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DESIGN AND IMPLEMENTATION OF TYPE-2 FUZZY LOGIC CONTROLLERS FOR THE POSITION CONTROL OF A DC SERVO MOTOR

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ABSTRACT: - Uncertainty is an inherent part in controllers for real world applications. In this paper we compare the performance differences between type-1 and interval type-2 fuzzy logic (IT2FLC) controllers, with five and three term membership functions. The controllers are used to control a PM DC motor in a closed loop real time system. The performance of system with each controller to a step is recorded. The results showed that there is a statistical difference between the fuzzy logic type-1 and type-2 controllers. It is also found that a type-2 five term controller is as good as a type-1five term or type-2 three term controller.

Keywords: Fuzzy Logic Controller, Type-2 Fuzzy Controller, IAE, Position Control.

1- INTRODUCTION

In 1975 Zadeh proposed ‘fuzzy sets with fuzzy membership functions’ as an extension of the fuzzy set [1]. Type-1 Fuzzy Logic Systems (FLSs) are unable to directly handle rule uncertainties, because they use type-1 fuzzy sets that are certain [2].

The general framework of fuzzy reasoning allows handling much of this uncertainty, fuzzy systems employ type-1 fuzzy sets, which represents uncertainty by numbers in the range [0, 1] [3]. However, when something is uncertain, like a measurement, it is difficult to determine its exact value, and of course type-1 fuzzy sets makes more sense than using crisp sets, but it is not reasonable to use an accurate membership function for something uncertain, so in this case what we need is another type of fuzzy sets, those which are able to handled uncertainties, the so called type-2 fuzzy sets [2, 4].

So, the amount of uncertainty in a system can be reduced by using type-2 fuzzy logic because it offers better capabilities to handle linguistic uncertainties by modeling vagueness and unreliability of information.

Type-2 FLSs use type-2 fuzzy sets which are described by membership functions which themselves are fuzzy. This allows Type-2 FLSs to model and handle the uncertainty of measurement and any rule uncertainty. Examples are the variability of expert opinion on a fuzzy set, and their self-referencing variability over time; opinions do change. Noise of the system and errors of measurement also have an effect [2]. However, some of the major problems with type-2 fuzzy sets are difficulty of understanding, envisaging how they look due to their 3-D nature, and the computational complexity needed to generate solutions. The derivations of union, intersection and complement all rely on the use of Zadeh's Extension Principle [1].

Mendel and John [5] addressed these issues by 'presenting a new representation for type-2 fuzzy sets' and 'using this representation to derive formulas for union, intersection and complement of type-2 fuzzy sets without having to use the extension principle'. By using interval type-2 fuzzy sets, characterized by secondary membership functions taking values of either 0 or 1, the type reduction necessary for defuzzification of type-2 fuzzy sets is simplified [6]. Although interval type-2 fuzzy logic controllers (IT2FLC) are a lot less computationally intensive than the general type-2 FLC, there remains more computational overhead than that required for a type-1 fuzzy logic controller, related to the number of rules fired [2].

Uncertainty affects all decision making and appears in a number of different forms. The concept of information is fully connected with the concept of uncertainty; the most fundamental aspect of this connection is that uncertainty involved in any problem-solving situation is a result of some information deficiency, which may be incomplete, imprecise, fragmentary, not fully reliable, vague, contradictory, or deficient in some other way [1].

Furthermore, the load characteristics of the servo systems can be often nonlinear. In such cases, not only does the performance of the model-based approaches dramatically decrease but also the complexity of the controller design increases. The uncertainties are generally coming from the noise in the measurements and the parameter changes due to the environmental and the operating conditions. [7]

2- TYPE-2 FUZZY LOGIC SYSTEMS

An IT2FLS is characterized by fuzzy IF-THEN rules, but the membership functions of the ITFLSs are now interval type-2 fuzzy sets (IT2FLSs).

A type-2 fuzzy logic system (FLS) is very similar to a type-1 FLS, the major structure difference being that the defuzzifier block of a type-1 FLS is replaced by the output processing block in a typ-2 FLS which consists of type-reduction followed by defuzzification block as shown in Fig. 1. [9].

Type-1 membership function, $\mu_A(x)$, is constrained to be between 0 and 1 for all $x \in X$, and is a two-dimensional (2D) function. This type of membership function does not contain any uncertainty. In other words, there exists a clear membership value for every input data point. If the points on the triangle function are shifted either to the left or to the right, membership function of fuzzy type-2 can be obtained.

