Wind Turbines Fault Detection and Identification Using Set Valued Observers

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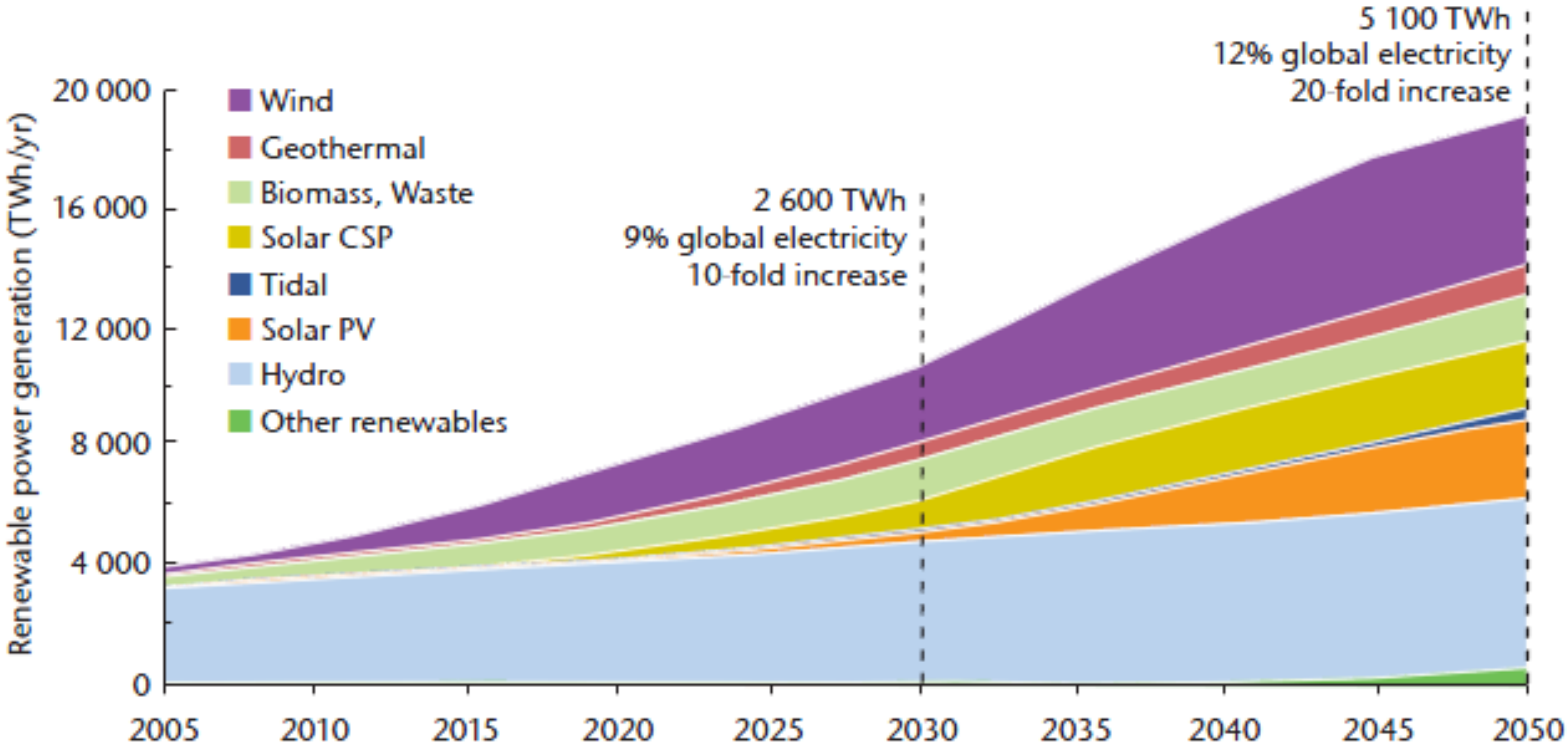
Advanced Control Systems Course

Outline

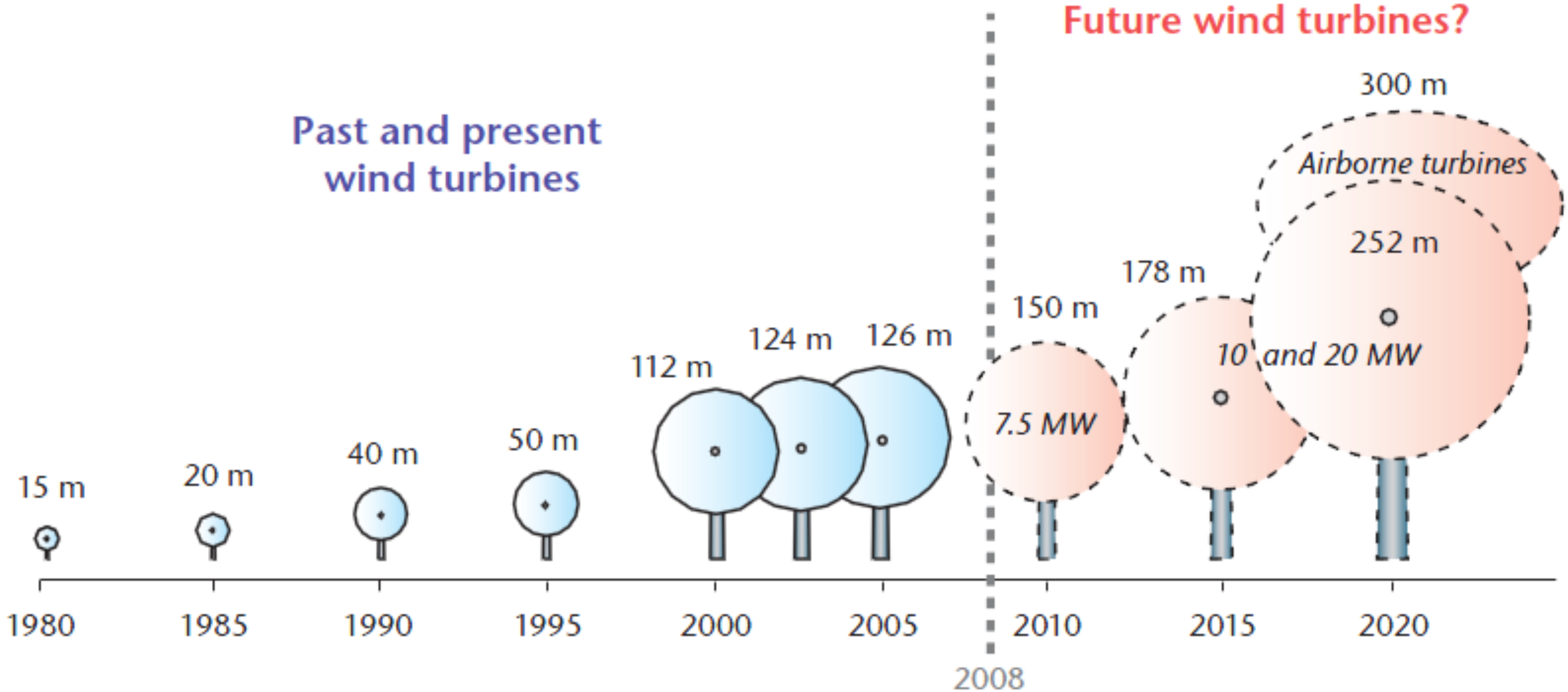
- Introduction
- FDI Using Set-Valued Observers
- The Wind Turbine Model
- Benchmark Results
- Conclusion

