Application of Artificial Neural Network in Forecasting Solar Irradiance and Sizing of Photovoltaic Cell for Standalone Systems in Bangladesh

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ABSTRACT
Generation of electricity from solar energy is gaining popularity as a solution to the growing energy demands. The most important parameter in renewable energy applications is solar radiation. Due to intense power crisis, more and more solar energy based solutions are being purchased. Drawbacks of these solutions are long payback period and comparatively less efficiency. To improve this scenario, the sizing of the PV arrays can be optimized to enhance the overall efficiency. This paper presents an application of artificial neural network to predict solar radiation from a dataset collected over a span of nine years. Then these forecasted values are used to size standalone PV systems for different locations.

General Terms
Artificial Intelligence, Renewable Energy, Neural Networks.

Keywords
ANN, Solar Irradiance, Sizing of PV Cell.

1. INTRODUCTION
Bangladesh is largely an agro-dependent with a population of 150 million people. Fossil energy resources in Bangladesh consist primarily of natural gas. Domestic oil supply is considered negligible. Several small deposits of coal exist on the north eastern region of the country, but these consist of peat; with low caloric value and very deep bituminous coal that will be quite expensive to extract. Only 25% of the total population has got access to the electricity. In 2010, only 12.2% of total households (mostly in urban areas) had piped natural gas connections for cooking and only 6.9% of total households used kerosene for cooking.

Due to increasing industrialization, the natural gas reserve is facing a dire situation. Per capita consumption of commercial energy and electricity in Bangladesh is one of the lowest among the developing countries. In 2010, more than 83% of total final energy consumption was met by natural gas, coal and different type of biomass fuels (e.g. agricultural residues, wood fuels, animal dung etc.). To meet the energy demand in the last decade,several projects have been funded by both the government and NGOs (non-government organization) to harness available renewable energy resources. Geographically, Bangladesh has afavorable prospect for the utilization of solar energy. Very few studies have been conducted so far to estimate the solar irradiance and optimum PV cell sizing.

Solar radiation data is considered as the most important parameter in the meteorology, solar conversion, and renewable energy application, particularly for the sizing of Standalone Photovoltaic (SPV) systems. Unfortunately, this parameter is not always available particularly in remote areas, where there are no meteorological stations installed in these locations, so several researchers have been interested in developing different approaches for generating this parameter.

2. ARTIFICIAL NEURAL NETWORKS
An Artificial Neural Network (ANN) is a computational model that is inspired by the structure and functional aspects of biological neural networks. It consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases, an ANN is an adaptive system that usually changes its structure based on external or internal information that flows through the network during the learning phase.

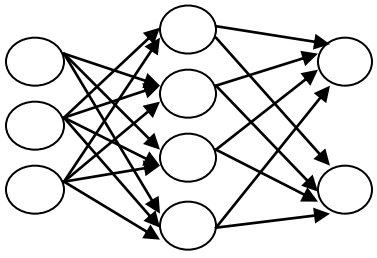

Figure 1: A simple Neural Network

A typical feed forward neural network has an input, a hidden and an output layer. Each component includes a neuron, weights and a transfer function. An input x_j is transmitted through a connection which multiplies its strength by a weight w_{ij} to give a product $x_j w_{ij}$. The product is an argument to a transfer function f which yields an output y_i represented by:

$$y_i = f(\sum_{j=1}^{n} x_j w_{ij})(1)$$

where*i* is a neuron index in the hidden layer and *j* is an index of an input to the neural network. Training is the process of modifying the connection weights in some orderly fashion using a suitable learning method.

Using artificial neural network as an estimation tool has proved its efficiency in predicting different parameters via other parameters that their relationship is not specified. So applying artificial neural networks can be valuable in prediction of solar radiation.

3. DATA COLLECTION

The meteorological data that have been used in this work are the solar radiation (Wh/m^2), relative humidity (%), wind speed (m/s), wind direction (^{0}) and precipitation (mm). These data were collected from locations listed below during 1992 to 2001[10].

Table 1. Locations of collected dataset

Name	Latitude	Longitude
Dhaka	23.76667	90.38333
Chittagong	22.26667	91.81667
Sylhet	24.9	91.88333
Jessore	23.18333	89.16667
Rangpur	25.73333	89.23333

The following equation was used to normalize data.

$$Normalized\ Output = \frac{Actual\ \ Value}{Maximum\ \ Value}(2)$$

The data was normalized between values 0 to 1 to avoid convergence problem.

