

An integrated multiple layer perceptron-genetic algorithm decision support system for photovoltaic power plant site selection

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ABSTRACT

There is a need for non-renewable energy sources in generation of power for almost every domestic and commercial purposes. This source of energy helps in the development of a country. Because of the increasing usage of the fossil fuels and depletion of these resources, our focus has been shifted towards the renewable sources of energy like solar, water and wind. Therefore, in the present scenario, the usage of renewable sources has been increasing rapidly. Selection of a solar power plant (SPP) requires environmental factor, local terrain, and local weather issues. Thus, a large amount of investment is required for installation. Multi-criteria decision making (MCDM) is a method that identifies one in choosing the best sites among the other proposed options. This paper gives a detailed study of optimal ranking of SPP site using analytical hierarchy process (AHP), multiple layer perceptron (MLP) neural network trained with back propagation (BP) algorithm and genetic algorithm (GA). Three SPP sites of India were considered and various important criteria like local weather, geographical location, and environmental factors are included in our study as SPP site selection is a multi-criteria problem. A precise comparison of these three methods is listed in this paper.

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1. INTRODUCTION

Energy is an essential part in our daily life. Human population is estimated to rise from 6.9 billion to 13.1 billion by the end of this century [1]. As a result, the consumption of energy is increase with the increase in population. Michael [2] reported that the demand in global energy is likely to be doubled in the 21st century. Thus, energy needs have become a very important international and national agenda. Fossil fuels are formed naturally and take a long time to form and their price increases as its reserves decreases. The burning of fossil fuels also severely degrades the environment; on the contrary, renewable energy sources are unlimited as they are replenished constantly in nature.

To compensate for the ever-growing demands, most of the countries have started using renewable energy sources for generation of power. Such sources of energy depend on social factor and environmental issues. Solar power plant (SPP) is a popular renewable source and are widely used across the globe. Investors have shown immense interest in solar power project because of its availability, pollution free environment, low maintenance and operating cost. This have enhance the solar power project to progress rapidly [3].

The multi-criteria evaluation (MCE) approach has been an important tool to assist decision-makers in sustainable energy planning. According to Rosen *et al.* [4], MCE helps in evaluating the performance criteria of the project. Haidipour *et al.* [5], identified areas for suitable shrimp aquaculture development using geographical information system (GIS), analytical hierarchy process (AHP), and MCE in the coastal region of Iran, Latinopoulos, and Keechagia. Shamboo *et al.* [6] demonstrated various soft computing methods to prioritize the sites of SPP in India. Malemnganbi and Shimray [7] presented a detailed review on site selection of solar power plant quoting various power plants and the methods used to rank the plants. SPP site selection techniques based on data envelope analysis (DEA) were proposed by Thongpun [8], in their work and criteria like temperature, land availability, and land cost were taken into consideration. A hybrid neuro-fuzzy decision support system [9] and multiple layer perceptron-genetic algorithm (MLP-GA) based decision support system were proposed and implemented for large hydro power plant selection. Ching-Ter also proposes a multi-choice goal programming model to deal with capacity expansion planning problem of the renewable energy industry [10].

Rapal *et al.* [11] benefits AHP to assess potential sites for wind and solar deployment project. In this paper, experts' opinions were evaluated to prioritize the scores. Four regions of Philippines were considered for the case study. Further it has also shown that solar/wind intensity is the most important consideration for selecting the site. In another paper authored by Tunc *et al.* [12], AHP has been analyzed for weighing the criteria and the weights were compared to the survey results, Analysis being performed using GIS software. Colak *et al.* [13], have done a case study for Malatya, Turkey using GIS and AHP for utility scale SPP. Fang *et al.* [14], also proposed technique for order preference by similarity to ideal solution (TOPSIS) and to select the proper sites of SPP. Garni and Awasthi [15] also portrayed GIS-AHP for site selection in Saudi Arabia. Akkas *et al.* [16] compared various methods that helps in prioritizing the SPP sites in Turkey. Evaluation of environmental and solar radiation characteristics is required that affects the technical performance. [17]. Rao and Lakshmi recently developed a new multi-attribute decision-making (MADM) method, named "R-method". This method is very simple, effective, and can be used to deal with any number of alternatives and attributes. The method is competitive to other well-known MADM methods and can be easily used to find the best alternative from among the available alternatives [18], [19].

