Design and development of a novel control regime for microgenerating wind turbines

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Fachbereich 2 Informatik und Ingenieurwissenschaften

Motivation

- Collaboral project between the Frankfurt University of Applied Sciences and the University of Huddersfield
- Wind turbine control using a magnetic brake
- Idea: small scale energy production for the mass market
- Rapid prototyping design methodology

Outline

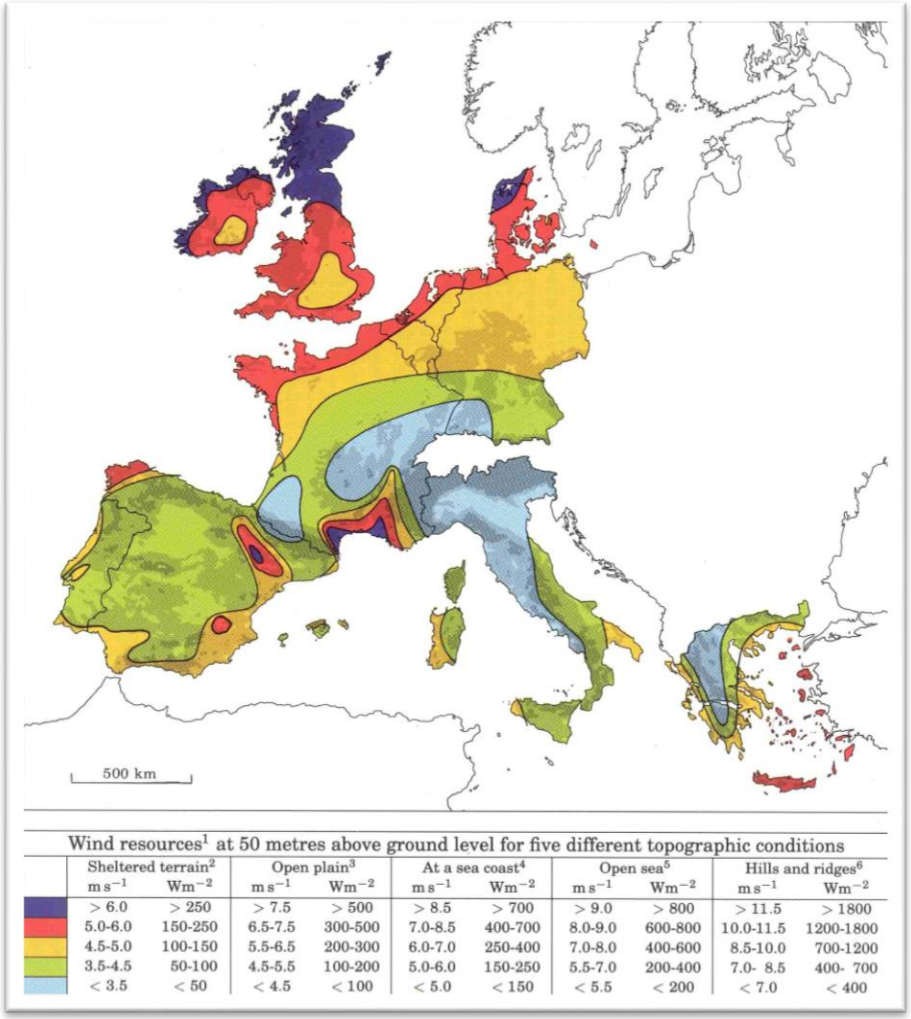
- Advantages of decentralized energy supply
- Some statistics
- Project part 1: Magnetic brake controller
- Project part 2: Wind turbine modelling
- Project part 3: Simulation and control of a wind turbine model
- Summary and prospects

Decentralized energy supply

- Large-scale wind turbines (WT) and transportation network expensive
- Urban areas demand major part in electricity (still)
- Sources should be located in proximity
- Distributed supply requires an extended utility grid
- Ideal: combining microgeneration with Smart Grids

Some statistics

- Wind energy in the UK ***2009***: **~2.5%** [1]
- Wind energy supply exceeds coal energy production in ***2016*** [2]:
  - wind energy = **11.5%**, 14,543 MW installed capacity
  - coal reached 9.2%
- Comparison with Spain/Germany in ***2016*** [3]:
  - Spain = 23,074 MW
  - Germany = 50,018 MW



Wind resources[1] at 50 metres above ground level for five different topographic conditions

Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

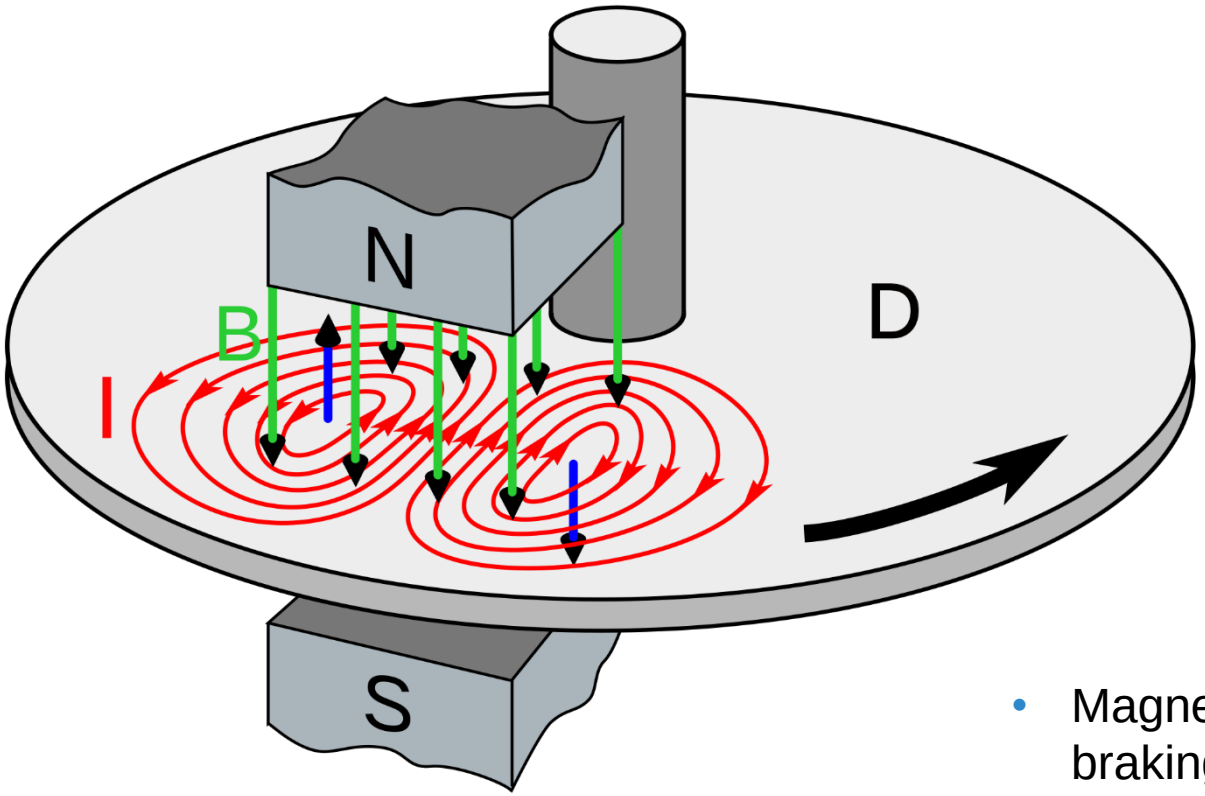
European Wind Atlas [4]

Urban wind engineering

- Horizontal axis wind turbines (HAWT) abundant, higher yield
- Vertical axis wind turbines (VAWT) mechanically simpler, potentially lower yield
- Drag-based VAWT: max. 15% efficiency
- Lift-based VAWT: e. g. patented Vortexis turbine, max. 35%
- Idea: inexpensive control design methodology

Image:
Building-mounted WT [5]

Project Part 1 – Magnetic brake control

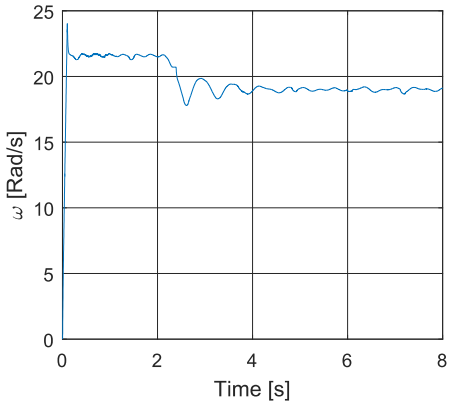


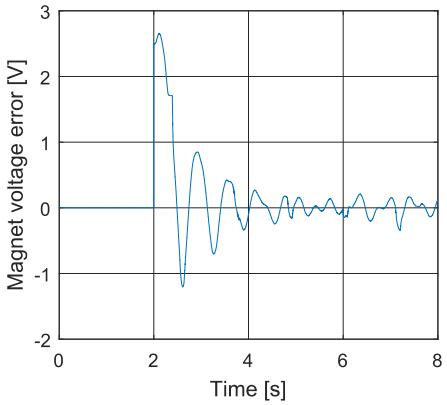
Eddy current brake [6]

