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Modelling of tranformers with on-load tap-changers (OLTC) in Python

MASTER THESIS

by

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Maximilian Köhler: *Modelling of tranformers with on-load tap-changers (OLTC) in Python,*
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Contents

All models are wrong, but some are useful.

— Albert Einstein

1 Introduction

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This leads to the following structure for the paper:

- **Chapter 2,**
  some description about chapter 2;
- **Chapter 3,**
  some description about chapter 3;
- **Chapter 4,**
  some description about chapter 4.

2 Fundamentals

3 Transformer Equipment Modeling

Some literature and fundamentals about transformers, control, stability assessment, fast-switching modules, and analysis in Python.

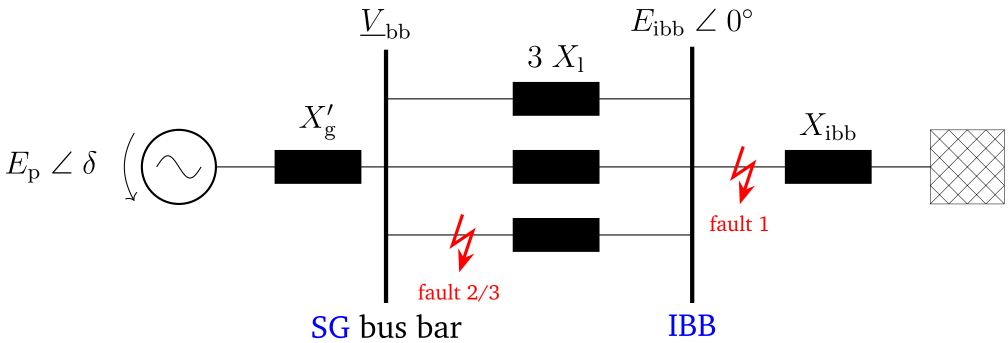

Figure 3.1: Representative circuit of a Single Machine Infinite Bus (SMIB) model with pole wheel voltage $E_{\mathrm{p}} \angle \delta$ and Infinite Bus Bar (IBB) voltage $E_{\mathrm{ibb}} \angle 0°$; positions of considered faults 1 to 3 are marked with red lightning arrows

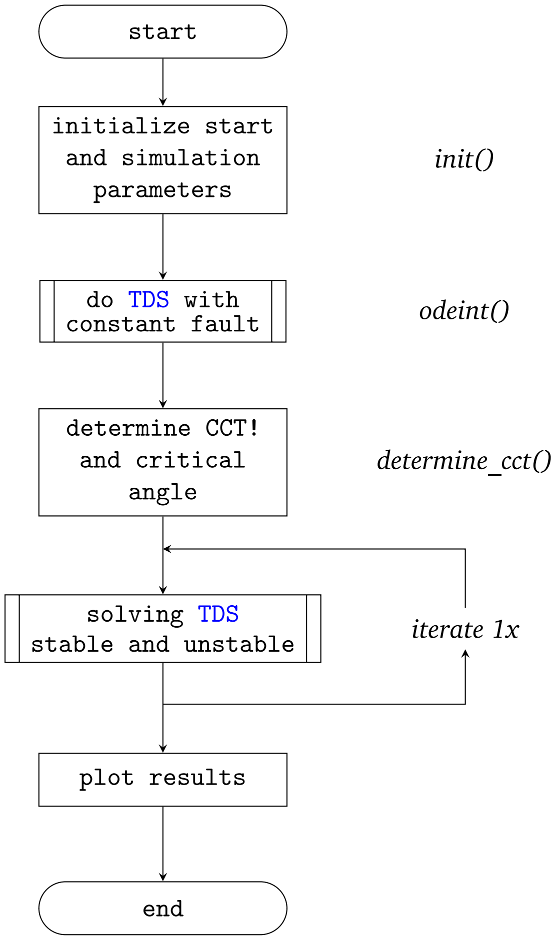

Figure 3.2: Program plan proposal for determining the **CCT!** (**CCT!**) t_{cc}, critical power angle δ_{cc} and the Time Domain Solution (TDS) of the Single Machine Infinite Bus (SMIB)-model; including the associated main function name

