Optimization of Wind Power Using Artificial Neural Network (ANN)

Dinesh Chauhan and Sunny Vig

Abstract Wind energy is one of the best alternatives for the fossil fuels in the field of electricity generation. They have many advantages, when compared to the fossil fuels, such as it is available naturally, does not have harmful effect on the environment and will not be get depleted with the passage of time. Besides all these advantages of the wind energy, when the wind is used for the generation of electrical energy, there are lot of issues related to wind like fluctuations in wind speed which cause major problems in power generation. Variation in wind speed can also cause power fluctuation, which will cause discomfort at the consumer level. Many developing nations have now moved towards wind energy to meet their growing energy demands. The problem of power output variation of wind farms can be optimized by various optimization techniques like particle swarm optimization, genetic algorithm and artificial neural network. In this study, the technique of artificial neural network is being used for the optimization of wind power. In the neural network toolbox, the optimum value for wind power is first determined individually for three different input variables (wind speed, tip-to-speed ratio and coefficient of power) and then the final optimum values are determined by using all these parameters as input variables at the same time.

Keywords Fossil fuels · Wind power · Tip-to-speed ratio · Coefficient of power Artificial neural network · MATLAB toolbox

1 Introduction

Since its invention in the nineteenth century, electrical energy has changed the world for good. The human race has become so dependent on electrical energy that today it is not possible to survive without electrical energy. All the luxuries,

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comfort and easiness in our life are mainly due to electrical energy. The working of a normal house to a large industry cannot be possible without electrical energy. After realizing the benefits, we get from electrical energy, and we simply kept our focus on the maximum generation of electrical energy. The major part of today's energy generation is done by coal and other fossil fuels. The unprecedented use of fossil fuels has resulted in many environmental issues like global warming, climate change and the increase in the quantity of greenhouse gases [1]. After realizing the harmful effects of fossil fuels, the government of each country is shifting its focus to renewable sources of energy. These renewable sources of energy have many advantages like they did not have any harmful effect on the environment and also, they are free of cost. Among these renewable sources of energy, wind energy is the important one as it will remain till the sun is there. Basically, wind is caused by the uneven heating of the earth surface by the sun. Throughout the world, wind energy has a huge potential which can be harnessed for the generation of electrical power. In India as on February 2017, the installed capacity for wind power is 28 GW [2]. This will further increase in the coming years as Indian Government is encouraging private partners to be associated in the field of power generation with renewable sources. But besides all these advantages, wind power with certain limitations like its generation is mainly dependent on the availability of the wind. If the wind is available, then the next issue is the speed of the wind. In large wind farms, multiple wind turbines are connected in parallel to get the maximum output. But with multiple wind turbines connected together, the speed with which wind hits the turbines is not the same for each turbine. So, we can optimize the wind power of each turbine. There are many optimization techniques available like particle swarm optimization, genetic algorithm and artificial neural network. In this study, artificial neural networks technique is being implied for the optimization of wind power.

2 Artificial Neural Networks (ANN)

In the field of artificial intelligence, there are two main branches: one is expert system and other is the artificial neural network [4]. Over a period of last decade, there has been the great development in the field of artificial neural network. In the recent years, ANN has been applied successfully for image recognition, sound, speech pattern identification and much more. Artificial neural networks are very much similar to the biological neural network and follow the same principle of learning of past experiences. The artificial neural network gives the best optimum value after training it multiple times. Figure 1 shows the diagram for a biological neuron.

It is estimated that human brain has billions of neurons connected together for the flow of information. Each neuron in the brain has the same four basic elements known by their biological names—dendrites, soma, axon and synapses [4]. The diagram showing the simplified model of the artificial neuron is shown in Fig. 2. ANN is basically formed by the interconnection of these artificial neurons. In such a system, excitation is applied to the input of the network. At the synapses, there is a