3. FORECASTING MODELS

From literature review, it was observed that researchers have forecasted solar irradiance using either historical data or different weather parameters. In this work, two models were developed for forecasting solar radiation. First was the Endogenous model which took only the solar radiation data as input. The other was the Exogenous model which used Relative Humidity, Wind direction, Wind speed and Precipitation.

Table 2. Correlation analysis between Solar Radiation and Exogenous variables

Solar Radiation	Relative Humidity	-0.5245
	Wind direction	0.1483
	Wind Speed	0.1921
	Precipitation	-0.0442

It can be seen from the above table, that wind direction and wind speed are positively correlated with solar irradiance. Whereas, relative humidity and precipitation are negatively correlated.

3.1 Endogenous Model

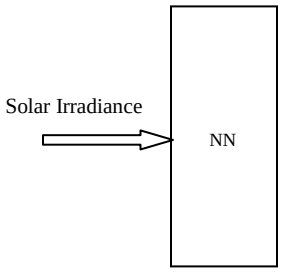

Figure 2: Endogenous Model

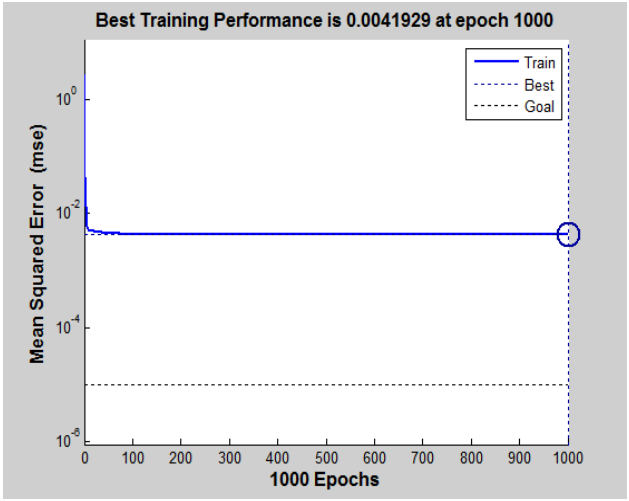

Figure 3: The performance goal met

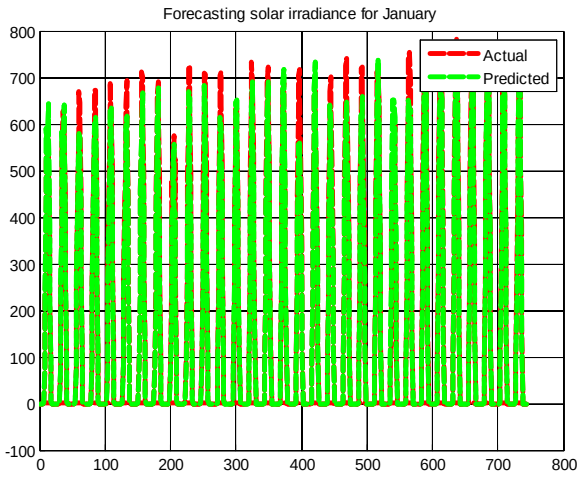

Figure 4: Comparing forecasted values with actual

3.2 Exogenous Model

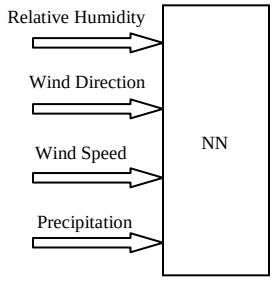

Figure 5: Exogenous Model

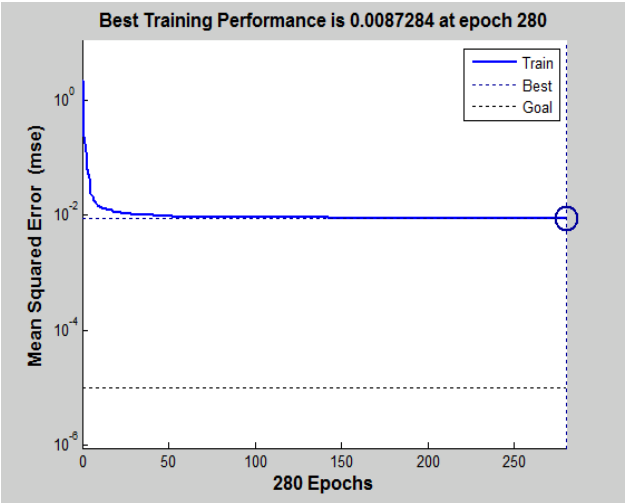

Figure 6: The performance goal met

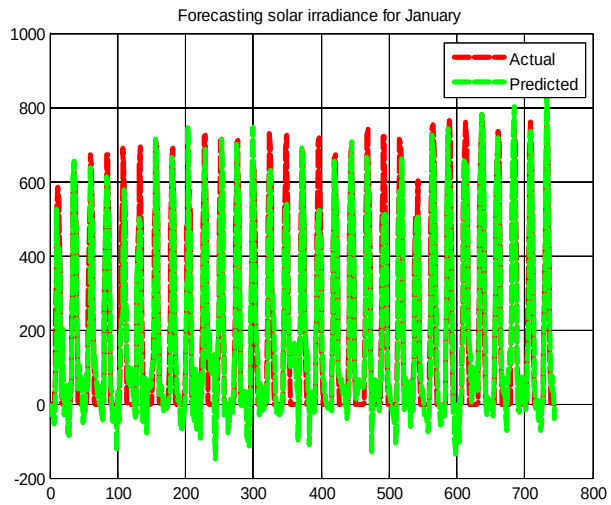

Figure 7: Comparing forecasted values with actual

5. SIMULATION RESULTS

Each model was trained using *trainlm* (Levenberg-Marquardt backpropagaton) training algorithm with the help of MATLAB's Neural Network Training tool. After that, each network was simulated and their performance was observed. Mean Square Error (MSE) performance measure function was employed.

$$MSE = \frac{1}{N}\sum_{i=1}^{N}[L_{actual}\ (n) - L_{predicted}\ (n)]^2 \quad (3)$$

Table 3. Comparison between different NN models

Model	MSE	Epoch	Time
Dhaka (Endogenous)	0.0042	1000	9:57
Dhaka (Exogenous)	0.0087	280	8:59
Chittagong	0.0046	1000	6:55
Sylhet	0.0042	1000	7:22
Jessore	0.0029	1000	7:42
Rangpur	0.0039	1000	7:25

