Control of hybrid systems based heat pump and using renewable energy

1. GENERAL INFORMATION

<table>
<thead>
<tr>
<th>Call</th>
<th>2018-18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topic</td>
<td>Networks</td>
</tr>
<tr>
<td>Keywords</td>
<td>Hybrid system, Renewable energy, Energy conversion and management, Heat pump, Heat transfer, Control system, Energy building</td>
</tr>
</tbody>
</table>

2. THESIS DIRECTOR(S), RESEARCH UNITS AND DOCTORAL SCHOOLS

<table>
<thead>
<tr>
<th>Thesis director</th>
<th>Rachid OUTBIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Unit</td>
<td>Laboratoire des Sciences de l’Information et des Systèmes</td>
</tr>
<tr>
<td>Doctoral school</td>
<td>ED 184 - Mathématiques et Informatique</td>
</tr>
<tr>
<td>Thesis co-director</td>
<td>Benjamin KADOCH</td>
</tr>
<tr>
<td>Research Unit</td>
<td>Institut Universitaire des Systèmes Thermiques Industriels</td>
</tr>
<tr>
<td>Doctoral school</td>
<td>ED 353 - Sciences pour l'Ingénieur : Mécanique, Physique, Micro et Nanoélectronique</td>
</tr>
</tbody>
</table>
1. DESCRIPTION OF THE PHD THESIS PROJECT

1.1 OBJECTIVES OF THE PROJECT BASED ON THE CURRENT STATE OF THE ART

At the edge of the 21st century, in front of a strong energy demand and an increasing pollution, the energetic context has been deeply modified during the last decade. In particular, the notion of sustainable development is nowadays crucial when dealing with control of energetic systems, such as thermal buildings, industrial processes or means of transportation. The notion of comfort also takes a growing share via automation or health-related risks. Many works describing each specific field are present in the literature. Nevertheless, it is not possible to conclude on a process efficiency in a global point of view. A global system approach taking into account all simultaneous phenomena is thus necessary to get efficient and viable solutions. In Europe, the building sector accounts for about 40% of primary energy consumption. In order to fulfill energy needs (electrical and thermal), the problems of energy production and its related uses must be addressed in a systemic and interdisciplinary way.

This project is a contribution to the problem of the design of energy production systems and their operations. The energetic systems considered will be hybrid in nature and based on renewable energy. The objective of the project is then to give some useful and valuable information on future conception rules for the building thermal regulation in 2020. The built buildings will be called “passive or positive energy”, which that means they will have to produce as much energy as they consume. This target, based on an energy annual balance, may not be so challenging neither in a scientific way nor technological one. It mostly involves economic considerations. However, in an instantaneous energy flux balance, the energy consumption or production at the building level can interact quite significantly with the electrical energy network. This one is subject to unstable characteristic conditions if the levels of the fluctuating renewable energy injection exceed 30% of the total production. Consequently, the scientific and technologic challenges are mainly relative to the instantaneous management of the energy flux between the energy uses and production, connected to the electrical network.

The first main objective of this project is to determine the topology of a process for local energy production constrained by the electrical network. More precisely, the goal is to develop a methodology for choosing all the components of the system (i.e. the energy sensors, the storage systems, etc.) according to local energy potential, technological and economic constraints. The system will be supposed using a heat pump for energy conversion and will be assumed to be equipped with a control system. Hence, the second main objective is to endow the process with a relevant management system based on energy conversion in order to optimize energy fluxes when dealing with the "fundamental" uses associated with the building sector.
The aggregate data on the annual consumption of general database buildings show a ratio between 2 and 4 between the energy consumed compared to that deducted from the calculation of the 2012 building regulation. The justification for these differences depends on different criteria, the importance of which will be necessary to clarify in order to avoid such behaviors in the future building regulation.

