

AC electrical architecture propelling systems for aeronautics

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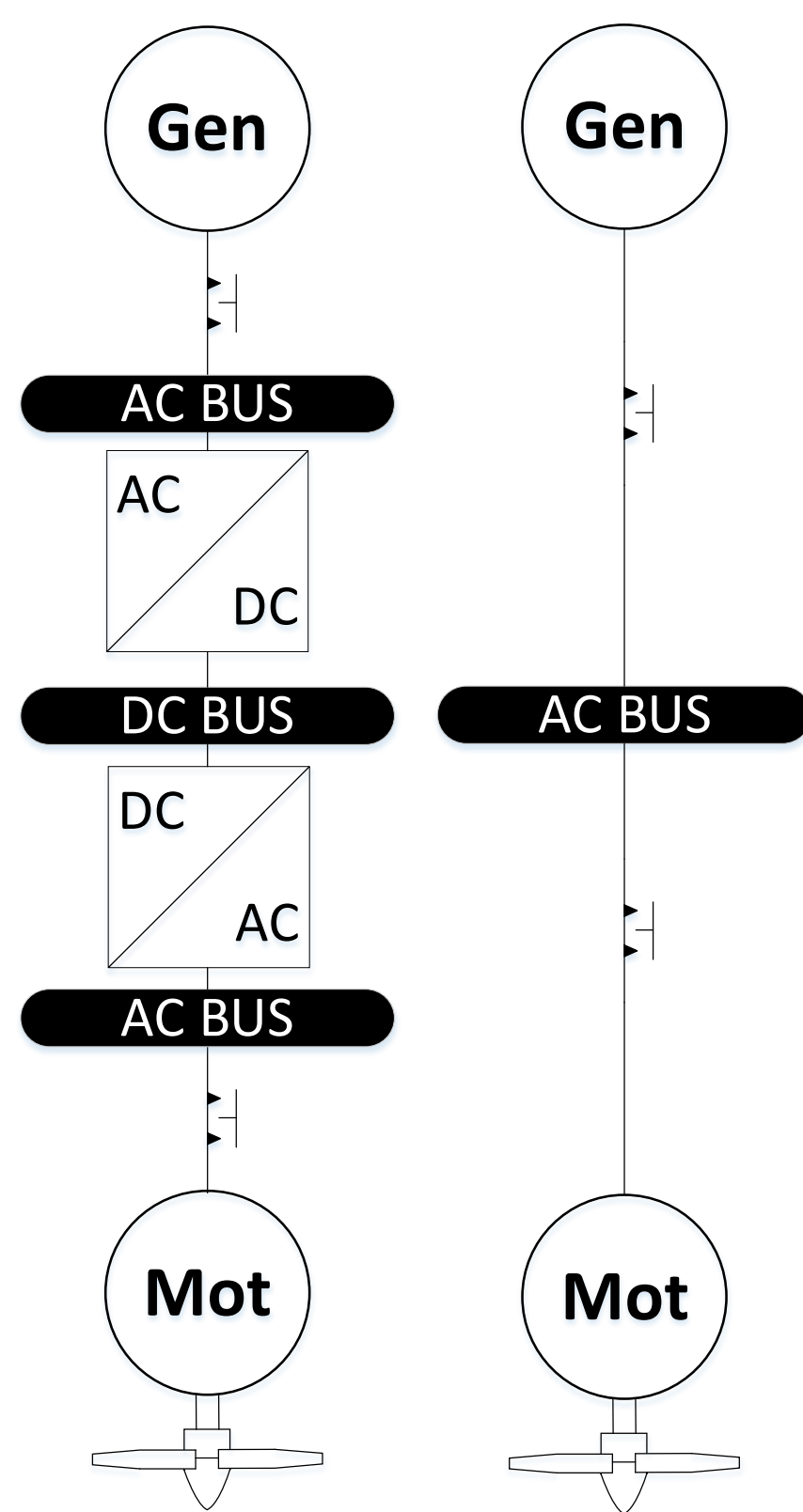
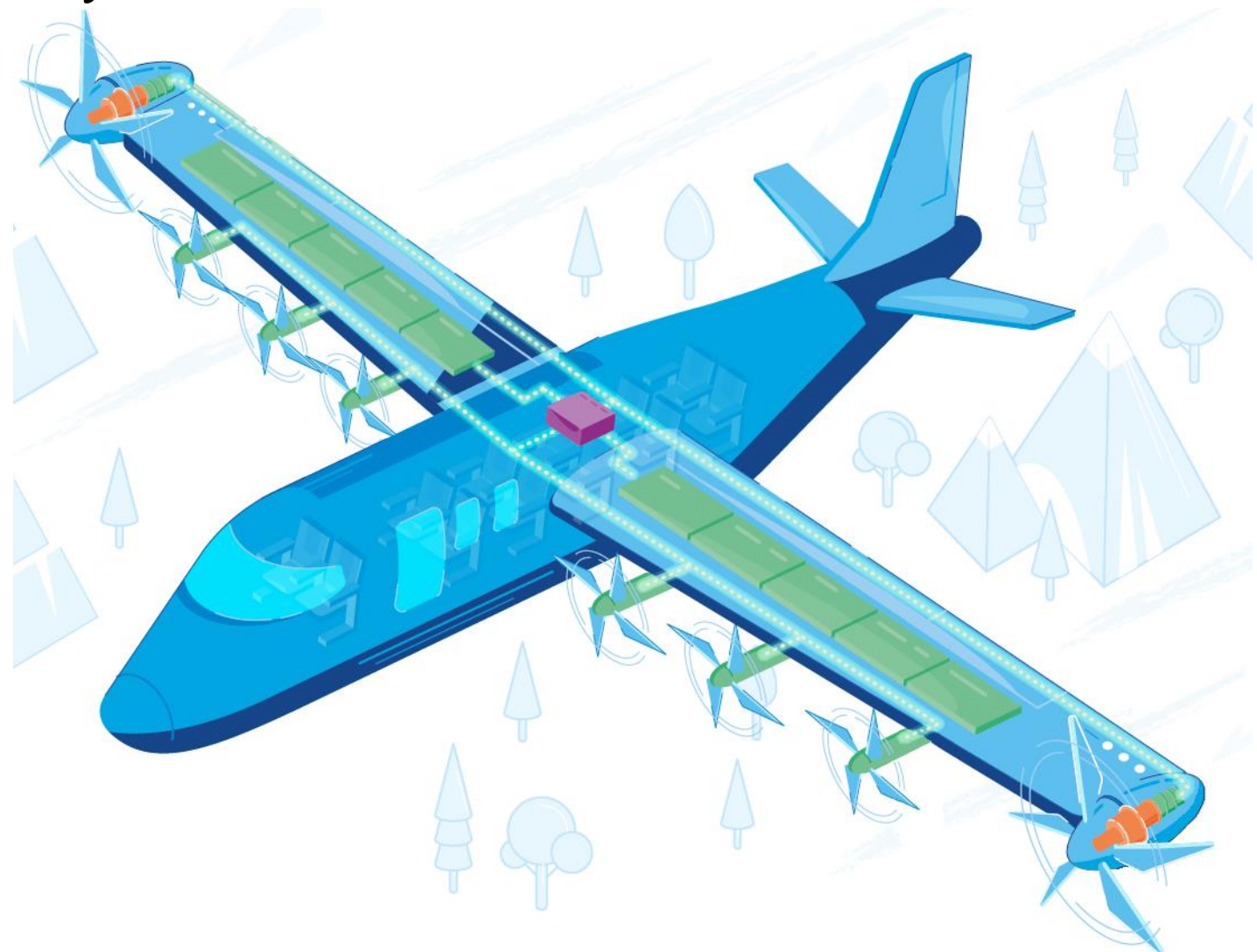
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Abstract : This work describes the study of an original “power electronic-less” AC electrical architecture for propulsive purposes in aeronautics. This architecture is composed of two **Permanent Magnets Synchronous Machines (PMSM)** directly linked to each other by an **AC bus**, one in generator mode driven by a gas turbine and the other one in motor mode, driving a propeller. Although this architecture may seem too rigid to be implemented, the absence of power electronic offers potential savings in mass and costs, which justifies its study to determine whether this architecture could be implemented and used for propelling systems or not.

