OPTIMIZATION OF PTL STRUCTURES FOR APPLICATION IN COMMERCIAL PEM ELECTROLYSIS STACKS

MAXIMILIAN KÖHLER

Master Thesis

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Maximilian Köhler: *Optimization of PTL structures for application in commercial PEM electrolysis stacks,* Master Thesis, © September 2024

SUPERVISORS:
Prof. Dr. Simon Thiele
Philipp Hörning, Dipl.-Phys.

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ABSTRACT

Short summary of the contents in English…a great guide by Kent Beck how to write good abstracts can be found here:

https://plg.uwaterloo.ca/~migod/research/beck00PSLA.html

ZUSAMMENFASSUNG

Kurze Zusammenfassung des Inhaltes in deutscher Sprache…

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LISTINGS

ACRONYMS

CCT critical clearing time

IBB infinite bus bar

ODE ordinary differential equation

SG synchronous generator

SMIB single machine infinite bus

TDS time domain solution

SYMBOLS

H_{gen}	s	inertia constant of a synchronous generator (SG)
P	W	Power; electrical or mechanical

1 FUNDAMENTALS

General sources in terms of standard literature: [1–4]

1.1 BASICS SYNCHRONOUS GENERATORS

The final swing equation system can be derived to following two equations, which have to be solved in every time step to determine the pole angle δ and the rotor speed ω, respectively the rotor speed change from its base value $\Delta\omega$:

$$\frac{d\delta}{dt} = \Delta\omega \tag{1}$$

$$\frac{d\Delta\omega}{dt} = \frac{1}{2 \cdot H_{\mathrm{gen}}} \cdot (P_{\mathrm{m}} - P_{\mathrm{e}}) \tag{2}$$

The generation of a time domain solution (TDS) for this equation system takes place in Section 2.3.

1.2 SYSTEM STABILITY ESP. TRANSIENT CONTEXT

With respect to the limitations, that

1. the machine is operating under balanced three-phase positive-sequence conditions,
2. the machine excitation is constant,
3. the machine losses, saturation, and saliency are neglected,

a simplified single machine infinite bus (SMIB) model can be considered for transient stability assessment (see Figure 1). The infinite bus bar (IBB) is working with a constant voltage E_{ibb} and angle δ_{ibb}, typically set to $0°$. The real power flowing from the SG to the IBB is then expressed within the Equation 3 and only dependent on the power angle δ. The reactance X_{res} is expressing the simplified reactance from the respective circuit.

$$P_{\mathrm{e}} = \frac{E_{\mathrm{p}} \cdot E_{\mathrm{ibb}}}{X_{\mathrm{res}}} \cdot sin(\delta) \tag{3}$$

The mechanical power of the turbine is assumed constant, due to the short occurance of transient stability problems.

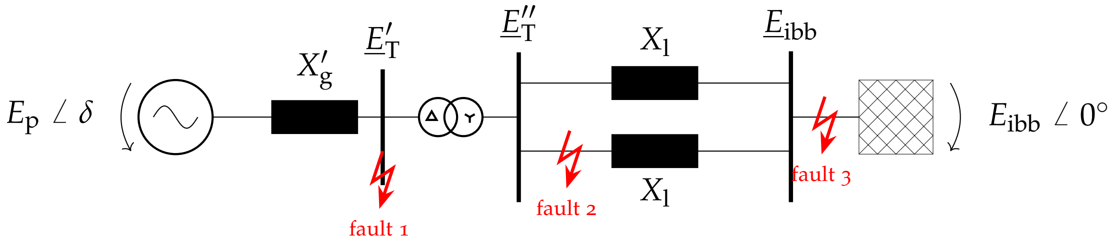

Figure 1: Representative circuit of a single machine infinite bus (SMIB) model with pole wheel voltage $E_p \angle \delta$ and infinite bus bar (IBB) voltage $E_{ibb} \angle 0°$; positions of considered faults 1 to 3 are marked with red lightning arrows

1.3 EVENTS HARMING THE SYSTEM STABILITY

The electrical energy system or network is a balance of power input (generation) and output (use). Changes and dynamics of this balance lead to system answers, which can result in a remaining stable system, or unlikely an unstable system. When specifically the generator is moving into an unstable operation, and can not stay in synchronous and stable speed with the rest of the system, it has to be disconnected from the power grid.

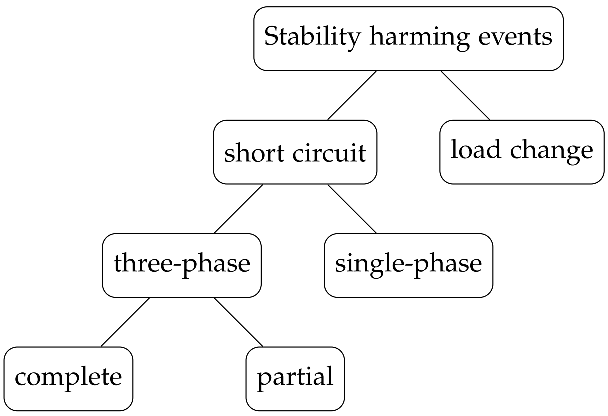

Figure 2: Overview of events harming the system stability of a power grid

Events that can harm the system stability are sketched in Figure 2. This Student research paper is interested in a three-phase short circuit, in the variants near a generator, far away of a generator and with a partial loss of a connecting overhead line.

