Gazi University Journal of Science
GU J Sci
24(3):437-449 (2011)

GUJS
www.gujs.org

A Fault Diagnosis of Engine Starting System Via Starter Motors Using Fuzzy Logic Algorithm

Ömer Faruk BAY[1♠], Raif BAYIR[2]

[1]Department of Electronics and Computer Education, Gazi University, 06500 Teknikokullar

[2] Department of Electronics and Computer Education, Karabuk University 78050, Karabuk / Turkey

Received: 22.07.2010 Revised: 04.10.2010 Accepted:26.11.2010

ABSTRACT

Uncertainties in the system models, the presence of noise and the stochastic behavior of several variables reduce the reliability and robustness of the fault diagnosis methods. For overcoming these kinds of problems, this study proposes the fault diagnosis of starter motors based on fuzzy logic methodology. A starter motor is a serial wound dc motor which is used for running the Internal Combustion Engine (ICE). If a fault occurs with the starter motor, the ICE cannot be run. Especially in emergency vehicles (such as ambulance, fire engine, etc), starter motor faults causes any other faults. In this study, a fuzzy logic based fault detection system has been developed for implementation on emergency vehicles. Information of the current and the voltage of a starter motor is acquired and then practiced on a fuzzy logic fault diagnosis system (FLFDS). For this purpose, a graphical user interface (GUI) software is developed by using Visual Basic 6.0 programming language. FLFDS is effective in detection of six types of starter motor faults. The proposed system can be used in a Quality Control unit of manufacturers and maintenance-repairing units.

Key words: Engine starting system; Starter motor faults; Fault diagnosis, Fuzzy logic.

1. INTRODUCTION

Although electric motors are well assembled and reliable, faults may reveal during their running. Electric motors convert electrical energy into mechanical energy so that electrical or mechanical faults or combination of both occur. Therefore, in application of electrical motors, safety, reliability, productivity and performance are the characteristics that are mostly interested and desired. Manufacturers or users of electrical machines take measures to prevent motor faults. But, the motor faults can be determined after a long time. The functions of electrical motors are getting more complex and used in places that have vital importance for people. Now it is very important to diagnose faults in advance, as unscheduled machine downtime may upset deadlines and cause heavy financial loss [1, 2].

Electric motors' applications range from the small dc motors, used in intensive care life support units, to the huge motors, used in power plants. The diagnostic methods, to identify the faults, may involve several different types of the scientific and technological fields.[3, 4, 5]. Human involvement in the actual fault detection decision making is slowly being replaced by automated tools, such as expert systems, neural networks, and fuzzy-logic-based systems [6].

The uncertainty of system models, the presence of noise and the stochastic behavior of several variables reduce the reliability and robustness of the fault diagnosis methods [7]. Fuzzy logic can easily and systematically translate heuristic, linguistic and qualitative knowledge (preferred by human) to numbers and quantitative knowledge (preferred by computers), and vice versa. This provides a simple method for heuristically implementation of fault detection principles and for heuristically interprets, and analyzes their results. Fuzzy logic has a wide spread of applications on domestic apparatus, automotive systems, heavy duty machines, production engineering, industrial technologies and automation [8, 9]. Fuzzy logic can also be used for fault

♠Corresponding author, e-mail: omerbay@gazi.edu.tr

detection and diagnosis successfully [5, 10, 11, 12]. The data, taken from motors, puts fuzzification process and it is progressed by the rules, obtained by the experts, and then the fault diagnosis is conducted.

Miguel and Blázquez, (2005) proposed a decision-making module based on fuzzy logic for model-based fault diagnosis applications [7]. In their study, a fault detection and isolation system, based on the input-output linear model parity equations approach, and including fuzzy decision-making module, has been successfully applied in laboratory equipment, resulting in a reduction of the uncertainty due to disturbances and modeling errors.

Igor, (1985) has explained the application of conditioning fuzzy technique to a real engineering device [13]. His study focuses on how to use pertinent fuzzy-set theoretic concepts for creating a fault diagnosis and prevention model of engineering system, and how to develop the application of induced fuzzy intersection formula.

It is shown that how fuzzy logic approaches can be applied to supervision process and fault diagnosis with approximate reasoning on the observed symptoms. Based on the proprieties of fuzzy logic approaches, the contribution makes a review and classification of the potentials of fuzzy logic in automation process. The task of fault diagnosis consists of determining the type of faults with as much details as possible such as the fault size, location and time of detection. The diagnosis procedure is based on the observed analytical and heuristic symptoms and the heuristic knowledge of the process [4].

Hamid et al. (1999) used fuzzy logic to determine the states of stator and phase currents of induction motors in their study [14]. The system in that study consists of the following sections; fuzzification interface, inference unit, rule base and defuzzification. Information acquired from the observation is used to set up fuzzy rules and membership functions. Fault diagnosis achieved by making the use of characteristically changes in magnitude of stator current. In fuzzy logic fault diagnosis system, 3 phase stator current is applied as input information. As output membership function, the states of stator and phase current are defined as good, bad and very bad.

Dominik et al. (2000) presented and applied a new diagnosis scheme to a dc motor [11]. The approach is based on the combination of structural a priori knowledge and measured data in order to create a hierarchical diagnosis system that can be adapted to different motors.

Olaf et al. (2000) proposed a method for the detection of faults in brushless dc motors [12]. Their study proposes a parameter estimation technique for the fault detection on this type of motor. Simply, by measuring the motor's input and output signals, its parameters can be estimated. This method is based on a mathematical model of the process.

Fault detection and diagnosis of dc motors in online monitoring and Quality Control draw growing attention among scientists and engineers [15]. In order to fulfill motor fault detection and diagnosis, sometimes, several methods or their combination should have been used. A test bed is established to collect the input and output data of the dc motor. The parameters of a normal dc motor are estimated at first, and then different faults are injected into the motor, such as wearing of the brush, opening of the coil, short circuit between adjacent commutator bars, etc. The parameter vectors estimated from the motor with faults then compared with the parameters of the normal dc motor. Using the difference between the two sets of parameters, faults can thus be detected, and to some extent they can be diagnosed. One of the main advantages of this diagnostic technique is that the parameters can be obtained easily without stopping the motor and loading [15].

