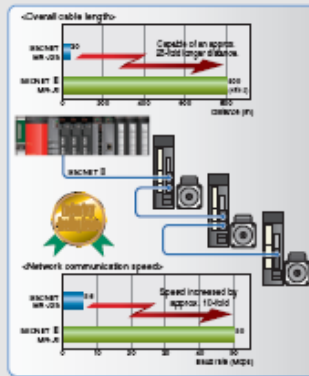


#### Easy and flexible wiring with optical communication

- Capable of long distance wiring (Maximum overall distance up to 50m between stations (Note 2) x number of axes).
- Reduced wiring by issuing the stroke limit signal and the proximity dog signal via the servo amplifier.
- Simple connection with dedicated cables, reducing both wiring time and chances of wiring errors.

#### Enhanced reliability

- Improved noise resistance with optical communication!
- Note: 1. The communication cycle varies depending on the number of axes connected and the controller operation cycle.  
2. When using a long distance cable: 50m between stations x 16 axes x 800m



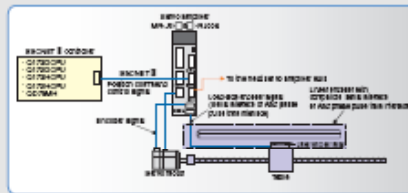
### Fully closed loop control compatible servo amplifier: MR-J3-B-RJ006

#### High accuracy and high response position control

- Dual feedback control provides the highest possible positioning response by using the position feedback signals from the motor encoder during high-speed rotation, and from the load-side encoder, such as a linear encoder, when positioning (stopping).

#### Flexible system structure

- With the wide variety of linear encoders, users can configure systems that meet their requirement. Compatible serial communication linear encoder for MR-J2S can be used without modification.
- Absolute position detection system is easily configured without a battery by using a serial interface ABS type linear encoder.
- ABZ phase differential input interface unit, MR-J2S-CLP01, that was necessary for MR-J2S series, is not required when using a compatible ABZ phase pulse train interface linear encoder.



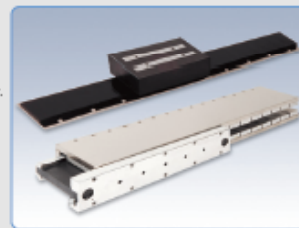
### Linear servo compatible: MR-J3-B-RJ004

#### High-speed, high-accuracy

- High-speed operation (2m/s) is now possible with this direct drive system. (Conventional transmission mechanisms typically can not achieve such fast operational speeds.)
- A fully closed loop control system is realized by using position feedback signals from a machine-end encoder such as a linear encoder.

#### Wide range of products

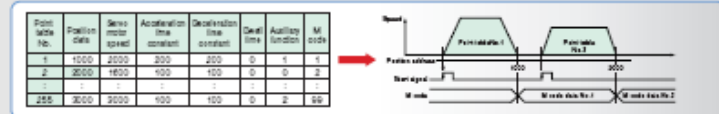
- Core type linear servo motor  
LM-H2 series: Continuous thrust 60 to 960N  
LM-F series: Continuous thrust 300 to 3000N (self-cooling)  
Continuous thrust 600 to 6000N (liquid-cooling)
- Cordless type linear servo motor  
LM-U2 series: Continuous thrust 50 to 800N



### CC-Link compatible built-in positioning function: MR-J3-T

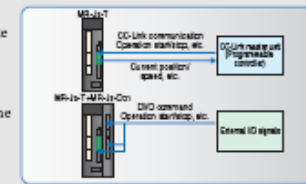
#### Built-in positioning function

- By setting position and speed data in the point tables in the servo amplifier, positioning operation is possible with a simple start signal from the positioning controller.



#### CC-Link communication compatible

- Setting position and speed data and operation start and stop is possible via CC-Link communication.
- Servo data information can be sent via CC-Link communication to the positioning controller and used for controlling the positioning application.
- CC-Link communication makes it possible to design the system with the servo amplifiers dispersed throughout.