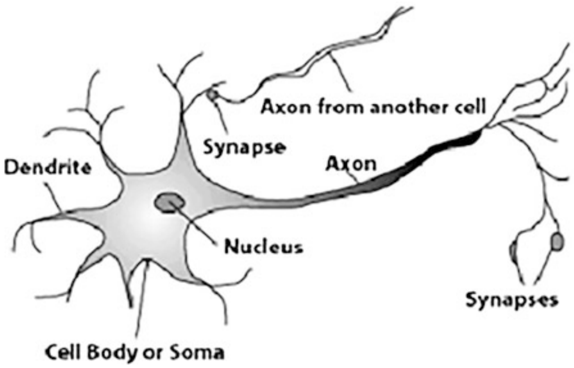


Fig. 1 Basic biological neuron

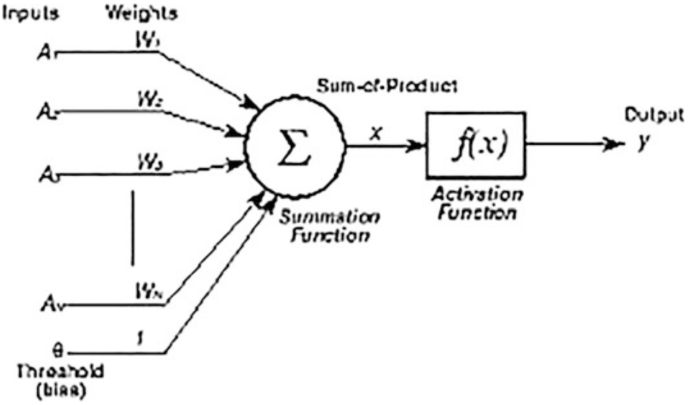


Fig. 2 Artificial neuron model

compilation of some potential which, in the case of the artificial neurons, is represented as a connection weight [4, 5]. These connection weights are modified continuously, based on the learning rules. When compared to biological neuron, the wires will replace the axon, the weight function will replace synapses and activity in soma is replaced by the activation function.

3 Data Used and Calculations

The maximum power that can be extracted from the wind turbine is given the mathematical formula described by Eq. (1) below

$$P = \frac{1}{2}\rho A C_P v^3 \tag{1}$$

In Eq. (1)

P Power that can be extracted from the wind.
ρ Air density.
A Area swept by the turbine blades.
C_p Coefficient of power.
V Velocity of the wind or simply wind speed.

For the calculation of wind power, the values for wind speed are taken from a report. Wind speed data for a place are taken on the monthly basis for a whole year. Average wind speed for each month of the year is shown in tabular form in Table 1. Air density is constant and its value is 1.23 kg/m^3. The most general rotor blade used in wind power plant has a radius of 52 m. Thus, the area swept by the blade will be calculated from the formula $A = \pi r^2$. The coefficient of power has a maximum value of 0.59, but its value varies with tip-to-speed ratio (λ). Tip-to-speed ratio is defined as the ratio of the blade tip speed and wind speed. Blade tip speed is defined by Eq. (2) shown below

$$\text{Blade tip speed} = \frac{\text{Rotational speed} * \pi * D}{60} \tag{2}$$

where D is the diameter of the rotor blade. Generally, the rotational speed of the turbine is between 15 and 20 rpm for the generation of power. For the calculation purpose, here, it is being taken as 15 rpm. The value of the coefficient of power is calculated manually for different tip-to-speed ratio value. The graph showing the variation of coefficient of power with the tip-to-speed ratio is shown in Fig. 3.

Table 1 Wind speed data on monthly basis over the year [6]

Sr. No	Month	Wind speed
1	January	5.0
2	February	5.6
3	March	6.3
4	April	8.3
5	May	10.1
6	June	12.1
7	July	13.9
8	August	12.5
9	September	9.8
10	October	5.9
11	November	5.8
12	December	6.5