4 Tap Changer Control Modeling

5 Simulative comparison of Continous and Discrete Control Methods

6 Indices for Voltage Stability

- Which indices can be implemented?
- Implementation and calculation

7 Implementation of Stability Monitoring

- Index combination and „traffic light“monitoring
- Restauration options and opportunities
- Local mapping
- Weak point identification

8 Approaches for wide-area-control mechanisms enhancing voltage stability

9 Representative Electrical Networks

10 Results from the Python Framework

11 Comparison to Results from PowerFactory

12 Discussion

13 Summary and outlook

Some conclusion.

Some outlook and nice blibla.

Acronyms

IBB	Infinite Bus Bar
RMS	Root Mean Square
SG	Synchronous Generator
SMIB	Single Machine Infinite Bus
TDS	Time Domain Solution

Symbols

δ	$^\circ$ / deg	power angle (or power angle difference)
$\Delta\omega$	$\frac{1}{\mathrm{s}}$	change of rotor angular speed
$\underline{\theta}$	-	transformer ratio; complex if phase shifting
A	-	acceleration or deceleration area
$\underline{E}$	V	voltage of SG or IBB
H_{gen}	s	inertia constant of a Synchronous Generator (SG)
$\underline{I}$	A	current
P	W	effective power; electrical or mechanical
Q	var	reactive power
R	Ω	ohmic resistance
$\underline{S}$	VA	apparent power
$\underline{V}$	V	voltage
$\underline{X}$	Ω	reactance
$\underline{Y}$	$\frac{1}{\Omega}$ / S	admittance
$\underline{Z}$	Ω	impedance

The different symbols are used with different indices, these are semantic and explained in the surrounding context. Following notation is commonly used for mathematical and physical symbols:

- Phasors or complex quantities are underlined (e.g. $\underline{I}$)
- Arrows on top mark a spatial vector (e.g. $\vec{F}$)
- Boldface denotes matrices or vectors (e.g. $\boldsymbol{F}$)
- Roman typed symbols are units (e.g. s)
- Lower case symbols denote instantaneous values (e.g. $\underline{i}$)
- Upper case symbols denote RMS or peak values (e.g. $\underline{I}$)
- References to objects are written capitalized Roman (e.g. $\underline{Z}_{\mathrm{TRAFO}}$)
- Subscripts relating to physical quantities or numerical variables are written italic (e.g. $\underline{I}_1$)

In the simulations and calculations the per unit system ($\mathrm{p.u.}$) is preferred, thus normalizing all values with a base value. Where necessary, absolute units are added to indicate the explicit use of the normal unit system. For more information about this per-unit system please refer to Machowski, Lubosny, Bialek, *et al.* [2], specifically Appendix A.1 provides a detailed description and explanation.

Bibliography

[1] S. Batchu, Y. Raghuvamsi, and K. Teeparthi, “A Comparative Study on Equal Area Criterion Based Methods for Transient Stability Assessment in Power Systems,” in *2022 22nd National Power Systems Conference (NPSC)*, New Delhi, India: IEEE, Dec. 17, 2022, pp. 124–129, ISBN: 978-1-66546-202-0. DOI: 10.1109/NPSC57038.2022.10069303. [Online]. Available: https://ieeexplore.ieee.org/document/10069303/ (visited on 12/14/2023).

[2] J. Machowski, Z. Lubosny, J. W. Bialek, and J. R. Bumby, *Power System Dynamics: Stability and Control*, Third edition. Hoboken, NJ, USA: John Wiley, 2020, 1 p., ISBN: 978-1-119-52636-0 978-1-119-52638-4.

Appendix

A Python modelling

A.1 Mathematical equations

c

B OLTC control

e

C Verification