Perfecting Power: A Guide to Using Control Analysis to Enhance the Capabilities of Our Electrical Grid

Max Rosenbäck and Frida Salehi

How can control analysis be employed to eliminate disturbances in an unpredictable power grid? This thesis investigates how to identify an unknown grid connected to an active dynamic filtering (ADF) system, and then how to use control to reach desirable system behaviours.

The world is experiencing a rapid change of direction. The post-industrial world focusing on fossil power sources is now becoming increasingly electrified with a movement towards renewable energies. This less predictable grid, together with power issues such as disturbances and harmonics, disrupts the electrical stability on which essential services are dependent.

An ADF system is a technology that removes unwanted voltage behaviour using a PI controller and a switching system. In the face of this grid unpredictability, how can this controller work in an optimal way? The result of this thesis is a workflow, based on control theory, consisting of methods for system identification and methods for control of a simplified ADF system. Thus, the following is a short summary of this workflow.

System Identification

In order to gain necessary knowledge about the system, the initial requirement was to reformulate the system as a mathematical model. Since very limited information of the system was known, a black box model was employed, where the important signals had to be identified. For the ADF system, these signals are the reference current, the output current, the error between the two and the control voltage. Knowing these signals, one moves on to identify the process inside the black box.

By measuring the system behaviour over a range of frequencies, an understanding of the system could be formed. With a frequency response for all important signals, the relation between the signals could be calculated, and from these relations, a transfer function could be estimated. With transfer functions between each signal, the system could be considered to be identified. Different validation techniques were applied to test the accuracy of the model and the transfer function estimations.

Control Design

The control objective of this thesis was to formulate a procedure, which constructs a controller, to reach a certain bandwidth with stable margins of the identified system. The bandwidth can be described as the frequency where the gain of the system decreases such that higher frequencies will have a limited impact. The phase margin is found at the cross-over frequency and should be as large as possible. The phase margin provides information of the amount of phase lag that a system can be subjected to before it becomes unstable.

The procedure of tuning the controller starts with choosing the proportional term of the PI controller to reach the correct bandwidth. By finding the gain of the process, $G(jf_b)$, at the wanted frequency of the bandwidth (f_b), the proportional term could be designed as $\frac{1}{|G(jf_b)|}$, which resulted in the desired bandwidth when the feedback loop was closed. This principle works if the transfer function of the process is simple before the cross-over frequency, which includes this ADF system connected to a simple grid. The integral term of the controller was placed such that the resulting corner frequency was at a suitable distance from the cross-over frequency. This term is necessary for reference tracking and for removing steady state errors, but it has a negative effect on the phase margin.

Through this procedure, the desired bandwidth was acquired as well as good margins. However, stability was not certain because of resonances in the capacitors in the electrical grid, which caused multiple cross-over frequencies. Attempts of solving this issue was made, such as adding filters to the system. These attempts were successful in the theoretical experiments, but they are considered too precise to be used in a real-life application.

Future Outlook

The results of this thesis could be applied to a real-life ADF system in the future, but first steps have to be taken to remove limitations and to adapt the workflow to more realistic environments. With this perspective, this thesis sets the foundation for a much larger project.