# Introducing the New Asynchronous Machine Force Element

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# Agenda

1 INTRODUCTION

2 BASIC EQUATIONS AND SETTINGS

3 VALIDATION OF THE MODEL

4 EXAMPLE: SIMPLIFIED DRIVE ARRANGEMENT

# INTRODUCTION

- **In the field of the vehicle dynamics tractive and braking forces are often neglected**
- **However, in some cases it is of interest to investigate this forces too, i.e. to obtain assumptions for exceptional loads like**
  - Torsional vibrations
  - Different types of short circuit
- **Therefore in 2010 Bombardier Transportation and SIMPACK decided to rebuild the asynchronous machine model using a more modular approach**

# BASIC EQUATIONS AND SETTINGS (1)

## FEATURES OF THE NEW ASM MODEL

- **Modular design**
  - Nearly every situation might be modelled
  - User is responsible for modelling the voltage source, which might be either controlled or not
    - Use the different elements of SIMPACK Controls, SIMAT or MATSIM
    - For complex models User Routines are highly recommended
- **Internally the so-called “stator-oriented” reference system is used. Thus the input might be either**
  - Three-phase voltage system with basically 120º phase shift $u_R$, $u_S$ and $u_T$
  - Two-phase voltage system with basically 90º phase shift $u_\alpha$ and $u_\beta$
    - in particular for use with control systems
- **The skin-effect (current displacement) is taken into account**
  - Increases the air-gap torque e.g. at starting point as well as in case of a short circuit

# BASIC EQUATIONS AND SETTINGS (2)

## EQUIVALENT CIRCUIT DIAGRAM AND EQUATIONS

### EQUATIONS

- **Following Kirchhoff's law we get the following equations:**

$$R_1 \cdot \underline{i}_1(t) + \frac{\partial}{\partial t}\underline{\psi}_1(t) = \underline{u}_1(t)$$

$$R_2' \cdot \underline{i}'_2(t) + \frac{\partial}{\partial t}\underline{\psi}'_2(t) - j \cdot \nu \cdot \underline{\psi}'_2(t) = 0$$

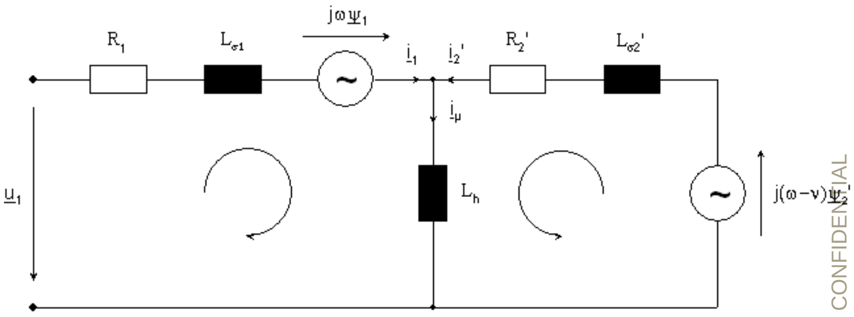
- **The air gap torque is the vector/cross product of the flux and the current**

$$i(t) \times \psi(t)$$

- **Using the orthogonal components we get:**

$$\tfrac{3}{2}\,p \cdot \left\{\, i'_{2\alpha}(t) \cdot \psi'_{2\beta}(t) - i'_{2\beta}(t) \cdot \psi'_{2\alpha}(t) \right\} = m_{el}(t)$$

