LABORATOIRE D'ELECTROTECHNIQUE ET D'ELECTRONIQUE DE PUISSANCE DE LILLE

Master thesis, 2026-2027

Study of a Synchronous Condenser for the Support of Modern Power Systems with a High Penetration of Renewable Energy Sources

Supervisors: Dr. Moez BELHAOUANE (L2EP – JUNIA) & Dr. Aymen AMMAR (Jeumont Electric)

Contacts: moez.belhaouane@univ-lille.fr — aymen.ammar@jeumontelectric.com

Context

The energy transition is accompanied by a massive integration of renewable energy sources connected to the power system through power electronic converters (wind power, photovoltaics, HVDC links, storage). In many areas, this results in a decrease of the electromechanical inertia, a reduction of the short-circuit power and an increased sensitivity to voltage stability issues, transient stability problems and poorly damped electromechanical oscillations.

In this context, synchronous condensers are attracting renewed industrial interest. These synchronous machines are dedicated to the supply of reactive power, inertia and short-circuit power, and are generally operated without any mechanical load. They provide voltage support (Q/V), an inertial contribution, a better robustness when the network exhibits a low short-circuit ratio (SCR) and an additional damping of the electromechanical oscillations.

Their optimal operation, however, requires an intelligent real-time supervision layer able to optimise the operating point of the condenser from the forecast of the network demand. It also requires robust local control strategies (AVR/excitation, PSS, thermal and current limitation, dynamic reactive power management, multi-asset coordination), validated on realistic grid scenarios, to manage the reactive power and to stabilise the transmission network under a high penetration of renewable energy sources.

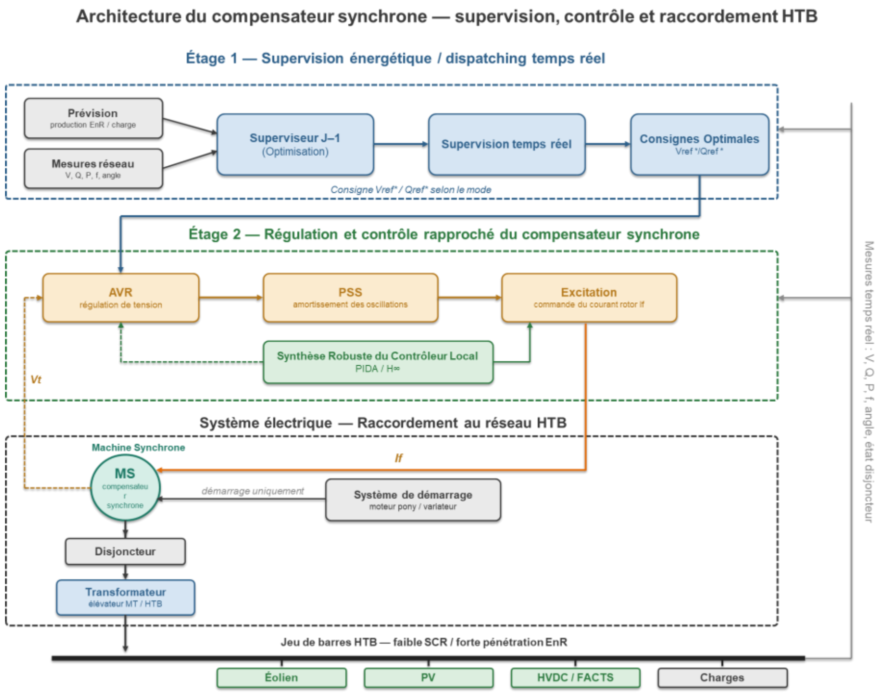

Fig. 1. *Overall architecture of the synchronous condenser: energy supervision layer (day-ahead and real-time), local control loops (AVR / PSS / excitation) and connection to the transmission network.*

Objective

The general objective of this Master thesis is to design and to validate by simulation an advanced supervision and control architecture for a synchronous condenser operated in a modern power system with a high share of renewable energy sources. The work is organised around the following specific objectives:

- An in-depth state of the art on the existing supervision and control methods for synchronous condensers;
- The modelling of a synchronous condenser together with its excitation and voltage regulation system (AVR);
- The proposal of a supervision layer relying on network data provided by Jeumont Electric or collected from the literature.

The 6-month (24-week) work programme is organised into five phases:

- **Phase 1 (weeks 1–4) – State of the art:** Role of synchronous condensers in modern power systems, AVR/PSS control and grid requirements (inertia, SCR, stability); analysis of the industrial architectures, available measurements, operating constraints and operating modes.
- **Phase 2 (weeks 5–8) – Modelling and network scenarios: (**d-q) model of the synchronous machine and of its excitation/regulation system (IEEE Std 421.5), integration into a benchmark network (HV substation, simplified equivalent grid, simplified RES/HVDC infeed) and model validation (voltage set-point steps, reactive power variations, network disturbances).
- **Phase 3 (weeks 9–16) – Intelligent supervision:** Study of the control architecture and energy management methodology, integrating day-ahead optimization with real-time supervision; preparation and processing of the required input data; and adaptation of the methodology to the synchronous condenser to determine optimal operating set-points.
- **Phase 4 (weeks 17–20) – Final validation by simulation:** Validation of the complete system equipped with both the control and the supervision layers, through a different operating condition.
- **Phase 5 (weeks 21–24) – Master thesis:** Writing of the final report and preparation of the defence.

Key words

Synchronous condenser; automatic voltage regulator (AVR); power system stabiliser (PSS); robust control; voltage stability; day-ahead supervision; real-time supervision.

References

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