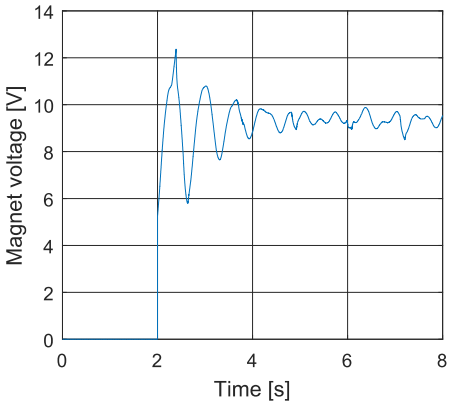
- WT speed control
- Magnetic braking advantageous

MB Control - results

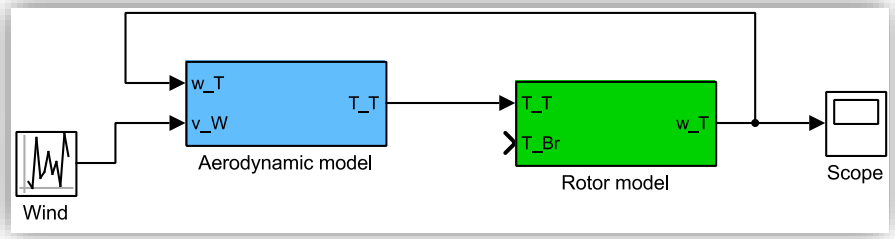
- Controller development via Simulink
- Automated design possible
- PI design/ HIL (Hardware-in-the-loop) tuning