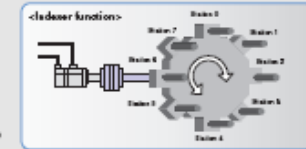
#### DI/O command with the extension IO unit, MR-J3-D01 (Optional)

- Selecting the point table and positioning operation start are possible by the DI command with MR-J3-D01. Also, alarm code and M code can be output with the digital signal. (CC-Link communication is not available when using MR-J3-D01.)



#### Parameter unit, MR-PRU03

- Parameter setting, monitoring, alarm display and test operation are possible by connecting to the servo amplifier, thus providing an efficient operation start.
- Up to 32 servo amplifier axes can be connected and controlled with a multi-drop connection.



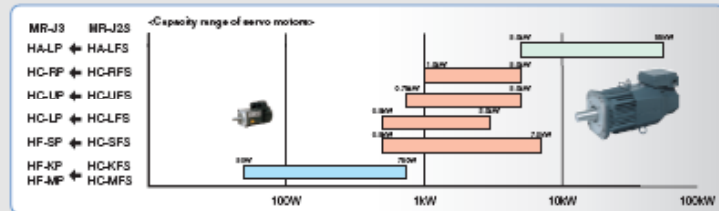
#### Operational functions

- Roll feed function
- Indexer function  
Capable of positioning to a set number of equally divided stations (up to 255 stations).

### Wide range of product lines

#### Diverse motor capacities

- Large capacity motors have been added to our product line. Now motors are available from 50W to 55kW. With the wide selection of motors provided, full retrofit of an MR-J2S series system is possible.



# Classic motor drive test bench

- Using real physical prototype
- Requires a 2<sup>nd</sup> motor drive to produce torque

Motor drive  
under test

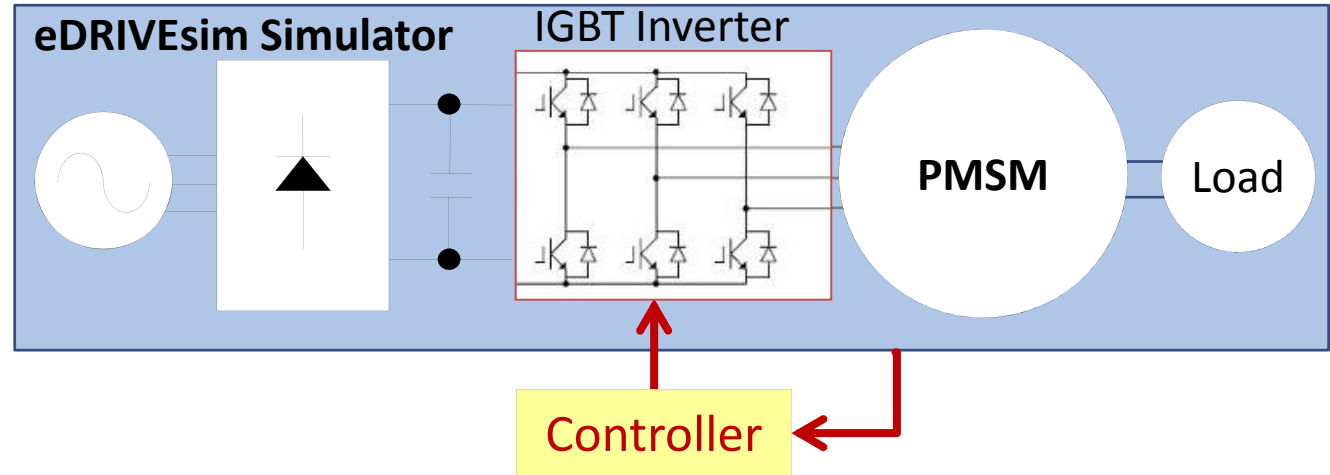


DC motor  
(torque production)

# Virtual motor test bench at MELCO

Simulated in RT:

- Diode converter
- IGBT Inverter
- PMSM motor
- Mechanical load



**eDRIVESim**  
Virtual Test Bench

Controller



# Challenges

- **Controller sample time is around 50  $\mu$ s**
  - We need a motor drive model that run much faster than this. 10  $\mu$ s is acceptable and near today's simulator limits (for CPU type. FPGA type PMSM model can run much faster!)
- **PWM frequency is around 10 kHz**
  - Interpolation of gate signals inside a 'direct analytical approach' must be used at 10  $\mu$ s to avoid under-sampling problems.
- **Fault modes**
  - A problem until now because of the switching-function approach (SFA).

