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Controlling the half-step mode operation of the variable reluctance stepper motor by using Mamdani type of fuzzy logic controller

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ABSTRACT

This paper proposed the step angle controlling of the half-step mode operation of the variable reluctance stepper motor (VRSM) by using Mamdani type of fuzzy logic controller (FLC). The MATLAB program was used to achieve the approach. The VRSM that was used in this paper has six stator poles and four rotor poles. The VRSM has three phases that represent the input variables and the step angle represents the output variable in the FLC in MATLAB. Membership functions were created for the input and output variables. The rules of the FLC were built in MATLAB. The theoretical step angles results of the VRSM were obtained by using mathematically equation while the practical results were obtained by using MATLAB. The obtained results are closer to the actual results depending on the comparison between the theoretical and practical readings. These results were written in table and were plotted in figure.

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1. INTRODUCTION

The stepper motor is one of the special machine types. It has stator and rotor poles (teeth). The stator poles are wounded while the rotor poles are not wounded. The number of wounded stator poles determine the number of phases. These phases are supplied by direct current (DC) voltage. When a phase is supplied, the current will flow through the wire and will produce magnetic field. The magnetic field will attract the rotor poles. After that the next phase will be supplied by the voltage. In the same way, this next phase will attract the rotor poles, and so on. This motion of rotor will be in steps. Therefore, this type of motor is called stepper motor. When the rotor pole moves from one position to another, an angle (θ) will be obtained. This angle is called step angle. Stepper motors are used in line printers, plotters, tape drives, and robotics. There are three types of stepper motor: variable reluctance stepper motor (VRSM), permanent magnet stepper motor (PMSM), and hybrid stepper motor (HSM) [1].

Different researches about the stepper motor have been proposed. A microcontroller (MCU) is used to control the position of multiple unipolar stepper motors in both directions, clockwise and counter clockwise, as in [2]. Silaban *et al.* [3] used the field programmable gate array (FPGA) to control the stepper motor in the both directions by making the motor move in the half and full step operations modes. A close loop system is used by Balai and Talati [4] to make the position and speed of the stepper motor rotor be precise. A sensor is used with the stepper motor to control video surveillance system [4]. Normanyo *et al.* [5] used proportional integral (PI) controller- depending on Mamdani type of fuzzy logic controller (FLC) for the

HSM. They used two input variables and one output variable. Hollinger *et al.* [6] presented an approach about using a fuzzy logic force controller on a MERLIN 6540 Industrial Robot built with stepper motors. Aranjo *et al*. [7] proposed a drive system gives an accurate control for stepper motors with minimum possible step angle to be used in robotic applications. Zhao *et al.* [8] used the sinusoidal pulse width modulation (SPWM) technique for controlling the micro stepping drive of the stepper motor to enhance the behavior of the stepper motor. SPWM can affect on the value of the electromagnetic torque. Oo *et al.* [9] used several equations for modeling an open-loop of the hybrid stepper motor. These modeled equations are used to know the system response of a stepper motor. Positioning control technique for a lab-scale heliostat by using of hybrid stepper motors and fuzzy logic controllers is proposed by Jirasuwankul and Manop [10].

There are three modes of operation of variable reluctance stepper motor: 1-Phase ON mode (full-step operation), 2-Phase ON mode, and half-step operation. 1-Phase ON mode (full-step operation) is done by supplying the voltage for each phase individually. It is shown in the Figure 1. The sequence of phases will be A, B, and C. The value of the step angle that the VRSM moves can be obtained by using (1). The Figures 1(a) to 1(d) depicts the movement of the VRSM. The Figure 1(e) represents the phases' coils circuit of the VRSM. The Figure 1(f) represents the truth table of this mode [1]. '+' represents ON case and '0' represents OFF case.