In this study, faults of the serial wound starter motor used in engine starting system are classified by using a fuzzy logic fault diagnosis system. Pre-results of this study has been published in [16]. For proposed fault diagnosis system, the GUI software is developed by using Visual Basic 6.0 programming language. This study discusses firstly the fault detection and the diagnosis techniques using fuzzy logic. Second section describes serial-wound starter motor and their faults. Third section explains how to develop fuzzy logic fault diagnosis system. Finally, fuzzy logic based fault diagnosis GUI software is presented and its performance is evaluated.

2. MEASUREMENT OF FAULTY STARTER MOTOR CURRENTS AND VOLTAGES

Starter motors convert electrical energy through a battery into mechanic al rotating energy. In starter motors, serial dc motors and their various connection types are used. These motors work under heavy load. They produce big power in a short time and in a small volume. Because of this, fault diagnosis of starter motors differs from that of general dc motors.

Starter motors is working under a heavy load. In a short time with its small volume it produces big power. It conveys its rotating energy with a pinion to the flywheel. This mechanical tie is fulfilled by a solenoid. For initiating Internal Combustion Engine, the rotating moment of starter motors should be requested to be greater. In the first step, the starting moment of a serial wound dc motor is high. For this reason as a starter motor, a serial wound dc motor and its various connection types are preferred.

When starting the Internal Combustion Engines with starter motor, considerable resistance resulting from compression, piston friction and bearing friction (static friction) must be overcome. These forces depend on engine type and number of cylinders, as well as on lubricant characteristics and engine temperature. Friction resistance is the highest at low temperatures. The starter motor must rotate the flywheel at a minimum starting speed. It must also continue to support rotation during initial combustion to maintain momentum until the engine sustains the operation [17].

A typical cranking current for light vehicle engine of the order of 150A, but this may peak in excess of 500A to provide the initial stalled torque. It is generally accepted that maximum voltage drop of only 0.5V, between the battery and the starter, should be allowed while operating. An Ohm's law calculation indicates that the maximum permitted circuit resistance is 2.5mΩ while using a 12V supply. This is the worst case in most applications, lower resistant values are used. The choice of suitable conductors is, therefore, very important [18].

The average starter motor has a service life which is roughly the same as the engine to which it is mounted. However, the starting system should be checked at appropriate intervals if subjected to severe loading such as in commercial vehicle use with frequent starts. This is because that the engines in vehicles, driven primarily in city traffic, are started roughly 2000 times per year, assuming an annual mileage 15 000 km [17]. Herbert (1985) has pointed that when an automotive electric motor does not run the system, it must be checked to identify the cause of the problem [19]. To achieve this, you will check the electrical system voltage, the condition of conductor, and the operating units. Motors must run at proper speeds drawing minimum electrical current.

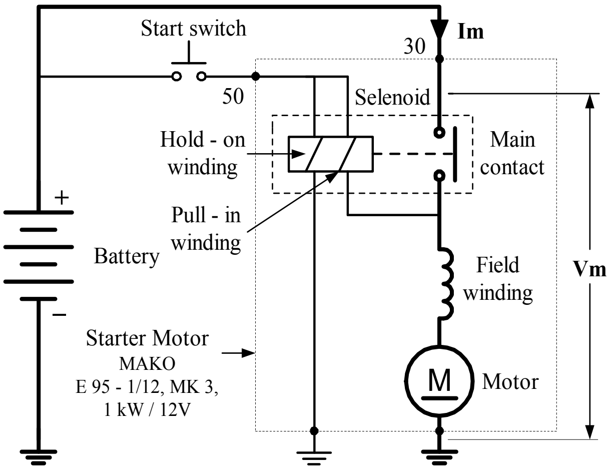


Figure 1. Simple starter system scheme of vehicle

In this study, fault diagnosis of starter motor that starts internal combustion engine has been carried out. Starter motor current (Im) and voltage across motor (Vm) (shown in Figure 1) has been measured and then faults are diagnosed by applying them to the fuzzy logic fault diagnosis system. Vm is the summation of voltages across the field winding and armature. Im is the current flowing through the field winding and armature. Pull-in winding current flows over the motor. The value of this current is very small.

The measurement of faulty starter motor signals is obtained by using a Pico ADC-212 which has low cost alternatives to traditional test equipment and data-acquisition products. ADC-212 has 12 bits high vertical resolution, accurate to ±1% and sampling rate 3MS/s. It has 32k waveform buffers, so it is possible to capture complex signals and then expand areas of interest to show fine detail. The current sensor is based on hall-effect technology and used to measure both DC and AC current values. This sensor may also be used in conjunction with multimeters, recorders and other suitable equipments. The measurement range of this sensor is 200A ACRMS or DC, besides a resolution of ± 100 mA. The motor revolution is calculated by using the interval time between two signal peaks of the current. The voltage and current of starter motor are measured directly with voltage and current probes, not used any sensors.

The faults occurred on starter motors are not only the result of motor. The other elements and materials, used on starter system, can be the reason of the faults. For instance, these are the weakness of battery, looses of battery poles, broken connection cables etc. The mostly observed faults on starter motors and starter systems are; battery fault, connection faults (broken connection cables, looses battery pole etc.), solenoid faults, brush faults, armature faults and field (excitation) winding faults [19, 20]. The torque of an internal combustion engine, in which the starter motor is used with, changes according to the inadequate level of lubricating oil or existence of lubricating problems or coldness of weather etc. Because of this internal combustion engine, an alternating and variable loading is created in front of the starter motors. Besides, the number of revolution, in serial wound DC motors, changes depending on the loading. This causes the errors due to the problem in loading although the starter motor is in good condition. Therefore, ICE has not been allowed to work, during the measurements of voltage and current signals. To measure the signals of faulty starter motors, the measurement rig, shown in Figure 2, has been prepared. In a healthy starter motor, the signal peaks of the current and voltage, drawn from battery, should be observed for a movement of every piston in a four-cylinder ICE (Figure 3).

