PREDICTION OF PERFORMANCE AND EMISSIONS OFCI ENGINE FUELLED WITH SUNFLOWER OIL AND ITS BLENDS WITH DIESEL USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT

In this modern era, alternate fuels for diesel engines are becoming increasingly important due to diminishing petroleum reserves and the environmental consequences of exhaust gases from petroleum fuelled engines. The use of ANN's for modeling the performance of IC engines is a more recent progress. ANNs is developed to predict the compression ignition engine performance. To acquire data for training and testing for the proposed ANN, four stroke diesel engine is fuelled with sunflower oil and diesel fuel blends in various proportions and operated at constant speed by varying loads. The two input variables are load and the percentage of sunflower blend with the conventional diesel fuel. The five outputs for evaluating engine performance are engine torque in Nm, specific fuel consumption (sfc) in kg/kW-hr, brake thermal efficiency and emissions of hydrocarbons and carbon monoxide. ANN model can accommodate multiple input variables to predict multiple output variables. The present work is the extension of work done by the same authors to the previous work of development of single network for multiple outputs prediction. Development of multiple networks to predict single output is attempted in the present work. Results show a better performance by the networks in the later approach.

Keywords: Artificial neural networks, Diesel engine, Emission parameters, Performance parameters, Regression coefficient.

I. INTRODUCTION

1.1 Utilization of Sunflower Oil as Fuel for Diesel Engine.

Due to gradual depletion of world petroleum reserves and the impact of environmental pollution of increasing exhaust emissions, there is an urgent need for suitable alternative fuels for use in diesel engines. In view of this, vegetable oil is a promising alternative because it has several advantages: it is renewable, environmental-friendly and produced easily in rural areas, where there is an acute need for modern forms of energy. Therefore, in recent years systematic efforts have been made by several researchers to use vegetable oils as fuel in engines. Sunflower is one of the leading oilseed crops cultivated for the production of oil in the world. It has also been considered as an important crop for biodiesel production, particularly in southern European countries. Numerous researches are working on suitability of sunflower oil as fuel in diesel engines and successful results were reported. Recep Altın et al. [1] investigated for performance and exhaust emissions of diesel engine with raw sunflower oil and other fuels and reported that sunflower oil is a promising alternative for diesel. Athanasios Balafoutis et al. [2] conducted experiments on agricultural tractor engine for performance and emissions with sunflower and other vegetable oils and their results showed decreased CO_2 emissions compared to other fuels.

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Turgut Ozaktas [3] carried out investigations on a Pancar motor E-108 type diesel engine with sunflower oil and reported satisfactory results compared to no. 2 diesel fuel. F Karaosmanoglu et al [4] examined the use of sunflower oil in diesel engine and inferred that sunflower oil replaces use of diesel oil up to some extent. All the research results are reported without any engine modifications and preheating or esterification is suggested to reduce viscosity and improve atomization. In the present investigation sunflower oil and its blends with diesel in various proportions are used as fuel.

1.2 Artificial Neural Networks and Their Application in the Field Of IC Engines.

An Artificial Neural Network (ANN) is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. Artificial Neural Networks has been motivated right from their inception by the recognition that the brain computes in an entirely different way from the conventional digital computers. Structure of biological neuron is presented in Fig.1

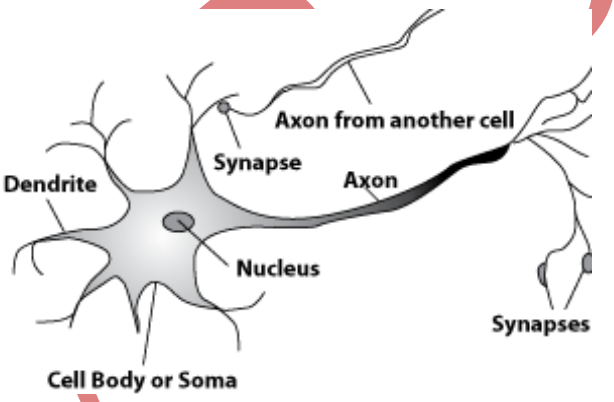


Fig.1 Structure of Biological Neuron

Following is the definition of an ANN viewed as an adaptive machine.

"Artificial Neural Network is a massive parallel distributed processor made up of simple processing units, which has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects:

(1) Knowledge is acquired by the network from its environment through a learning process.

(2) Inter-neuron connection strengths, known as synaptic weights, are used to store the acquired knowledge".

A neuron is an information processing unit that is fundamental to the operation of a neural network. The block diagram of Fig.2 shows the model of a neuron, which forms the basis for designing artificial neural networks.

1.3 The Three Basic Elements Of The Neuron Model Are

1. A set of **synapses**, each of which is characterized by a weight or strength of its own. A signal x_j at the input of synapse j connected to neuron k is multiplied by the synaptic weight w_{kj}. The first subscript refers to the neuron

in question and the second subscript refers to the input end of the synapse to which the weight refers. The synaptic weight of an artificial neuron may lie in a range that includes negative as well as positive values.

2. An **adder** for summing the input signals, weighted by the respective synapses of the neuron.

3. An **activation function** for limiting the amplitude of the output of a neuron. The neuronal model of Fig.2 also includes an externally applied bias, denoted by b_k. The bias b_k has the effect of increasing or lowering the net input of the activation function, depending on whether it is positive or negative, respectively.

