Verification of Fuzzy Logic Controller for Direct Current Motor

(Pengesahan Pengawal Logik Fuzzy untuk Motor Arus Terus)

*AHMAD ZAMBREE ABDUL GHANI, MOHD ROSLI MAT ISA, NOR ASIAH MAT YUNUS
Department of Electrical Engineering, Polytechnic Kuching, Sarawak

Abstract

Direct current motors are widely used in the industry for variable speed applications since the most demanding speed and torque characteristics. Speed of direct current motor will fluctuate or imbalance, when there are variable loads, is applied. To overcome this situation, it will require a controller to maintain the speed and performance of the motor. Conventionally PID is used as the controller to control the speed of the direct current motor. The goal of this research is to verify the suitability of fuzzy logic controllers through simulation in MATLAB Simulink to control the speed of the direct current motor. It starts with the development of a variable load testing rig to measure the torque applied and speed of the motor. The purpose is to determine the capability and performance of the motor simultaneously to create fuzzy rules for the controller. Simulink simulation in the MATLAB software will be used to verify the fuzzy logic controller that has been designed. All of the results indicated that applying a fuzzy logic controller to maintain the speed of a direct current motor is ineffective.

Keywords: Speed torque characteristics, fuzzy logic controller, variable load testing rig, fuzzy rules, Simulink simulation, MATLAB

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* Corresponding author: a.zambree@poliku.edu.my

INTRODUCTION

A direct current motor is a machine that converts electrical power from direct current to mechanical power (Jain et al., 2019). This project will evaluate a fuzzy logic controller for a direct current motor by simulating it with a varied load. A controller was created by using the concept of fuzzy logic to ensure that a direct current motor can run at a specified speed due to demanding speed-torque characteristics. Direct current motors are commonly applied in the industry for variable speed applications (Nagpal et al., 2019). For example, to transport the product at a specific time, a direct current motor on the conveyor system must achieve the necessary speed. The direct current motor performance will be degrading when a changeable load is given. It is unable to run at a specified rate in accordance with the load. When using a conveyor, the system must move a product from one station to another at a set rate and avoid the process becoming slow as the product's weight increases. As a result, a controller is required for the motor to operate at desired speed so the process can maintain efficiency. Making a controller regulate the speed of a direct current motor at the appropriate speed is important (Katke & Rangdal, 2015). This research makes use to verify the suitability of a fuzzy logic controller. The speed of a direct current motor can be changed by varying the voltage at the armature (Chengaiah, 2014).

A variable load testing rig must be set up for this research. The variable load testing rig is used to determine the torque applied to the motor as well as the speed at which the motor can operate. Therefore, to test the capability and performance of the motor. Next is to close the loop of the system by adding fuzzy logic controller into the system to maintain the speed of the direct current motor. Speed of the motor will be regulated by implementing the fuzzy idea. Construct and verify the fuzzy logic controller in MATLAB. The verification process is carried out through simulation by using Simulink inside the MATLAB software.

Connection for shunt direct current motor is armature will be connected in parallel with field windings. The resistance of shunt field winding was always high due to the number of turns is higher compare to armature winding (Babaker et al., 2021). Because of that, makes current at the armature winding is higher than at shunt field winding. Shunt direct current motors are the most ideal for applications (Jain et al., 2019) that require a constant speed, such as winding machines.

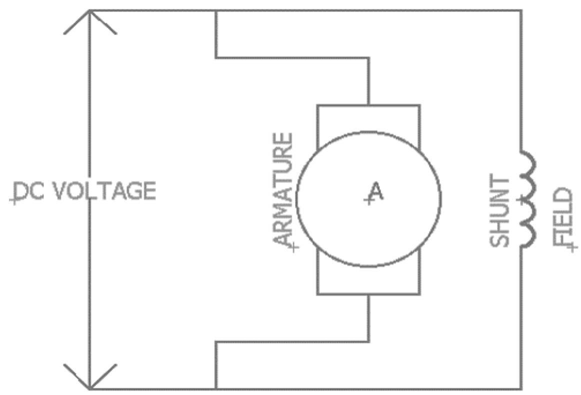

Figure 1**.** Shunt direct current motor circuit (Jain et al., 2019)

Fuzzification, knowledge base, inference engine, and defuzzification are the four major operations of a fuzzy logic system. Fuzzification is a first process which is a transformation process from the measured input into suitable linguistic variables (Chengaiah, 2014). Then knowledge base is the second process. The knowledge base is a set of fuzzy if-then rules that determine what action the controller should take based on linguistic control rules. This is also the same as the rule evaluation. Next is the inference engine which is rule aggregation for output, for the system to work appropriately. Defuzzification is the final step. Defuzzification is an output interface that transforms a fuzzy set generated by an inference engine into a crisp value.

