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Design and Simulation of Modified Type-2 Fuzzy Logic Controller for Power System

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ABSTRACT- This Article exhibits the structure of a Modified Type-2 (MT2) Fuzzy Logic (FL) Controller (MT2FLC), direction line programming of development, also performance optimization for different power systems. The implementation of the MT2FLC for control of a power system. New participation capacities were considered in adjusting a domain for an Interval Type-2 (IT2) Fuzzy Logic (FL) System (IT2FLS). Another structure in graphic user interface (GUI) mimicked four controllers: an optimal PID controller, FLC, a Type-1(TIFLC), an Interval Type-2 ((IT2FLC), and the MIT2FLC. Their yields were analysed, different periods of the structure procedure for the fuzzy framework, from beginning depiction to conclusive execution, can be gotten from the altered tool compartment (whose capacity to create complex frameworks and adaptability in broadening the accessible usefulness into working with adjusted type2 fuzzy administrators, phonetic factors, IT2 participation capacities, and defuzzification strategies, just as in assessing the MIT2FLC are its best characteristics). Case study for this work, all the optimization controllers implemented for a Brushless DC (BLDC) Motor with MATLAB Ver.2012a was utilized in the recreation and plan of the entirety of the procedure GUIs. Satisfactory results are obtaining which improve the implementation of the using of MIT2FLC controller as practical solution of power system.

General Terms: Brushless DC (BLDC) Motor, Generalized Ponens (GMP), Generalized Mode Tollens (GMT)
Keywords: (MT2FLC) Modified Type-2 Fuzzy Logic Controller, (GUI) graphic usage interface, (BLDC) Optimizations performance.

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1. INTRODUCTION

A BLDC presents the example of a power system engine has a magnet, supplied by a 6-transistor inverter with a rotor position determined for switching on or off. It doesn't have brush nor commutates, and the feature of torque speed its Resemble a traditional DC constant magnet without any possible brush / commutation malfunction [1]. In the high performance, variable speed drive, the BLDC motor is becoming more common, it wants comparatively very few repair, less inertia, the ratio of power to volume is bigger, friction is minimal, noise is fewer in comparison with a traditional permanent-magnet DC devices motor of a similar Outside rating. None the less, BLDC engine controller is more complex than a traditional engine controller. Sequentially, these are very expensive features. Nevertheless, for the successful operation of a BLDC engine, should be a high Responsiveness of the armature current [2].

BLDC motors Possesses supreme power density compare with the different motors (e.g., induction motors) as a result of there's no shortage of no commutation and rotor copper [3]. It has sturdy shape and compressed. The factors are contributed to increase in the prevalent of BLDC engines in critical competency applications and wherever commutation-induced Screws are not desired. The utilization of a Rotor location sensor and also used the reflector is required for the commutation. Nevertheless, the sensor can add cost-effectiveness and size of the instrument and reduce reliability and noise tolerance. The research in [4], the sensor in motors can control site, speed, and/or torque while not using sensitive shaft-mounted site [5].

One characterizations of modern intelligent techniques it does not need accurate models, therefore it is widely applied to govern, develop, or replace traditional control techniques. Zadeh's smart Fuzzy Logic (FL) is frequently utilized to the design of controllers [6]. The main benefit of fuzzy control methods is that there is no sensitivity to the precision of a dynamic design. There is growing interest in using (IT-2) (FLC) interval T-2 fuzzy logic control due to the (T2 FLS) T-2 fizzy logic system and its ability to manage uncertainty. The well-known, ordinary, type-1 fuzzy groups concept was extended when the T2 fuzzy groups concept was first introduced. [7].

This article shows the appliance, the motor mathematical paradigm and drawback of its control were characterized in *part 2* and the theory of the IT-2 Fuzzy group was given in *part 3*. The design of the controller which employs the suggested blueprint was presented in *part 4*. The control system plan's graph in addition to the emulation effect was accorded in *part 5*. Finally, the simulated results were presented in *part 6*.

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A BLDC motor is an electrical spinning mechanism the stator is three-phase traditional, like to the induction motor. The rotor has constant magnet mounts (*fig. 1*). The magnet rotates whilst constant Connectors. Engine is the equivalent of a reversed DC-commutator generator [8].