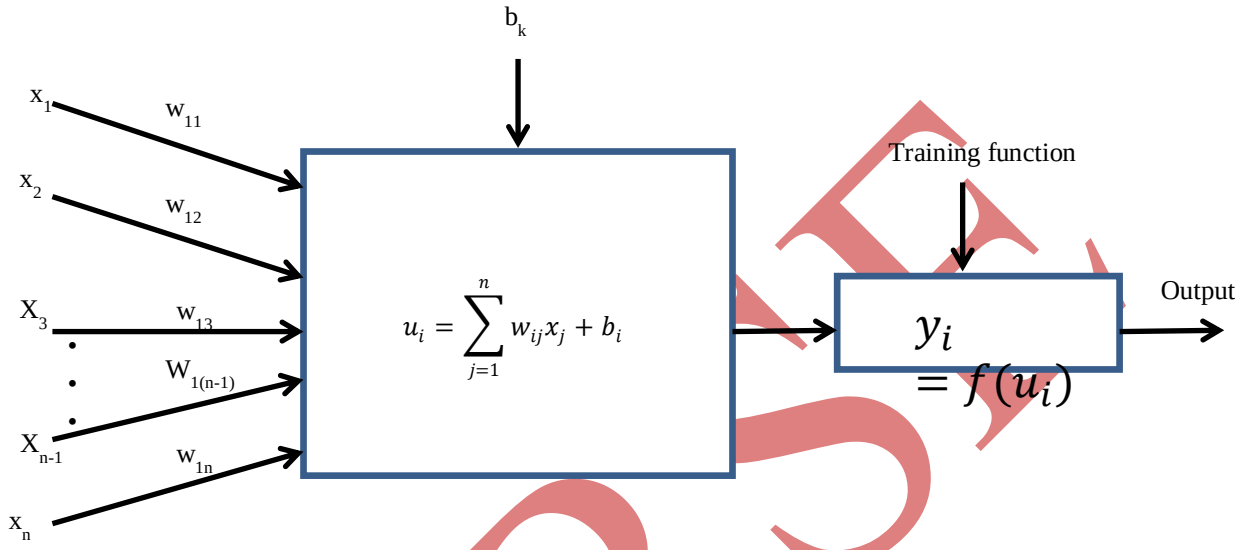


Fig.2 Structure of Artificial Neuron

ANNs are used in various aspects in the field of IC engines such as for prediction of parameters nbby function approximation, fault diagnosis, monitoring and control etc. Several investigations were carried on applications of ANNs for IC engines as presented below.

Sarala et al.Senthil kumar et al. [5,6] conducted experiments on CI and developed ANN to predict performance and emissions with BPNN algorithm and good correlation coefficient was achieved. Further many researchers developed ANNs for prediction of various performance and emission parameters like torque, bsfc, brake thermal efficiency and reported that ANNs are best candidates to perform prediction tasks [7,8,9]. Yusuf Cay et al. [10] experimented with SCG (scaled conjugate Gradient) and LM (Levennberg-Marquardt) training functions by varying number of neurons and finally developed best network was identified with 6 hidden nodes with LM training function as it gave correlation coefficient of 0.999931.

In this paper ANN is developed and trained with BP algorithm and used to predict performance and emission parameters of a diesel engine.

II. EXPERIMENTAL SETUP AND MEASUREMENTS

A single cylinder Direct Injection type four Stroke water cooled vertical diesel engine test rig developing 3.5 kilo Watts at approximately 1500 RPM is coupled to AC alternator with loading bank for experimentation purpose. AC alternator is fixed to engine flywheel and the engine is mounted on a mild steel channel frame and further mounted on anti-vibration mounts. Panel board is used to fix the burette with 3-way cock, digital RPM indicator and u-tube manometer. Load is varied by varying resistance. The fuel is supplied from the main fuel tank to the measuring burette. An air drum is fitted on the panel frame and connected to engine through an air

base. The air drum facilitates a magnified orifice and pressure pick up points are connected to end u-tube manometer limbs. The difference in manometer readings is taken at different loads.

Emissions CO and HC are measured using a gas analyzer which measures with a good accuracy.

2.1 Experimental Setup, Materials and Methodology

Experiment was carried out with various blends on 4-s C.I engine at 6 load settings. Engine was run with each fuel/blend for duration of 2 hours and each load setting for 20 minutes. Each reading was noted 3 times and averaged for accuracy. Fig.3 shows experimental setup used for investigations followed by engine specifications.

Fig 3. Experimental Setup

2.2 Engine Specifications

Make	:	Kirloskar
BHP	:	5 hp
Bore	:	80 mm
Stroke	:	110 mm
Speed	:	1500 RPM
Method of cooling	:	Water Cooled
Air Drum Orifice Dia	:	20 mm
Type of ignition	:	Compression Ignition
Method of loading	:	Electric dynamometer.
Maximum Load	:	12.5 Amp

Experiments were carried with eight different proportions of diesel, sunflower oil combinations as fuels which are given below.