Referred in the literature but rarely treated, the question that arises concerns the robustness of the performances of the energy conversion systems to the variability of the boundary conditions, as the energy production with the renewable energies, or as the energy uses which are dependent on the occupancy and the activity in the building. In one hand, most authors who work on energy systems as buildings use typical or predefined energy profiles. In consequence, an optimal regulation has been proposed for each specific profile. In the other hand, the qualification of the performances of the energy conversion equipment is established under standard conditions. This represents an interest in the comparison of the various equipment of the market. However, the indicated energy performance is rarely achieved under conditions of real use, with the variability in the energy resource and demand. In the equipment qualification test, the quality of the regulation is not really analyzed.

To improve the prediction of the performance of the energy conversion systems in real conditions, there is a necessity not only to have some good knowledge in the physical mechanisms of the components, but also and mostly in the physical mechanisms resulting in the couplings or interaction between the system components. The analysis of the dominant mechanisms that generate the main energy degradation will give some directions to adapt some regulation strategies to improve the performance robustness of the energy systems whatever the variable boundary conditions.

Keywords: Hybrid system, Renewable energy, Energy conversion and management, Heat pump, Heat transfer, Control system, Energy building

1.2 METHODOLOGY

The approach will be based on modeling, model reduction and global optimization techniques. The modeling development will be support by the results of the experimental setups already existents in the AMU research laboratories LSIS (Laboratoire des Sciences de l’Information et des Systèmes) and IUSTI (Institut Universitaire des Systèmes Thermiques Industriels). The control strategies will be also developed and validated on the basis of academic experiments carried out within the platforms.

The project is organized around the following steps:

1. Mapping of energy conversion systems starting from energy needs (useful energies) from a bibliographic study. This study will take into account various impact criteria.
2. From the building database of the inter-sectoral partner, analyze the origin of the building energy performance gaps between the calculation and the real operation.
3. Modeling including all physical phenomena involved in the different uses.
4. Sensitivity analysis to highlight the most influential couplings on energy efficiency considering different impact criteria.
5. Development of control and management strategies
6. Global optimization of the system to highlight specific operating points.

On this basis, it is necessary to establish alternatives of energy conversion systems to fulfill needs based on various impact criteria (Energy, environmental footprint, social impacts, economics, ...).

The experimental validation will be obtained by using a specific platform dedicated to hybrid systems based on renewable energy (see Figure 1).
1.3 WORK PLAN

**Working Tasks:**

1. Bibliography works on hybrid systems, control and management
2. Getting started with LSIS hybrid platform, basic tests
3. Implementation of thermal regulation for hot water storages in LSIS platform
4. Analysis of the building energy performance and experimental campaign for sensitivity analysis
5. Numerical modeling of the system
6. Development of the strategies for control and management
7. Optimization of the system
8. Experimental tests and analysis
9. Redaction of the manuscript

The schedule of the various tasks is presented in the following Gantt chart:

![Gantt chart](image)

Some national and international conferences are also scheduled during the thesis:

- Energy thematic: SFT 2019 and 2020
- Automatic control thematic: ACC 2019, IFAC World Congress 2020

The work will be published in international journals as Applied Energy, Energy and Buildings, etc.

1.4 SUPERVISORS AND RESEARCH GROUPS DESCRIPTION

The research in Aix-Marseille University is organized around five priority themes. This project, which fully fits one of the priority themes of the PR2I "Energies" research center at Aix-Marseille University. The two research groups are at the origin of the “OSE” working group (Optimization of Energetic Systems) of PR2I “Energies”. This working group is opened to all university researchers and its partner interested in the themes of energy systems. Through this research group the objective is twofold: to ensure a cycle of seminars on energy systems and develop activities on energy systems. The aim is to respond to problems requiring synergy between several disciplines in order to design innovative systems to satisfy the needs in terms of electrical energy (light, operation of machines, etc.) and thermal energy (heating, air conditioning and hot water).