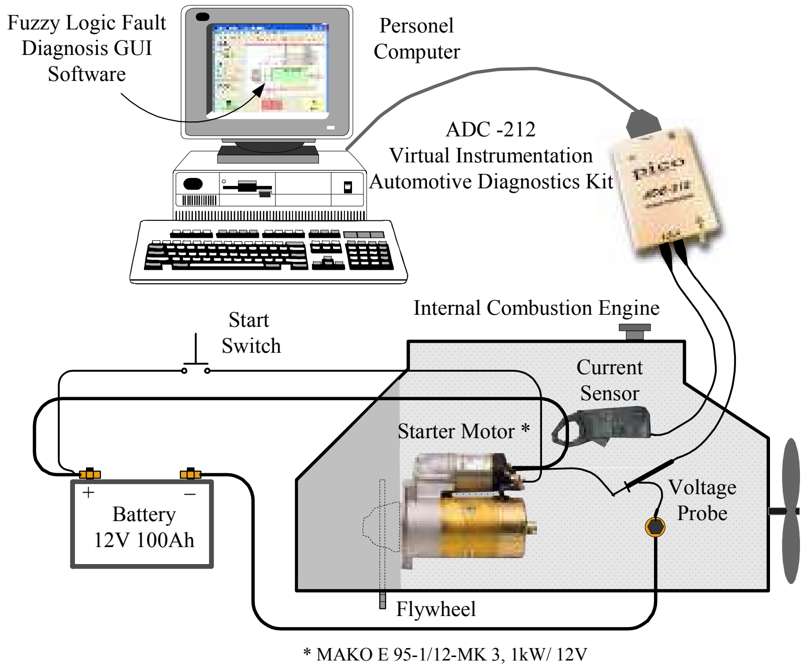


Figure 2. Measurement bench for serial wound starter motor current and voltage

In the case of a brush fault, the sparks occur between the starter motor commutator and the brushes. The reasons of this are unsmooth contact of the brushes, dirty collector or brushes, unadjusted brush pressure springs, oval shaped collector and consumed brush life. In these conditions, the movements of pistons cannot be observed from the signals (Figure 4 a, b). Even if there is no contact in a brush, starter motor sometimes stops (Figure 4 b).

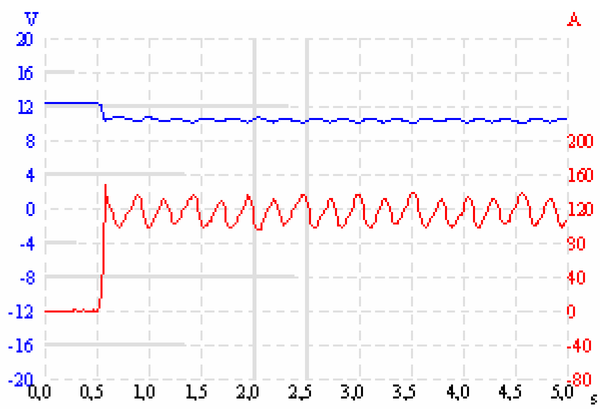
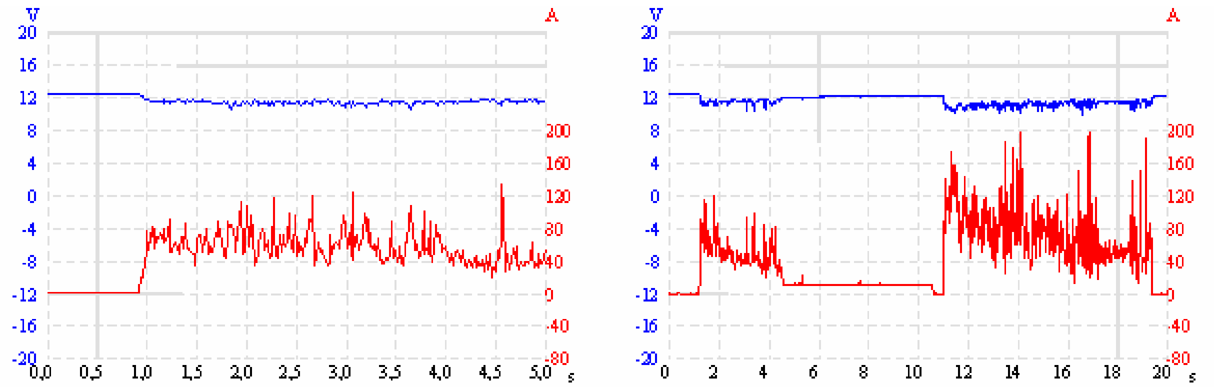


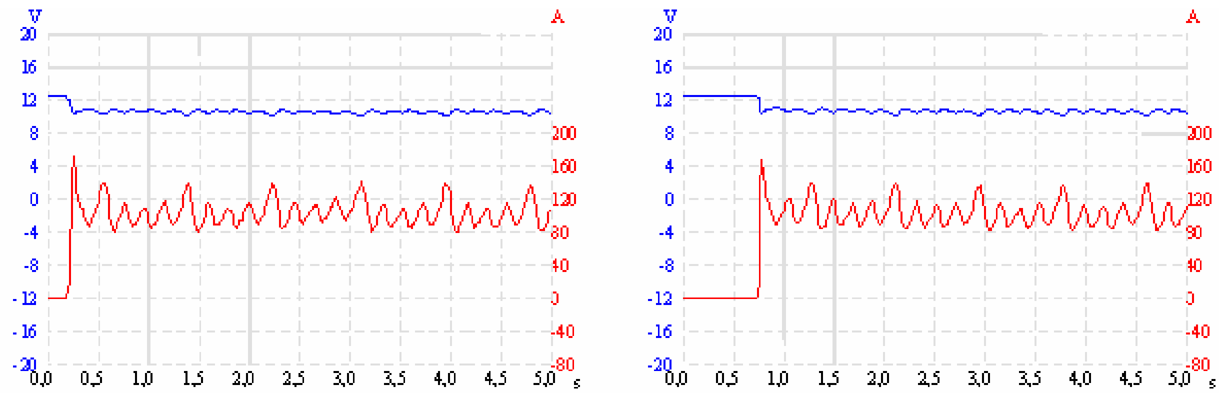
Figure 3. Current and voltage of the healthy starter motor in operation.



(a) (b)

Figure 4. Brush faults (a) Unsmooth contact of the brushes (b) Dirty collector or brushes.

The connection fault is called as open circuit which is investigated under three sub sections. These are the cross-section reduction of connection cable, the loose cable connection and the loose battery pole. The cross-section of connection cable for starter motor is so essential. Decreasing the cross-section of cable results in increasing the current; however, if the reduction is too much, it causes the effect on revolution. In the loose connection, when the contact resistance increases, starter motor current goes up (Figure 5 a, b).



