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ATP-Based Fuzzy Logic Controller Model for Electromagnetic Transients Studies.

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نموذج لمتحكم المنطق المبهم في برنامج الظواهر الكهرومغناطيسية العابرة

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الملخص

في العقود الأخيرة يتم تطوير برنامج حساب الظواهر الكهرومغناطيسية العابرة ATP وقد ظهر ذلك من خلال النسخة الجرافيكية ATP Draw . ويعتبر المتحكم المبهم Fuzzy احد نظم التحكم المعقدة وغير الخطية التي تحتاج نموذج بسيط لاستخدامه في البرنامج.

ويقدم هذا البحث نموذج لمتحكم المنطق المبهم والذي يمكن استخدامه لدراسة الظواهر الكهرومغناطيسية العابرة في نظم القوى. والنموذج المقترح يجعل تمثيل متحكم المنطق المبهم بسيط دون استخدام أي برنامج مساعد آخر بخلاف ATP. والنموذج المقترح يتكون من ثلاث أجزاء هي: تكوين الدوال ، القواعد الحاكمة ، تحويل الدوال المبهمة. والنموذج المقترح تم اختباره من خلال أمثلة رقمية حيث تم المقارنة بين نتائج الحسابات الرقمية ونتائج النموذج المقترح. ولقد أثبتت المقارنة صحة ودقة نتائج النموذج المقترح.

Abstract

Alternative Transient Program (ATP) has been steadily developed and improved in the last decades. Today, ATP Draw, a graphical framework, is available, which has improved the use of the program significantly. However, fuzzy controller is one of complex models for which a simplified model can be a very useful tool. This paper introduces a model for fuzzy logic controller in ATP for electromagnetic transients' studies of power system. The proposed model introduces a first model of fuzzy logic in ATP. This facilitates power system and fuzzy logic controller simulation in ATP without needing any other programs. The proposed model is implemented in ATPDraw environment. The proposed fuzzy logic controller model consists of three parts; Membership functions (triangular and trapezoidal shapes), Rules and Defuzzification. The proposed model is verified using numerical examples. The membership degree, the rules, and the defuzzification are calculated using both numerical calculation and the proposed model. The proposed model verification shows acceptable results.

Key words
Fuzzy, AI, ATP, EMTP, Control, Electromagnetic Transients

1. Introduction

Alternative Transient Program (ATP) has been steadily developed and improved in the last decades. Today ATP Draw [1], a graphical framework, is available, which has improved the use of the program significantly, above all for the less experienced users. However, many other resources are also available, but just waiting for improvements. Among those resources are the user specified models which allow for a more complex model to be modularized, making available just the essential information to the user [2]. Fuzzy controller is one of these complex models for which a simplified model can be a very useful tool in ATP Draw.

For modeling the power system, control and interactions between them it can be chosen from among more options. First, an ATP [3, 4] code can be used to simulate the power system, and Transient Analysis of Control System (TACS), or to use the programming language MODELS in ATP. The main advantage of this approach is in simple interfacing between the power system and the control model

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because the TACS and MODELS are parts of ATP.

Next, a model of the power system in ATP can be used with a control model is developed in Matlab interconnected with ATP by an interaction for exchanging data. It is a direct connection of the computation engine of Matlab to ATP but suffers from an excessive simulation time and the use of two programs causes a lack of integrity [5].

The third option is a model of the power system created in Matlab/Simpower and the control model is developed in Matlab/Simulink [5]. Interfacing of models is easily attained because both are in Matlab but the simulation is slow when large power system is modeled in Matlab [6, 7].

Intelligent systems based on fuzzy logic are fundamental tools for non-linear complex system. The advantages of fuzzy logic controller over conventional controllers are that they do not require an accurate mathematical model, can work with imprecise inputs, can handle non-linearity and are more robust than conventional PI controllers [8].

In last three decades, fuzzy logic control has received more attention. The advantages of fuzzy logic control application in power system are apparent. Modern power systems are large, complex, geographically widely distributed and highly nonlinear systems. Moreover, power system operation conditions and topologies are time varying and the disturbances are unforeseeable. These uncertainties make it difficult to effectively deal with power system problems through conventional controller that is based on linearized system model.

Therefore, the fuzzy logic control, as one area of artificial intelligence, has been emerging as a complement to the conventional approach. The fuzzy logic controller is an intelligent controller and this is its most added advantage of. Also, the fuzzy logic controller is not sensitive to system topology, parameters and operation condition changes. These features make it very attractive for power systems applications [9-10]. Fuzzy logic controller is used in many applications such as photovoltaic systems and protection systems [11-13].

This paper introduces a model for fuzzy logic controller in ATP for electromagnetic transients' studies of power system. This model facilitates to simulate power system and fuzzy logic controller in ATP without needing any other programs.

This paper is organized as follows. In section 2, the fuzzy logic control strategy is described in details. In section 3, the proposed ATP-based fuzzy logic controller model is simulated using TACS. In section 4, the verification of the proposed model is introduced. The conclusion is given in section 5.

