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Artificial neural network model to predict the diesel electric generator performance and exhaust emissions

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ABSTRACT

The growing demand of DG (diesel electric generators) has led to air pollution and green house gas emissions, especially CO_2 (Carbon-di-oxide). Hence, it is necessary to predict the level of CO_2 released from the DG, to ensure the minimum level of emission. Forecasting the CO/CO_2 ratio, flue gas temperature (T_F) and gross efficiency (η), ensures the effective and smooth operations of DGs. Keeping this in view, in this paper, ANN (artificial neural network) models are proposed for the prediction of CO_2, CO/CO_2 ratio, T_F and (η) of DG. The training and testing data required to develop the ANN were obtained through a number of experiments in 3 phase, 415 V, DG of different capacities operated at different loads, speed and torques. Three different capacities of DGs such as 180, 250, and 380 kVA have been investigated. Back propagation algorithm was used for training the ANN. The application of the newly developed models shows better results in terms of accuracy and percentage error. The co-efficient of multiple determination values are found to be above 0.99 for all the models. It is evident that the ANN models are reliable tools for the prediction of the performance and exhaust emissions of DGs.

1. Introduction

DG (diesel electric generators) are utilized in almost all kinds of engineering industries, hospitals, hotels and in educational institutions, to meet the power requirement and to compensate the power shortage. During their operation, a significant amount of emissions is also released. Hence, it becomes essential to ascertain and predict the level of emissions and performance of the DG, for its smooth and effective operations. Electric power generation systems require continuous monitoring to ensure safe, reliable operation and to predict future behaviour [1,2]. Generally, flue gas analyzers are used to compute the amount of CO_2 emitted from DGs. This approach requires costly equipment and is also time consuming. Alternatively, the ANN (Artificial Neural Network) can be applied to estimate the CO_2 emission. The ANN is an information processing methodology inspired by the working of the human brain [3]. ANN models are more accurate [4] and efficient in handling the nonlinear relationship of data [3,5]. Prediction through ANN is achieved from training on experimental data which can be validated by self-determining data sets [6]. Selection of an appropriate neural network topology is therefore very important in terms of model accuracy and model simplicity. Various researchers have shown ANN as a powerful modelling tool for predicting multifaceted relationships. The ANNs approach has been useful to predict the performance of various thermal and energy systems [7].

Neural networks have been applied to different engine investigations such as modelling of engine performance and prediction of exhaust emissions [8–11]. ANN model has been developed to predict a correlation between brake power, torque, brake specific fuel consumption, brake thermal efficiency, and emission components using different gasoline ethanol blends and speeds as input data. A standard Back-Propagation algorithm was used in that model. It was observed that the ANN model was capable of predicting the engine performance and exhaust emissions [12]. The ANN was developed for a gasoline engine to predict the brake specific fuel consumption, effective power and exhaust temperature of the engine. To acquire data for training and testing the proposed ANN, a four-cylinder, four-stroke test engine fuelled with gasoline was operated at different engine speeds and torques. It

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Nomenclature

A	ampere
ANN	artificial neural network
Bi	bias
BSFC	break specific fuel consumption
CO	carbon monoxide
CO_2	carbon-di-oxide
R^2	co-efficient of multiple determination
w_{ij}	connection weights between the ith neuron and the jth inputs
DG	diesel electric generator
E_L	electrical load (Ampere)
T_F	flue gas temperature (°c)
HC	hydrocarbon
Hz	hertz
kVA	kilo-volt-ampere
MSE	mean square error
N	speed (Rpm)
N-m	Newton metre
NOx	nitrogen oxide
out_i	output of the ith neuron in the layer under consideration
out_j	output of the jth neuron in the preceding layer
Pf	power factor
Rpm	revolution per minute
RMSE	root mean square error
BP	standard back propagation
T	torque (N-m)
UHC	un burnt hydrocarbon
ΔW_{ij}	weight adjustment
W_{ij}	weight from hidden unit i to output unit j at time k
η	gross efficiency

also proved that the ANN approach can be used to accurately predict the performance, temperature and other parameters of internal combustion engines [13].