An important part of the research activities will be dedicated to the study of hybrid systems composed of several sources of energy and will mainly concern processes with renewable energies (wind, solar panels, fuel cell, etc.). Renewable energy resources (solar, wind, geothermal, etc.) are complementary and can be used simultaneously to meet energy needs (electrical and/or thermal). Indeed, for stationary applications (housing), the energy solution of tomorrow will most likely be of a hybrid nature. That is, a system composed of several energy sources and storage systems. It is therefore necessary to develop methodologies for design and
management, to optimize energetic flows, based on multidisciplinary, under constraints that may be technical, climatic, socio-economic, etc.

The activities of both partner laboratories are now presented.

IUSTI research laboratory:
Researchers belonging to the scientific operation “Optimization of Energetic Systems” from IUSTI laboratory possess specific and complementary skills for the present project:
- Energy systems, thermal of the habitat, numerical methods and experimental set-up, ...
- Combustion, radiation and fluid turbulence, ...
- Fluid mechanics, heat and mass transfer, ...
- Acquisition systems, regulation

The different members involved are the followings: Benjamin KADOCH (associate professor) and Olivier LE METAYER (full professor).

LSIS research laboratory:
The involved team of LSIS is ESCODI. The skills of team researchers are those of the automatic control. They are interested on dynamical modeling, control and diagnosis of systems. The methodologies considered are based on non-linear analysis, feedback stabilization and observer synthesis. Energy process (namely, fuel cells, hybrid system, etc.) is one of the main considered application. The goal is to propose strategies for control, conversion and energy management.

The LSIS laboratory has a platform (see synoptic given by Figure 1) on energy management for hybrid system composed by renewable energy sources (solar panels, heat pump, PEM fuel cells, etc.). The platform will be used for validation of mathematical models, control strategies and the emulation in the context of a global system. The members involved are: Rachid OUTBIB (full professor), Philippe POULET (teacher), Mohamed ZEROUGUI (associate professor).

Figure 1: Plate-form on renewable energy developed at LSIS.
2.3 DIMENSIONS AND OTHER ASPECTS OF THE PROJECT

2.1 INTERDISCIPLINARY DIMENSION

The skills of both teams are fully complementary in the context of this project. The members involved in the project of LSIS laboratory are specialized in control, automatism, regulation and related optimization in systems. In particular, their knowledge of the electrical systems and their command are of particular importance. The researchers from IUSTI laboratory have an expertise on modeling, thermic, fluid mechanics and thermal regulation applied in energetic systems. The collaboration enables strong improvements of the skills relative to heat transfer and its storage (hot water and heating). Both teams will be able to match their regulation approaches and their respective optimization techniques.

This project fully addresses the “Network” interdisciplinary research axes. Indeed, the energetic systems considered will be hybrid with high fluctuating renewable energy production leading to the electricity network connection.

2.2 INTERSECTORAL DIMENSION:

Two external partners are involved in this project. The first partner is the association “Envirobat bdm” which brings together buildings professionals. The objectives are to enhance the knowledge, good practices and innovations in the field of sustainable construction, rehabilitation and management in the Mediterranean region. The collaboration will enable to share knowledge on the building feedback as well as databases. The link between the research laboratories and “Envirobat bdm” will improve the integration of the problems of energy uses in real conditions. The second partner is “General electric”. This partner is a global leader in the domain of energy and in particular on "Smart grid". The partner will bring to the project the important knowledge on the problematic related to the electrical energy, namely, the infrastructure, the transport and the distribution. The partners will be involved in the supervision of the PhD thesis and will participate to a series of technical meeting.

Note that the project answers to the following SRI-S3 objectives of PACA region: “Transition and energy efficiency”. One of the major objectives of the project is to increase the production part of renewable energies in the context of smart grids.

