WFPS High Frequency Analysis

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This study has been developed during 4 months work placement in EirGrid during 2016

Contents

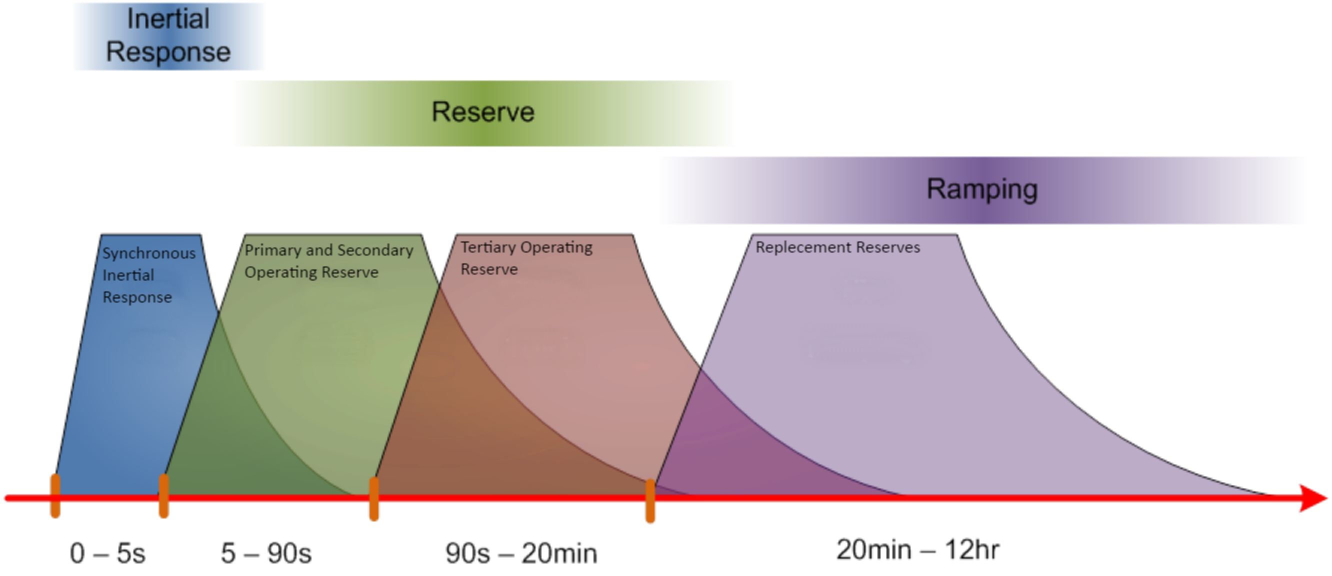
- Introduction
- Over-frequency events
- System modelling
- Mitigation strategies proposed
- Results
- Conclusions

Introduction

What if WFPSs displace synchronous generators?

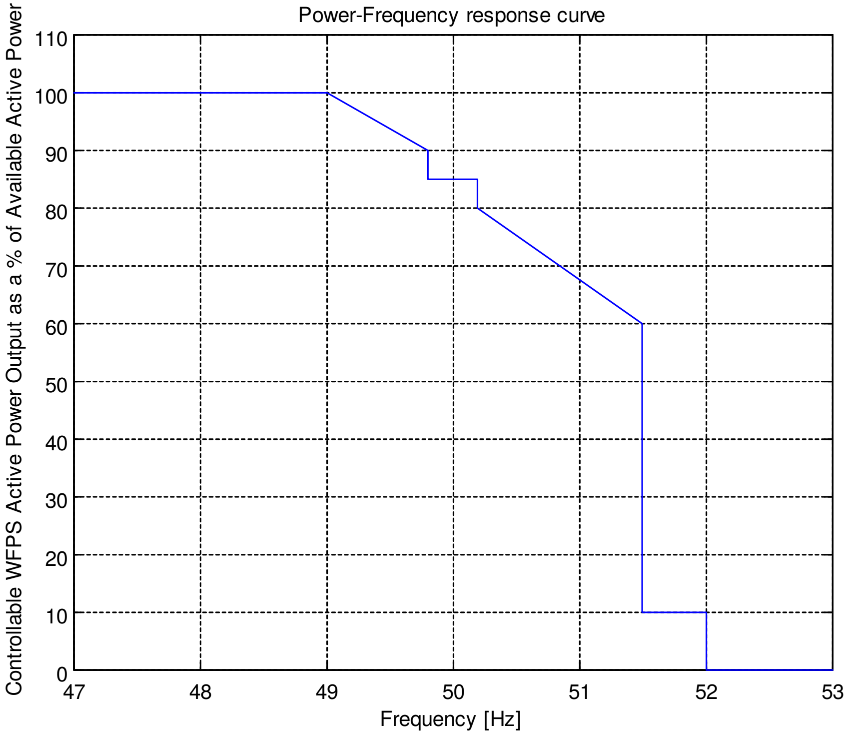
- Stability issues for small systems, characterized by a reduced number of synchronous generators online with high instantaneous System Non-Synchronous Penetration (SNSP)
- Needs of frequency regulation provided by Wind Farm Power Stations (WFPSs)

- **With increasing penetration of WFPSs, the frequency regulation capacity, the source where we get the capacity from, moves across different time frames becoming a reserve problem**



Over-frequency events
Overview

- Loss of a large load in the form of an exporting interconnector
- Increase of the system frequency violating its normal limits (49.9 - 50.1 Hz) following a temporary power unbalance
- Wind farm controller provides for frequency support according to a Power-Frequency response curve
- The deadband allows small fluctuation of the frequency around 50 Hz without providing droop response, reducing excessive regulation and stress on the turbine controllers