MOTIVATIONS

- Study of a “power electronic-less” architecture that directly links through an AC bus two PMSM for aeronautics
- Creates a constraint between the speeds of the two PMSM questioning the dynamic behaviour and the stability of this architecture



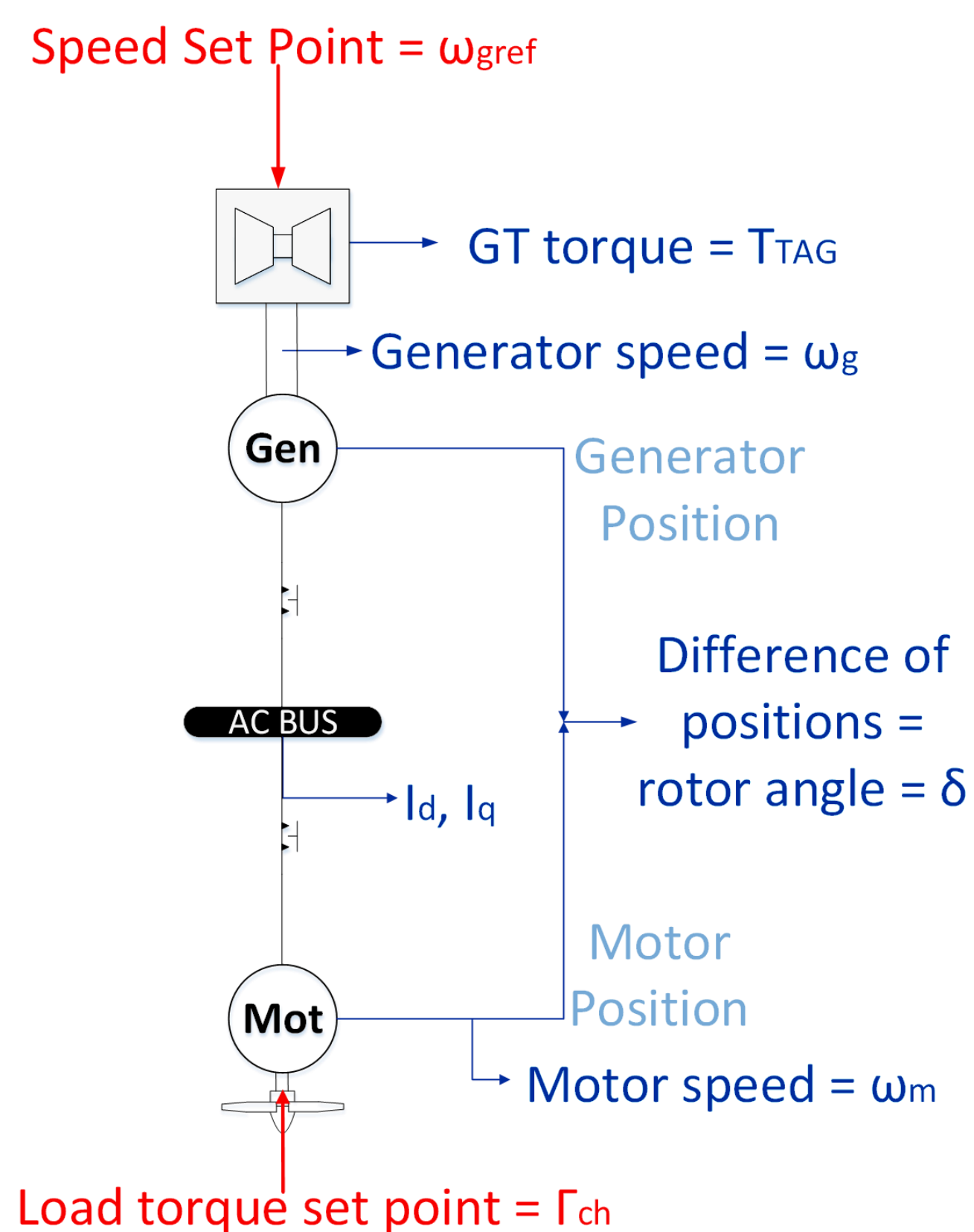
ANALYTICAL MODEL

- State model representation of the associated system :

$$\frac{d}{dt} \begin{pmatrix} I_d \\ I_q \\ \delta \\ \omega_g \\ \omega_m \\ T_{TAG} \end{pmatrix} = A \begin{pmatrix} I_d \\ I_q \\ \delta \\ \omega_g \\ \omega_m \\ T_{TAG} \end{pmatrix} + B \begin{pmatrix} \omega_{gref} \\ \Gamma_{ch} \end{pmatrix}$$

