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An Adaptive Neuro-Fuzzy Inference System based Algorithm for Long Term Demand Forecasting of Natural Gas Consumption

Ferdous Sarwar, Md. Mamunur Rashid, Debasish Ghosh
Department of Industrial and Production Engineering,
Bangladesh University of Engineering and Technology
Dhaka-1000, Bangladesh

Abstract

This paper represents a successful implementation of Adaptive Neuro-Fuzzy Inference System (ANFIS) to develop an algorithm to predict the long term demand of Natural Gas Consumption. The developed ANFIS model is also applicable to forecast in other related fields though it is generated on the perspective of the environment of energy sector in Bangladesh. After identifying all the reasonable factors that affect the demand of Natural Gas Consumption we have considered five parameters to construct and examine the plausibility of ANFIS model. This study also provides results from generated FIS model and evaluates them. The proposed ANFIS model provides a suitable and special algorithm for the demand forecasting of Natural Gas Consumption. The outcomes are considerably better than the forecasting of the demand of Natural Gas consumption in traditional methods.

Keywords
Demand Forecasting, Natural Gas (NG), Adaptive Neuro-Fuzzy Inference System (ANFIS)

1. Introduction
In the area of resource management, demand forecasting always has to deal with very challenging issues. Planning for future and keeping our eyes on the horizon is of equal importance and the most effective style to plan the future is to cautiously study previous trends. In business management, Demand forecasting is an inherent part of business. Without substantial ideas of what our future demand is going to be, it is difficult to carry off our inventory management or our cash flow or planning for growth or to satisfy the consumers fulfilling their needs. The intention of demand forecasting is to provide consummate information that can be used to make levelheaded business decisions. Without forecasting demand, it is very difficult to channelize the company in the right direction. We must not always guess that the spring is the slowest season, so if we invest so much on inventory it will only be invested to the shelves. If we only give attention to those analysts who predict on the basis of occasional sales a robust growth and thus potential consumers will be lost in the business market.

2. Background
(Escobar and Perez 2008)devised a model of Short-term load forecasting (STLF) using neural networks, fuzzy logic and support vector machines.(Ying and Pan 2008) developed an ANFIS model to forecast the regional electricity load of Taiwan. (Yun, Quan et al. 2008) developed a method of forecasting the short term load combining radial basis function (RBF) and ANFIS. (Yurdusev and Firat 2009) devised an approach for municipal water consumption modeling using ANFIS.(Efendigil, Önüt et al. 2009) proposed an ANFIS algorithm to predict the demand of consumer goods industry in Istanbul, Turkey. (Tabesh and Dini 2009) formulated short term water demand forecasting of Tehran. (Kaynar, Yilmaz et al. 2010) predicted natural gas consumption of Turkey by means of three approaches; Autoregressive Integrated Moving Average (ARIMA), Artificial Neural Network (ANN) and Adaptive Neuro Fuzzy Inference System (ANFIS). The results generated by these three models are compared.(Behrouznia, Saberi et al. 2010)developed an adaptive-network-based fuzzy inference system (ANFIS)-fuzzy data envelopment analysis (FDEA) for long-term natural gas (NG) consumption forecasting and analysis (data based on South America).(Chang, Fan et al. 2011)excogitated a method of forecasting of monthly electricity demand of Taiwan using weighted evolving fuzzy neural network (WEFuNN) approach. (Azadeh, Asadzadeh et al. 2011)formulated an adaptive network-based fuzzy inference system-stochastic frontier analysis (ANFIS-SFA) approach for long-term natural gas (NG) consumption prediction and analysis of the behavior of NG consumption. (Azadeh, Saberi et al. 2013) build up a Neuro-fuzzy-multivariate algorithm for accurate gas consumption estimation in South America

with noisy inputs using Adaptive Neuro-Fuzzy Inference System (ANFIS) and fuzzy data envelopment analysis (FDEA).

