Int. J. Advance. Soft Comput. Appl., Vol. 4, No. 2, July 2012
ISSN 2074-8523; Copyright © ICSRS Publication, 2012
www.i-csrs.org

SPEED CONTROL TECHNIQUES USING FUZZY LOGIC AND RESPONSE SURFACE METHODOLOGY

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Abstract

A better control of rotating speed of DC shunt motor has been presented with less number of data for achieving the desired speed of rotation. The methodology to accurately control the rotating speed shown in the paper can be used as powerful tool to control various machineries in the shop floor and also useful to the control engineers. The physical implications of the equations regarding device behavior, and the need for speed control, are easily understood. The present research work deals with the application of Fuzzy Logic and Response Surface Methodology (RSM) for controlling as well as estimating the rotating speed of a DC shunt motor. As the rotating speed of DC shunt motor depends on armature voltage and field current applied to the shunt motor, therefore, these two process parameters were varied during experimentation. Moreover, empirical model has been developed to predict any desired speed of rotation of the DC shunt motor and the model has been validated through confirmation experimentations. The present paper will be useful for the students to readily draw a mental picture regarding the rotating speed of the shunt motor and applied voltage and current.

Keywords: *DC shunt motor, Speed control, Fuzzy Logic, Response surface methodology, Computational intelligence.*

1 Introduction

When voltage is applied to the motor, the high resistance of the shunt coil keeps the overall current to flow at low value. The armature for the shunt motor is similar to the series motor and it will draw a current to produce a magnetic field strong enough to cause the armature shaft and load to start turning. Like the series motor, when the armature begins to turn, it will produce back electro-magnetic force (EMF). This back EMF will cause the current in the armature to begin to diminish to a very small level. The amount of current that the armature will draw is directly related to the dimension of the load when the motor reaches its full speed. Since the load is generally small, the armature current will be small. Whenever the motor reaches its full rpm, its speed will remain fairly constant.

Generally, the rotational speed of a DC motor is proportional to the voltage applied to it, and the torque is proportional to the current. Speed control can be achieved by variable battery tapings, variable supply voltage, resistors or electronic controls. The direction of a wound field DC motor can be changed by reversing either the field or armature connections but not both. This is commonly done with a special set of contactors (direction contactors).The effective voltage can be varied by inserting a series resistor or by an electronically controlled switching device made of thyristors, transistors, or, formerly, mercury arc rectifiers.

The application of fuzzy logic is an effective alternative for any problem where logical inferences can be derived on the basis of causal relationships. As a mathematical method which encompasses the ideas of vagueness, fuzzy logic attempts to quantify linguistic terms so the variables thus described can be treated as continuous, allowing the system's characteristics and response to be described without the need for exact mathematical formulations [1]. Such concepts can often be introduced best in the classroom by example. In this paper, the application of fuzzy-logic concepts to the speed control of a simple dc motor is illustrated. The device model is straightforward and the physical implications of speed control are readily perceived. Thus student attention is concentrated upon the fuzzy logic aspects of the problem rather than upon the complexities of the model. Specifically, the paper describes the development of a fuzzy-logic controller to maintain constant speed in a shunt connected dc motor operating under various shaft-loading conditions. Using a commercially available fuzzy logic development kit, fuzzy sets and fuzzy "If-Then" rules are developed for this application, and minimization is performed on a speed error signal. The purpose of speed control is to automatically return the speed of the motor to a specified value following a load change.

Response Surface Methodology has been introduced to control the rotational speed of DC shunt motor statistically by varying the armature voltage and filed current applied to it. There is a problem faced by experimenters in many technical fields, where, in general, the response variable of interest is *y* and there is a set of predictor variables *x1*, *x2*,…, *xk*. For example, in Dynamic Network Analysis (DNA) Response Surface Methodology (RSM) might be useful for sensitivity analysis of various DNA measures for different kinds of random graphs and errors. In social network problems usually the underlying mechanism is not fully understood, and the experimenter must approximate the unknown function *g* with appropriate empirical model

$$Y= f(X_1,X_2,\ldots..X_k)+ € \qquad (1)$$

where, the term ε represents the error in the system. Usually the function f is a first-order or second-order polynomial. This empirical model is called a response surface model.