1. 0% of sunflower oil and 100% of diesel
2. 10% of sunflower oil and 90% of diesel
3. 20% of sunflower oil and 80% of diesel
4. 25% of sunflower oil and 75% of diesel
5. 30% of sunflower oil and 70% of diesel

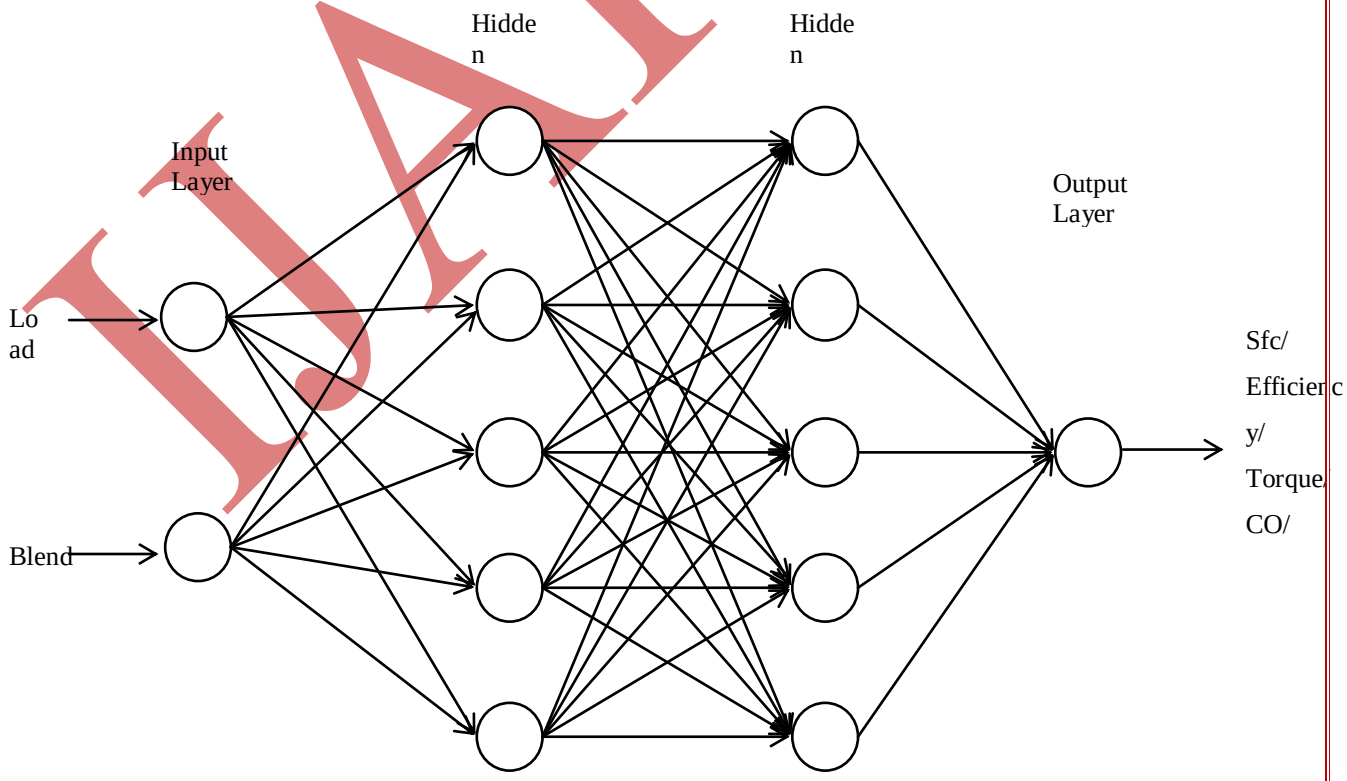
6. 40% of sunflower oil and 60% of diesel
7. 50% of sunflower oil and 50% of diesel
8. 100% of sunflower oil and 0% of diesel

With each fuel, steady state short term tests were conducted at six load settings over entire range of engine operation and observations were recorded for emissions and to calculate performance parameters. Short term experiments were conducted to collect data. For accuracy each observation is recorded three times and averaged. Using conventional formulae, brake specific fuel consumption, torque and brake thermal efficiency were calculated. An exhaust gas analyzer is used to record CO and HC emissions.

III DEVELOPMENT OF ANN FOR PREDICTION OF PARAMETERS

The artificial neural networks (ANN) are used to create such computationally efficient models. This technique of ANN is an application that alters certain variables in response to a set of corresponding input and output patterns. In the present work, back propagation neural network is developed with number of nodes in hidden layers and training rule are varied to arrive at best configuration. From the experiment 48 sets of data were obtained. 40 sets were used for training and 8 sets were used for testing. Two inputs to the network are percentage of sunflower oil in the blend and load on the engine. Five outputs are sfc (specific fuel consumption), torque, brake thermal efficiency, CO and NO_x. Five different neural networks with two hidden layers are developed to predict each output parameter. Further in each network number of nodes in hidden layers are varied from 5-7. Two training rules are used namely gda and gdm.

Fig.4 indicates the structure of neural network developed.



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Before training, it is often useful to scale the given data so that they always fall within a specified range which facilitates network for better training. Data is normalized in the range [-1 1] by using formula given in equation (1).

$$y = \left(\frac{y_{max} - y_{min}}{x_{max} - x_{min}}\right) * (x - x_{min}) + y_{min} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Performances of networks are presented in the next section.

IV RESULTS AND DISCUSSIONS

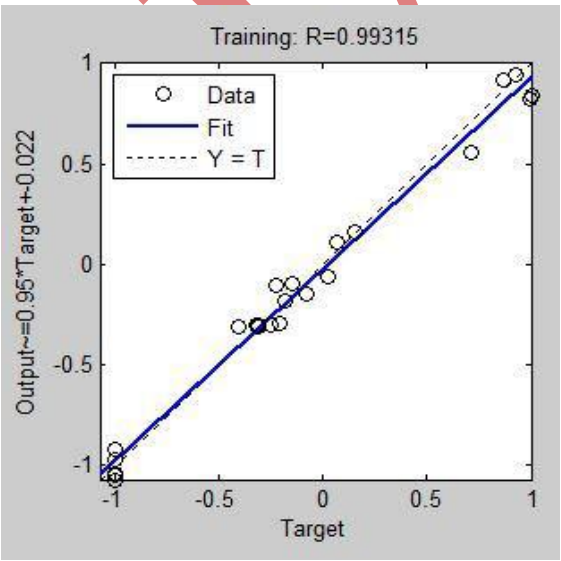
Variation of correlation coefficient with number of nodes in hidden layer is presented in the form of the tables and graphs.

