ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
Vol 5, Issue 2, February 2018

Scope of Artificial Intelligence Techniques for Exhaust Emission Prediction of CI Engines and Renewable Energy Applications

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***Abstract* - Increasing demand for limited natural resources is leading to a situation of the global energy crisis. Energy consumption patterns have to be changed in order to face the energy crisis and more focus has to be brought on utilizing the renewable energy resources. Major challenges faced in the implementation of renewable energy resources include the development of technology with ensured commercial viability and awareness on environmental concerns. Exhaust emissions from the diesel engines are found to be toxic and carcinogenic in nature. Artificial intelligence techniques can be applied as an effective method for attaining the future goals of renewable energy and also for the prediction of exhaust emission characteristics from compression ignition engines. Artificial neural Network is a proven technique in modelling of nitrate and soot emissions from the diesel engines and acts as an alternative for real-time experimentation which is time-consuming and expensive. In this paper, a detailed study has been carried out on the application of single and hybrid artificial intelligence approaches in the research and development of renewable energy resources. Also, the effectiveness of Artificial Neural Network (ANN) technique in the prediction of diesel engine exhaust emissions has been reviewed.**

Keywords: Artificial Intelligence, Emission, Renewable Energy, Soot.

1. INTRODUCTION

Energy production by conventional methods is found to have an adverse effect on environment and human health. At the same time, the demand for energy produced from natural resources which are limited, is increasing at a rapid rate, leading to a situation of energy crisis[1]. Effective production and management of electricity is one of the major factors affecting the world economy. More focus has to be brought by research and development in governmental and other levels to explore the renewable energy resources to meet the energy needs at global level [2]. Renewable energy sources are often referred to as alternate energy sources since it could not provide uninterrupted supply of required demand at specific situations [3]. Various challenges faced by the renewable energy production bring up the requirement of a technology or a machine which could solve the problems for each research domain. Artificial Intelligence techniques mainly work developing such intelligent machines and software's to ease the domain application. Depending on the source of generation, renewable energy is classified into wind, solar, hydrogen etc. Wind energy works by converting mechanical energy developed in wind mills from the blowing wind into electrical energy[4]. Solar energy makes use of sun's radiations to generate electricity by photovoltaic effect. Geothermal energy is generated from the displacement of tectonic plates which leads to breaking of lava that is formed in the lower layers of earth due to gradual decay of radioactive elements. Detailed classifications of various types of renewable energy sources are shown in figure no 1.

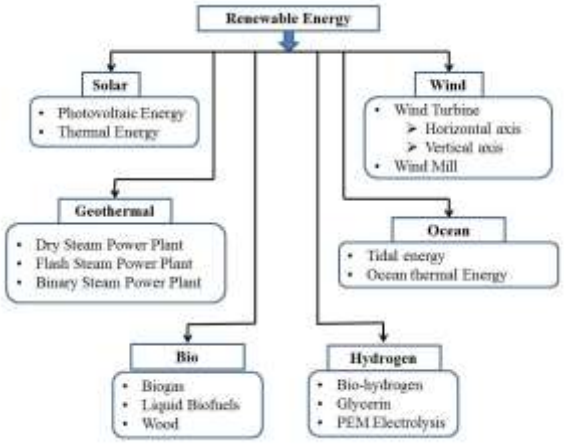

Figure no 1 Classifications of RE sources

Exhaust emission from compression ignition engines have proved to one of the leading sources of soot particles which are carcinogenic in nature[5]. Various studies have been carried out to reduce these emissions with an objective to make it less toxic, where the results showed that these emissions can be reduced by pre-treating or

