Get to Know Your Power

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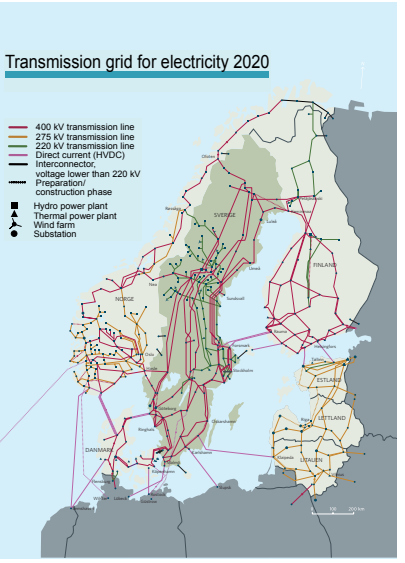
The dissertation can be downloaded from: http://www.control.lth.se/publications

Unless you have been hibernating in a remote cave, you have heard of the clean energy transition that will radically transform the generation and distribution of today's electricity around the world and in particular in Sweden. Swedish energy decision-makers and operators (e.g., Svenska Kraftnät) target carbon neutrality by the year 2040 [1]. In reality, the large rotating machines responsible for regulating the response of power generators to consumers' demand, will soon be replaced by, much smaller in size, fast-actuated, power electronics devices or inverters. They function by drawing power from a renewable energy source; e.g., solar, to provide consumers with electricity, and will be thereby responsible for maintaining waveforms at desired 50 Hz frequency and 230 V magnitude. This thesis is concerned with deriving methods to achieve the successful integration of inverters into power generation.



Sweden's transmission grid is a part of the Nordic power system.

Now, imagine that on an extremely windy morning in southern Sweden, you have just finished your shower, picked up your hairdryer, and introduced it into the wall socket. You press the 'on' button, but the device does not seem to work. Don't wonder for a long time about the cause because the answer is in front of your eyes. It is the storm that pressures the electrical system at that moment, which in turn failed to provide power. This scenario is inspired by real-life events of the blackout that spread over southern Sweden and

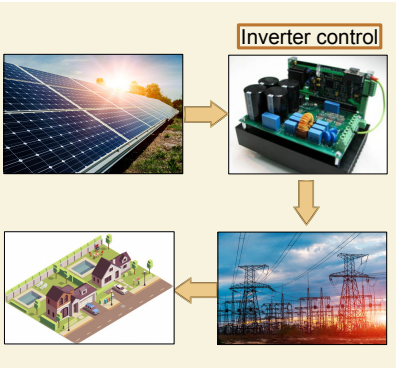
[1] [**https://www.svk.se/siteassets/om-oss/rapporter/2018**]

Denmark in September 2003, in the aftermath of a storm that hit a power line [2]. This shows how disturbances such as weather conditions can disrupt or even shut down the operation of power systems. In this thesis, we aim to develop tools to understand and counteract the effect of disturbances in power systems largely dominated by inverters.

The inverters left alone, will fail to provide any service, unless they are equipped with a *suitable* controller. Control theory is a field concerned with the mathematical explanation of dynamical systems and the adequate intervention to change their behavior to a desirable one. Our research aims to exactly find such control solutions that help accelerate the energy transition in Sweden and build resilience against disturbances such as unpredictable weather conditions. In short, the goal of our work can be summarized as follows:

Find control algorithms for inverters that are robust with respect to perturbations in power systems. They should also be responsible for maintaining frequency synchronization, i.e., all inverters' output voltages oscillate at a common frequency around nominal (50 Hz) with provable guarantees, while providing reliable power supply.

Our work lies at the intersection of topics in control theory, the backbone of our results. To reach our goal, we first propose the *matching control*, a controller that is inspired by the classical operation of power systems with rotating machines. Second, we use optimization tools, a branch of mathematics that deals with finding the best solutions that minimize a given cost, to derive *angle controllers*. All the above-mentioned controllers allow for synchronization at desired frequency and respond quickly to changes, e.g., when power demand fluctuates. We show the usefulness of these controllers in theory and simulations to help experts gain insights into control strategies for tomorrow's Nordic power system.



From renewables to consumers: the power supply goes primarily through inverter control.

[2] [**http://news.bbc.co.uk/2/hi/europe/3132332.stm**]