Improving the Frequency Response of the System through Voltage and Reactive Power Control

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Summary

- Research question
- Voltage Frequency Control through FACTS
- Remote Voltage Measurements to improve frequency control of DERs
- Conclusions

Introduction

- Traditionally, voltage and frequency control have been considered decoupled.
- This has led to design and study these two classes of controllers as they were independent from each other.
- This presentation will show two applications where exploiting the interaction of voltage and frequency measurements and control can lead to improve the overall dynamic behavior of the system.

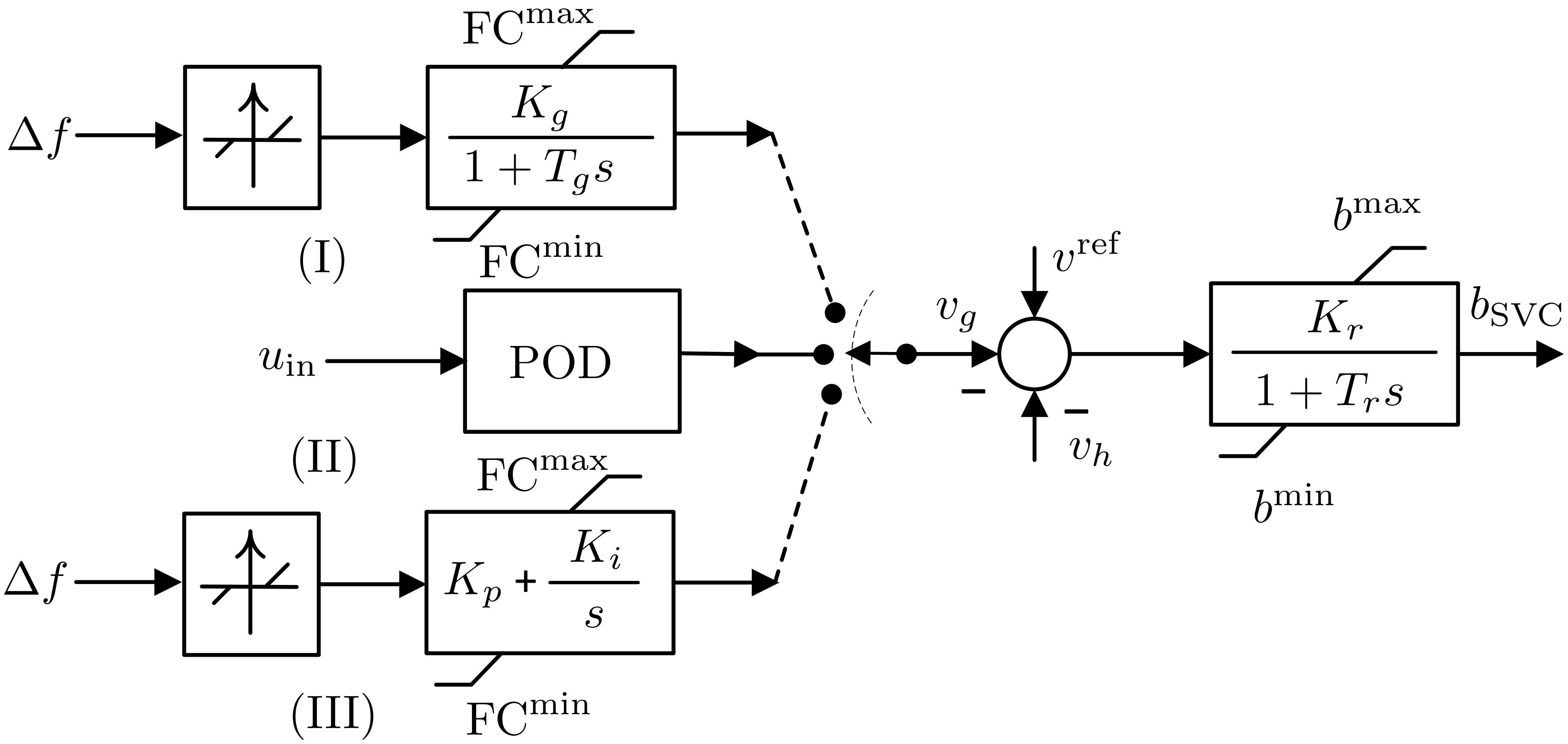
Voltage-based Frequency Control

- Frequency control through exploitation of the sensitivity of load power consumption to voltage variations is known as Voltage-based Frequency Control (VFC).
- VFC exploits the voltage dependency of the load power consumption.

