Dynamic Drive Control for Wind Power Conversion with PMSG: Modeling and Application of Transfer Function Analysis

Assignment 1 (23 Points):
Electric System Modeling and Current Command Synthesizer

Renewable Energy Technology in Electric Networks

M.Sc. Stefan Häselbarth
Chair of Sustainable Electric Networks
and Sources of Energy
Technische Universität Berlin

Overview

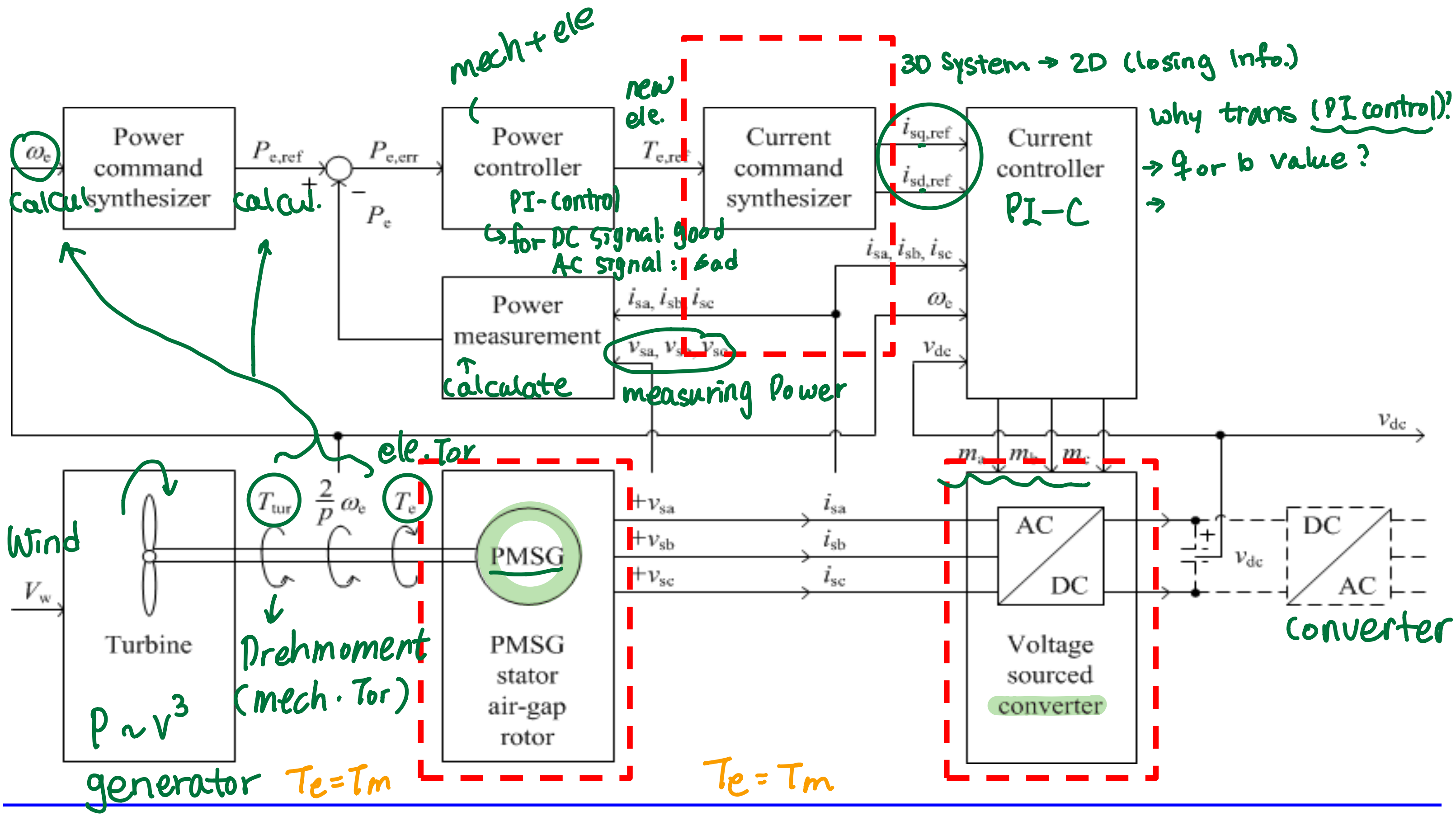
- Assignment 1: Electric System Modeling and Current Command Synthesizer
- Assignment 2: Current Control
- Assignment 3: Turbine Rotor Interaction Process
- Assignment 4: Power Control

Reference

- M. Kuschke, K. Strunz, „Energy-Efficient Dynamic Drive Control for Wind Power Conversion With PMSG: Modeling and Application of Transfer Function Analysis," IEEE Journal of Emerging and Selected Topics in Power Electronics, 2014.
- Paper available at ieeexplore. Please use the following link: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6678202&quer

