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Parameter Optimization Using ANN for CI Engine with SCR

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Abstract

This paper deals with the optimization of six chosen parameters such as load, clearance of piston head, number of holes in nozzle, pressure of injection, catalysts used for reduction and oxidization in order to improve performance and minimize emissions like carbon mon oxide and oxides of nitrogen from CI engine equipped with Selective Catalytic Reduction (SCR). Artificial Neural Networks (ANN) is ultilized for the purpose of optimization. The optimized parameter set is found using a trained network. The experimental outputs are compared with the output predicted by the ANN and the results are discussed. This optimized parameter set when used in engine is found to improve performance of the engine and decrease harmful emission produced from the engine thus promoting a cleaner environment.

Keywords: CI engine; SCR; ANN; Optimization; Emission

Introduction

The heat created during compression in an internal combustion engine is utilised to ignite the fuel, which is delivered into to the combustion chamber during the last stage of compression. The Diesel cycle is the foundation for the construction of a diesel engine. The diesel engine has the highest thermal efficiency of any conventional IC engine or EVC engine in the market due to its exceptionally high compression ratio. Low-speed diesel engines (used on ships and many other applications in which total engine weight is not a major consideration) frequently achieve thermal efficiencies in excess of 50%. The fuel's chemical energy is transformed into mechanical energy by the diesel engine (moving the piston up and down inside closed spaces called cylinders) [1]. The pistons are linked to the engine crank shaft, which converts the reciprocating action of the pistons into the rotational motion required to drive the vehicle wheel forward. At maximum loading condition, diesel engines emit relatively low carbon monoxide because they let the burning of fuel take place in extra air, even if the amount of fuel being injected during each cycle is about 50 percent less than their stoichiometric ratio. They may, however, emit soot particles (or, more precisely, diesel PM) as a byproduct of their combustion. Because of the low temperatures in the area where the fuel has not been completely atomized, the black smoke contains carbon molecules that were not combusted, resulting in the formation of black smoke [2].

Low temperatures are seen near the cylinder walls as well as on the exterior of big drops of fuel. The charge is particularly rich in these regions since they are very cold (in contrast with the lean overall mixture). Because the rich fuel-air combination has relatively lower amount air to burn, some of the fuel is converted to carbon deposits. In modern automobile engines, carbon particles are collected by a Diesel Particulate Filter (DPF), which are then burned at regular intervals with additional fuel that is fed directly into the DPF. This helps to minimise carbon buildup at the cost of a tiny amount of fuel being wasted in the process.As the need for fuel is growing disproportionately over time coupled with increased cost and the fuel resources are fast depleting, there is alarming need for its conservation. Euro and Bharat norms clearly indicate the need for reduction in harmful emissions such as (NOx and CO). Although there are no stringent norms for stationary engines bellow 8 HP, reduction in these emissions will conserve the environment as such engines are widely used for agricultural applications. This has paved way for this work [3].

Artificial Neural Network

ANN stands for Artificial Neural Network, and it is a kind of paradigm used process information that is based on the way organic nerve systems, like the brain, process data. It is the information processing system's one-of-a-kind structure that is the distinguishing feature of this paradigm. It is composed of a number of processing components. (Neurons) that are highly linked and work together to solve particular issues in a coordinated fashion. ANN, like all humans, learns by watching others. An artificial neural network (ANN) is trained to perform a particular task, such as recognition of pattern or categorization of data, via a learning process [4]. Changes in synaptic connections which happen across neurons are involved in the process of learning in biological systems. This is also true in the case of ANN. It is possible to utilise neural networks, which have a remarkable capacity to draw meaning from difficult or ambiguous data, to observe patterns and identify trends from data that is too complex to be detected by people or other computer methods. A neural network which is trained may be regarded as an "expert" in the field of data it was trained with, and this is true regardless of how it was taught. Once a new scenario of interest is identified, this expert may be utilised to offer predictions and to answer hypothetical queries such as, "what if?" Other benefits are as follows:

- A capability to understand how to do a job depending on the data provided for the purpose of training or first experience is referred to as adaptive learning.
- Self-Organization: An ANN has the ability to organise or to reflect the data it receives throughout learning time in its own way.
- Operation in Real-time: Calculations in ANN can be carried out parallelly, and specific hardware devices are currently developed and brought into market to take advantage of this capacity.
- Tolerance to Fault through Robust Information Coding: When a network is partially destroyed, the performance of the network suffers as a result of the resulting deterioration. Some network

capabilities, on the other hand, may be maintained even if the network has been severely damaged.