The footprint of uncertainty (FOU) of the membership function (MSF) in the IT2FLS is the area which limited by two MSF, the overhead limitation is the upper membership function UMSF and the down limitation is the lower membership function (LMSF), as shown in Fig. (2).

Due to the complexity of the type reduction, the general type-2 FLS becomes computationally intensive. In order to make things simpler and easier to compute meet and join operations, the secondary MFs of an interval type-2 FLS are all unity which leads finally to simplify type reduction. (See Fig. 3). [7, 8].

T2FLSs are characterized by fuzzy IF-THEN rules, the parameters in the antecedent and the consequent parts of the rules include type-2 fuzzy values. In the design of IT2 FLC, the same configuration as that of type-1 FLC is chosen. There are two-input single-output and each input /output variable has same linguistic variables.

Fuzzy Inference system (FIS) which is used in this paper is Mamdani method or used to call Max-Min method. Operation on Interval type-2 fuzzy set is identical with an operation on type-1 fuzzy set. However, on interval type-2 fuzzy system, fuzzy operation is done at two type-1 membership function which limits the FOU, UMSF and LMSF to produce firing strengths.

In a type-2 fuzzy rule both sides, i.e. the antecedent and consequent parts may be type-2 or one of the sides may be type-2. In many researches, consequent part in (2) is taken as type-1 fuzzy set [6].

3- FITNESS FUNCTION

The most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE) and integrated of squared error (ISE) that can be evaluated analytically in the frequency domain [9, 10].

These three integral performance criteria in the frequency domain have their own advantage and disadvantages. For example, disadvantage of the IAE and ISE criteria is that its minimization can result in a response with relatively small overshoot but a long settling time because the ISE performance criterion weights all errors equally independent of time.

Although the ITSE performance criterion can overcome the disadvantage of the ISE criterion, the derivation processes of the analytical formula are complex and time-consuming. The IAE, ISE, and ITSE performance criterion formulas are as follows:

$$\mathrm{IAE} = \int_0^\infty |r(t) - y(t)| dt = \int_0^\infty |e(t)| dt \quad (1)$$

$$\mathrm{ISE} = \int_0^\infty e^2(t)\, dt \quad . \quad (2)$$

$$\mathrm{ISTE} = \int_0^\infty te^2(t)\, dt \quad (3)$$

Where y(t) is the output variable of the system, r(t) is the required variable (set point), and e(t) is the error variables.

In this paper integral of the absolute error (IAE) is used, in the discrete system the equation will be as:

$$\mathrm{IAE} = \sum_1^N \|e\| \quad (4)$$

Where N is the number of the samples.

4- CONTROLLER STRUCTURE

Unlike conventional control, which is based on mathematical model of a plant, a FLC usually embeds the intuition and experience of a human operator and sometimes those of designers and researchers. While controlling a plant, a skilled human operator manipulates the process input (i.e. controller output) based on e and Δe with a view of minimizing the error within shortest possible time. The controlled variable of fuzzy controller is u(t). Once the fuzzy controller inputs and outputs are chosen, one must think about the membership functions (MSFs) for these input and output variables. In this paper, all membership functions for the conventional fuzzy controller inputs (e and Δe) and the controller output are defined on the common normalized domain [-1, 1].

We use symmetric triangles (except the two MFs at the extreme ends) with equal base and overlap with neighboring MFs. This is the most natural and unbiased choice for MFs.

The actual control input voltage for the main fuzzy controller (In the case of PI-type FLC) can be wtritten as:

$$u(k) = u(k-1) + \Delta u(k) \quad (5)$$

Where k is the sampling instant, $u(k)$is the crisp at k sampling instant and $\Delta u(k)$ is the incremental change in controller output. Du and Ying [12] showed that an IT2 fuzzy-PI (or the corresponding PD) controller is equivalent to a nonlinear PI (or PD) controller with variable gains and control offset.

5- EXPERMINTAL RESULTS

The test of the system is divided to three parts, the first test when the FLCT1 is 5 terms and FLCT2 is 3 terms with 0.2 FOU. The second system test is used FLCT2 alone with 3 term, and different values of FOU. The last system test with FLCT2 with 5 terms and different values of FOU.