### T- EQUIVALENT CIRCUIT DIAGRAM

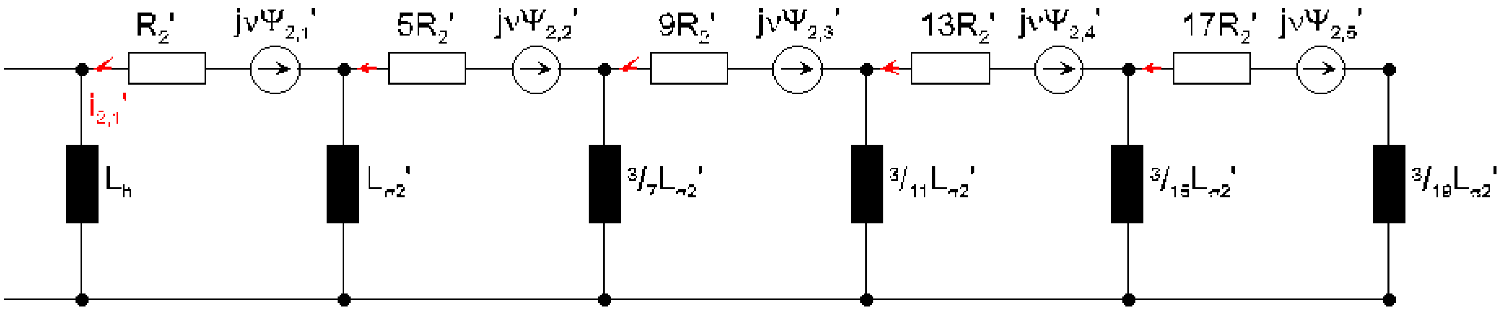


- **Γ-equivalent circuit diagram may be used instead by re-calculating the input parameters**
- **The input parameters may be found in the input data sheet**

# BASIC EQUATIONS AND SETTINGS (3)

## CONSIDERING THE SKIN EFFECT

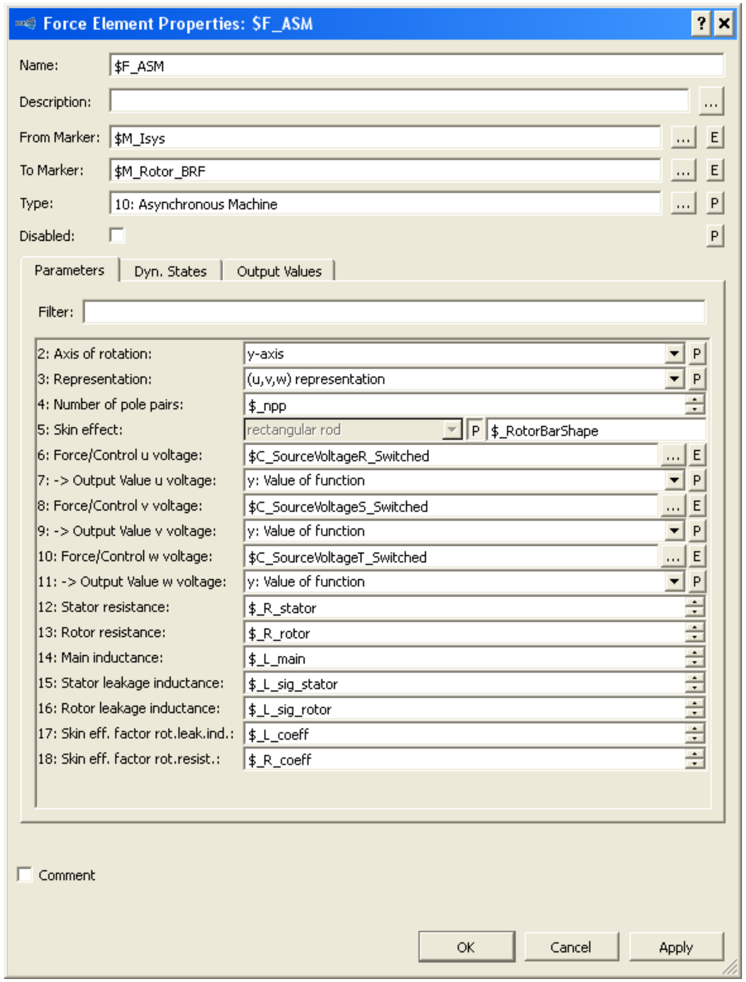
- **The skin effect is modelled using a lattice network for the rotor as follows:**



