Generalized Model of VSC-based Energy Storage Systems for Transient Stability Analysis

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Introduction

- The capability of Energy Storage Systems (ESSs) to improve the transient behavior of power systems and to increase the competitiveness of non-dispatchable power production technologies has led to a huge investment in research, prototyping and installation of different energy storage technologies.
- Still not commonly accepted simple yet detailed models of ESSs for transient stability studies are available.

Objectives:

- **To develop a simple yet accurate generalized model of ESSs that can be commonly adopted and for which data can be easily defined.**
- **To provide a comprehensive validation of the dynamic response of the proposed ESS model versus detailed ones representing specific technologies.**

System Overview

- Figure 1 shows the overall structure of an ESS connected to a grid through a Voltage Source Converter:

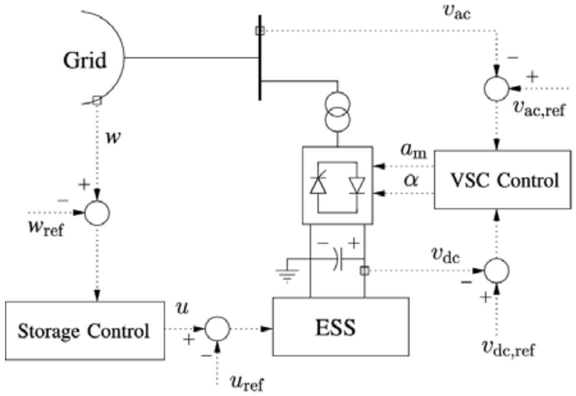

Fig. 1 Scheme of an ESS coupled to a grid

Proposed Model of ESS

- We part from the set of nonlinear Differential Algebraic Equations (DAEs) that describes the storage device. After linearizing around the equilibrium point, the expression for linear time-invariant dynamical system particularized to ESSs is obtained:

$$\mathbf{\Gamma}_x \dot{\boldsymbol{x}} = \mathbf{A}_{xx}\boldsymbol{x} + \mathbf{A}_{xz}\boldsymbol{z} + \mathbf{B}_{xu}u + \mathbf{B}_{xv}v_{dc} + \mathbf{K}_x$$
$$\mathbf{\Gamma}_z \dot{\boldsymbol{z}} = \mathbf{A}_{zx}\boldsymbol{x} + \mathbf{A}_{zz}\boldsymbol{z} + \mathbf{B}_{zu}u + \mathbf{B}_{zv}v_{dc} + \mathbf{K}_z$$
$$i_{dc} = \mathbf{C}_x\boldsymbol{x} + \mathbf{C}_z\boldsymbol{z} + \mathbf{D}_u u + \mathbf{D}_v v_{dc} + \mathbf{K}_i$$

- Neglecting the dynamics of the variables belonging to $\boldsymbol{z}$, the proposed generalized model for ESSs can be written as follows:

$$\tilde{\mathbf{\Gamma}}\dot{\boldsymbol{x}} = \tilde{\mathbf{A}}\boldsymbol{x} + \tilde{\mathbf{B}}_u u + \tilde{\mathbf{B}}_v v_{dc} + \tilde{\mathbf{K}}_x$$
$$i_{dc} = \tilde{\mathbf{C}}\boldsymbol{x} + \tilde{\mathbf{D}}_u u + \tilde{\mathbf{D}}_v v_{dc} + \tilde{\mathbf{K}}_i$$

- The general expression of the energy stored in the device is given by:

$$E = \sum_{\mathrm{i}=1}^{n} \rho_{\mathrm{i}} \left(x_{\mathrm{i}}^{\beta_{\mathrm{i}}} - \chi_{\mathrm{i}}^{\beta_{\mathrm{i}}} \right)$$

Results

- The case study considered in this work is the WSCC 9-bus test system.
- A comparison of the dynamic response of the proposed model with detailed ones is provided for the following technologies: Superconducting Magnetic Energy Storage (SMES), Compressed Air Energy Storage (CAES) and Battery Energy Storage (BES).

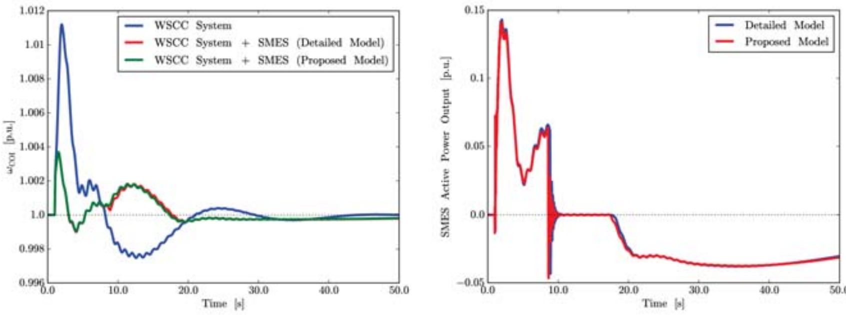

Fig. 2 Results for the WSCC system with a SMES after a three-phase fault. The SMES reaches its maximum storable energy after 10 seconds of simulation

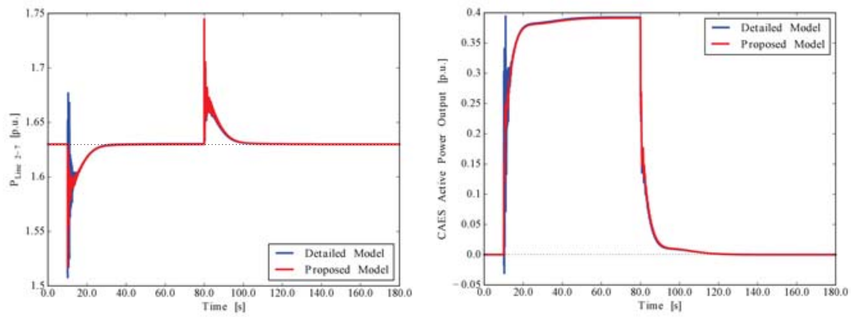

Fig. 3 Results for the WSCC system with a CAES after a loss of load

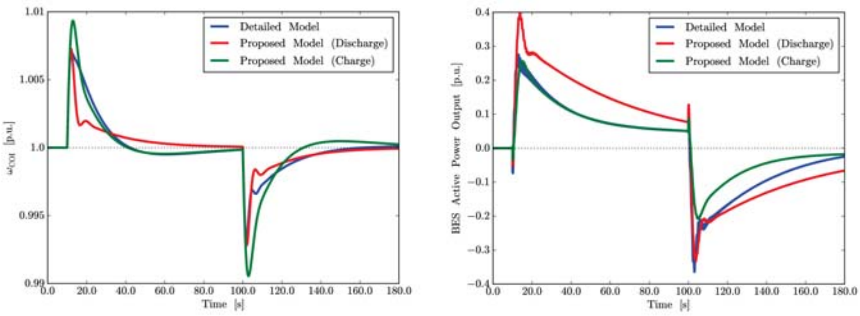

Fig. 4 Results for the WSCC system with a BES after a loss of load.

Conclusions

- **The proposed generalized model is able to accurately emulate the dynamic behavior of detailed ESS models for large disturbances, namely faults and loss of loads.**
- **The non-linearity of ESS controllers, i.e., hard limits, are properly taken into account by the proposed model.**
- **Future work will focus on synthesizing advanced control strategies to improve the dynamic response of different ESSs.**

Acknowledgement

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