Identifying and fitting from experimental data an appropriate response surface model requires some use of statistical experimental design fundamentals, regression modeling techniques, and optimization methods. All three of these topics are usually combined into Response Surface Methodology (RSM). The RSM is also extremely useful as an automated tool for model calibration and validation especially for modern computational multi-agent large-scale social-networks systems that are becoming heavily used in modeling and simulation of complex social networks. The RSM can be integrated in many large-scale simulation systems such as BioWar, ORA and is currently integrating in Vista, Construct, and DyNet.

During the last 25 years, there have been significant developments in methods for model based control [2]-[3]. A recent survey of evolutionary algorithms for evaluation of improved learning algorithm, control system can be found in [4]-[5]. Among the techniques found out, intelligent techniques and computational optimization techniques have found themselves a place in tuning of the parameters. The intelligent techniques like artificial neural networks (ANN), fuzzy logic (FL) have been developed over the last ten years [6]-[7]. Neural and fuzzy logic mimic the functioning of human intelligence process [8]. But their real time implementation is quite difficult [9]. Hence as a result of the above said problems optimization algorithms have received increasing attention by research community [10]. In recent years, there have extensive research on heuristic stochastic search techniques for optimization of the PID gains [11]-[12]. An optimization algorithm is a numerical method or algorithm for finding the maxima or the minima of a function operating with certain constraints [13]. An optimal control is a set of differential equations describing the paths of the control variables that minimize the cost function [14]-[15]. Computational intelligence was the way in which optimization was done. Computational intelligence (CI) is a successor of artificial intelligence relying on evolutionary computation, which is a famous optimization technique. Computational intelligence (CI) combines elements of learning; adaptation and evolution to create programs that are, in some sense, intelligent. Computational intelligence research does not reject statistical methods, but often gives a complementary view [16]. The importance of CI lies in the fact that these techniques often find optima in complicated optimization problems more quickly than the traditional optimization methods.

2 PROBLEM DEFINITION

The rotation of a DC shunt motor depends on the armature voltage and field current applied to the particular motor. In the present paper, an attempt has been taken to achieve the desired speed of a DC shunt motor by varying these two process parameters such as armature voltage and field current. The Fuzzy Logic approach and a statistical method i.e. response surface methodology (RSM) has been applied to construct the design of experiments (DOE). The experiments have been conducted on different sets of process parametric settings and for each experiment, rotating speed of the DC shunt motor have been noted with the help of a Tachometer. The results have been obtained with the help of fuzzy logic tool box of Matlab then the results of rotating speed were analysed in a statistical software i.e. MINITABTM version 15.0. A model has been developed which can be used to achieve any particular rotating speed of DC shunt motor. The developed model has been validated with another set of confirmation experiments

3 EXPERIMENTAL APPROACH

The present experimentations have been carried out using an experimental set-up which includes number of apparatus such as DC shunt motor, two variable resistors, one DC ammeter, one DC voltmeter, tachometer etc. Table 1 shows the list of instruments used with their detailed specifications. In Fig. 1, the schematic representation of the detailed connections of the instruments is shown. The photographic view of the set-up with various instruments connected with the DC shunt motor is shown in Fig. 2. It is evident that the rotating speed of a DC shunt motor depends on armature voltage and field current applied to the shunt motor. Therefore, in the present experiments, these two process parameters were varied keeping other parameter as constant.

Name of instrument	Specifications
DC shunt motor	Type: DC 112.178.302 Volt: 220 V, Amp.: 12 A HP: 3.0, RPM: 1500
Variable Rheostat (Vh) Vh 1 Vh 2	 360 Ω, 1.1 Amp 50 Ω, 3.3 Amp
Ammeter	0 – 1 Amp
Voltmeter	0 – 300 V
Tachometer	Range: 0-2000 RPM