Methodology

A single-cylinder, four-stroke, 5.968 kW Kirloskar diesel engine with a brake drum that measures 0.2242 metres in width is used for the investigation. The engine also has a injector nozzle with three-hole with 1.4 mm clearance of piston head and 170 bar injection pressure (factory settings). Full factorial test (testing all possible combinations) is proposed to be conducted on the engine. The sequence of steps to optimize diesel engine parameters is specified bellow,

- Obtaining information on the engine's performance and exhaust emissions (output).
- Choosing the parameters for optimization.
- Selecting the operating range of variation of each parameter.
- Measuring the output of the engine by varying the selected parameters.
- To create a model in ANN.
- To create quadratic model to relate input and output.
- Optimizing using GA by the model created for general and specific loads.
- Predicting the output for input suggested by GA through ANN.
- Implementation of the optimum parameters for general specific loads for maximum performance and minimum emission.
- Confirming the prediction through experiments.

Parameter selection

The following parameters were chosen based on previous research. The parameters were varied based on engine operating range, price and availability.

Parameters	Level 1	Level 2	Level 3
Number of holes in Nozzle	3	4	3 and 4
Clearance of piston head (mm)	1.2	1.4	1.6
Injection pressure (bar)	160	170	180
Load (kg)	3	6	9
Oxidization catalyst	MgO	CH_3COOH	CuO
Reduction catalyst	V_2O_5	WO_3	W_2O_3

Table 1: Parameters variation.

The variation of the selected parameters shown in Table 1 is discussed below.

Nozzle holes (NOH): As manufacturing a nozzle for an application with specific number of holes is complicated. Hence three hole and four hole nozzle which is readily available are used.

Piston head clearance (PHC): The piston head clearance was changed by changing the gasket between the head of the piston and the cylinder block, the gaskets measuring 1.2 mm, 1.2 mm and 1.6 mm were used. The choice of gaskets is made in accordance with availability and the operating range of the engine [5].

Injection pressure (IP): The injection pressure is varied from 160 bar to 180 bar with 10 bar interval the nozzle was set for this pressure using a nozzle tester. The injection pressure was selected in harmony with the operating range of the engine.

Load (L): The maximum load of the engine setup is 12 kg, as that load may damage the engine lower loads are selected. Arbitrarily 25%, 50% and 75% of maximum load are selected.

Oxidization catalyst (DOC): Magnesium oxide, Anhydrous acitic oxide and Cupric oxide are selected based on cost and availability.

Reduction catalyst (SCR): Catalysts such as vanadium pentoxide, platinum, tungsten oxides, and zeolites are examples of materials that may be used. Generally, the working temperature of the catalyst is more than 200°C, and the operating pressure has only a small impact on the overall performance of the catalyst. On the basis of cost and availability, vanadium pentoxide, tungsten (III) oxide, and tungsten trioxide are chosen as catalysts. In this study, a full factorial design was used to test the effect of varying the parameters. In order to achieve the maximum number of possible engine settings, the chosen parameters must be varied in the 486 (2×3^5) ways.

Analyzing performance and emissions using artificial neural networks as a predictive tool

The combustion process and the formation of emissions are fundamentally nonlinear, and standard mathematical models are unable to provide satisfactory answers. In real time, Artificial Neural Networks (ANNs) may be used for diagnostics, modelling, control, and optimization. They are capable of detecting non-linearity in controller parameters and may be utilized to enhance system performance. A unique learning capacity of ANNs allows them to retrieve the necessary information straight from the data they are presented with. In a complicated situation, they have the ability to learn from nonlinear data. and predicting the required values with a high degree of accuracy. Ordinarily, an ANN has three layers: an input layer, many hidden layers, as well as an output layer [6].