3. Problem Description

In Bangladesh, natural gas found its way to be used in different purposes, but the whole country is now suffering from gas shortage. Condition in urban areas is worse due to the huge deficit of gas. Unauthorized use, illegal license delivery, corruption, poor maintenance and most importantly wastage are the major causes of gas deficiency in Bangladesh. At the current rate of natural gas use in Bangladesh, about 1000 Millions of cubic feet per day (mmcfd), the current estimated proven reserves would last 45 years. Even if the present rate of use increases at 10 percent per year, these reserves would last only about 17 years.(Jaccard, Khan et al. 2001)

The demand of natural gas consumption varies with time. With the passage of time, population, household use of gas, increase of natural gas vehicles (NGV) and industrialization will move to an expansion; so will the demand of gas consumption. Generation of more electricity also demands huge amount of gas on a daily basis. Due to the heavy industrial growth the use of gas is increasing in alarming rate. In the field of agriculture the demand of gas is also increasing. Thus five major sectors for natural gas consumption have been identified and considered as input parameters in this problem of demand forecasting.

At last, the increasing trend in energy consumption necessitates appropriate investments and financial supports on energy sectors. For this reason, accurate demand forecasting of energy (natural gas) consumption is of prime importance for strategic decision making regarding generation and distribution in energy sector. In this work, a mathematical model has been developed to forecast the demand of natural gas consumption of Bangladesh.

4. Mathematical Foundation

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a kind of neural network that is based on Takagi–Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has the potential to capture the benefits of both in a single framework. ANFIS is an adaptive network. It is called adaptive because some, or all, of the nodes have parameters which affect the output of the node. These networks are learning a relationship between inputs and outputs. These techniques provide a method for the fuzzy modeling procedure to learn information about a data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. This learning method works similarly to that of neural networks.

5. Proposed Methodology

The success and accuracy of an ANFIS model mostly dependson howappropriately the given datasets resemble to the actual occurrences.The training datasets should contain all the features of the real situation so that all uncertainties inherent in the system get included in the ANFIS model during training phase. Also the datasets should have low noise. As the checking and testing data sets play important roles in validating the model, they should also have resemblances with the real system. To achieve this appropriateness all of these datasets should be chosen wisely to get a good ANFIS model.

Step 1: Firstly, a clear and straight-cut output parameter must be selected. Here the selected parameter is the demand of natural gas consumption which is going to be forecasted by the developed ANFIS model.
Step 2: Then the variables that can affect the output parameters are identified and the major factors are selected as input parameters.
Step 3: Collecting of necessary real life datasets to develop the model.
Step 4: Preparing the collected datasets and dividing them into Training, Testing and Checking Datasets.
STEP 5: With loading datasets, selecting the appropriate training parameters, ANFIS model need to be trained.
STEP 6: After that the developed ANFIS model is checked with testing and checking datasets.
STEP 7: Then finding out the results against the checking datasets from the developed ANFIS model.
STEP 8: Finally, to validate the developed ANFIS model, different error measure techniques such as: RMSE, MAD, MAPE, TS are calculated and either the calculated errors are satisfactory then the developed ANFIS model is accepted or the training parameters are changed until the model is accepted with minimum error.