4.1 Prediction of specific fuel consumption from ANN

Table.1 shows variation of correlation coefficient with no. of neurons in hidden nodes. The best regression value is obtained with the combination of 7, 5 nodes in hidden layers with the regression value of 0.98609. Training, testing, validation and over all regression are shown in graphs from figures 4-7.

Table.1 Performance of various networks to predict Specific Fuel Consumption

S.No	Activation Function	Hidden Layer 1		Hidden Layer 2		R
		Training rule	No. of Neurons	Training rule	No. of Neurons	
1.	Tansig/purelin	gda	5	gda	5	0.9276
2.	Tansig/purelin	gda	6	gda	5	0.9114
3.	Tansig/purelin	gda	6	gda	6	0.92906
4.	Tansig/purelin	gda	7	gda	5	0.98609
5.	Tansig/purelin	gdm	7	gdm	7	0.8762



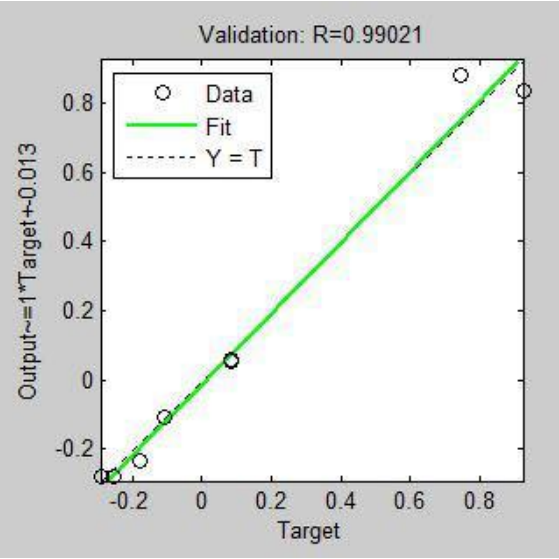


Fig.4 Regression analysis of training of BPNN **Fig.5 Regression analysis of validation of BPNN**

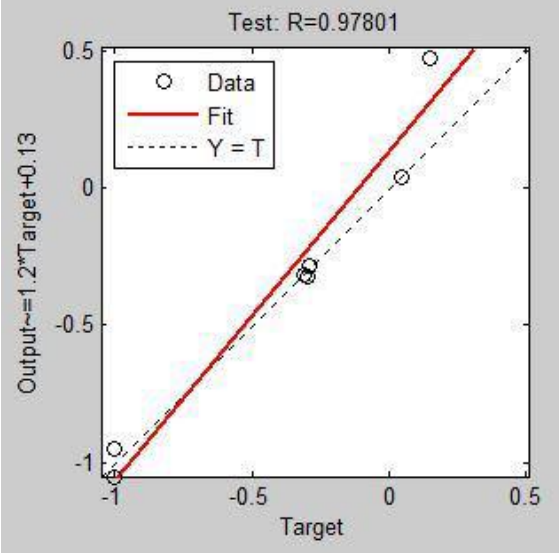


Fig.6 Regression analysis of test of BPNN

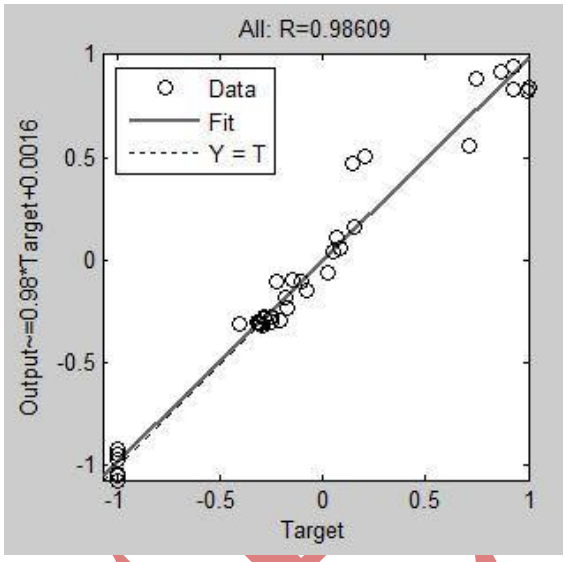


Fig.7 Overall regression analysis of BPNN

4.2 Prediction of Brake Thermal Efficiency from ANN

Table 2 shows variation of correlation coefficient with no. of neurons in hidden nodes. The best regression value is obtained with the combination of 5, 5 nodes in hidden layers with the regression value of 0.99007. Training, testing, validation and over all regression are shown in graphs from figures 8-11.