[=> A solution is presented here](#)

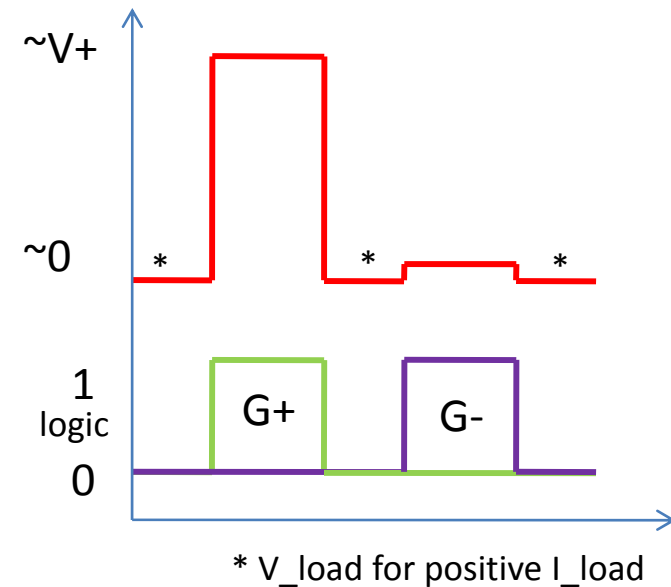
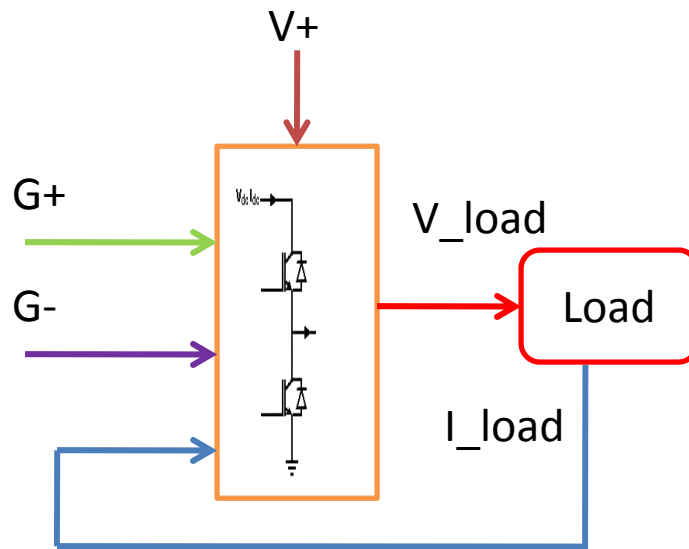
# Direct Analytical Approach

## Advantages

- Simple controlled voltage source
- -> Very fast method

## Disadvantages

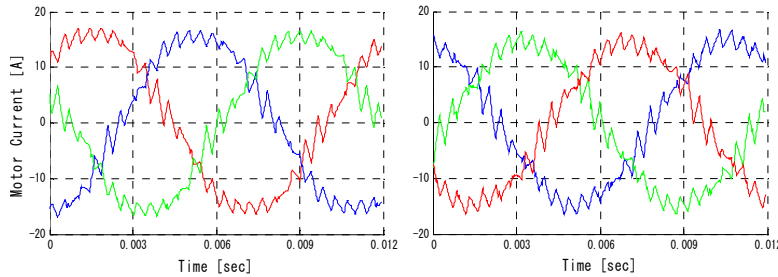
- Has limited functionality when used in rectification and faulty mode because of the high-impedance mode cannot be modeled by a voltage source