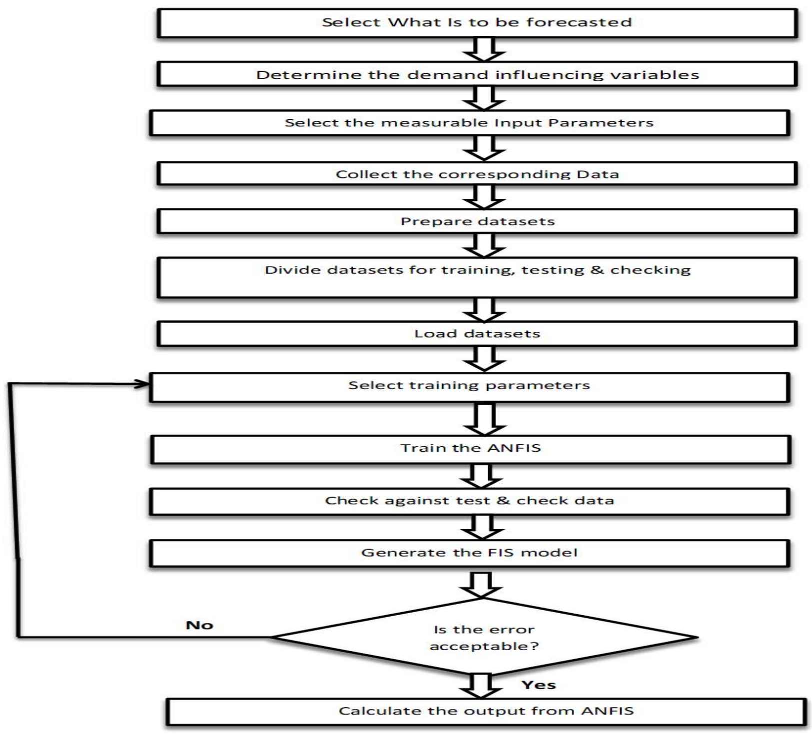


Figure 1: Algorithm for forecasting demand using ANFIS

6. Case Study

In order to forecast yearly gas consumption of Bangladesh, five factors have been considered as input parameters and the amount of gas consumption has been considered as output parameter. The relationship between different input data and the output data and the uncertainties due to various real world reasons was decided by the ANFIS artificial intelligence. Though it is not possible of this fuzzy logic based method to be fully accurate, attempts have been taken to keep the error in the result as small as possible to apply in the real world. In this work, Matlab fuzzy Logic Toolbox has been used to implement the designed algorithm in ANFIS.

Input parameters

As all of the variables influencing gas consumption are not measureable and corresponding data collection of all parameters often becomes difficult, it is not possible to include all the variables in the ANFIS model. Considering the influencing of variables on gas consumption specifically in the environment of Bangladesh and depending on the availability of related data, five variables have been selected as the input parameters to model the ANFIS structure. Selected parameters are:

I. Population (household)

Population is one of the influencing factors that affect gas consumption in Bangladesh. The relation between population and the amount of gas consumption is directly proportional. In the recent years, the practice of joint family is being broken. So, the number of nuclear ménage is increasing day by day. For this reason as the population, as well as the number of nuclear family is increasing the demand of gas consumption is increasing.

II. Power generation

For electric power generation Natural gas is one of the cardinal fuel input. In recent years, Combined-Cycle Technology has introduced natural gas power plant and becoming very popular nowadays. Natural gas is also going to play a pivotal role in power plants in the near future also. There are few advantages using natural gas in power plants over other fossil fuels. Such as: lower heat rate, reduced air pollutant emissions, shorter construction lead times and higher efficiency etc.[Gas]

III. No. of natural gas vehicles

A natural gas vehicle (NGV) is an alternative fuel vehicle that uses compressed natural gas (CNG) or liquefied natural gas (LNG) as a cleaner alternative to other fossil fuels. For their speed and size natural gas vehicle especially CNGs are one of the most attractive modes of transport in Bangladesh. CNGs are popular in crowded and narrow streets in the urban areas and also preferable for long distance in the rural areas. In the recent times almost all the buses are being converted in to CNG. So Gas Vehicles consume large amount of gas daily. As the no of natural gas vehicle increases the amount of natural gas consumption increases.