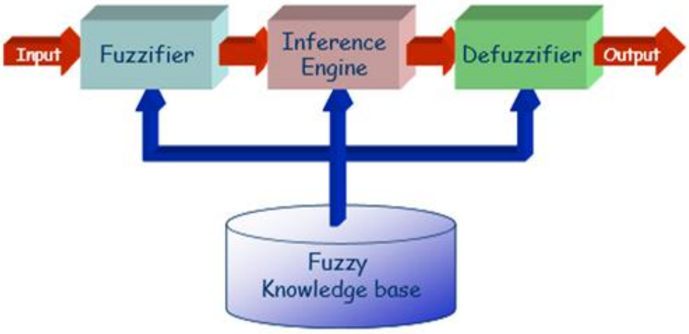

Figure 2. Structure of fuzzy logic controller

METHODOLOGY

RESEARCH DESIGN

This research starts with the study of characteristics of the direct current motor. Based on that, the shunt type of direct current motor has been selected due to the best characteristics in producing constant speed. Next is the development of a variable load testing rig. The purpose is to measure the torque and speed of the motor. Once know the performance of the motor, fuzzy rules can be created and complete the design of the fuzzy logic controller in MATLAB. The controller needs to be tested by doing the simulation in Simulink to know either pass or failed. The last process collects all the data and makes an analysis. Figure 3 shows a flowchart of the research's main process.

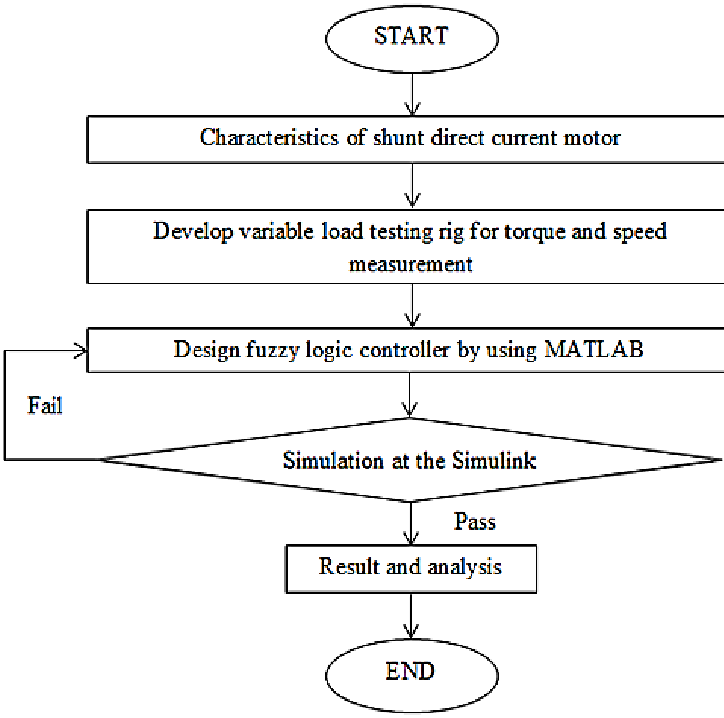

Figure 3. Main flow process of the research

BLOCK DIAGRAM FOR A COMPLETE SYSTEM

Operation of the direct current motor will be disturbing or braking by prony brake to give load and measure the torque given as shown in Figure 4. The speed of the motor will be determined by using a tachometer. A fuzzy logic controller will have three linguistic variables which are actual speed, speed error, and difference in error. Input will be speed error and different in error for the fuzzy logic controller. The difference between actual speed and reference speed is a speed error. Next is a classification type of error which is different in error. After that control signal, Cs will vary the pulse width modulation according to the defuzzification process that has been set in the controller to get desired speed.