5.1- Experimental FLCT1 and FLCT2

By using the FLCT1, FLCT2 with 3 term and FOU=0.2 w. r. t. UOD controllers' individual with motor, the resulted closed loop system response is shown in Fig.4 and the response parameters of the different type of controller are illustrated in table I.

From table I, the rise time of the FLCT2 is (6.1314 sec) and this is faster than that for the FLCT1, and the settling time for FLCT2 is 7.7163 sec and this is also faster than that for the FLCT1, there is an overshoot 0.95% for FLCT2 and this is smaller than that appears using FLCT1 finally. The IAE for the FLCT2 is 492.9 and this is smaller than that for FLCT1. We can see that the FLCT2 treats the nonlinearity of the motor for the base link better than FLCT1.

5.2- Experimental Results for FLCT2 with 3 TERM

Using the flexibility of FLCT2 for handling the nonlinearity of the system, can change the value of FOU which is accountable to treat the nonlinearity by variation of FOU w. r. t. UOD of the input and output MSF. Changing FOU from 0.2 to 0.6 in step of increment by 0.1.the response of the motor using the FLCT2 with 3 MSF with different values of FOU w. r. t. UOD is shown in Fig.5. Table II illustrates the characteristic of this response.

From table II we can see that the controllers with FOU=0.2 and 0.3 have the faster t_r (6.1314 sec) and faster t_s (7.7163 sec), but the minimum value of the maximum peak overshoot is for the controller with FOU = 0.4 equals 0.07, and the minimum value of the IAE equals 492.7 for the controller with FOU equals 0.3.

5.3 Experimental Results for FLCT2 with 5 Term

The response of the motor using the FLCT2 with 5 terms with different values of FOU from 0.2 to 0.6 w. r. t. UOD is shown in Fig.6. Table III is illustrates the characteristic of this response.

From table III we can see that the faster system with t_r is the controller with FOU=0.5 is t_r = 5.756 sec. The minimum value of t_s for the controller with FOU= 0.2 and 0.5 is t_s=7.2992 sec. The minimum value of the maximum peak overshoot is for the controller with FOU = 0.2 and 0.3 equals 0.07. Finally the minimum value of the IAE equals 468.9 for the controller with FOU equal 0.5.

5.3- Experimental For FLCT2 with Different Number of Term

Now comparing the response of the system for the controllers have same FOU with changing the number of MSF, we can see that the minimum value of the IAE for the controller with 5 MSF with faster system and minimum an overshoot for all cases.

For the controller FLCT2 with three terms the mean of the IAE equals 498.736 and standard deviation equal 5.772, for the controller FLCT2 with five term the mean of the IAE equals 474.094 and standard deviation equals 8.096.

6- CONCLUSION

The FLCT2 has been proposed for position control of DC servo motor. Performance of the proposed FLST2 was compared with corresponding conventional FLC's with respect to several parameters such as rise time Tr, settling time Ts, maximum peak overshoot (MP%), and integral of absolute error (IAE).

The experimental results show that using a type-2 FLC in real world applications can be a good option since this type of system is more suitable system to manage high levels of uncertainty, as we have seen in the results shown in tables I, II and III.

Experimental results indicate that the performance of the FLCT2 better even if it has a small number of rules. The performance of the system being better with increasing the number of terms and FOU for the FLCT2. Comparing the statics value of the standard division of the FLCT2 showed that the controller with three terms is closely together than that for FLCT2 with five terms, means the system will be sensitive to changing the value of FOU with increase the number of terms. Obviously these results are specific to our DC servo motor and not transferable to all DC servo motors.

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Table I: Numerical result for the DC motor with FLCT1, FLCT2 with 3 term and 0.2 FOU.

Type of controller	t_r (sec)	t_s (sec)	%MP	IAE
FT1	7.5495	9.3013	1.49	577.3
FLCT2 with 3-Term and FOU=0.2	6.1314	7.7163	0.95	492.9

Table II: Numerical result for the DC motor with FLCT2 with 3 terms.

3 Term FLCT2	t_r (sec)	t_r (sec)	%MP	IAE
FOU=0.2	6.1314	7.7163	0.95	492.9
FOU=0.3	6.1314	7.7163	0.12	492.7
FOU=0.4	6.2148	7.7998	0.07	500.5
FOU=0.5	6.2565	7.8832	0.95	501.7
FOU=0.6	6.2565	7.7998	0.95	505.9

Table III: Numerical result for the DC motor with FLCT2 with 5 term.