It was seen that the developed models were capable of predicting solar irradiation with a small error margin. Though the exogenous model required less number of epochs, it took almost the same amount of time as the endogenous model. Also, this model required much larger dataset. So, it is preferable to use endogenous model for forecasting.

6. GENETIC ALGORITHM

The Genetic Algorithm (GA) is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. It repeatedlymodifies a population of individual solutions. At each step, the geneticalgorithm selects individuals at random from the current population to beparents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution.

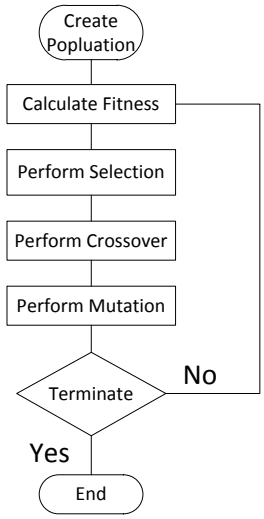

Figure 8: Steps of Genetic Algorithm

The genetic algorithm differs from a classical, derivative-based, optimization algorithm in two main ways:

1) GA generates a population of points at each iteration. The best point in the population approaches an optimal solution.
2) GA selects the next population by computation which uses random number generators.

7. SIZING OF PV SYSTEM

A stand-alone PV power supply system is established as a reliable and economical source of electricity in rural remote areas; especially in developing countries where the population is dispersed, with low income and a lack of power supply due to viability and financial instability. They are defined as autonomous systems that supply electricity without being connected to the electricity grid.

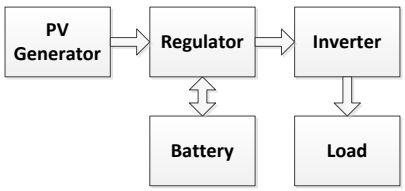

Figure 9: Simplified schematic of standalone PV system

A basic configuration of a standalone photovoltaic system with constant load [4] was considered (Fig. 6). The sizing pair C_A and C_S can be given by the following formulae:

$$C_A = \frac{\eta A G}{L} \quad (4)$$

$$C_S = \frac{C_V}{L} \quad (5)$$

where A is the PV-array area, η is the PV-array efficiency, G is the average daily irradiation on the PV-array, L is the average daily energy consumption, C_S is the storage capacity and C_V is the useful accumulator capacity.