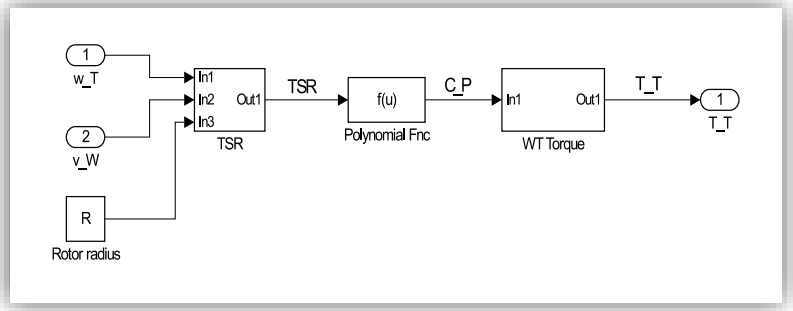




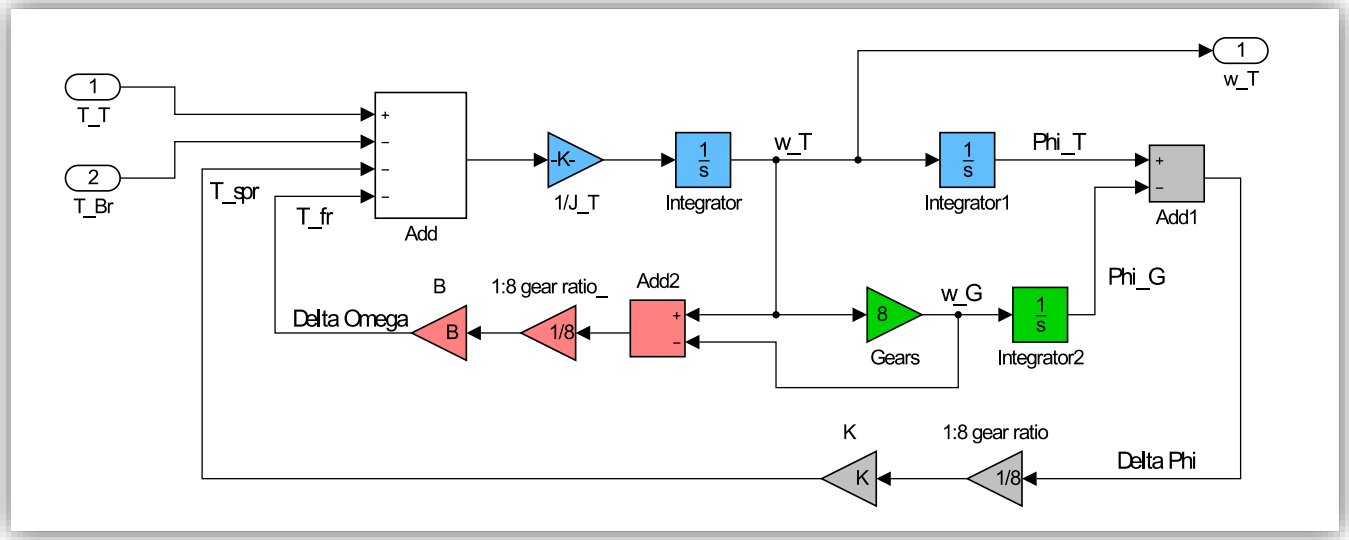
Project part 2: Wind turbine modelling



Wind turbine open loop model

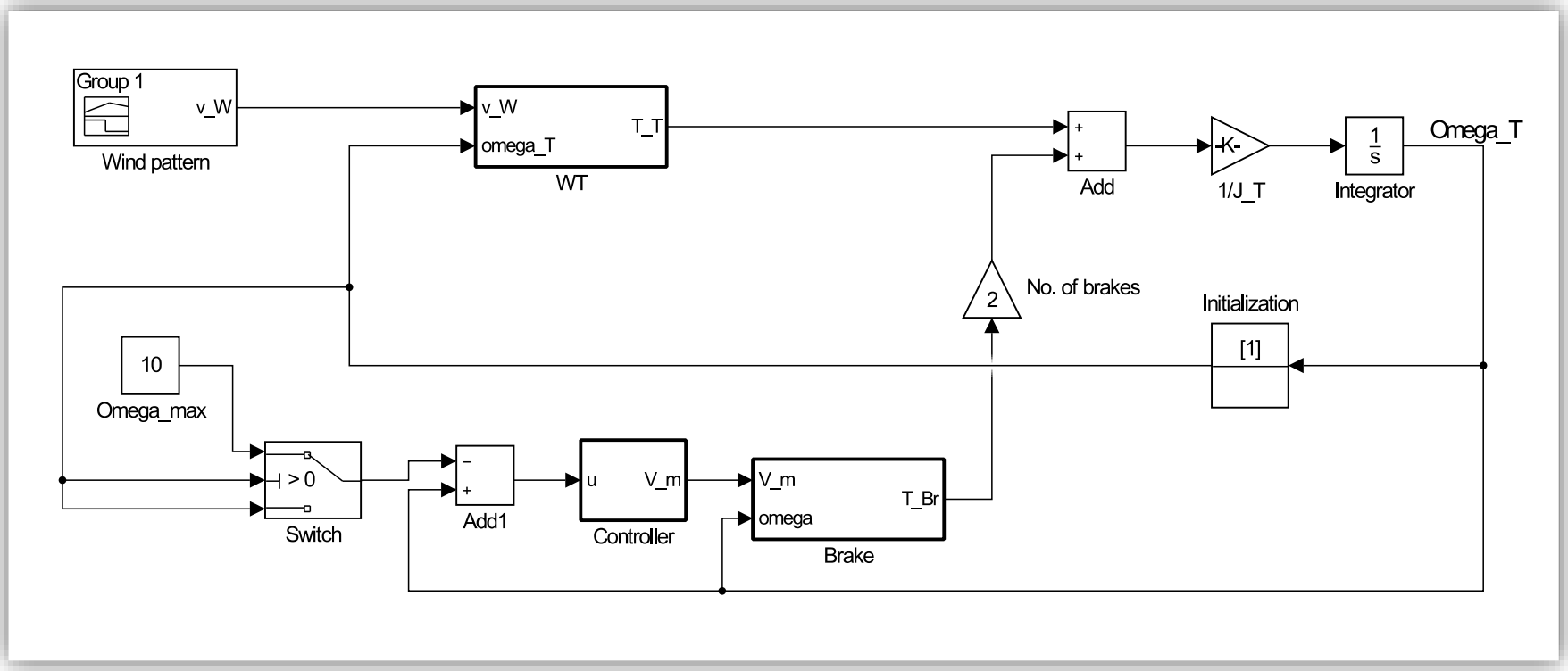


Subsystem: Aerodynamic model



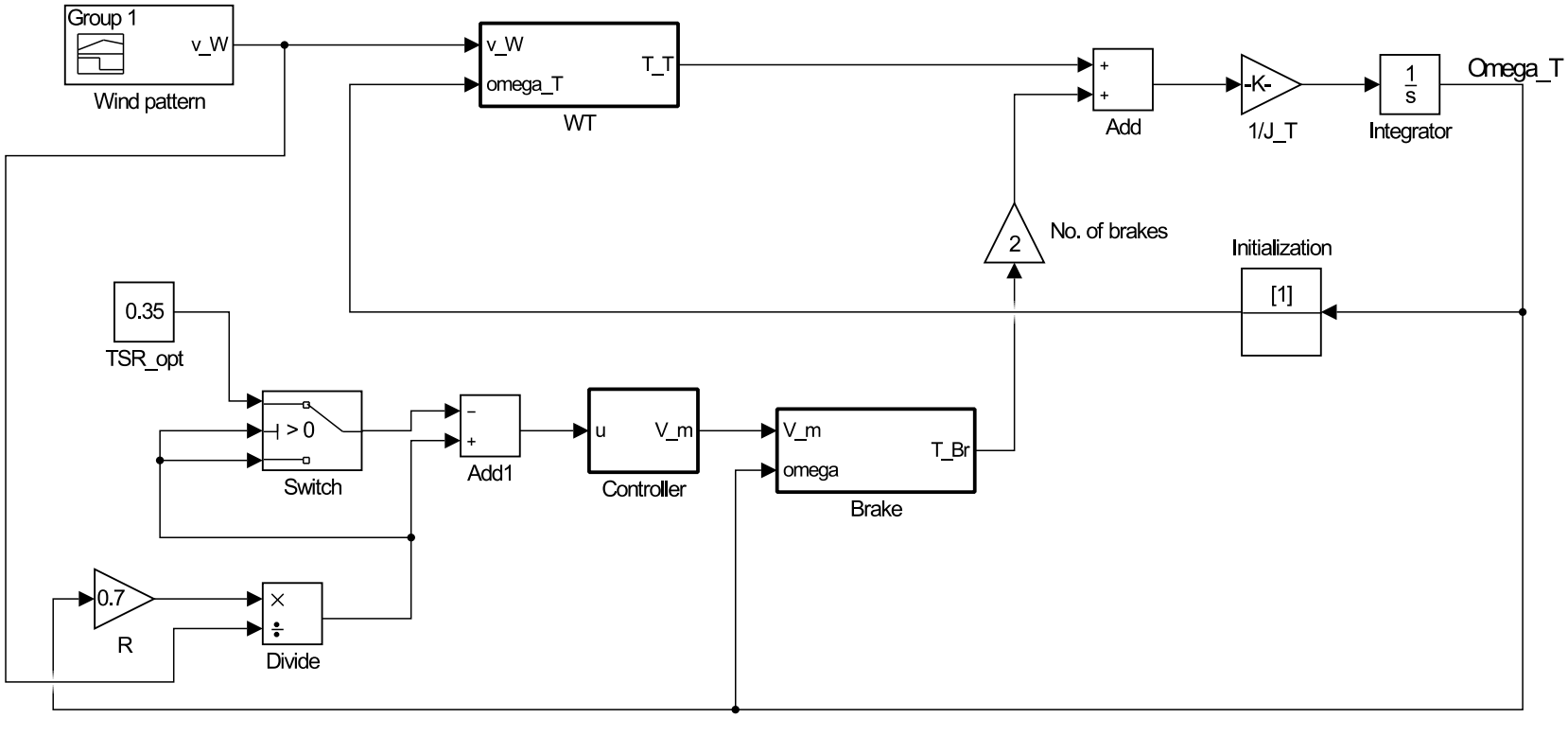
Subsystem: Rotor model

Project part 3: Simulation and control I



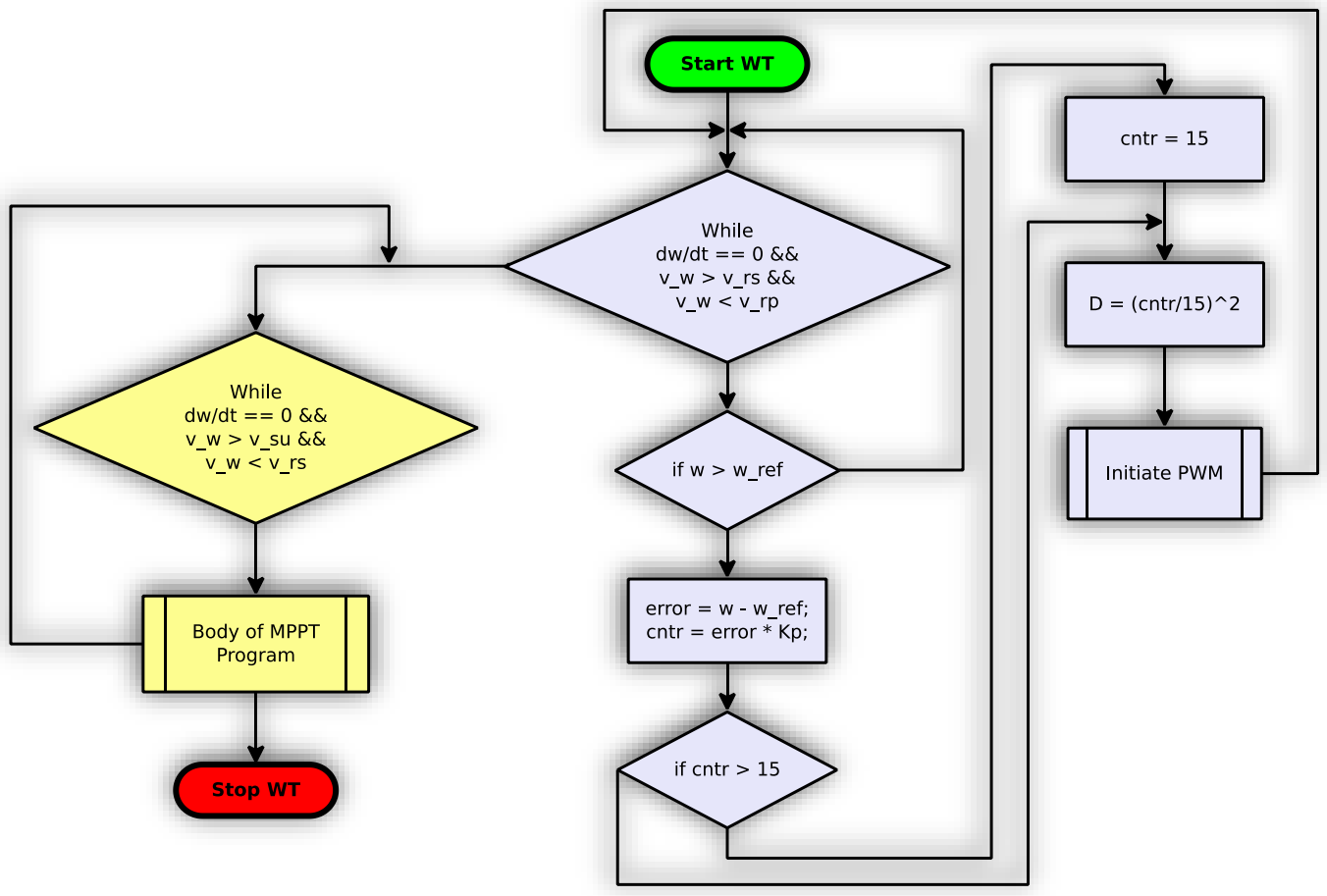
WT speed control mode

Project part 3: Simulation and control II



WT Tip Speed Ratio (TSR) control mode

Project part 3: Supervisory control



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Summary