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post-treating them by various methods. Pre-treatment means treating these harmful emissions prior to its generation in the engine cylinder which can be achieved by modifying the cylinder design, fuel injection techniques etc [6]. Application of biofuels is also found to be a suitable alternative to reduce these emissions whereas biofuels are found to increase the nitrate emissions. Post treatment techniques include the treatment of exhaust gases generated by engine before releasing it to the environment. It can be achieved by techniques like particulate filtration, oxidation catalysis and catalytic reduction. All these studies require repeated experiments for optimization of operating parameters for reduced emission. Artificial Intelligence techniques are found to be a possible alternative to optimize the input parameters so that the validation test can be done on experimental test bench and also various experiment sets can be avoided. Development of digital computers provided a platform for carrying out various calculations by using ANN methods and introduction of high speed computer systems increased its application at a fast rate. Compared to simulation programs and mathematical modelling, ANN is found to be efficient since it doesn't require any iterative calculations for solving differential equations[7]. Application of ANN in diesel engine applications for analyzing the engine performance based on cetane number were studied in [8]. Research studies have also shown that ANN can accurately predict the performance of engine and also emission characteristics even in the case of non-linear and complex conditions[9]. In this paper, a detailed study has been carried out to determine the scope of artificial intelligence techniques in the prediction of the exhaust emission characteristics of diesel engine and also for the renewable energy applications.

II. EXHAUST EMISSION PREDICTION BY ANN

ANN techniques find vast applications in automotive research for prediction of engine reliability, tribology and emission characteristics. It is a powerful tool for estimating output parameters by modelling the system if certain experimental or input data is provided. ANN doesn't require formulation of the systems physical relations instead it requires only parameter values of the systems in similar context. It is composed of elements whose operation is inspired from human nervous system. For performing a particular task, the neural networks are trained by varying the connection values between adjoining elements called as weights.

Neuron works by receiving the input signals from parameters $(x_1, x_2, \ldots x_i)$ with weighing factors $(w_1, w_2, \ldots w_i)$ and then combining them after adding its summation value with a constant bias value to perform a particular operation in the output as shown in equation no 1 and 2. Where the following parameters are used namely output value of summarizers (u_i) and neuron output value (y_i). ANN system has the ability to develop the relationship between the input and output parameters without complete information about the system. Pictorial representation of neuron is shown in figure no 2.

Summarizers output value = $u_i = \sum_{j=1}^{n} w_{ij} x_j + b_i$ (1)

Neuron output value = $y_i = f(u_i)$ (2)

Training of networks can be carried out using a number of algorithms out of which most commonly used one are back propagation algorithm where regression analysis is used for determining the performance of ANN results in comparison to actual results. Main aim of network training is to obtain the optimum values of weights and bias so that the network results are close to the experimental results. Neural networks can be trained to obtain the best results only if there exists a logical relationship between the input and output data.

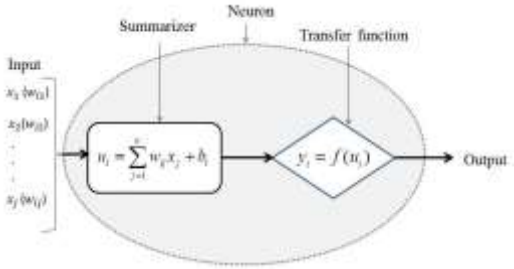

Figure no 2 Pictorial representation of neuron

ANN network is comprised of three layers namely input, hidden and output layer. Experimental data was used for developing ANN model in [10], where the input layers and output layers were established as shown in figure 3. The number of neurons in the hidden layers is determined based on problem complexity and availability of data. It has to be derived by using trial and error method. Results of optimization calculations carried out in neuro intelligence software shows that the 4-2-1 architecture is the best for engine emission prediction[11]. Earlier

ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
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studies have shown that the accuracy of the output results will be reduced if more than one component is present in the output layer of the system architecture. Therefore for finding the output values of the nitrate emissions and soot emissions using network modelling, similar network architecture has to be used but independently.

