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Electrical consumption forecasting in hospital facilities: An application case

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ABSTRACT

The topic of energy efficiency applied to buildings represents one of the key aspects in today's international energy policies. Emissions reduction and the achievement of the targets set by the Kyoto Protocol are becoming a fundamental concern in the work of engineers and technicians operating in the energy management field. Optimal energy management practices need to deal with uncertainties in generation and demand, hence the development of reliable forecasting methods is an important priority area of research in electric energy systems. This paper presents a load forecasting model and the way it was applied to a real case study, to forecast the electrical consumption of the Cellini medical clinic of Turin. The model can be easily integrated into a Building Management System or into a real time monitoring system. The load forecasting is performed through the implementation of an artificial neural network (ANN). The proposed multi-layer perceptron ANN, based on a back propagation training algorithm, is able to take as inputs: loads, data concerning the type of day (e.g. weekday/holiday), time of the day and weather data. In particular, this work focuses on providing a detailed analysis and an innovative formal procedure for the selection of all the ANN parameters.

1. Introduction

Large buildings certainly represent some of the great consumers of electric energy. It is estimated that worldwide energy demand of buildings reaches about 32% of total energy consumption. In Europe the buildings are responsible for 36% of CO_2 emissions [1]. The need to achieve Europe's 2020 energy targets, i.e. 20% improvement in the EU's energy efficiency and 20% reduction in EU greenhouse gas emissions from 1990 levels [2], together with the need to ensure operational goals with the minimum energy cost and environmental impact have contributed to the interest growth towards the Building Management Systems (BMS). These systems can contribute to achieving energy and thus cost savings [3,4].

Load forecasting can be a useful function of a generic BMS, as well as representing a common problem and a key factor in electrical distribution systems. Several studies have been developed about short-term load forecasting [5–7], often using statistical models [8,9], regression methods [10], state-space methods [11], evolutionary programming [12], fuzzy systems [13] and artificial neural networks (ANN) [14–16]. Among these algorithms, ANN has received more attention because of its clear model, ease of implementation and good performance.

Load forecasting can provide vital information, for energy evaluation within a single utility and for efficiency purposes, particularly when medium and low voltage energy distribution systems are considered. Load forecasting is also advantageous for system economics. In fact, it can provide valuable information to detect in advance opportunities and risks. The new energy market and the smart grid paradigm ask for both better load management policies and for more reliable forecasts from single end-users, up to system scale. The necessity of coordinating uncertain renewable generation with actual demand is becoming more and more important [17].

Load forecasting with lead-times from a few minutes to several days is an essential tool to properly manage Buildings and facilities. The correct forecast of the interchange between the site and the main grid is a key issue for the new paradigm of Smart Grid Management since a correct forecast will lead to control unbalance on the network. This may be of great importance in micro-grid configurations, largely expected in future power systems.

Moreover, if the work environment is a hospital facility, where a continuous energy and electricity utilization is required, all the aspects previously listed are amplified and of a greater importance, due to continuous use of technological loads.

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A hospital can be defined as a highly complex organization under a functional, technological, economic, managerial and procedural standpoint. A modern hospital can be compared to an industrial plant for the multiplicity and the type of its functions, and tasks. The electric energy is the essential element for the operation of a hospital facility, so it must be measured and managed both under the technical and economic aspects. In recent years the problems related to electrical energy consumption have achieved considerable importance. The procurement and proper use of electric energy are crucial steps for any complex structure wanting to reach an optimal level of energy management.

This work proposes a day-ahead load forecasting procedure. The load forecasting has been performed through the implementation of an ANN and has been tested to predict the electrical consumption of the “Cellini” clinic of Turin, which is a multi-specialist hospital facility, part of the “Humanitas Mirasole” group. This type of approach has been chosen because it does not require a physical-mathematical model, representing the power consumption of the examined facility.

In particular, the focus of this work is to provide a detailed analysis and an innovative formal procedure for the selection of all the relevant ANN parameters (architecture type, inputs, transfer functions, training algorithm, neurons number) for modeling and predicting electrical loads in buildings. Electrical load forecasting is an essential component for a better dynamic management of thermal behavior of buildings (HVAC-Heat Ventilation and Air Conditioning) for energy saving policy.