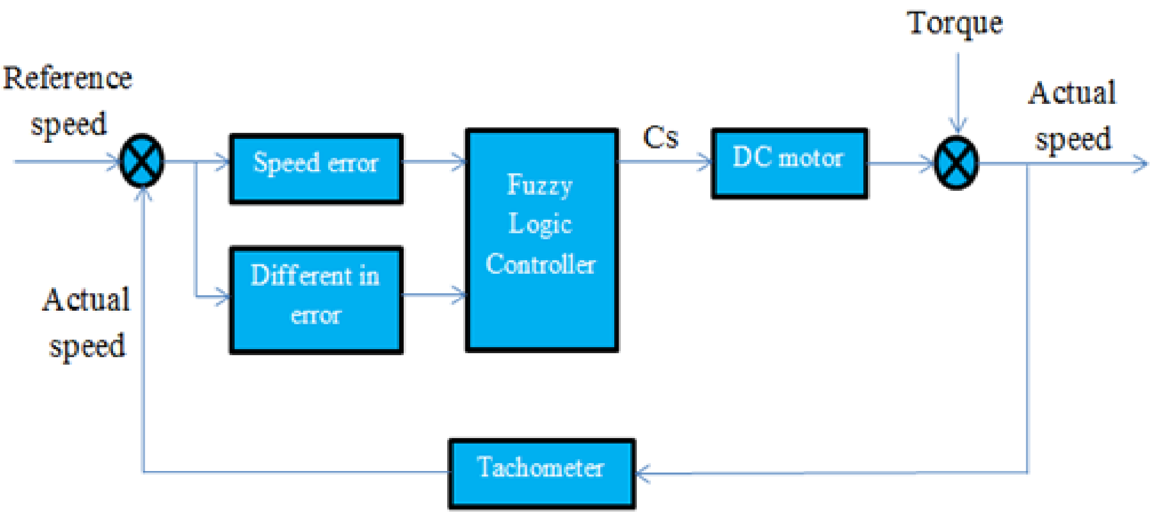

Figure 4. Block diagram for a complete system of fuzzy logic controller for direct current motor

<u>VARIABLE LOAD TESTING RIG</u>

A variable load testing rig was developed in this research to measure the torque and speed of the motor. In order to apply several loads to the motor as shown in Figure 5, a prony brake or was used together with digital spring balance to read the value of torque given. Another measuring tool is a tachometer. It is used to measure the speed of the motor.

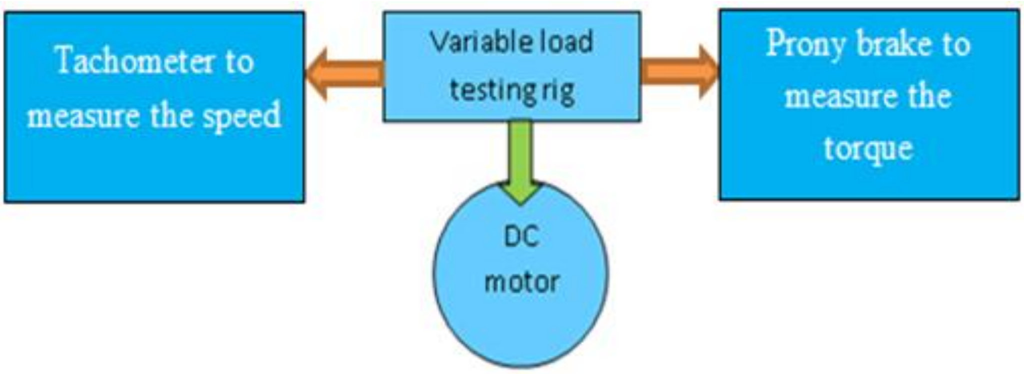

Figure 5. Block diagram for variable load testing rig

RESULT AND DISCUSSION

VARIABLE LOAD TESTING RIG

Development of variable load testing rig consists of the motor and prony brake. A compatible coupler is required to connect the output shaft of the motor with prony brake and rubber type coupling is used as shown in Figure 6. The reason for this is because while the motor rotates, it may absorb vibration. For torque measurement, digital spring balance is used. The aim is to make measurement activity easier and more precise. Another part is speed measuring, which is performed with a tachometer.