$$\frac{\partial}{\partial t}\begin{bmatrix}\underline{\psi}_1\\ \underline{\psi}'_{2,1}\\ \underline{\psi}'_{2,2}\\ \underline{\psi}'_{2,3}\\ \underline{\psi}'_{2,4}\\ \underline{\psi}'_{2,5}\end{bmatrix}=\begin{bmatrix}\underline{u}_1\\ 0\\ 0\\ 0\\ 0\\ 0\end{bmatrix}-\begin{bmatrix}R_1\cdot\underline{i}_1\\ R_2'\cdot\underline{i}'_{2,1}\\ 5R_2'\cdot\underline{i}'_{2,2}\\ 9R_2'\cdot\underline{i}'_{2,3}\\ 13R_2'\cdot\underline{i}'_{2,4}\\ 17R_2'\cdot\underline{i}'_{2,5}\end{bmatrix}+j\cdot\begin{bmatrix}\underline{\psi}_1\\ \nu\cdot\underline{\psi}'_{2,1}\\ \nu\cdot\underline{\psi}'_{2,2}\\ \nu\cdot\underline{\psi}'_{2,3}\\ \nu\cdot\underline{\psi}'_{2,4}\\ \nu\cdot\underline{\psi}'_{2,5}\end{bmatrix}$$

# BASIC EQUATIONS AND SETTINGS (4)

## INPUT SETTINGS



Force Element Properties: $F_ASM

|  |  |
|---|---|
| Name: | $F_ASM |
| Description: |  |
| From Marker: | $M_Isys |
| To Marker: | $M_Rotor_BRF |
| Type: | 10: Asynchronous Machine |
| Disabled: | ☐ |

Filter:

|  |  |
|---|---|
| 2: Axis of rotation: | y-axis |
| 3: Representation: | (u,v,w) representation |
| 4: Number of pole pairs: | $_npp |
| 5: Skin effect: | rectangular rod<br>$_RotorBarShape |
| 6: Force/Control u voltage: | $C_SourceVoltageR_Switched |
| 7: -> Output Value u voltage: | y: Value of function |
| 8: Force/Control v voltage: | $C_SourceVoltageS_Switched |
| 9: -> Output Value v voltage: | y: Value of function |
| 10: Force/Control w voltage: | $C_SourceVoltageT_Switched |
| 11: -> Output Value w voltage: | y: Value of function |
| 12: Stator resistance: | $_R_stator |
| 13: Rotor resistance: | $_R_rotor |
| 14: Main inductance: | $_L_main |
| 15: Stator leakage inductance: | $_L_sig_stator |
| 16: Rotor leakage inductance: | $_L_sig_rotor |
| 17: Skin eff. factor rot.leak.ind.: | $_L_coeff |
| 18: Skin eff. factor rot.resist.: | $_R_coeff |

☐ Comment

## MODELLING AND BASIC SETTINGS

- **A basic model consists only of the rotor, a rotational/cylindrical joint and the force element**
- **Set the initial velocity of the rotor to synchronous velocity**