Introduction



International Energy Agency . *Wind Energy Technology Roadmap*. 2009

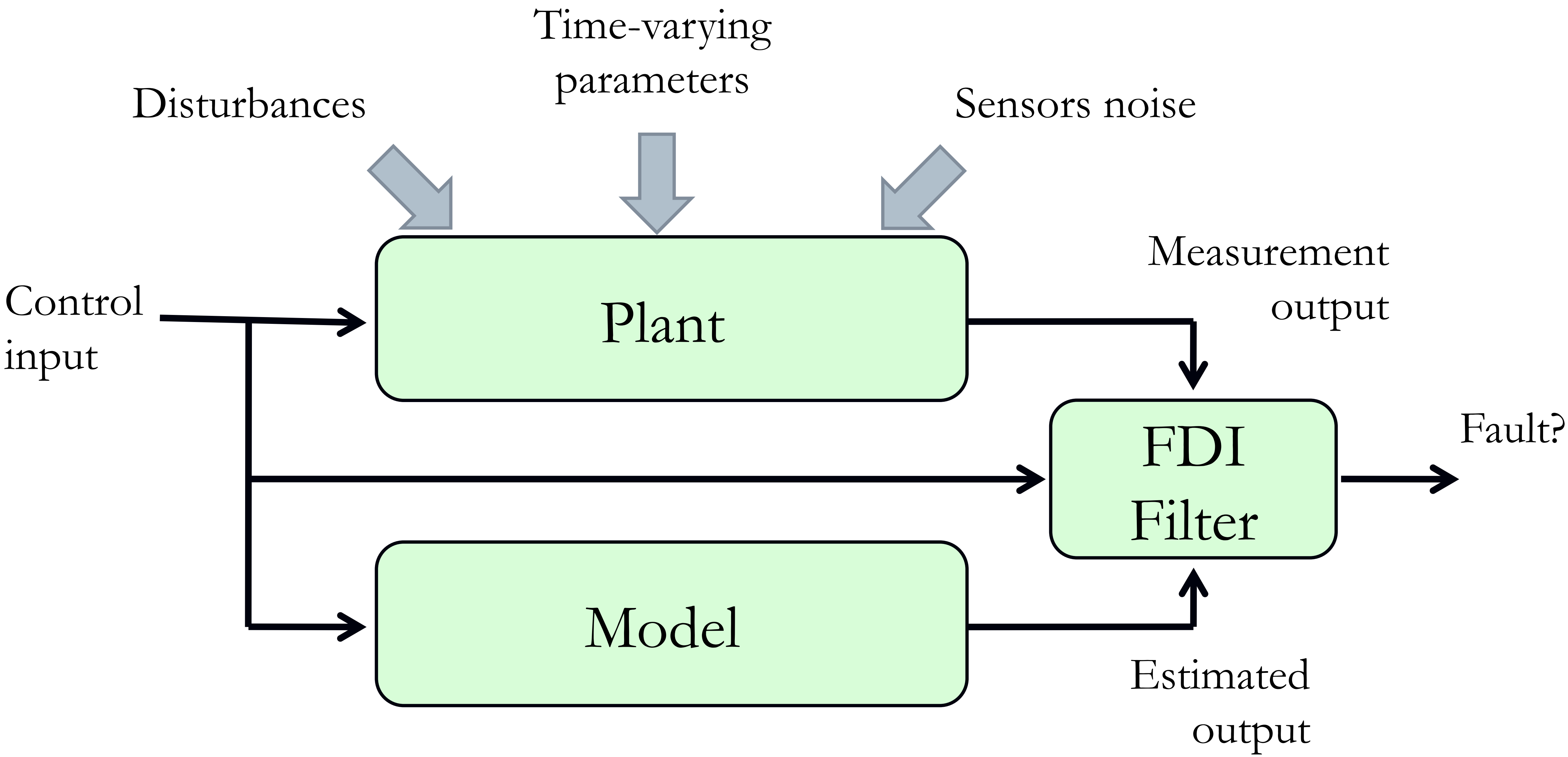
Introduction (cont'd)



Milestone: Fundamentally design new generation of turbines for offshore application, with minimum O&M requirement.