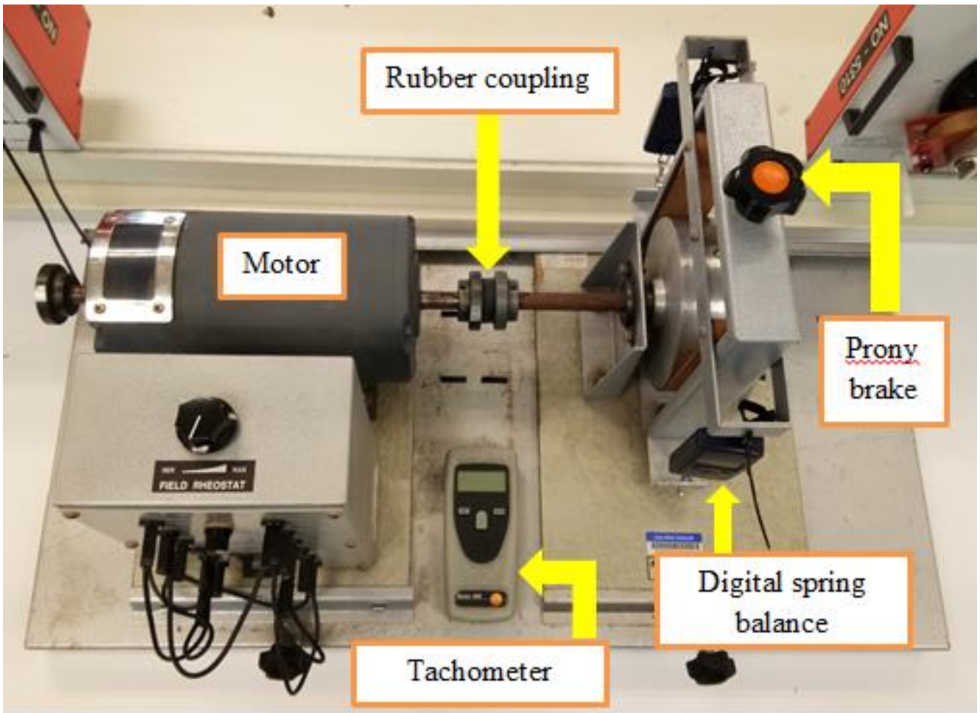

Figure 6. Overall component of the variable load testing rig

FUZZY LOGIC CONTROLLER

To implement a complete fuzzy logic controller, several components need to consider which are fuzzification, knowledge base, inference engine, and defuzzification. Chopper (Chinnaiyan et al., 2014) or direct current to direct current converter is applied in the experiment conducted by using the real apparatus at the lab. The purpose is to change from one level to another level of direct current supply. While in the MATLAB through Simulink simulation, the buck converter is applied to give different levels of direct current supply. Direct current motor as a load has been tested in Simulink simulation from no-load until several loads by giving different pulse widths to varying the voltage and current. Both results obtained from experimenting at the lab and through the Simulink simulation are recorded. The purpose is to compare the trend of a graph and the observed performance of the direct current motor. At the same time to test the characteristic of shunt type direct current motor either suitable or otherwise for constant speed application. Performance of the motor to run at highest and slowest speed also recorded. This part is important to have a range of motor speed in creating the knowledge base or fuzzy rules. It is also to verify the ability of the motor to run at a certain load for safety purposes and do not break the motor.

Table 1. Specification of shunt direct current motor

Perkara????	Perkar???
Voltage (V)	220
Power (W)	250
Current (A)	1.76
Speed (rpm)	1770