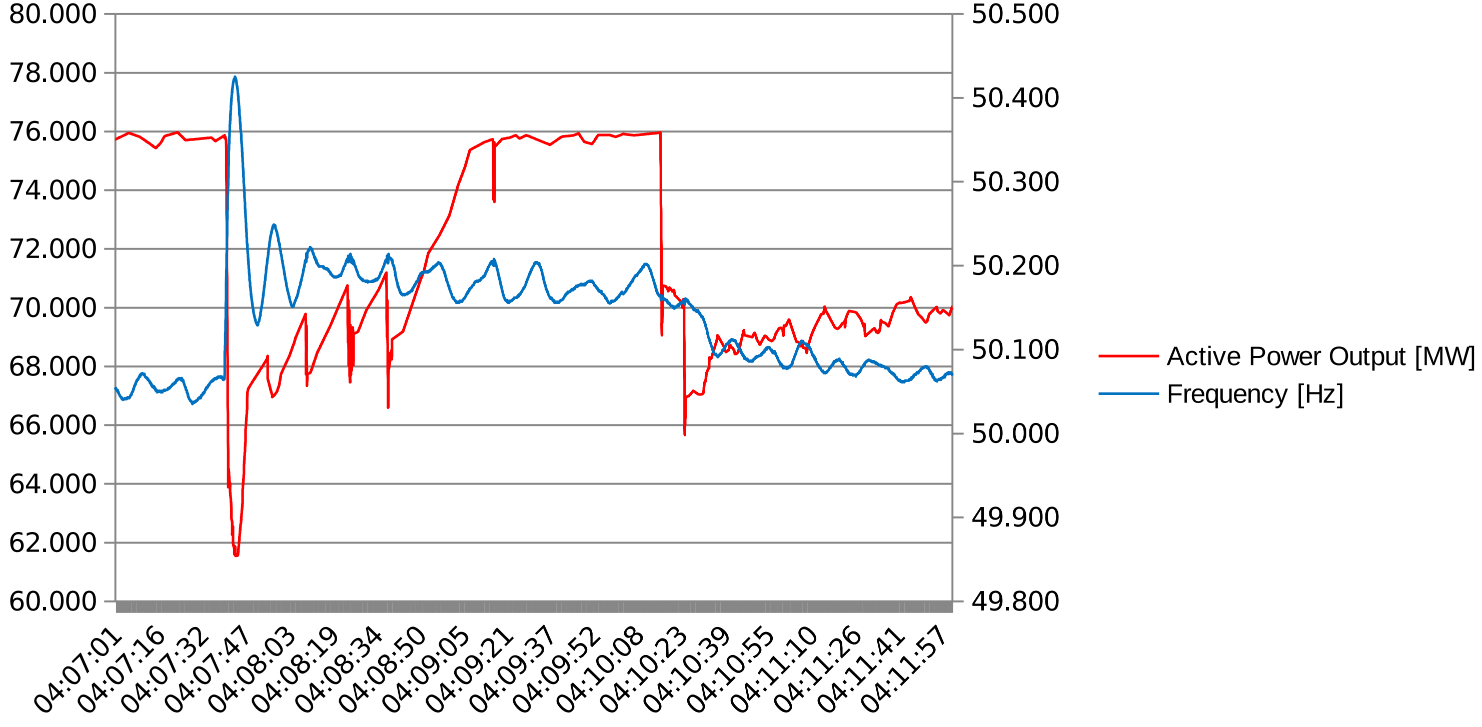


- 200 mHz deadband
- 4% droop response calculated with respect of the center of the deadband
- Steps at the deadband limits

Over-frequency events

A real case happened

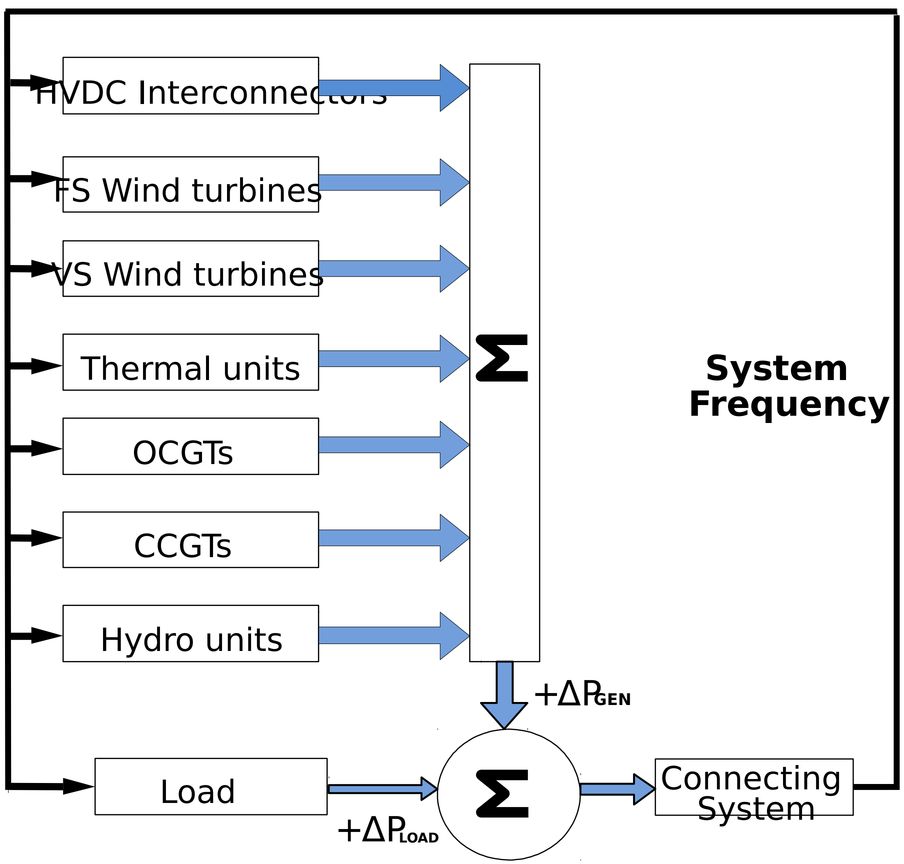
- EWIC Interconnector tripping from 293 MW while exporting power from Ireland to Britain
- Data recordered at a windfarm located in the Midlands of Ireland
- PMU measurements sampling time: 20ms



System modelling

System modelling

Single Frequency Model (SFM)



- 53 individual unit models, based on different technologies, including steam turbines, OCGT, CCGT, hydroelectric
- 1 pumped storage model including a hydro governor model representing pumping, ramping and trip control
- 2 HVDC interconnectors (i.e. EWIC, Moyle) totalling 1000MW
- Contracted interruptible load
- Variation of load response with frequency and total dispatch
- A wind generation model enabled with Rate of Change of Frequency (RoCoF) protections, governor control, droop control, inertial response, and fault ride through
- **Non-conventional frequency controllers for WFPSs**

System modelling
Dispatches

- 2018 and 2020 cases
- Wind energy export up to 500 MW
- Different SNSP levels (from 10% to 75%)
- Wind power generated (from 500MW to 4000MW)
- From 3 to 9 units online