International Energy Agency . *Wind Energy Technology Roadmap*. 2009

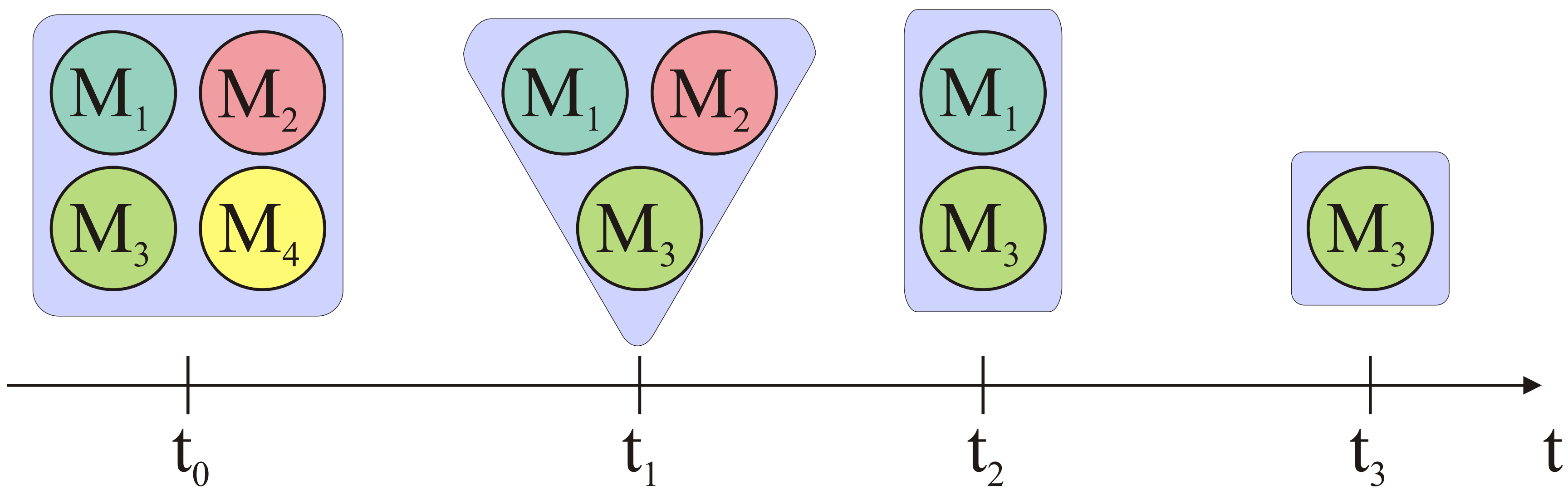
FDI Using Set-Valued Observers



Paulo Rosa, *Multiple-Model Adaptive Control of Uncertain LPV Systems*, PhD Thesis, Instituto Superior Técnico, 2011.

Model Falsification

- Main idea:
  - Set of plausible models for the plant
  - Discard models that are not compatible with the input/output sequences



- Model falsification for FD
  - A fault is detected when the model of the non-faulty plant is invalidated

But… How can we invalidate models?