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} Rs & 0 & 0 \\ 0 & Rs & 0 \\ 0 & 0 & Rs \end{bmatrix} + \begin{bmatrix} Ls-M & 0 & 0 \\ 0 & Ls-M & 0 \\ 0 & 0 & Ls-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad (1)$$

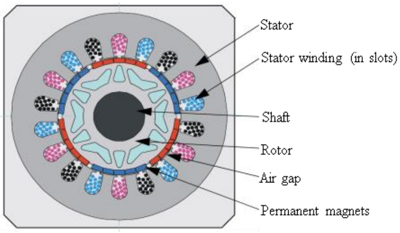

Figure 1: BLDC Motor, cross-sectioned [5].

2. A MODIFIED T-2 FUZZY SET THEORY

Standard technologies have replaced Fuzzy technology in different scientific and systems engineering implementations, particularly style distinction and control system. Information system, knowledgeable technology and decision-making popularly use the Fuzzy system within a kind of approximation reasoning through its sturdy dialectics and restricted standards. To show the information mathematically and in order to get a solemn tool for uncertainty, essential inaccuracy and confusion, fuzzy sets have been made for treating data that has probabilistic uncertainties by L. A. Zadeh (1965). Fuzzy sets and fuzzy logic form fuzzy logic-based smart systems, which are elementary instruments to model nonlinear congregation systems and the brain's manipulation of inaccurate information. [4].

Uncertainties will be lost post-fuzzification through the using of classical Fuzzy logic (type-1) therefore it will not be modelled, while its recommended to use type-2 Fuzzy logic as the reasoning way to considerable uncertainty cases. The type -1 Fuzzy groups form the main construction blocks for type-1 FL system. [2]. The groups of Fuzzy type-1 expand fragile groups, mastery partial group membership, where an element's membership range is measured by one worth inside the interval [0, 1]. One fragile range could not paradigm either shape of uncertainty [12]. Take into account these logic assurances:
(1) Worth x is zero A
(2) Worth y is 0.77643 A
(3) Worth z is one A

The associateship degree of a fuzzy group ought to be developed to a T-1 fuzzy group in order to employ it to model non-certainty for that reason Zadeh planned for the generalized T-2 fuzzy groups, that are currently known, which provide practical mapping, a site for the possibility measurements or a membership degree [3,5]. A generalized Type-2 fuzzy group membership degree considered as type-1 fuzzy group by [0, 1] as a specific support which will be understood as secondary MF.
(1) Value x is approximately 0:77643Ã
(2) Value y is an essential amount Ã
These confirmations are equivalent to the membership degree in a generalised Type-2 fuzzy group. An example of a Type-2 fuzzy group Ã will be numerated below in *eq. (2)*:

Ã=about0.77643/x+asubstantial amount y+{0.3/0.5+0.8/0.6+ 1/0.7+ 0.2/0.8}/z (2)

And a fundamental amount of 0.77643, with {0.3/0.5+0.8/0.6+1/0.7+0.2/0.8}, being type-1 fuzzy groups, and x, y, and z the items of some separated universe of discourse U. An inference operation by Type-2 fuzzy groups will let Type-2 fuzzy Logic system to distribute the modeled uncertainty [8].

A T-2 fuzzy group expresses impreciseness and non-certainty and, for a component belonging to a group, the degree of indeterministic fact. A T-2 fuzzy group means by Ä is described by a T-2MF, $\mu\ddot{A}^{(x,u)}$, where

$x \in X$, $u \in J_x^u \subset [0\ 1]$ $0 \leq \mu_{\ddot{A}}(x,u) \leq 1$ is realized in *eq. (3).*

$$\ddot{A} = \{(x, \mu_{\ddot{A}}(x)) / x \in X\} = \{\int_{x \in X} [\int_{u \in Jxu \subset [0\ 1]} fx(u)/u]/x\} \quad (3)$$

An epitome of a T-2 MF created in the IT2-FLS Tools is formed by the MFs of a Pi elementary and a Gbell type-1 secondary (As shown in *fig. 2* below).