- Focusing on the electrical part of the system (I_d and I_q state variables), the electrical model of each PMSM is taken :

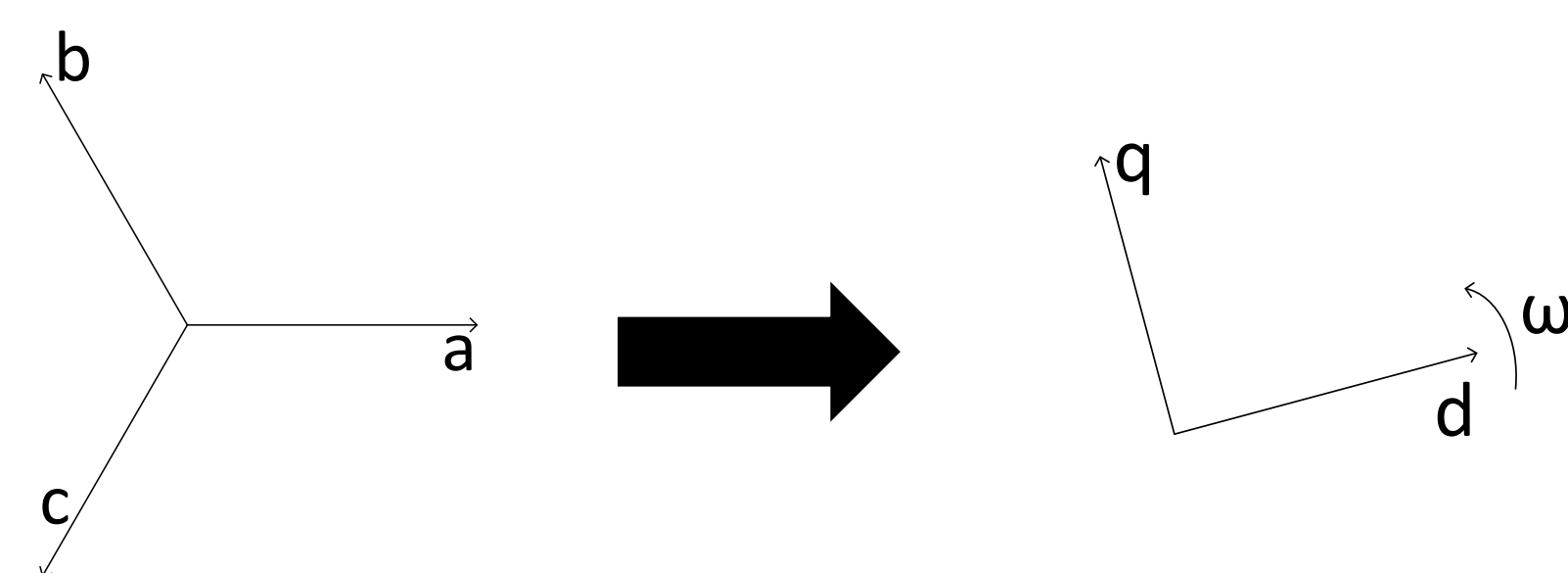
- At first in their particular ABC reference frame
- Then in their particular DQ0 reference frame



Generator equations (ABC): Motor equations (ABC):

$$U_{abc} = -R_g I_{abc} + \frac{d}{dt} \Phi_{g,abc}; \quad U_{abc} = R_m I_{abc} + \frac{d}{dt} \Phi_{m,abc};$$

$$\Phi_{g,abc} = -L_g I_{abc} + \phi_{a_g}; \quad \Phi_{m,abc} = L_m I_{abc} + \phi_{a_m}$$



Generator equations (DQ0 generator's reference frame):

$$U_{dq0}^g = -R_g I_{dq0}^g - L_g \frac{d}{dt} (I_{dq0}^g) - L_g \omega_g \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot I_{dq0}^g + \omega_g \phi_{a_g} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

Motor equations (DQ0 motor's reference frame):

$$U_{dq0}^m = R_m I_{dq0}^m + L_m \frac{d}{dt} (I_{dq0}^m) + L_m \omega_m \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot I_{dq0}^m + \omega_m \phi_{a_m} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