TABLE 1 Details of instruments used during experiments

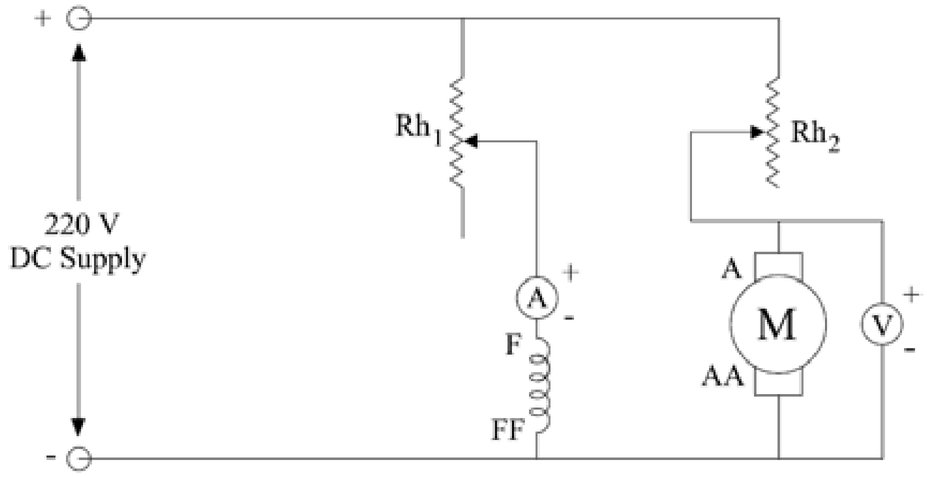

Fig. 1 Schematic diagram of connections for the instruments used during experiment

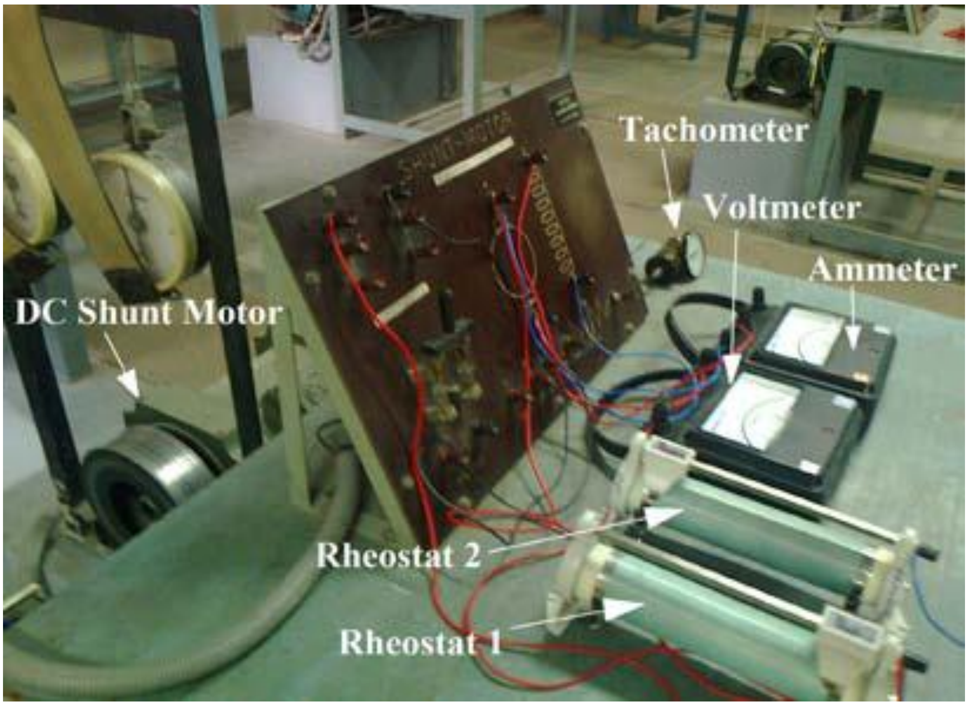

Fig. 2 Photographic view of the experimental set-up with various instruments connected

Thirteen sets of experiments were performed in the laboratory and the values so obtained were noted down.

EXPERIMENT NO.	**PARAMETRS**		**RESPONSE**
	Armature Voltage(V)	**Field Current(A)**	**Shunt Motor Speed (RPM)**
1	190	0.50	1320
2	200	0.40	1515
3	195	0.35	1573
4	190	0.40	1442
5	190	0.45	1403
6	190	0.3	1622
7	180	0.40	1430
8	190	0.40	1442
9	185	0.45	1365
10	185	0.35	1535
11	195	0.45	1420
12	190	0.40	1466
13	195	0.45	1420

Table 2: Experimental values obtained in laboratory

3.1 Proposed Methodology and Results

3.1.1 Fuzzy Logic Approach:

The data achieved by the experimental results based on that certain sets of rules are written in fuzzy logic tool box of Matlab. Based on the rules written in Matlab, with the help of rule viewer the speed is determined for each of the voltage and current inputs.