2. CASE STUDY

The sites that have been considered in our study are those that are approved under the solar park scheme of ministry of new and renewable energy (MNRE). Solar radiation, Temperature, humidity, precipitation for these sites, have been collected. Distance to national highway (NH), coastal area and reserved area for the proposed site are referred [20]. The important criteria and sub criteria that are used in our present studies are explained in below:

a. Temperature

The PV modules' efficiencies decrease as temperature rises. In general, the PV modules' characteristics were determined at standard temperature 25 C. For every rise in temperature (°C), the efficiency of silicon modules gets reduced by 0.5%.

b. Distance from the national highway

SPP should be located in the area which is easily accessible [21]. Nearness to the national highway is considered as an important criterion. This will help in reducing the cost of equipment loading and transportation.

c. Solar resources

Annual solar irradiation received in the proposed location is an important criterion for optimal site selection of SPP. diffuse horizontal irradiation (DHI), direct normal irradiance (DNI) and global horizontal irradiance (GHI), describes the solar resources of any location. Higher the energy resources, higher will be the energy yield.

d. Distance from the protected area

A large SPP requires a large area to be cleared which may negatively affect ecological balance and result in loss of important and endangered species of plant and animal. Human activities have lots of chances to affect protected areas [21]. Therefore, before installing SSP, distance from the protected area must be considered.

e. Sunshine hour

Sunshine hour, one of the most important factors, signifies the amount of solar radiation reaching the earth's surface. Khan and Rathi [22] acknowledge that there are 250 to 300 clear sunny days in India in a year.

f. Wind speed

The mounting structure of SPP must withstand a wind speed of 150 km/hr. The area with heavy wind speed should be avoided as it may affect the tracking system.

g. Seismic zone

High-risk Seismic zone areas are not recommended for setting up large SPP.

h. Humidity

Approximately 30% of the solar energy was either absorbed or reflected by the ocean, clouds, and landmass. Loss in solar energy occurs due to the reflection/absorption of solar energy by landmass, oceans, and clouds. There will be an increase in the efficiency of the solar cell if the humidity decreases and vice versa.

i. Distance to coastland

The salt level in the atmosphere may also lead to the acceleration of corrosions and the distance to SPP sites to sea should be considered as important criteria.

3. PROPOSED METHOD

3.1. Analytical hierarchy process (AHP)

It is a process that is based on expert’s opinions and measures the expert scale and acquire the priorities with the help of a binary comparisons [23]. Designing the decision hierarchy is the first step in the process of AHP. The weights of the criteria, sub-criteria calculated using AHP is given in Table 1. The last step is to prioritize the three SPP sites using the values obtained from the case study. The priorities weights are given in Table 1.

Table 1. Weights calculated

Criteria	Sub Criteria	Pavagada Solar Park	Bhandla Solar Park	West Bengal Solar Park
Climate 0.531163	GHI	0.215928	0.210961	0.19643
	DHI	0.215928	0.188094	0.189606
	DNI	0.215928	0.193946	0.197682
	Temperature	0.082454	0.080698	0.075693
	Sunshine Hour	0.162751	0.161840	0.162491
	Wind Speed	0.050228	0.050228	0.042553
	Precipitation	0.028390	0.009746	0.028390
	Humidity	0.028390	0.016735	0.028390
	Geography	Seismic Belt	0.058254	0.055667
Transportation	Distance from National Highway	0.285380	0.221431	0.094434
	Distance form Coastal Area	0.125196	0.125196	0.003994
Environment				
Overall Priority		1.351796502	1.354799024	1.039075

3.2. MLP-BP

Multiple layer perceptron (MLP) uses a supervised network configuring various layers of neurons. It comprises of three layers viz. input layer, the hidden layer which is considered as the brain of the network, and an output layer as shown in Figure 1. The i^{th} layer of each neuron is connected to $(i+1)^{th}$ layer of all neurons. This connection weight has to be determined by using a training algorithm known as back propagation [24].