(a) (b)

Figure 5. Open circuit faults (a) Loose or corroded cable connection. (b) Battery pole connection loose or corroded.

In battery fault, the battery cannot provide enough current in order to turn the flywheel. So the distance between the two peaks is quite longer. The voltage, dropped on motor, is about 7-8V. If the battery voltage, at start up, is 6.5-6V, the starter motor does not work (see Figure 10). In this condition, the battery is fully discharged or there is a problem on charging system. There will be dead (trimmed) regions at the signal peaks, and the starter motor almost stops at these stages (Figure 6). The revolution of the motor will be too low.

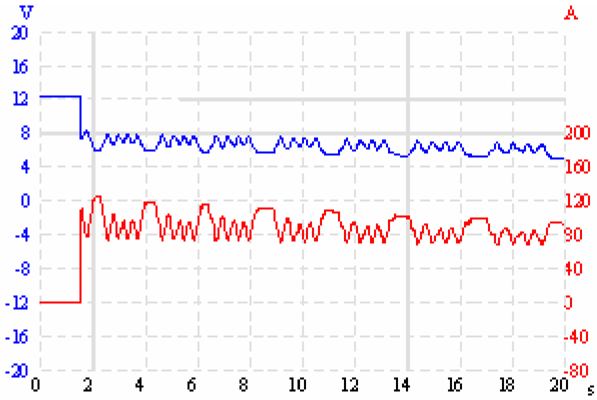
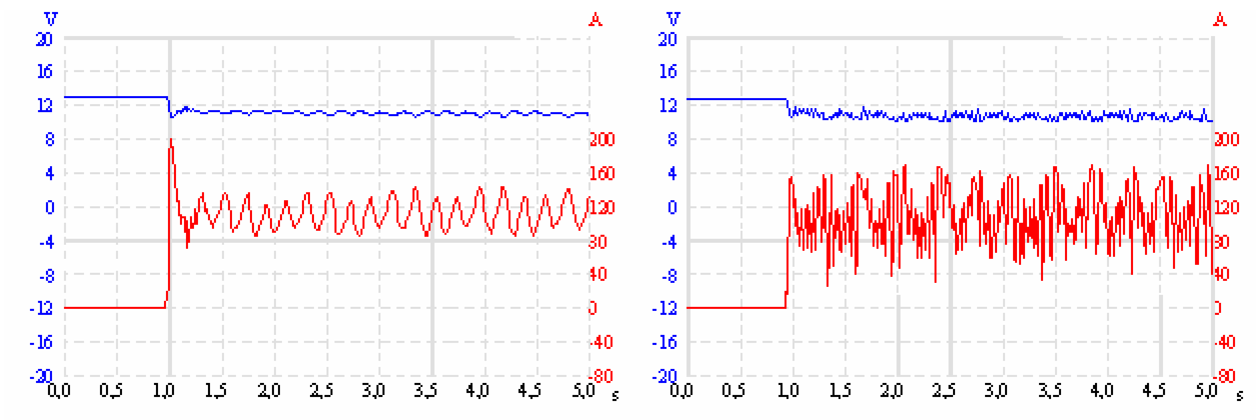


Figure 6. Battery fault.

Becoming short circuit of armature windings, bad armature bearing, and becoming open circuits of armature windings are classified as armature faults. When a short circuit is occurred on armature, the current, drawn, is getting increased, then it is observed that the peaks formed by piston movements are getting worse and their periods are increasing (Figure 7 a). If there is a short circuit on armature winding, one of the armature windings of motor is cancelled. In this case, the motor can be seen as working properly; however the movements of the pistons cannot be observed from the signals (Figure 7b). If the brush comes across with this broken winding, the motor does not start.



(a) (b)

Figure 7. Armature faults (a) Short circuit in armature. (b) Broken coil in armature.

Field winding fault is investigated as becoming short circuit with the ground and the short circuit between own windings. In the latter, the motor turns but there are waves in torque due to the no existence of enough and smooth magnetic field (Figure 8). The motor draws too much current subject to the largeness of short circuit. The starter motor does not turn because there are not enough magnetic fields. This is also called as short circuit fault. The case of short circuit between field windings and ground is given in Figure 9.

.

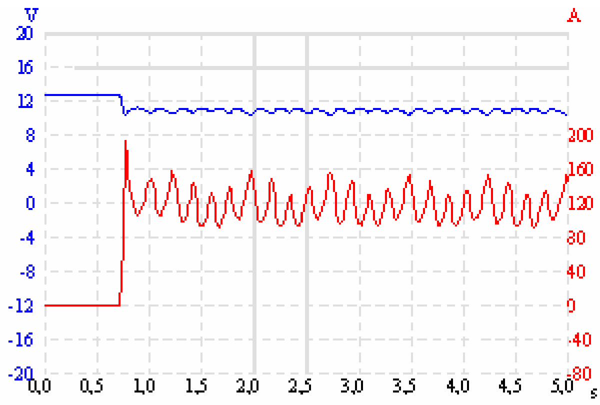


Figure 8. Field winding fault (short circuit between field winding coils).

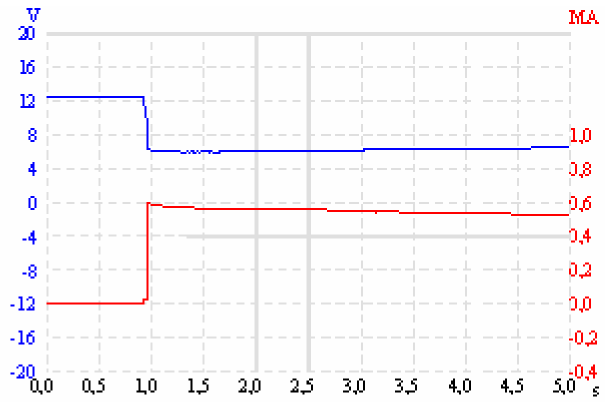


Figure 9. Short circuit fault.

3. DEVELOPING A FUZZY LOGIC BASED FAULT DIAGNOSIS SYSTEM

The first point that should be carried out in a fuzzy logic, based on the fault diagnosis system, is the determination of the variables to be used. The input variables are the current (i) drawn by motor, the motor voltage (v) at tips, and the motor revolution per minute (rpm). The reasons of preferring the variables are that they are used by the experts to diagnose the faults. It can be seen that, the most commonly used variable is the current in fault diagnosis studies. The fuzzy-set approach to fault diagnosis and prevention has several advantages:

- The use of linguistic hedges makes it possible to develop the model of a system based on verbal formulation, and subsequent quantification of the state of the system under study.
- The knowledge base, thus generated, can be refined, as more experience of the behavior of the system is gained, to yield more dependable result.
- Simulations of various aspects of the fault prevention process are possible.
- The fuzzy-set theoretic operations are simple and easy to program for the computer.