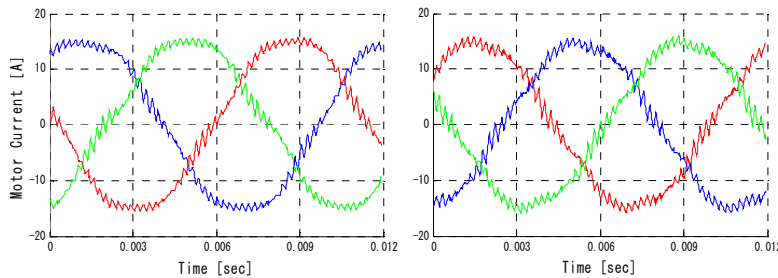
# Results (active mode)

## Effect of PWM frequency

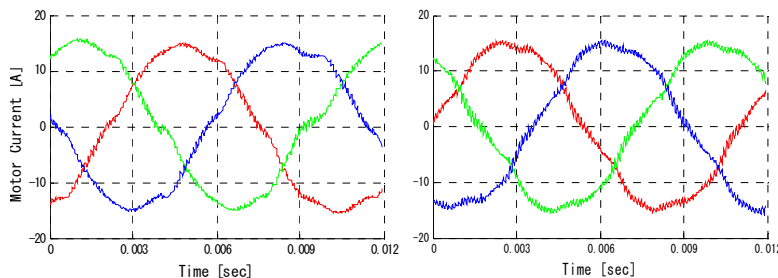
HIL simulation    Actual System



2.25 kHz



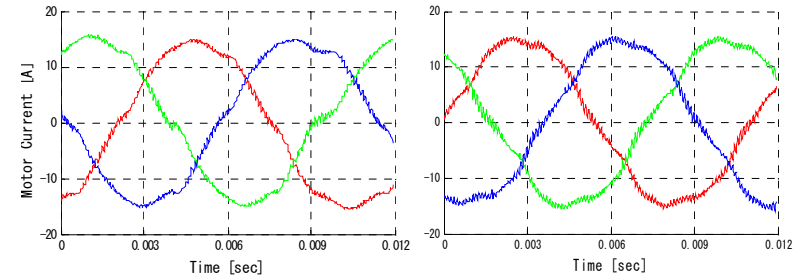
4.5 kHz



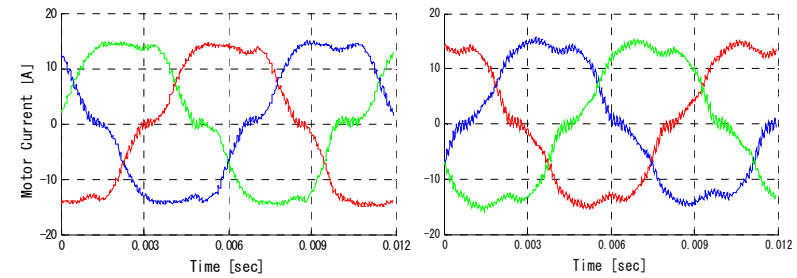
9 kHz

