ANN-Based Sizing of Battery Storage in a Stand-Alone PV System

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***Abstract*—Sizing of electric energy storage for effective operation of photovoltaic (PV) systems is very important particularly in remote areas. Because of the intermittent nature of sun and varying inclinations of PV modules, there is no single definite rule for sizing batteries. The period of time in which the weather is cloudy and little or no sunlight is available must be considered and the number of days batteries supply the load must be computed. In this research, the optimal battery size for stand-alone PV system is determined using ANN model. Thus, calculation of optimum battery storage for a stand-alone PV system can be automated without needing extensive mathematical calculations or graphical analysis techniques.**

***Index Terms*—battery storage, PV system sizing, artificial neural networks, system availability, peak sun hour, inclination angle**

I. Introduction

The continuous decrease in photovoltaic cost and government incentives lead to an increase in PV installations. In a stand-alone PV system, the first viable storage option is to store the electricity in batteries. Among different battery technologies, lead-acid batteries continue to be the most popular in PV systems, thanks to the fact that they are the least expensive option.

The sizing of storage batteries in a stand-alone PV system is crucially affected by system cost. Therefore, percent of times that the storage system meets the load demand must be determined beforehand. Daily incoming solar irradiation values and weather conditions in a given place, as well as inclinations of PV modules can be used for sizing.

Ref. [1] presented a method for optimal sizing of a stand-alone PV system for remote areas. PV array tilt angle and the size of system's energy sources were designed optimally for better performance and lower energy cost. PV module tilt angle, PV array size and storage battery capacity were optimized using numerical methods. Because the weather conditions are statistically random artificial intelligence (AI) techniques can be employed in sizing. AI-techniques have proven their viability in sizing PV-systems based on published literature [2]-[4]. In Ref. [2], Radial Basis Function (RBF) networks were used for prediction and modeling of daily global solar radiation data from sunshine duration and air temperature. An application for sizing of stand-alone PV system has been presented. Ref [3] studied possibility of using an adaptive ANN to find a suitable model for sizing stand-alone PV systems, based on a minimum of input data.

In this paper, ANN-based sizing of storage batteries in a stand-alone PV system is analyzed by simulations. In the next section, sizing of battery storage in a stand-alone PV system is described. Afterwards, in Section 3, employed ANN models for battery sizing is explained. Furthermore, in Section 4, the results and discussion is presented and finally, the conclusions are given in Section 5.

II. Sizing of Battery Storage in a Stand-Alone PV System

A stand-alone PV system shown in Fig. 1 consists of a photovoltaic array, storage batteries and power management components. The PV array is made up of some combination of series and parallel connected modules. The storage batteries store the electrical energy for use when solar energy is not available. The control components manage the operation of the system. The power electronic circuits are used to convert the dc output of the photovoltaic array into a form needed by the user. The charge controller optionally include maximum power point tracking algorithm to obtain higher efficiency. Energy storage requirements can be reduced by including other energy sources beside PV to obtain a hybrid system.

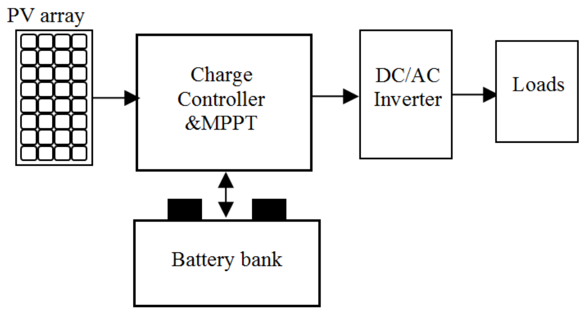

Figure 1. A stand-alone PV system diagram

Although there is an optimal inclination angle for mounting PV modules, in stand-alone systems they are sometimes mounted directly to the roof of a house. For aesthetic concerns, the PV modules are directly attached to the roof and available roof orientation is used.

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Therefore, it is necessary to estimate insolation on tilted surfaces [5].

System availability is a measure of a power system to meet load requirements. In a stand-alone system, it gives the percentage of time the batteries are available. The percentage depends on the nature of the loads, i.e. the non-critical systems are designed with an availability of 95% whereas critical ones such as telecommunication repeater stations may require 99% availability.

For simple representation of data, average daily insolation values can be given in “peak sun hours”. This approach is used to compress the received energy into a duration in which the insolation is 1 kW/m^2 [6]. The total measured daily insolation kWh/m^2 is thus transformed into the number of peak sun hours.

