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"Smart buildings" integrated in "smart grids": A key challenge for the energy transition by using physical models and optimization with a "human-in-the-loop" approach

Le « bâtiment intelligent » intégré dans les « réseaux intelligents » : un défi clé pour la transition énergétique. Modèles physiques et optimisation associés à une approche intégrant l'acteur humain dans la boucle

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ABSTRACT

The big challenge for the 21th century is to decrease fossil energy use and to increase renewable energies in the framework of the climate constraint. The paper will show that smart buildings, connected to smart grids, can significantly contribute to this objective. Indeed, buildings are, on one side, the biggest consumers of energy in the electrical grid and could be among the greatest producers of renewable energy, especially thanks to the concept of energy positive buildings, and this by offering at the same time high flexibility in energy demand. That is why the paper focuses on methodologies using physical models and optimization for smart design and smart supervision for valorizing those buildings energy properties and contribute thus to the emergence of the concept of smart buildings (SBs) integrated in smart grids (SGs): we will give an overview of the mathematical optimization method used and of the kind of physical models we have developed over 10 years of active research in order to propose by this way a smart software dedicated to those SBs integrated in SGs. We explain also our global research strategy for improving this smart software, by a so-called "human-in-the-loop" approach, in which we consider that they there will be no "smart building" without "smart users". This means a complex multi-disciplinary research that we develop in a "living lab", in which the inhabitants are involved as "pro'sumers", i.e. as active and implicated designers and users.

RÉSUMÉ

L'enjeu du XXI[e] siècle est de faire décroître la consommation des énergies fossiles au profit des énergies renouvelables sous la pression climatique. Ce papier montre que les bâtiments intelligents (*smart buildings*), intégrés dans des réseaux intelligents (*smart grids*),

Abbreviations: ADEME, French Agency for Environment and Energy Management; ESP, Energy Sketch Phase; ESOT, Energetic Sketch Optimization Tool; HVAC, Heating Ventilation and Air conditioning; MILP, Mixed Integer Linear Programming; PV, Photovoltaics; IOT, Internet of Things; SB, Smart Buildings; SG, Smart Grids; SQP, Sequential Quadratic Programming; STEP, "Station de transfert d'énergie par pompage"; V2H, Vehicle to Home.

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peuvent significativement contribuer à cet objectif. En effet, les bâtiments sont, d'une part, les plus grands consommateurs d'énergie dans le réseau électrique et pourraient devenir l'un des plus grands producteurs d'énergie renouvelable, en particulier grâce au concept de bâtiment à énergie positive, et ceci en offrant dans le même temps un important gisement de « flexibilité » en demande énergétique. C'est pourquoi cet article se focalise sur des méthodologies utilisant des modèles physiques et l'optimisation pour une conception et une supervision « intelligentes », afin de valoriser les propriétés énergétiques de ces bâtiments et contribuer ainsi au concept de *smart building* intégré dans des *smart grids* : nous donnerons un aperçu des méthodes mathématiques d'optimisation utilisées et des types de modèles physiques que nous avons développés au cours d'une recherche qui s'est déroulée sur plus de dix ans, de manière à proposer ainsi des approches logicielles dédiées à ces *smart buildings* intégrés à des *smart grids*. Nous détaillerons aussi notre stratégie globale de recherche pour améliorer ce type de logiciel « intelligent », par une approche dite « humain dans la boucle » (*human in the loop*), dans laquelle nous considérons qu'il n'y aura pas de « bâtiments intelligents » sans « utilisateurs intelligents ». Ceci implique une recherche interdisciplinaire complexe, que nous développons dans un *living lab* dans lequel les usagers sont impliqués comme consom'acteurs (*pro'sumers*), c'est-à-dire comme concepteurs et usagers actifs.

1. The necessity of an energy transition for the climate

Energy transition is a well-known necessity due to the climate constraints for the next century. This was the main objective of the COP21 conference.[1]

2. The smart grid as part of the solution for climate issues

Faced to this urgency of energy transition, electrical engineering aims to bring a big contribution thanks to the concept of "smart grid" (SG): SG should allow collecting and use smartly intermittent renewable energies thanks to an energy network in which the fluxes of energy will be multidirectional and massively orchestrated thanks to information and communication technologies (i.e. internet massive use)[2] [1,2]. This results in a new scheme and new architecture for the electrical network. The new specificities are a huge introduction of decentralized production, especially renewable energy, with small unities producing energy from wind and sun, like wind turbines, PV panels, small hydraulic plants… The resulting problematic of management of intermittent energy will be solved in SG by using software and communications allowing an active and smart coordination between consumption and production units.

3. "Smart buildings" as key partners of the "smart grid" for the energy transition

3.1. The concept of "smart building"

"Smart building" (SB) can be first seen as the adaptation of the SG concept at the level of the building micro-grid. The idea is to propose a multi-source, multi-load, and multi-storage system, all of it massively orchestrated by information and communication technologies. This concept should also be based on the emerging revolution of IOT and Big Data.

From an electrical and physical engineering point of view, the SB can thus be seen as an energy micro-grid connecting micro-turbines, PV panels, wind turbines, fuel cells, energy storage capabilities, electrical vehicles, global building loads…. This micro-grid should be managed by software that will use information like energy market constraints (energy price), weather forecast, and other external and internal constraints.

With no doubt, if the previous view could be the entry view as an electrical or energy engineer, we must also define what could be a SB for the building's users, in other words for the inhabitants. Fig. 1 is a proposition in which the users and inhabitants are the input and center point. They basically need and want to live in a building offering them services through equipment usage, and this under fundamental comfort requests and constraints (provided by the building envelop and the use of energy systems for heating, cooling, ventilation…).

Thus, SBs are indeed a complex system, involving of course physical law, technological systems, software, but also inhabitants as human actors. Those inhabitants need help to find the best compromise between their comfort feeling and energy consumption.

[1] http://www.cop21.gouv.fr/.

[2] See also "Technology Roadmap Smart Grids" from the AIE (Agence International of Energie) available at https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf.

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