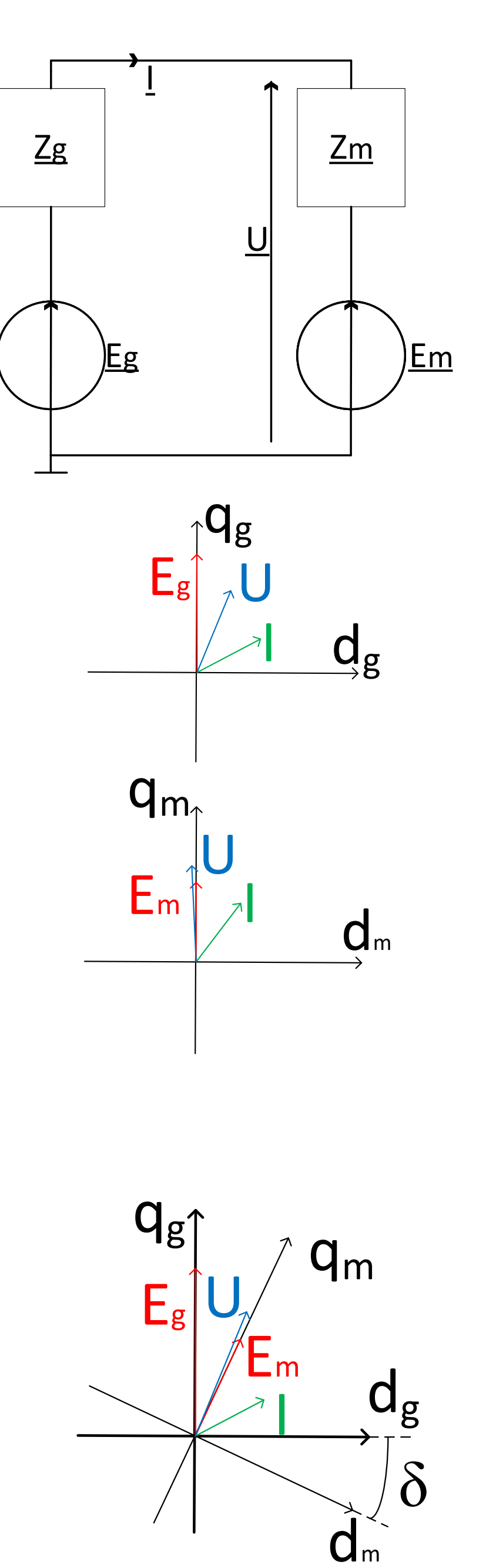
- In order to describe the whole system, the same DQ0 reference frame must be used otherwise the two PMSM can not be linked electrically

Electrical equations (I_d and I_q state variables) (DQ0 generator's reference frame):