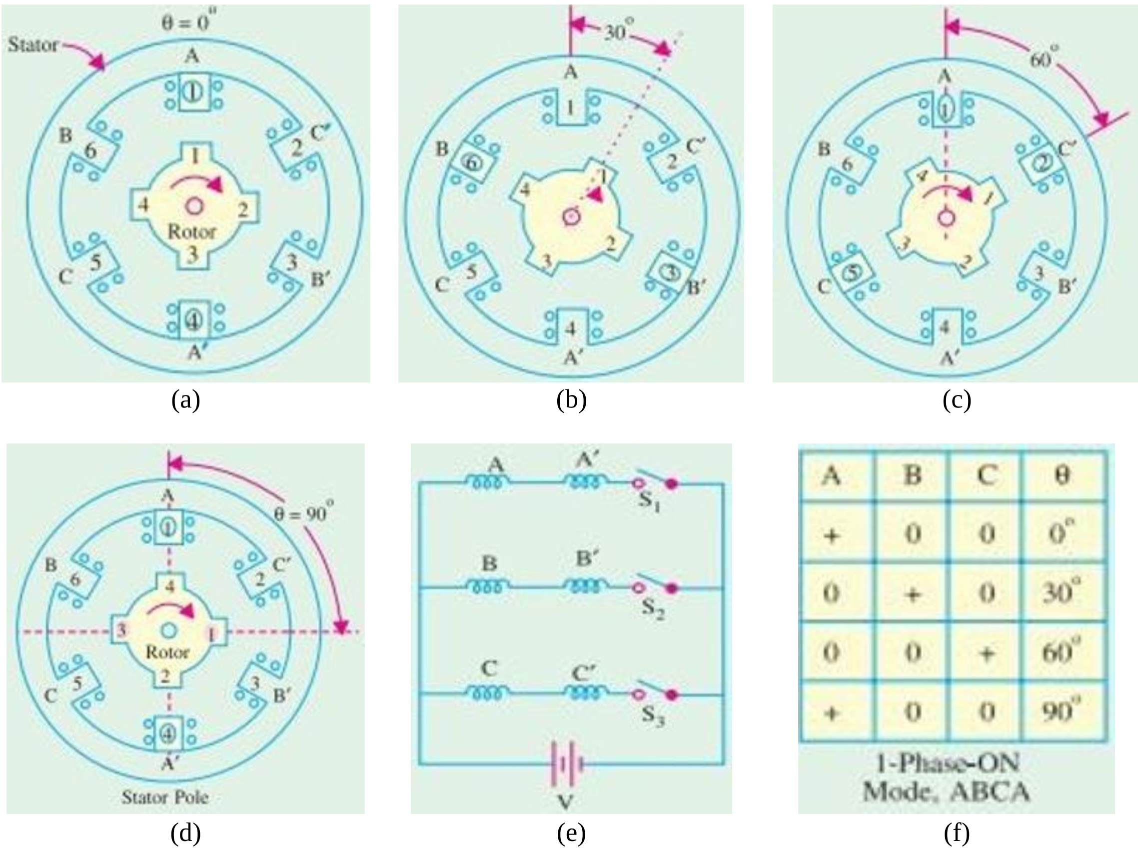


Figure 1. 1-phase ON mode (full-step operation) of variable reluctance stepper motor in (a), (b), (c), (d) VRSM movement, (e) VRSM phases' coils circuit, and (f) the mode truth table [1]

2-Phase ON mode has two phases which are supplied in the same time with equal currents. The rotor tooth will be located at the mid between two energized phases. After that the movement will take 30° to in each next two excited phases [1]. Half-step operation rotor pole will move half step angle of the full operation mode because there are two phases are supplied. The third phase will not be supplied. The phases' sequence will be A, AB, B, BC, C, CA, and so on to complete the movement of 360°. Therefore, the step angle for the variable reluctance stepper motor (VRSM), which has six poles in the stator and four poles in the rotor, will be 15°. Figure 2 depicts this mode of operation [1]. The Figure 2(a) represents the phase an only. The Figure 2(b) represents the phase A and B simultaneously. The Figure 2(c) represents the phase B only.

The VRSM rotor pole transition from one position to another for half step mode operation is very important, which depending on the step angle, because the performance of the motor depends on it. Therefore, the control of the transition is required. FLC is an appropriate method to control the step angle. This paper used the FLC Mamdani type to control the VRSM half step mode operation.