The figure below shows how armature voltage is defined. By clicking on the input voltage parameter the membership function are plotted as shown in the fig.similarly all the values for current and speed is assigned. Finally through rule viewer the speed response with respect to current and voltage can be seen.

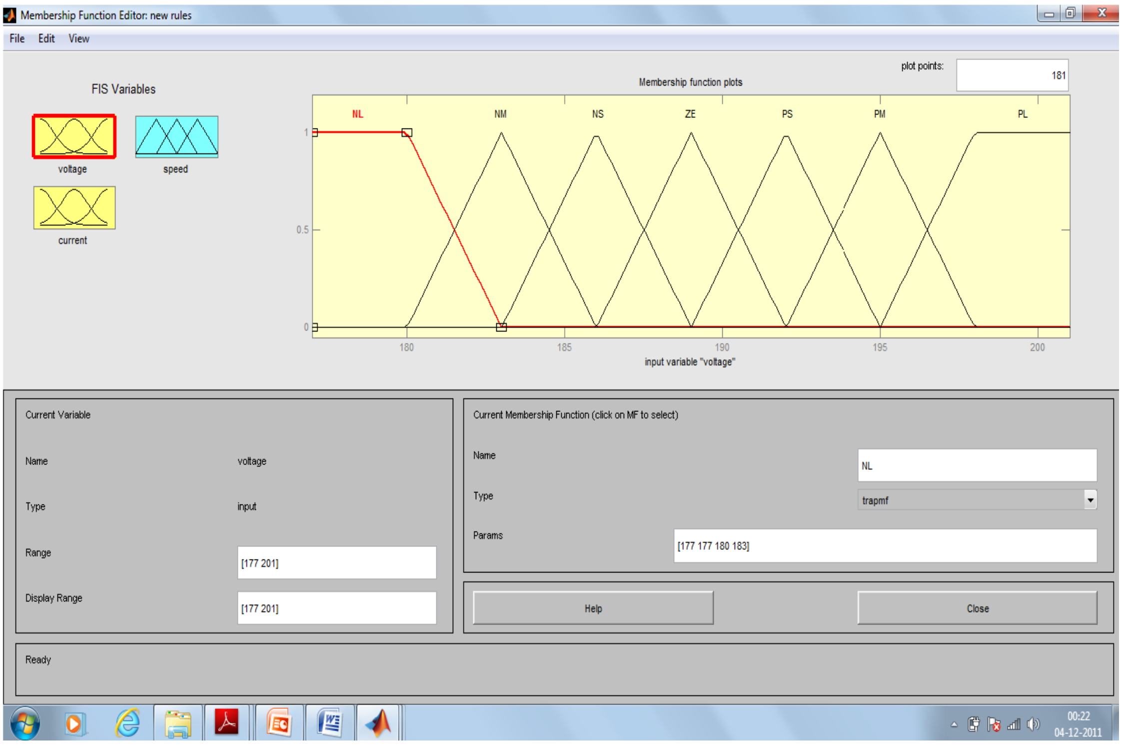

Fig. 3: Plotting of membership values

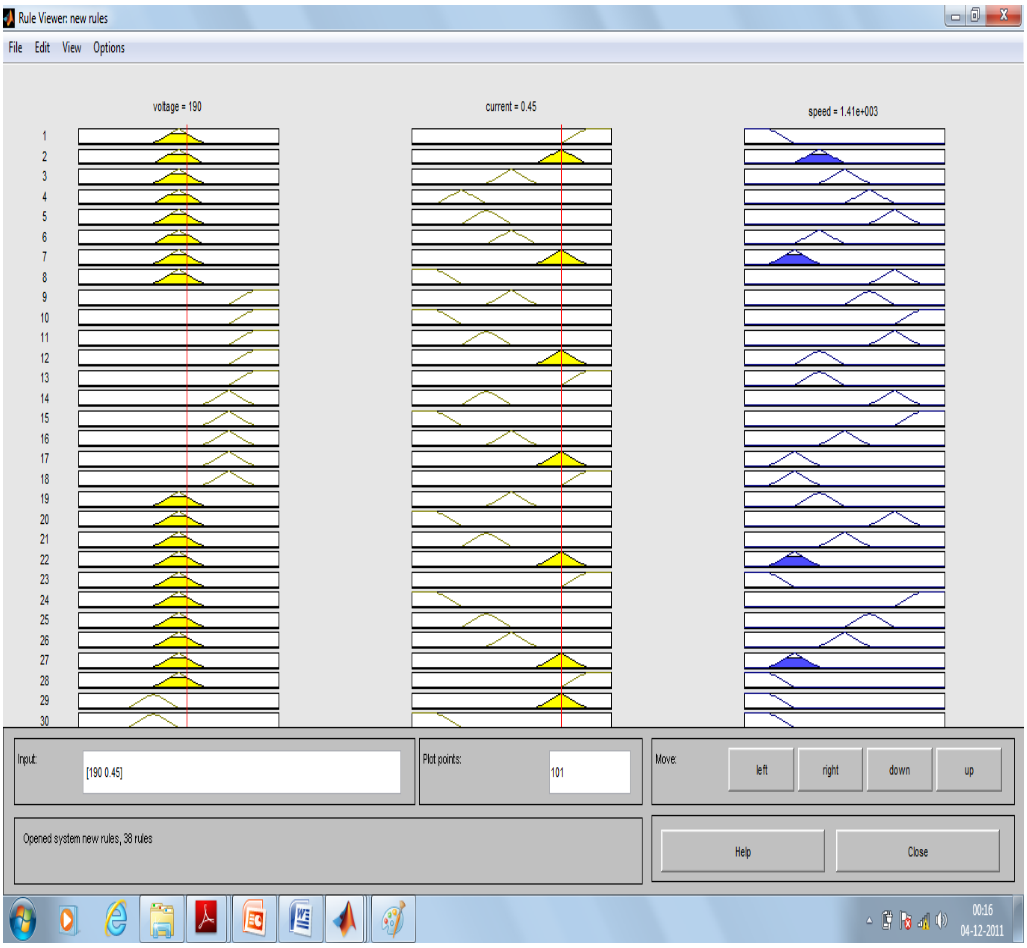

Fig 4: Rule viewer

3.1.2 Response Surface Methodology Approach:

Response surface methodology (RSM) based approach has been considered to construct the design of experiments (DOE). Experiments have been carried out based on central composite rotatable second-order rotatable design (CCRD) experimental plan [18]. The considered range of these two process parameters with coded and uncoded levels are enlisted in Table 2. The ranges and the levels of the process parameters have been selected after conducting lot of trial experiments using the machine set-up. The second-order polynomial response surface empirical model can be represented as:

$$Y_u = \beta_0 + \sum_{i=1}^{n} \beta_i X_{iu} + \sum_{i=1}^{n} \beta_{ii} X_{iu}^2 + \sum_{i<j}^{n} \beta_{ij} X_{iu} X_{iu} + e_u \quad (2)$$

where, Y_u represents the corresponding response and the X_{iu} are coded values of the *i*th process parameters. The terms β_0, β_i, β_{ii} and β_{ij} are the regression coefficients and the residual, e_u measures the experimental error of the *u*th observations. According to the design based on response surface methodology, it was observed that there are 13 numbers of experiments for two process parameters and five level values of each of the parameters. Table 3 shows the details of the experimental settings of all those experiments. Each experiment was conducted three times and the average value of the three rotating speeds of the DC shunt motor was calculated. The results of the rotating speed measured during experimentations were analyzed in a statistical software i.e. MINITAB™. Based on the results of rotating speed, a mathematical model has been developed which can be utilized to achieve any desired rotating speed of the DC shunt motor.

3.2 Response Surface Regression: speed versus armature voltage, field current

The analysis was done using coded units.