IV. Industrial production growth rate

Natural gas has a multitude of industrial uses, including providing the base ingredients for such varied products as plastic, fertilizer, anti-freeze, and fabrics. In fact, industry is the largest consumer of natural gas, accounting for 43 percent of natural gas use across all sectors. Natural gas is the second most used energy source in industry, trailing only electricity. Lighting is the main use of energy in the industrial sector, which accounts for the tremendous electricity requirements of this sector.(V. Chidambaram(GAS)

In Bangladesh not only the numbers of industries are increasing day by day but also production growth rate per industry and even shifts per day are increasing. Most of the industries are either directly or indirectly rely upon natural gas. So, amount of natural gas consumption increases as the Industrial production growth rate increases.

V. Agriculture

There are several ultra-technological methods such that Controlled Atmospheric Storage, Blanketing, Drip Irrigation, Greenhouse Atmosphere Enrichment, Grain Fumigation where natural gas is used in agriculture. As the population of Bangladesh is increasing, the need for food is also increasing. To satisfy this nimiety demand the production of agricultural crops is to be increased. So gas is more consumed than before in agricultural field. Thus the demand of natural gas consumption is being increased.

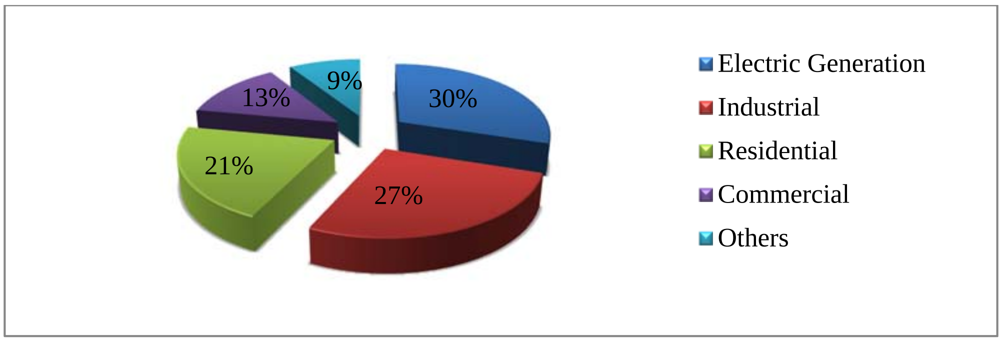


Figure 2 : Natural Gas Consumption by End Use in 2010

Output parameters

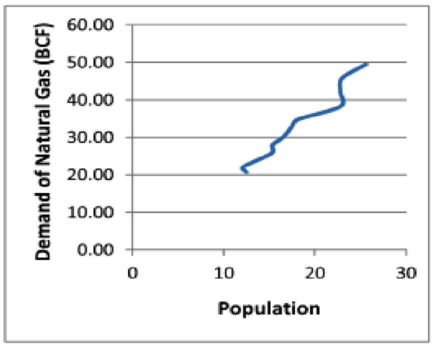
The output is the yearly demand of gas consumption expressed in the units of Billions cubic feet (BCF). Here the number of output parameter is one. Generally there are two type of forecasting: one step ahead and multi-step ahead. In iterative type forecasting number of output node is one and in non-iterative direct process output is more than one. The proposed ANFIS model has used iterative forecasting process where number of output parameter will be one. The developed algorithm forecasts the demand for 12 months of the year given values of the input parameters.

Data collection and Input-output dataset

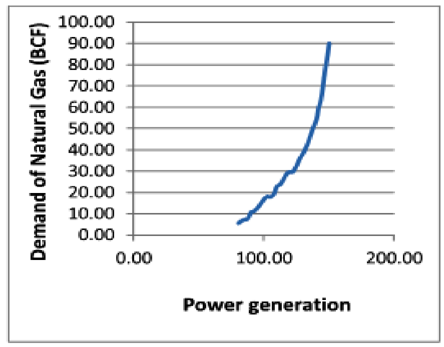
Real data have been used to model and validate the forecasting in ANFIS. Gas consumption data for thirty consecutive years (1973-2012) have been collected from previous history and used for the ANFIS modeling, performance measurement and comparison with other tradition forecasting methods against the demand data for 40years, corresponding data of the input parameters have been collected and expressed as the following units as shown in Table 1.

