



Recognition of the importance of using artificial neural networks and genetic algorithms to optimize chiller operation

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ARTICLE INFO

Article history:

Received 31 October 2011

Accepted 4 January 2012

Keywords:

Genetic algorithm

Chiller

Optimization

Control

ABSTRACT

This paper presents the optimization of chillers operating using artificial neural networks and genetic algorithms. For the needs of generating chiller models, an artificial neural network was used, trained with data collected from an actual chiller. For that purpose the basic characteristics of artificial neural networks are shown as well as the process of making specific chiller models used for testing the results of application of the genetic algorithm in usage optimization. The optimal criteria with the shown steps for the use of the genetic algorithm and optimization results is also displayed in the paper. The results of use of artificial intelligence methods in optimization of chiller operation are verified through an actual office building model created in the simulation software EnergyPlus and through a series of experiments on an actual office building, equipped with a modern integrated BMS.

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1. Introduction

Growing environmental and energy problems impose a number of challenges concerning the conservation of renewable and nonrenewable energy reserves. Imbalance between energy consumption, particularly fossil fuels, and their available quantities as well as excessive emissions of carbon dioxide into the atmosphere are the two dominant problems our civilization is facing. This paper aims to contribute to the only viable approach in solving the problem of excessive energy consumption and pollution, which is through savings and optimization.

Chillers belong to the group of the biggest energy consumers in modern business–residential objects and represent a real challenge when it comes to creating a comfortable and productive work environment while rationalizing energy consumption. A large number of authors have presented different methods of chiller optimization in their scientific papers, such as: Afonso [1], Yu and Chan [2,3] through the optimization of systems with multiple chillers, Calm [4] and Ma et al. using PMES methods and genetic algorithms [5].

The aim of this part of the paper is to check, on a specific example, how much can the optimal management help reduce electricity consumption during the operation of the system and what are the financial savings achieved through this.

The necessary condition for the development of optimal control is an appropriate model of the entire process on which the optimization algorithm is later applied. To form the system model, in this paper, an artificial neural network is used, while the optimization algorithm used is a genetic algorithm.

The artificial neural network and genetic algorithm are a very suitable choice in solving chiller optimization problems, because

the network is able to model complex nonlinear systems like the observed chillers and the genetic algorithm can find a global optimum [6]. Neural network is imposed as a logical choice, considering the chiller model was unknown and a large amount of data necessary for network training was available, thanks to an integrated central system for monitoring and control, which offered the possibility of generating a system model [7,8].

2. Chiller model identification using the artificial neural networks

Today, the neural networks are used for solving a growing number of daily problems with significant complexity as in the case of modeling chillers.

The basic and most important condition for good optimization is a good system model, which requires, particularly, a good representation of the available data.

The data used for network training includes the information gathered thanks to the integrated central system for monitoring and control of the building whose chiller was used in this research. Of the numerous data collected for the neural network training, the following data was used: external temperature, the temperature of the refrigerant which is returned from the building (return temperature), the temperature of the refrigerant which is coming out of a chiller (outlet temperature), as well as the condition of each chiller compressor.

In accordance with the plan optimization, according to which the optimal refrigerant outlet temperature should be determined and consumption be kept on a minimal possible value, all three pre-specified temperatures are selected for the input parameters in

Table 2.1

The Artificial neural networks of different architectures with the corresponding mean-square error.

Network architecture	Number of epochs	Mean-square error in training	Mean-square error in testing
3-2-4	1895	0.323745	0.3245
3-3-4	6818	0.162302	0.1387
3-4-4	6561	0.15976	0.1212
3-5-4	7075	0.141003	0.1374
3-4-5-4	4825	0.140219	0.1427

Bold values represent the adopted architecture of the artificial neural network.

artificial neural network training, and compressor statuses as the output, because in that way the output receives the information about the consumption, which will then be minimized, by use of a genetic algorithm and thus the given task will be solved.

The parameters for the training of an artificial neural network:

Input parameters:

- outlet temperature;
- return temperature;
- external temperature.

Output parameters:

- the status of compressor1;
- the status of compressor2;
- the status of compressor3;
- the status of compressor4.