Table 2: Performance of Various Networks To Predict Break Thermal Efficiency

S.No	Activation Function	Hidden Layer 1		Hidden Layer 2		R
		Training rule	No. of Neurons	Training rule	No. of Neurons	
1.	Tansig/purelin	gda	5	Gda	5	0.99007
2.	Tansig/purelin	gda	6	gda	5	0.9714
3.	Tansig/purelin	gda	6	Gda	6	0.9309
4.	Tansig/purelin	gda	7	Gda	5	0.9530
5.	Tansig/purelin	gda	7	Gda	7	0.9554

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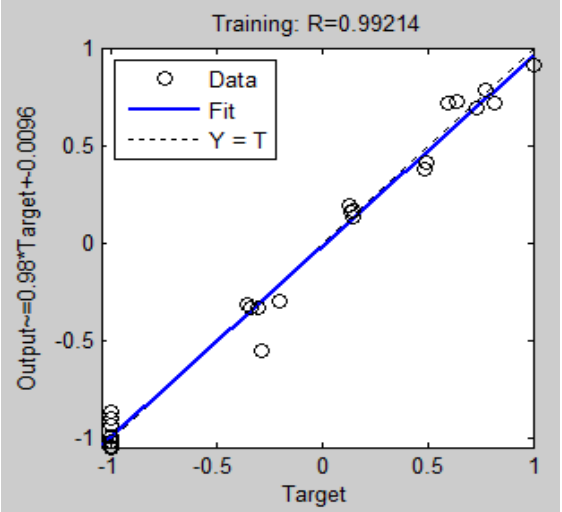

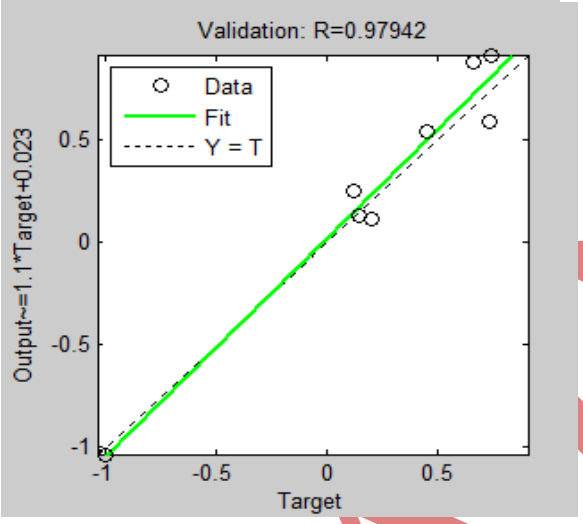

Fig.8 Regression analysis of training of BPNN Fig.9 Regression analysis of validation of BPNN

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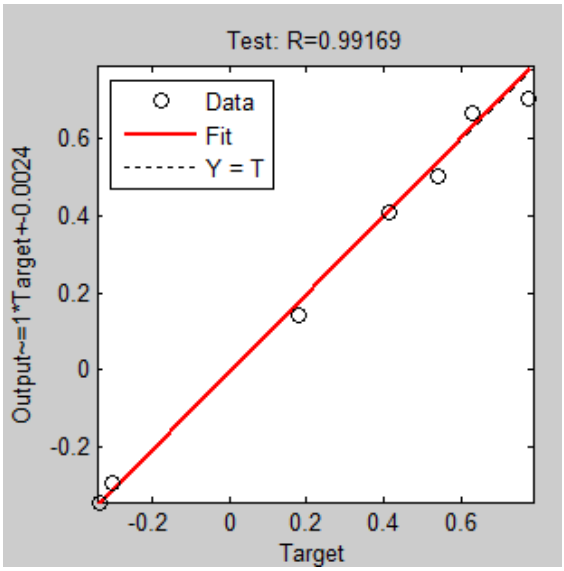


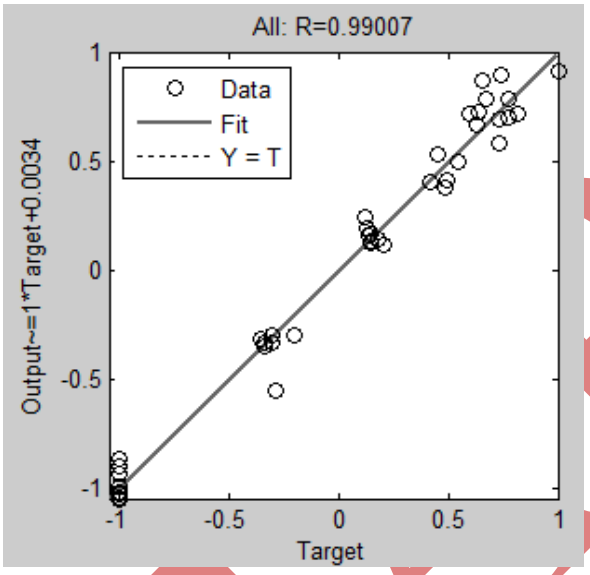


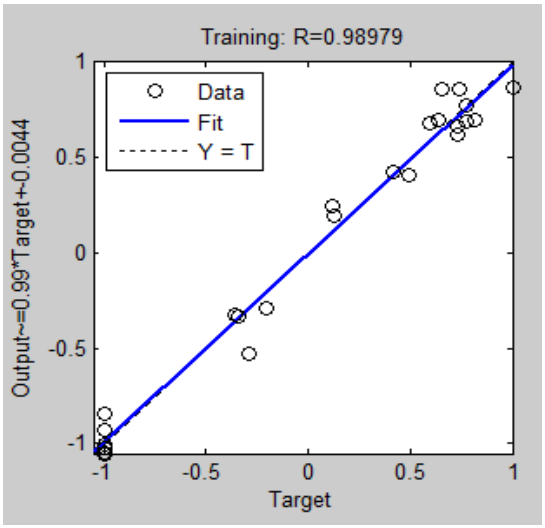
Fig.10 Regression analysis of test of BPNN **Fig.11 Overall regression analysis of BPNN**

4.3 Performance of Various Networks to Predict Torque

Table.3 shows variation of correlation coefficient with no. of neurons in hidden nodes. The best regression value is obtained with the combination of 5, 5 nodes in hidden layers with the regression value of 0.99022. Training, testing, validation and over all regression are shown in graphs from figures 12-15.

