Towards Zero Energy Balance in Tertiary Buildings ⋆

A. Lluna I. Benítez J. Monreal I. Díaz

Energy Technological Institute, Paterna, Valencia, 46980 Spain (e-mail: andres.lluna@ite.es,ignacio.benitez@ite.es,javier.monreal@ite.es,inma.diaz@ite.es)

Abstract: The present work details the development of an integrating system of energy processes and resources within tertiary buildings, including the design of an intelligent management system that learns and predicts future scenarios and actions based on historical data. The work being done includes the development of a centralized data warehousing system, energy consumption and generation monitoring and visualization, and full SCADA and automation designs and systems integration, concerning renewable energy resources, energy consumptions and the addition of a solar energy based refrigeration system. Above all the different levels, an intelligent control development produces the adequate actions to manage all the processes based on dynamic models and prediction of scenarios and future outcomes.

Keywords: Automatic process control, Distribution automation, Communication protocols, Energy management systems, Energy monitoring, Modelling, Simulation, Intelligent control.

1. INTRODUCTION

The Energy Technological Institute (ITE) has as one of its objectives the improvement of energy efficiency at tertiary buildings, aiming to achieve a reduction in energy consumption that may lead to a zero energy balance. In this context, the following paper describes the work being developed to integrate all the energy subsystems of an offices' building (energy consumption, distributed generation, energy storage, weather conditions) under a global, intelligent management system, able to gather information from the different processes, and apply machine learning (Nilsson (1996); Bishop (2006)) and intelligent control techniques (Yu (2009)) in order to produce the necessary actions to achieve an improvement in energy consumption.

1.1 Scenario of analysis and development

The development of the systems integration and control design is being applied on the ITE offices building. There are a number of existing resources and infrastructures in the building, dealing with renewable energy resources and energy integration. These are:

- A pilot plant that implements generation from three different resources: photovoltaic (PV) panels, wind turbine and a PEM fuel cell.
- Energy storage, in the form of batteries of different technology, and supercapacitors.
- A solar-energy fired absorption machine refrigeration system, which is being implemented to aid the existing conventional heat pump of the building. This system includes a deployment of conveniently sized solar collectors, in order to provide hot water from solar energy to the absorption machine.

Within this context, the global objective is focused on studies, research and development aiming to optimize energy consumption, a fully integration of systems and management and tools to easily gather, visualize and record historical data concerning all the relevant variables of energy consumption, generation, and climate conditions. This project brings into a common specification different research areas related with energy efficiency, optimization and distributed renewable energy resources, such as domotics and comfort conditions, process control, Smart Homes (Augusto and Nugent (2006)), machine learning and artificial intelligence (Himanen (2003)), and systems engineering.

1.2 Objectives

This work follows the ITE concern with sustainability, energy efficiency, systems integration and renewable energy resources, either in tertiary or residential buildings. Specific objectives of this implementation are the following:

- Improving the energy balance of a building by optimization of energy resources, both conventional and renewable, and storage options, by improving the use of these resources, their operation, management and interaction.
- Optimal integration of all the energy systems (generation and demand) within a global framework, able to monitor all the variables and produce control actions or automate reference values generation by implementing decision algorithms based on machine learning and artificial intelligence techniques.

⋆ The development of this work has been supported by the IMPIVA (Institute of the Small and Medium-sized Industry), which is attached to the Conselleria de Industria, Comercio e Innovación (Industry, Trade and Innovation Regional Minister) of the Valencia Regional Government, and the European Regional Development Fund (ERDF) from the European Commission.

