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Energy rating of a water pumping station using multivariate analysis

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Abstract

Among water management policies, the preservation and the saving of energy demand in water supply and treatment systems play key roles. When focusing on energy, the customary metric to determine the performance of water supply systems is linked to the definition of component-based energy indicators. This approach is unfit to account for interactions occurring among system elements or between the system and its environment. On the other hand, the development of information technology has led to the availability of increasing large amount of data, typically gathered from distributed sensor networks in so-called smart grids. In this context, data intensive methodologies address the possibility of using complex network modeling approaches, and advocate the issues related to the interpretation and analysis of large amount of data produced by smart sensor networks.
In this perspective, the present work aims to use data intensive techniques in the energy analysis of a water management network. The purpose is to provide new metrics for the energy rating of the system and to be able to provide insights into the dynamics of its operations. The study applies neural network as a tool to predict energy demand, when using flowrate and vibration data as predictor variables.

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Keywords: water supply system; energy rating; energy efficiency; neural network

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1. Introduction

Water is a fundamental element for life but its scarcity is caused by a number of factors such as climate change, population growth, urbanization, agricultural and industrial activities. Global water withdrawals are projected to increase by 55% through 2050 due to growing demands from manufacturing (400%), thermal electricity generation (140%) and domestic use (130%). In addition, there is clear evidence that groundwater supplies are diminishing, with an estimated 20% of the world's aquifers [1]. Energy is required for two components of water provision: pumping and treatment (before and after use). In these applications, electricity costs are estimated to be responsible of a share ranging from 5% to 30% of the total operating cost of water and wastewater utilities, but in some developing countries such as India and Bangladesh, it is as high as 40% of the total operating cost [1]. It is therefore of the utmost importance to address the sustainability of water cycle from the viewpoint of both an efficient use of the resource, and the maintenance of high quality service standards. In this respect, water infrastructures require a profound transformation in terms of withdrawal, resilience and reliability.

The Water Supply System (WSS) consists of a series of operations based on the distribution of drinkable or treated water to end-users, as well as the collection and treatment of wastewater and their restitution into the environment.

In parallel to the preservation of water resources, the reduction of the energy flows involved in the process has to be taken into account also, by promoting the proper management of the energy use in the various operations required to guarantee the service. Water and energy flows represent the main resources involved in the WSS and as such they have to be preserved through sound management.

Specific Energy Performance Indicators (EnPI) have been defined for WSSs [2-4], most of them proposed by the International Water Association (IWA) [5]. In this number, customarily used metrics are the pumping capacity utilization, normalized energy demand, reactive energy demand and energy recovery [5].

In the energy rating of WSS issues can be correlated to: i) the correct selection of EnPI to account for the dependence from the observed (and monitored) process, and ii) the impossibility to describe the system dynamics using a single energy indicator at component of system levels [6, 7].

The energy behavior of WSS depends upon a large number of variables, even external to the process itself [8, 9] (e.g. amount of water source, seasonality, rainfall, and other environmental parameters). A simple indicator is not able to catch all these dependences. The analysis of these interconnections allows to achieve full understanding of the energy behavior; for this reason data intensive techniques prove to be a valuable tool.

Data intensive techniques consist of several disciplines, including statistics, data mining, machine learning, neural networks, social network analysis, signal processing, pattern recognition, optimization methods and visualization approaches. There are many specific techniques in these disciplines, and they overlap with each other [10]. Among these, Artificial Neural Network (ANN) has wide range of application coverage: pattern recognition, image analysis, adaptive control, and other areas. Research on neural-network-based control systems has received a significant consideration over the years. Many methods have been developed and successfully applied to real industrial processes [11, 12].

A neural network based control architecture is used to estimate the behavior of unknown nonlinear systems and the controller is then formulated using the estimation results. The estimation uses the measured inputs, the formulation of the control signal is then determined from the neural-network model, which approximates the system which is nonlinear with respect to its input arguments [13]. In particular, in many engineering problems, such as process controllers employing model predictive algorithms, it is essential that at any given time the process outputs will be predicted many time-steps into the future without the availability of output measurements in the horizon of interest. For this reason, in forecasting and in fault monitoring and diagnosis applications, the availability of accurate empirical models with multi-step-ahead (MS) predictive aptitudes are desirable [14, 15].

Among predictor design based on nonlinear model structures, Nonlinear Auto Regressive models with eXogenous input (NARX model) has proven to be successful in many applications [16], and more recently, has been proposed and extensively used in the identification and control of dynamic systems [17, 18].

This paper aims to define and apply new metrics for the energy rating of a water supply system. These metrics are defined employing data intensive tools, specifically the NARX neural network. NARX performs the forecasting of the energy demand providing a model for the energy behavior of the system. The deviation of the energy demand