Estimated Regression Coefficients for speed

Term	Coef	SECoef	T	P
Constant	1442.00	5.642	255.589	0.000
Armature voltage	26.65	4.460	5.975	0.001
Field current	-90.40	4.460	-20.268	0.000
Armature voltage*armature voltage	12.31	4.783	2.574	0.037
Field current*field current	24.81	4.783	5.188	0.001
Armature voltage*field current	4.25	6.308	0.674	0.522

S = 12.6156 PRESS = 7922.30

R-Sq = 98.56% R-Sq(pred) = 89.73% R-Sq(adj) = 97.52%

Analysis of Variance for speed

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	76001.6	76001.6	15200.3	95.51	0.000
Linear	2	71063.6	71063.6	35531.8	223.25	0.000
Square	2	4865.8	4865.8	2432.9	15.29	0.003
Interaction	1	72.3	72.3	72.3	0.45	0.522
Residual Error	7	1114.1	1114.1	159.2		
Lack-of-Fit	3	1114.1	1114.1	371.4	*	*
Pure Error	4	0.0	0.0	0.0		
Total	12	77115.7				

Unusual Observations for speed

Obs	StdOrder	speed	Fit	SE Fit	Residual	St Resid
5	7	1639.000	1619.474	9.974	19.526	2.53 R
6	2	1573.000	1591.929	9.974	-18.929	-2.45 R

R denotes an observation with a large standardized residual.	
Estimated Regression Coefficients for speed using data in uncoded units	
Term	**Coef**
Constant	1442.00
armature voltage	26.6510
field current	-90.4028
armature voltage*armature voltage	12.3125
field current*field current	24.8125
armature voltage*field current	4.25000

