Master thesis proposals – academic year 2019-2020

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1. Automatic identification of the share of rotating machines (motors) behind a distribution feeder based on PMU recordings

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Context and objective of the thesis

Air conditioning devices impact negatively the power system (voltage) stability. In power systems dominated by these devices (e.g. power systems in Golf countries), it is crucial to use load models reflecting accurately the share of rotating machines (mainly induction motors) often located within distribution systems (in the low voltage part, so not directly observable). Thanks to recording devices installed in the power system, more and more measurements (U/I/P/Q) of the behavior of the system at the medium voltage level are available. Because the system is permanently subjected to small disturbances, the objective of the MSc thesis will be the identification of the share of motors based on a linearized model of the system composed by a distribution feeder and using optimization methods. For that purpose, the MSc thesis will first aim at understanding the involved electrical phenomena and their modeling based on a simple example, will then develop the identification techniques based on data obtained through simulations (without measurement noise on one hand, and with artificial addition of noise on the other hand), and will finally apply these techniques on real measurements coming from countries with a large share of air conditioning.

Requested skills
Power system modelling, application of system theory, programming skills in Matlab
2. Battery Pack State Estimation

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Context of the work

Recently, a great interest has been placed on renewable energies and electric transportation as cornerstones for the development of a sustainable future society. Both aspects require batteries to make them operationally profitable. Nevertheless, batteries are expensive and bulky since they are conservatively designed to ensure safety and longevity. Such conservatism can be avoided by using a battery-management system (BMS), which controls the battery in the most efficient way and makes it more affordable.

Figure 1 shows a battery pack representation (i.e. series/parallel arrangement of battery cells) along with its BMS. Thanks to the switches this battery pack can take different configurations or topologies. The aim of this project is to estimate the state of the battery pack (notably the state of charge of the individual cells). This will allow spotting potentially weak cells in the battery pack and disconnecting them. The challenge is to achieve this goal with a limited number of current, voltage and temperature sensors deployed throughout the battery pack.

A battery pack simulator is available in MATLAB and it will serve as a starting point for the master thesis project.

Figure 1 Battery pack comprised by series/parallel battery cells arrangement with a BMS monitoring/controlling the system.
3. Development and Implementation of an active balancing grid for battery packs built with commercial Li-ion batteries

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Rechargeable Li-ion battery packs have become popular as power sources of many devices in our lives (computers, electric vehicles, etc.). A battery pack is a series-parallel arrangement of single battery cells built in order to fulfill some desired requirements of power and output voltage. Imbalances (on voltage and state-of-charge) may appear between cells within the pack, thus decreasing the performance of the whole pack. These imbalances may appear due to manufacturing differences, temperature differences along the pack, and different aging rates of the cells.

Commercially, in order to reduce these imbalances, balancing protocols are implemented either to dissipate the excess of the energy in the overcharged cells (passive balancing) or to transfer the excess of energy from the overcharged cells to the non-charged one (active balancing). Usually, the design of the logical balancing protocols depends on the power topology of the pack without taking into account the electro-chemical phenomena occurring in each cell.

The “Service d’Automatique et d’Analyse des Systemes” (SAAS) has been developing advanced Battery Management Systems (based on constrained control techniques) in order to reduce the charging time while accounting for degradation mechanisms that may accelerate the aging of the cell. Extending these advanced BMSs for the case of a battery pack requires taking into account the balancing protocol to counteract imbalances during the charge. Instead of dissipating or transferring the excess of energy, the balance of a string of batteries can be achieved by disconnecting the risky or overcharged cells while manipulating the charging current. Therefore, a suitable setup built with commercial Li-ion cells (Fig. 1) needs to be developed in order to validate constrained charging/balancing policies aiming at avoiding degradation mechanisms. Thus, the main goal of this project is to develop an active balancing grid (Fig. 2) that can be used as a reliable setup for the development of constrained balancing techniques.
Figure 2. Proposed Balancing Grid
4. Development of low computationally cost constrained control techniques for the charge and balance of a string of commercial Li-ion batteries.