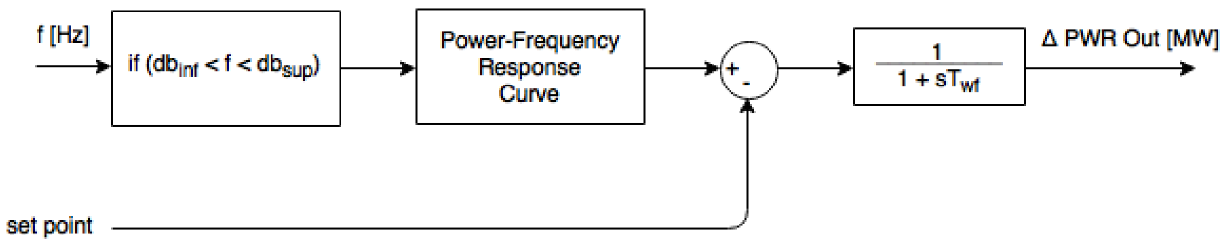
Disp. No.	1	2	3	4	5	6
SNSP (%)	64.36	63.89	64.11	64.69	65.67	68.20
Wind Generation (MW)	2497.66	2402.70	2460.66	2619.14	2888.30	4141.44
Import Power (MW)	157.13	131.68	239.08	419.77	453.35	494.65
Units Online	4	5	6	5	5	6
Disp. No.	**7**	**8**	**9**	**10**	**11**	**12**
SNSP (%)	68.20	68.00	65.84	74.82	69.07	65.40
Wind Generation (MW)	4108.92	4120.86	4032.94	3602.87	2927.66	3155.95
Import Power (MW)	485.85	412.53	588.97	288.88	606.00	386.00
Units Online	6	6	6	6	7	7
Disp. No.	**13**	**14**	**15**	**16**	**17**	**18**
SNSP (%)	54.03	54.44	44.35	68.78	75.47	19.52
Wind Generation (MW)	1818.40	1885.14	1723.95	3678.87	4853.49	524.53
Import Power (MW)	161.00	300.00	386.00	386.00	300.00	386.00
Units Online	8	8	9	7	8	9
Disp. No.	**19**	**20**	**21**	**22**	**23**	**24**
SNSP (%)	11.50	57.84	41.26	38.81	74.20	53.35
Wind Generation (MW)	428.37	2290.53	1513.34	1701.48	4543.56	2171.82
Import Power (MW)	292.00	386.00	158.35	385.45	127.94	466.75
Units Online	9	7	5	5	3	4
Disp. No.	**25**	**26**	**27**	**28**	**29**	**30**
SNSP (%)	55.52	66.05	64.14	67.99	67.85	69.21
Wind Generation (MW)	2370.64	3350.90	3463.92	3355.25	3367.31	4842.15
Import Power (MW)	466.75	429.96	80.51	127.94	549.34	158.35
Units Online	4	3	3	3	3	5

Mitigation strategies proposed

Mitigation strategies

Active power output controller for wind turbines including deadband and standard droop response

- The function monitors the active power output of the WFPS evaluating the instantaneous value of the frequency. According to the Power-Frequency response curve
- If the frequency lies within the deadband limits, the control provides a specified margin by generating less power than is available from the wind (set point)
- The output provided by the function is the delta active power in MW



Variable name	Unit	Recommended value
db_{inf}	Hz	49.8
db_{sup}	Hz	50.2
set point		0.85
T_{wf}	s	0.15

Mitigation strategies

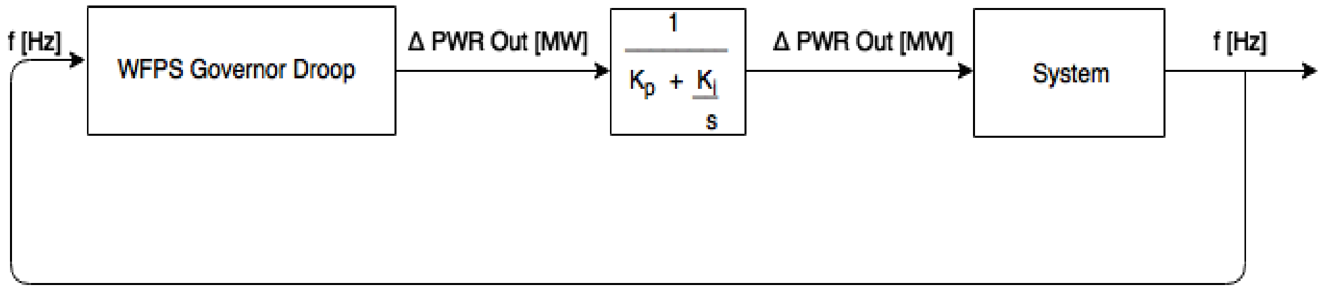
Active power output controller for wind turbines including deadband and dynamic droop response

- The slope of the Power-Frequency response curve dynamically changes depending on the change in frequency (Δf) and the magnitude of the contingency occurring (ΔP)

$$droop_{\%} = \frac{\left(\frac{\Delta f}{f_{nom}}\right)}{\left(\frac{\Delta P}{P_{nom}}\right)} \cdot 100$$

Mitigation strategies
PI controller

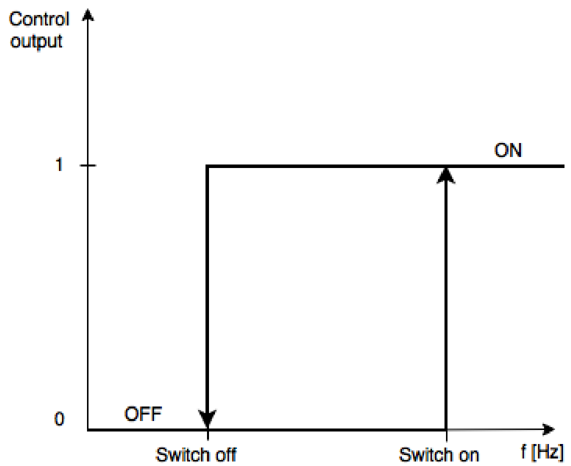
- A proportional-integral (PI) controller is a control loop feedback technique characterized by a proportional term producing an output K_p times proportional to the input, and an integral term which leads the process to the set point reducing the steady-state error due to the proportional term with time constant $T_i = 1/K_i$

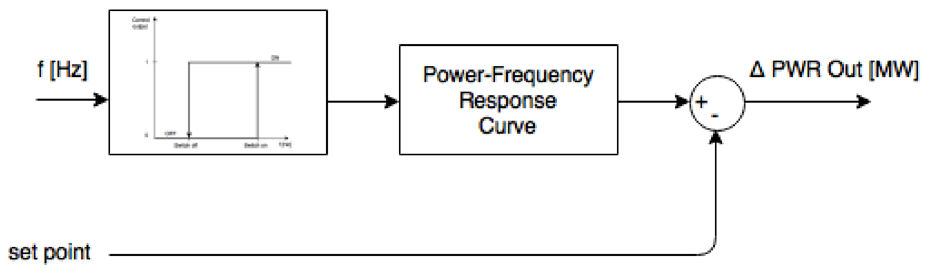


Mitigation strategies

Hysteresis

- The function evaluates the instantaneous value of the frequency and the control provides a specified active power margin according to the droop function if this value rises above the ‘Switch on’ threshold
- The droop control will remain active until the frequency drops below the ‘Switch off’ threshold