The data from input layer is analyzed in one of the hidden layer, and the output vector is generated in the output layer. The hidden layer and the output layer almost always include activation functionality. To its input patterns, the Sigmoid activating function applies a sigmoid transfer function, which is a suitable non-linear element to use in the construction of the hidden layers of a neural network. A layer of this kind is referred to as the sigmoid layer in this context. The training phase is required when incorporating a neural network. During the training step. The network is fed an input along with the intended output, the values of bias and weights are selected at random, and the values are modified such that the network tries to generate the desired output. Whenever a satisfactory performance level (a performance goal value of 0.001) is reached, the training is finished, and the network makes decisions depending on the values learnt during training. A neural network can learn to resolve issues by simply shifting its interconnections (biases of the preferred weights and Output Layer) as well as back-propagating the difference between current output of the neural network with that of the desired outcome. This is known as supervised learning. In the training method, a virtual point is moved around a multidimensional error surface until a satisfactory minimum is achieved, in order to find the optimum mix of weights or network biases.

It changes the bias of the Layers and the weight of the Synapses in accordance with the gradient computed by the instructor neuron, and it is transmitted backward via the backward-transportation mechanism. The feed forward back-propagation method is the name given to such an algorithm. It is possible to find several different optimization searching methods based on the way of computing the gradient. The data patterns have been trained and tested.via the use of the back propagation method by Levenberg-Marquardt in this study. Moderately large feed forward neural networks are being trained quickly with up to hundreds of weights using this technique [7].

The 'trainlm' method of training described above is implemented in the MATLAB programming environment’s Neural Network Toolbox. The following parameters are required for this method to function: the rate of learning, which denotes the'speed' of the imaginary location along the error function represented by the array in the picture, and the momentum, which reflects the 'inertia' of the imaginary location along the error function. Data patterns for the diesel engine have been compiled from 486 different experimental data sets. The data patterns in aggregate have been utilised for validation and testing. Because the sample set is tiny, the input and desired values were not standardised to be within the range [0, 1] before being used (less than 1000 data). A transfer function (Sigmoid) was employed for the neurons in the hidden layers since no transfer function has been utilised for the neurons in the input and output layers. It is decided how many neurons to use depending on the difficulty of the issue and the degree to which there is a nonlinear connection between the input and desired values. The output values obtained during the testing stage for all of the analyses were obtained in less than 1000 training epochs. Using SPSS, the predictions produced for the Levenberg-Marquardt method and the architecture which is shown in figure 1 were examined.

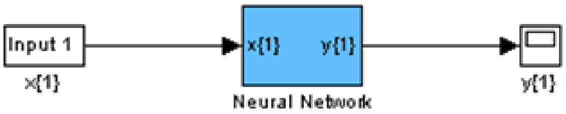

Figure 1: Network architecture.

To achieve the desired outcome, we set out to design the smallest and most basic neural network conceivable, one that operates on an optimization method that is as quick as feasible and results in error reduction in the shortest amount of time. RMSE, or root mean square error, are errors that occur throughout the learning and testing phases.

Experimental Results

The emission and performance characteristics of the diesel engine by varying the selected parameters through the acceptable range were analyzed. The observations for randomly selected nine experiments are given in Table 2.

NOH	PHC	IP	L	SCR	DOC	FC	NO_x	HC	CO	CO_2	BTE
3	1.2	160	3	181.88	40.3	210	473	22	0.03	4.2	18.42
3	1.2	170	3	181.88	40.3	231	520	26	0.04	4.6	20.26
3	1.2	180	3	181.88	40.3	254	572	31	0.05	5.1	22.28
4	1.4	160	6	213.85	60.05	150	445	31	0.04	6.1	26.31
4	1.4	170	6	213.85	60.05	162	585	36	0.04	6.7	28.42
4	1.4	180	6	213.85	60.05	182	644	43	0.05	7.4	31.93
4	1.6	160	9	415.7	79.55	113	569	28	0.05	9.5	29.73
4	1.6	170	9	415.7	79.55	126	628	32	0.05	10.4	33.16
4	1.6	180	9	415.7	79.55	141	690	38	0.05	11.5	37.1

Table 2: Emission and performance characteristics of the diesel engine.

Analysis using ANN

The results from ANN were analyzed and the corresponding results for the randomly selected nine experiments given in Table 2 are shown in Table 3.