Robust Set-Valued Observers

- Problem formulation:
  - Dynamic system with no disturbances

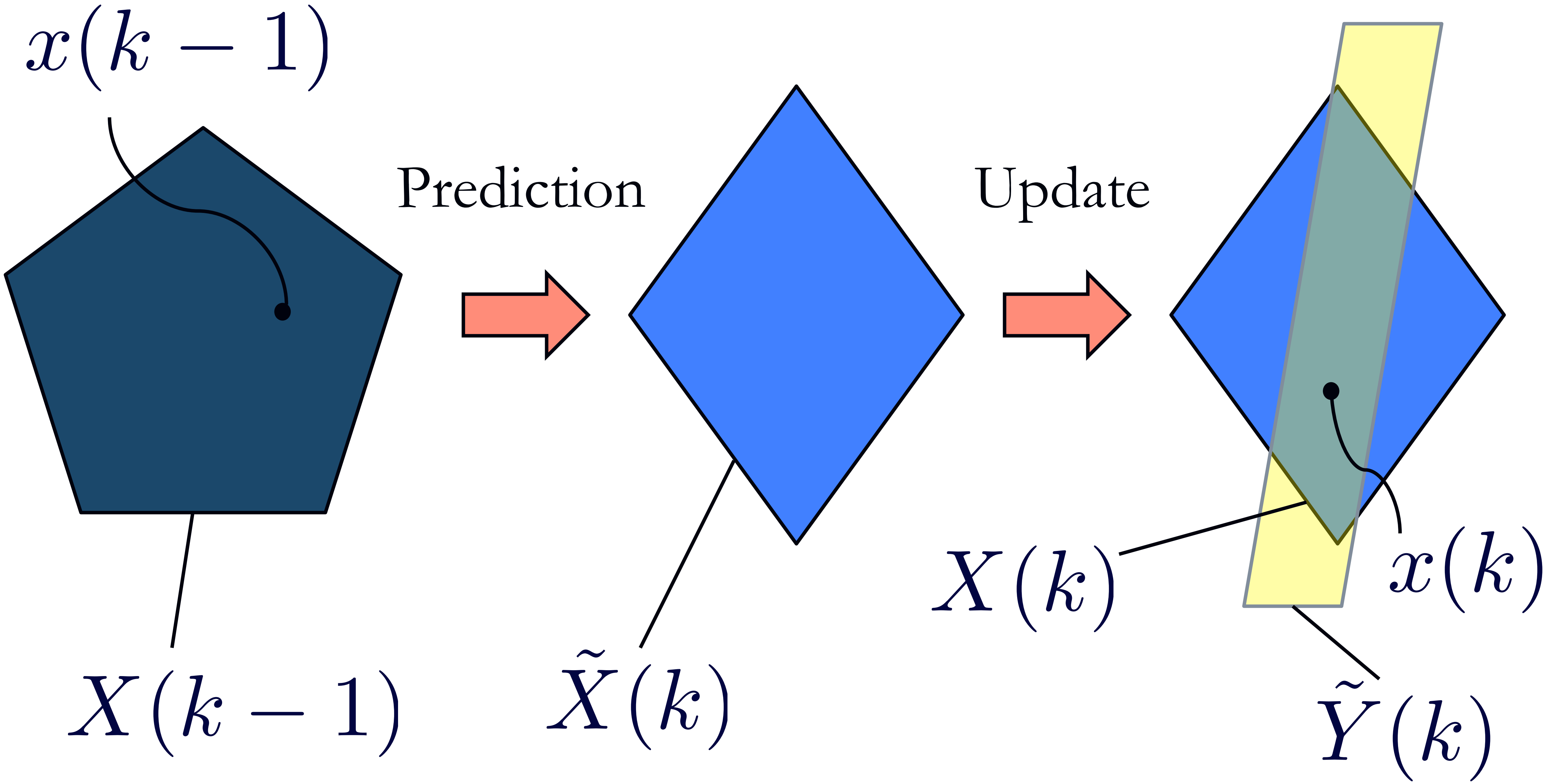
$$x(k+1) = f(x(k), u(k))$$

  - Dynamic system with disturbances, unknown initial state and model uncertainty

$$x(k+1) \in F\left(x(k), u(k), \bar{d}(k), \bar{\Delta}(k)\right)$$

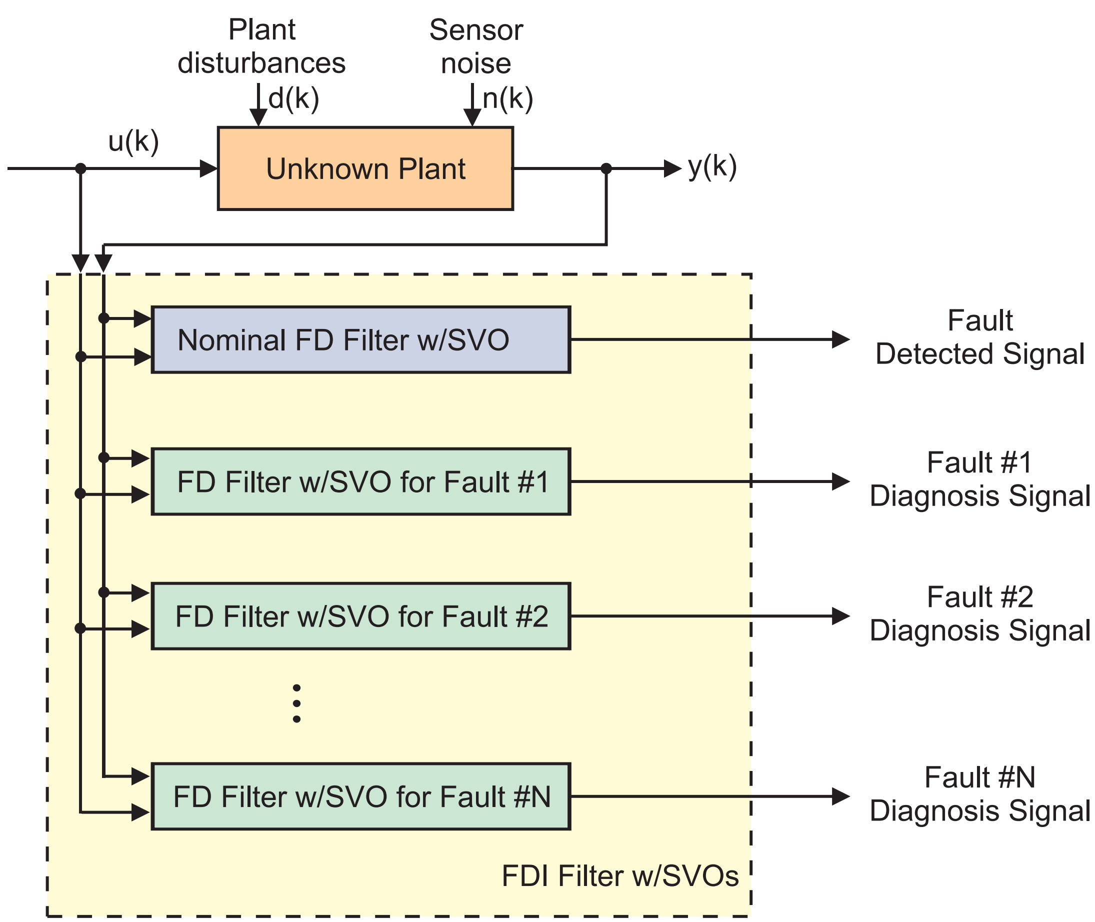
solution is a set, rather than a point!

Robust Set-Valued Observers (cont.'d)