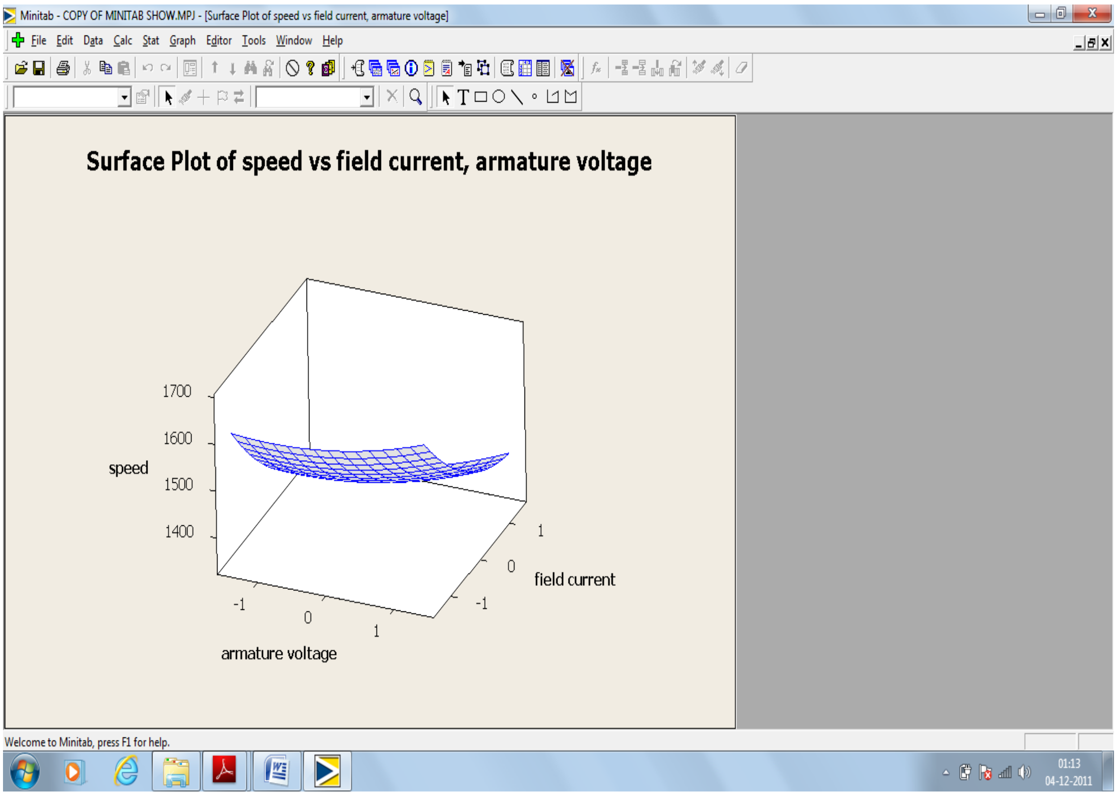

Fig 5: Surface Plot of speed with field current and armature voltage

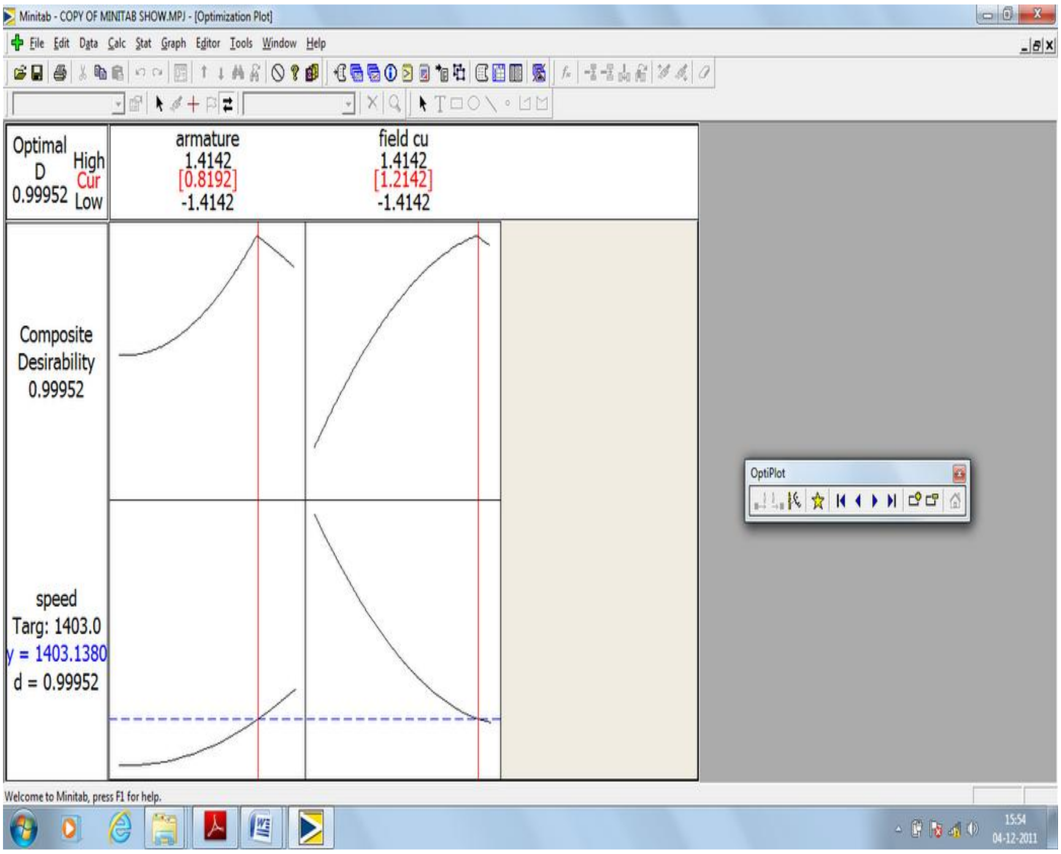

Fig 6: Optimization plot obtained in minitab

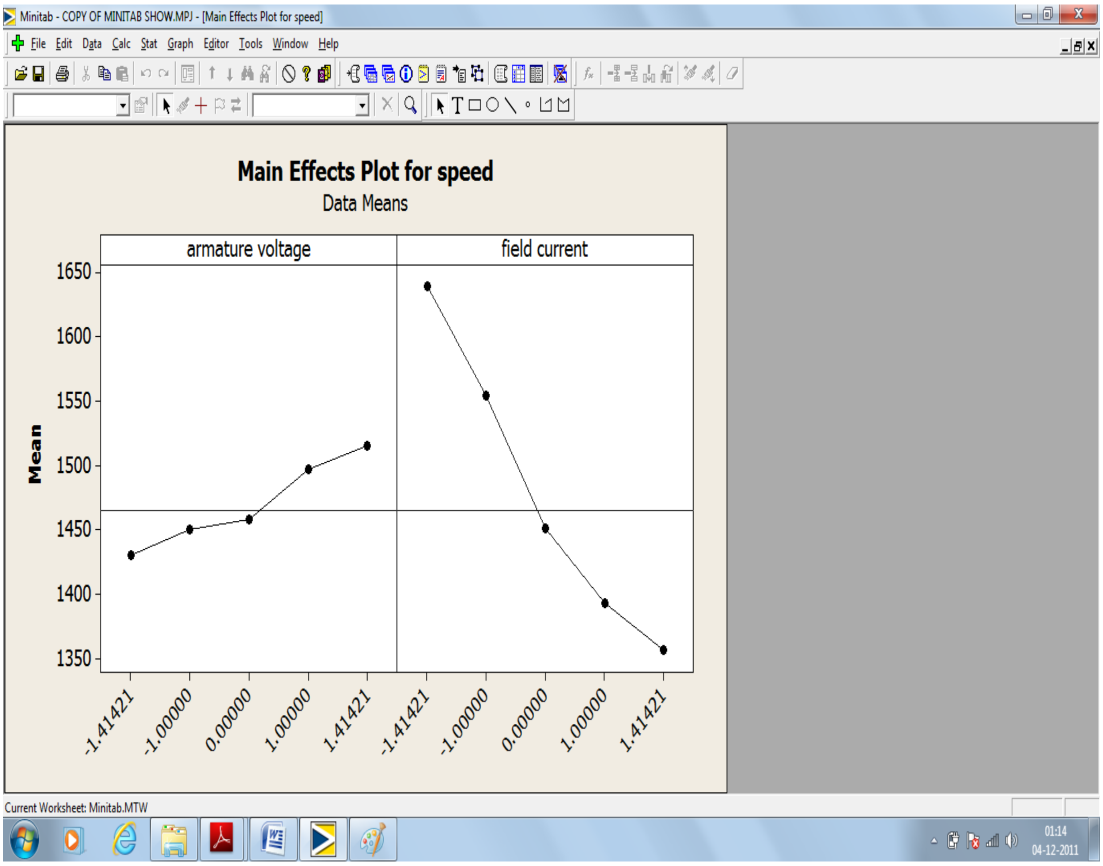

Fig 7: Main effect plot

Comparison of the speed values obtained for different inputs in Response Surface Methodology with the experimental values of speed . The results and error are shown below:

SL NO.	PARAMETERS		SHUNT MOTOR SPEED (RPM)			PREDICTED PERCENTAGE ERROR	
	Armature Voltage (V)	Field Current (A)	Experimental Results	Fuzzy Results	RSM Generated Results	Between Experimental & Fuzzy Results	Between Experimental & RSM Results
1	180	0.40	1430	1440	1428	0.00699	0.00139

2	190	0.30	1622	1630	1619	0.0049	0.0018
3	200	0.40	1515	1540	1504	0.0165	0.0072
4	195	0.45	1420	1390	1419	0.0211	0.0007
5	190	0.40	1442	1460	1442	0.0124	0

Table 3: Results comparisons between experimental, Fuzzy Logic and RSM methodology

The results show the comparison between the experimental results, RSM results and Fuzzy results. The RSM generated results are more close to the experimental results performed in laboratory, hence the percentage error is less in case of RSM than in Fuzzy logic. The steps for the results are more and complex in case of RSM compared to the steps followed in Fuzzy logic.

4 Conclusion

In the present paper, Fuzzy logic approach and Response surface method (RSM) has been successfully applied to estimate and control the speed of DC shunt motor by varying the armature voltage and field current. The fuzzy logic model is developed with fuzzy logic tool box in Matlab. Different sets of rules are written keeping the experimental results obtained in laboratory. The results obtained were compared with the experimental results. The design for the experiments for RSM method has been planned based on central composite design (CCD) for experiments and the results of rotating speed of DC shunt motor for various set of process parameters were used to develop a RSM model. The adequacy of the developed model was checked through ANOVA test. An empirical model has been developed and the model has been validated with further experimentations. From the results of confirmation experiments, it is revealed that the developed model can estimate the process parametric setting to achieve a desired rotational speed of the DC shunt motor very accurately. A better control of rotating speed of DC shunt motor has been presented with less number of data for achieving the desired speed of rotation. The methodology to accurately control the rotating speed shown in the paper can be used as powerful tool to control various machineries in the shop floor and also useful to the control engineers

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