Many problems in fault diagnosis and prevention in engineering systems can, indeed, be solved by fuzzy sets only [13]

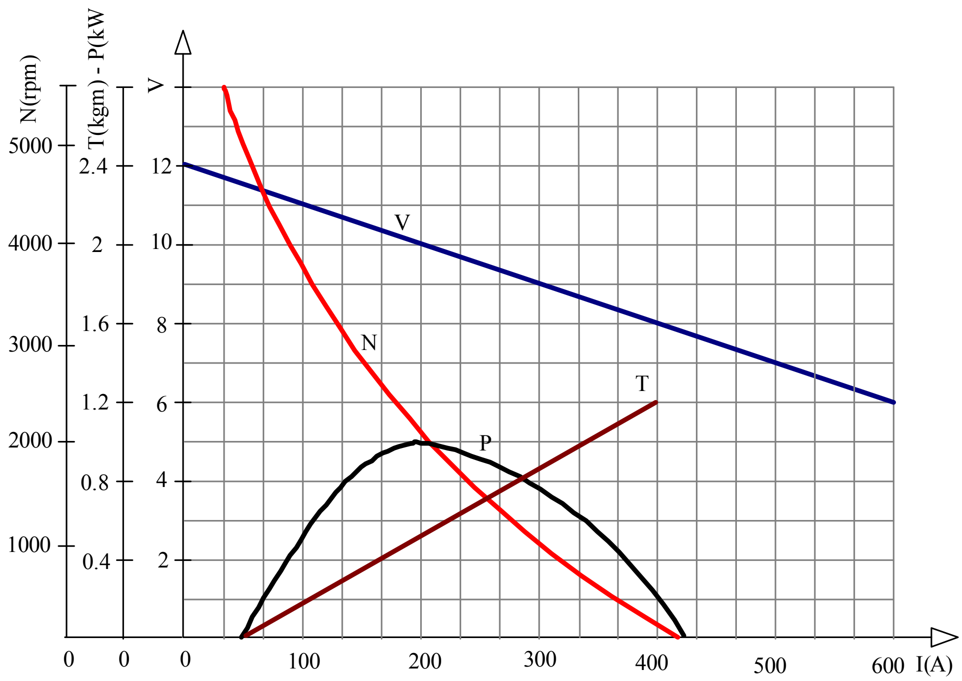


Figure10. Performance graph of the serial-wound starter motor (MAKO E 95, 1 kW/ 12V)

The current, drawn by motor, provides correct information about the motor. A performance graph belongs to a motor used in fault diagnosis is given in Figure 10. Here, the curves of revolution (rpm), power (P), torque (T) and voltage (V) are drawn subjects to the current. According to the values of variables, the status of the motor is diagnosed by the help of the performance graph [20]. If these values are too high or low from the desired values, it is understood that some breakdowns have already occurred or will occur soon in the motor.

A block diagram of fuzzy logic fault diagnosis system is given in Figure 11. The system comprises four sections. In the first section, the input values are accepted. The values of input variables (current and voltage) are acquired by sensors to the program by using a Pico ADC-212 data acquisition card. The motor revolution is calculated using the interval time between two signal peaks of the current. The second one is the fuzzification section that fuzzification process takes for the one or more membership functions that the values of "0" and "1" or between "0" and "1" based on the values of input variables. In this section input variables (currents, voltages and revolution) are fuzzified. The third one is the fuzzy inference section. In this section, the rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. The logical products of each rule are combined or inferred before being passed on to the defuzzification process for crisp output generation. Combined logical products are used to find the result of the fuzzy fault diagnosis system in the last section .

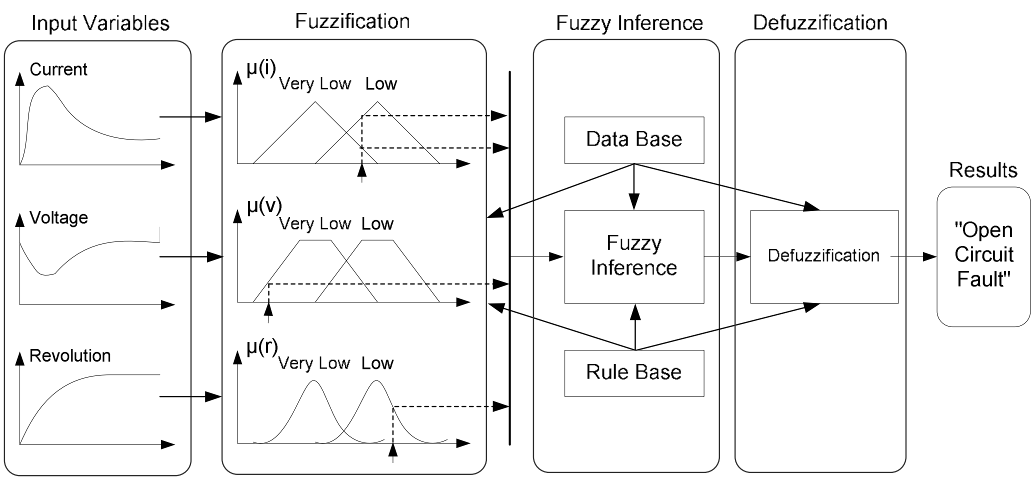


Figure 11. Block diagram of fuzzy logic fault diagnosis system

Fuzzification is a process of converting the physical input information into the fuzzy logic information that can be expressed by linguistic characters. The whole information does not necessarily be certain (not fuzzy) information. Fuzzification process accepts quite number of information, which is not certain, and fuzzificates them. The values of all input variables are assigned here as degree of membership.