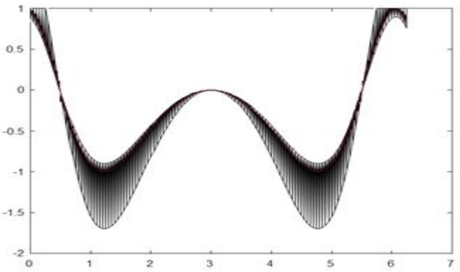

Figure 2: The FOU of MT-2 MFs [14]

If $f_x(u) = 1$, $\forall u \in [J_{-x}^{u}, J_x^{-u}] \subset [0,1]$ the membership role of type-2 $\mu_{\ddot{A}}(x,u)$ is elucidated from one side membership role of type-1 $J\_x^u \equiv \mu\_A(x)$ and one superior membership role of type-1, $J_x^{--u} \equiv \mu^{-}_A(x)$ which is named as an interval type-2 fuzzy group, illustrated by (4), (5) [9]:

$$\ddot{A} = \{\int_{x \in X} [\int_{u \in \mu_A(x), \mu A(x) \subset [0,1]} 1/u] /x\} \quad (4)$$

The MF will be then illustrated by (5) when $A^{\approx}$ is a T-2 fuzzy singleton:

$$\mu_{\ddot{A}}(x) = \begin{Bmatrix} 1/1 & six = x \\ 1/0 & six \neq x \end{Bmatrix} \quad (5)$$

3. A MODIFIED T-2 FUZZY INFERENCE SYSTEM MODELLING

Human data are presented like a fuzzy rules group, essentially IF < Background > Then < Consecutive > form and represent a fluid relationship or proposal. The reasoning in FL is vague and approximate; one rule is sufficiently inferential to deduce it, although the precedent does not comply entirely. The

Generalized Ponens (GMP) and the Generalized Mode Tollens (GMT) are simple abstract methods of thinking, each reflecting the expansion or generalization of classical reasoning amidst rules and reasoning laws [10]. GMP is called the Direct Reasoning method and it's described as Rule:

Rule: When *A* represents *x* then B represents *y*, Fact *x* is *A'*,
Conclusion: *y* is B (6)

A, A', B and B' are all fluffy sets' kind. *Fig.3* illustrates the simple thinking with Fuzzy Inputs of Interval T-2. The Inference Fuzzy System is a rule-based system which uses FL instead of the logic of the Boolean data analysis. It is made up of four elements in its fundamental structure (*Fig.3*)

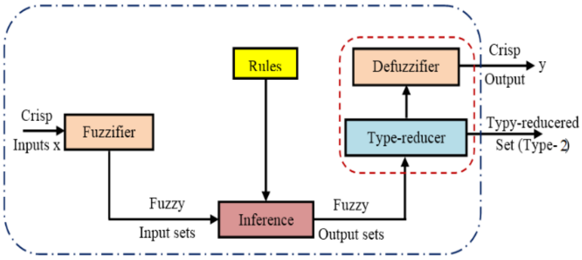

Figure 3: Structure of a traditional T-2 inference fuzzy system [17].

The characterization of a T-2 fuzzy set is not simple like T-1 fuzzy set. A T-2 fuzzy set, indicated by $\tilde{A}$, which can be indicated by a T-2 MF , $\mu_{\tilde{A}}(s,u)$ note that x€X, u€$J_x \subset [0,1]$, which mean [11]:

$$\tilde{A} = \{((x,u),\mu_{\tilde{A}}(x,u))/\forall u \in J_x \subset [0,1]\} \quad (7)$$

Where, $0 \leq \mu_{\tilde{A}}(x,u) \leq 1$, Ã is indicated as:

$$\tilde{A} = \int_{x\in X} \int_{u\in Jx} \frac{\mu\tilde{A}(x,u)}{(x,u)}\, Jx \, ⊆ [0,1] \quad (8)$$

Where $\iint$ indicating unity over all allowable *x* and *u*.

$\mu_{\tilde{A}}(x,u)(x\in X,\ u\in J_x)$

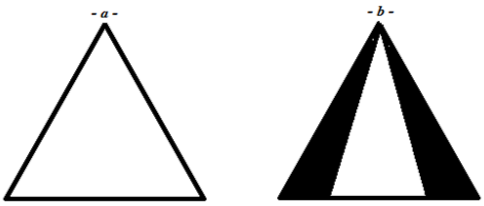

Figure 4: Type-1 MF and Blurry type-1 MF, respectively [19].