Table 1: Input and Output Parameters

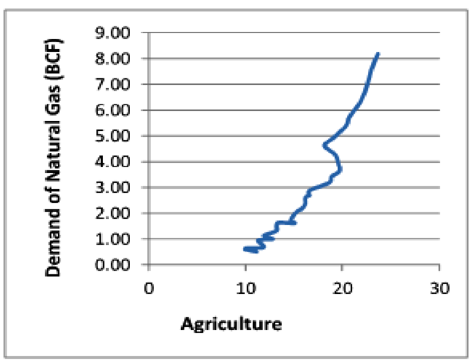
Type	Parameter	Unit
Input	Population	In million
	No. of natural gas vehicles	Pieces
	Power generation	Billion KW
	Industrial production growth rate	Percentage (%)
	Agriculture	kilo Metric ton
Output	Demand of Natural Gas	Billion Cubic Feet (BCF)



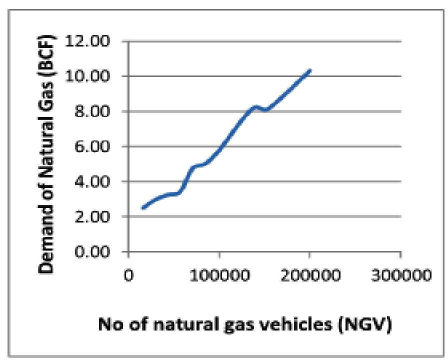
(a) Changes of Gas consumption with Population



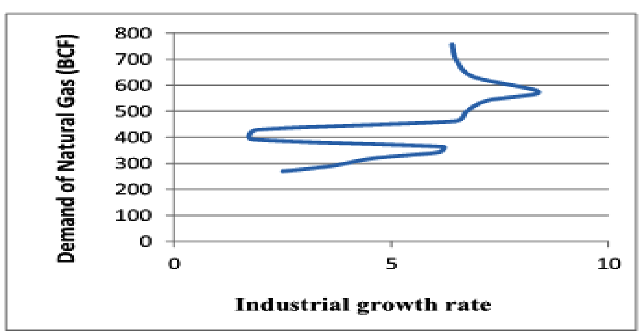
b) Changes of Gas consumption with Power Generation



(c) Changes of Gas consumption with Agriculture



(d) Changes of Gas consumption with No. of NGV.



(e) Changes of Gas consumption with Industrial Growth rate

Figure 3. Changes of demand with input parameters

From the collected data of thirty consecutive years datasets have been prepared. Among these 12 datasets has been taken for testing and another 8 datasets for checking purpose. Rest of the 33 sets of data has been used for training the ANFIS. As there are no general for the division of training, testing and checking datasets, maximization of the no of datasets for training has got concern. For the selection of testing and checking data, random sampling has been applied.

ANFIS Training, Testing and Checking

To train the ANFIS model five input neurons have been selected to determine one output. Three input membership functions has been taken. A total of 20 input-output membership functions type is possible to consider for the generation of the FIS. The selection of input-output type has been completed based on trial and error method. Then the testing of the data is run. The datasets for testing the ANFIS model are loaded which will be displayed as dataset index. After testing the testing data the FIS output is given against index. After choosing the input output membership function the FIS is generated and ANFIS model structure is created. This structure shows the relationship between input and output membership functions and generates rules following this relationship. The training and testing datasets are shown in Table 2 and Table 3.