$$p_h = p_{h0} \left(\frac{v_h}{v_{h0}} \right)^{\alpha_p}$$

$$q_h = q_{h0} \left(\frac{v_h}{v_{h0}} \right)^{\alpha_q}$$

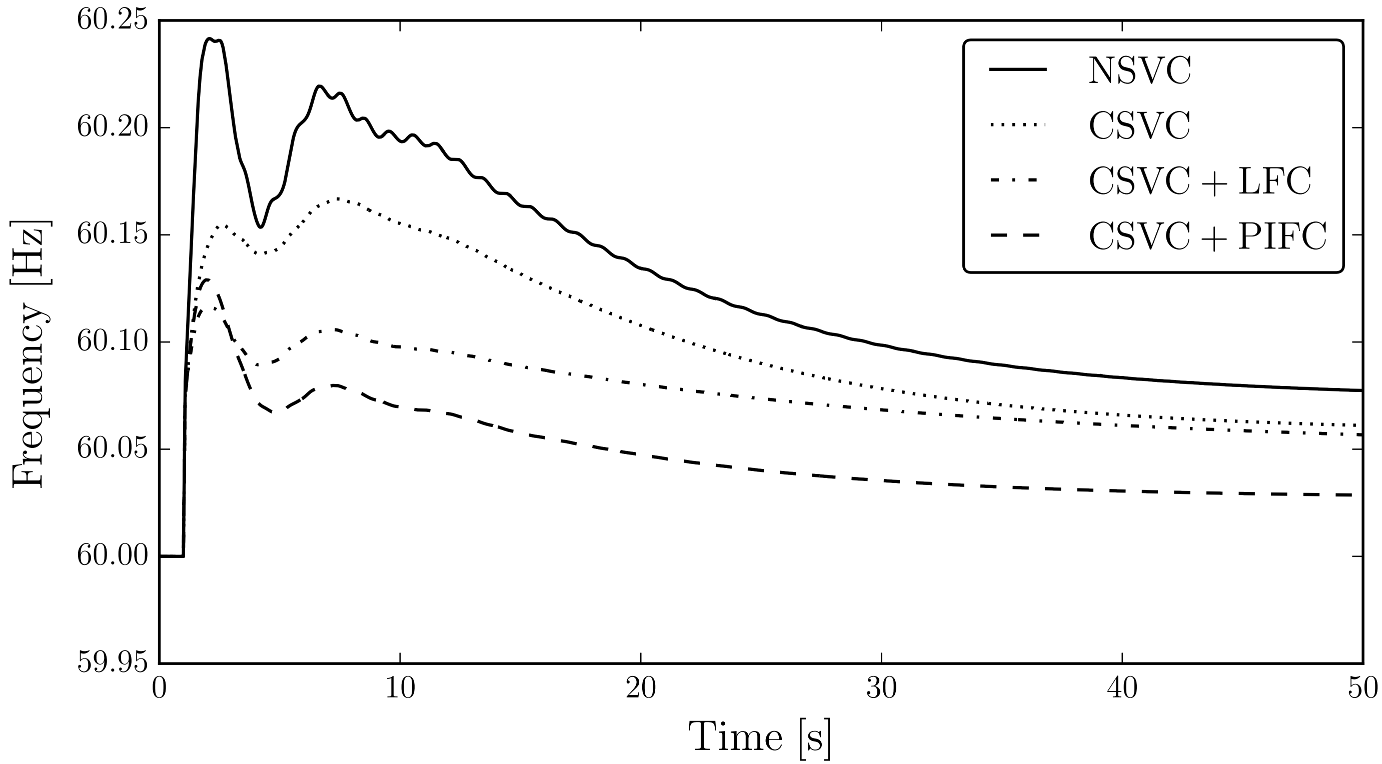
Modified SVC Scheme



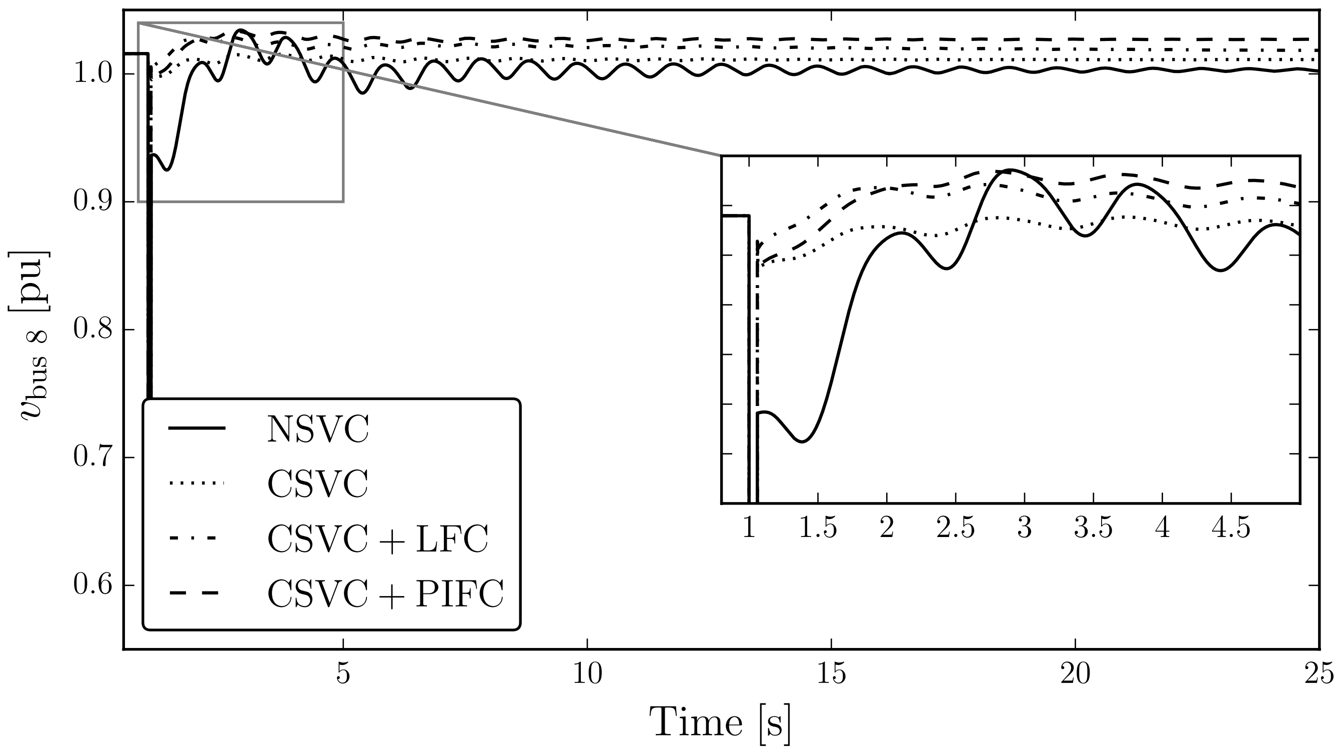
Tests on the WSCC 9-bus System

- The SVC is connected at bus 8.
  The contingency is the tripping of the line that connects buses 6 and 9 of IEEE 9-bus system.
- Four scenarios are tested and compared by carrying non-linear time domain simulations:
  - Without SVC (NSVC);
  - Conventional SVC with POD (CSVC);
  - CSVC with lag frequency controller (LFC);
  - CSVC with PI frequency controller (PIFC).