2.2 INTERNATIONAL DIMENSION:

The association "Envirobat bdm" is already involved in various European projects:

- CESBA ALPS: Deployment and evaluation of the sustainable development policies of a territory. This project brings together communities, universities, research institutes and associations from Italy, France, Germany, Slovenia and Liechtenstein
- IMPULSE: Development of an integrated management support system for the mapping of energy efficiency interventions in public buildings (better management of energy in public buildings at the transnational level). This project is based on a transnational approach which involves extensive testing in pilot cities of six countries (Greece, Spain, France, Italy, Croatia, Bosnia and Herzegovina)

Beside, The partner “General Electric” is involved in several projects related to energy around the world. Thus, the partner will bring important information about several aspects concerning the energy use in the world. This will ensure a very relevant working environment for the project team and in particular for the PHD student.

Furthermore, it should be noted that some team works are realized in collaboration with international laboratories. For instance, the PHD Theses [T1] and [T2] (see section 5.1 part A) have been co-directed with Pr. M. BASUALDO from university of Rosario (Argentina) and with Pr. R. YOUNES from University of Lebanon, respectively.
Journal papers:

Conference Proceedings Papers:
[C3] Z. Li, S. Ben Elghali and R. Outbib “Energy management for hybrid energy storage systems: a comparison of current tracking control methods” IECON, Beijing, China 2017

Book

PhD Thesis
4. EXPECTED PROFILE OF THE CANDIDATE

The candidate will have a master degree or engineer diploma in energetics with a strong knowledge in automatic control or a diploma in automatic control with a strong knowledge in energetics. He or She will have a significant interest on energy management in buildings and smart grids. The applicant should justify of a numerical background and an experience on laboratory experiments should be appreciated. The candidate must be able to work autonomously as well as in group with the perspective to animate the coordination between the different academic and intersectoral partners.

Expected skills: energetic systems, numerical methods, heat and mass transfer, thermal habitat, regulation, resolution algorithms, modelling, renewable energies, system control, automatic control

5. SUPERVISORS’ PROFILES

5.1. First Supervisor

Rachid OUTBIB (AMU/LSIS)

Short bios Prof. Rachid OUTBIB received his Ph.D. degree in applied mathematics in 1994 and his HDR in Automatics control in 1998, respectively from university of Metz and university of Amiens (France). He was full professor at the University of Technology at Belfort (France), from 2003 to 2006. Since 2007 he is full professor at Aix-Marseille University. He is a head of “Estimation Control and diagnosis” research team (40 researchers) of the laboratory LSIS. His main research interest is concerning nonlinear systems methods with applications to energy process.

A. selection of PHD thesis supervised

[T1] F. Kojok “Performance study of hybrid cooling systems for the utilization in buildings” PHD Thesis of Aix-Marseille University (2016). Duration 5 years (She was in holy during her thesis). She has a fixed position in the national company of electrical network in Lebanon.


B. Peer-reviewed publications related to those theses


C. Theses currently being supervised


5.2. Second Supervisor

Benjamin KADOCH (AMU/IUSTI)

Maître de conferences (Associate professor)
Birthdate: 19/12/1981

Short bios
Benjamin KADOCH received his Ph.D. degree in fluid mechanics in 2009 from university of Provence ("Transport and mixing in homogeneous and confined turbulent flows"). He was research assistant at Ecole Centrale Marseille in 2009-2010. He obtained a visiting professor position in USA at University of San Diego (Sept. 2010 - Dec.2010). He was a guest scientist at Technische Universität Darmstadt in Germany (Feb. - May 2011) and postdoc at university of Provence (Jul. - Aug. 2011). Since September 2011, he has been an associate professor at Aix-Marseille University.

Activities in relation with energy:
• Working group Osé
• Steering committee of the regional observatory of energy (ORECA)
• Steering committee of the interdisciplinary and intersectoral research center PR2I " Energies" of AMU

Teachings done at Polytech' Marseille, Energy and Mechanics Department, relative to the proposal:
Energy Systems Optimization, Numerical Methods, Fire simulations, Combustion, Semi-transparent media

Skills:
Numerical methods, Fluid turbulence, Transport and Mixing, Combustion, Radiation, Heat and Mass Transfer, Optimization, Signal Analysis (wavelet and Fourier analysis)

Internships supervised:
• Cristóbal Andrés Parrado Riquelme, Centro de Desarrollo Energético Antofagasta (CDEA, Chily), 2015.