$$(L_g + L_m) \frac{d}{dt} (I_{dq0}^g)$$

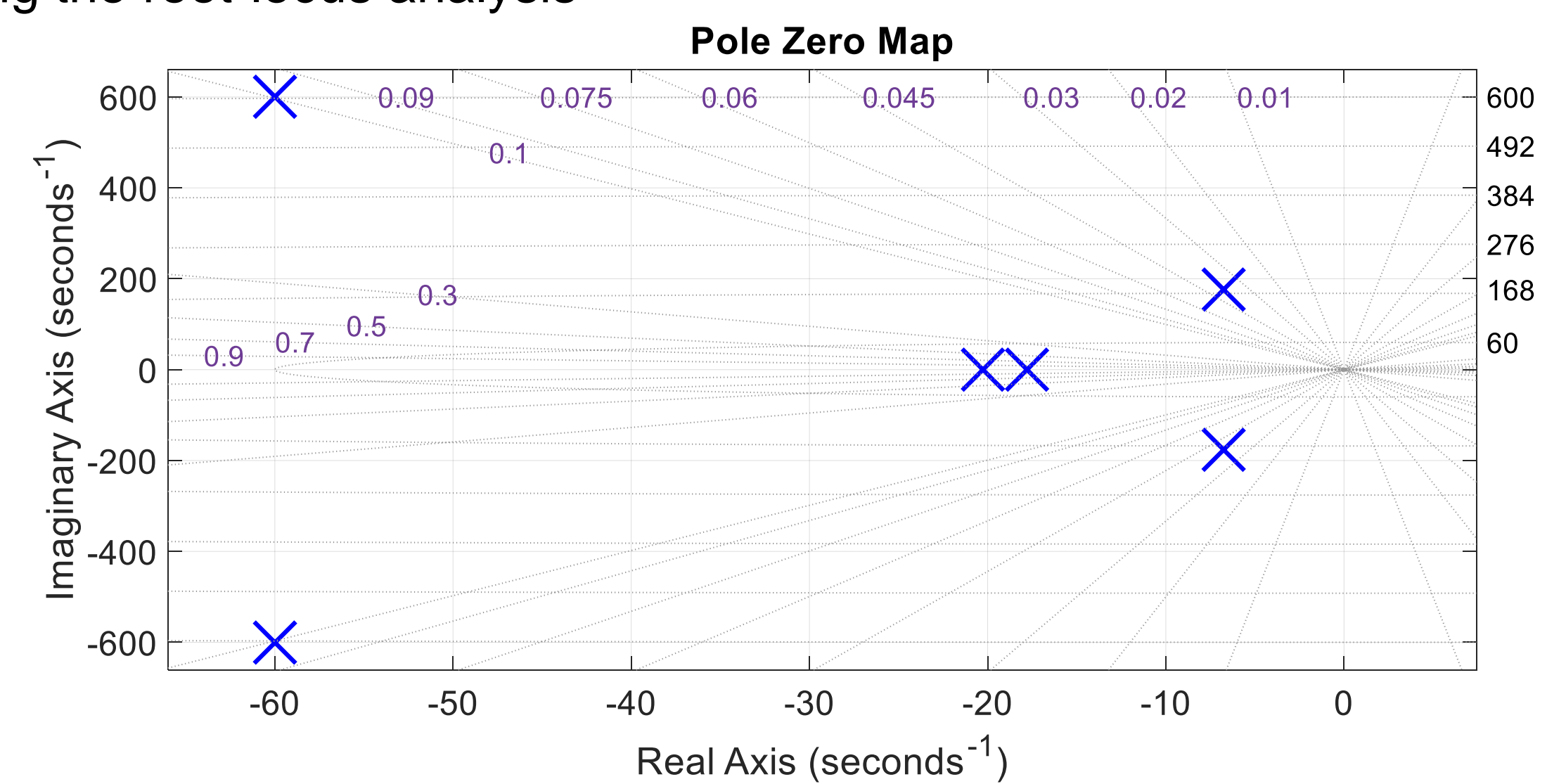
$$= -(R_g + R_m) I_{dq0}^g - (L_g + L_m) \omega_g \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot I_{dq0}^g$$

$$- \omega_m \phi_{a_m} \begin{pmatrix} \sin(\delta) \\ \cos(\delta) \\ 0 \end{pmatrix} + \phi_{a_g} \omega_g \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$