Frequency Response



Voltage Response



Components of the Active Power

- Differentiating the well-known power flow equations one has:

$$p_h(t) = v_h(t) \sum_{k \in \mathbb{B}} v_k(t)\, G^{hk} \cos\theta_{hk}(t) + v_h(t) \sum_{k \in \mathbb{B}} v_k(t)\, B^{hk} \sin\theta_{hk}(t)\,,$$

$$dp_h = dp'_h + dp''_h\,,$$

$$dp'_h = \sum_{k \in \mathbb{B}} \frac{\partial p_h}{\partial \theta_k} d\theta_k\,, \quad dp''_h = \sum_{k \in \mathbb{B}} \frac{\partial p_h}{\partial v_k} dv_k\,.$$

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Effective Frequency Control (1)

A device that regulates the frequency imposes dp_h at its point of connection.

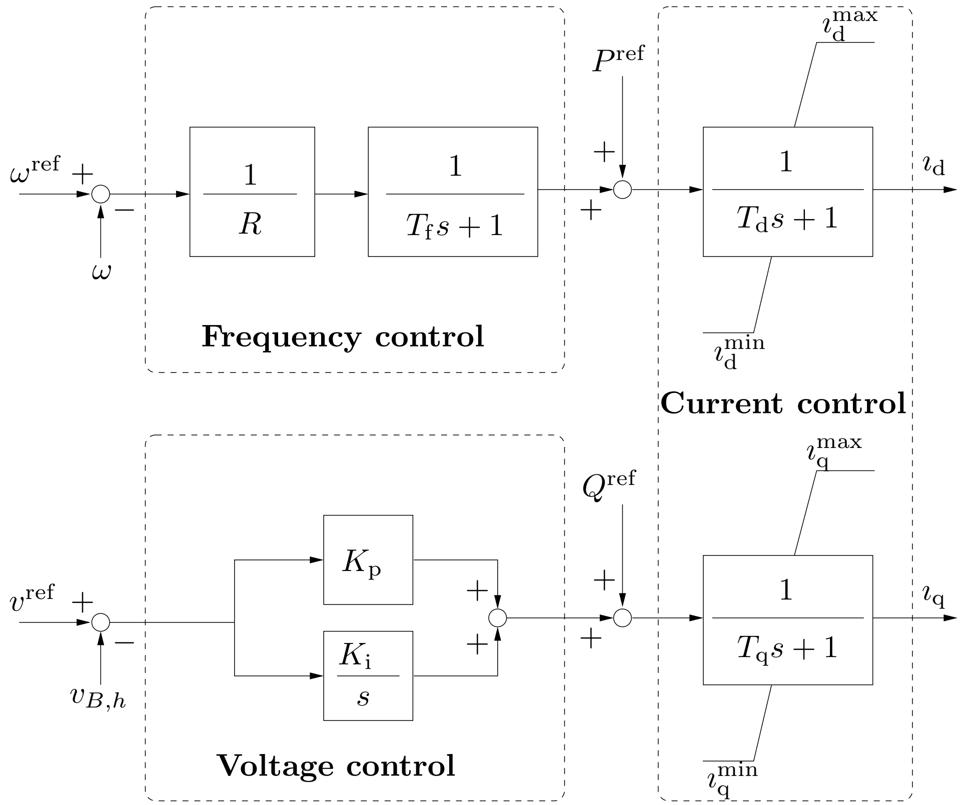
Thus, the idea is to design a control that has the objective to reduce – ideally, to nullify – the term dp''_h.