The secondary level is in *eq. (1)*. Just think of blurring the type-1 MF by either shifting the points on the left or right triangles but maybe not by the same quantities. The MF no longer has a single value of x, say x3; instead the MF takes values for wherever the vertical line intersects the blurred [12]. Such values need not be weighted identically, so a three-dimensional MF is created in the x u x, aT-2 MF that characterizes a T-2 fuzzy set. These values could all be given an amplitude distribution. We can represent these values in a vertical slice as:

$$\tilde{A} = \int_{x\in X} \frac{\mu\tilde{A}(x)}{x} \int_{x\in X} \frac{[\int_{u\in Jx} fx(u)/u]}{x} J_x \subset [0,1] \quad (9)$$

The primary membership of x is a naming of a secondary MF domain, where $J_x \subseteq [0,1] \forall u \in X$. When both *X* and *Jx* discrete $\tilde{A}$ will be as shown in (10) below:

$$\tilde{A} = \sum_{x\in X} \frac{[\sum_{u\in Jx} fx(u)/U]}{x} = \sum_{i=1}^{N} \frac{[\sum_{u\in Jx} fxi(u)/U]}{xi} = \frac{[\sum_{k=1}^{M1} fx1(u1k)/u1k]}{x1} + \ldots + \frac{[\sum_{k=1}^{Mn} fxn(unk)/unk]}{xn} \quad (10)$$

All the primary memberships are uniformed by uncertainty (Karnik & Mendel, 2000) [13]

$$FOU\ (A) = U_{x\in X}\, J_x \quad (11)$$

The FOU definition, together with the lower and upper MF definitions, makes T-2 fuzzy set simple to describe. In shape, position of a type-1 fuzzy set, the FOU model uncertainties. Fig. 8 shows the FOU (shaded) of a T-2 fuzzy MF. A Gaussian MF form 1 with mean mk and standard deviation σk is obtained by blurring. Consider Gaussian primary MF with a fixed average mk and an uncertain default value in [σk1, σk2].

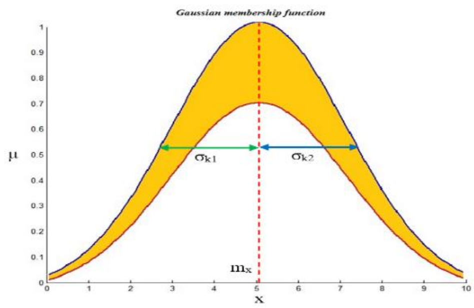

Figure 5: FOU for a Gaussian primary MF with an uncertain standard deviation

The fragile numbers are identified into fuzzy by the fuzzifier in the general T-2 FLS. Turn on rules with associated fuzzy sets that are expressed in linguistic variables. Sets in soft output sets on the fuzzy data maps of the inference engine. By the output processor of many FLS applications, a crisp number is produced at fussy sets output [14].

4. IMPROVED INTERVAL TYPE-2 FUZZY (MIT2-FC) CONTROLLER ARCHITECTURE

Compared to traditional controls based on the mathematical model of a plant, FLC usually include the anticipation and skillfulness of a human operator, who are sometimes control designers and scientists. The aim of a qualified human operator is the management of process input (i.e. control output) as quick as possible and with e and ubiquitous-based error, the variable managed by the Fuzzy controller is u(t). After selecting inputs and outputs of the fuzzy controller, the input and output variables of MFs have to be taken into account. The paper sets out MFs for standard input (e and /e) and supervisor output in a popular structured field [-1, 1]. Symmetric triangles with a similar base and 50 percent overlap with a neighboring MF were used (except for the two extreme MFs). This is the naturally most impartial choice for MFs. The seven MFs are listed in *figure 8*. The process of design allows the actual voltage control of the main fluid controller (for PI-type FLC) to be formulated as follows:

$$u(k+1) = u(k) + \Delta u(k) \quad (17)$$

K is the current sample, and the gradual increase of the controller outcomes is denoted as Δu (k). The FOU space is MF in the type-2 FLS period, which is restricted to 2 kinds of MF-1, Upper MF(UMF) and Lower MF(LMF). For the same seven linguistic variables, there is a combination of duo inputs and single output to every of input/output variables. The T-2 Fuzzy set interval procedure was similar to the Fuzzy set type-1 procedure. However, in interval T-2, fuzzy-type MFs are used to reduce the firing strength of FOU, LMF and UMF, which is limited to the type1 MFs.