## Effect of dead time

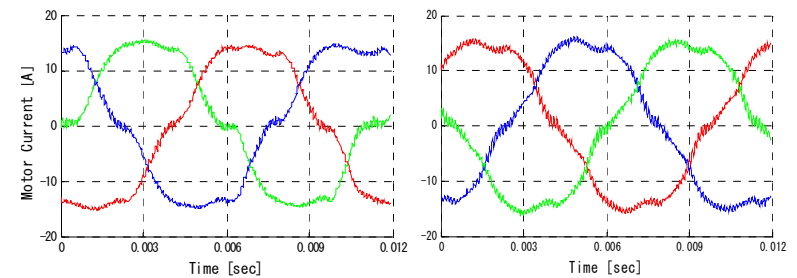
HIL simulation    Actual System



4.2 μs



8.4 μs

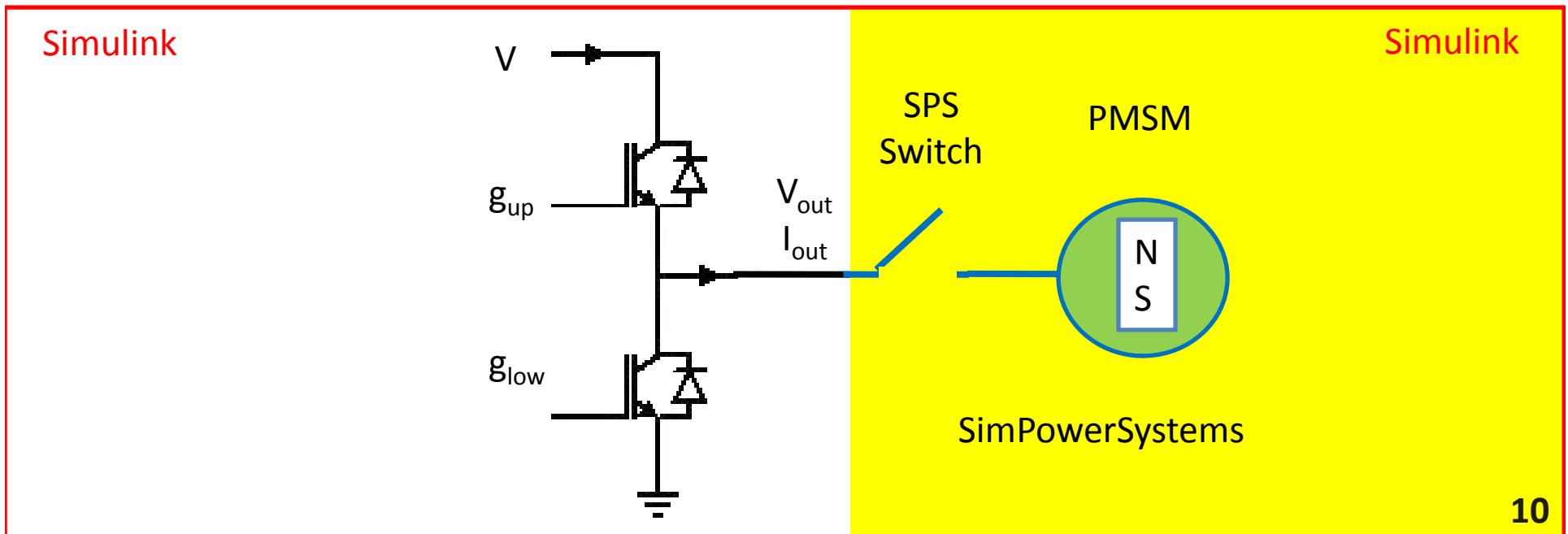


12.6 μs

Motor currents (A)

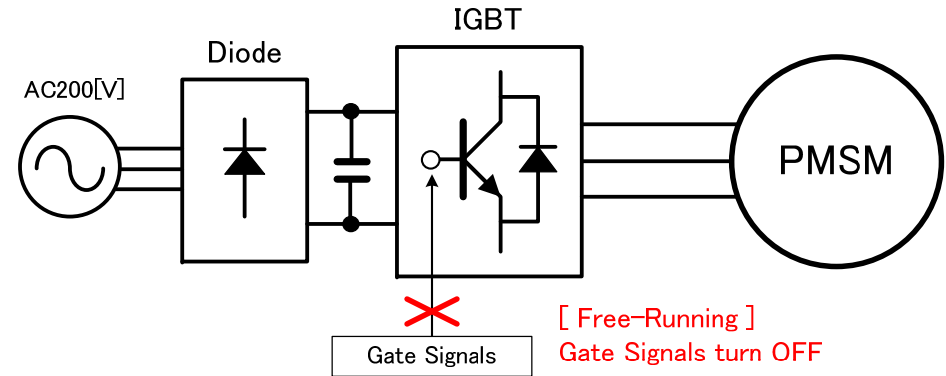
# How to implement high impedance mode in 'direct analytical approach'?