Assuming for simplicity a lossless transmission system, i.e. $G^{hk} = 0$, and defining $\tilde{B}^{hk} = B^{hk} \sin\theta_{hk}$, one has:

$$dp''_h = \sum_{k \in \mathbb{B}} \tilde{B}^{hk}(t) \left(v_k \, dv_h + v_h \, dv_k \right) .$$

DER Implementation

The remote voltage measurements are utilized to modify the reference voltage



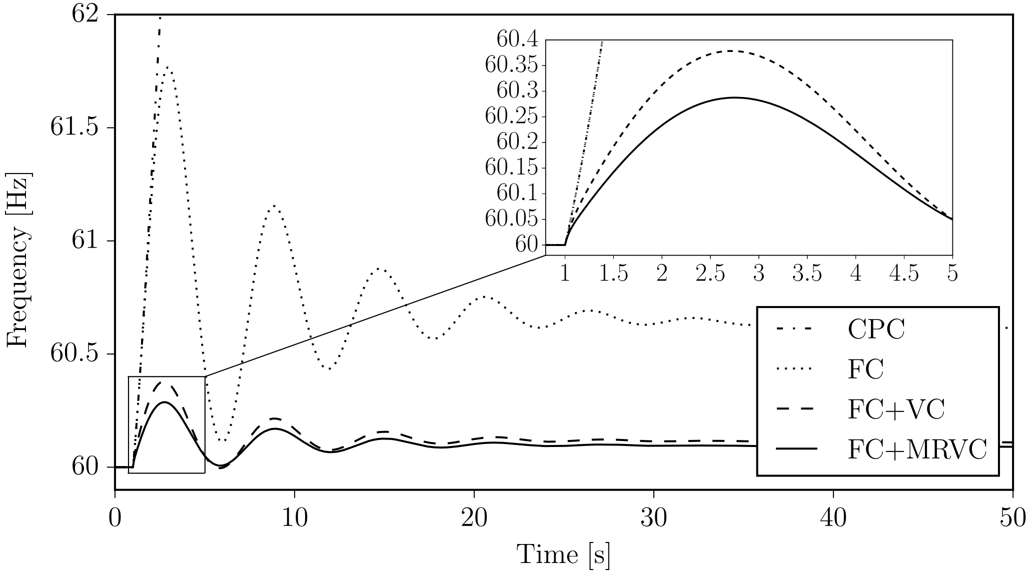
Case Study 1

We consider the WSCC 9-bus system substituting machines 1 and 2 with DERs and the tripping of line 4-6.

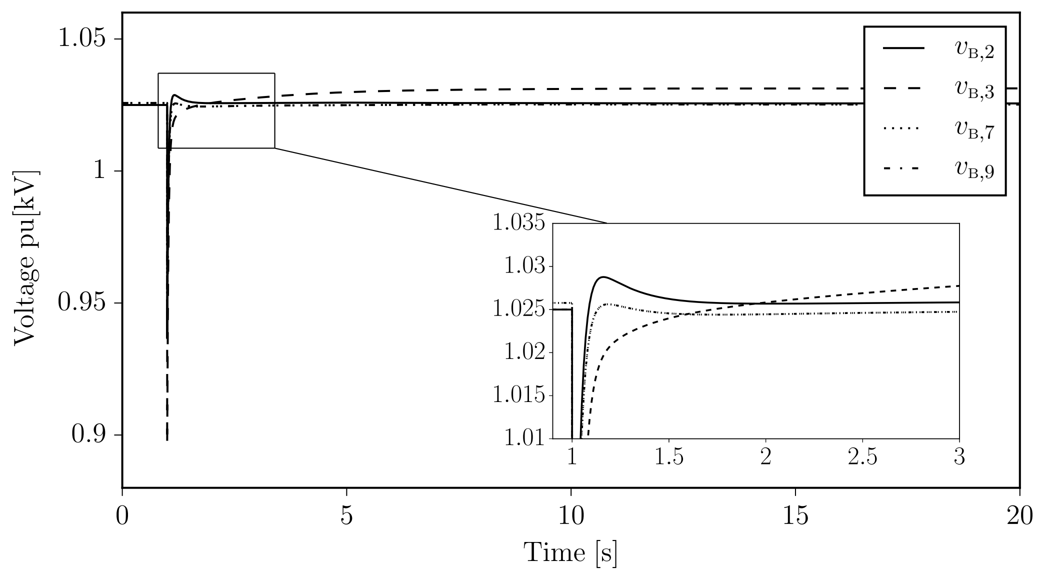
The following scenarios are compared:

- CPC (Constant Power Control), i.e. without the frequency and voltage control loops;
- FC, i.e. with the frequency loop connected and the voltage control disconnected;
- FC+VC, i.e. with both frequency and voltage control and constant voltage reference;
- FC+MRVC, i.e. with both frequency and voltage control and adaptive voltage reference.

Case Study 1



62
61.5
61
60.5
60
Frequency [Hz]
0
10
20
30
40
50
Time [s]
60.4
60.35
60.3
60.25
60.2
60.15
60.1
60.05
60
1
1.5
2
2.5
3
3.5
4
4.5
5
CPC
FC
FC+VC
FC+MRVC



1.05
1
0.95
0.9
Voltage pu[kV]
0
5
10
15
20
Time [s]
$v_{B,2}$
$v_{B,3}$
$v_{B,7}$
$v_{B,9}$
1.035
1.03
1.025
1.02
1.015
1.01
1
1.5
2
2.5
3

Case Study 2

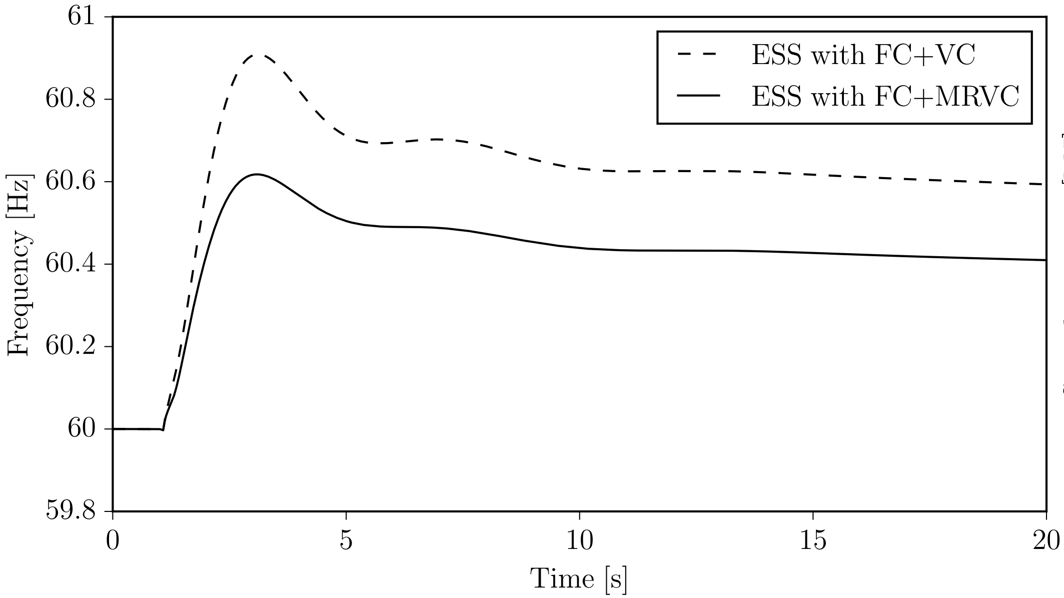
We now consider the WSCC 9-bus system with DERs at buses 1 and 2 and an ESS at bus 5.