$$\omega_0 = -\frac{2*\pi*f_1}{p}$$

- **Set the initial dynamic states $\psi_{1\alpha}$ and $\psi_{2\alpha}$**

$$\psi_{1\alpha 0} = \psi_{2\alpha 0} = -\frac{U_{max}}{2*\pi*f_1}$$

$$\psi_{1\beta 0} = \psi_{2\beta 0} = 0$$

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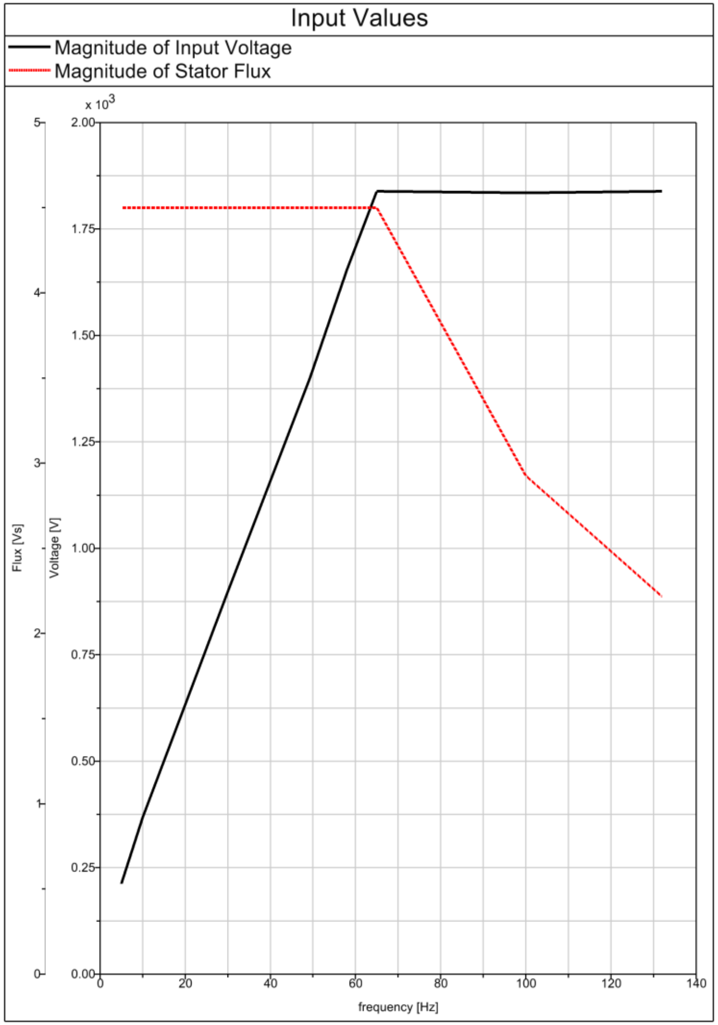
# BASIC EQUATIONS AND SETTINGS (5)

## INPUT SIGNALS



- **(Sinusoidal) Voltage source is modelled using Control Elements and Function Expressions**
- **Magnitude of input voltage increases linearly up to its maximum in order to get a constant motor flux, i.e. the maximum utilization of the magnetic circuit**
- **When the maximum voltage is reached the motor flux will be reduced with increased frequency/rotor speed**
  - This effect usually is called “field weakening”
  - Air gap torque is reduced by 1/Ù$^2$

# VALIDATION OF THE MODEL (1)

## IDLE RUNNING

- **Usually the motor data sheets provide sufficient data points for validating the model**

- **If available, measurements might be used too**
  - **– The values in the data sheet often calculated using similar formulas**

- **The model of the ASM should be validated at least at one operating point both in idle running mode and with (nominal) load**