1.4 NUMERICAL METHODS FOR TDSS AND SYSTEM MODELING

System dynamics is a method for describing, understand, and discuss complex problems in the context of system theory **[SOURCE]**. They often can be described through a set of coupled ordinary differential equations (ODEs), most resoluted in time dimension.

ODEs can be solved through numerical integration with different methods. An easy and less complex method is Euler's method. It uses a linear extrapolation to calculate the functions value at the next timestep, so following the iterable function

$$f_{t+1} = f_t + \left(\frac{df}{dt}\right)_t \cdot \Delta t, \tag{4}$$

with t being the time and f an on t dependent function. Generally a system of second order ODEs can be rewritten as two first order equations. This often simplifies the calculation or the use of numerical methods. The presented swing equation of a SG in Equation 1 and Equation 2 has been split up by that principle.

2 NUMERICAL MODELLING

Following chapter will describe the implementation of Python Code for solving the derived ODE system (see Section 1.1). For this the Python version 3.9 was used, in combination with the packages scipy, numpy, and matplotlib.[1] The complete code is included in the **??**.

2.1 STRUCTURE OF THE **cct!** ASSESSMENT

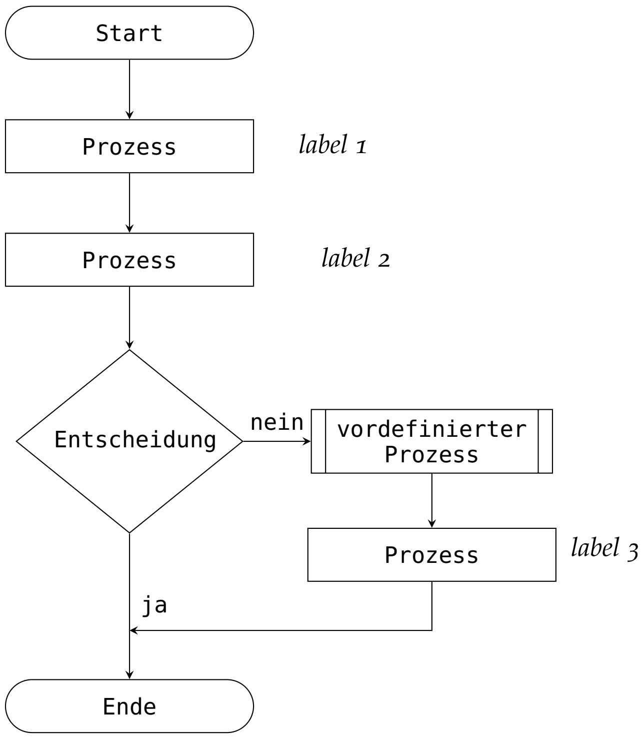

Figure 3: Program plan for determining the critical clearing time (CCT)

1 documentation and manual can be found on *https://scipy.org/* [5], similiar for *matplotlib*, and *numpy* packages

2.2 ELECTRICAL SIMPLIFICATIONS AND SCENARIO SETTING

2.2.1 *Electric networks*

2.2.2 *Initial value calculation*

2.3 IMPLEMENTATION OF THE TIME DOMAIN SOLUTION

2.4 IMPLEMENTATION OF THE EQUAL AREA CRITERION

2.5 IMPLEMENTATION OF HELPING FUNCTIONS

3 RESULTS

3.1 ANALYTICAL RESULTS

3.2 NUMERICAL RESULTS

3.3 DISCUSSION

BIBLIOGRAPHY

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[3] Jan Machowski, Zbigniew Lubosny, Janusz 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.

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[5] Pauli Virtanen et al. "SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python." In: *Nature Methods* 17.3 (Mar. 2, 2020), pp. 261–272. ISSN: 1548-7091, 1548-7105. DOI: 10.1038/s41592-019-0686-2. URL: https://www.nature.com/articles/s41592-019-0686-2 (visited on 01/13/2024).

APPENDIX

A

APPENDIX TEST

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More dummy text.

A.1 APPENDIX SECTION TEST

Test: Table 1 (This reference should have a lowercase, small caps A if the option `floatperchapter` is activated, just as in the table itself → however, this does not work at the moment.)

LABITUR BONORUM PRI NO	QUE VISTA	HUMAN
fastidii ea ius	germano	demonstratea
suscipit instructior	titulo	personas
quaestio philosophia	facto	demonstrated

Table 1: Autem usu id.

A.2 ANOTHER APPENDIX SECTION TEST

Equidem detraxit cu nam, vix eu delenit periculis. Eos ut vero constituto, no vidit propriae complectitur sea. Diceret nonummy in has, no qui eligendi recteque consetetur. Mel eu dictas suscipiantur, et sed placerat oporteat. At ipsum electram mei, ad aeque atomorum mea. There is also a useless Pascal listing below: Listing 1.

Listing 1: A floating example (`listings` manual)

```
for i:=maxint downto 0 do
begin
{ do nothing }
end;
```

DECLARATION

Put your declaration here.

Erlangen, April - September 2024

Maximilian Köhler