Table 3: Performance of various networks to predict torque:

S.No	Activation Function	Hidden Layer 1		Hidden Layer 2		R
		Training rule	No. of Neurons	Training rule	No. of Neurons	
1.	Tansig/purelin	gda	5	gda	5	0.99022
2.	Tansig/purelin	gda	6	gda	5	0.9707
3.	Tansig/purelin	gda	6	gda	6	0.9596
4.	Tansig/purelin	gdm	7	gdm	5	0.9564
5.	Tansig/purelin	gda	7	gda	7	0.9581



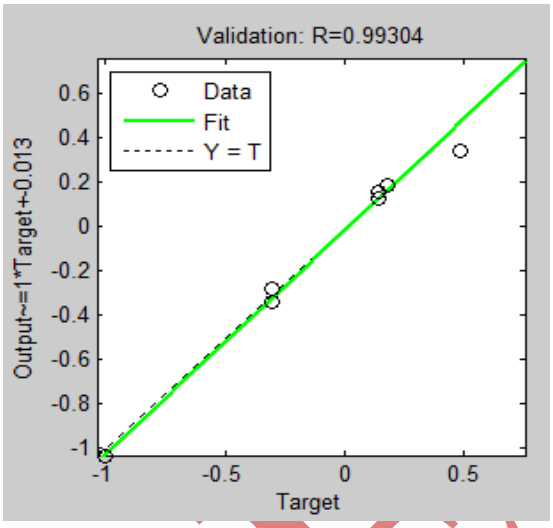
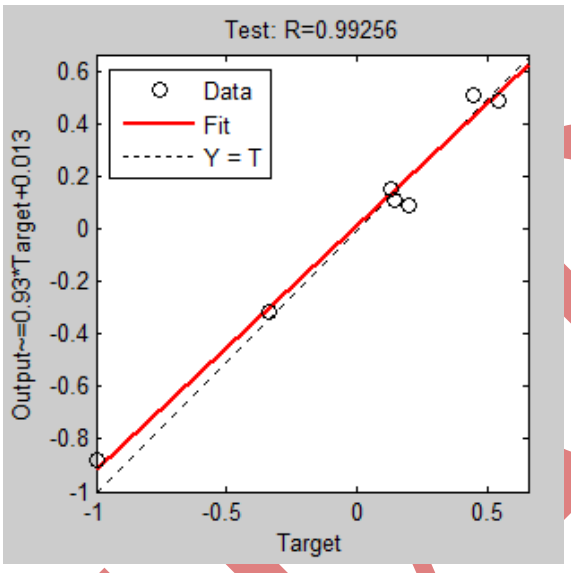


Fig.12 Regression analysis of training of BPNNFig.13 Regression analysis of validation of BPNN



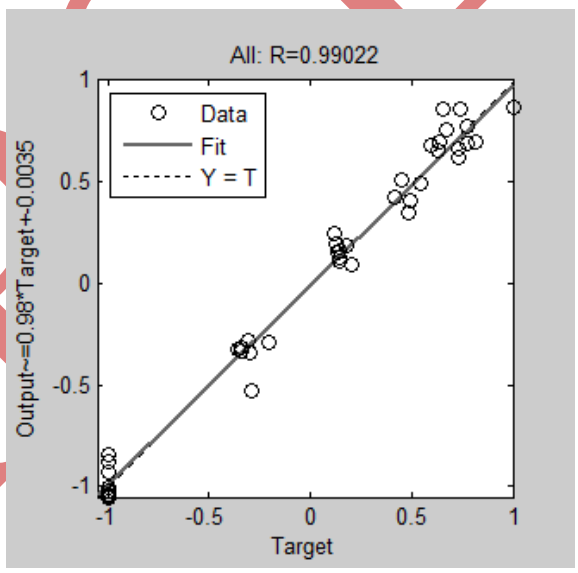


Fig.15 Overall regression analysis of BPNN **Fig.14 Regression analysis of test of BPNN**

4.4 Performance of Various Networks to Predict CO

Table 4 shows variation of correlation coefficient with no. of neurons in hidden nodes. The best regression value is obtained with the combination of 5, 5 nodes in hidden layers with the regression value of 0.98998. Training, testing, validation and over all regression are shown in graphs from figures 16-19.

Table 4: Performance of various networks to predict CO

S.No	Activation Function	Hidden Layer 1		Hidden Layer 2		R
		Training rule	No. of Neurons	Training rule	No. of Neurons	
1.	Tansig/purelin	gda	5	gda	5	0.98998
2.	Tansig/purelin	gda	6	gda	5	0.9714
3.	Tansig/purelin	gda	6	gda	6	0.9309
4.	Tansig/purelin	gda	7	gda	5	0.9530
5.	Tansig/purelin	gda	7	gda	7	0.9554