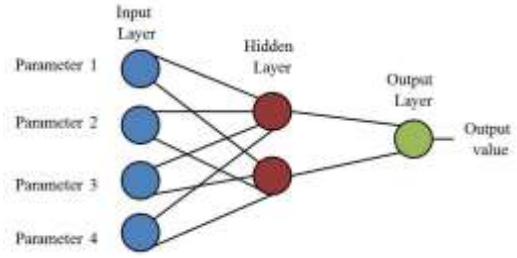

Figure 3 Simple ANN network model 4-2-1 architecture

Various algorithms can be used for building the relationship network output and actual output, out of which back propagation algorithm is most common where the network performance is evaluated by regression analysis. The error determined by regression analysis can be reduced by adjusting the weights of network and the optimum values can be determined by carrying out iterations. Once the optimum values of the network weights are determined, this network can be used for predicting the emission characteristics at different input values. Absolute values of the input parameters has to be normalized using equation no.3 before introducing it to the network since large differences in the values will complicate the learning process of the network model [12]. The input parameter values has to be normalized to the range of [v_l = .001, v_h = 1.00]Mean square error of the output values are calculated to evaluate the performance of the system using equation no 4.

$$v_{normalized} = \frac{v_a - v_{\min}}{v_{\max} - v_{\min}} \times (v_h - v_l) \qquad (3)$$

$$MSE = \frac{1}{n} \sum_p \sum_k (t_{pk} - f_{pk})^2 \qquad (4)$$

Most of the studies carried out to determine the scope of artificial intelligence techniques in exhaust emission prediction showed that the network results achieved are close to the experimental results. Application of ANN in exhaust emission prediction was tested and validated in the case of single cylinder diesel engine with rapeseed biodiesel as fuel in [11]. The results of investigation showed that the value of regression coefficient was close to unity and there was less than 5% relative error in the test data obtained. Nitrate emissions and smoke opacity was modelled by using ANN methods in [13], by considering parameters like speed, fuel injection pressure and valve position in the input layer of the network. Results of the analysis proved that the nitrate levels can be predicted by ANN methods but there were higher error values in smoke levels since its formation is complex to be defined with limited parameters. Various algorithms can be used for building the relationship between network output and actual output in ANN modelling. Nitrate emissions from power plant boilers were reduced by applying ANN methods where optimized operation parameters were obtained by Ant Colonial Optimization (ACO) algorithm combined with regression modelling. Genetic Algorithm can also be combined with the ANN models for prediction of emission characteristics [12].

III. RENEWABLE ENERGY APPLICATIONS OF ANN

Artificial Intelligence technique works to develop smart systems which have the ability to understand human thinking up to a certain level. Artificial Intelligence techniques are found to an effective tool in renewable energy research for meeting various objectives like design optimization, estimation, analysis etc [14]. Installed capacity of various energy sectors in India from 2005 to 2015 is shown in figure 4. Application of AI techniques in various renewable energy sources are detailed below.

A. Wind Energy

One of the major factors affecting the wind energy is estimation of speed and power of wind in a particular location. Back Propagation Neural Network (BPNN) technique is most commonly used for prediction of wind speed in a particular location [15]. The actual wind speed and the speed estimated by ANN models were found to have a close co-relation coefficient of about 0.95. A combination of fuzzy logic and BPNN was used in [16], to improve the prediction capability and also the applicability in wind farms. The design of wind power generation system was done by fuzzy logic.

B. Solar Energy

AI techniques also have an important role in the design, modelling, and sizing of photovoltaic systems. Solar energy research involves the application of both single and hybrid approach of artificial intelligence [16]. BPNN

ISSN (Online) 2394-2320

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technique was used for forecasting the Global Solar radiation by considering temperature and humidity as input parameters in the network architecture. Performance of the BPNN system were compared with other methods like batch learning ANN [17], Angstrom's linear methods [18] and empirical regression methods [19]. BPNN is found to have better performance compared to other techniques. Evolutionary AI techniques like genetic algorithm can be used for optimizing the design of solar water heating system. The plate collector area was optimized by genetic algorithm with a solar fraction of about 98%[20]. Various hybrid AI techniques like historical similar mining model, genetic swarm optimization, fir fly algorithm etc. were found to be every much effective in prediction and estimation of PV energy. Other application of AI techniques in solar energy include prediction of solar radiation, solar irradiance, solar beam radiation, maximum power, building energy, clearness index, PV energy and sie optimization of PV.