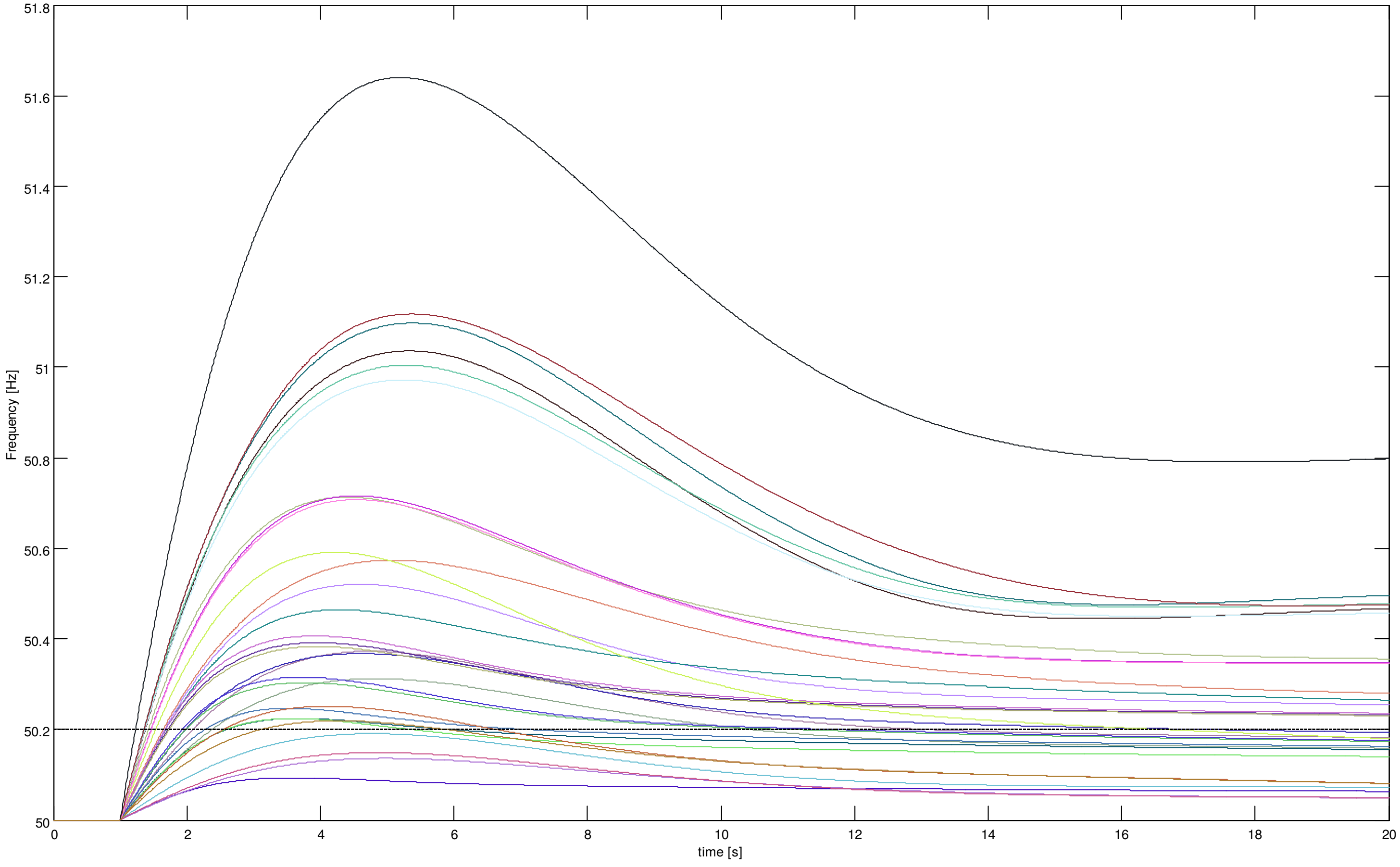
Variable name	Unit	Recommended value
Switch on	Hz	50.2
Witch off	Hz	50.015

Results

Results

No WFPS droop response

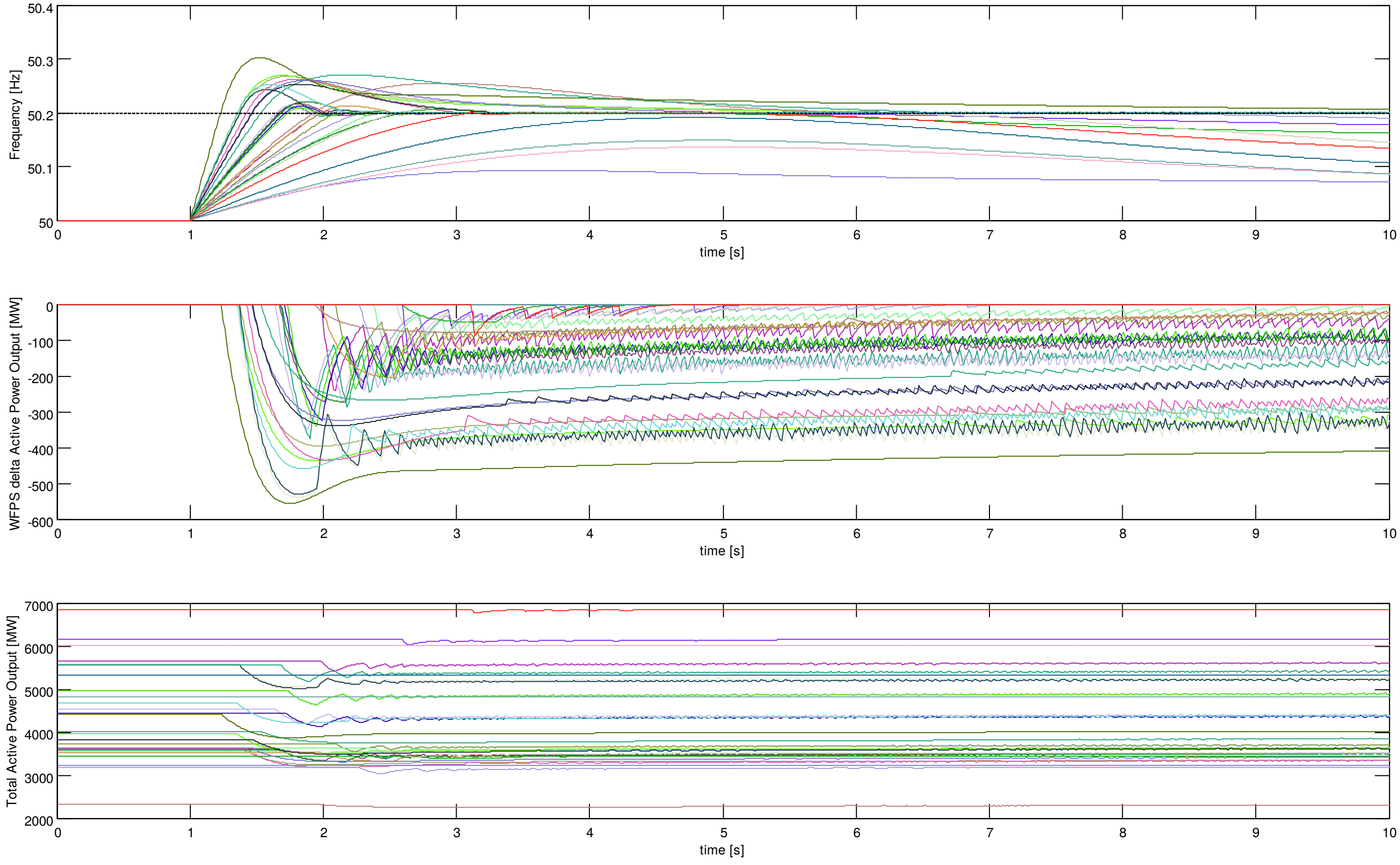
- Trip of the EWIC interconnector in exporting mode occurring at t = 1s