III. ANN-Based Models for Sizing Battery Storage

Artificial neural networks (ANN) have been widely employed in literature for solving complex nonlinear problems in various fields of applications including pattern recognition, identification, classification, prediction and control systems [7]. By means of ANNs, the desired information can be obtained directly from the measured experimental data. Thus ANN can offer a compact solution for the nonlinear and multi-variable problems.

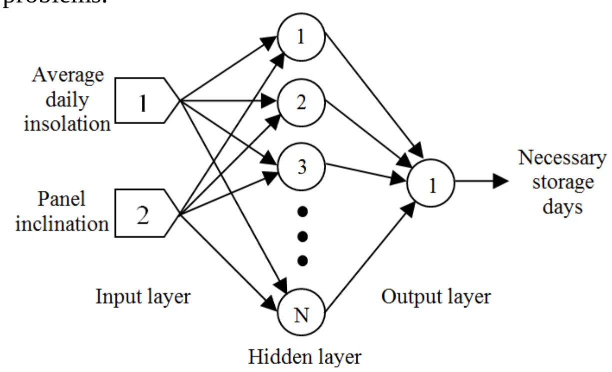
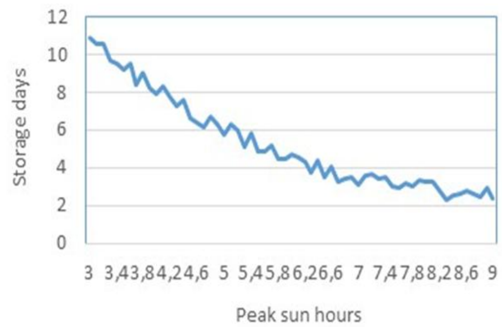


Figure 2. Implemented multi-layer perceptron ANN topology for 95% and 99% system availability

For stand-alone PV systems, as the requirement of each application is different and solar energy varies at the site, the cost of the system must be obtained by determining the size of batteries and PV modules [8]. The proposed ANN model can be used to give an idea on the designed PV system. Because of the variability of solar energy, battery sizing does not involve very simple calculations. Calculating the necessary storage cannot be done such that the storage batteries supply the loads through the night until the sun shines again the next day. The physical and environmental factors make the sizing problem nonlinear and ANN can be employed here because of the provided advantages in the case of lacking complete data. Fig. 2 shows the configuration of multilayer perceptron ANN structure employed in this study. This configuration was used in this study for both 95% and 99% system availabilities. Therefore, two ANN models have been developed and the training was implemented for two different input-output dataset. The required data for system modeling are collected from a PV system built in Konya, Turkey (Latitude: 37, 97°, Longitude: 32, 56°, Altitude: 1031m). Based on trial and error approach, the ANN with 1 hidden Layer and 5 neurons in this layer yielded the best performance. For two ANN models of 95% and 99% system availabilities, obtained measurement results to be used in ANN trainings are shown in Fig. 3 and Fig. 4, respectively, for inclination angles of (a) 0^o (b) 20^o (c) 30^o (d) 40^o (e) 50^o (f) 60^o (g) 90^o.



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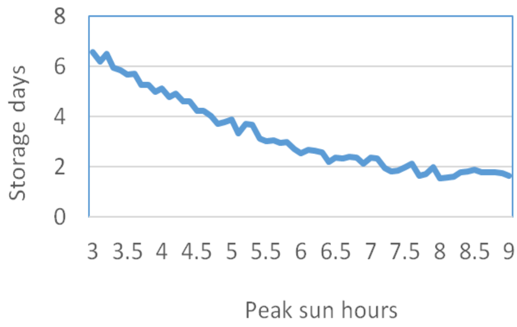

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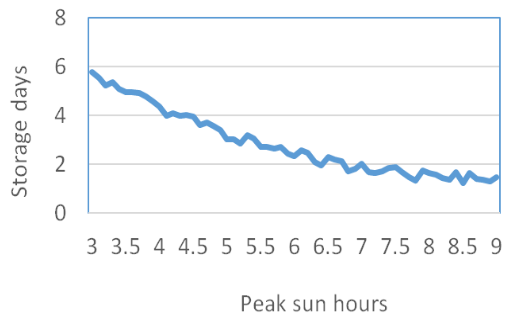