- Distributed supply in Smart Grids preferable in utility grid
- Wind statistics: UK provides a proven suitable site
- Magnetic brake controller successfully developed using HIL
- Wind turbine model retrieved from experimental data and CFD (computational fluid dynamics)
- Simulation and control of a WT using a magnetic brake and a two-mode control scheme supervised by a monitoring program

References

[1] IEA Energy Statistics – for Electricity/ Heat [online]. Available: http://www.iea.org/stats/prodresult.asp?PRODUCT=Electricity/Heat.

[2] The Guardian, “UK wind power overtakes coal for the first time”. Available: https://www.theguardian.com/business/2017/jan/06/uk-wind-power-coal-green-groups-carbon-taxes

[3] Global Wind Statistics 2016 [pdf]. Available: http://www.gwec.net/wp-content/uploads/vip/GWEC_PRstats2016_EN_WEB.pdf

[4] I. Troen, E. L. Petersen, European Wind Atlas. Risø National Laboratory, Roskilde: DTU National Laboratory, Denmark, 1989

[5] Photo by dclerch, “Twelve west rooftop wind turbines”, creative commons license available at (image used in original form): https://creativecommons.org/licenses/by-nc-sa/2.0/legalcode

[6] Diagram by Chetvorno (Own work) [CC0], via Wikimedia Commons