2. Fundamentals of Fuzzy Logic Controller

The operating principle of fuzzy logic controller is similar to a human operator. It performs the same actions as a human operator does by adjusting the input signal looking at only the system output [14]. A fuzzy based logic controller is composed of four components, as shown in Fig. 1 [15].

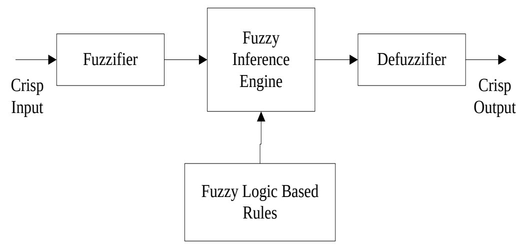


Fig.1.The main parts of the fuzzy logic based controller

Fuzzification is the first step of fuzzy logic, where the input values are mapped into fuzzy values through membership functions. To create a fuzzy control system, membership functions are first developed for the input variables. These membership functions could be defined by triangular, sigmoid, gauss, bell-shaped, etc. functions. In fuzzy logic, it is important for a variable to belong to a membership function with a relative membership degree [10].

Secondly, fuzzified values are processed in the fuzzy inference engine to define the appropriate control action. The formation of rules is in general the canonical rule formation. For any linguistic variable, there are three general forms in which the canonical rules can be formed [14, 16]; (a) assignment statements, (b) conditional statements, and (c) unconditional statements.

At the end of inference, the output of the fuzzy interface engine is determined, but cannot be directly used to provide the operator with precise information or control an actuator. It is needed to move from the "fuzzy world" to the "real world": this is known as defuzzification [17].

On the conventional fuzzy logic control scheme, an input fuzzy set fires k fuzzy rules in the rule base at one time and each fired rule has a clipped or scaled output. The final output corresponding to the firing input is the union of the k fired rules' clipped or scaled outputs. If the consequent fuzzy set membership function's shape of each rule is triangular or trapezoidal, the union of the output fuzzy sets is always a function of irregular shape [17]. The most common of which is calculation of the centre of gravity (COG) of the fuzzy set that can be computed by;

$$du(k) = \frac{\int_{i=1}^{k} \mu_i(du) \quad du_i}{\int_{i=1}^{k} \mu_i(du)} \qquad (1)$$

where k is the number of rules and $\mu_i(du)$ is the output of the rule [17].

3. The Proposed Fuzzy Logic Controller Model

The proposed fuzzy logic controller model consists of three parts; membership functions (triangular and trapezoidal shapes), rules and defuzzification.

3.1-Membership Functions Model

The mathematical equations of each of the triangular or trapezoidal shapes are used for simulating the membership function in ATP. TACS is used for the simulation. Each linguistic variable is expressed as a number to get the type of membership, which the input is belonged to it. For instance, tall as linguistic variable is symbolized by the number 1, very tall by the number 2 and short by the number 3. The purpose here is to get the membership degree and its type.

A-The trapezoidal shape

The trapezoidal type membership function is shown in Fig. 2 [14]. *a*, b, c, and d are the parameters of the function. The mathematical expression of the trapezoidal type membership function is given in equation 2 [10]. Fig. 4a shows the ATP Draw model of the trapezoidal type membership function.

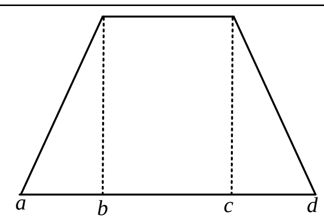


Fig. 2. The trapezoidal type membership function

$$\mu(input) = \begin{cases} \frac{input - a}{b - a}, & a \le input \le b \\ 1, & b \le input \le c \\ \frac{d - input}{d - c}, & c \le input \le d \\ 0, & otherwise \end{cases} \qquad (2)$$

For example, the parameters of the trapezoidal membership; *a*, b, c, and d are assumed to be 2, 5, 8, and 10, respectively. Fig. 4b illustrates the output of the proposed model "membership degree" which has a trapezoidal shape as proposed.

B- The triangle shape

The triangular type membership function is a special case of the trapezoidal type. Fig. 3 illustrates a triangular type membership function. The point *a* is the start point of the triangle, b is top point and c is the end point of the triangle. The mathematical expression of the triangular type membership function is given in equation 3 [10]. The triangular type membership model in ATPDraw is shown in Fig. 5a.

$$\mu(input) = \begin{cases} 0, & input \le a \\ \dfrac{input - a}{b - a}, & a \le input \le b \\ \dfrac{c - input}{c - b}, & b \le input \le c \\ 0, & c \le input \end{cases} \quad (3)$$

For example, the parameters of the triangular membership; *a*, b, and c are assumed to be -2, 1, and 3, respectively. Fig. 5b illustrates the output of the proposed model "membership degree" which has a triangular shape as proposed.

As a special case of triangular membership type that the right or the left slop of the triangular needs to be represented. Equation (3) is divided into to two parts; the first two conditions and the last two conditions. They can be used to simulate the left and the right slops, respectively.