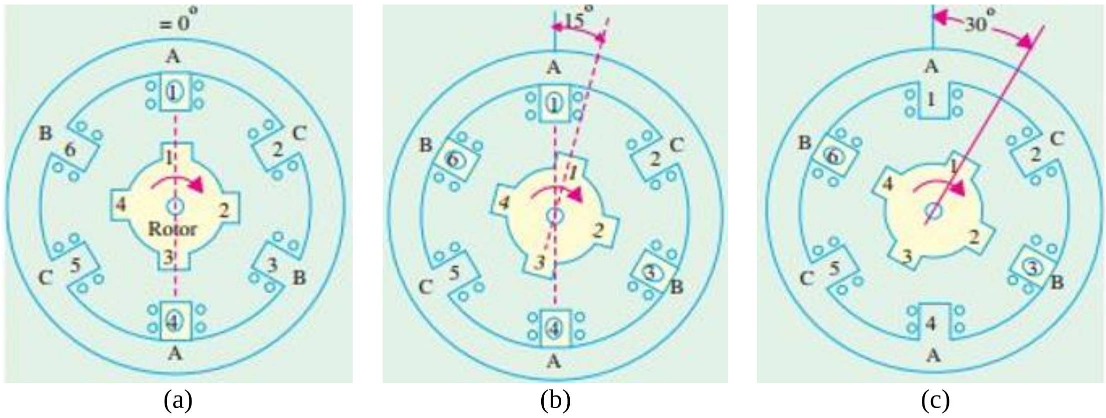


Figure 2. Half-step operation; (a) phase A only, (b) phase A and B simultaneously, and (c) phase B only [1]

FLC is a controlling system that depends on input variables to determine the output variables. Each input and output variables have a number of membership functions. Several rules are created to assign the relationship between the input and the output membership functions. These rules are conditional statements to define the expected output. The construction of FLC has three main parts: fuzzifier, inference engine (decision making), and defuzzifier. Fuzzifier is the responsible part for changing the crisp values to fuzzy values. The inference engine is the responsible part on processing the fuzzy values. It represents the rules base part. The methods that are used in the inference engine are Mamdani or Sugeno. The defuzzifier is the responsible part on changing the fuzzy values to crisp values [11], [12]. The block diagram of the FLC can be illustrated in the Figure 3.

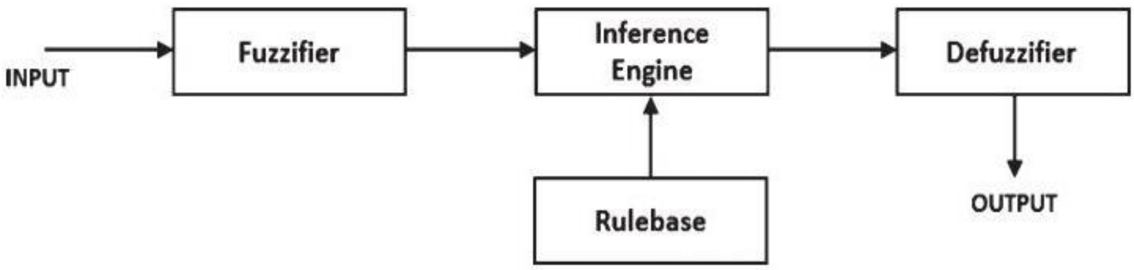


Figure 3. FLC block diagram [11]

There are a lot of researches about the FLC. Fuzzy logic was used to control the Static var compensator (SVC) for improving the power system damping [13]. Mekrini and Bri [14] used FLC to reduce electromagnetic torque ripple. The fuzzy logic was used by Cusipag *et al.* [15] for controlling the rotation speed of the fan of indoor air purifier. Using FLC with the unified power flow controller (UPFC) for enhancing the power quality was proposed in Alsammak and Mohammed [16]. The FLC was used to design the gripper motion of the arm robot manipulator to make the motion smooth and making the gripping power not too much [17]. Mamdani-based FC for travel angle control of bench-top helicopter was used in [18]. Missed data of the failed sensors were estimated by using FLC and with integrated microcontrollers to reduce the increment in error [19]. A normalized fuzzy logic controller (NFLC) was used to control quadruple-tank process (QTP) [20]. The researchers of [21] used both types of FLC on the air conditioning system. They presented a comparison between Mamdani and Sugeno types. Hammam and Georganas [22] used both

Mamdani and Sugeno types for obtaining the quality of experience (QoE) of a multimodal virtual environment and discussed the comparison between them. The brushless DC motor speed was controlled by using FLC. The results was compared with the PI controller [23]. A new design of FLC for the photovoltaic system was proposed to control a boost converter for getting a faster convergence and excellent behavior [24]. Both FLC and artificial neural controller (ANC) were proposed to inspect the behavior of DC motor with diverse loads [25]. Nasir *et al.* [26] presented an algorithm to make the FLC parameters optimized to track the hub angle of a flexible manipulator system. Also, Ahmad *et al.* [27] used proportional-derivative (PD)-FLC and PD-FLC-FLC in their research to achieve their approach for trajectory tracking and vibration control of a flexible joint manipulator. PD-FLC is designed. Farhan *et al.* [28] used single-input fuzzy logic controller (SIFLC) to fix the problem of the inconsistence contact force between the catenary and pantograph. A new kind of FLC, which is called intuitionistic fuzzy logic control (IFLC), was presented to automate the closed-loop anti-cancer drug [29].