NOH	PHC	IP	L	SCR	DOC	FC	NO_x	HC	CO	CO_2	BTE
3	1.2	160	3	181.88	40.3	210	475.736	22.3772	0.0448	4.1599	18.4366
3	1.2	170	3	181.88	40.3	231	525.3633	25.8815	0.0549	4.5956	20.2965

3	1.2	180	3	181.88	40.3	254	574.0066	31.0484	0.056	5.0626	22.2999
4	1.4	160	6	213.85	60.05	150	504.5465	31.523	0.0355	6.0758	26.3618
4	1.4	170	6	213.85	60.05	162	588.8403	36.3945	0.0671	6.6502	28.4326
4	1.4	180	6	213.85	60.05	182	648.0077	41.9237	0.0745	7.3465	31.9425
4	1.6	160	9	415.7	79.55	113	549.2204	27.8872	0.033	9.4429	29.8205
4	1.6	170	9	415.7	79.55	126	624.1235	32.2046	0.0551	10.3303	33.1354
4	1.6	180	9	415.7	79.55	141	693.2963	38.6717	0.0806	11.4703	37.0686

Table 3: ANN output for diesel engine emission.

Initially a program was created in ANN to analyze all 486 input values and to achieve the target values then the input values were fed in their respective places and the program is run i.e., the data is analyzed in Artificial Neural Network (ANN) with Number of Nozzle Holes (NOH), Piston Head Clearance (PHC), Injection Pressure (IP), Load (L), Selective Reduction Catalyst (SCR) and Direct Oxidization Catalyst (DOC) as input against any one of the output and similarly the other output are predicted. Regression values, curves from neural network training tool and target values from the command window(Neural network training tool, regression graph and command window baring output for brake thermal efficiency were analyzed. The number of neurons, number of epochs, time for calculation, regression values and absolute error for all output is shown in Table 4.

Properties	**Number of neurons**	**Number of epoch (iterations)**	**Time for calculation (s)**	**Regression values**	**Absolute error**
NO_X	35	1000	69	0.9935	-0.00119
HC	15	1000	35	0.9984	-0.00068
CO	650	7	165	0.9983	-0.20184
CO_2	15	31	1	0.9998	-53
BTE	15	50	2	0.9999	$1.36*10^{-6}$

Table 4: Properties from neural network tool of MATLAB.

The regression values pertaining to accuracy is close to unity, hence training is satisfactory and absolute error which is the average error of individual experiments is very low in all cases hence the output from ANN is reliable. The performance and emission values predicted by ANN for optimum sets for general load and specific load applications when imposed on the engine are given. The results of the optimum set of standalone engine for NOx is obtained from MATLAB output window. The results for other optimum sets are obtained similarly [8]. It is clear that the values found out by ANN have a strong correlation with the experimental findings, indicating that ANN may be utilised as a forecasting tool in addition to other applications. Because the values acquired by ANN are much more accurate, it is recommended that predictions be made using ANN. According to the factory default settings (three hole injector nozzle, 1.4 mm clearance of piston head, and with a pressure of injection 170 bar), performance and exhaust emission for the loading condition chosen are given. As a consequence of the aforementioned findings, NO_X emissions decreased by 3.73 to 7.68 percent, HC emissions decreased by 8.33 to 10.53 percent, CO emissions decreased by 0 to 50 percent, CO_2 emissions increased by 1.11 to 7.69 percent, and brake thermal efficiency increased by 0.54 to 1.39 percent. In this way, altering engine settings increased combustion efficiency and decreased carbon dioxide emissions, while catalytic response reduced the production of carbon monoxide and nitrogen oxides in the atmosphere.

Conclusion

A conventional single cylinder, four stroke diesel engine is investigated in this research, with a number of parameters being varied and the engine's performance and emissions being evaluated. The most efficient and least polluting settings for generic and particular loading conditions have been identified, as well as the lowest possible emissions. The hazardous emissions (Carbon monoxide and Nitrogen oxides) produced by the engine are decreased as a consequence of the use of the best-practice settings. Substantial reductions in carbon monoxide are achieved, as are significant reductions in hydrocarbons, and significant reductions in nitrogen oxides. This has a significant impact on reducing the environmental impact of the engine. In addition to reducing emissions, the use of the optimal parameter setting results in a marginal improvement in efficiency owing to full and improved combustion, which has been shown via laboratory tests. Additionally, the particular optimum settings for various load applications will result in improved efficiency, which will result in economic advantages for the consumers. More parameters, such as retardation of injection timing, change in the number of injectors, swirl optimization during inuction, utilizing pre-chamber combustion, altering the combustion chamber shape, and so on, may be selected in order to obtain better configurations, reducing emissions and improving performance, among other things.

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