Results

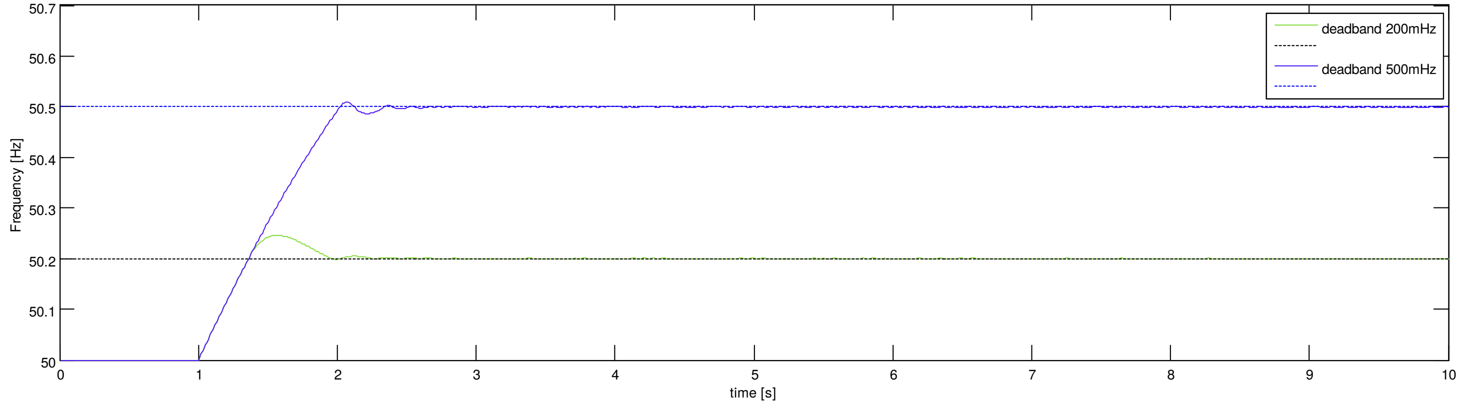
Static linear 4% droop with deadband

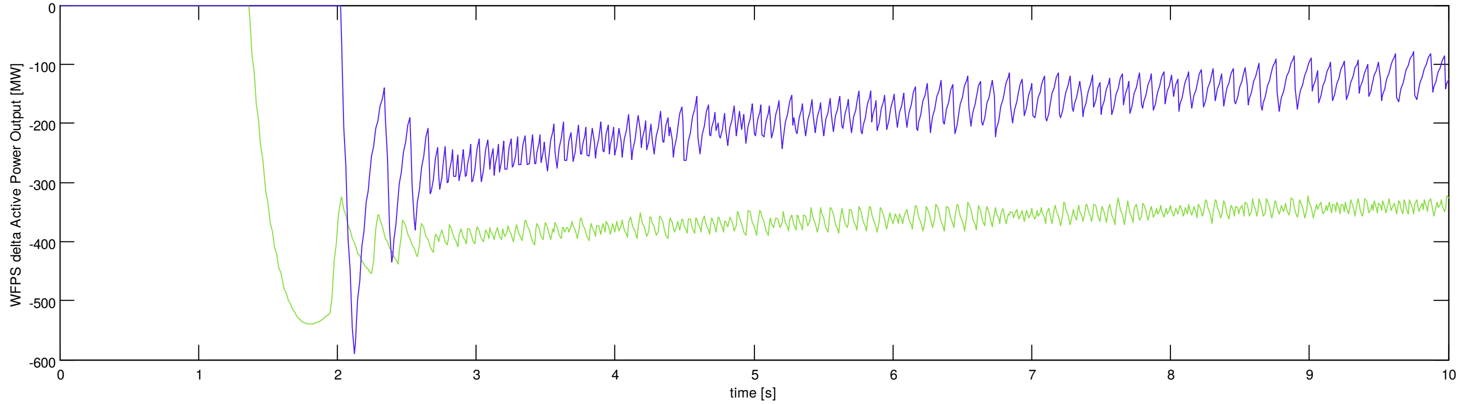
- Improvement of frequency zenith



Results
Static linear 4% droop with deadband

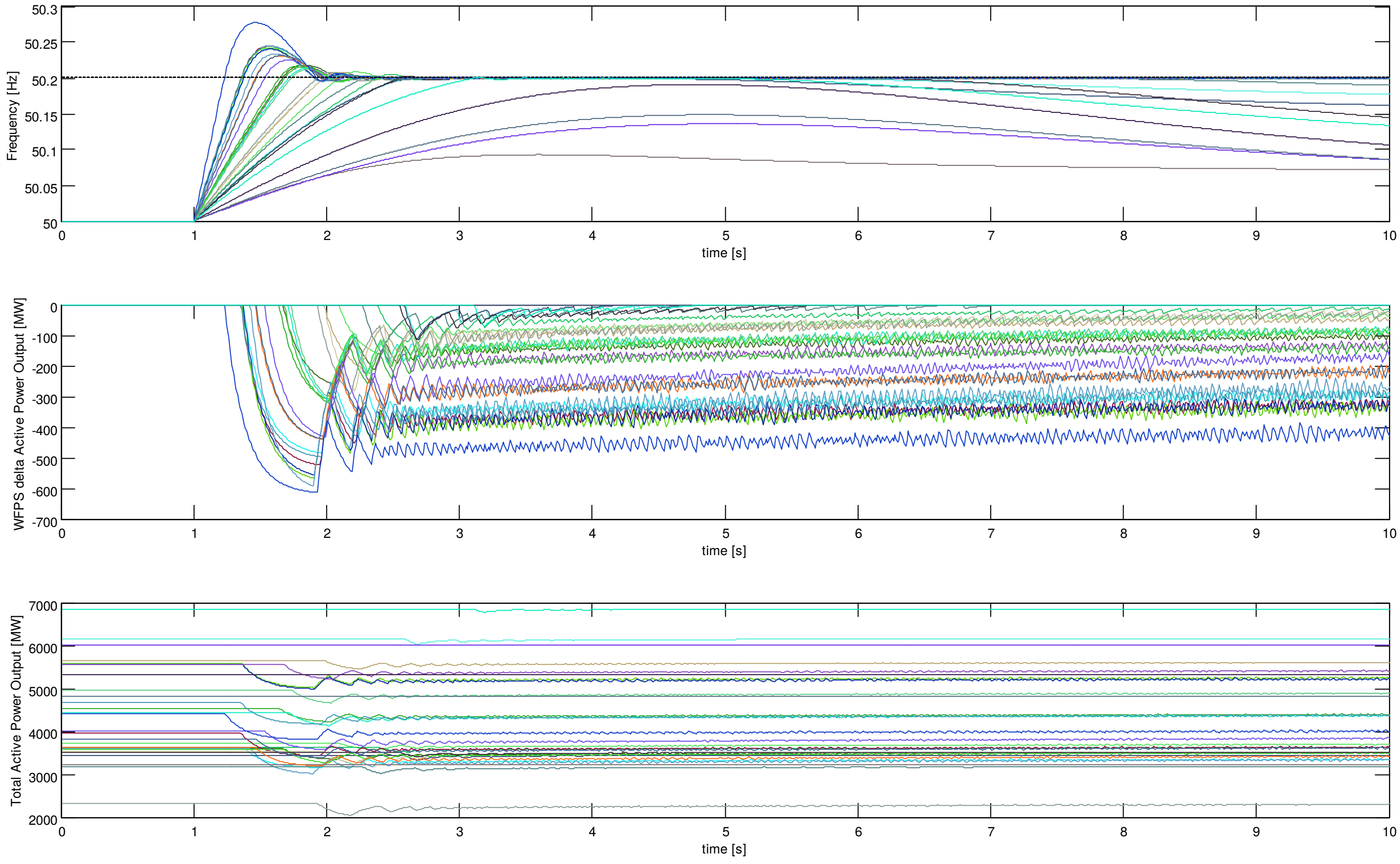
- The oscillatory trend is due to the step at the edge of the deadband characteristic