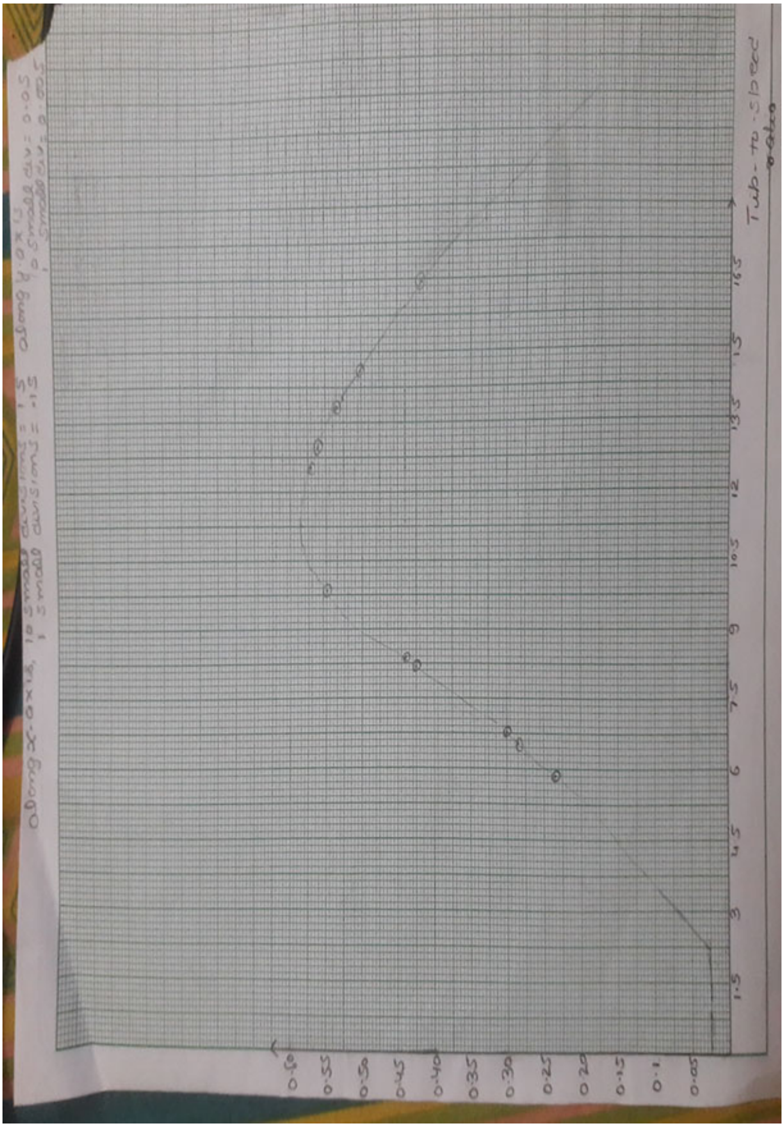


Fig. 3 Values of coefficient of power corresponding to the values of tip-to-speed ratio

Table 2 All calculated parameters (tip-to-speed ratio, coefficient of power and power output)

Sr. No	Wind speed (m/s)	Tip-to-speed ratio (λ)	Coefficient of power (C_p)	Power output (MW)
1	5.0	16.32	0.415	0.27
2	5.6	14.57	0.503	0.46
3	6.3	12.95	0.560	0.73
4	8.3	9.83	0.550	1.64
5	10.1	8.08	0.425	2.29
6	12.1	6.74	0.300	2.27
7	13.9	5.87	0.235	3.29
8	12.5	6.53	0.285	2.90
9	9.8	8.33	0.440	2.16
10	5.9	13.83	0.535	0.57
11	5.8	14.07	0.525	0.53
12	6.5	12.56	0.570	0.81

Thus, by knowing each parameter, the value of wind power is calculated by using Eq. (1) corresponding to each wind speed. Every calculated value in the tabular form is shown in Table 2.

4 System Modelling and Observations

After calculation of the parameters, the optimum values for power output are obtained by neural network toolbox in MATLAB. In neural network toolbox, the optimum values for power output are calculated by using wind speed, tip-to-speed ratio and coefficient of power as input variables individually and output power as output variable for each one of them. In this study, back proportion feed-forward algorithm is used for the calculation of optimum values. The mean square error curves for each case are shown in Figs. 4, 5, and 6, respectively.

The mean square error curves shown above are obtained after retraining the network multiple times. The network is retrained till the time the validation data curve becomes constant. These curves show the best validation performance of the data. The best performance is obtained after 19 iterations when wind speed is used as the input variable, after 30 iterations when the tip-to-speed ratio is used as the input variable and after 4 iterations when the coefficient of power is used as the input variable. The regression curves showing the relationship between the output and target for each case are shown in Figs. 7, 8, and 9.