2. VRSM MATHEMATICAL CALCULATION

The mathematically calculation of the step angle of the VRSM can be obtained by using this formula:

$$\theta = \frac{N_s - N_r}{N_s * N_r} * 360^{\circ} \tag{1}$$

where, θ: step angle, N_s: number of stator poles, and N_r: number of rotor poles. For six Stator Poles and four Number of Rotor Poles, the step angle of the 1-Phase ON mode (full-step operation) is:

$$\theta = \frac{6-4}{6*4} * 360^{\circ} = 30^{\circ}$$

If the two excited phases (2-Phase ON mode) are AB, BC, CA, and AB, the step angles will be in the Table 1. For the half-step operation, the step angles will be in the Table 2 [1].

Table 1. Truth table of the 2-Phase ON mode [1]

A	B	C	θ
+	+	0	15°
0	+	+	45°
+	0	+	75°
+	+	0	105°

Table 2. Truth table of the half-step operation [1]

Step No.	A	B	C	θ
1	+	0	0	0
2	+	+	0	15°
3	0	+	0	30°
4	0	+	+	45°
5	0	0	+	60°
6	+	0	+	75°
7	+	0	0	90°

3. RESEARCH METHOD

Six steps of the half step operation of the VRSM in the Table 2 are modeled in FLC Mamdani's type by using MATLAB. The phases A, B, and C are the input variables, and the step angle (θ) is the output variable. Each input variable has two membership functions OFF and ON cases. The OFF case is 0v while the ON case is 12 v DC voltage. The range of OFF and ON for each phase is OFF: 0 0 0 and ON: 0 12 12.

The output variable has six membership functions: VL, L, M, H, VH, and VVH. The range for each one is VL: -30° 0° 30°, L: -15° 15° 45°, M: 0° 30° 60°, H: 15° 45° 75°, VH: 30° 60° 90°, and VVH: 45° 75° 105°. Both input and output membership functions are represented in triangle. The Figure 4 shows the construction of the FLC with the VRSM. The membership functions of the input variables are shown in the Figure 5. The Figure 5(a) represents phase A membership function. The Figure 5(b) represents phase B membership function. The Figure 5(c) represents phase C membership function. The membership functions of the output variables are shown in the Figure 6.

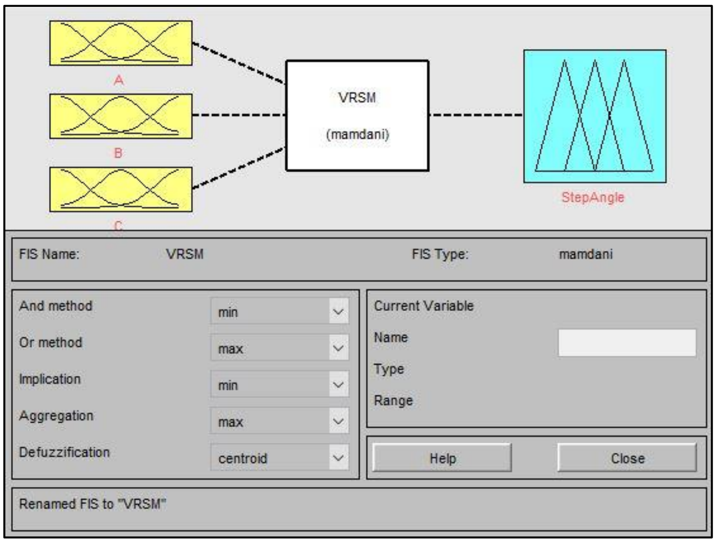
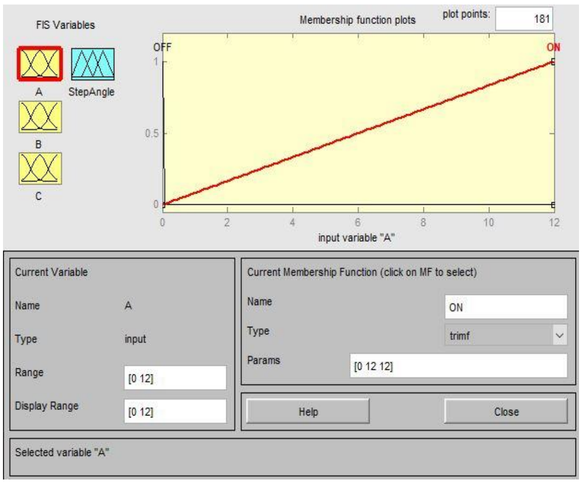
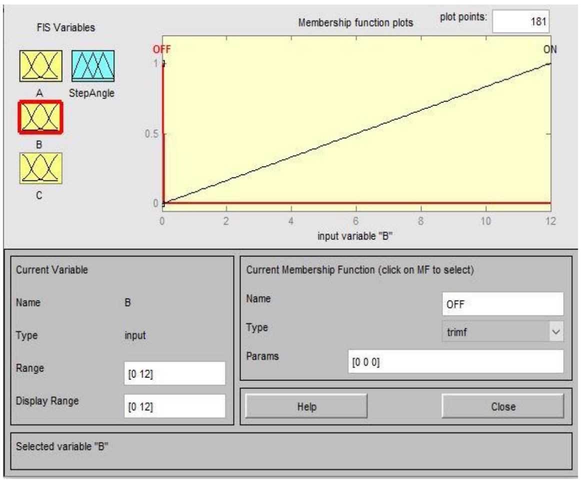