- The smaller the deadband, the smaller the jump on the edge of the deadband, the smaller the magnitude of the oscillations of the response





Results
Dynamic droop with deadband

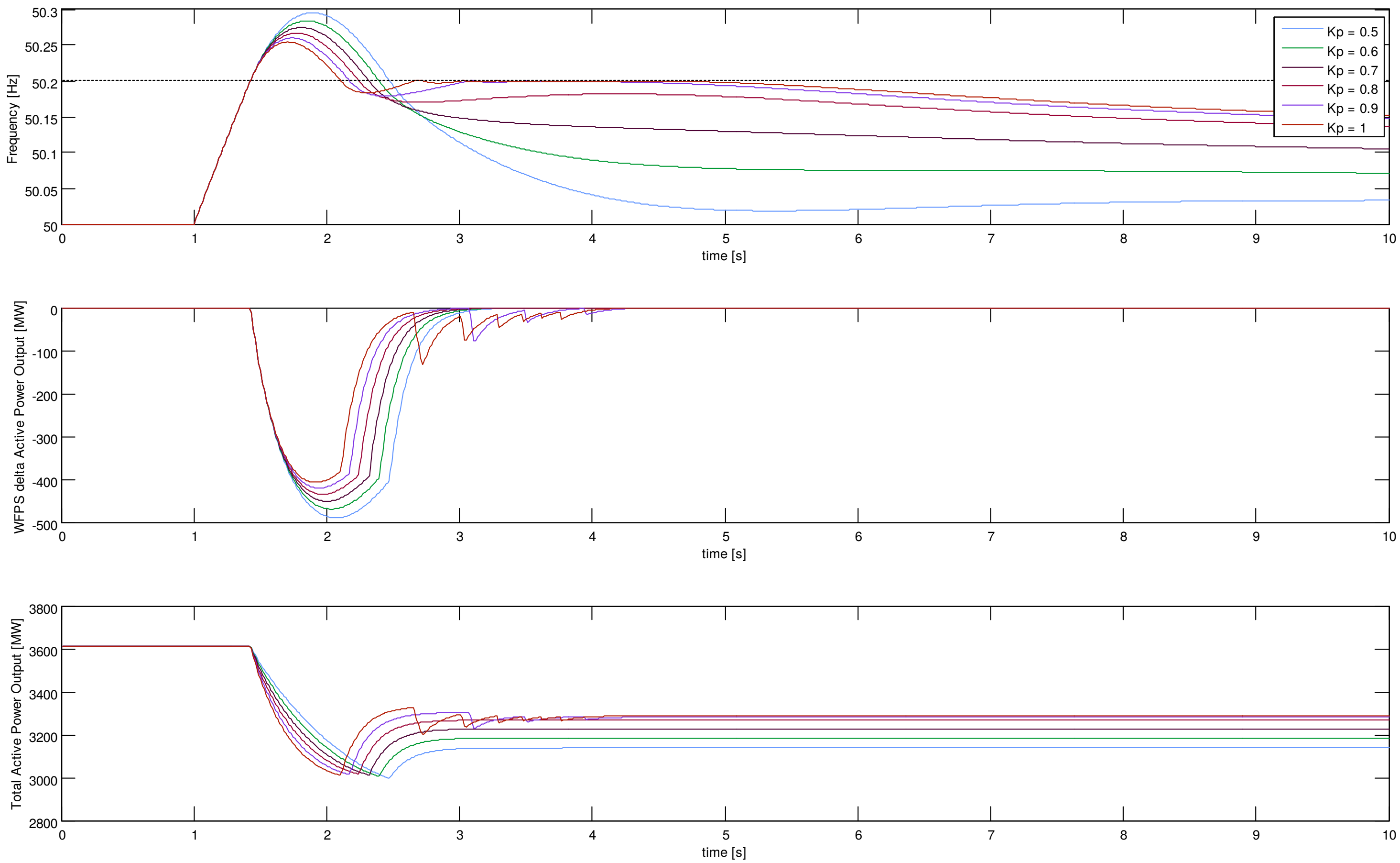
- Responses settle on the deadband in about 1s
- Persistent oscillations of frequency around the deadband limit before recovering inside the band



