**Title:** Data-driven Sensors of Power Converters for Smart Renewable Energy Applications
**Research Unit:** AMPERE
**PhD thesis supervisor:** Ass. Prof. Minh Tu PHAM
**Job location:** INSA Lyon, France


**Abstract**

Current trends in global energy production indicate that renewables will continue to increase their market share due to continuous efficiency improvements and cost reductions. Power converters constitute the interfaces that enable energy transfers in microgrids between sources, storage and loads, playing a fundamental role in their operation. These devices are required to meet particular efficiency, robustness and stability requirements to guarantee a proper operation. The thesis proposal is focused on the particular problem of state observation of power converters in order to improve control performances or to ensure the safety. Indeed, in renewable energy applications, some key variables are always difficult to measure online due to technical or economic limitations. As an effective solution, data-driven soft sensors provide stable and reliable online estimation of these variables based on historical measurements of easy-to-measure process variables. An algorithm called observer can be constructed using the mathematical model of the system in order to obtain an estimate of the true state. In our case, this problem is difficult to solve because of the nonlinearities and complex behaviors present in power converters. Furthermore, the adequate mathematical model used to represent power converters is the switched system formalism. Based on this model we would like to take elements from direct filtering technique in order to propose novel approaches to observe of switched systems specifically when continuous/discontinuous conduction modes are operated. Another approach consists in investigating deep learning as a novel training strategy. This technique has recently become a popular data-driven approach in the area of machine learning. An accurate analysis between the advantages and the drawbacks of deep learning technique and direct filtering over other traditional techniques needs to be addressed. Practical implementations on actual power converters of several renewable energy applications are expected.


**Context**

Power converters are devices that manage the transfer of power between different elements in a power system. They can modify the levels and waveforms of the voltages and currents to adapt to the application requirements, and have high efficiency and low conduction losses. These devices are present in multiple applications notably for renewable energy such as solar panel, wind turbine and energy storage systems. Advances in semiconductor technology have allowed achieving blocking voltages/conduction currents up to thousands of volts/amperes. Also, advances in converter topologies have allowed using more mature medium voltage semiconductor devices in cascaded configurations that allow them to operate at higher power levels.

In switched power converter applications, having accurate measurements of currents and voltages is an important requirement for achieving high performance in control and heath monitoring tasks. In particular, current measurement is critical in several feedback control strategies and is a good indicator for fault detection. However, accurate current measurements require special sensing circuits which in some applications may increase complexity and be cost prohibitive. Furthermore, these measurements are contaminated by switching noise. An alternative is not to measure the currents directly, but to estimate them using observers. The usual approach relies on the availability of other measurable signals (inputs and outputs), and on knowledge of a mathematical model for the system. With this information, the observer is able to make predictions on the system behavior, providing estimates of the unmeasurable signals.

The different semiconductor devices present in a power converter must be activated in a coordinated way to achieve the performance objectives defined by the application. This requires the design of accurate observers in order to design observer-based controllers that must satisfy

performance objectives such as stability, reference tracking, disturbance rejection, harmonic distortion, efficiency, response time, etc. The highly nonlinear characteristics of the semiconductor devices used in power converters increase the complexity in the design of these observers.
This thesis focuses on the development of novel approaches to the observation of power converters for renewable energy applications. Our main motivation stems from the importance of power converters in real-world applications, and from the interest in applying and testing recent theoretical advances in observation of nonlinear and switched systems.

**Key words:** Observers, direct filtering, deep learning, power converters

**Aim of the thesis and Scientific challenges**

The main objective of this thesis is to capture some of the ideas and theoretical results recently developed for switched and nonlinear systems and to extend them to solve observation problem in general for switched systems, and in particular for power converters in DC microgrid or MV/HVDC grids. The advantage of this approach is that the developed methods do not depend on the particular details of the converter topology, but are abstracted to the structure of the switched model, allowing them to be applied to different converter topologies. The objective of this thesis is to propose novel observation methods with stability guarantees, fast dynamical response, suitable for continuous/discontinuous conduction modes and practical implementation.

**Expected original contributions and research Program**

We have recently introduced a data-driven approach for the observation of switched systems. This method involves the design of a direct filter that computes worst-case bounds on the estimation error. This approach has different advantages, which are it does not require an explicit system model, it allows to represent the dynamics in the complete operating range (continuous and discontinuous mode), it provides a measure of uncertainty of the estimation, finally its structure is inherently stable (Finite Impulse Response). The work to do is to test the direct filter approach for converters with multiple inputs (for instance multicellular converter) and investigate the dependence of estimation performance on parameters. A methodic comparison of this approach with other methods has to show the benefits of this new technique. Implementation will be performed first in OPAL-RT real-time simulator, and then in power mock-up.

**Scientific supervision**
The PhD student will be supervised by Minh Tu Pham (Ass. Prof, INSA Lyon). The PhD student will benefit from the expertise of:
- Minh Tu Pham (Ass. Prof) in control engineering,
- Xuefang Lin-Shi (Professor) in electrical engineering,
- Diego Patino (Professor) in control engineering
- Gerardo Becerra (PhD, post-doc) in control engineering

**Expected Collaboration**
A part of the work will be developed with Pontificia Universidad Javeriana at Bogota in Colombia.

**Pre-requisite qualifications of the applicant**
The applicant should ideally have a background in control and its practical implementation. Knowledge in power electronics or in deep learning would be appreciated. We are looking for an

enthusiastic and autonomous student, highly motivated and interested in making connection between theoretical concepts and practical engineering problems.

**Skills developed by the successful candidate during the PhD project**

The multidisciplinary aspects of the project will allow the PhD student to develop his or her capacity for openness and synthesis. Skills in electrical systems but also in the design of modern control. Due to the theoretical and practical aspects of this proposal, the successful PhD student will be able to join research departments in both industry and academia.

**Objectives for the valorization of research work**

Submission of papers to the main international conferences and to the international journals of control and power electronics engineering. Given the strong application component of the topic, transfer activities to the community will also be targeted, via the development and distribution of turnkey solutions.

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