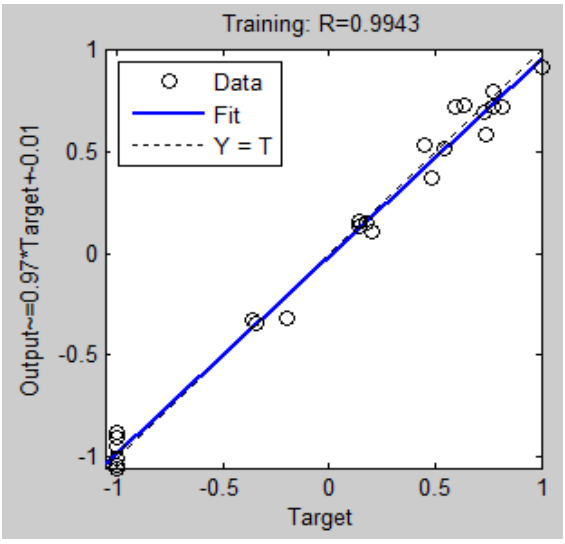


Fig.16 Regression analysis of training of BPNN

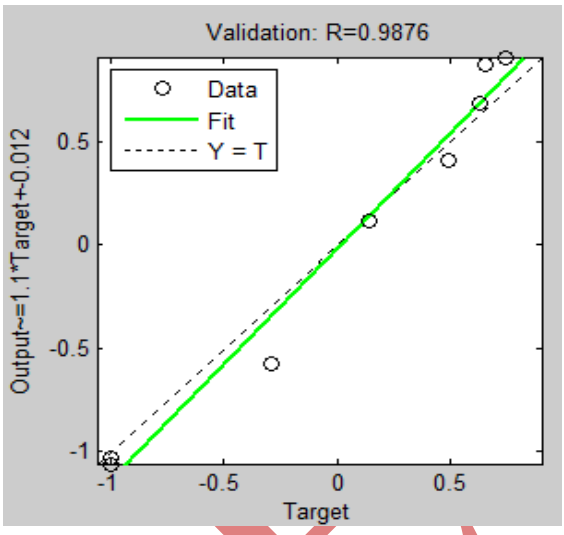


Fig.17 Regression analysis of validation of BPNN

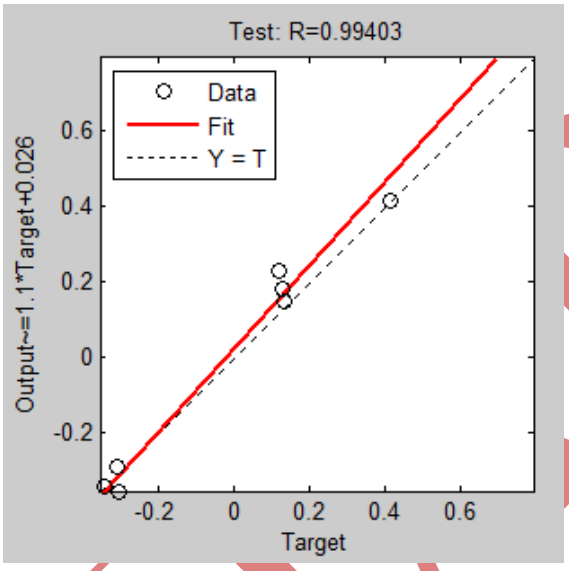


Fig.18 Regression analysis of test of BPNN

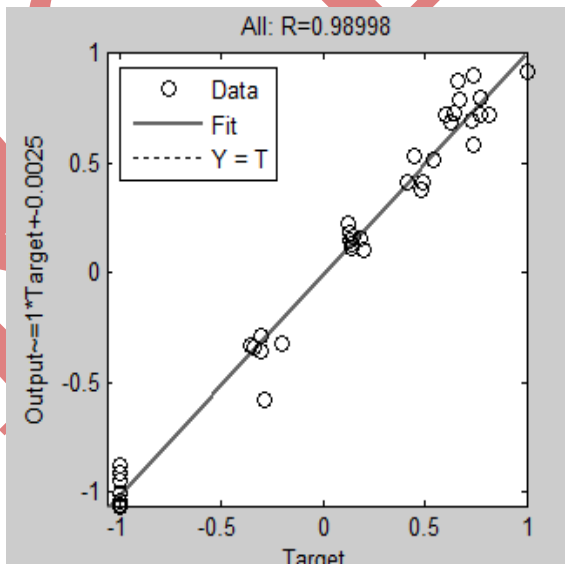


Fig.19 Overall regression analysis of BPNN

4.5 Performance Of Various Networks To Predict (HC)

Table 5 shows variation of correlation coefficient with no. of neurons in hidden nodes. The best regression value is obtained with the combination of 7, 7 nodes in hidden layers with the regression value of 0.979. Training, testing, validation and over all regression are shown in graphs from figures 20-23.

Table 5: Performance of various networks to predict HC:

S.No	Activation Function	Hidden Layer 1		Hidden Layer 2		R
		Training rule	No. of Neurons	Training rule	No. of Neurons	
1.	Tansig/purelin	gda	5	gda	5	0.9025
2.	Tansig/purelin	gda	6	gda	5	0.9012
3.	Tansig/purelin	gda	6	gda	6	0.99022
4.	Tansig/purelin	gda	7	gda	5	0.98998
5.	Tansig/purelin	gda	7	gda	7	0.979