FLCT2 with 5 Term	t_r (sec)	t_r (sec)	%MP	IAE
FOU=0.2	5.7977	7.2992	0.07	472.2
FOU=0.3	5.7977	7.3410	0.07	469.3
FOU=0.4	5.7977	7.3410	0.17	471.7
FOU=0.5	5.7560	7.2992	0.17	468.9
FOU=0.6	5.9228	7.4244	0.61	488.3

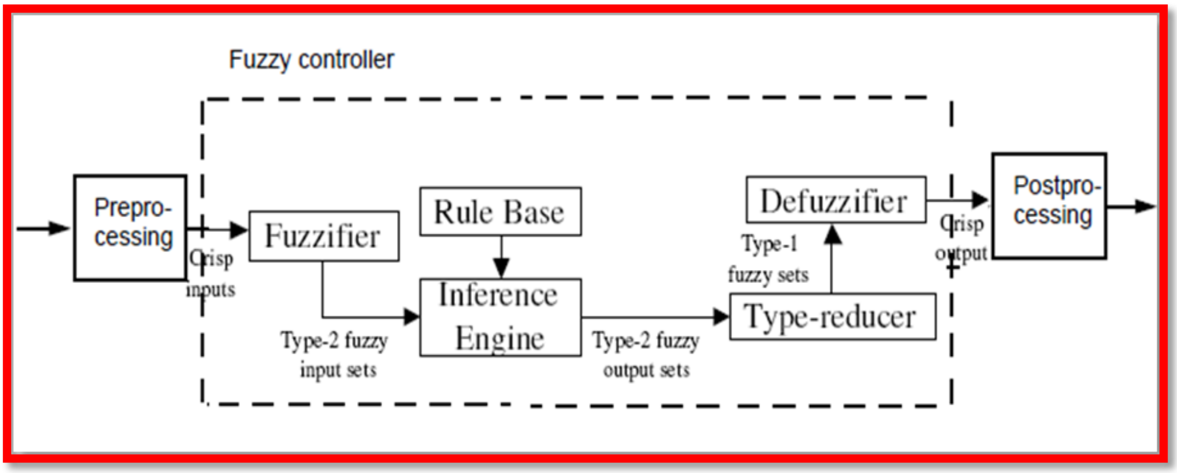

Fig. (1): structure of a type-2 FLS.

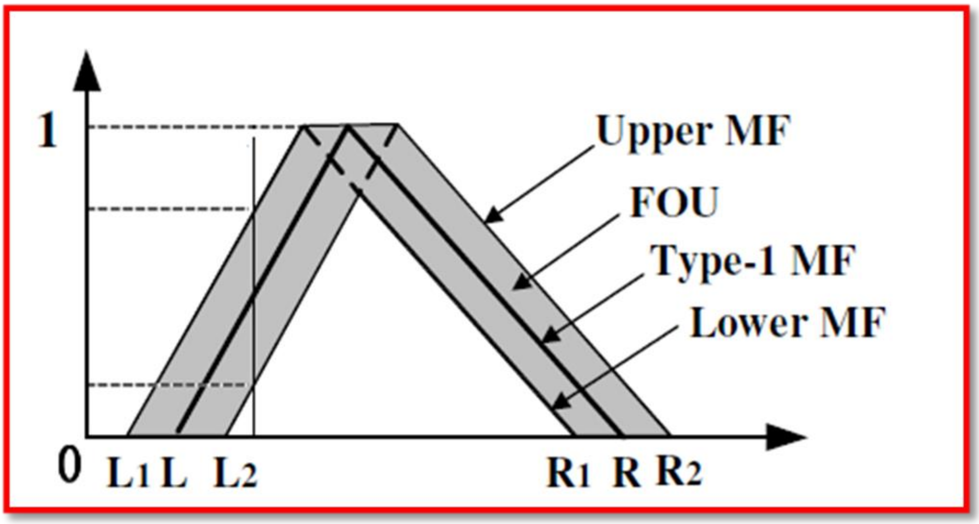

Fig. (2): Membership Function of FLCT2.