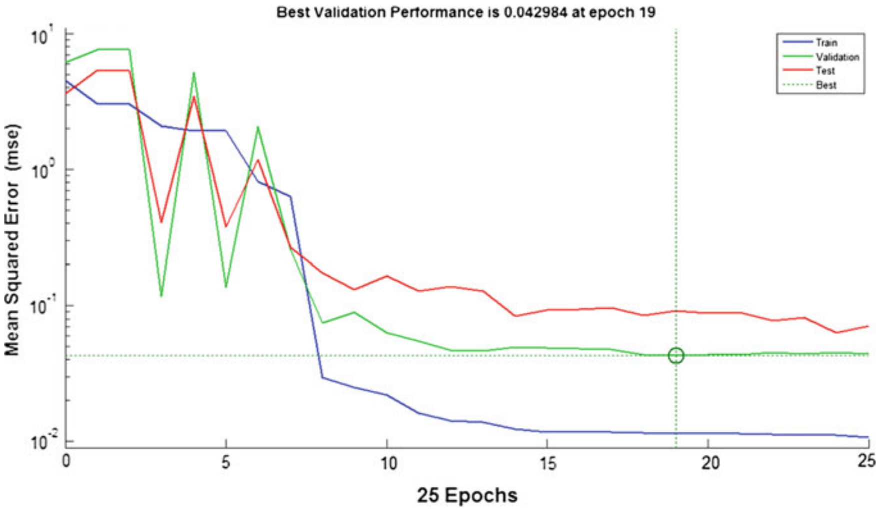


Fig. 4 Mean square error curve when only wind speed is used as an input variable

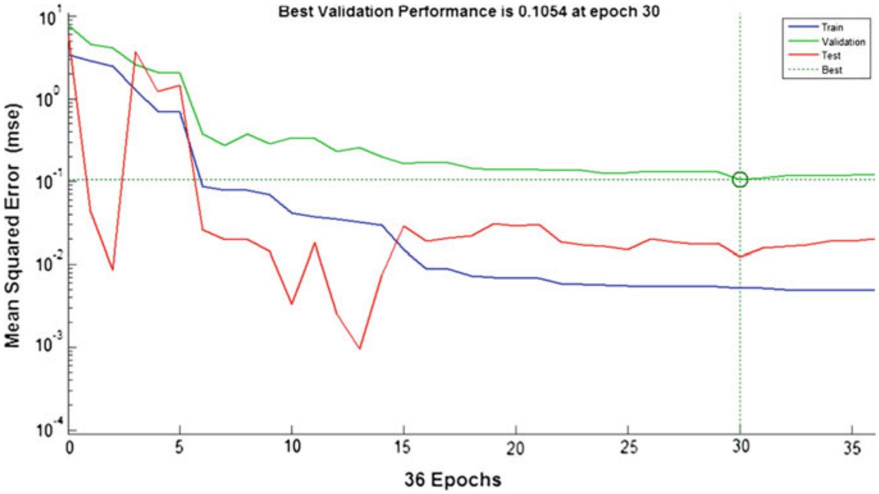


Fig. 5 Mean square error curve when only tip-to-speed ratio is used as an input variable

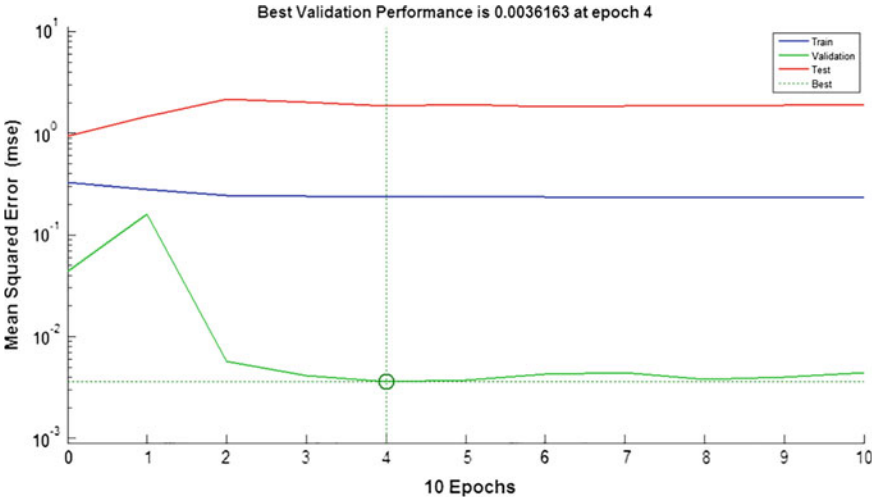


Fig. 6 Mean square error curve when only coefficient of power is used as input variable

The optimum values obtained for each of these cases are shown in Fig. 10.