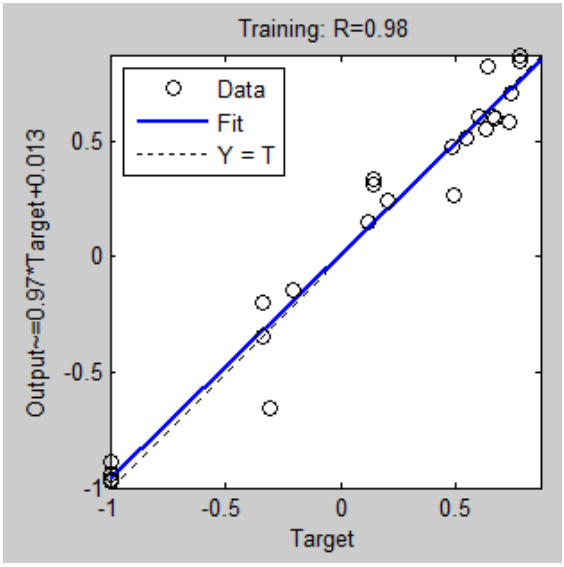


Fig.20 Regression analysis of training of BPNN

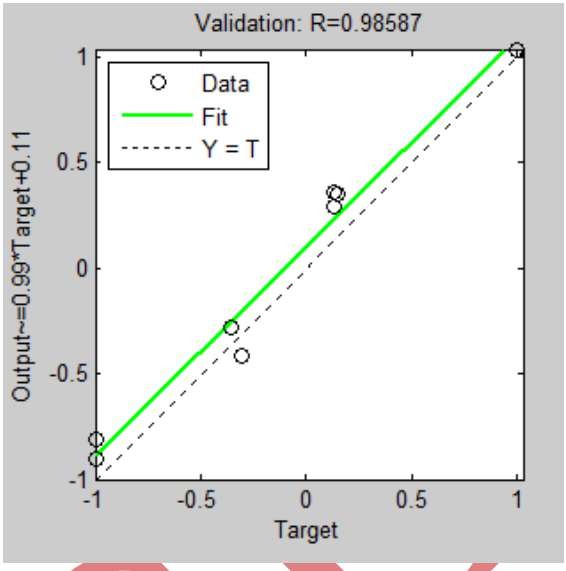


Fig.21 Regression analysis of validation of BPNN

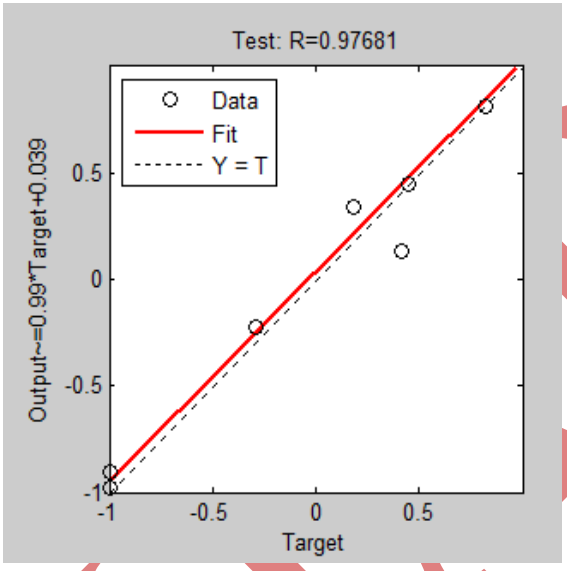


Fig.22 Regression analysis of test of BPNN

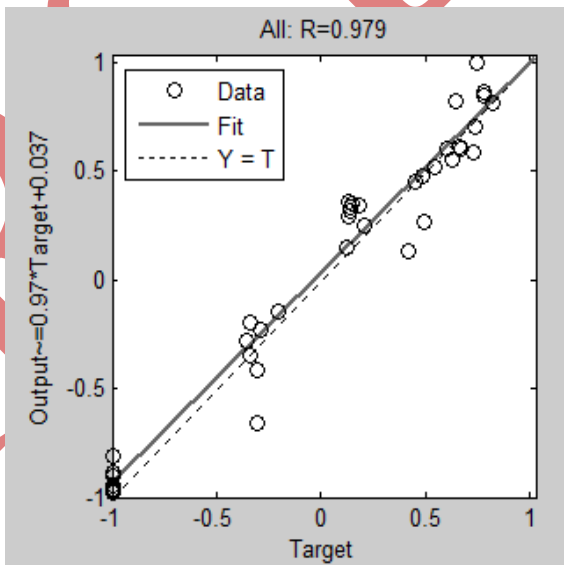


Fig.23 Overall regression analysis of BPNN

Table 6: Summary of Five Different Network Parameters

S.No	Parameter	Hidden Layer 1		Hidden Layer 2		R
		Training rule	No. of Neurons	Training rule	No. of Neurons	
1.	Sfc	gda	7	gda	5	0.98609
2.	Brake thermal efficiency	gda	5	gda	5	0.99077
3.	Torque	gda	5	gda	5	0.99022
4.	CO	gda	6	gda	6	0.98998
5.	HC	gda	7	gda	7	0.979

V CONCLUSIONS

The suitability of ANNs for prediction of engine performance and emission parameters has been investigated. Percentage of sunflower oil with diesel in the fuel blend and load on the engine are the two inputs. Contrary to

previous investigations, different networks are developed for each output. From the analysis of results, it may be observed that gda training rule is best suited for the purpose of prediction. Different parameters are predicted with more accuracy, with different number of hidden nodes in 2- layers. Further correlation coefficient for various outputs ranges from 0.979-0.99007. Authors had developed a single network to predict five outputs with the same data. In such case regression coefficient for CO is 0.89137, whereas single output network can predict same parameter with 0.979 of regression coefficient.

Hence it may be concluded that for certain type and nature of data multiple networks with single output are best suited than single network with multiple outputs.

VI SCOPE FOR FUTURE WORK

The present work may be extended to develop networks with more number of algorithms and training functions.

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