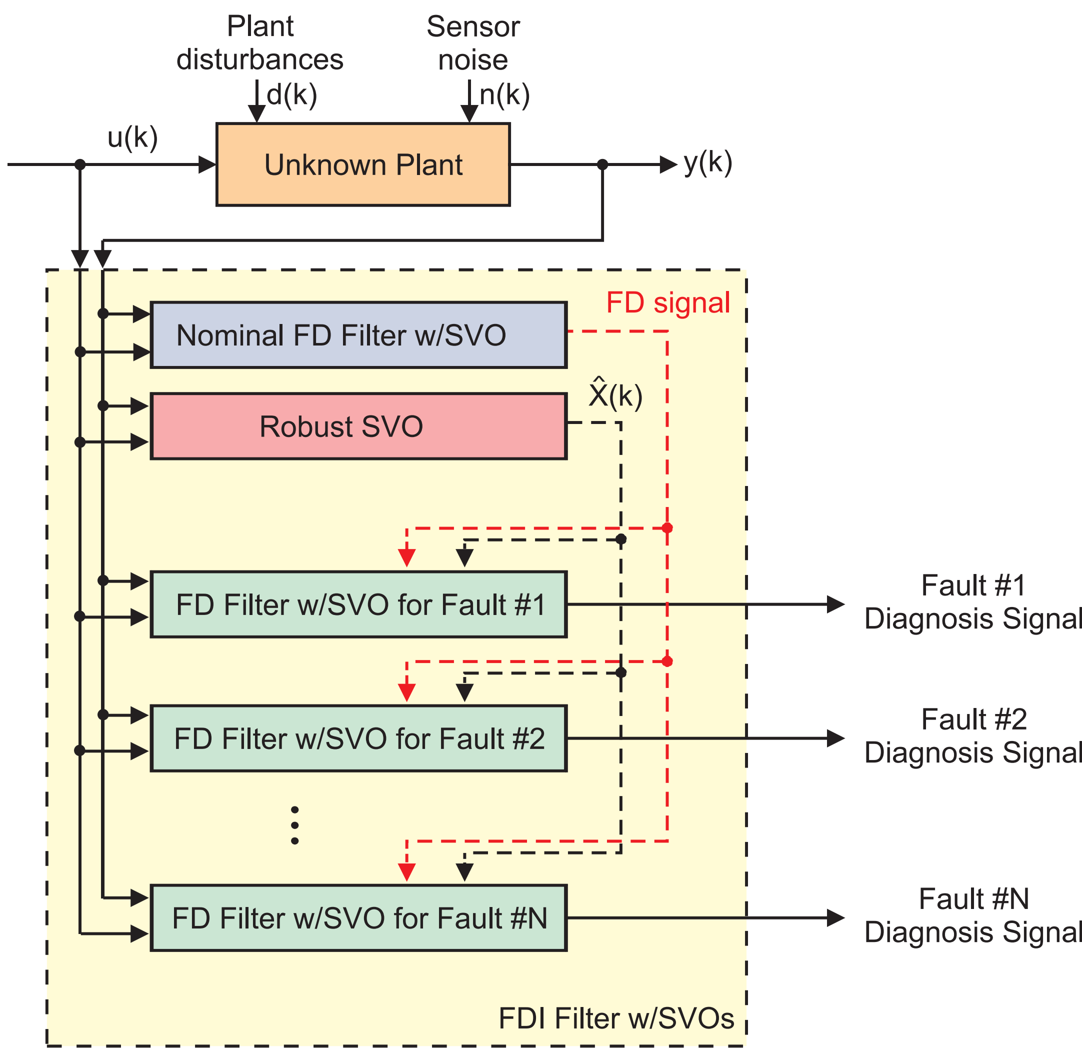
FDI using SVOs

Architecture I



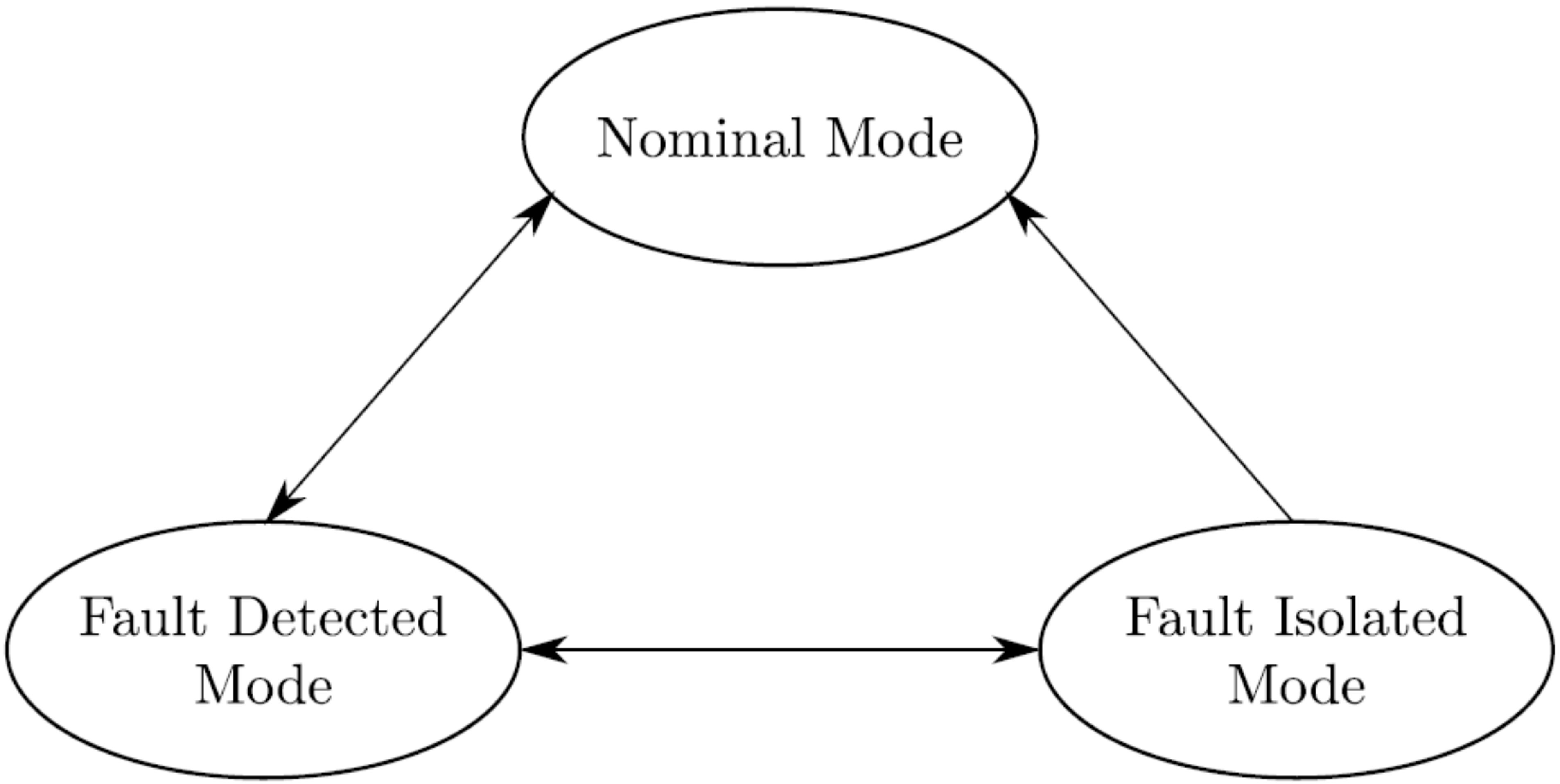
- Detects faults using nominal SVO
- Preferable if nominal model is included in every faulty model