5. DESIGN SIMULATION AND ANALYSIS

The current IT2FLC was used for the DC motor speed control to test the feasibility and validity of the proposed system. A fluid inference graphical interface type-2 with a MATLAB type-2 toolbox was created to dynamically monitor the controller device. The time and maximum rate of success had to be addressed. MATLAB 7-Simulink program obtained the phase response plots and compared the time and over-shoots of the two controllers. The reliability of the controllers was based upon two commonly used output indices:

$$AE(k)= |y(k)- y_d(k)| \quad (18)$$

$$RMS\ (k) = \sqrt{(y(k) - yd(k))} \quad (19)$$

5.1 A conventional controller Simulation for a BLDC motor

The control system with two loops is shown in *figure 3*: the current control loop that controls the engine torque and the velocity control loop that changes the motor speed. The model applies to all research types but several parameters for the current controller or speed controller make it possible to introduce Fuzzy Controller Types 1 or 2 before defining them. The typical controller layout is shown in *fig. 6*. With MATLAB / Simulink, BLDC engine model and study were carried out. A three-phase engine (see *Table 1* of the parameters) is fed by a six-step voltage inverter, a MOSFET bridge from Sim-Power Systems Library. A velocity sensor controls the DC bus voltage. Decoding the engine's Hall Effect signal produces signals from inverter gates.

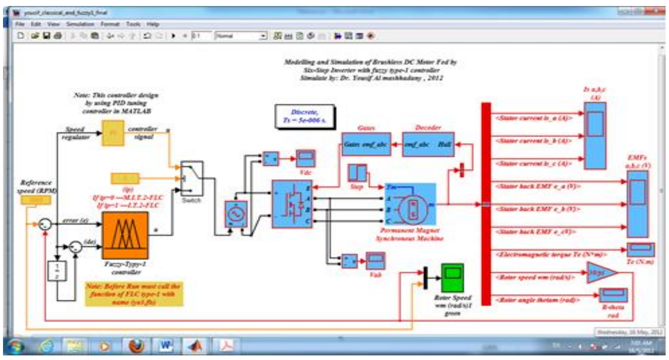

Figure 6: Simulation of classical control in the BLDC

The three-phase output of the inverter is applied to the stator windings of the PMSM block. The load torque on the machine shaft is set to zero and is set at t=0.1 sec at its nominal value (11 Nm).

Table 1. BLDC MOTOR PARAMETERS

parameter	Value	(unit)
Rated speed	3000	(rpm)
Rating voltage	500	(Vdc)
Rating (P)	1.00	(kW)
Number of phase (connection)	3 (star)	
Stator phase resistance Rs	2.8750	(ohm)
Stator phase inductance Ls	8.5e-3	(H)
Flux linkage established by magnets (V.s)	0.175	
Voltage Constant	146.6077	(V_peak L-L / krpm)
Torque Constant	1.4	(N.m / A_peak)
ack EMF flat area	120	(degrees)
Inertia, friction factor, pole pairs	[0.8e3,1e-3 4]	[J(kg.m^2) F(N.m.s) p()]
Initial conditions	[0,0, 0,0]	[wm(rad/s) thetam(deg)ia,ib(A)]

Table 2. DECODER-FED INVERTER TRUTHTABLE

ha |	hb |	hc ||	Emf_a|	Emf_b|	Emf_c|
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	_1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

Fig. 7 and *fig. 8* give the classical controller's simulation performance, which have been most efficient for fast resolution and strong 0.99 percent error /PWM= 2982 in a steady-state error value (see *fig. 7*). The results show the inverter output which precisely supplies the engine via the encoder module with the link tables.