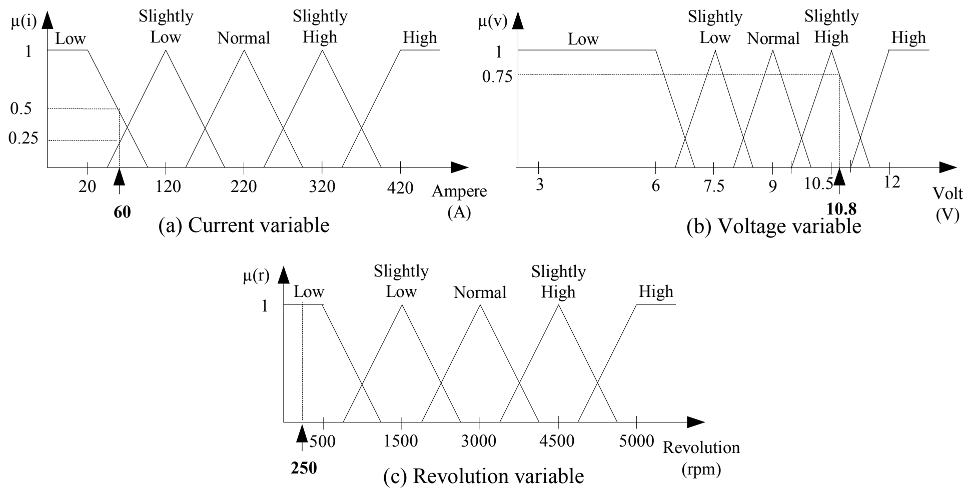


Figure 12. Fuzzification process for variables a) current, b) voltage, c) revolution

Membership functions belong to the variables, used in fault diagnosis system, are shown in Figure 12. Membership functions, which belong to revolution and current, are located in equal gaps; however, the voltage variable is different. The reason is when the voltage of battery reduces less than 6V; the starter motor does not work. As an example, for the value of current is 60A, the value of voltage is 10.8V and the value of revolution is 250 rpm, fuzzification process is shown in Figure 12. These values can point out one or more membership functions. The variable of current states "low" and "slightly low" fuzzy sets, the variable of voltage states "slightly high" fuzzy set, and the variable of revolution states "low" fuzzy sets. In this case, after fuzzification process it is understood that two rules are fired. Fuzzification is the inference based on the rules obtained such as "brush fault" and "open circuit fault". These are:

- IF the current of motor is "low" AND the voltage is "slightly high", the revolution is "low" and THEN "open circuit fault".
- IF the current of motor is "slightly low" AND the voltage is "slightly high", the revolution is "low" and THEN "brush fault".

The results of the inference system are still fuzzy. They are in need of being converted into physical and crisp numbers. This is called as "defuzzification". Various defuzzification methods were developed to perform this defuzzification operation. The membership functions of logical inferences, obtained from fuzzy processor, can be one or more. In Figure 13, fuzzy inferences consist of two parts. Both of them are in trapezoid shapes. The fuzzy inference, obtained, should be a result of these sets. Fuzzy inferences can be more than two, and the forms of membership functions can be in different shapes. The most proper one among them should be chosen for the system. Structure of the system and experiences of the users are also bases for choosing of the defuzzification methods. In proposed system, center of gravity or mean of maxima defuzzification methods can be selected.

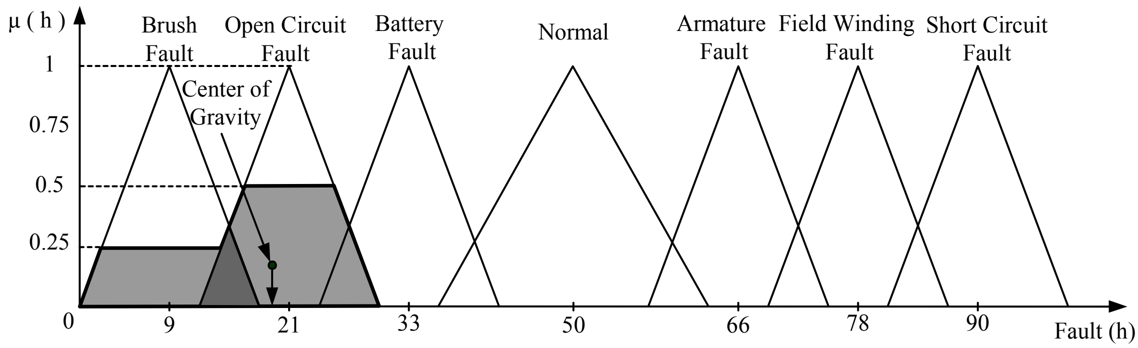


Figure 13. Fault inference membership functions and defuzzification

4. PROPOSED FUZZY LOGIC FAULT DIAGNOSIS GUI SOFTWARE

The main menu of the fault diagnosis software is seen in Figure 14. The system can receive input variables in four ways; the computer can produce the value of variables of a starter motor randomly (for test purposes), the user can enter them manually (for off-line diagnostics) and obtain results for them, the values recorded earlier in a file can be used and make a diagnosis for them, or the data can be received in real time (for on-line diagnostics) by using a Pico ADC - 212. The fault diagnosis program has two modes, as automatic and manual. In automatic mode, the system can read the data in specified intervals and it results the diagnosis. The data reading process can be done whatever the user can prefer. In the manual working mode, the user should first read the data and then the result can be seen by pressing the start button. The result can be expressed by the name of fault. In some cases, the system can give more than one fault results. In addition, if the values entered to the system in motor's working mode such that current and voltage do not exist, revolution is very good etc., the software prompt us "these are not valid input variables values".