The present paper is organized as follow: Section 2 describes the hospital facility, Section 3 collects the information about the exploited dataset, Section 4 illustrates the ANN architecture and the selection procedure of the: inputs, transfer functions, training algorithm, neurons number. Section 5 presents the results of the simulations and finally Section 6 presents the conclusions and the possible future developments of the work.

2. Case study description

The Cellini clinic started its service in 1903 and received the accreditation by the National Health Service in 2003, as a result of a structural and plant expansion. This has allowed the Cellini clinic to double its space, enhancing the quality of its services with high technological and architectural standards.

The activities and the services offered by the Cellini clinic are considerable, given its structural and organizational size. During the year 2011 the clinic has performed 9698 hospital admissions according to the data of the National Health Agency, with a daily average of 27 recoveries. The clinic is spread over a total area of 9500 squares meters and is divided into 3 main blocks named A, B and C (see Fig. 1).

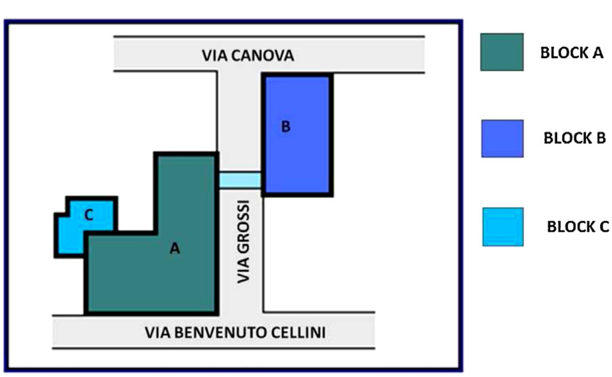

Fig. 1. Cellini clinic buildings.

The supply of electrical energy takes place through a medium voltage (15 kV) Point of Delivery (PoD).

This PoD feeds two medium voltage/low voltage substations, named Station A and Station B, which present respectively one and two 630 kVA transformers. Station A supplies the block A of the Cellini clinic, while Station B feeds buildings B and C. Station A and Station B feed all the hospital equipment at low voltage. The whole clinic presents a yearly electric energy consumption of nearly 3 million kWh.

3. Dataset

Station A and Station B feed, through the transformers, all the hospital equipment at low voltage with an electric energy consumption of nearly 3 million kWh per year.

In order to accurately evaluate the load absorption of the Cellini clinic, the electrical energy consumption data, measured every 15 min, was gathered from the local distribution system operator. The collected data refer to the year 2012 and amounts to 266,2325 kWh, as shown in Table 1.

From the available dataset it is possible to notice that the energy consumption in summer is 30% higher than in winter due to the presence of air conditioning. This is because the effect of the air conditioning is absent in the winter months. The winter load peaks are among 450 kW and 480 kW, while in the summer peaks are included between 600 kW and 650 kW.

The dataset also contains information about the outside ambient temperature, whose linear correlation with electrical consumption is shown in Table 2 [18]. In this case the two vectors are composed of the daily electrical energy consumption and the minimum/maximum temperature of the day.

At the beginning of this study also the humidity has been considered, but in the final dataset composition it has been excluded for the low correlation with the load (see Table 3, where the correlation has been evaluated as in the temperature case).

For the considered dataset, the forecasting experiment has been carried out by partitioning the population of data into two subsets: training set and test set. The training set was used to train a knowledge database for the ANN and consists of an input vector and a score vector. The Test set was used to assess the strength and effectiveness of the predictive relationship and to calculate the forecasting error in terms of *Mean Absolute Percentage Error (MAPE)*,

Table 1
Electrical consumption related to year 2012.

	Total Electrical Consumption (kWh)	*Parametrized Electrical Consumption (kWh/m^2)*
2012	2662325	131.06

Table 2
Correlation values between electrical consumption and minimum and maximum temperature.

	Minimum Temperature	*Maximum Temperature*
Correlation Year 2012	0.72	0.70
Correlation Summer 2012	0.45	0.41
Correlation Winter 2012	0.43	0.32

Table 3
Correlation values between electrical consumption and minimum and maximum humidity.

	Minimum Humidity	*Maximum Humidity*
Correlation Year 2012	0.10	0.12
Correlation Summer 2012	0.03	0.04
Correlation Winter 2012	0.02	0.03