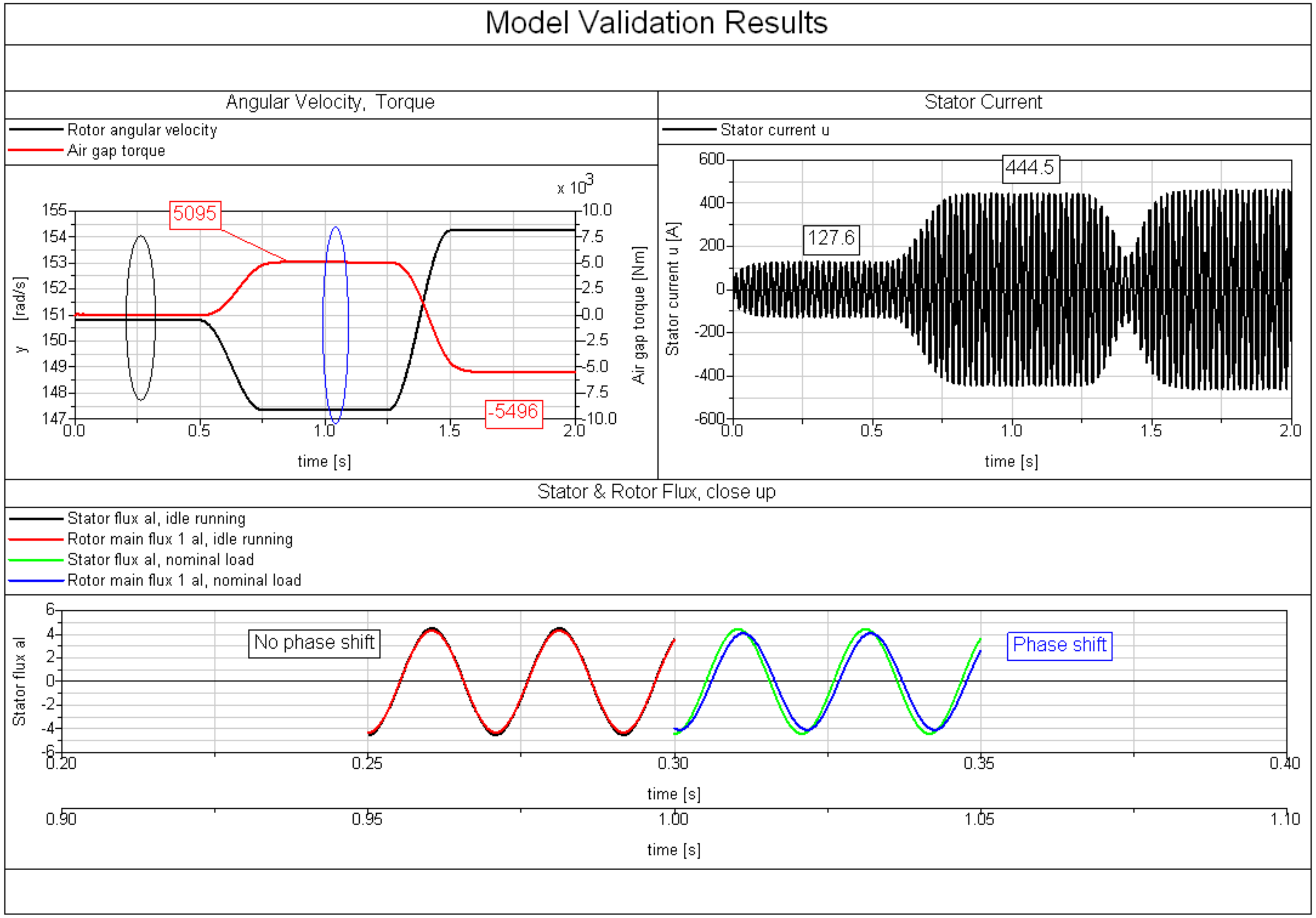
- **To validate the ASM in idle running follow the steps:**
  - **Set frequency and magnitude of input voltage as requested**
  - **Set the rotor angular velocity to it’s synchronous value**
  - **Check**
    - **Air gap torque is zero**
    - **Motor current is equivalent to the magnetisation current**

# VALIDATION OF THE MODEL (2)

## NOMINAL LOAD

- **To validate the ASM with (nominal) load**
  - **Set frequency and magnitude of input voltage as requested**
  - **Then either**
    - Fix the rotor angular velocity to the desired value [(1 – s) * $n_s$ ]
    - Check
      - » Air gap torque and motor current met the values in the data sheet
  - **or**
    - Apply the nominal torque to the rotor with inverse direction (braking)
    - Check
      - » Rotor angular velocity and motor current met the values in the data sheet
- **The breakdown torque might be used for validation purposes too**
  - Attention: This is rather a “quasi-static” value, i.e. the angular de- or acceleration must be rather low