- Develop a centralized data warehousing system, to acquire, process, store and visualize data from all the processes and systems being integrated.
- Develop and integrate data mining techniques (Jackson (2002); Han and Kamber (2001)), able to describe patterns of use and discover interesting relations among generation, demand and climate conditions, and to build prediction models able to anticipate future outcomes and energy needs.
- Implementation of advanced communication protocols and networks to allow efficient data acquisition and systems control of all the processes involved.
- Development of the appropriate automation and SCADA systems to integrate and control all the processes involved in the building's energy systems.
- Efficient integration and management of distributed renewable energy resources, energy storage devices, data acquisition and systems control within a centralized management application.
- Development of dynamic models to define the behaviour of all the components and subsystems included in the design. Simulation of scenarios and design of advanced control techniques to improve energy efficiency and systems integration.
- Distributed monitoring and visualization of all the energy consumptions, generation and environmental conditions at the building.
- Implementation of domotics or home automation systems for lighting and refrigeration management.
- Integration of solar energy with the existing refrigeration installation at the building.
- Development of autonomous decision-making systems, able to analyze all the available information and make decisions that anticipate the future scenarios of energy consumption and demand, based on intelligent control techniques and the multiagent designing methodology (Ferber (1999)).

These tasks are being currently developed, grouped under three research and development areas. At a first stage, a task on modeling and simulation has been performed, with the objective to obtain dynamic models of the renewable energy resources and the solar energy refrigeration plant, in order to simulate different scenarios and provide valuable information that will help to design advanced integration and control systems.

Following, an automation task deals with the physical implementation of the following aspects:

- A distributed control system of the solar energy refrigeration plant, and its connection and interaction with the existing heat pump of the building.
- Automation and process control of the refrigeration system of the building.
- Monitoring and visualization of all the energy variables considered, such as: electric energy used, as registered by the building's meter; energy generation from all the available energy resources; energy consumption in refrigeration measured in specific meeting rooms of the building; generated solar energy from the solar collectors to feed the absorption machine system.
- Data warehousing of all the monitored data, including redundancy storage and easy accessibility.
- Integration of the mentioned systems, by design and implementation of communication protocols, centralized applications and visualization options.

Finally, a higher level of management is being studied, based on artificial intelligence, with the objective to design an intelligent control system, able to produce its own decisions in order to improve energy efficiency and integration, assuring the comfort margin.

These steps of design and development are described in the following sections.

2. SYSTEMS MODELLING AND SIMULATION

The objective of modelling and simulation is focused on the following issues:

- Modelling and simulation of the available renewable energy resources (PV panels, wind turbine and PEM fuel cell).
- Modelling and simulation of the refrigeration system based on solar energy and absorption machine.
- Modelling the systems integration of building's heat pump and solar energy refrigeration system.

The two first items are described next, whilst the third is still in its initial stage.

2.1 Modeling and simulation of renewable energy resources

In the context of the integration of distributed renewable energies, the ITE has set an experimental plant for electrical energy production and supply, which implements PV modules with a total of 7.5 kWe (2.5 kWe per phase), a wind turbine of 6 kWe, a 4 kWe PEM Fuel cell, a 6 kWe Electrolyzer, and a meteorological station, that collects the values of different weather variables. A research has been done to analyze the relation among the different combinations of weather conditions and the resulting outcome of electrical energy production from the PV modules and wind turbine.

The methodology applied makes use of multilayer Artificial Neural Networks (ANN) (Haykin (1994)) to build prediction models of electrical energy production, as a function of the climate conditions. The input and output variables chosen for the models have been selected based on a correlation analysis. The ANNs have been trained and validated making use of monitored data of production and weather conditions, through the years 2007 and 2008. Figure 1 displays, for instance, predicted values of active power generated by the PV panels, as a function of ambient temperature and solar irradiance.

The PEM fuel cell has been modeled making use of recursive ARMAX models, with the structure written in 1. The data to train and validate the model has been extracted from different experiments made through the year 2008, varying initial conditions and load values. Figure 2 displays the training process of a model of power generation from the cell.

$$A(q)y(t) = \sum_{i=1}^{n_u} B_i(q)u_i(t - n_k i) + C(q)e(t) \qquad (1)$$