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The Service d’Automatique et d’Analyse des Systemes (SAAS) has been developing advanced Battery Management Systems or BMS (based on constrained control techniques) in order to reduce the charging time while accounting for degradation mechanisms that may accelerate the aging of the cell. The extension of these advanced BMS by including balancing can be done with a protocol able to by-pass risky or overcharged cells by manipulating electric switches and the charging current of the whole pack (Fig. 1). However, the formulation of a constrained control policy for the charge and balance in a centralized fashion yields a mixed-integer problem, which turns out to be NP-hard, i.e., difficult to solve in polynomial times. Accordingly, the main goal of the project is to develop and validate constrained techniques for the charge and balance of a string of cells, while accounting for degradation mechanisms such as side reactions and temperature limitations of the pack. In order to reduce the computational complexity, constrained techniques such as Model Predictive Control (MPC), Reference Governors (RGs), and Explicit Reference Governors (ERGs) will be tested.

![Figure 1. Proposed Charging and Balancing Strategy](image-url)
5. Force feedback and physiological motion compensation for a master-slave device with 3 degrees-of-freedom

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Context of the work

Minimally invasive surgery consists in operating through small incisions in which surgical tools as well as a camera are inserted. This approach results in interventions with less trauma for the patient, but they also make the operations of the surgeon less intuitive and comfortable. Robotized teleoperated surgery aim at alleviating these drawbacks and at increasing the dexterity of the surgeon inside the patient’s body notably. However, the main commercial master/slave device, the Da Vinci robot, does not include force feedback, which can be interesting for gestures such as suturing or needle insertion at a precise location.

A 3 degree-of-freedom master-slave device has been designed and built at SAAS. Previous works have resulted in the position control of the master robot with physiological motion compensation and in a force feedback control when the slave robot is in contact with the environment. However, the physiological motion compensation is not realistic presently because it assumes a perfect knowledge of the distance between the organ and the tool.

Work to be done

1) Small state of the art regarding teleoperated robotics for surgical applications
2) Emulation of the movement of the organ (due to the patient respiration) by controlling a 1-degree-of-freedom positioning device.
3) Development of a system for measuring the distance between the tool and the organ (probably based on optical markers and image analysis)
4) Position control of the slave robot with motion compensation based on the measurements performed in the previous step.
5) If possible, introduction and, if necessary, adaptation of the previously developed force feedback scheme in the global control strategy.

Requested skills

Good understanding of control theory, taste for experimental work, programming skills in MATLAB/SIMULINK
6. Implementation of a didactic force-feedback teleoperation palpation device for minimally invasive thoracic surgery

Supervising staff
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Context
Minimally Invasive Surgery (MIS) is the growing trend in modern operative methods. In MIS, the operated zone is not fully incised by the surgeon. The procedure takes place through small incisions where tools are inserted for the surgeon to manipulate and perform surgery on internal organs. The main advantage is the reduced trauma due to the absence of large wounds, and all benefits related to this (faster recovery, less bleeding, lesser risk of infection...). Drawbacks include all consequences of the fact that the surgeon does not have direct visual or physical contact with the patient. Force-feedback can help to recover this. This can be achieved thanks to a master/slave device equipped with adequate control laws. A specific application concerns the palpation of lungs during thoracic surgery.

The biomedical track at EPB will propose a team project as a didactic mean to teach biomedical engineering in BABl3. Students will, in this regard, use a problem-based learning to better understand major topics related to biomedical engineering. To this end, a preliminary design of a teleoperated (master/slave) device has already been performed. Such a device will be used by the students in the framework of their project, so that they can study, design and implement various constituting elements. The two major topics targeted by the project are instrumentation and system control. They are both inherently interrelated and crucial to design and implement the device. This project will therefore give to the students a global vision of the design and implementation of such a device as well as important links between instrumentation and system control, in a context that is clearly biomedical.