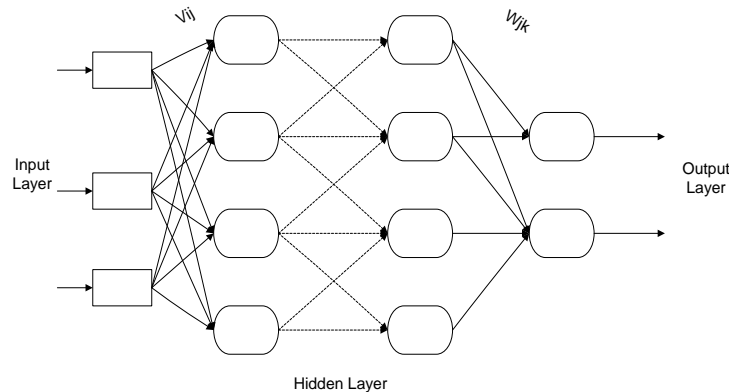


Figure 1. MLP architecture

3.3. Multiple layer perceptron-genetic algorithm (MLP-GA)

In multilayer perceptron with a genetic algorithm (MLP-GA), the neural network is trained by using genetic algorithm to find the correct connection weights [25]. Here back propagation is replaced by GA to overcome the unfitting selection of the starting weights as improper initial weights can cause delay in convergence. While GA, executes a comprehensive search, and has less chance of getting caught in local minima. The various steps of MLP-GA are explained in the section 3.3.1 to 3.3.6.

3.3.1. Weight initialization

To advance MLP, the GA genotype is defined as the weight list. The weights are characterized by a binary number. Every solution is a bit string and it signifies the connection weights of the neural network layers.

$$TW = (I * HN + HN * ON) \quad (1)$$

Where TW=no of total weights, I=input pattern size, HN=no. of hidden neurons, ON=no. of output neurons. In our study, I=13, HN=3, ON=2 Thus, TW=45. Now

$$GL = [B(I * HN + HN * ON)] \quad (2)$$

where, GL=gene length, B=No of bits/weight. In our study B=16 (16 bit binary number). Hence, GL=720.

3.3.2. Reconstructing phenotype from the genotype

If we consider

$$y_m = \sum_{k=1}^B b_{mk} 2^{-k} \quad (3)$$

where, b_{mk} = k^{th} bit from m^{th} weight. Then

$$w_m = y_m * A + B \quad (4)$$

where, w_m =weight in the string or solution, A=scaling factor, B=shifting factor. In our work A=20, B=-10, for the weights to take value from [-10, 10]. Thus, we can calculate the weights v_{jm} and the weight w_{kj} . Where, v_{jm} =Weight from the m^{th} input to the j^{th} hidden neuron, w_{kj} =Weight from the j^{th} hidden neuron to the k^{th} output neuron.

3.3.3. Hidden layer and the output layer output

To calculate the output of the hidden neurons, the (5) and (6) are used:

$$S_1 = \sum_{m,j} v_{jm} * x_{pm} \quad (5)$$

$$y_j = \text{sigmoid}(S_1) \quad (6)$$

where sigmoid=unipolar activation function, y_j =the output of the j^{th} hidden neuron. To calculate the output of the output neurons:

$$S_2 = \sum_{j,k} w_{kj} * y_j \quad (7)$$

$$o_k = \text{sigmoid}(S_2) \quad (8)$$

where o_k =output of the k^{th} output neuron. For all the input patterns, (7) and (8) is implemented to find the output. The (9) is used to update the error,

$$E = \frac{1}{2} \sum_{k=0}^k (d_k - o_k)^2 \quad (9)$$

where d_k =desired output. All these steps are executed for all the training samples.