Above values and curves are obtained when these input parameters are used individually. The best optimum value of the wind power can be obtained from neural network toolbox by using all these parameters as input variables together and power output as output variable because power depends upon these input variables. The mean square error curve, regression curve and the optimum values for this case are shown in Figs. 11, 12, and 13, respectively.

5 Results and Conclusions

The optimum values obtained from the whole data for each case are put in the tabular form in Table 3. From this research paper, it can be concluded that the artificial neural network (ANN) optimization technique can be helpful in finding the best optimum value of wind power by using multiple values of the wind. In this paper, monthly based data are used for different values of wind. For future work, data can be taken on yearly basis.

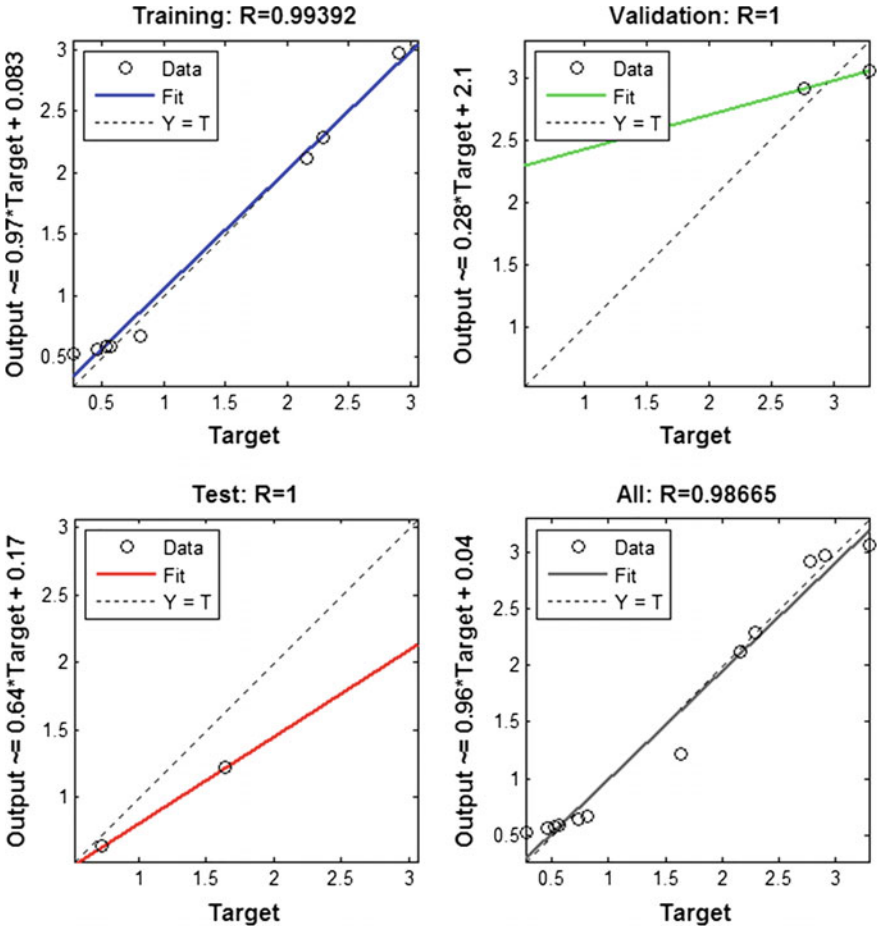


Fig. 7 Regression curve when wind speed is used as input variable

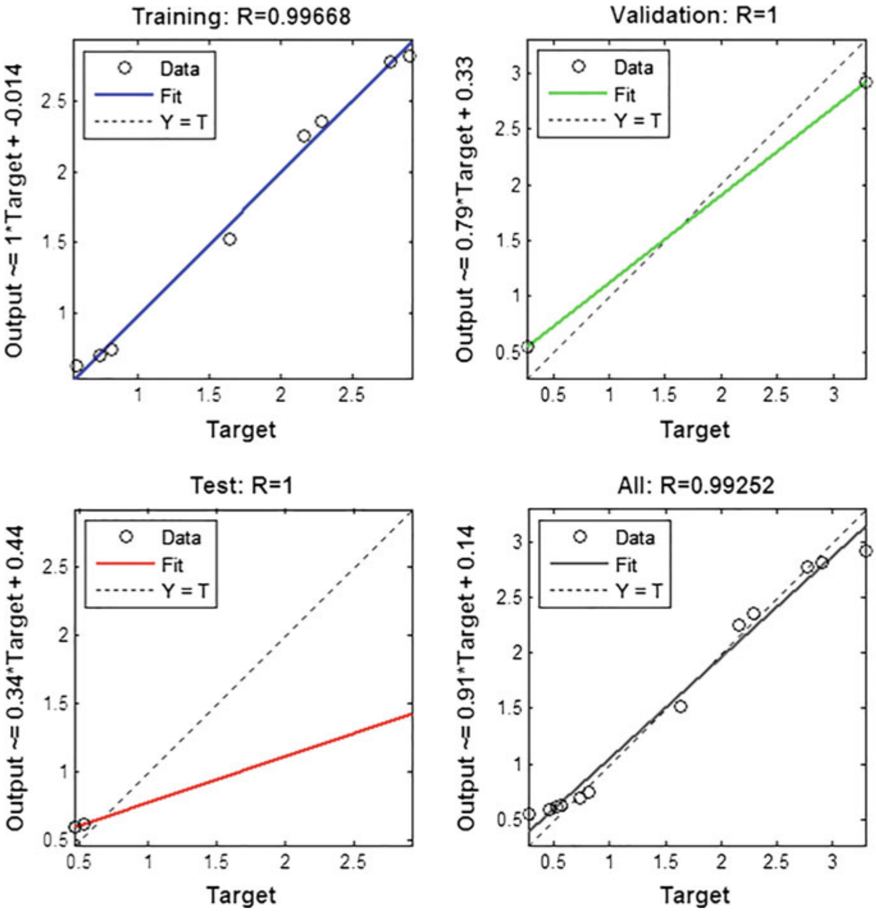


Fig. 8 Regression curve when tip-to-speed ratio is used as input variable

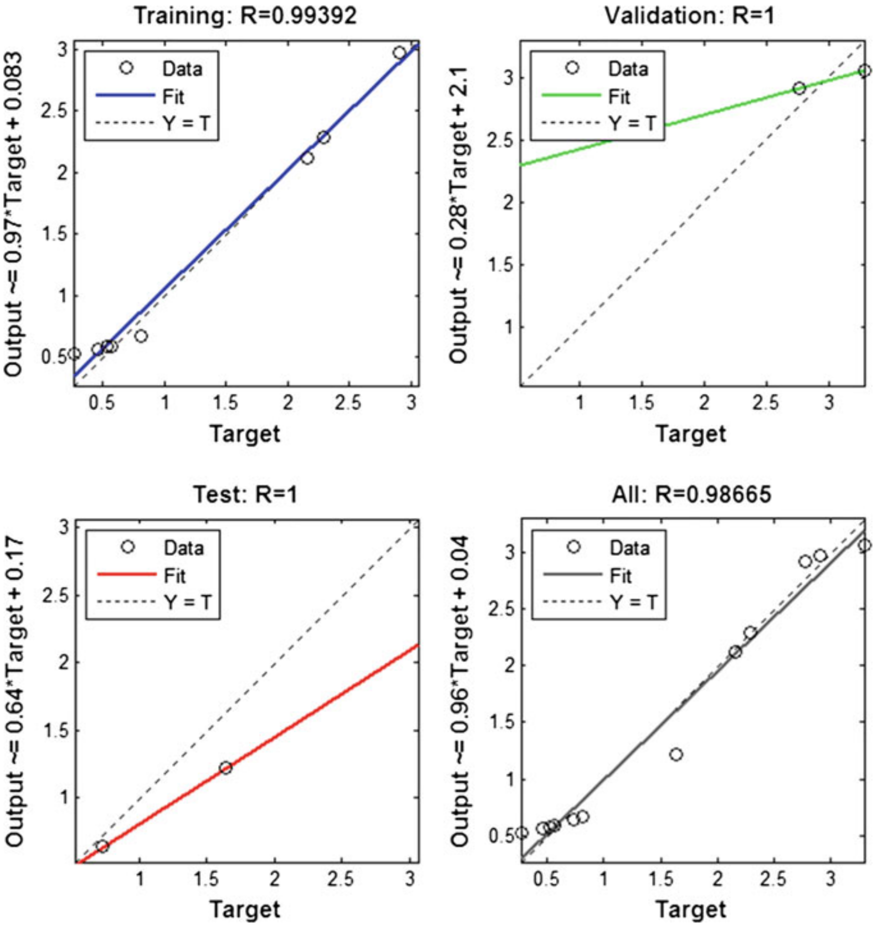
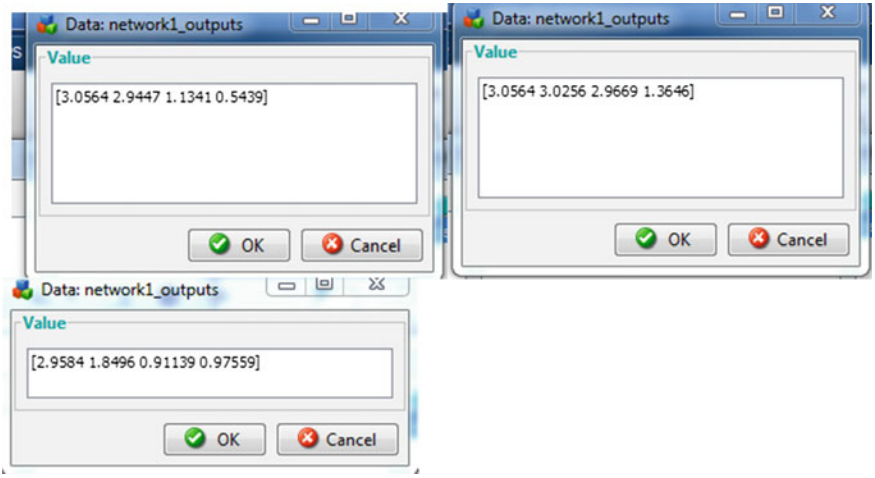


Fig. 9 Regression curve when coefficient of power is used as input variable



[3.0564 2.9447 1.1341 0.5439]

[3.0564 3.0256 2.9669 1.3646]

[2.9584 1.8496 0.91139 0.97559]