→ PDF : Energy-Efficient Dynamic ~ / ~ 20.Jan.2021

Wind Energy Conversion System basic Principal



Wind Turbine and PMSG Parameters

See overview

	Symbol	Quantity	Value
Turbine	P_{tur}	Rated Power	3.5 MW
	V_{w}	Rated wind speed	12 m/s
	n	Rated mechanical angular velocity	20 rpm
	$C_{\mathrm{p,opt}}$	Maximum power coefficient	0.4378
	r	Rotor radius	50 m
	λ_{opt}	Optimal tip speed ratio	6.7
	H	Inertia constant of turbine and PMSG	6 s
PMSG	p	Number of poles	180
	R_{s}	Stator resistance	60 mΩ
	L_{sd}	Stator d-axis inductance	6 mH
	L_{sq}	Stator q-axis inductance	8 mH
	Φ_{m}	Flux induced by magnets	17.3 Wb

Assignment 1: Task 1 → see the table 1 in the overview

- Initialize the given turbine and PMSG variables in MATLAB.
- Calculate the following parameters from the given wind turbine and generator parameters. Assume that P_e equals P_{tur}. $(P_e = P_{tur})$
  - Rated electrical angular frequency ω_e, given in rad/s
  - Rated electrical torque T_e
  - Rated generator voltage v_s, given as rms,phase-to-phase value

- Give equations and results in the report.

- Power relation is cubic : $P_o \sim v^3$

→ conversion from mechanical speed to electrical speed

I. $\omega_m = 2\pi \cdot \frac{n}{60}$ n = rounds per minute

II. $\omega_e = \omega_m \cdot \frac{p}{2}$ p = Poles

- No losses ! (due to fiction ?) $P_{tur} = P_{el}$

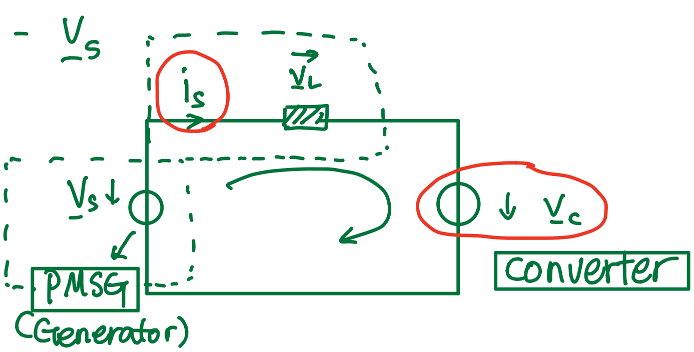
→ mechanical torque $P_{tur} = T_m \cdot \omega_m$ | insert eq. II.

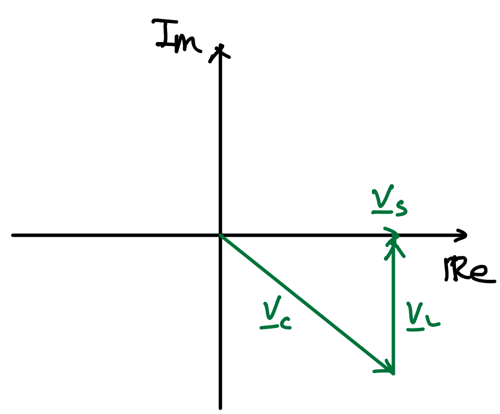
$$\rightarrow T_m \cdot \frac{\omega_e \cdot 2}{p} = P_{el} \; ; \quad T_e = \frac{P_{el} \cdot p}{2 \cdot \omega_e}$$

my calculation

$$\rightarrow \omega_m = \frac{P_{tur}}{T_m} \Rightarrow (\text{II}) \quad \omega_e = \frac{P_{tur}}{T_m} \cdot \frac{p}{2}$$

- $\underline{V}_s$





$$\underline{V}_s = \underline{V}_L + \underline{V}_c$$

$$\underline{i}_s = \frac{\underline{V}_L}{j\omega L} = \frac{\cancel{j}X}{\cancel{j}\omega L} = \frac{X}{\omega L}$$: active current

E_q ^ R2 :

$$V_{sd} = \underbrace{L_{sq} \cdot i_{sq} \cdot \omega_e}_{\neq 0} - \underbrace{L_{sd} \cdot \frac{di_{sd}}{dt}}_{0} - \underbrace{R_s \cdot i_{sd}}_{0}$$

| control
$i_{sd} = 0$

$\approx 0 \rightarrow$ x important

$$V_{sq} = (\phi_m - \underbrace{L_{sd} \cdot i_{sd}}_{=0}) \cdot \omega_e - \underbrace{L_{sq} \cdot \frac{di_{sq}}{dt}}_{0} - \underbrace{R_s}_{\ll 1} \cdot i_{sq}$$