Architecture II



- Starts FDI filters only when a fault is detected
- Each FDI filters requires initialization

FDI using SVOs (cont.'d)

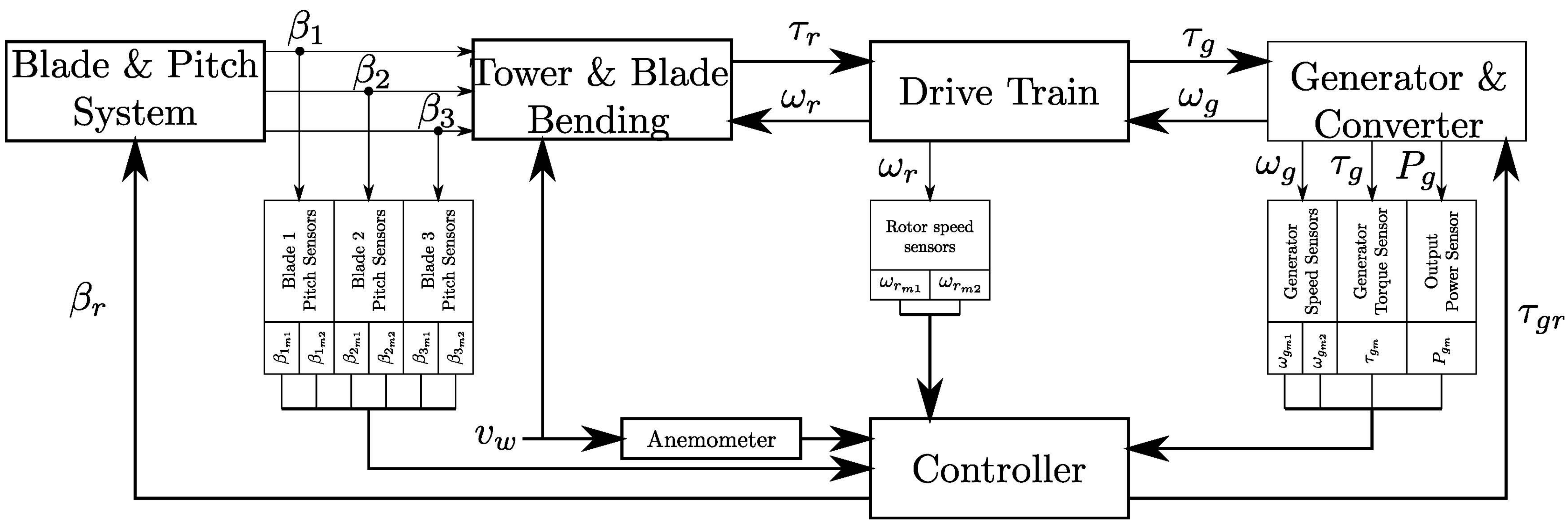


FDI using SVOs (cont.'d)

- Main properties
  - No need to compute a decision threshold
  - Model uncertainty and bounds on the disturbances and measurement noise are explicitly taken into account
  - Applicable to LTI and LTV systems

- Shortcomings
  - Computationally heavier than the classical FDI methods

The Wind Turbine Model



P. F. Odgaard, J. Stoustrup, and M. Kinnaert. *Fault tolerant control of wind turbines - a benchmark model*. In 7th Symposium on Fault Detection,Supervision and Safety of Technical Processes, 2009.