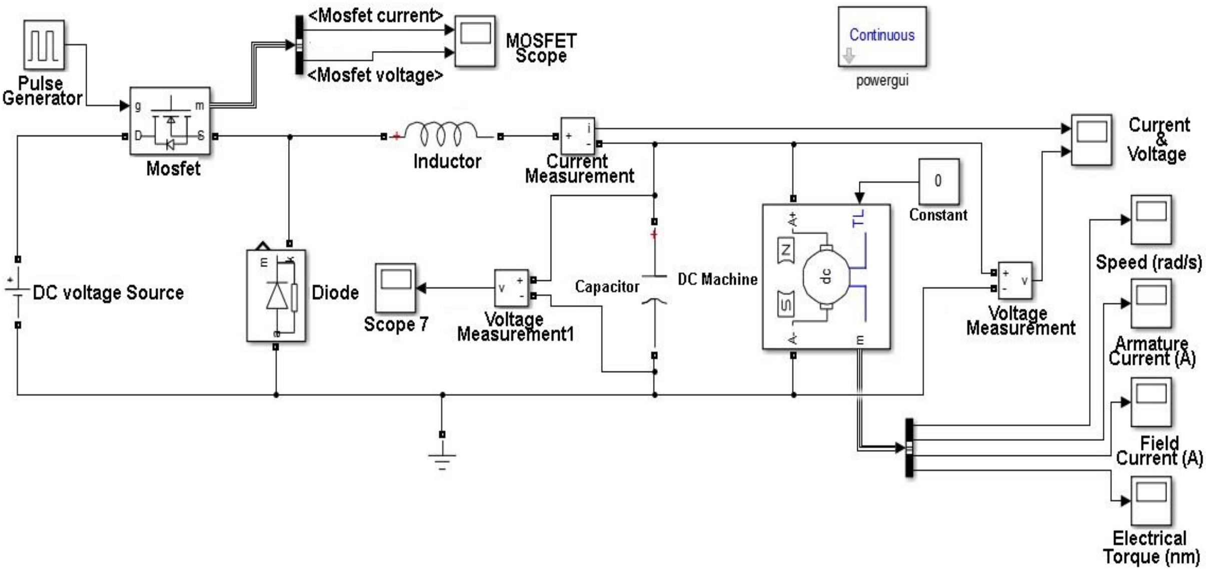

Figure 7. Direct current motor is applied to buck converter as a load.

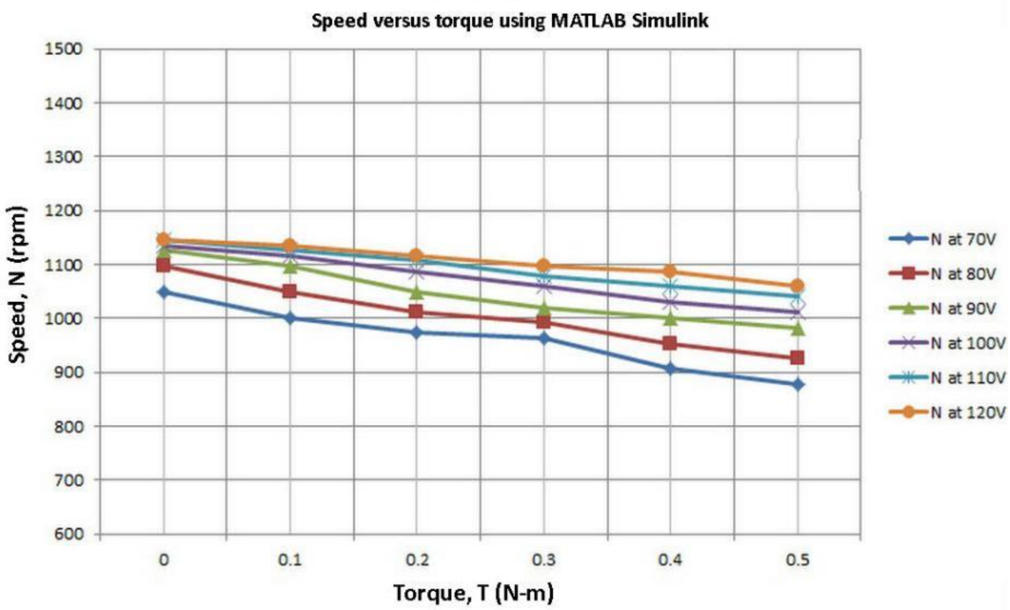

Figure 8. Speed versus torque characteristics graph of a shunt direct current motor in MATLAB Simulink

From the data obtained speed versus torque characteristics graph can be constructed. The graph trend shows that the speed decrease when the torque becomes higher. The velocity of motion of the motor drops by the additional load given.