3.3.4. Fitness of the string or solution

To calculate the fitness of the string or solution (10) is carried out,

$$\text{fitness} = \frac{1 - E}{N} \quad (10)$$

where N =no. of patterns or training samples. The steps from 3.3.2 are repeated for every string or solution of the population.

3.3.5. Selection

In the selection process, the solution or string that has the maximum fitness value is determined. The operation will terminate only when maximum fitness value is larger than the desired fitness value. For the testing phase, the weight associated with maximum fitness value string or solution is used.

3.3.6. Reproduction

Mutation and Crossover are used to modify the population. Until we obtain a string or solution having the fitness value larger than the desired fitness value, the steps from 3.3.2 are repeated.

4. IMPLEMENTATION

This section illustrates the result attained after applying AHP, MLP-BP and MLP-GA. For training the neural network using the proposed algorithm the selected sub-criterion is classified into different class as poor, average, and good as shown in Table 2. The numeric data for the solar power plants used in this paper is given in Table 3. Our work consists of 12 input, 3 hidden neurons, and 2 output neurons. The desired output is set as (0, 0) for poor (0, 1) for average, (1, 0) for good. We run the algorithm for different numbers of training cycles starting from 1,000 cycles to 10,000 cycles.

Table 2. Selected criteria

Criteria	Sub-Criteria	Class good	Class Average	Class Poor
Climate	Global Horizontal Irradiation (GHI)	$5.7 \leq$	4.5-4.99	0.01-4.49
	Direct Horizontal Irradiation (DHI)	1.8-3	1.5-1.79	0.01-1.49
	Direct Normal Irradiation (DNI)	5.7-7	5-5.69	0.01-4.99
	Temperature	0.01-26	22-26	26.01-70
	Sunshine Hour	13.01-24	12-13	0.01-11.99
	Wind Speed	0.01-9	9.01-20	20.01-100
	Precipitation	0.01-40	40.01-100	100.01-300
Geographical	Humidity	0.01-400	40.01-100	65.01-100
	Seismic Belt	0-4.9	5-5.9	6-9
Transportation	Distance from National Highway	0.01-9.99	10-30	30.01-200
Environment	Distance from protected area	50.01-200	20-50	0.01-19.99
	Distance from coastal area	500.01-1500	50.01-500	0.01-50

4.1. MLP-BP and MLP-GA comparison

MLP trained with BP and MLP trained with GA are compared in this section for various training cycles. The results obtained using the MLP-GA algorithm are given in Table 3. Figure 2 shows a better analysis for different iterations. The comparison in Tables 4 and 5 show that MLP-GA achieves better results than MLP-BP algorithm and AHP. Also, with lesser number of iterations, MLP-GA can precisely rank the power plant sites. Figure 2 shows the classification rate graph of MLP-BP and MLP-GA for 1000, 5000, 10000, 30000, 60000, 80000 and 100000 iterations.

Similarly, it is shown that the classification rate for MLP-GA has achieved a 100% success rate starting from 5000 learning cycles which means, it can accurately rank the given solar plant installations. On the other hand, the classification rate is only 75% at 30000 to 1lakh iterations. Therefore, it can be concluded that that MLP neural network trained by GA shows much better efficiency in accurately classifying and identifying potential sites for the installation of solar power plants. In our quest for reasonable and acceptable solution for optimal site selection of SPP, we explore two soft computing technique viz.-MLP-BP, MLP-GA and a MCDM technique AHP. A comparison of these three techniques is presented in Table 5. Thus, from this table, we can conclude that Bhandla SPP in Rajasthan, being the highest estimated solar energy potential in India, is the most suitable site for SPP followed by Pavagada SPP in Karnataka and West Bengal SPP.