A simple cost function was considered as follows:

$$C_t = C_A C_{PV} + C_S C_B + C_M \quad (6)$$

where, C_{PV}= initial investment that represents the cost of the PV-array and the battery system,

C_B = price corresponding to the replacement numbers of the storage battery system during the considered period,

C_M = cost of the operation and maintenance.

From [8], we obtained:

Table 4. Cost assumptions for PV array and battery

	Parameter	Value	Unit
PV array	Capital Cost	274	TK/W
	Operation and maintenance	50	TK/KW/yr
Battery	Capital Cost	7000	TK/KWh
	Replacement Cost	6000	TK/KWh
	Operation and maintenance	50	TK/KW/yr

Minimizing the cost function using Genetic Algorithm, we obtained C_A = 1.1001 and C_s = 0.9803.

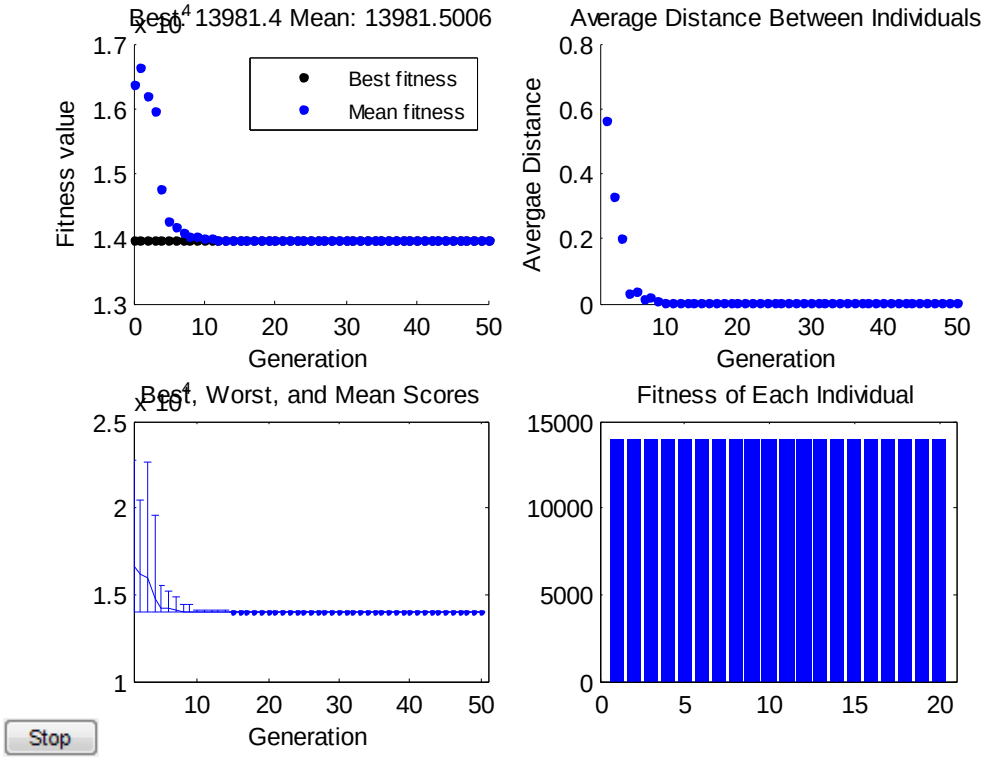

Figure 10: GA simulation results for 50 generations

Using these values, the required PV array areas were calculated by rearranging (4).

Table 5. Proposed PV array area

Location	Area (m^2)
Dhaka	1.5709
Chittagong	1.5257
Sylhet	1.6345
Jessore	1.5231
Rangpur	1.5883

8. CONCLUSION

Developed models offer the possibility to predict the solar irradiance data from both endogenous and exogenous variables. The prediction of data is done in a very simple manner using a simple feedforward model, which have 30 neurons in input layer and one neuron in output layer.The prediction model is unique, as it is the first of its kind to be developed for Bangladesh.

As renewable energy is a booming sector in Bangladesh and massive investments are on going, our research will optimize the generation process. Obtained results indicate that establishing regional hub or sub-grid will be much more appropriate for harnessing most of the investment.

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