$\because i_{sq} = i_{sd}$

: very small

$$V_{sq} \approx \phi_m \cdot \omega_e - \underbrace{R_s \cdot i_{sq}}_{\ll 1}$$

not change
= same
const. flux

= flux induced by magnets

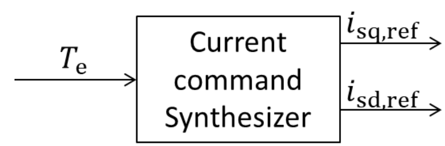
Assignment 1: Task 2

For different wind speeds, the wind power conversion system operates at different operating points. Thus, the values for example of ω_e , T_e or i_s change.

- In a first step, calculate the current references $i_{sd,ref}$, $i_{sq,ref}$ for the rated torque $T_{e.}$ Then, vary T_e from zero to the rated value and determine the corresponding current references.

  Solution: Specify a suitable torque vector by yourself and give a reason for your choice. Remember that the torque is changing, when the wind speed changes. Thus, a small step size is beneficial because it increases the accuracy of $i_{sd,ref}$, $i_{sq,ref}$. Doing so, the wind power conversion system operates with a higher efficiency. Parameters $i_{sd,ref}$, $i_{sq,ref}$ will be stored in a so-called look-up table later and allocated to a specific $T_{e.}$

- Determining $i_{sd,ref}$, $i_{sq,ref}$, an iterative method is to be used. Apply the Newton-Raphson method programmed by yourself.
- Plot $\boldsymbol{i_s}$ versus $T_{e.}$



- Show your calculations, the values for the rated current reference and the figure in the report. Explain the length of your torque vector.

Power synthesizer (Eq. 25 & 26)

→ start with eq. 26 ($\because$ quadratic) $i_{sq_{n+1}} = i_{sq_n} - \dfrac{f(i_{sq,n})}{f'(i_{sq,n})}$

→ close solution for $i_{sq,ref}$

insert in (25) get $i_{sd,ref}$

We know $i_{sd,ref}$ and $i_{sq,ref}$, what's i_s

$$\underbrace{i_s = (i_{sq}^2 + i_{sd}^2)^{\frac{1}{2}} \cdot \frac{1}{\sqrt{2}}}_{\text{RMS Stator Current}}$$

Assignment 1: Task 3

- For a balanced three-phase system the following equation is valid:

$$i_{\mathrm{dc}}(t) = \frac{1}{2}\left(m_{\mathrm{a}}(t)i_{\mathrm{sa}}(t) + m_{\mathrm{b}}(t)i_{\mathrm{sb}}(t) + m_{\mathrm{c}}(t)i_{\mathrm{sc}}(t)\right) \tag{1.1}$$

→ You just take it!

- This expression is transformed to dq-frame:

$$i_{\mathrm{dc}} = \frac{3}{4}\left(m_{\mathrm{d}}i_{\mathrm{sd}} + m_{\mathrm{q}}i_{\mathrm{sq}}\right) \tag{1.2}$$

- Derive equation (1.2), giving current i_{dc} in dq-frame, from (1.1). Show the coordinate transform you use and how it is applied to (1.1). Furthermore, include all intermediate steps and assumptions in your report.

- *Solution:*

  - Transform directly from abc- to dq-frame, choose from next slide
  - Assume a suitable value for the angle theta

Coordinate Systems – abc-to-dq Transform

clock system : 2D Subspace

- Example given for a voltage; similar for other quantities (angle θ aligned between d- and α-axis; q-axis is leading d-axis by 90°)

transformation-Matrix → 3D

$$\begin{pmatrix} V_\mathrm{d}(t) \\ V_\mathrm{q}(t) \end{pmatrix} = \frac{2}{3} \begin{pmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{pmatrix} \cdot \begin{pmatrix} V_\mathrm{a}(t) \\ V_\mathrm{b}(t) \\ V_\mathrm{c}(t) \end{pmatrix} \qquad (1.3)$$

germany : 230V

- With $\theta = \omega_\mathrm{e} t + \theta_0$
- Inverse matrix

$$\begin{pmatrix} V_\mathrm{a}(t) \\ V_\mathrm{b}(t) \\ V_\mathrm{c}(t) \end{pmatrix} = \begin{pmatrix} \cos(\theta) & -\sin(\theta) \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{pmatrix} \cdot \begin{pmatrix} V_\mathrm{d}(t) \\ V_\mathrm{q}(t) \end{pmatrix} \qquad (1.4)$$

real value

dq-system

Exam :- Perhaps canceled on 11. Feb. 2024

- Old Exam will be provided