Results

PI controller – Kp variation

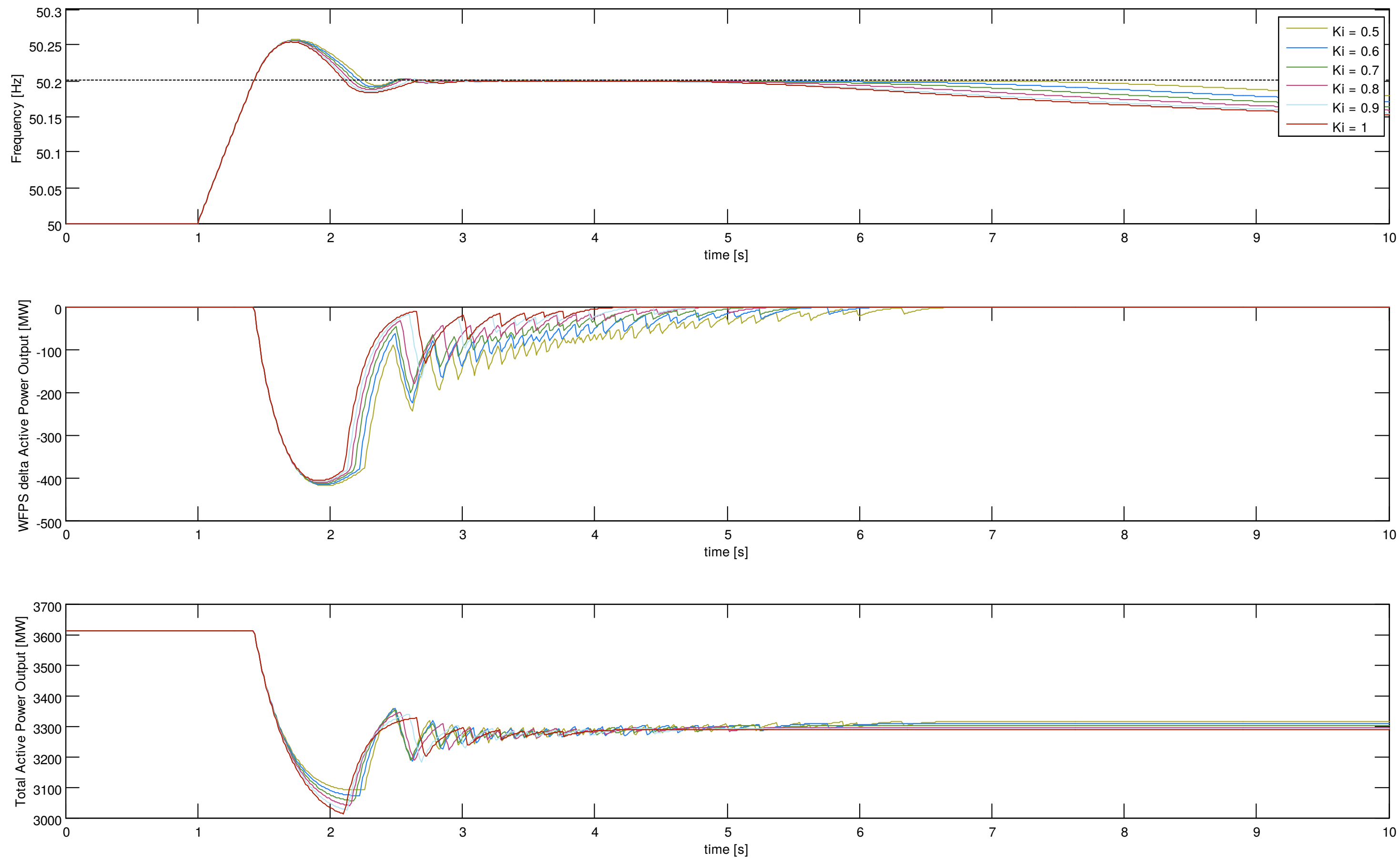
- The bigger K_p, the smaller the overshoot, the higher the steady error after the contingency