6 most significant publications

13 Publications in international journal, 156 Citations, H-factor 7 (Google Jan. 2018)

Referee for Journal of Turbulence; Computers & Fluids; Experimental Thermal and Fluid Science; Physics of Plasmas
AVIS DES DIRECTEURS DES LABORATOIRES CONCERNES PAR LE PROJET DE THESE

Avis du directeur du laboratoire du directeur de thèse, OULADSINE Mustapha

☑ Favorable  ☐ Défavorable

Commentaires : Projet interdisciplinaire très intéressant. Il permettra de renforcer une thématique prioritaire de notre laboratoire

Fait à Marseille, le 22/12/17

Signature

Mustapha OULADSINE
Directeur du LSIS

Avis du directeur du laboratoire du co-directeur de thèse,

☑ Favorable  ☐ Défavorable

Commentaires :

Projet dans une thématique novatrice et très soutenue au laboratoire, à l’interface entre disciplines et aux forts enjeux sociétaux.

Fait à Marseille, le 03/01/18

Signature

Olivier Poulguen
Directeur de l’IUSTI

Olivier POULGUEN
Directeur du laboratoire IUSTI
UMR 7343
CNRS - Aix Marseille Université
POLYTECH MARSEILLE
Monsieur Romain LAFFONT
Directeur
Aix-Marseille Université
Luminy
163 Avenue de Luminy
13009 MARSEILLE

A l’attention de Monsieur Benjamin KADOCH

Marseille, le 08 janvier 2018

N°/Réf : 180102-JPS/SoD
Objet : Thèse “Control of Hybrid systems based heat pump and using renewable energy”

Cher Monsieur,

Par la présente lettre, nous vous faisons part de notre intérêt à interagir avec la thèse Control of Hybrid systems based heat pump and using renewable energy.

Notre organisme est intéressé aux études et résultats de ce travail à plusieurs titres,

• La Démarche BDM s’attache à capitaliser les retours d’expérience sur des bâtiments de la Région Provence-Alpes-Côte d’Azur (le retour en phase usage est précieux), et fait de notre association un observatoire du bâtiment reconnu ;
• En tant qu’association du bâtiment durable, nous avons un rôle de relais de l’information et du savoir sur l’optimisation des systèmes, et les avancées de ce travail seront un plus pour notre association ;
• Nous avons d’ailleurs un axe sur le partage de nos retours d’expérience, avec un poste dédié en 2018 sur ces thématiques qui pourraient interagir avec le doctorant choisi afin de lui en faire bénéficier ;
• Nous participons à l’expérimentation FlexGrid, dans laquelle les sujets d’innovation et d’énergie sont extrêmement présents et les éclairages de ce travail seront valorisés.

Pour mémoire, notre ancrage Régional et local est complété par une présence nationale et une influence reconnue auprès d’organismes de renoms tels que le Plan Bâtiment Durable, l’association Effinergie. (http://www.effinergie.org/web/index.php/association/administrateurs)
Nous participons également à 3 projets européens sur la période 2016-2019.
- CESBA-Alps  http://www.envirobatbdm.eu/club-innovation
- IMPULSE  http://www.envirobatbdm.eu/impulse

Nous vous prions d’agréer, Monsieur, l’expression de mes sentiments distingués.

Jean-Pascal SCHAEFER
Directeur
Paris, le 03/01/2018

Objet : Lettre de soutien

Monsieur,

Par la présente, nous soutenons le travail de la thèse intitulé :

"Control of hybrid systems based heat pump and using renewable energy".

Cette thèse sera effectuée à l'université d'Aix-Marseille et conjointement aux laboratoires LSIS et IUSTI.

Frédéric HELIODORE
Chief Data Scientist
GE Grid Solutions