STABILITY STUDY

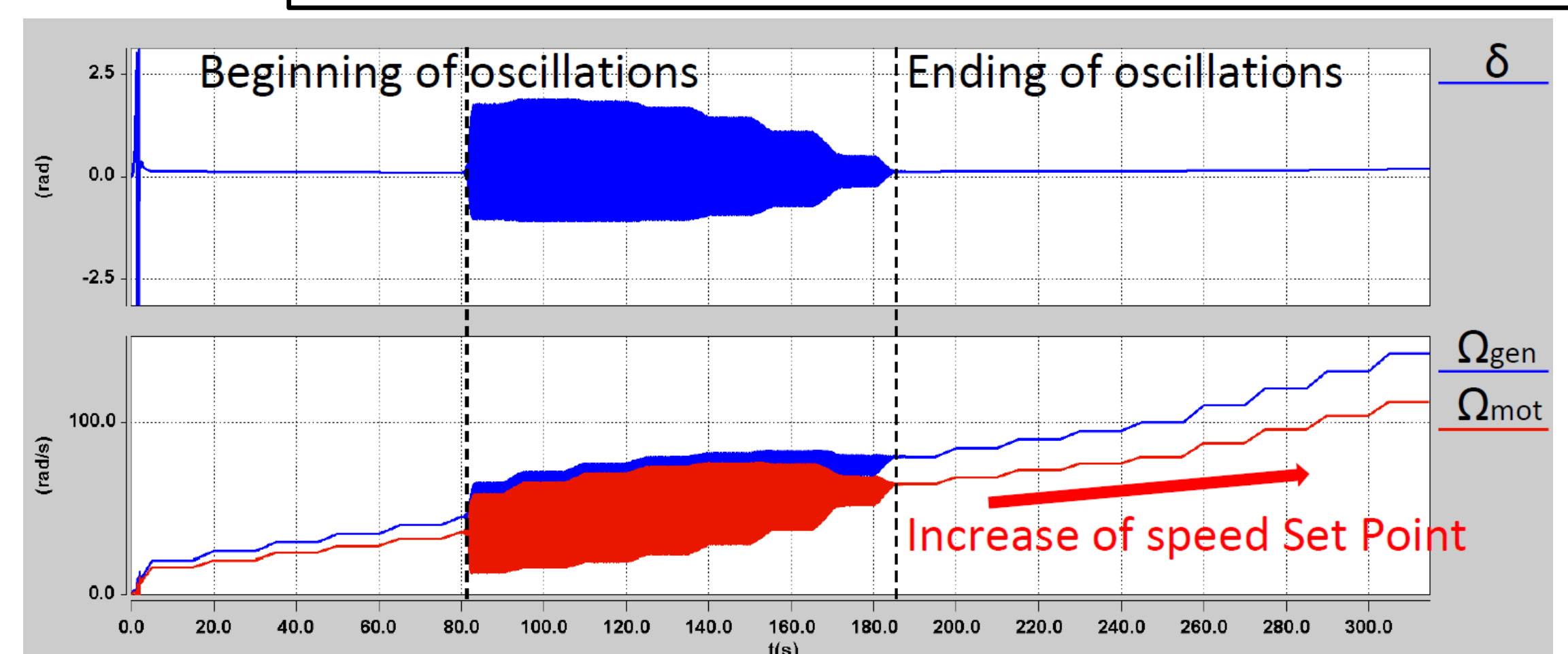
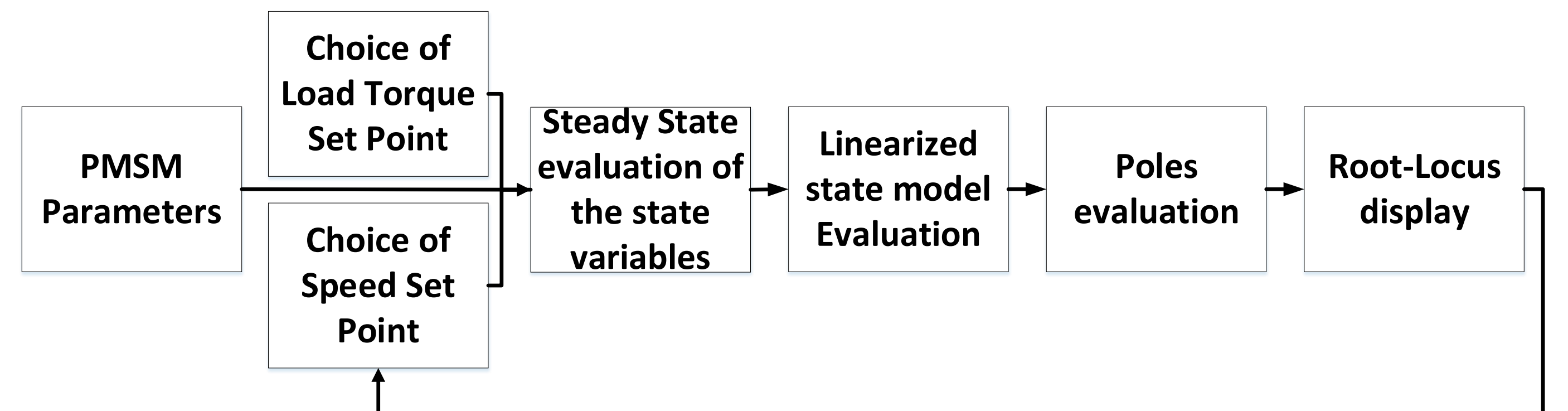
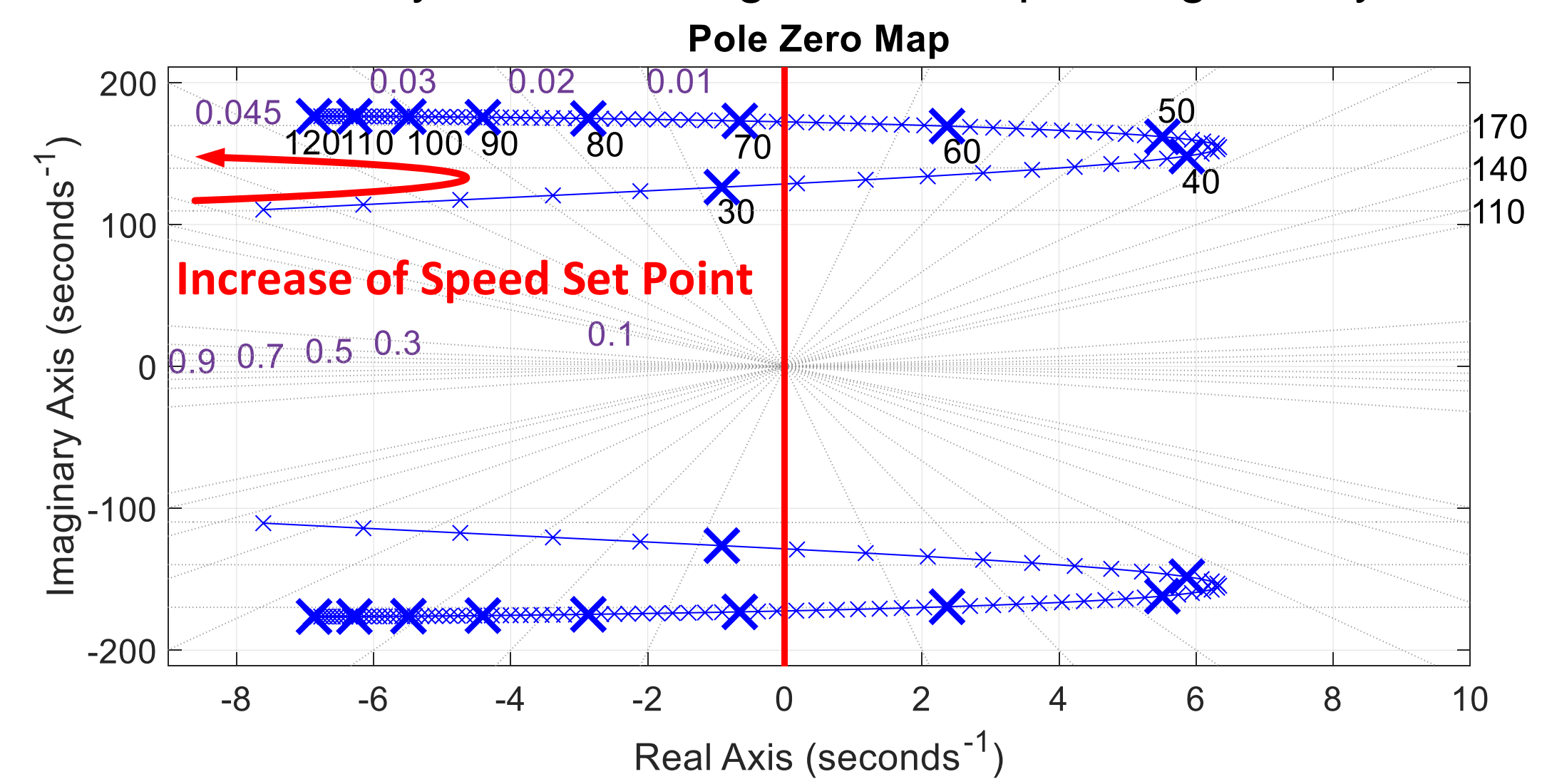
- The analytical model shed a light on potential oscillations and stall situations
- Study of the stability of the AC architecture thanks to the analytical model using the root-locus analysis



- The poles pair that can create oscillations and potentially instabilities, by passing in the right-hand plane, is the pair of imaginary poles on the right of the above figure

- Study of the evolution of this pair of poles under set point variations :

- Comparison of the system operation at steady state and a transient time simulation of the system crossing the corresponding steady states



- The oscillations coincide with the passing in the right-hand plane of the studied pair of poles with an approximation of a few radians per second
- The approximation is mostly due to the “small signal linearization” that gives the root locus approach

CONCLUSIONS

- A complete state model has been established enabling to fully describe a “power electronic-less” AC architecture
- Oscillations and sometimes system stall may appear with this architecture, certainly because of the stiffness of this AC architecture
- The root-locus (linearized approach) is appropriate for a first characterization of the stability of this AC architecture