One of the studies predicted six engine-out responses from a spark ignition engine using back-propagation ANN [14] with R values equal to 0.98, 0.96, 0.90, 0.71, 0.99 and 0.96 for CO (carbon monoxide), CO_2, HC, NOx, torque and brake power respectively. Another study utilized ANN approach, to compute the levels of engine torque, specific fuel consumption, and CO and HC emissions with R values of 0.948, 0.999, 0.929 and 0.999 respectively [5]. In another study, ANN was used to model the complex interactions between engine control variables and engine-out responses. Optimization methodology and the performance of ANN were evaluated using the MSE (mean square error) and R values as evaluation criterion. The results indicated that back-propagation feed-forward neural network was suitable [15]. It was reported in another study that ANN was able to predict the engine performance and exhaust emissions with a correlation coefficient of 0.9986, 0.9776, 0.9983 and 0.9960 for the BSFC, CO, HC and AFR (air-fuel ratio) for testing data, respectively. It is obvious that the developed ANN model is fairly powerful in predicting the performance and exhaust emissions of internal combustion engines [16]. In most cases, statistical approach using the MSE (mean square error) and correlation coefficient are typically set as the criteria to determine the accuracy level of the predicted data from a formulated ANN model [17,12,18]. Here, MSE quantifies the difference between ANN predicted values and the true values of the parameters of interest and R is the proportionality value between the predicted and actual data [17,12,18].

Though, numerous studies have been carried out on diesel engines in relation to ANN modelling, only a limited number of studies have been conducted, concerning ANN model development to predict and forecast the performance and exhaust emissions of a DG. In this paper, ANN models are developed for the prediction of CO_2, CO/CO_2 ratio, T_F and η of DG. Three different capacities of DGs such as 180, 250, and 380 kVA were investigated. This study is unique as it considers different input parameters such as electrical load, engine speed and torque, and the application of the ANN model to predict the performance and exhaust emissions of a DG. The results of the findings are presented in this paper. The developed model can be utilized to estimate the amount of CO_2 generated by the DG, CO/CO_2, gross efficiency and flue gas temperature in real time. Using the above details, the operator can take necessary steps to reduce the emission level and to increase the efficiency of the DG.

2. Methodology

2.1. Proposed approach

The proposed method for developing the estimation model for exhaust emission parameters from a DG was based on ANN. The objective is to estimate the exhaust emission parameters under different loading conditions. The Neural network approach for any application has two stages: training stage and implementation stage. During the training stage, the network is trained using the training data. While training the network, DG loading condition is given as the input for ANN and the exhaust emission parameters as output. The input and output are first normalized between 0 and 1. After normalization, the input variables are given to the neural network for training. Training is accomplished by sequentially applying input vectors, and adjusting network weights according to a predetermined procedure. After training, the networks are evaluated through different sets of input and output data. Once the training and testing of the network is complete, the network is ready for application. The detail of the neural network is given in Section 2.3.

2.2. Procedure

The procedural steps involved in the development estimation model for exhaust emission Parameters from a DG are shown in Fig. 1. The procedure followed to develop the ANN model is based on the bottom-up approach [19,20] in which the individual base elements/steps are first specified in detail. The main advantage of this approach is that it first defines and tests all the specific requirements (conducting preliminary studies, experimentation, data collection etc.) needed to develop the model. The description of the various stages such as preliminary studies, data collection and development of neural network is presented below:

1. Selection of performance parameters for the identified equipment such as loading conditions, speed, fuel supply rate, and efficiency etc., based on the requirement of the generic tool development.
2. In the selection of variables, the connected load (Amps), speed, torque were considered as the inputs and CO_2, the ratio of CO/CO_2, exhaust T_F and η were selected as the output.
3. Collection of relevant emission related data by conducting experiments in real system i.e. DG.