The preliminary design of a teleoperated (master/slave) device validates the feasibility and the concept of the project but lacks, however, many features and a proper implementation to be usable by the students.

Work
The aim of the project is to improve the design, implement a simplified version of the force-feedback teleoperated palpation device for minimally invasive thoracic surgery and to validate it from a didactic point of view.
7. Design of new didactic devices

Supervising staff

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Context:

The framework of the project is the teaching of control system theory to future engineers. The goal consists in designing new modular, evolving, and open-source solutions to provide a better, more practical learning experience to the student.

Currently, the development of the first prototype comprising an experimental setup, based on the application “ball in the tube”, as well as a Python-based software part is in progress. A portable pilot version called “take-home lab” is expected to be available at the end of the year. It will provide the student with a set of experiments that could be performed at home in parallel to the theoretical course. That version will be actively used during the teaching activities in the framework of the MATH-H-304 course.

The master thesis proposal consists in upgrading the pilot version by creating/implementing new applications (inverted pendulum, rotary beam, ball and beam, slave UAVs ...) or modifying/designing new features involving mechanical, electrical, as well as software parts. You will be integrated into a young and passionate team in charge of designing, developing and maintaining these teaching devices.

Key objectives:

- selection of the sensors/actuators
- design of the signal conditioning / acquisition stages
- design of the experimental setup (SolidWorks, 3D printer ...)
- design of the power supply & cable management
- implementation of a control strategy (Python, Arduino/C programming)
- setup of some didactic experiments & their related teaching materials

Requested skills:

- quick & autonomous learner in a dynamic environment
- team player, creativity
- basic knowledge in control theory, digital signal processing, electronics
8. Design and development of a demonstrator for a wind turbine condition monitoring system

Supervisors:

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Context

A condition monitoring system aims at early detection and localization of malfunctions within the different components of a wind turbine. An early warning allows one to perform maintenance operations in due time and during low wind periods in order to avoid production losses. Such a condition monitoring system has been under development at the SAAS. To validate this system, one uses both actual data recorded on wind farms in Europe, as well as synthetic data generated by a wind turbine simulator. For the moment it is indeed not possible to obtain well documented data for the different faulty modes, hence the need to resort to a simulator.

Objective of the master thesis

The objective is to develop a demonstration platform made of two software tools running on two PC’s interacting with each other. The first PC (PC1) should run the wind turbine simulator, where the data acquisition system available in most wind turbines (i.e. the SCADA system) will be emulated in order to generate synthetic data. Both normal and faulty operating modes will be considered. The second PC (PC2) should run the condition monitoring system able to process on-line the synthetic data and issue a diagnosis on the state of health of the different wind turbine components (sensors, actuators, etc.).
- **PC1: wind turbine simulator**
  The available wind turbine simulator runs in the MATLAB/SIMULINK environment, and it is based on the FAST software developed by the National Renewable Energy Laboratory (NREL, USA). The aim of the thesis is to introduce additional faulty scenarios in the simulator and to develop a friendly user interface for this simulator, starting from the work that has been done previously on this interface. The simulation of the data acquisition system and the communication interface with the PC2 should also be developed.

- **PC2: condition monitoring system**
  Different methods have been developed for the monitoring of individual sensors, redundant sensors, the pitch system and the global wind turbine performance. These methods have been validated independently. To complete this work, the following tasks are required:
  - the interplay between the different software modules implementing the above mentioned methods should be studied;
  - how best to group the outputs of the different modules to end up with a global diagnostic solution is also an open issue;
  - the on-line implementation has only been considered for some of the methods.

The aim of the thesis is thus to design and validate, on the basis of synthetic data and actual SCADA data, a library of easily configurable software modules suitable for the implementation of an on-line condition monitoring system. The MATLAB/SIMULINK environment will be used for the software development. The library will be exploited to design a demonstrator of wind turbine condition monitoring adapted to the wind turbine simulator.