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ANN modeling of water consumption in the lead-acid batteries

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Abstract

Due to importance of the quantity of water loss in the life cycle of lead-acid batteries, water consumption tests were performed on 72 lead-acid batteries with low antimony grid alloy at different charge voltages and temperatures. Weight loss of batteries was measured during a period of 10 days. The behavior of batteries in different charge voltages and temperatures were modeled by artificial neural networks (ANNs) using MATLAB 7 media. Four temperatures were used in the training set, out of which three were used in prediction set and one in validation set. The network was trained by training and prediction data sets, and then was used for predicting water consumption in all three temperatures of prediction set. Finally, the network obtained was verified while being used in predicting water loss in defined temperatures of validation set. To achieve a better evaluation of the model ability, three models with different validation temperatures were used (model 1 = 50 °C, model 2 = 60 °C and model 3 = 70 °C). There was a good agreement between predicted and experimental results at prediction and validation sets for all the models.

Mean prediction errors in modeling charge voltage–temperature–time behavior in the water consumption quantity for models 1–3 were below 0.99%, 0.03%, and 0.76%, respectively. The model can be simply used by inexpert operators working in lead-acid battery industry.

Keywords: Water consumption; Artificial neural network; Model; Lead-acid batteries

1. Introduction

The two most common types of batteries widely used today are the sealed or maintenance-free lead–calcium battery and the low maintenance lead–antimony battery. The calcium or sealed battery uses less water and does not corrode nearly as much as the lead–antimony battery does. The lead–antimony battery (which mostly includes deep cycle batteries and batteries that have removable caps for adding water to battery cells) withstands continuous charge/discharge cycles and generally accepts charges more readily than a calcium battery. External corrosion problems associated with the sulfuric acid fumes being carried out of the battery by an extensive gas evolution due to electrolysis during charging [1].

To achieve long battery life, the lead–antimony battery requires frequent water additions to maintain proper electrolyte levels and the corrosion must be regularly removed from posts, cables, hold downs and battery trays.

Calcium is a mineral and antimony is a metal. The more antimony in the battery, the deeper discharge. However, the more antimony in a battery, the more gassing, corrosion and water consumption will be.

Some of the main reasons why batteries do not get full life cycles are corrosion, sulfation and water consumption [2–8]. The water level should never go beyond top border of plates and because of the presence of ingredients such as iron, chlorine etc. available in tap water always distilled water should be added and not tap water. If one battery is rated at a100 min reserve capacity and the plates in battery are 10 in. tall and water level gets 1 in. below the plate, this part of the plate will now dry out and becomes hard and at least 10% of batteries capacity just is lost while if water level gets 2 in. below the plate, at least 20% is lost. As a battery ages or gets older, it will lose some parts associated with charge acceptance and so it will use more water

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and thus it should be checked more frequently. Reduced charge acceptance is attributed to some different phenomena such as sulfation, passivation and other processes can also make some part of negative or positive paste inactive, so that at constant amount of charge coulombs, in old battery, more amount of electricity should be used for the electrolysis of water to realize the gas. But, at test time, there is not considerable change at amount of charge acceptance so; we do not attach a lot of importance to it in this model.

Because of the importance of water consumption especially in the antimony–lead-acid batteries and the necessity for its periodic determination and also long time spent on doing current available tests, we decided to use a model for calculating the amount of water loss in these batteries.

Being based on artificial neural network, this model can easily help the laboratory operator to control the water consumption at any time.

The basic units of neural networks, the artificial neurons, simulate the four basic functions of natural neurons. Various inputs to the network are represented by the mathematical symbol, $x(n)$. Each of these inputs is multiplied by a connection weight. These weights are represented by $w(n)$. In the simplest case, these products are simply summed, fed through a transfer function to generate a result, and then output. This process lends itself to physical implementation on a large scale and in a small package. This electronic implementation is still possible with other network structures which utilize different summing functions as well as different transfer functions. In currently available software packages these artificial neurons are called “processing elements” and have many more capabilities than the simple artificial neuron described above. Inputs enter into the processing element from the upper left. The first step is for each of these inputs to be multiplied by their respective weighting factor ($w(n)$). Then these modified inputs are fed into the summing function, which usually just sums these products. The output of the summing function is then sent into a transfer function. This function then turns this number into a real output via some algorithm. It is an algorithm that takes the input and turns it into a number like as 0, 1, −1 or some other. The transfer functions that are commonly supported are sigmoid, sine, hyperbolic tangent, etc. This transfer function can also scale the output or control its value via thresholds. The result of the transfer function is usually the direct output of the processing element. Finally, the processing element is ready to output the result of its transfer function. This output is then input into other processing elements, or to an outside connection, as dictated by the structure of the network.

Basically, all artificial neural networks have a similar structure or topology as shown in Fig. 1. In this structure, some of the neurons interface to the real world to receive its inputs. Other neurons provide the real world with the network’s outputs. This output might be the particular character that the network thinks it has scanned or the particular image it thinks is being viewed. All the rest of the neurons are hidden from view [9].

There are many reports describing various attempts for utilizing various computational approaches to estimate the state of charge (SOC), cold cranking ability (CCA) and impedance modeling of intermediate size lead-acid batteries [10–19]. In lead-acid batteries, water consumption is the most important process. Some processes including charge, overcharge and evaporation can reduce water content of the battery. It should be mentioned that water loss is one of the major processes which cause battery failure [4]. Therefore, simulation and modeling of water consumption in lead-acid batteries will be important and very interesting. However, to the best of our knowledge, no attempts has been made to model water consumption in lead-acid batteries.

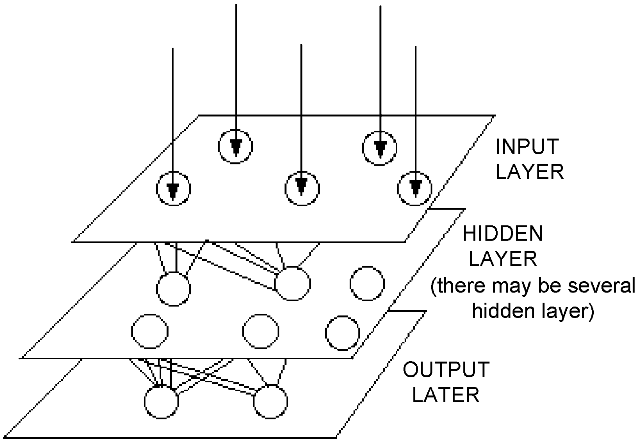

Fig. 1. A simple neural network diagram.

In this paper, the water consumption computation model based on artificial neural network (ANN) for lead-acid batteries is introduced for the first time. The result of experiments proved further improvement of accuracy with the proposed model. Computation values are in good agreement with experimental data.

2. Experimental

2.1. Reagents and materials

All materials and reagents used in these experiments were industrial grade and all of them were obtained from Iranian companies. All lead-acid batteries 50 Ah used in the study were produced by Sepahan Battery Industrial Complex (Isfahan, Iran).

2.2. Instrumental

Provision of low temperature (0 °C) was carried out by industrial freezer (ARMDFB, Iran). Charging of batteries was performed by charge/discharge instrument (Moran, Italy). For determination of batteries weight, a balance with accuracy of 0.1 g was used (AND, Japan). A water bath (Pars Horm Co., Iran) was used for providing constant temperatures.

2.3. Methods

Six positive plates with the dimension of 107 mm × 143 mm (or total surface of 1836.12 cm^2 for two side surface of six positive plates) and five negative plates with the same dimension (or