Table 2: Training Datasets

Year	Population (in million)	No of Natural Gas vehicles	Power Generation (Billion KWh)	Industrial Production Growth Rate (%)	Agriculture (kilo metric ton)	Total Gas Consumption (BCF)
1973	80.624	0	0	0	11.14	50
1974	82.956	0	0	0	9.96	59.68
1975	85.288	0	0	0	10.04	65
1976	87.620	0	0	0	11.88	68.6
1977	89.952	0	0	0	11.28	95
1978	92.284	0	0	0	12.84	100
1979	94.878	0	0	0	11.88	113
1982	97.473	0	0	0	13.16	131.3
1983	100.067	0	0	0	13.18	150.09
1984	102.662	0	0	0	13.42	164.21
1985	105.256	0	0	0	15.05	162
1986	107.702	0	0	0	14.67	173
1987	110.148	0	0	0	15.28	206.24
1988	112.595	0	0	0	15.74	215.77
1990	115.041	0	0	0	16.16	234.84
1991	117.487	0	0	0	16.17	260.27
1992	119.908	0	0	0	16.59	269.45
1993	122.329	0	0	2.5	16.54	269.45
1994	124.750	0	0	3.62	16.65	289.58
1995	127.139	16480	0	4.6	18.68	319.6
1997	129.592	30060	12.5	6.1	18.87	342.56
1998	131.789	43640	12.06	6.2	19.7	363.74
1999	133.989	57220	13.49	1.8	19.59	392
2000	136.189	70805	15.33	1.9	19.21	429.08
2002	138.388	84385	15.33	6.5	18.15	462.63
2003	140.588	97975	16.45	6.7	19.13	494.41
2005	142.209	111550	17.42	7.2	20.4	541.03
2006	143.829	125130	18.09	8.4	20.73	574.58
2008	145.450	138715	22.78	6.9	21.86	632.14
2009	147.071	152300	22.78	6.5	22.56	697.47
2011	148.692	165875	22.99	6.4	22.98	757.62
2012	150.314	200000	25.62	6.8	23.67	819.065

Table 3: Testing Datasets

Population (in million)	No of Natural Gas vehicles	Power Generation (Billion KWh)	Industrial Production Growth Rate (%)	Agriculture (kilo metric ton)	Total Gas Consumption (BCF)
88.786	0	0	0	11.58	81.8
93.581	0	0	0	12.92	106.5
98.77	0	0	0	13.17	140.695
108.925	0	0	0	14.98	189.962
118.698	0	0	0	16.38	264.86
125.95	13435	0	4.11	17.67	304.6
130.691	36850	12.55	6.15	19.05	353.15
135.089	64010	14.41	6.4	19.4	410.75
139.488	91180	15.89	6.6	18.64	478.52
143.019	118340	17.76	7.8	20.55	557.8
146.261	145510	22.78	6.7	22.21	664.81
149.503	182940	24.31	6.6	23.33	788.35

Results and Analysis

After the training of the ANFIS being completed, Gas consumption demands for the upcoming years have been calculated from the generated FIS. The results of Gas consumption demand obtained from ANFIS are shown in Table 4.

Table 4: Checking Datasets

Year	Population (in million)	No of Natural Gas vehicles	Power Generation (Billion KWh)	Industrial Production Growth Rate (%)	Agriculture (kilo metric ton)	ANFIS Demand Total Gas Consumption (BCF)	Actual Total Gas Consumption (BCF)
1980	95.15	0	0	0	15	**58.3576**	61.25
1981	96.18	0	0	0	13.05	**119.97**	125.5
1989	113.82	0	0	0	15.68	**224.5762**	227.45
1996	128.32	25145	10.7	5.15	18.36	**361.8155**	328.9
2001	137.288	77600	15.15	6.5	19.02	**454.4043**	445.45
2004	141.255	104750	16.83	6.65	19.6	**500.9989**	518.2
2007	144.64	131930	20.25	6.65	21.4	**590.4560**	612.31
2010	147.882	164225	23.55	6.7	22.77	**711.7304**	726.6

Comparison with Actual Occurrence

The graph in the Figure 4 and Figure 5 shows the difference between the ANFIS forecast and the actual Gas consumption of corresponding time period. Curve representing actual and forecasted demands show very little discrepancies between the forecast and actual occurrence.