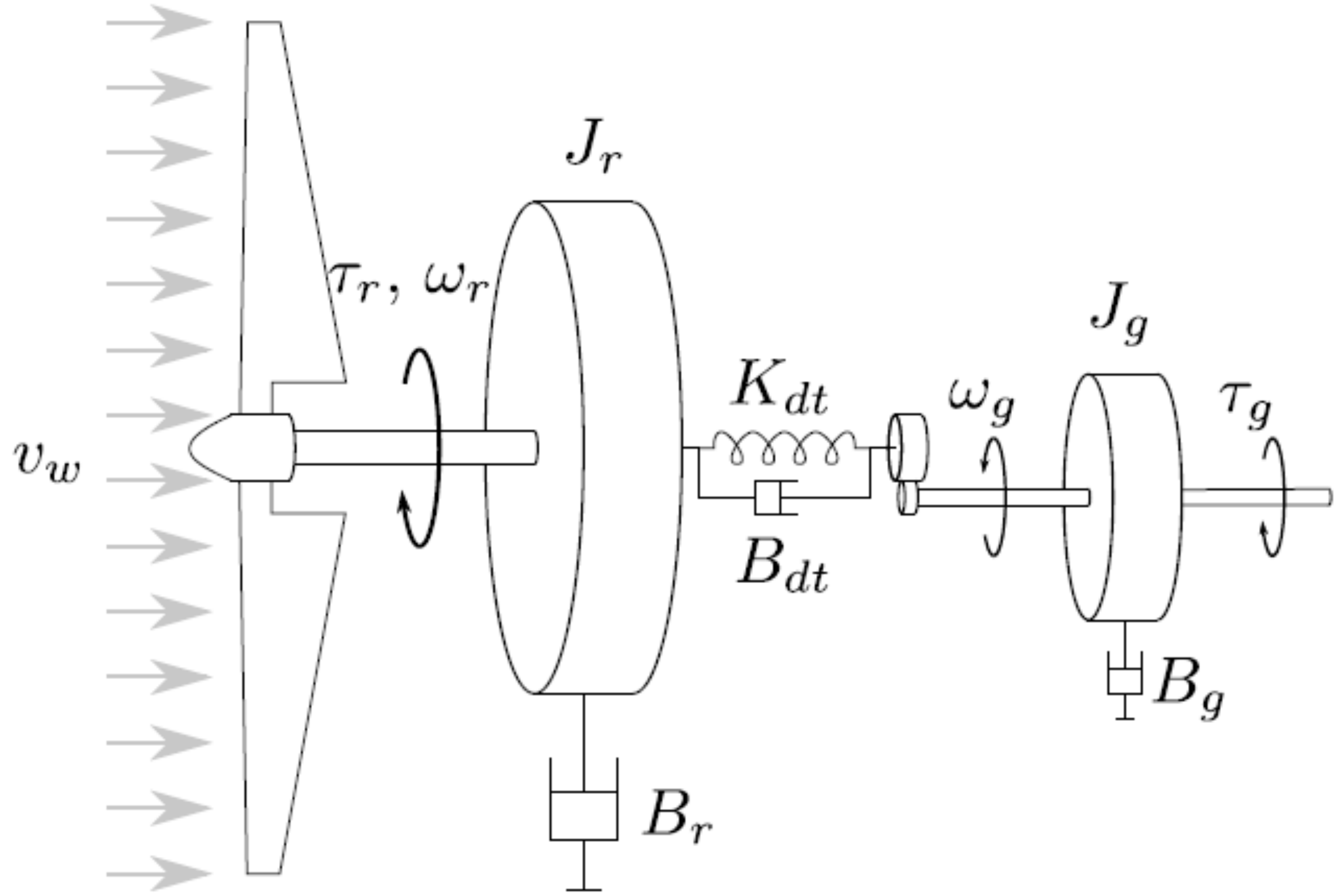
The Wind Turbine Model

$$\frac{\tau_g}{\tau_{gr}} = \frac{\alpha_{gc}}{s + \alpha_{gc}}$$

$$\tau_r \approx \sum_{i=1}^{3} \frac{\rho \pi R^3 C_q(\lambda, \beta_i) v_w^2}{6}$$

$$\frac{\beta_i(s)}{\beta_r(s)} = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$\begin{bmatrix} \dot{\omega}_r \\ \omega_g \\ \theta_\Delta \end{bmatrix} = \mathbf{A}_{dt} \begin{bmatrix} \omega_r \\ \omega_g \\ \theta_\Delta \end{bmatrix} + \mathbf{B}_{dt} \begin{bmatrix} \tau_r \\ \tau_g \end{bmatrix}$$



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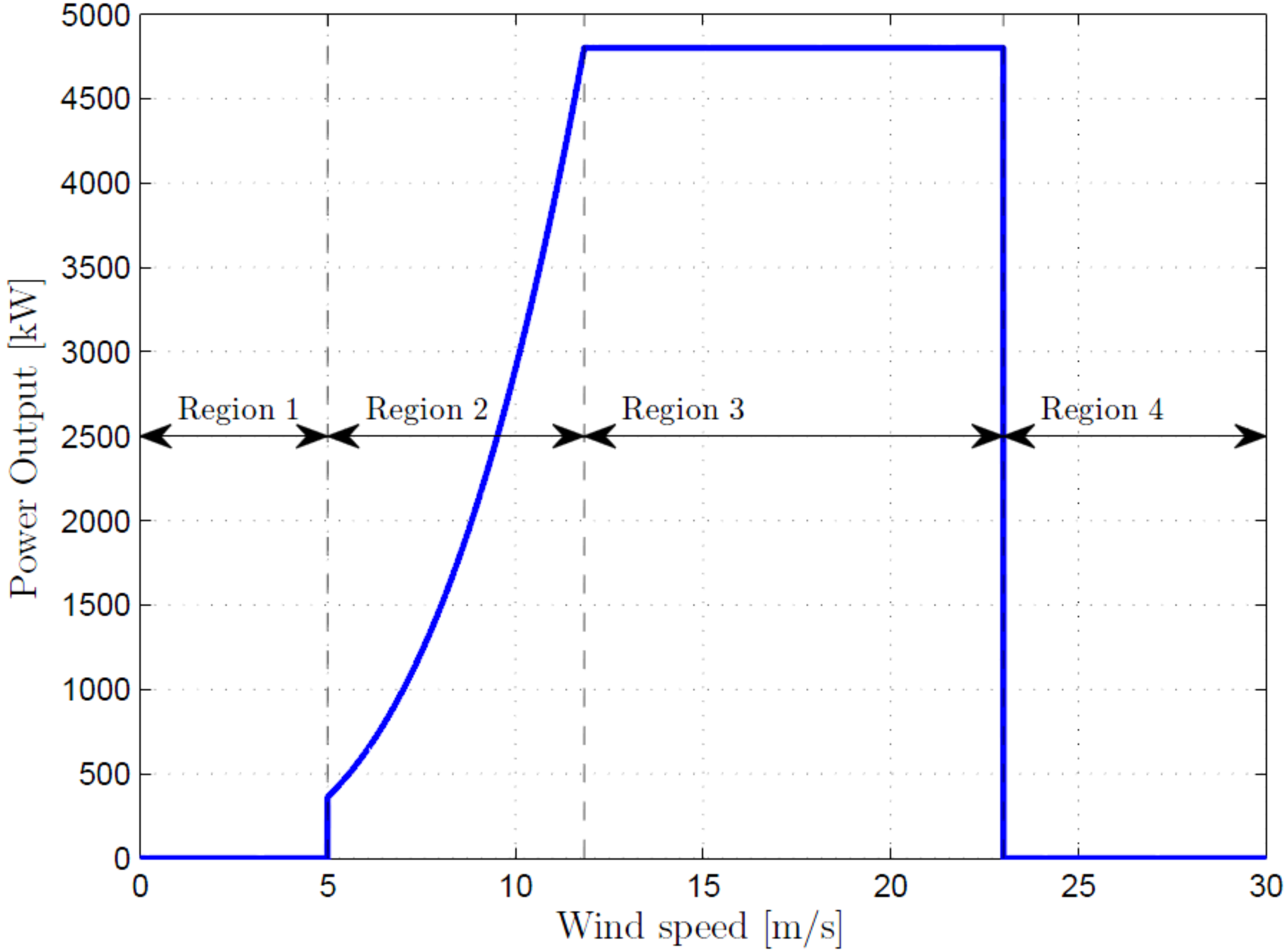
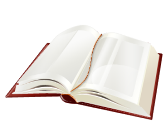
The Wind Turbine Model