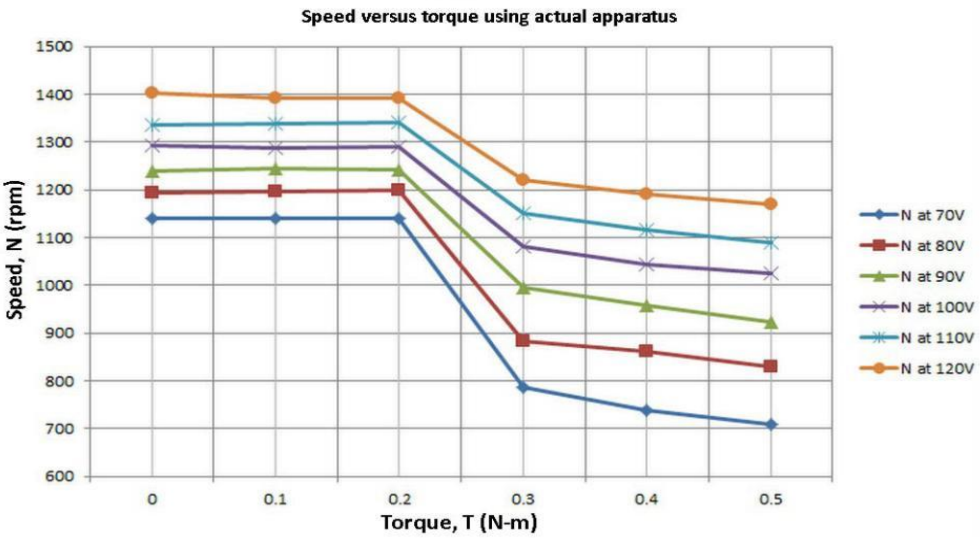

Figure 9. Speed versus torque characteristics graph of shunt a direct current motor in actual apparatus

While at the lab actual apparatus also has been tested and collected the data. The graph trend constructed also similar to the graph trend tested in MATLAB Simulink. The speed decrease when the torque becomes higher. The velocity of the motor falls from no-load until a full load is given. From the graph also the highest speed and slowest speed can be obtained. It can be the reference to build fuzzy rules.

The design of the close loop system is continued after the analysis performance of the motor is done. By closing the loop of the system, an error can be calculated. The purpose of close loop system is to reduce the error until zero error. In the close loop system, an error will be the input for fuzzy. For the fuzzy controller, it needs a knowledge base or fuzzy rules. From the previous experiment carried out and analysis have been done, the capability of the motor has been determined. It shows the highest torque can be applied to the motor under the rated specification of the motor and given several voltages. This means the motor still can run at the given torque and current of the motor not more than the rated current.

The fuzzy process will start from fuzzification, knowledge base, inference engine, and defuzzification. The triangular membership function is used for the fuzzy logic controller design. Table 2 shows there are three linguistic variables which are speed error (S.E), the difference in error (D.E), and actual speed (A.S) to set as an input and an output for the fuzzy logic controller. Input elements are speed error (S.E) and different in error (D.E) while for output element is actual speed (A.S). Table 3, Table 4, and Table 5 shows these three linguistic variables are divided into five linguistic variables which are very small (VS), small (S), medium (M), large (L), and very large (VL). Their range also has been divided and set.

Table 2. Linguistic variables in fuzzy logic controller

Character	**Linguistic variable**

S.E	Speed error
D.E	Different in error
A.S	Actual speed

Table 3. Range for speed error (S.E) linguistic variable

Character	Linguistic variable	Range
VS	Very small	[525,700,875]
S	Small	[700,875,1050]
M	Medium	[875,1050,1225]
L	Large	[1050,1225,1400]
VL	Very large	[1225,1400,1574]

Table 4. Range for different in error (D.E) linguistic variable

Character	Linguistic variable	Range
VS	Very small	[0,1,2]
S	Small	[1,2,3]
M	Medium	[2,3,4]
L	Large	[3,4,5]
VL	Very large	[4,5,6]

Table 5. Range for actual speed (A.S) linguistic variable

Character	Linguistic variable	Range
VS	Very small	[0,1,2]
S	Small	[1,2,3]
M	Medium	[2,3,4]
L	Large	[3,4,5]
VL	Very large	[4,5,6]

Table 6. Fuzzy rule matrix

D.E / S.E	VS	S	M	L	VL

VS	VS	VS	VS	L	M
S	VS	VS	S	M	L
M	VS	S	M	L	VL
L	S	M	L	VL	VL
VL	M	L	VL	VL	VL

Table 6 shows there are twenty-five rule matrix has been built in this fuzzy logic controller. Both inputs speed error (S.E) and different in error (D.E) will be calculated from very large until very small error to achieve the nearest reference speed.