Results

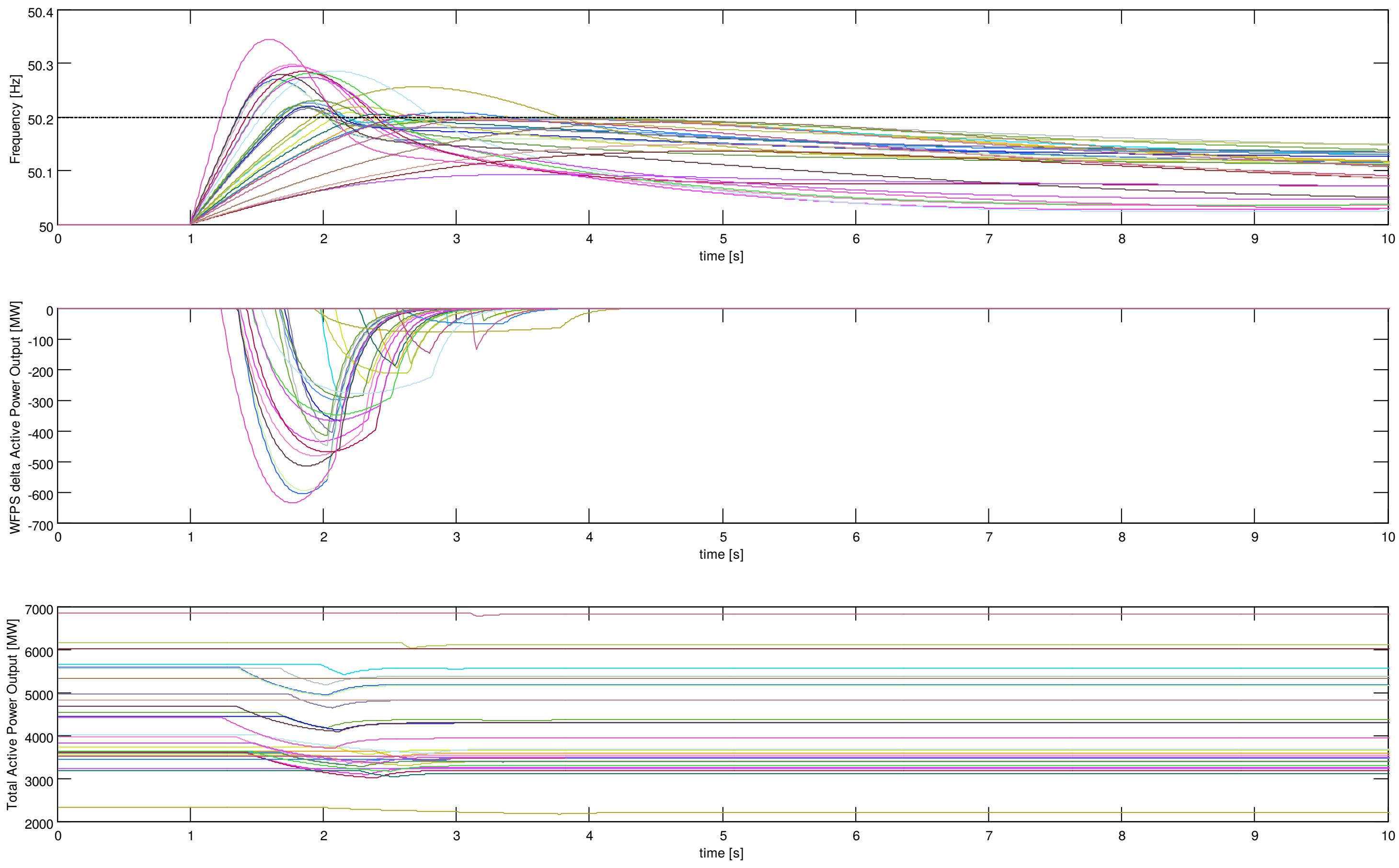
PI controller – Ki variation

- The bigger K_i, the faster the response of the system in recovering the frequency, the less the oscillations of both frequencies hence WFPS power output



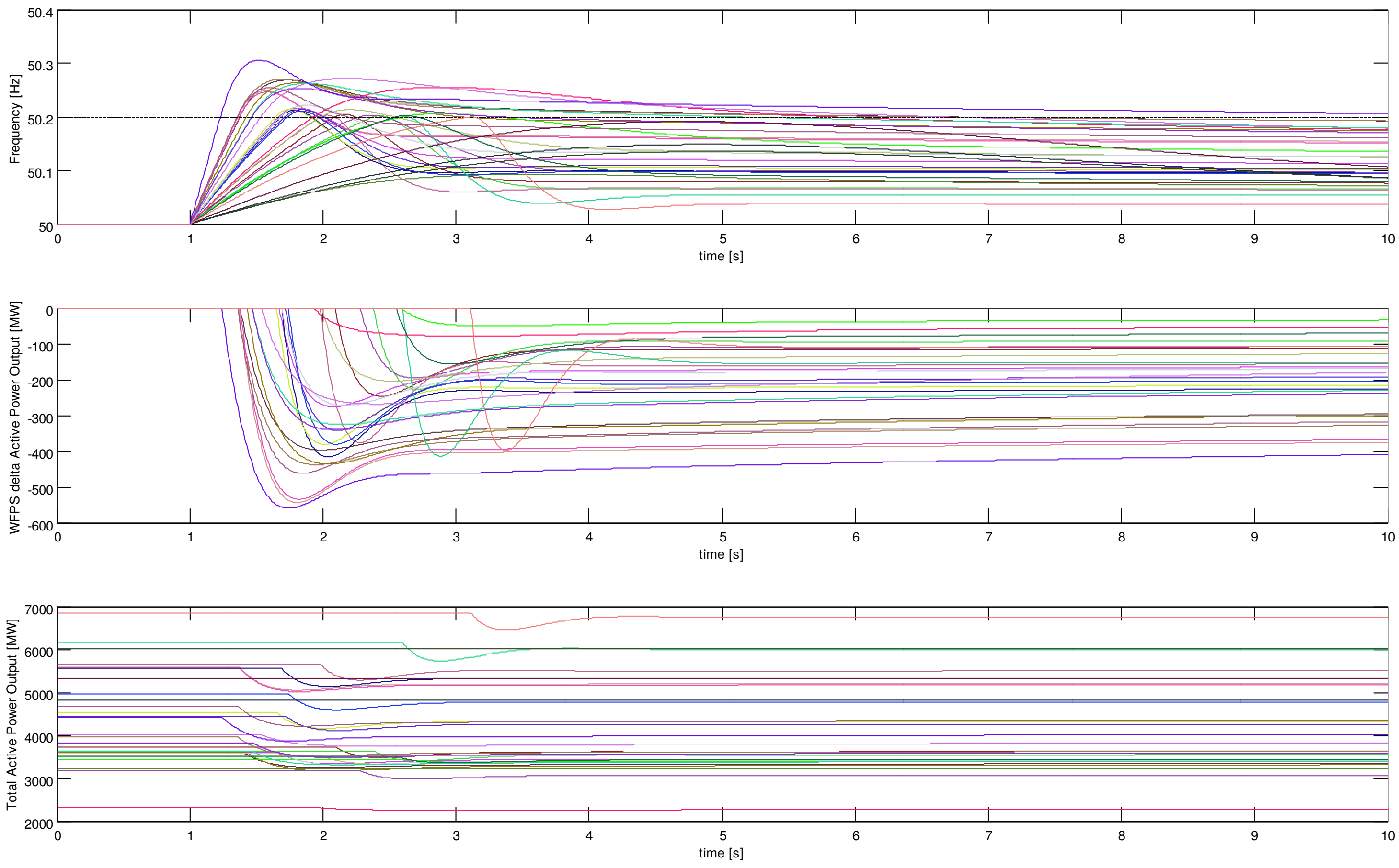
Results
PI controller

- $K_p = 0.6$, $K_i = 1$



Results
Hysteresis

- Reduction of the overshoot for most of the trajectories
- Oscillatory behavior disappeared



Conclusions

- With the increasing penetration of renewable sources in the Irish system, the loss of a large load in the form of an exporting interconnector may present a more significant contingency scenario than the loss of a large generation unit

- The wind frequency control including the deadband improves the response of the system by reducing the zenith of the frequency following the contingency, but an undesired oscillation may also occurs

- The mitigation strategies analysed are able to support the response recovering the system frequency within the deadband limit and reducing its oscillatory behavior in up to 5s

- Wind turbine owners can choose which part of the wind turbine block diagram should be modified to implement the mitigation strategy which suits them better

- The magnitude of oscillations is dependent on the width of the frequency deadband. A tighter deadband on the wind farms in times of high exports on the interconnectors may by a possible solution


THANK
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GRACIAS
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