The real time system operation data was used for the training, so that the artificial neural network was able to recognize the link between the data and, based on the input values, predict the output. 1842 measures were performed, so that for the training purposes 1842 different combinations of input and output values were used.

There are no exact rules by which a training algorithm should be selected, a number of hidden layers or a number of neurons within them, so, by using an experimental way, the network that offers the best results, minimal errors, was found. The Table 2.1 displays the experimental results of the artificial neural networks with the corresponding values of a mean-square error.

The adopted network structure has three neurons in the input layer, four neurons in the hidden layer and another four neurons in the output layer. This network is adopted as a chiller model on which, in the next work phase, a genetic algorithm is applied. Backpropagation algorithm is selected for training. The activation functions for input and output layers are linear and for the hidden layer the tangent-hyperbolic function is chosen, which represents a special form of a sigmoid function, shifted to the output values covering the interval $[-1,1]$. A mean-square error is selected as a measure for the evaluation of the error and its value is 0.15976. The Fig. 2.1 displays the comparative response of the real chiller and its neural model.

3. The optimal criteria

A Chiller has a large number of parameters, by controlling which work optimization and minimization of total costs can be achieved. In the past, most researches were based on work optimization of individual components of the chiller systems and there is little information regarding the global optimization of the entire system [9,10]. There are numerous studies which emphasize the advantage of optimizing the entire system in relation to the optimization of individual components [11]. When optimization is related to the entire system there is an interaction between chiller components, building needs and the necessary size. After implementation of the system with the optimal control, minimizing the total costs can be easily achieved thanks to the aforementioned interaction [12].

In contrast to that, the control of individual components is based on a local feedback and there are much fewer possibilities and flexibility when it comes to minimizing the same costs, because there is no controller which will gather all the necessary information,

respectively there is no interaction between system components, nor between the system and building.

The aim of this research is achieving minimal electricity consumption during the operation of system. The best way to realize the desired goal is finding the optimal temperature of the output refrigerant from the chiller, which would enable the maintenance of desired values of ambient temperature in the entire building.

The main goal of optimization in this research is, as stated earlier, achieving of minimal electricity consumption. Since the consumption is directly proportional to the work time of the compressor and the number of active compressors is defined by the temperature, to which the refrigerant that is coming out of the chiller should be cooled, it is clear that by finding the optimal values of the outlet temperature the number of active compressors in a certain moment will also be optimized. In that way the waste of energy will be prevented and significant financial savings will be achieved.

The genetic algorithm has the task of generating a set of optimal outlet temperatures for the specified temperatures of the refrigerant which is returned from the building and the external temperature.

All three temperatures are presented by a 21 element vector, considering that the period of system observation is 10 h and the sampling period is 30 min.

For successful operation of the genetic algorithm, a “well” defined optimal criteria is needed, where the word “well” implies the accurate identification and true display of the problem, for which the minimal value will be sought.

The optimal criteria, the objective function, gives a quantitative measure of usefulness and the validity of the proposed solution. The objective function receives a set of parameters and returns a measure of its usefulness – which can be efficiency, price etc.

In the case of chillers, the objective function usually refers to the minimization of energy consumption, as is the situation in this research, so the objective function is:

$$F = \sum P_i, \quad i = 1, 2, 3, 4, \dots, 21 \quad (3.1)$$

where P_i is the consumption of electricity in 30 min.

The period of system observation is from 7 to 17 h, which corresponds to the observed work time of an office building, while the values of all parameters were read every half an hour. The values attained in the corresponding time period of every half an hour make up the 21 elements of the objective function.

The observed chiller, modeled in operation, has four compressors, which are not frequently controlled, so they can be exclusively in on or off state. Depending on the need for cooling refrigerant, chiller compressors are turned on according to the next schedule: no compressor is turned on, two compressors are turned on, while two are off and all four compressors are turned on. Considering that the power of the compressor is 24 kW and the modeling time period observed is half an hour, there are only three values for the consumption of P within 30 min and they are: 0, 24 and 48 kW, which correspond to the state when no compressor is turned on, two compressors are turned on and all four compressors are turned on, respectively.

3.1. The basic steps in operation of the genetic algorithm

After generating the system model and defining the optimal criteria, the next step is to access the optimization of the problem by use of genetic algorithm. The operation of the genetic algorithm comes down to the application of genetic operators to

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