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Model predictive control for energy and climate management of a subway station thermo-electrical microgrid

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Abstract

Electricity consumption in urban railway stations accounts for almost one third of the total energy consumption of a subway network of a city like Paris. The overall system's efficiency can be optimized by taking advantage of available sources of energy such as regenerative braking of trains or local renewable energy resources. This can be achieved by handling the intermittent nature of the various sources and consumption points and by redesigning the station energy grid in a global approach.

Microgrids have been an actively researched subject since a few years with the growing interests in smart electricity networks as a mean to decentralize the global power supply facilities. We present hereby a methodology for the optimal management of a microgrid connecting regenerative braking energy sources, eventual distributed energy resources, heating, ventilation, air conditioning (HVAC) systems, specific electricity consumptions and electricity storage systems (ESS) for energy management in subway stations. The overall energy cost is minimized adjusting in real-time electricity demand and availability using demand--response strategies while ensuring an optimal thermal comfort and a safe indoor air quality environment.

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1. Introduction

Urban railway stations consume approximately a third of the overall energy provided to railway transport infrastructures of cities like Paris. We present herein a methodology to optimize the thermal and electrical energy management in a subway station. Our methods are based on a review of the state of knowledge of subway stations energy consumption and production opportunities, a review of thermal, aeraulic and electrical modelling of subway stations as well as innovative technologies and techniques to store and manage energy.

The control, or management, strategy is based on Model Predictive Control (MPC), an online dynamic optimization method, which computes nearly optimal strategies for both power dispatch and HVAC operation impacting thermal comfort and indoor air quality. The control strategy involves a detailed thermo-electrical model representing both the behavior of the grid from an electrical point of view, the building temperature dynamics and the indoor air quality evolution. It consists in minimizing a cost function measuring the energy cost and the gap between the desired temperature and air quality at some points and the model's response. Appropriate constraints on control variables are considered in this paper. This continuous time optimization problem is solved using an adjoint-based approach and the Levenberg Marquardt algorithm which is provided and built in the energy optimization and simulation software toolbox Retrofit. It enables a fast resolution of the problem for a sufficiently large prediction horizon and a small time step between control policy generations producing a feedback mechanism addressing the microgrid uncertainty issues.

The whole methodology is applied to a test subway station. Simulation results using existing and experimental station data are provided to a priori assess the performances and reliability of the optimization, MPC scheme and of the microgrid with respect to the actual energy management strategy. We briefly introduce the experimental campaigns under way in order to highlight the experimental conditions of our tools.

2. Energy in subway stations

2.1. Energy consumption

Some measures campaigns have been conducted to understand the consumption profile of each electrical equipment in a subway station. It appears that the amount of energy required for the HVAC systems and the escalators represent an important part of the total energy consumption in various subway stations. The total daily energy consumption of a Paris subway station may vary between 1MWh and 3MWh based on these studies results.

Researchers of the European project OSIRIS (Turkay et al. 2015) noticed that a network energy consumption profile over a day is correlated with passenger traffic during operating hours. In particular there are peaks of power demand during passenger traffic peak hours. A scatter plot of electrical consumption over passenger traffic made by RATP displays a clear linear tendency. The energy contract of Paris subway stations main operator, RATP, displays two tariffs distinguished by a power threshold. Under a particular power consumption the price of electricity per unit of power is low, on the opposite when this limit is reached the tariff is high. Therefore during peak hours the operator consumes a large amount of energy that is more expensive than during off-peak hours. Lowering peak hours consumption could consequently lead to significant economic savings. Shaving peaks is often described as a major objective of smart grids. It is in fact a heuristic of judgment. It seems obvious that shaving peaks will provide economic gain but what we are looking for is the best economic gain or savings. There's an important probability that the economic optimization of the grid will lead to shaved peaks but that's not our direct objective. Letting an optimized controller generate an appropriate command law is what makes an electrical grid smarter.

2.2. Energy production opportunities

A subway station and its railway environment are not exclusively energy consumers, there exists some energy production opportunities due to its specific architecture and functions.