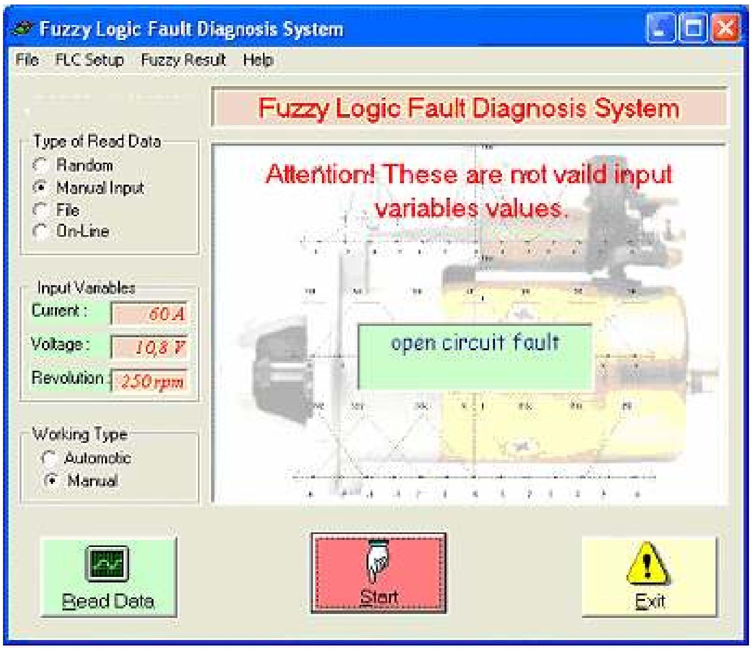


Figure 14. Main menu of fuzzy logic fault diagnosis system software

The input and output variables, the number of membership functions and their types can be chosen using software in proposed fuzzy fault diagnosis system. The user can specify the values of each membership function using the FLC Setup menu. The user can draw membership function for the specified values to use them in fault diagnosis. In addition, left shoulder and right shoulder of the membership functions can be chosen. When the changes are accepted, it can be returned to the main menu by pressing the OK button. If the Cancel button is selected, the parameters previously entered will be valid. In the fault diagnosis system, the most appropriate type and the number of membership functions can be determined by using these features (Figure 15).

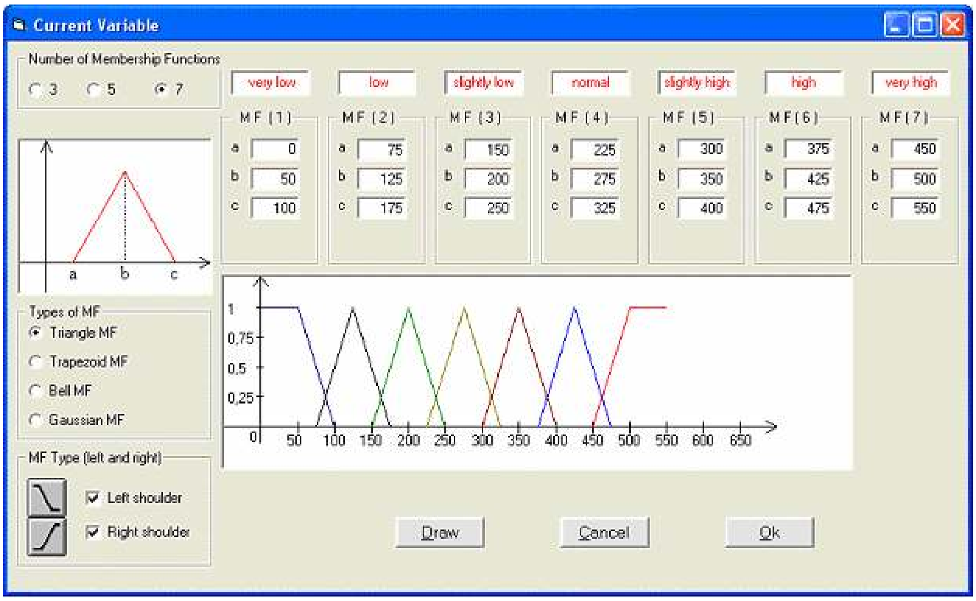


Figure 15. Fuzzy set description form for each input variables (for motor's current)

The number of membership functions can be chosen as 3, 5 or 7. If seven membership functions are chosen, these are "very low", "low", "slightly low", "normal", "slightly high", "high" and "very high". There are also seven membership functions for output variables. These are ""brush fault", "open circuit fault", "battery fault", "normal", "armature fault", "field winding fault" and "short circuit fault". Each fuzzy set defines one fault type. These fuzzy sets can be defined by using four different types of membership functions.

The rule base and fired rule(s) can be seen in Rule Base form of GUI software. If the user wants to change the rule base, he/she can choose another rule base. The user can add new rules to the current rule base and change them. So the most appropriate rules for fault diagnosis can be determined. Accessing to the rule base and changing these rules get flexibility to the GUI software. The user can also build his own rule base by selecting New Rule File in File menu.

List of active membership functions for output variable can be seen in the Defuzzification form of GUI software (Figure 16). In addition, output membership functions and their degrees can also be seen.

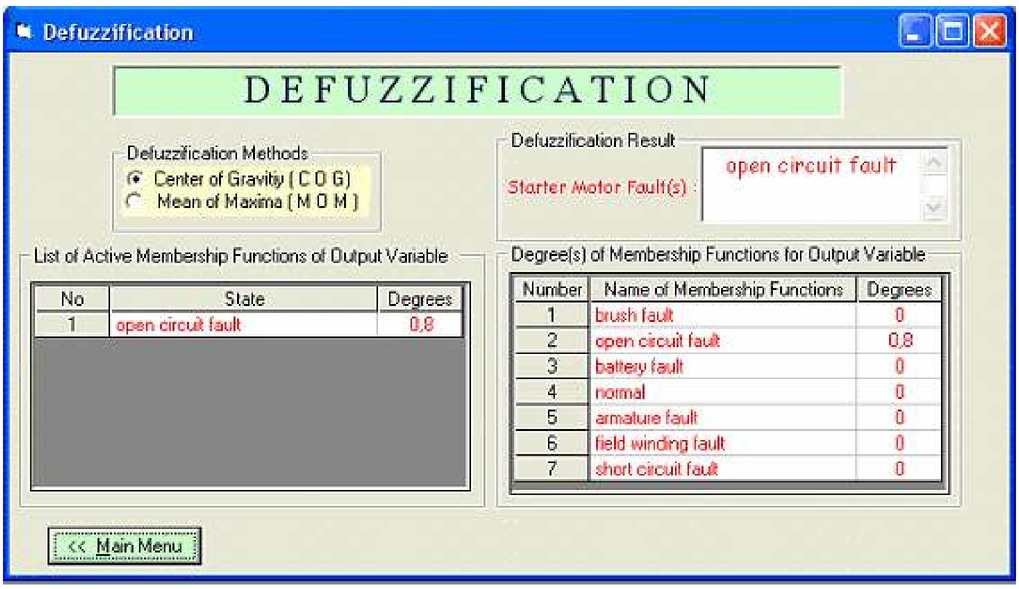


Figure 16. Defuzzification form

The fuzzy logic fault diagnosis system can point out more than one fault when the inference released come across to the intersection of membership functions of fault variables. If it is not desired, the values of membership functions can be arranged in a way that they do not intersect one another from the fault variable menu. The required current values of motors can be changed in summer and winter. Intersecting of output membership functions can give proper results for these cases. In the case of intersection, more than one fault is given as results. They are written in descending order by weighting percentage.