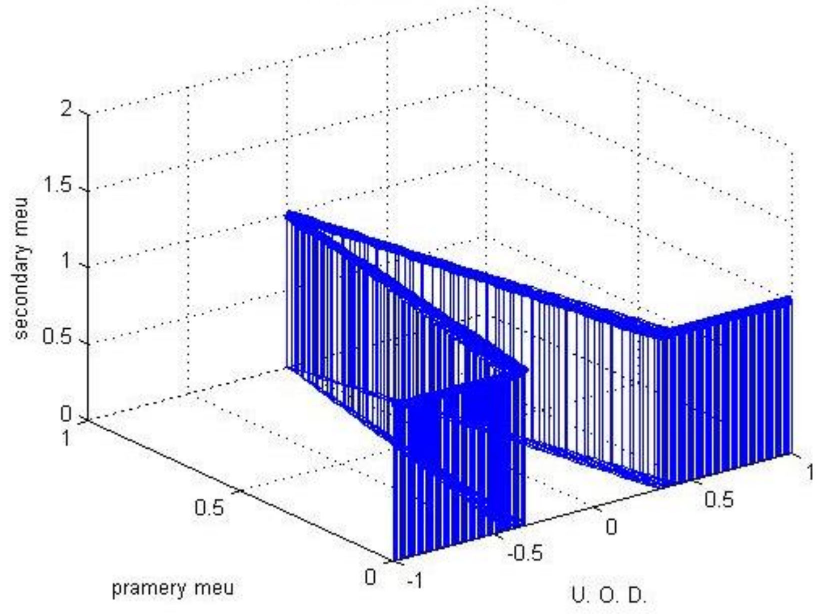

Fig. (3): Three Dimension interval of the MSF for FLCT2.

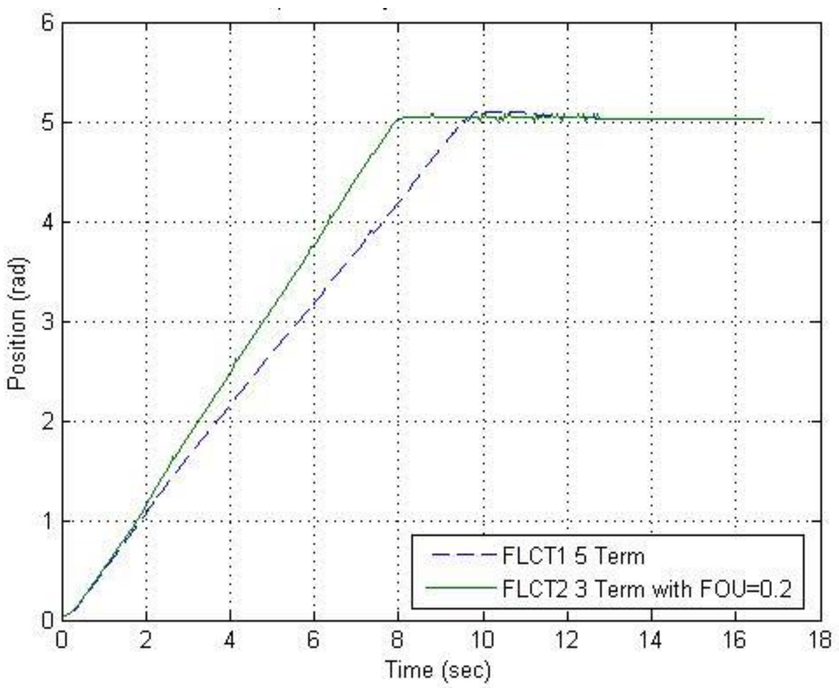

Fig. (4): Response of the DC motor with FLCT1, FLCT2 with 3 terms and 0.2 FOU.