# Validation of the model (3)
## Output Signals



# VALIDATION OF THE MODEL (4)

## RESULTS

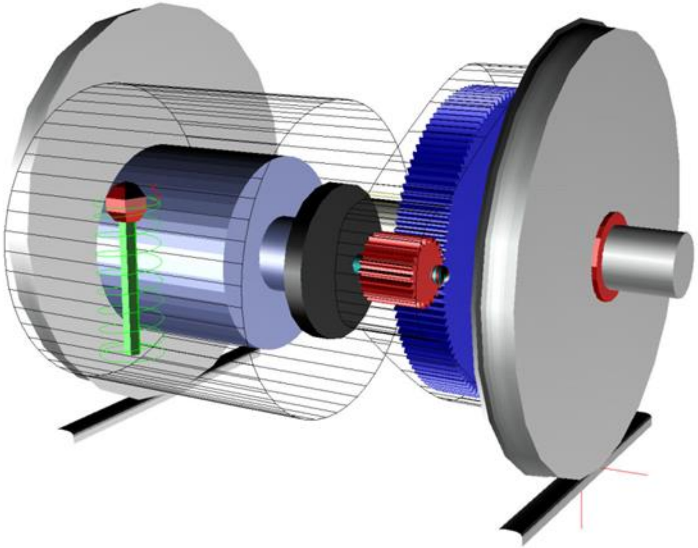
| | | | Rated Values | | | |
|---|---|---|---|---|---|---|
| | | | Idle state | | Rated load | |
| | | | Simulated | Data Sheet | Simulated | Data Sheet |
| **Frequency** | **f** | **Hz** | **48** | | | |
| **Voltage** | **Û** | **V** | **1363** | | | |
| **Rotor Angular Frequency** | **ω** | **1/s** | **150.8** | | **147.3** | |
| **Slip** | **s** | **-** | **0** | | **0.0229** | |
| **Torque** | **T** | **Nm** | **-6** | **0** | **5095** | **5090** |
| **Current** | **Î** | **A** | **127.6** | **127.6** | **444.5** | **446.9** |

# EXAMPLE: SIMPLIFIED DRIVE ARRANGEMENT (1)

- **Hence it is rather difficult to obtain measurement values - especially of such critical incidents like short circuits - an approximately 25 years old system has been selected as example.**
- **It is a special design of a nose-suspended drive, known as “SLM-Schiebe-Tatzlagerantrieb”.**
- **The large gearwheel is mounted to the wheelset by means of a “soft” tangential spring. Thus the arrangement may rather compared with a quill tube/hollow shaft drive type than a nose suspended one.**
- **On the other hand a very simplified model of this drive type needs only to add one rotational body “wheelset” to the former example.**
- **The rotational spring-damper is added too and also a saturated friction force.**
- **Thus the natural frequency of the drive is approximately 8.6 Hz if the friction is fully applied and 14.9 Hz in case of no friction.**

# EXAMPLE: SIMPLIFIED DRIVE ARRANGEMENT (2)

## ADVANTAGES OF USING THE DOE ENVIRONMENT



- **Using the re-introduced Parameter Variation/ DOE might help to study the behaviour of the drive arrangement e.g. for different frequencies**
- **The first factor set includes**
  - Frequency and magnitude of input voltage
  - Main inductance
- **The second factor set has been used to modify the maximum friction force, expressed by the maximum friction coefficient $\mu$.**
  - Rotor bar cross section (0, 1 or 2)
  - Skin effect factors for rotor resistance and rotor leakage inductance
- **The responses e.g. include**
  - Air gap torque w/o & with filter “maxabs”
  - Rotor angular velocity
  - Input voltage also w/o & with filter “maxabs”
  - The torque at the spring-damper
  - Filters of type “maxabs” were used