- A series switch in SimPowerSystems
  - Facilitate inclusion of other contingencies like breaking resistors



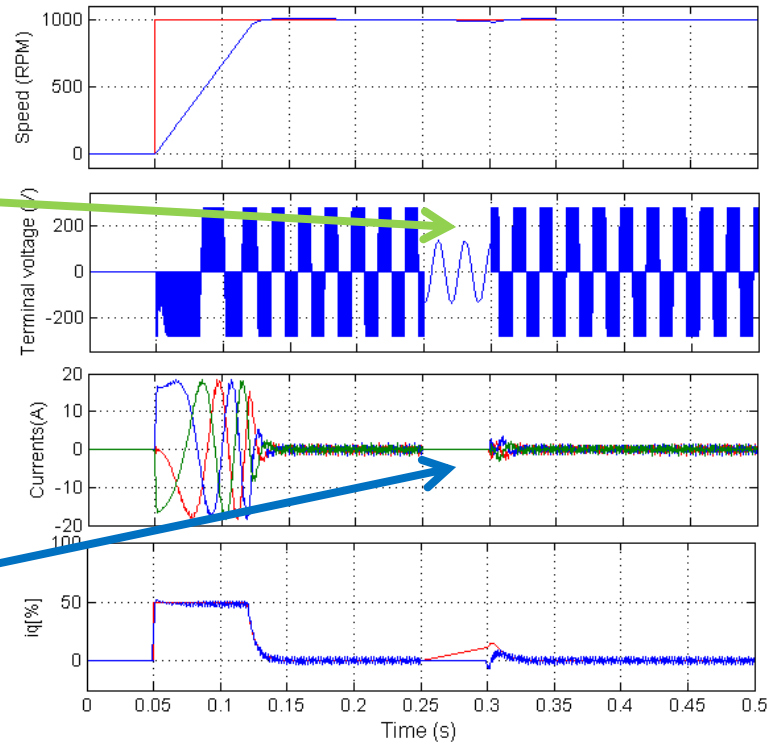
# Free-running simulation

- When no IGBT gates are present are present



Back-EMF present during shutoff

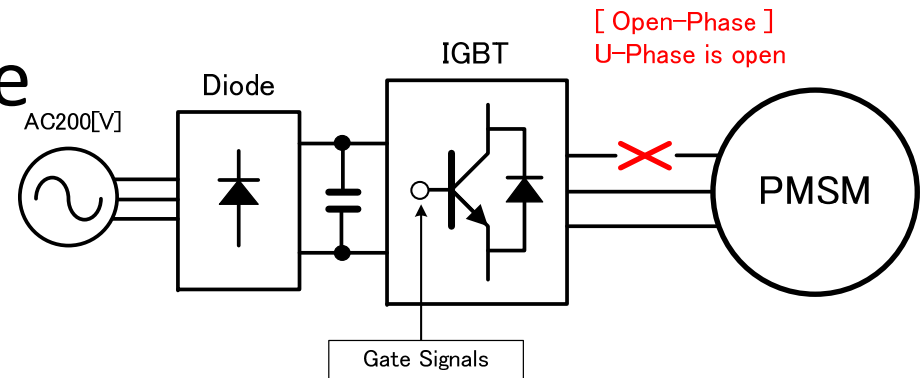
Currents go to zero during pulse shutoff



