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# Thesis by Jef Beerten: “Modeling and Control of DC Grids” – outstanding work at the forefront of international research

- New fundamental insights into phenomena governing the stability of HVDC grids
- Tools for the assessment of future interoperability requirements
- Foundation for major developments in future transmission systems

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Jef Beerten’s doctoral thesis details his new methods for modeling high-voltage direct current (HVDC) power networks. With the increasing demands placed on the grid by renewable energy sources, long-distance transmission lines are rapidly gaining importance. HVDC promises a more efficient and cost-effective method for creating not just point-to-point links, but regional meshed HVDC grids as well. Current tools for studying power systems are however typically designed for behavior specific to AC grids. Jef has devised new methods of modeling and controlling meshed HVDC grids, which use fast-switching power electronic converters for AC-DC conversion.

**Background**

Since the early days of electrification alternating current has been the de facto worldwide standard for electrical power transmission. Much has changed since then. The energy transition to offshore windfarms and large solar parks requires moving large quantities of power across long distances. The aging AC grid in its current form cannot accommodate the necessary changes to how and where electricity is generated. The benefits of DC transmission have become apparent.

**The DC advantage**

We’re seeing a major shift in investments towards DC technology worldwide, especially for high-voltage transmission grids. HVDC links have the advantage of lower line losses and allow using longer high-voltage cable connections compared to AC. That makes long-distance, high-power lines an obvious application. Most offshore wind farms have HVDC links to the mainland, and a number of EU nations are also connected via HVDC cables, both undersea and underground.

**A tangled web?**

Existing HVDC connections are mostly point-to-point connections that consist of two terminals. Greater efficiency can be achieved with a multi-terminal or meshed DC network, much like the current AC power grid. In a meshed DC network, power could potentially reach its destination via any number of paths, a more cost-effective solution than laying a new line for each source and destination terminal. The potential for such a system can already be seen in the North Sea, where a growing number of offshore windfarms are connected to the grid via HVDC links. Eventually, a new European overlay grid is envisioned as a DC backbone to support our existing AC infrastructure.

Building a meshed HVDC grid presents numerous technical challenges. HVDC requires fast-switching power electronic converters to convert AC power to DC. These voltage source converters (VSCs) react much faster than the equipment used in AC grids. As a result, the models and theories that have been used for many years to understand AC grid behavior do not apply to meshed HVDC grids. Jef Beerten’s doctoral thesis represents an important step in modeling and analyzing meshed HVDC grids, a task of critical importance to the architects of the renewable energy future.

**Technical details of the thesis**
DC voltage control after HVDC grid contingencies such as converter outages presents a challenge to HVDC networks. First, the control is much faster than typical AC system control. Second, when the control is distributed by means of a voltage droop, it typically affects the entire system.
This thesis represents the first time that detailed steady-state and dynamic models for HVDC grids have been developed that include DC voltage droop characteristics. Interactions between the AC and DC systems have also been examined. The influence on AC grid stability of the unavoidable power balancing after a control response, for instance, has been analyzed. Furthermore, it is shown to what extent not only voltage droop settings, but also HVDC grid characteristics influence this balancing power distribution. More advanced control schemes have been developed by combining existing control methods.

As part of the project, a new open-source hybrid AC/DC power flow software package was created, and a dynamic cascaded converter control model was also designed. Various voltage droop control schemes were modeled and compared in detail — both dynamically and in steady state.

**Steady-state model for VSC meshed networks**
In the past, research on VSC HVDC technology mainly focused on two-terminal systems. All models presented in this thesis however are conceived with multi-terminal systems in mind. The power flow models presented in the thesis solve the AC and DC systems sequentially, iterating between them. Alternatively, all equations (AC & DC) can be solved at once, but this eliminates a key benefit of the sequential approach, namely, it is compatible with existing AC power flow software.

**New open-source MatACDC software package**
For the thesis, Jef developed a completely new open source software package, MatACDC. MatACDC is the first software of its kind and uses the sequential approach described above. It also extends the HVDC converter models to represent DC voltage droop control characteristics. The software has been integrated with the Matlab-based AC power flow package Matpower, making it possible to investigate the steady-state influence of DC voltage control on both the AC and DC system. In this way, meshed, interconnected AC and HVDC grids with any topology can be modeled. MatACDC lets researchers analyze droop settings and contingencies such as converter outages.

**Conclusion**
As the constructor of the world's first commercial HVDC link in 1954, ABB has a long history of innovation with high-voltage DC power transmission. Out of the 69 theses submitted to the ABB Research Award's committee, Jef Beerten's work stands out for its quality, significance, and applicability to real-world problems in the field of power and automation.