Fault Scenarios

No.	Fault Location	Cause	Max FDI Time
1	Blade 1 Pitch Sensor 1	Output offset 5º	$10T_s$
2	Blade 2 Pitch Sensor 2	Decrease in gain by 20%	$10T_s$
3	Blade 3 Pitch Sensor 1	Fixed value output of 10º	$10T_s$
4	Rotor Sensor 1	Fixed value output of 1.4 rad/s	$10T_s$
5	Rotor Sensor 2	Increase in gain by 10%	$10T_s$
5	Generator speed sensor 2	Decrease in gain by 10%	$10T_s$
6	Blade 2 hydraulic system	Modified plant parameters	$8T_s$
7	Blade 3 hydraulic system	Slow change in plant parameters	$600T_s$
8	Generator	Torque offset of 2 kN	$5T_s$



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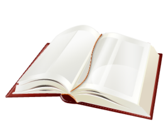
FDI Requirements

- Be able to detect each fault within the specified maximum time for detection;
- Keep false detections separate by at least 100000 sampling periods;
- Turn off a false detection after 3 sampling periods;
- Be robust to disturbances;
- Be able to respond rapidly to failures, by either stopping the wind turbine operation or by reconfiguring the controller structure.



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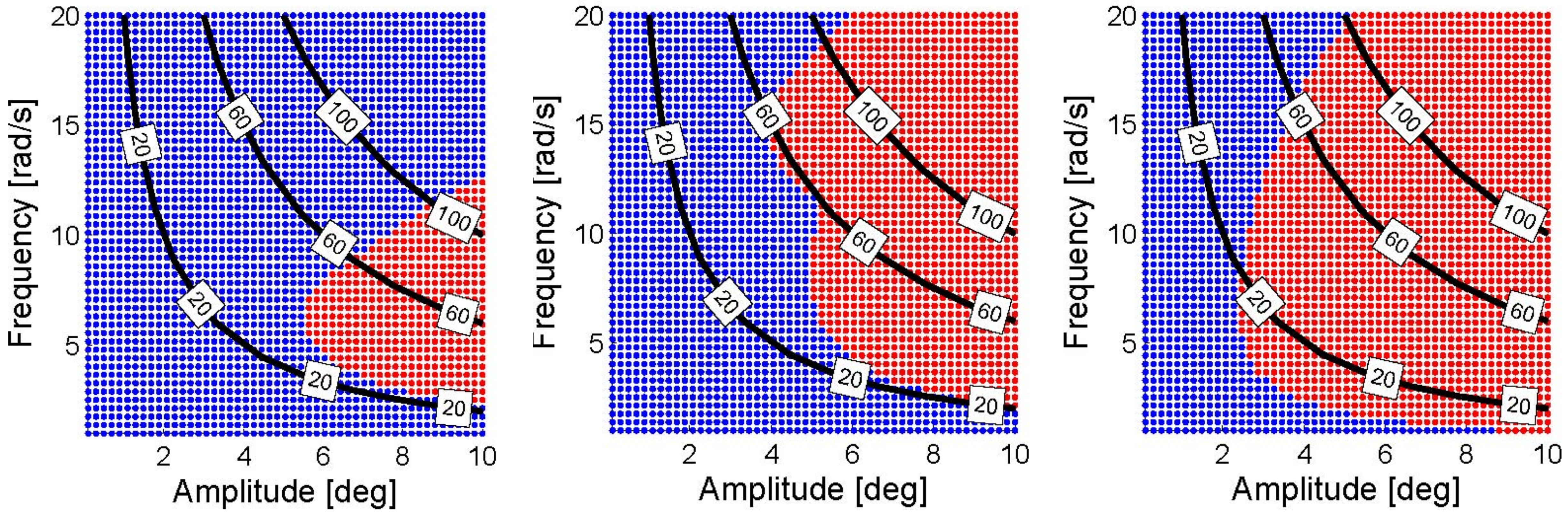
Distinguishability under Input Excitation

Since Faults #2, #6 and #7 are not distinguishable under nominal turbine operation, we add the input excitation:

$$\eta_r(t) = 8\sin(6t) + 7$$



FD of Wind Turbines

Fault Detection results on the benchmark model by *Odgaard et. al*:

No.	Median Detection Time [s]	Max. Detection Time [s]	Median Isolation Time [s]	Max. Isolation Time[s]
1	0.01	0.01	0.01	0.02
2	0.01	0.05	0.045	3.13
3	0.01	0.01	0.01	0.01
4	0.06	0.06	0.01	0.011
5	0.01	0.01	0.01	0.01
6	0.18	0.27	0.20	0.32
7	7.12	8.89	7.125	8.9
8	0.01	0.01	0.01	0.04

Conclusions

- The application of Set-Valued Observers (SVOs) to the Fault Detection and Isolation (FDI) of Wind Turbines was introduced.

- The FDI algorithm using SVOs performs well for a reasonable number of faults and can be complemented with different techniques for improved performance.

- Future work includes the study of the issue of distinguishability and other algorithms with lower computational requirements.

Thank You

Questions/Comments?