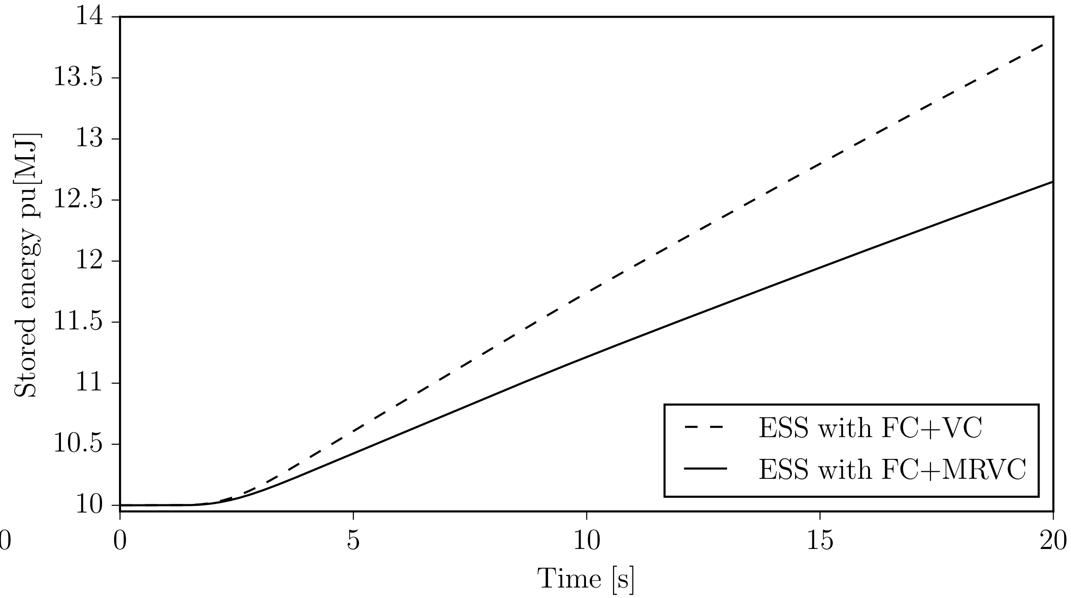
The test system is simulated considering a three-phase fault at bus 6. The fault occurs at $t = 1$ s and is cleared after 80 ms by tripping the line that connects buses 6 and 9.

The following scenarios are compared:

- ESS with FC+VC, i.e. with both frequency and voltage control and constant voltage reference;
- ESS with FC+MRVC, i.e. with both frequency and voltage control and adaptive voltage reference.

Case Study 2


61
60.8
60.6
60.4
60.2
60
59.8
Frequency [Hz]
0
5
10
15
20
Time [s]
ESS with FC+VC
ESS with FC+MRVC


14
13.5
13
12.5
12
11.5
11
10.5
10
Stored energy pu[MJ]
0
5
10
15
20
Time [s]
ESS with FC+VC
ESS with FC+MRVC

Conclusions

Coupling between P and Q

The coupling between voltage and frequency control is stronger than what one could expect.

Remote Measurements

Remote measurements can help improve existing controllers in an inexpensive way.

DERs are opportunities

Thank to the flexibility of power-electronic based devices, there is the opportunity to design new effective controllers.

References

- M. A. A. Murad, G. Tzounas, M. Liu, F. Milano, *Frequency Control Through Voltage Regulation of Power Systems Using SVC Devices*, IEEE PES General Meeting, Atlanta, GA, 4-8 August 2019.
- Y. Wan, M. A. A. Murad, M. Liu, F. Milano, *Voltage Frequency Control using SVC Devices coupled with Voltage Dependent Loads*, IEEE Transactions on Power Systems, vol. 34, no. 2, pp. 1589-1597, March 2019.
- G. Tzounas, F. Milano, *Improving the Frequency Response of DERs Through Voltage Feedback*, IEEE PES General Meeting, Washington, DC, on-line event, 25-29 July 2021.

Thank you!