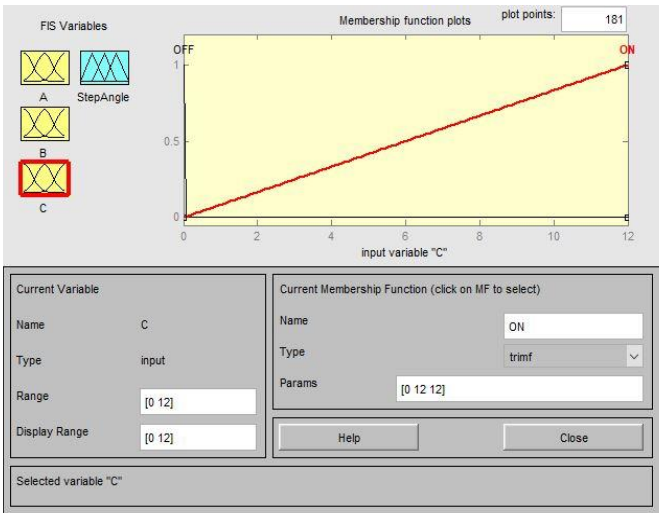
Figure 4. The construction of the FLC with the VRSM



(a)



(b)



(c)

Figure 5. The membership functions of the input variables: (a) phase A, (b) phase B, and (c) phase C

The rules can be constructed depending on the values in Table 2. Six rules are created for six steps.
1) If (A is ON) and (B is OFF) and (C is OFF) then (StepAngle is VL) (1)
2) If (A is ON) and (B is ON) and (C is OFF) then (StepAngle is L) (1)
3) If (A is OFF) and (B is ON) and (C is OFF) then (StepAngle is M) (1)
4) If (A is OFF) and (B is ON) and (C is ON) then (StepAngle is H) (1)
5) If (A is OFF) and (B is OFF) and (C is ON) then (StepAngle is VH) (1)
6) If (A is ON) and (B is OFF) and (C is ON) then (StepAngle is VVH) (1)

All rules can be viewed from MATLAB. One of these rules (the rule 4) is illustrated in the Figure 7.