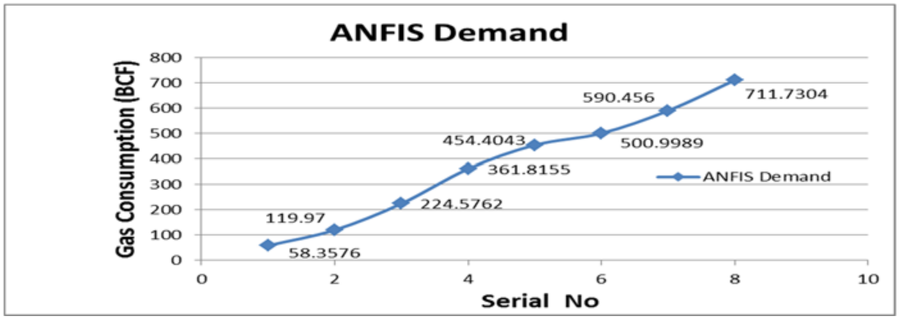


Figure 4: Demand of Gas consumption obtained from ANFIS

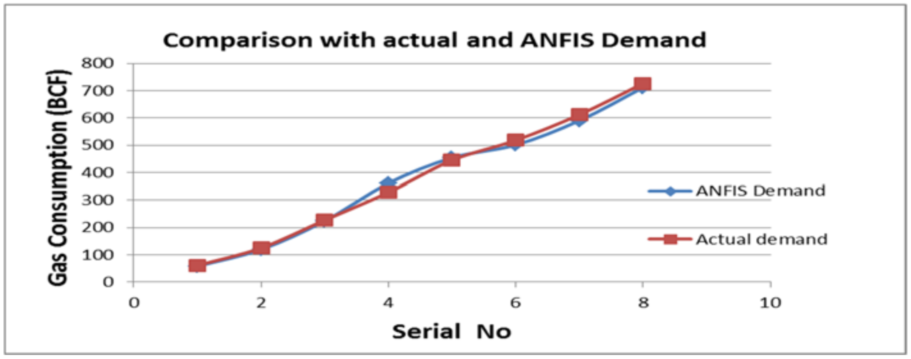


Figure 5: Comparison of actual and forecasted demand by ANFIS

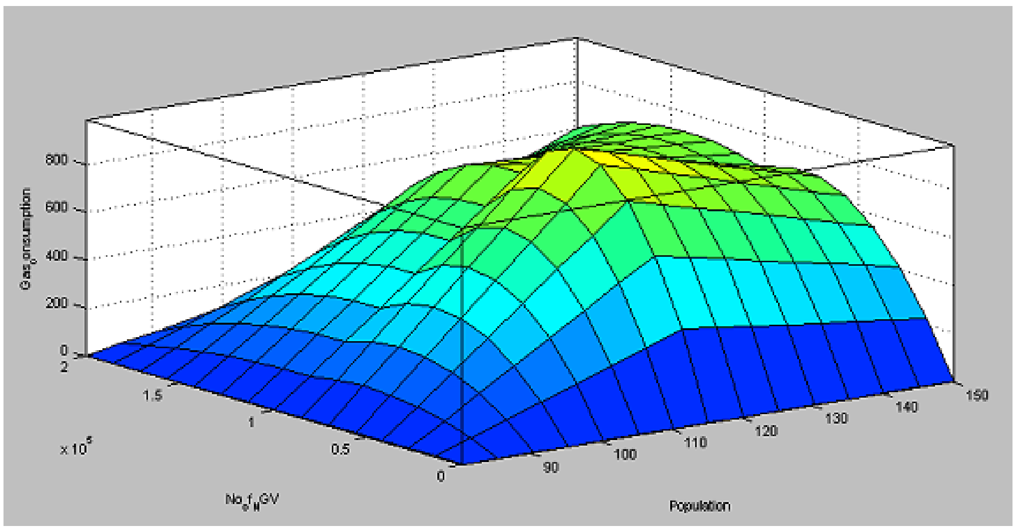


Figure 6: Control Surface generated by the developed ANFIS model showing relation between Natural Gas Consumption with population & number of NGV