Table 3. MLP-GA results

Power Plant Site	Test input (x_{pm}) (The 12 attributes in each plant)	Output from hidden layer $Y_j = \text{sigmoid}(s_1)$ Where $s_1 = v_{pm} * x_{pm}$	Output from output layer $O_k = \text{sigmoid}(s_2)$ where, $S_2 = w_{kj} * x_{pm}$	Rank
Pavagada SPP, Karnataka	5.32,1.94,5.21,24.05,12.5,9.1,89.63,8 7.83,4.3,22.5,88.5,379, -1	Y [0] =1.000000 Y [1] =1.000000	0.000000, 0.992683	II
Bhandla SPP, Rajasthan	5.2,1.69,5.8,25.64,12.55,10.74,30.77, 51.83,4.5,29,146,752, -1	Y [0] = 1.000000 Y [1] = 0.000000	1.000000, 0.000000	I
West Bengal solar park	4.84,1.73,5.31,23.58,12.57,10.42,267. 5,76.67,5.5,6.8,186,2.4, -1	Y [0] =0.000000 Y [1] =1.000000	0.000000, 0.000000	III

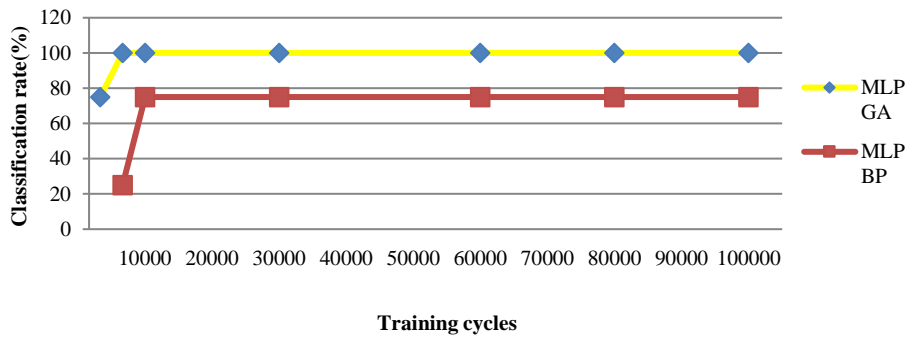


Figure 2. Classification rate graph

Table 4. Results comparing for 5000 and 10000 training cycles

Sl. no	Power Plant	No. of iteration	MLP-BP The output from the output layer	Rank	MLP-GA The output from the output layer	Rank
1	Pavagada SPP	5000	0.484145,0.515413	I	0.000000, 1.000000	II
2	Bhandla SPP	5000	0.484145,0.515413	I	1.000000, 0.000000	I
3	West Bengal Solar Park	5000	0.484145,0.515413	I	0.000000, 1.000000	II
1	Pavagada SPP	10000	0.484256,0.515524	I	0.000000, 0.992683	II
2	Bhandla SPP	10000	0.484256,0.515524	I	1.000000, 0.000040	I
3	West Bengal Solar Park	10000	0.007202,0.007228	II	0.000000, 0.000000	III

Table 5. Result for MLP-BP application

Sl. no	Power Plant	MLP-BP The output from the output layer	Rank	AHP Priorities	Ranking	MLP-GA The output from the output layer	Ranking
1	Pavagada SPP	0.484256,0.515524	I	1.351796502	I	0.000000, 0.992683	II
2	Bhandla SPP	0.484256,0.515524	I	1.354799024	I	1.000000, 0.000040	I
3	West Bengal Solar Park	0.007202,0.007228	II	1.039075495	II	0.000000, 0.000000	III

5. CONCLUSION




The investigation process for installing a SPP mounting structure involves the participation of different stakeholders which even include a common man. Unmistakably identifying suitable sites for the

solar plant helps in saving time and money of the decision-makers and also promotes future infrastructure developments. Also integrating related factors into the decision making process will provide an improved results and the make the site selection technically and economically achievable. Various decision-makers 'shots to rap power without bearing in mind the unpleasant effect which may, in turn, be a threat to human existence. In our present work, a detail analysis to assist decision making body is taken up using two robust soft computing techniques. The methodology applied can accurately rank the probable sites for solar power plant installation. A certain set of quantitative and qualitative factors may also be required in site selection problem. There is also a requirement for linguistic information. Thus, application of fuzzy logic can be of great help to address multi criteria site selection problem such as power plant sites and will be the future research work related to our present study.




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