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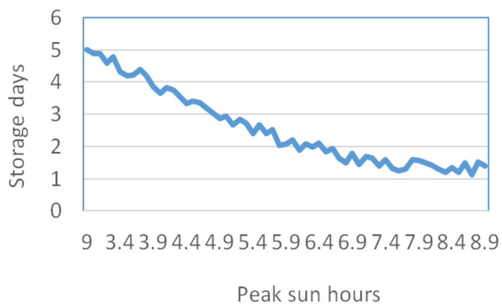

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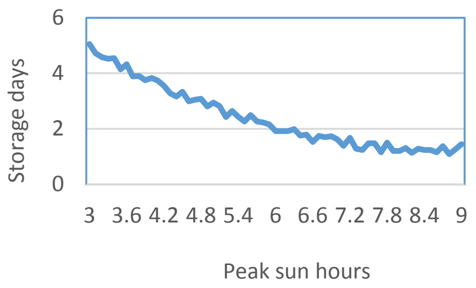

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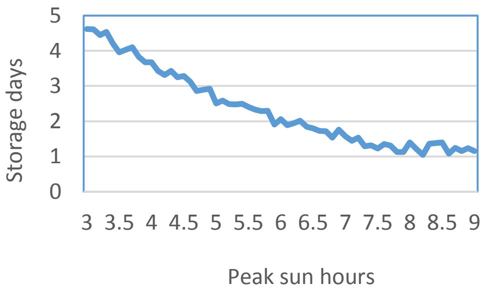

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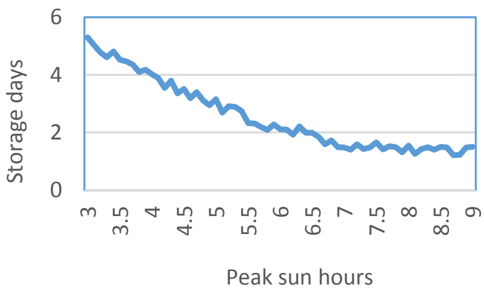
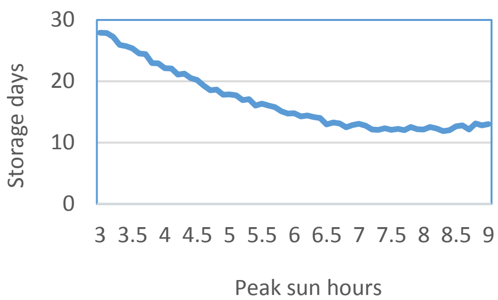


(g)

Figure 3. Changing of storage days in regard to the peak sun hours for 95% system availabilities for inclination angles of (a) 0^o (b) 20^o (c) 30^o (d) 40^o (e) 50^o (f) 60^o (g) 90^o



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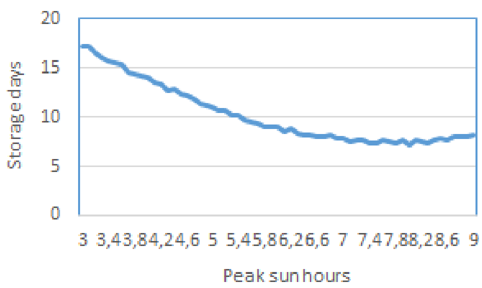

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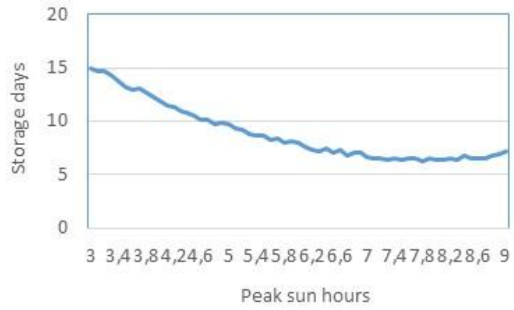

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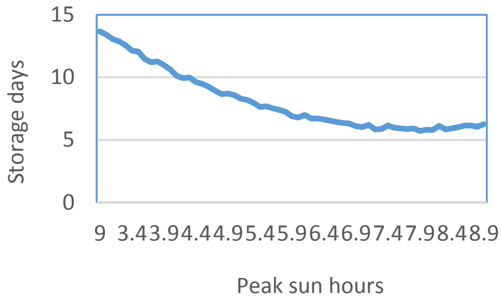