Fig. 10 Optimum values of the power obtained for the different cases

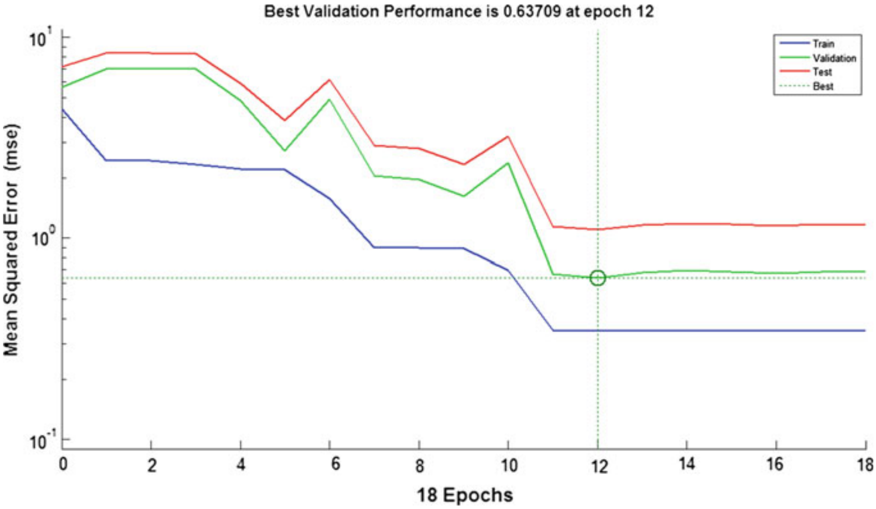


Fig. 11 Mean square error curve when all three are used as input variables

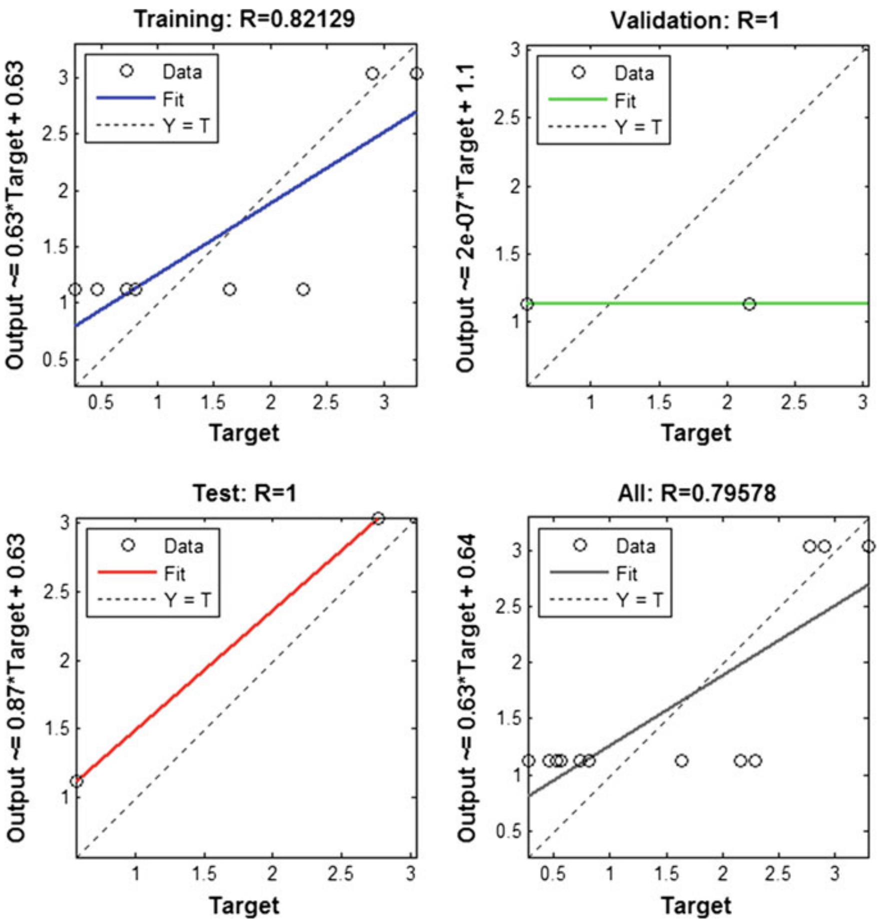
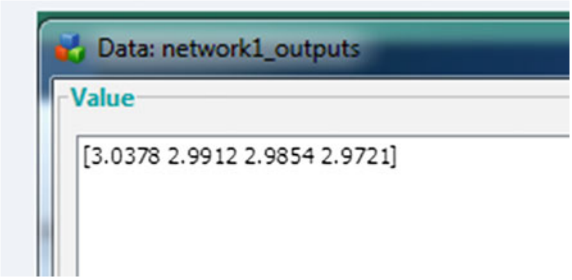


Fig. 12 Regression curve when all three are used as input variables

Fig. 13 Optimum value when all three are used as input variables



[3.0378 2.9912 2.9854 2.9721]

Table 3 Optimum values for all the different cases

Sr. No	For wind speed as input variable (MW)	For tip-to-speed ratio as input variable (MW)	For coefficient of power as input variable (MW)	When all are used as input variables (MW)
1	3.05	3.05	2.95	3.03
2	3.02	2.94	1.84	2.99
3	2.96	1.13	0.91	2.98
4	1.36	0.54	0.97	2.97

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