Real-time simulated motor

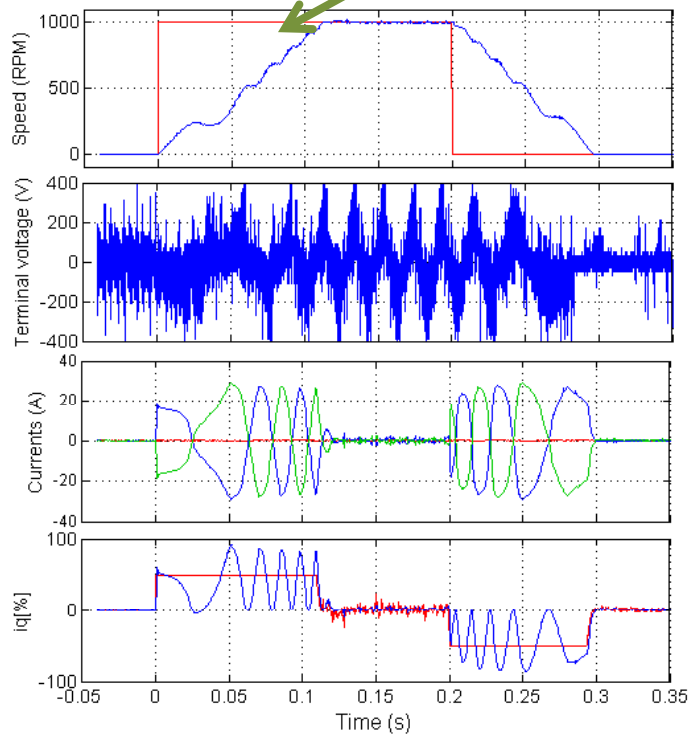
# Open-phase simulation

- When one motor phase is opened

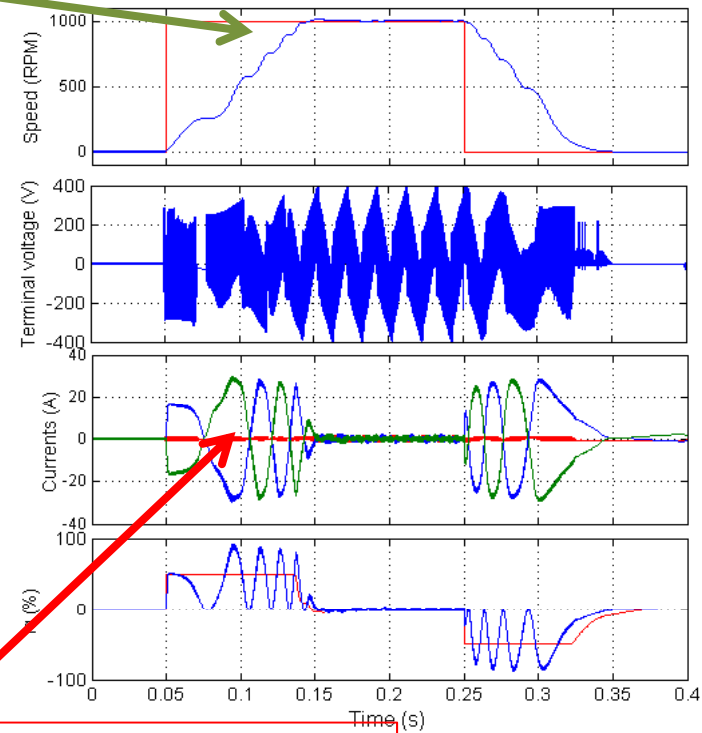


Acceleration is different

Actual motor



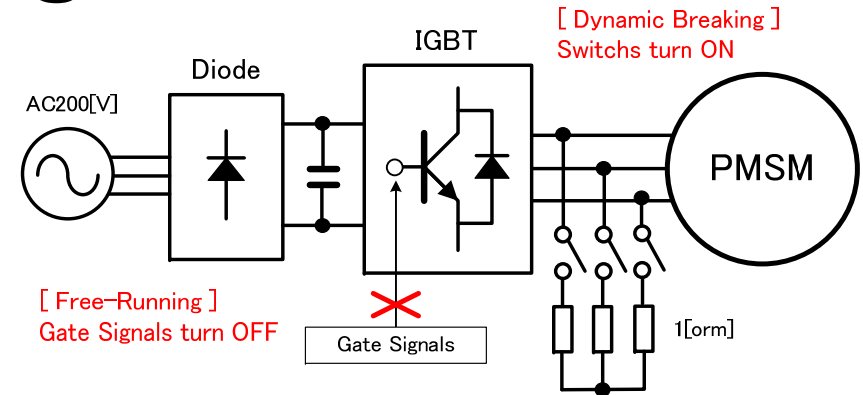
Real-time simulated motor



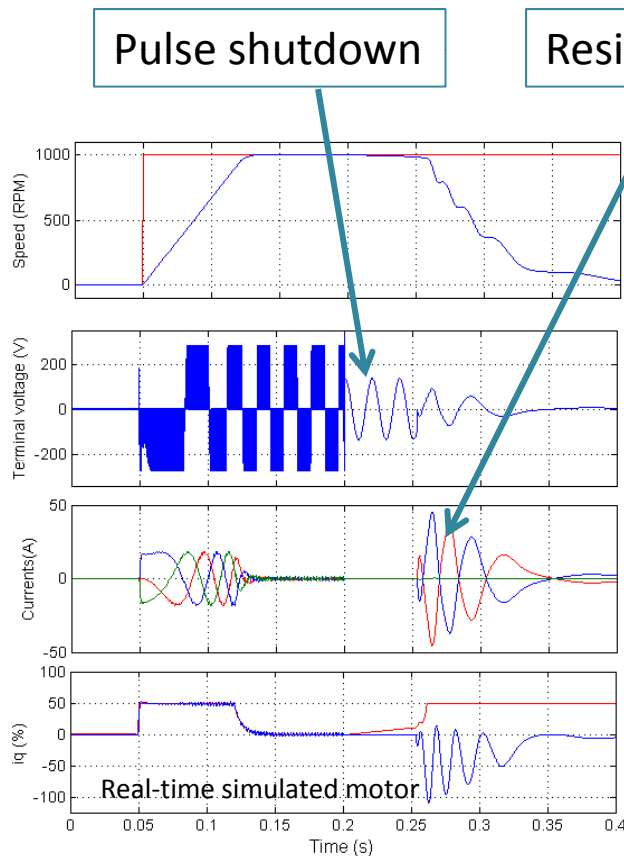
Non-null open-phase current

# Dynamic breaking simulation

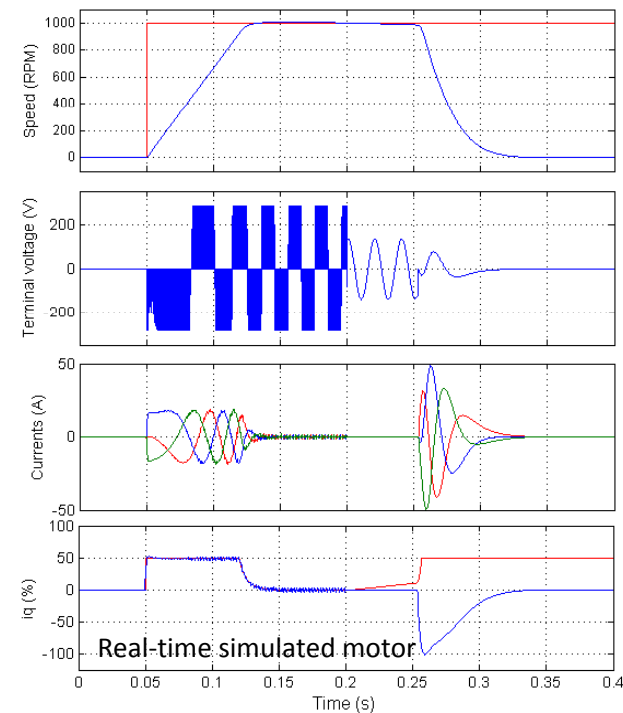
- Force the motor to a halt by dissipating its kinetic energy into resistors



2-phase breaking



3-phase breaking



# Summary

- The most common method to simulate a motor drive in real-time is with the use of switching function methods.
  - However, the high impedance case is a problem in this method.
- By combining ‘direct analytical approach’ and a global solver (SPS here), it’s possible to simulate the high impedance effect of the inverter by using a SPS switch model in series with a switching function approach
- This enabled MELCO to make several passive control and fault mode tests not previously possible in RT.

## Conclusion (2)

- Accuracy of the proposed model is good. However:
- Non-null current during open-phase test
  - a limit exist on the maximum resistance of the high impedance resistor because of the delay between SPS and SFA parts.
  - This limit does not diminish the usefulness of the tests that can be made with the model.
- A different acceleration occurred in the open-phase model.
  - This may be caused by the motor model itself which is a standard d-q model with no saturation and sinusoidal back-EMF.
  - An FEA-model of the PMSM could be better. JMAG-RT provides such real-time models for RT-LAB.

Thank you for your attention!