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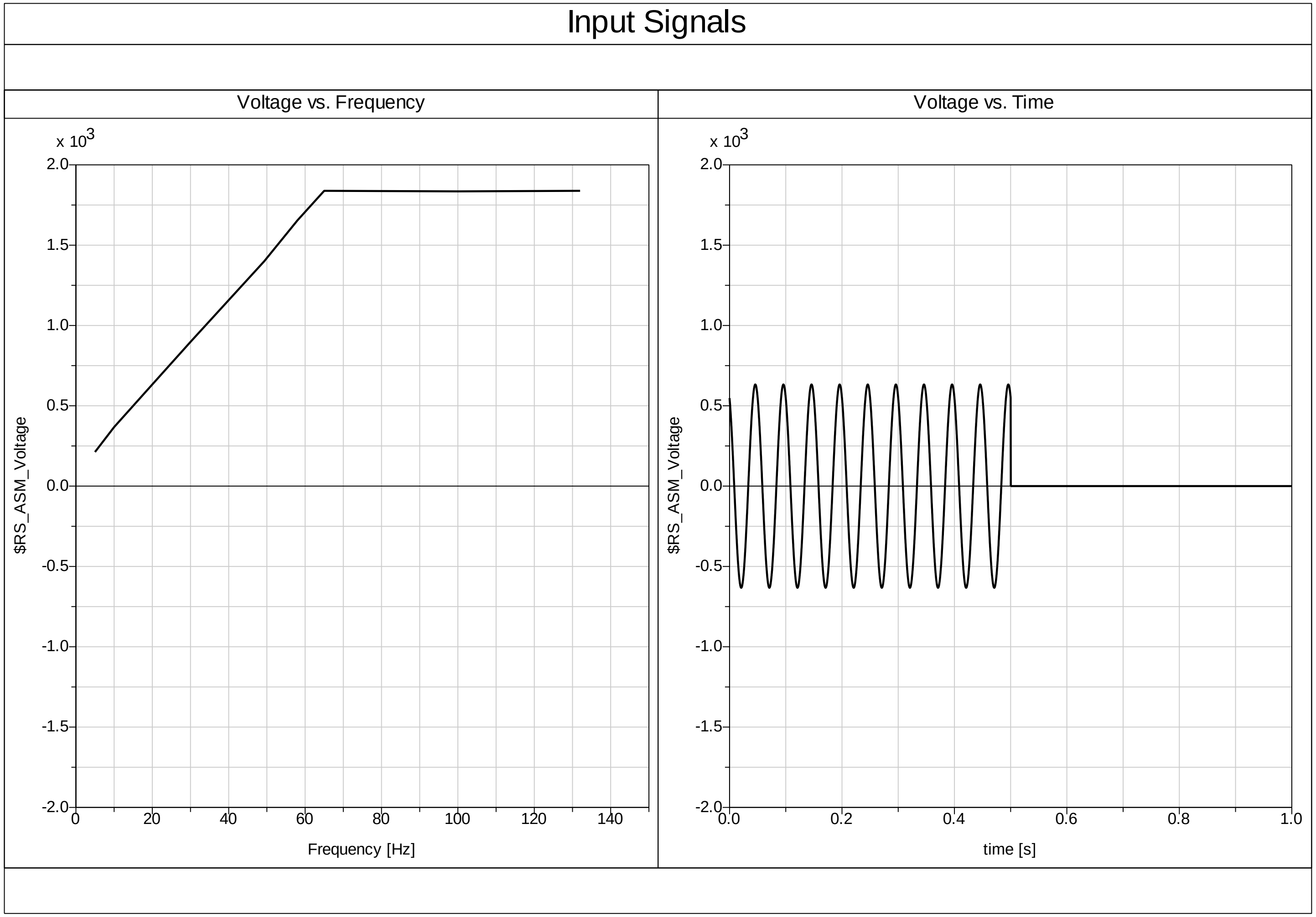
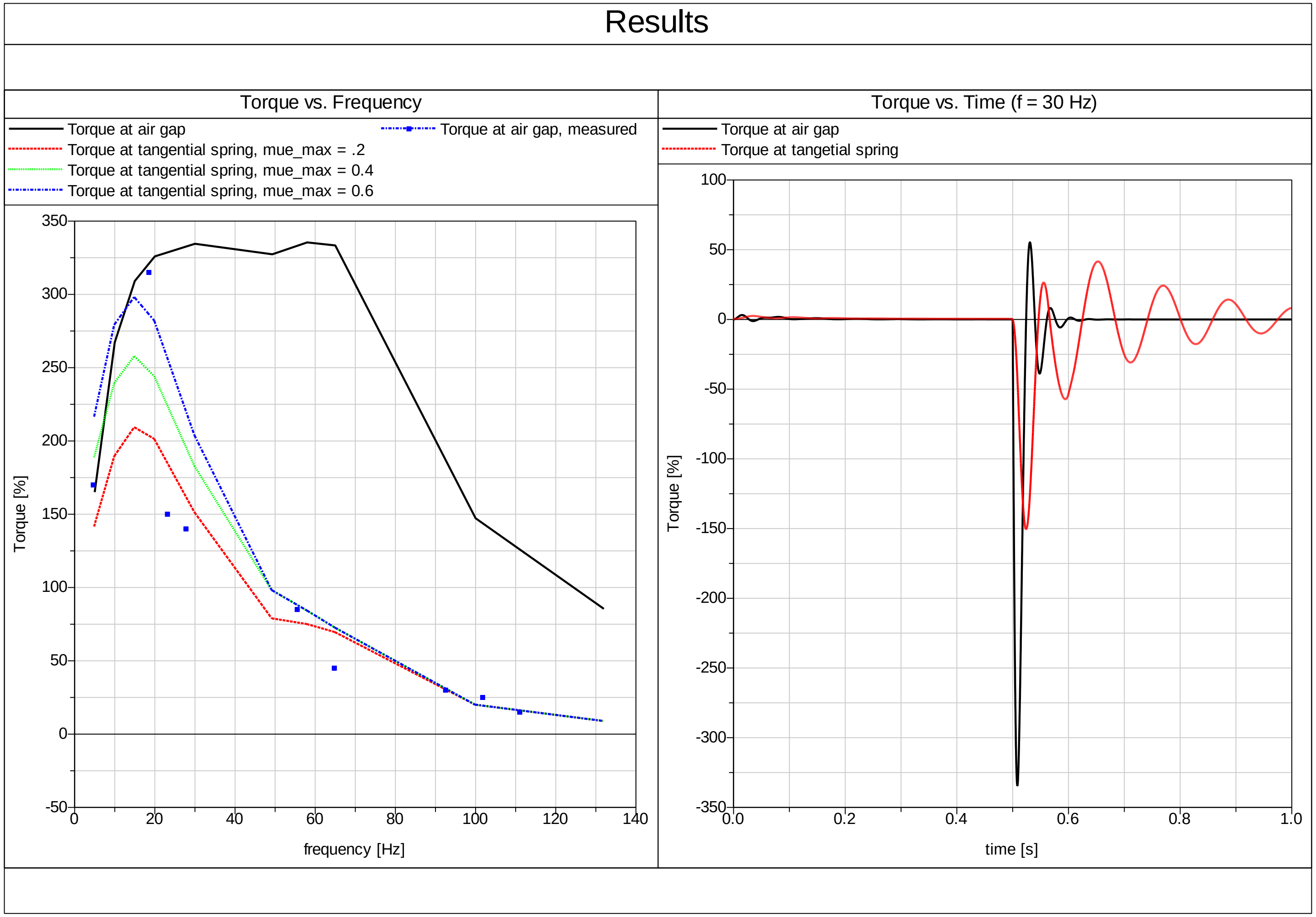
# EXAMPLE: SIMPLIFIED DRIVE ARRANGEMENT (3)

## INPUT SIGNALS



# EXAMPLE: SIMPLIFIED DRIVE ARRANGEMENT (4)

## RESULTS


Results

Torque vs. Frequency

Torque vs. Time (f = 30 Hz)

# ? Q&A

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