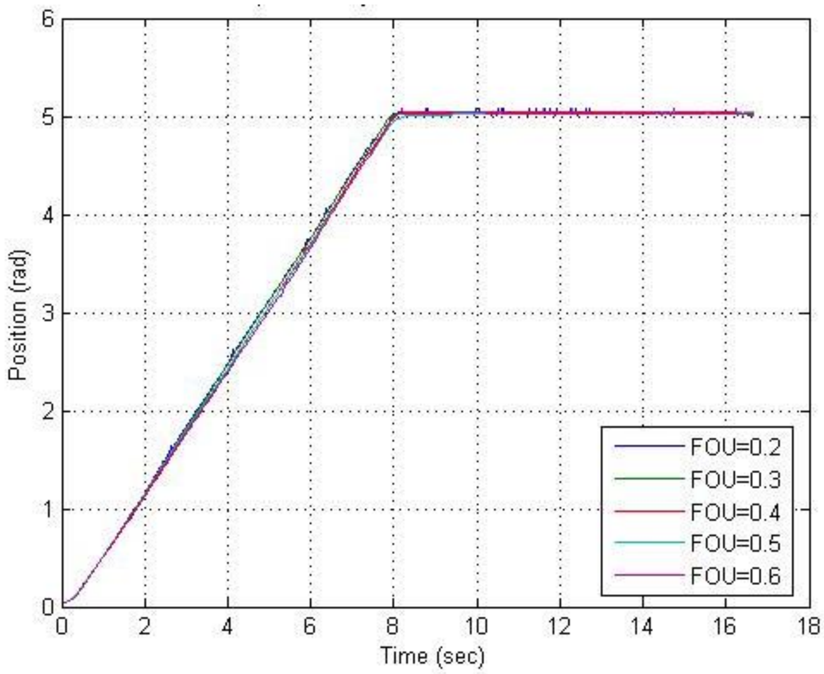

Fig. (5): Response of the motor with FLCT2 with 3 terms.

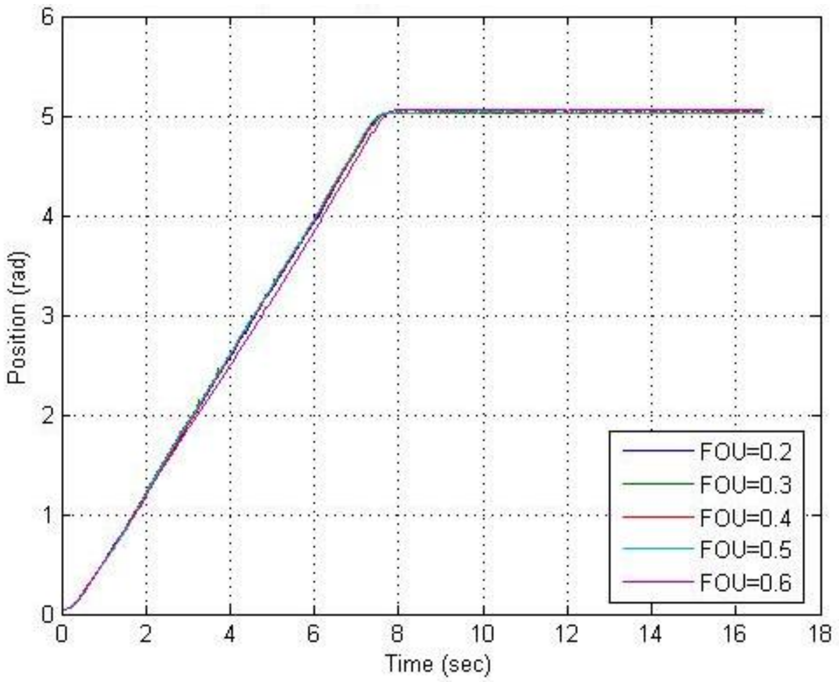

Fig. (6): Response of the motor with FLCT2 with 5 terms.

تصميم وتنفيذ لمسيطر منطقي مضبب النوع الثاني للسيطرة على موقع لمحرك التيار المستمر

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الخلاصة

ان الحيرة جزء متاصل لتطبيقات السيطرة في العالم الحقيقي. في هذا البحث تمت مقارنة الاختلاف بين اداء المسيطر المضبب النوع الاول والمسيطر المضبب النوع الثاني، مع استخدام ل خمس و ثلاث دوال عضوية. تم استخدام المسيطرات للسيطرة على موقع محرك تيار مستمر بمغناطيسية دائمية بحلقة مغلقة وفي الزمن الحقيقي. تم توثيق سلوك المنظومة مع كل المسيطرات لاشارة الخطوة.

النتائج بينت الاتي هناك اختلاف احصائي بين المسيطر المضبب النوع الاول والنوع الثاني. كذلك اثبتت النتائج ان المسيطر من النوع الثاني الذي يستخدم خمس دوال عضوية هو افضل من النوع الاول بخمس دوال عضوية او النوع الثاني بثلاث دوال عضوية.

الكلمات الدالة:- المسيطر المنطقي المضبب، النوع الثاني من المسيطر المضبب، مسيطر الموقع.