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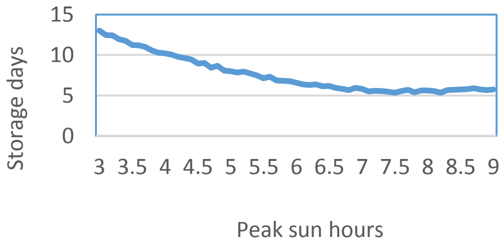

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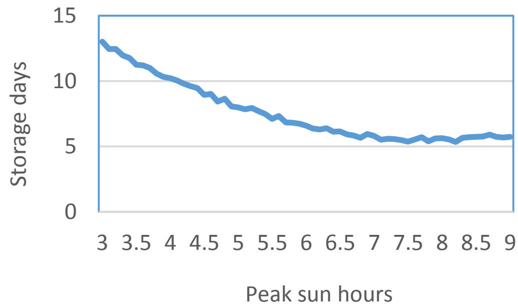

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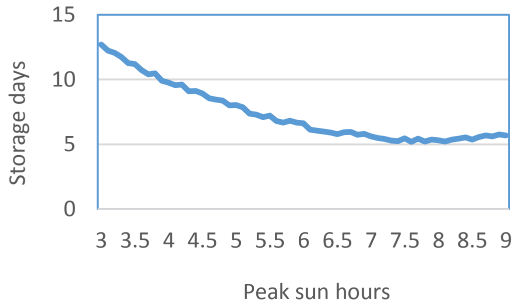

(g)

Figure 4. Changing of storage days in regard to the peak sun hours for 99% system availabilities for inclination angles of (a) 0^o (b) 20^o (c) 30^o (d) 40^o (e) 50^o (f) 60^o (g) 90^o

IV. Results and Discussion

ANN model for 95% system availability were trained and error histograms and training regression results were obtained as shown in Fig. 5 and Fig. 6, respectively. Similar results for the ANN model for 99% system availability are shown in Fig. 7 and Fig. 8, respectively. Levenberg-Marquardt algorithm has been used for training the networks. From the validation data set previously not used in training, very accurate estimation with correlation coefficient over 99% were obtained. The results demonstrate that the models can successfully be used for sizing stand-alone PV systems.

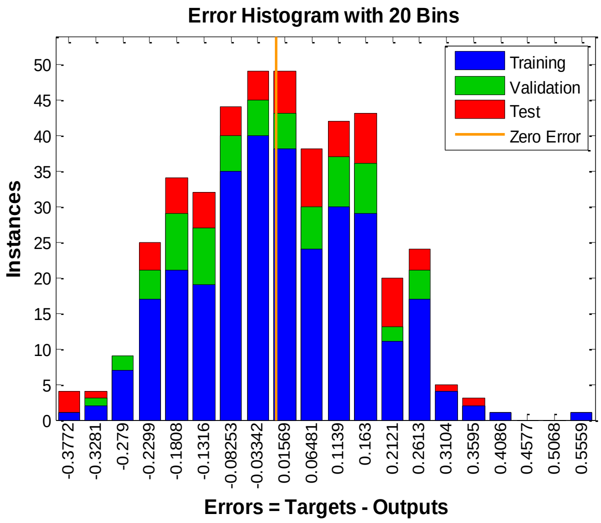

Figure 5. Error histogram for ANN model trained for 95% system availability

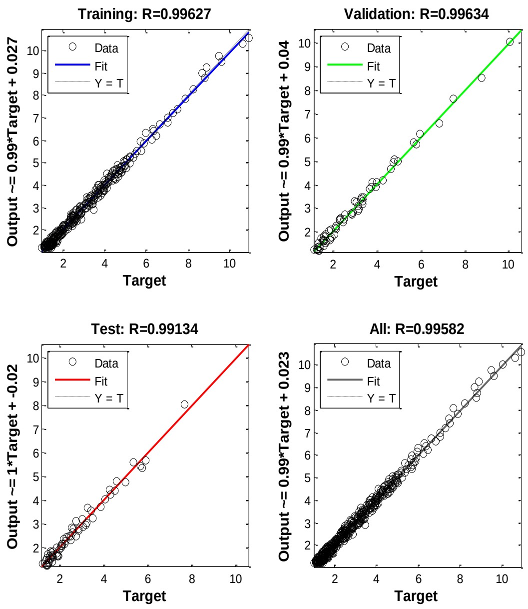

Figure 6. Neural network training regression results for the model with 95% system availability