5. RESULTS AND DISCUSSION

To prove the validity of the proposed method, the system was tested using 50 samples data, obtained real starter motors, shown in Table 1. The fault diagnosis success rate of FLFDS is %90. The reason of having 10% faulty results is that, some fault symptoms similar to each other (for instance battery fault symptoms look like connection faults) and the required starting current values of the motor can be changed in the months of summer and winter. Because outside temperature decreases, starter motor torque decreases, cranks the engine to its minimum speed and starter motor current increases. These reasons have arisen from wrong diagnosis.

.

Table 1. Experimental results.

Number	Faults & State	Number of Sample	Number of Correct Classification	Number of Wrong Classification	Results of Wrong Classification
1	Normal	11	11	-	-
2	Brush fault	5	5	-	-
3	Connection fault	7	6	1	Battery fault
4	Battery fault	8	6	1	Normal
				1	Armature fault
5	Armature fault	8	8	-	-
6	Field winding fault	4	3	1	Normal
7	Short circuit fault	6	6	-	-
8	Unknown signals	1	-	1	Undefined
Total		50	45	5	
Percentage (%)		100%	90%	10%	

The faults occurred on starter motors are not only the result of the starter motor. The other elements and materials used in starter system and IC engine can be the reason of the faults.

6. CONCLUSION

In general, the conventional methods are used to detect the faults on starter motors. The expert can determine the faults with the experience and some measurements from the motor. In this study, the faults to be revealed in starter motors are investigated using fuzzy logic. Fault diagnosis and detection have been carried out base on expertise knowledge and using fuzzy logic algorithm. As a result, the six types of fault occurred in starter motors can successfully detected by using proposed system. The system can be used both in Quality Control unit of starter motor's manufacturers and maintenance-repairing units. In proposed GUI system, the types and the number of membership functions for input - output variables can be altered. The software also allows making changes and additions of rules in rule base. These properties give flexibility to the fault diagnosis system and provide more clear results.

REFERENCES

[1] Peter, V., "Parameter Estimation, Condition Monitoring and Diagnosis of Electrical Machines", New York, ***Clarendon Press***, Oxford, (1993).

[2] Subhasis, N. and Hamid A., T.,. "Condition Monitoring and Fault Diagnosis of Electrical Machines - a Review", ***in Proc. Industry App. Conf. 34th IAS Annual Meeting,*** 1, 197-204, (1999).

[3] .Steffen, L, and Mihiar, A., "Methods of Fault Diagnosis, ***Control Eng. Practice***, 5, 5, 683-692, (1997).

[4] Isermann, R. "Supervision, Fault-Detection and Fault–Diagnosis Methods an Introduction", ***Control Eng. Practice***, 5, 5, 639-652, (1997).

[5] Xiao Z. G. and Seppo J. O., "Soft Computing Methods in Motor Fault Diagnosis", ***Applied Soft Comp.,*** 1, 73-81, (2001).

[6] Nandi, S.; Toliyat, H.A.; Xiaodong Li;"Condition monitoring and fault diagnosis of electrical motors-a review", ***IEEE Transactions on Energy Conversion***, 20, 4, 719–729, (2005)

[7] Miguel, L. J, Blázquez, L. F., "Fuzzy logic-based

[8] decision-making for fault diagnosis in a DC motor" , ***Engineering Applications of Artificial Intelligence***, 18 , 4 , 423-450 (2005)

[9] Mendel, J. T. "Fuzzy Logic Systems for Engineering: A Tutorial", ***Proceeding of the IEEE,*** 83, 3, 345-377, (1995).

[10] Daniel G. S., George J. K., Harold W. L. and Yoshinori E., "Application of Fuzzy Sets and Approximate Reasoning", ***Proc. the IEEE***. 82, 4, 482-495, (1994).

[11] Isermann, R. "On Fuzzy Logic Applications for Automatic Control, Supervision and Fault Diagnosis", ***IEEE Trans. Sys., Man and Cyber., Part A,*** 28, 2, 221-235, (1998).

[12] Dominik F. and Rolf I., "Hierarchical Motor Diagnosis Utilizing Structural Knowledge and a Self-Learning Neuro-Fuzzy Scheme", ***IEEE Trans. Ind. Elec.*** 47, 5, 1070-1077, (2000).

[13] Olaf, M. and Rolf, I., "Application of Model-Based Fault Detection to a Brushless DC Motor", ***IEEE Trans.Ind. Elect***, 47, 5, 1015-1020 (2000).

[14] Igor, G., "Fault Diagnosis and Prevention by Fuzzy Sets", ***IEEE Transaction on Reliability***, R-34, 4, 382-388, (1985).

[15] Hamid N. and Mohamed El Hachemi B., Application of fuzzy logic to induction motors condition monitoring, ***IEEE Power Eng., Rev***. 19, 52–54, (1999).

[16] Xiang-Qun L., Hong-Yue, Z., Jun, L. and Jing, Y., "Fault Detection and Diagnosis of Permanent-Magnet DC Motor Based on Parameter Estimation and Neural Network", ***IEEE Transactions on Industrial Electronics***, 47, 5, 1021-1030, (2000).

[17] Bay, Ö.F., Bayir, R., "Fault Diagnosis of Starter Motors Using Fuzzy Logic", ***3rd. International Advanced Technologies Symposium***, Ankara, Turkiye, (2003)

[18] Klaus, B., Automotive Electric/Electronic Systems, ***Robert Bosch GmbH***, Stuttgart Germany, 346-375, (1995).

[19] Tom, D., Automobile Electrical and Electronic System, 2. Edition, ***Arnold Pub., Printed in Great Britain***, (2000).

[20] Herbert, E. E, Automotive Electrical Systems, 2nd Edition, ***Prentice-Hall Inc.***, New Jersey, USA, (1985).

[21] William, H. C., Automotive Electronics and Electrical Equipment. 10th Edition, ***McGraw-Hill Inc.,*** USA, (1986).

[22] Young, A. P., Griffiths, L. and Fardon, G. E., Automobile Electrical and Electronic Equipment., England, ***Butler & Tanner Ltd.,*** (1980).