Speed Control of Synchronous Machine by Changing Duty Cycle of DC/DC Buck Converter

Rashid Al Badwawi
University of Exeter

The work is financially supported by the Government of Oman and EPSRC-DST funded RESCUES project (EP/K03619X/1)
Contents

• Objectives

• What is DC/DC buck converter?

• Hybrid system with DC microgrid

• Wind energy system

• Wind turbine modelling

• Speed control of wind turbine

• Simulation results

• Conclusion

• Q & A
Objectives

• Develop wind system model.

• Measure wind speed.

• Develop two models to control turbine speed.

• Use measured wind speed as input for wind turbine.

• Use duty ratio of DC/DC buck converter to control speed of wind system.
What is DC/DC buck converter?
Hybrid System with DC Microgrid
Wind energy system
Wind Turbine Modelling

• Power generated $P_m$ by wind turbine:

$$P_m = \frac{1}{2} \rho \pi R^2 u^3 C_P$$

$P_m$ : Turbine mechanical power
$\rho$ : Air density
$R$ : Turbine rotor radius
$u$ : Wind speed
$C_P$ : Turbine performance coefficient (function of tip speed ratio $\lambda$ and pitch angle $\beta$ in a pitch controlled system)

$$\lambda = \frac{R\omega}{u}$$

$\omega$ is turbine rotational speed

$$\omega = \frac{1}{J} \int (T_m - T_e) \, dt$$

$T_m$ : Turbine mechanical torque
$T_e$ : Turbine electrical torque
$J$ : Rotational inertia
Wind Turbine Modelling

- **Mechanical torque** $T_m$ can be calculated:

  $$ T_m = \frac{P_m}{\omega} $$

  $P_m$: Turbine mechanical power  
  $\omega$: Turbine rotational speed

- **Electrical torque** $T_e$ can be calculated:

  $$ T_e = K_I I_s $$

  $K_I$: Machine torque constant  
  $I_s$: Machine stator current

In this system, electrical torque is controlled by buck output current $I_L$.  
Electrical torque can be related to buck current by new defined constant $K_T$

  $$ T_e = K_T I_L $$
Speed Control of Wind Turbine

a) Stored Power curve

\[ P_m = \frac{1}{2} \rho \pi R^2 \omega^3 \lambda^{0.5} \]

\[ T_m = \frac{1}{sJ} u^3 \]

b) PI Control of the TSR
Speed Control of Wind Turbine

![Graph 1: Tip Speed Ratio (λ) vs. Efficiency (η)]

![Graph 2: Turbine Speed (RPM) vs. Power (W)]

![Graph 3: Wind speed (m/s) vs. Time (s)]
Simulation Results

a) Stored Power curve

- Generated electrical energy = 28.81 kJ

b) PI Control of the TSR

- Generated electrical energy = 24.75 kJ
Simulation Results

PI Control of the TSR

Generated electrical energy = 30.39 kJ
Detailed Overall System of Wind Turbine
Simulation Results

Power & speed for detailed model with machine torque constant equal to 5.308 N.m / $A_{\text{peak}}$

Generated electrical energy = 32.05 kJ
Conclusion

- A wind turbine connected to a PMSM was modelled in Simulink.
- DC/DC buck converter was used at the load side.
- A comparison between two methods of controlling a wind turbine in a microgrid was done:
  1. Stored power curve
  2. PI control of the speed tip ratio
- PI method provides more controllability, but it requires an anemometer to measure wind speed.
- Stored energy method is easier to implement, but amount of energy extracted can be less.
Thanks for Your Kind Attention

Rashid Al Badwawi
rsm202@exeter.ac.uk