Table 3. THE INVERTER SWITCHES TRUTH TABLE

Emf_a|	Emf_b|	Emf_c||	Q1|	Q2|	Q3|	Q4|	Q5|	Q6|
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	_1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

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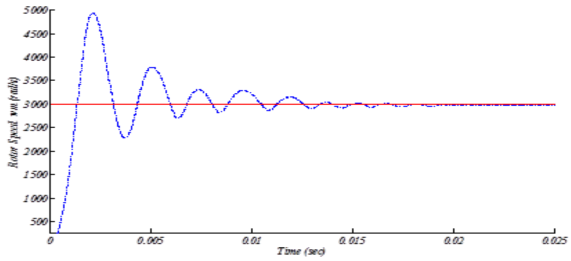

Figure 7: The classical-controlled BLDC motor's rotor speed output

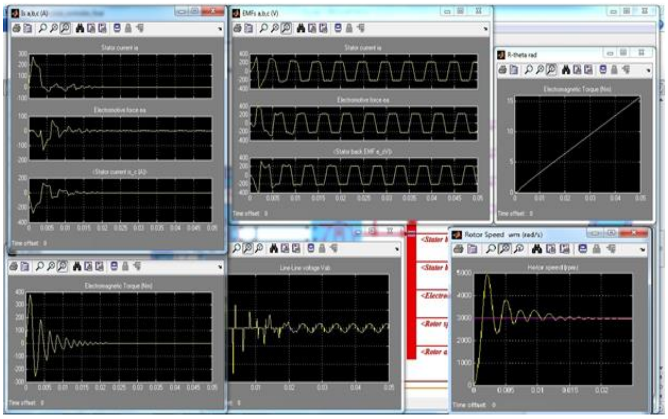

Figure 8: BLDC motor's classical controller Simulation

BLDC engine research assumed an unsaturated BLDC motor for simplicity and precision, equal resistance to stators, continuous self-induction, fixed mutual inductance, perfect semiconductor inverter systems, minimizable iron losses, and the corresponding EMF back shapes for all phases. Based on the derived dynamic *equation (1)* and on the BLDC engines and VSI circuits, the results were completed. The equation for movement is presented as follows:

$$\frac{dwm}{dt} = \left(\frac{p}{2J}\right)(T_e - T_l - Bw_r) \text{ and } \frac{d\theta}{dt} = w_r \quad (20)$$

with Te representing the electromagnetic torque, TL the load torque (in Nm), J the moment of inertia (in kgm2), B the frictional coefficient (in Nms/rad), ωm the rotor speed in mechanical rad/s, and ωr the rotor speed in electrical rad/s.

5.2 Modified Type-2 Fuzzy controller Simulation

Fig. 9 presents for any FLC with two inputs (e_1, e_2) with single o/p (u). An error is determined by extracting reference velocity from an actual speed.

$$e_1(k) = w_r(k) - w_m(k) \quad (21)$$

With e_1 referring to the error, w_r represents the reference speed. The actual motor speed is referred to as w_m. With e1(k-1) being the preceding error value, the equation (22) determines the change in error ($e_2(k)$).

$$e_2(k) = e_1(k) - e_1(k-1) \quad (22)$$

FLC approach sets 2 standardization parameters (e1N, e2N, input) and 1 de-normalization parameter (uN, output), i/p values are normally choose with the range (-1, + 1) and the o/p value for the FC is translated to a value which depends on a terminal control variable in a de-normalization. Diffused into a crisp output (u) value are the fuzzy value obtained from the fuzzy inference method. The nine clusters shown in an earlier section and the figures for each input or output value are therefore represented as a triangular fuzzy MF. 9.

In this work, the new Toolbox with MATLAB deal with fuzzy system was based on the Type-2 Fuzzy Logic Toolbox (SATVIR 2008, Juan 2007) [ref tool1] In this study, the Fuzzy toolbox was updated. This modified FLC has been built using the GUI of MATLAB. The FIS structure has also been calculated and developed using the GFS algorithm. For FIS and GFS systems this GUI has introduced ANFIS (adaptive Neruo Fuzzy Inference System). The design and simulation of the three types of engine BLDC controllers (classical, FT1 and IFT2) is described in five GUI windows (see *fig. 9*). The premier window introduces the concept behind the modified interval of FT2 controller and calls all simulation windows.