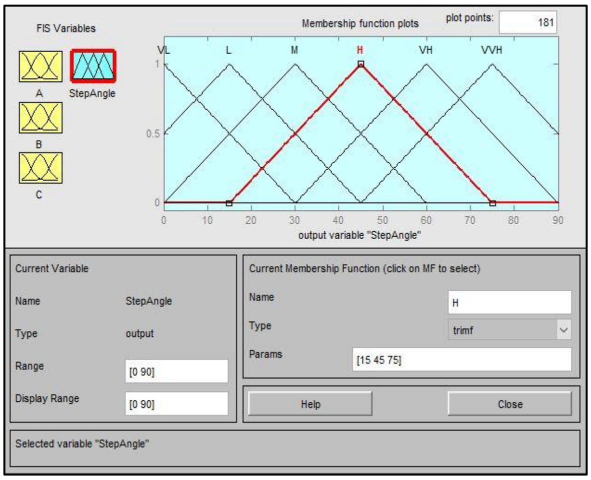


Figure 6. The membership functions of the output variables

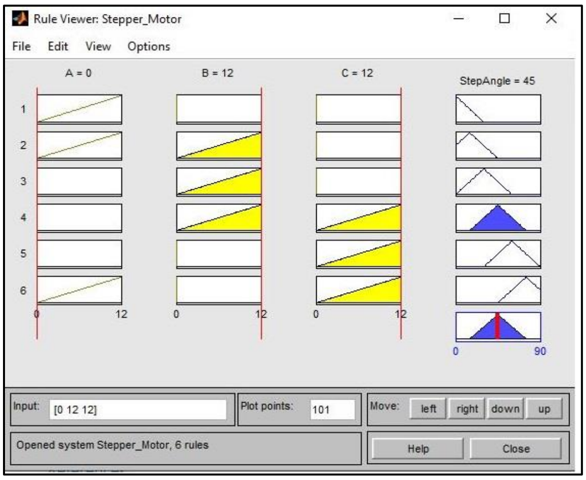


Figure 7. The rule viewer of the rule 4

4. RESULTS AND DISCUSSION

The results can be obtained from MATLAB. The result of the rule 4 is obtained 45° as shown in the Figure 7. The practically result for the rule 4 is equal to the theoretically result in the step 4 in the Table 2. The theoretically results are written in the Table 2.

If the constructed rules for the VRSM are written in the Table 3, the practically step angles results by using FLC Mamdani's type can be obtained from MATLAB program in the Table 4. The Table 4 represents the defuzzification process. The matching between the rows and columns of the Table 4 represents the ON case for each phase. The AA means that the phase A is energized only by 12 v. The AB means that both phases A and B are energized by 12 v. The AC means that both phases A and C are energized by 12 v, and so on.

The comparison between the theoretically and practically results of the step angles of the VRSM for six steps only can be done in the Table 5. Some of the theoretically and practically results are exactly the same while the rest of the results are slightly different. The comparison between the theoretically and practically results can be shown in the Figure 8.

Table 3. The constructed rules for the VRSM

	A	B	C
A	VL	L	VVH
B	L	M	H
C	VVH	H	VH

Table 4. The practically results obtained from MATLAB

	A	B	C
A	9.7°	17.7°	72.3°
B	17.7°	30°	45°
C	72.3°	45°	60°

Table 5. Theoretically and practically step angles results of the VRSM

Step No.	A	B	C	Theoretically step angles	Practically step angles
1	+	0	0	0°	9.7°
2	+	+	0	15°	17.7°
3	0	+	0	30°	30°
4	0	+	+	45°	45°
5	0	0	+	60°	60°
6	+	0	+	75°	72.3°

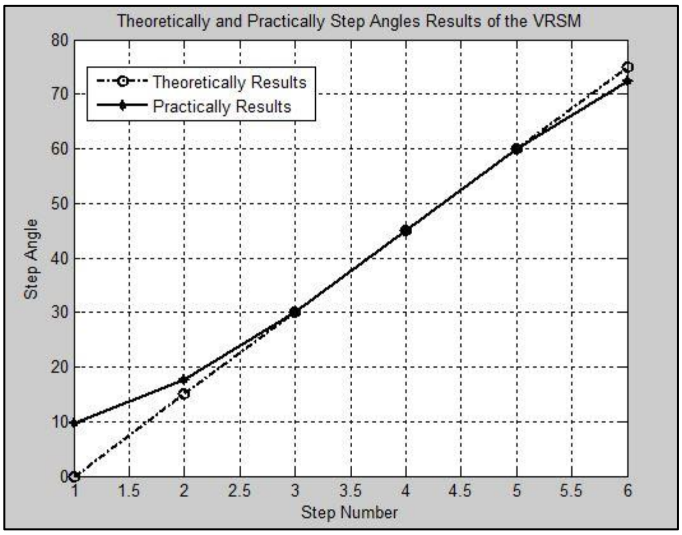


Figure 8. Theoretically and practically step angles results of the VRSM

5. CONCLUSION

The step angle of the VRSM half step mode operation was controlled by using FLC Mamdani type. The proposal research was achieved by using MATLAB program. The results were gotten from MATLAB. The research discussed the theoretically and practically results. These results were illustrated tables and the figures.

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