C. Geothermal Energy

Approach of AI techniques for simulation and modelling of geothermal reservoirs prior to the well drilling phenomena helps in developing effective design and control of system[21]. BPNN technique based on Levenberg-Marguardt (LM) technique provided higher prediction efficiency of geothermal reservoir with an model consisting of 8 neurons in its hidden layer. Also it was found to be effective in prediction of static formation temperature inside the geothermal well. BPNN model with seven neurons in the hidden layer and input parameters as vapor fraction, temperature and geothermal fraction predicted the pump power with a relative mean square error of 1.5289 [21]. Other applications of AI techniques in geothermal energy include prediction of power, ammonia-nitrogen concentration, temperature, controller efficiency and modelling of site location.

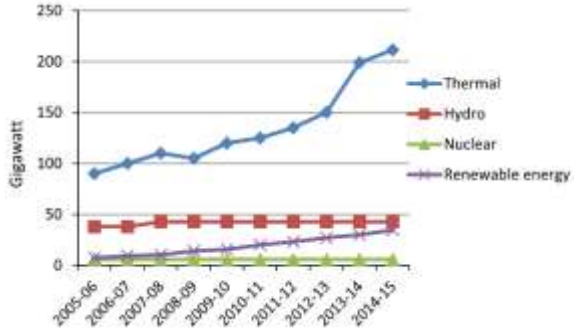

Figure 4 Installed capacity of energy sectors in Indian scenario from 2005 to 2015[22]

D. Hydro Energy

Design and control of hydropower plants can be achieved by artificial intelligence approaches. BPNN technique can be used for prediction of steam flow in river basins during different seasons [23]. Comparison of BPNN technique with auto regressive (AR) technique for river flow modelling and results showed that the BPNN technique has better performance than that of AR technique. Integration of ANN with expert systems was found to be effective in acoustic prediction and predictive maintenance of hydro-power plants. Various hybrid approaches with application of techniques like artificial bee colony algorithm, case based reasoning etc. were also found to be an effective platform for performance prediction of hydropower plants. Other applications of AI techniques in hydro power plant includes rainfall run-off prediction, estimation of power discharge, scheduling of hydrogenation, prediction of water release and prediction of stream flow.

E. Ocean Energy and Bioenergy

AI approach is mostly used in ocean energy platforms for prediction of variation in sea level, sea wave height, dispersion coefficient, wave hind casting and carbon dioxide flux. BPNN technique was used for forecasting the ocean wave condition with an accuracy level of 67% [24]. Hybrid approaches were found to have better efficiency in prediction of ocean levels. Single and hybrid AI approaches can be applied for optimization of various parameters in forest biomass for effective bioenergy generation. Various applications of AI techniques in bioenergy include prediction of cetane number, density, methane concentration, hydrogen sulfide & ammonia concentration and biogas production. Electricity generation by using microbial fuel cells is one of the latest approach where the fuel cell acts as a bioreactor[25].

CONCLUSION

Artificial Intelligence techniques are found to be an effective tool for modelling and prediction of exhaust emission from the compression ignition engines. Network architecture model with four input parameters, two hidden layers and one output layer is considered to be most effective in prediction of nitrate and soot emissions from the engines. The exhaust emission norms are getting stringent and also it has been made mandate by the latest emission norm (EURO VI) to bring down the soot and nitrate emissions from the engines to acceptable levels. Various researches in national and international level is in progress to develop a system to reduce the toxicity of

emissions from the engines. All these testing require expensive experimental setup and also several sets of experimental investigations for validation purpose. Artificial Intelligence techniques prove to be a suitable alternative for reducing the number of experimental run and also for optimization and prediction of output parameters with reference to input parameters. Renewable energy resources are considered to be the major energy source in future since the fossil fuel extinction and energy crisis. Since most if the renewable energy systems are in development stage, AI techniques will provide a platform for optimizing various parameters involved in the design and development of effective renewable energy systems. In this paper a detailed study about the application of AI techniques on exhaust emission prediction has been conduction and future scope of this work involves the comparison of experimental results with the ANN model results. Currently the authors are working on a project in developing an intuitive exhaust collection system for reducing the soot particle emission from the diesel engines where the AI techniques will be used for prediction of engine parameters generating lowest emissions to meet EURO VI emission norms.

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