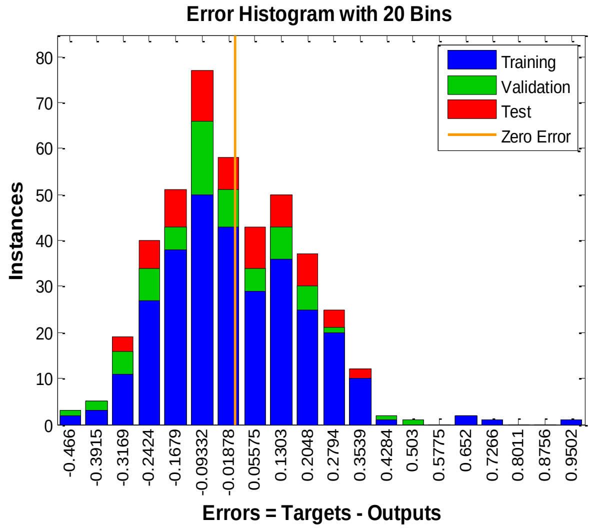

Figure 7. Error histogram for ANN model trained for %99 system availability

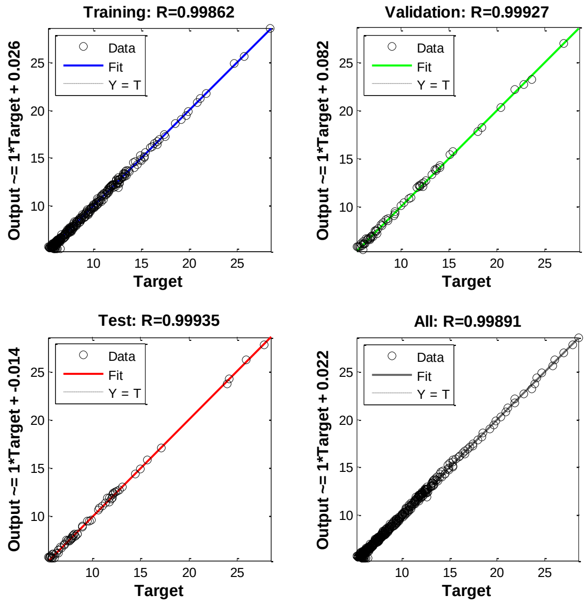

Figure 8. Neural network training regression results for the model with 99% system availability

To validate the results of ANN, design examples were conducted for the city of Konya in Turkey to determine the capacity of stand-alone systems. ANN model is used to obtain useful battery capacity and numerical calculation is used to determine the PV array power and area for the system load demand. As the sizing should implemented for the month having the worst solar irradiance conditions, peak sun hour value of 1.77 is used corresponding to month of December in the given site. ANN result was obtained for the inclination angle of 52^{o} facing south. From the ANN model for 95% system availability, the obtained result is a storage day of 6.54. ANN model predicts the optimum storage battery capacity and PV module size can be calculated depending on this result. For a simulated dc load of 1000Wh/day and with a system voltage of 24V, usable storage of the batteries can be calculated by;

$$1000\text{Wh/day} \times 6.54 \text{ days} / 24\text{V} = 272.5 \text{ Ah}$$

Using the characteristics of the PV array and solar irradiation data, this value can be used to numerically calculate power and area of PV array.

From the ANN model for 99% system availability, the obtained result is 17.0 storage days. For a load of 1000Wh daily, the usable storage of batteries can be calculated by;

$$1000\text{Wh/day} \times 17.0 \text{ days} / 24\text{V} = 708.33 \text{ Ah}$$

From these results, it can be seen that sizing a battery bank to meet the demand with 99% availability, the cost of batteries can be about three times more than the one meeting demand of 95% availability.

V. CONCLUSION

The objective of this work was to determine the size of storage batteries using experimentally obtained data for training the ANN. The implemented method offers a simple approach using ANNs to identify the feasible configurations for meeting a given load. The results show the potential of ANN in sizing PV system components. It was demonstrated that based on some experimentally obtained available data, PV system sizing can be implemented with reasonable accuracy.

A disadvantage of this method is that a large training data set covering a wide range of environmental conditions must be obtained to ensure high accuracy of the results. Although obtained results in this study refer to a site in Turkey, the method can be applied to any geographical site over the world. It should also be noted that the simulations in this study can give approximate results as the model of PV system components are quite complicated.

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