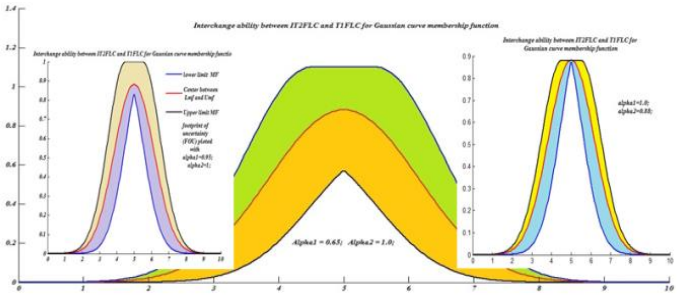

Figure 9: MT2-FLS dimensionality decrease

As a starter point for tuning in this work, the embedded T1-FS located in the middle of each FOU is used. After transforming the IT2-FSs to T1-FSs, by using MATLAB 2020A to measure and map the limitations of this update, the MF parameter tuning is achieved. The last MIT2-FLC setup can be viewed on the fourth button. The MT2-FLC block simulation diagram is shown in *fig. 10*, in order to choose the switch mechanism for using of both controllers in the same field.

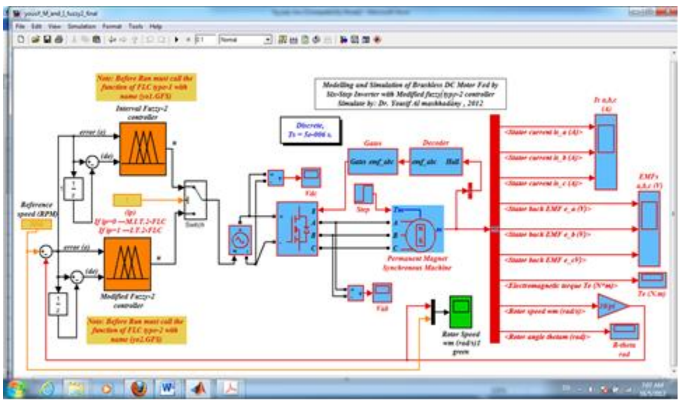

Figure 10: MIT2-FLC final simulation

When calculating and designing the FLC system, controllers were used. *Figure 11* shows the simulated results: four o/p's for both controls, each under a same BLDC motor simulation initial condition. In comparison with other controllers, the T2-FLC was revised to provide the lowest possible overview value, overcome the overflow and achieve the best possible remedying time.

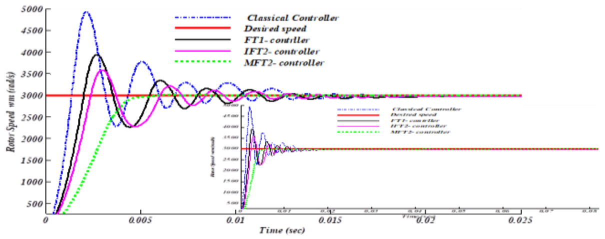

Figure 11: Optimization performance of BLDC with MIT2-FLC controller

6. CONCLUSIONS

The analysis of simulation results show that the proposed GUI can give direct control of a BLDC engine through an altered interim sort 2 fluffy controller. This work likewise thought about the aftereffects of the four controller types. The GUI procedure's utilization empowers the controllers' concurrent running and their correlation. The structure and execution that were first completed by the IT2FLS Toolbox utilizing are possibly significant to inquire about interim T-2 fuzzy rationale, as the suggested new Toolbox configuration model of the MT2FLC controller is to take care of complicated issues of different applications. A future proposed work applies to improve a new MT2FLC Toolbox with the force framework tool stash-based GUI for a wide range of controllers. For the time being, The MIT2FLS has indicated elite that outflanks the entirety of different controllers regarding speed reaction and overshoot is minim. A GUI planned here has indicated high usefulness and usability (the most straightforward technique by a long shot) for the recreation of the MT2FLC for a BLDC engine. The work is made arrangements for a complete tool compartment that can reproduce any machine controller.

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