University of South-Eastern Norway

Faculty of Technology, Natural Sciences and Maritime Sciences, Campus Porsgrunn

FMH606 Master's Thesis

Title: Hybrid Machine Learning and Mechanistic Thermal Model of Synchronous Generator

USN supervisor: Bernt Lie, professor, co-supervisors Madhusudhan Pandey, PhD student, and Thomas Øyvang, associate professor

External partner: Skagerak Kraft (Ingunn Granstrøm)

Task background:
A thermal model of a synchronous generator was proposed in Øyvang (2018), and studied in a group project in course FM1015 Modelling of Dynamic Systems, Lie (2018). The model from Lie (2018) was further studied in a MSc thesis in 2019 (Pandey *et al*., 2019), and in a subsequent summer job (Pandey, 2019). The purpose of such a model is to allow for monitoring/control of the generator temperature, and thereby open up for relaxed constraints on the power factor in the operation of generators.

A possible extension of the model in Lie (2018), is the case of temperature dependence in heat capacity and/or heat transfer of air/water in a counter-current heat exchanger. A steady state model of a counter-current heat exchanger in general leads to a two-point boundary value problem, which can be solved numerically; numerical solution is relatively costly for on-line use. With temperature independence in heat capacity/heat transfer, it is possible to find an efficient explicit/analytic expression as in Lie (2018). When we cannot find an analytic expression, it is still possible to solve the heat exchanger problem numerically for each time step in the remaining model, but this leads to very long simulation time. To speed up the solution time, it is of interest to consider the following strategy:

- The heat exchanger model is solved many times off-line for a variety of conditions (inlet temperature of water and air, flow rates, thermal dependencies, etc.), and the results are stored in a data matrix.
- A regression model is fitted to the data leading to an explicit expression relating influent temperature of water/air to effluent temperature of water/air.
- When solving the dynamic thermal model of the generator, for each time step: instead of solving the heat exchanger model numerically as a two-point boundary value problem – which is slow, we solve it by the regression model – which is fast.
- Experience with similar problems indicate that this strategy should give several decades faster solution time.

Different types of regression models can be considered, e.g., (i) linear regression methods as in Chemometrics, and (ii) nonlinear regression methods such as in Neural Networks.

Even when extending the model from Lie (2018) with a more realistic heat exchanger model, it will not be possible to get perfect fit of the mechanistic model to available experimental data as used by Øyvang (2018) and Pandey (Pandey *et al*., 2019, Pandey, 2019). To get improved model fit, one possibility is to model the system as good as possible with a mechanistic model, and then add a dynamic regression model to describe the difference between the mechanistic model and the experimental data, see, e.g., Lie (2019). Related ideas are available in package DiffEqFlux.jl as part of the DifferentialEquations.jl package for computer language Julia.

In summary: combination of mechanistic and data-driven/empirical/machine learning models is a hot research topic. The promise is to get good model fit, with efficient model simulation. Furthermore, a mechanistic model can be built and studied without available experimental data, while a machine learning model/improved fit can only be built after experimental data become available. The results from this thesis has very wide applicability in every field of science.

The modern computer science language *Julia* has class leading differential equations solvers, optimization code, plotting facilities, and easy-to-use machine learning tools. Julia takes the best from MATLAB, Python, and R, and is free. In this project, the work should be carried out using Julia.

References:

Lie, Bernt (2018). *Group project task, course FM1015 Modelling of Dynamic Systems*. University of South-Eastern Norway.

Lie, Bernt (2019). “Surrogate and Hybrid Models for Control”. *Proceedings of SIMS 2019*, August 2019. To be published in Linköping University Electronic Press.

Øyvang, Thomas (2018). *Enhanced power capability of generator units for increased operational security*. Ph.D.-thesis, University of South-Eastern Norway.

Pandey, Madhusudhan, Øyvang, Thomas, and Lie, Bernt (2019). “State Estimation of a Thermal Model of Air-cooled Synchronous Generator”. *Proceedings of SIMS 2019*, August 2019. To be published in Linköping University Electronic Press.

Pandey, Madhusudhan (2019). Unpublished results from summer job, University of South-Eastern Norway.

Task description:
The following tasks are relevant:

1. Give an overview of a thermal model of a synchronous generator, with ideal and non-ideal heat exchanger model. Discuss how the model can be solved with a non-ideal heat exchanger sub-model by using a two-stage strategy (two-point boundary value problem to be solved for each time step in the dynamic model).
2. Develop an explicit data-driven model for the non-ideal heat exchanger model. This should be expressed as a correction expression to the ideal heat exchanger model. The correction factor will be a function of inlet temperatures, flow rates, temperature dependence of heat capacities, etc.
3. Compare the execution speed of the two-stage strategy (point 1 above), with that of the use of the data-driven model.
4. Use available experimental data, and compare the predictions from the mechanistic model with those of the experiments. Next, discuss principles of fitting an empirical/data-driven/machine learning model to describe the error in the model. In particular, discuss the needs of data to fit an empirical model.
5. If there is time, try to fit an empirical model to describe the mechanistic model deviation, and discuss the results.
6. Report the work in the Master’s Thesis, and possibly in a suitable conference/journal paper, e.g., SIMS 2020.

Student category: EPE, IIA, PT, EET (EPE students will have more appreciation of the actual model of the generator, but the ideas are valid and useful within all scientific fields).

Practical arrangements:
A working place for the candidate will be offered at University of South-Eastern Norway, Campus Porsgrunn; candidates can choose to sit elsewhere. Some information about generator data, etc. will be provided by Skagerak Kraft, e.g., in relation with the Grunnåi power plant.

Supervision:
Weekly supervision meetings are offered on Mondays (up to 1 hour per week) until Week 15, April 6, 2020; for net based students and Industry Master students, meetings can take place via Skype/Teams.

The candidate is expected to hand in partial reports every three weeks, and will receive feedback on these. The last month (after Easter), the candidate is expected to work independently. If the candidate chooses to write a paper based on the work, supervision on the paper writing will be given until early June 2020. Observe: it will not be possible to get feedback on the thesis itself from the principal supervisor after Week 15. Because of this, use the opportunity to get feedback on partial reports prior to Week 15.

Signatures:

Supervisor (date and signature):

Student (write clearly in all capitalized letters):

Student (date and signature):