From the actual demand data, related performances measures have been calculated to validate the ANFIS modeling. The Root Mean squared Error (RMSE), Mean absolute deviation (MAD) and Mean absolute percentage errors (MAPE) were 16.6, 13.39 and 3.918 respectively. The tracking signal (TS) was found 1.744 suggesting the forecasting model is in control.

7. Conclusion

The developed ANFIS model is generated to forecast the long term demand of natural gas consumption. The result of developed model indicates that the proposed model is suitable and preferable to forecast over the common practice of traditional approaches because of its very less error Mean absolute percentage error (MAPE) only 3.918%. The tracking Signal (1.744<3.75) indicates promised service level is more than 99% .The developed model is applicable to forecast in most of the countries where all these five input parameters are available. As almost all the input variables are considered while developing the model and the outcome is almost equal with the actual with only a little deviation with respect to the environment of energy sector of Bangladesh, So, an algorithm that will able to forecast gas consumption demand with respect to our country environment with more accuracy will play a major role in the development of our energy sector. Besides, the developed model can also be used to forecast the optimum demand of natural gas consumption of other countries also.

The demand of natural gas consumption is highly uncertain with respect to the change of influencing variables. Thus this uncertain demand of natural gas is very difficult to forecast with traditional approaches. With training and testing datasets an artificial intelligence - fuzzy inference system, Adaptive Neuro Fuzzy Inference System (ANFIS) model is developed which provide a minimal error. Lower value of Tracking Signal (TS) ensured in 99% cases the developed algorithm will give accurate forecast. So, it can be said that the efficiency of the ANFIS model developed in this paper has been verified. This clearly indicates the viability of developed ANFIS model to forecast the highly uncertain long term demand of natural gas consumption.

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Biography

Ferdous Sarwar is an Assistant Professor in the Department of Industrial and Production Engineering of Bangladesh University of Engineering and Technology (BUET). He received the B.Sc. (summa cum laude) and M.Sc. degrees in Industrial and Production Engineering from the same university, in 2004 and 2007, respectively. He received the Ph.D. degree in Manufacturing Engineering from the North Dakota State University (NDSU), USA in 2012. He started his academic career as a Lecturer at BUET in 2004. He was with the Center for Nano scale Science and Engineering (CNSE) of NDSU, as a Graduate Research Assistant, from 2008 to 2012. He has been involved in numerous research projects in the area of advanced packaging methods for flexible microelectronics systems at CNSE. Mr. Sarwar is a member of the International Microelectronics and Packaging Society, the Surface Mount Technology Association, and the Institute of Industrial Engineers.

Md. Mamunur Rashid is continuing his M.Sc. in Industrial and Production Engineering, faculty of Mechanical Engineering at Bangladesh University of Engineering and Technology, Bangladesh. He also completed his Bachelor of Science degree in Industrial and Production Engineering from the same university. His research interest includes artificial intelligence, reliability engineering, supply chain management, operations scheduling, multidisciplinary optimization, inventory management and lean manufacturing.

Debasish Ghosh is currently working at DBL Group as an executive of Production Planning Department. Besides He is also working as a coordinator of Lean Manufacturing at DBL Group .He completed his Bachelor of Science degree in Industrial and Production Engineering, faculty of Mechanical Engineering at Bangladesh University of Engineering and Technology, Bangladesh in 2013. His research interest includes multidisciplinary optimization, Analytic Network process in Supplier selection, fuzzy logic, ANFIS, Linear & Non-linear Programming, Inventory Management, operations scheduling, supply chain management, genetic algorithm and artificial neural network.