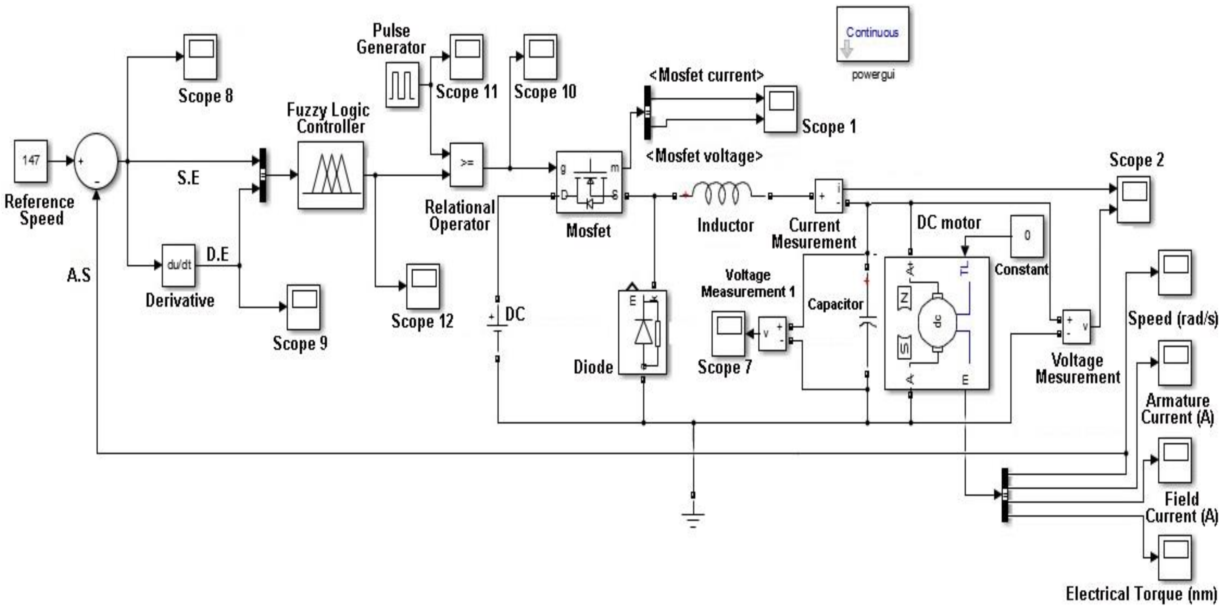

Figure 10. Fuzzy logic controller

The highest speed motor can achieve is 1402 rpm during experiments conducted in the lab. The unit needs to convert from rpm to rad/s because in MATLAB Simulink rad/s will be used. After conversion, it is about 147rad/s. Therefore, the reference speed for this controller is set at 147 rad/s. There is a problem during the run of the simulation. Output from the relational operator block only produces '1' and '0'. So it will be on and off state. Then it will be input for MOSFET to close and run the circuit. The value of the voltage at the output or motor is the same as the voltage supply and the voltage cannot be varied. The total voltage applied will be the same or equal to the total voltage absorb. The next problem is the fuzzy controller. Input for the fuzzy controller is not enough. Speed error (S.E) input can be calculated but for different in error (D.E) input cannot be calculated or classified. Different in error (D.E) input is only the differentiation from the speed error (S.E) that has been calculated. Speed error (S.E) is a number or constant. When differentiating constant, the result will be zero. As the effect difference in error (D.E) input cannot be generated. This controller has less input and cannot operate properly.

CONCLUSION

A motor is a machine that produces mechanical output rotation from an electrical supply as input. This research focused on the direct current motor. There are several types and characteristics of direct current motor depend on whereas to apply such as speed application. In this research, a variable load testing rig is made for the purpose to measure the speed and load given to the motor. For the most suitable tool torque measurement at the motor, a prony brake is used in the rig. The analog spring balance is upgraded to the digital spring balance to make it easy to take the measurement. While for the speed measurement, the tachometer is used. Speed torque characteristic experiment for the direct current motor can be conducted by using this rig. A suitable buck converter design is used to analyze the performance and capability of the direct current motor in Simulink simulation inside MATLAB. Data obtained from the experiment conducted at the lab by using actual apparatus and through Simulink simulation inside the MATLAB will be the idea to create fuzzy rules for the controller. After gained the range of the speed motor, fuzzy rules were created. The result shows that maintaining the speed of the direct current motor is not suitable by using the fuzzy logic controller. It is because it has less input for the fuzzy controller. The reason is direct current motor is a linear component. However, this research has been tested and proves that fuzzy is not suitable for a linear component. Inside the MATLAB through Simulink simulation shows that maintaining the speed of the direct current motor by using the fuzzy logic controller is impossible. The objective of this research is to verify fuzzy logic controller for direct current motor in maintaining speed application shows impossible. So for future recommendations, it is better to maintain the use conventional method which is a proportional integral derivative controller. Another recommendation is by using a fuzzy proportional integral derivative.

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