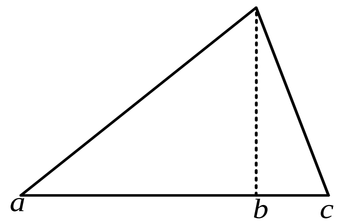
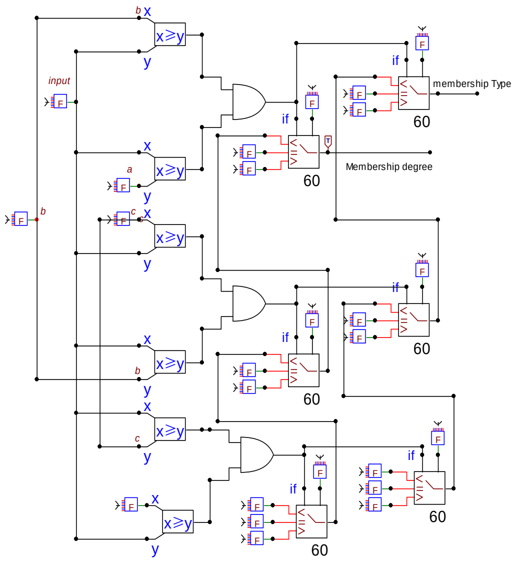
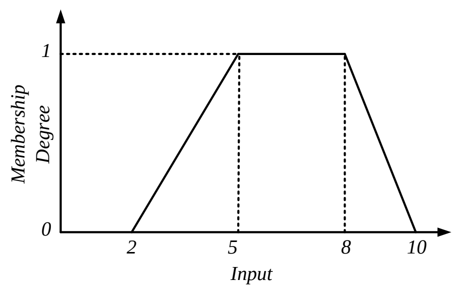


Fig. 3. The triangular type membership function



(a)The ATPDraw model



(b) The output of the model

Fig. 4.The trapezoidal membership model

3.2. Rules model

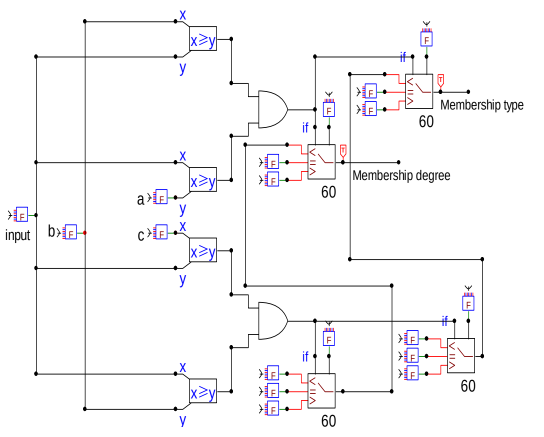
A- Assignment statements

The assignment statements are those in which the variable is assigned with the value. The variable and the assigned value are combined by the assignment operator,"=". The assignment statements are necessary for forming fuzzy rules. The value to be assigned may be a linguistic term [15]. FORTRAN statements is used to simulate this type of rules in ATP by converting the linguistic variable (low, hot, blue, …., etc.) to a number to facilitate the simulation.

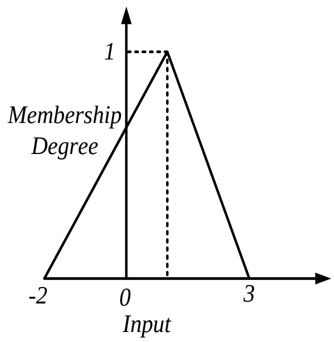
B- Conditional statements in ATP

Using the conditional statements, specific conditions are stated. If the conditions are satisfied then it continues to the following statements "called restrictions". These statements are said as fuzzy conditional statements, such as [16]; "*If condition Then restriction"*

For example of this statements "If Mark ≥ 50 then Pass". TACS is used to simulate it, where pass is assumed to be equal to 2. Fig. 6 shows the conditional statement model in ATP.



(a) The ATPDraw model



(b) The output of the model

Fig. 5. The triangular membership model

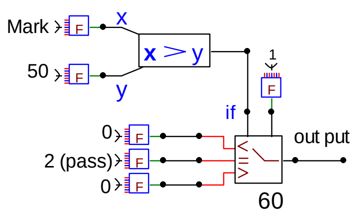


Fig. 6. The conditional statement model in ATP

C- Creating fuzzy rules

Fuzzy rules are a collection of linguistic statements that describe how the fuzzy inference system (FIS) should make a decision regarding classifying an input or controlling an output. Fuzzy rules are written in the following form:

If (input 1 is membership function 1) and/or (input 2 is membership function 2) and/or…… then (output n is output membership function n).

D- Case study for rules model:

"If temperature is high and humidity is high then room is hot"

The above rule's example states that *input 1* is the membership degree of *temperature*, *input 2* is the membership degree of *humidity*, *membership function 1* is *high*, *membership function 2* is *high*, *output membership function is hot* [18]. The illustrated rule example is simulated in ATP. Linguistic high is assumed equal to "1". In this case "AND" is the logic connect between the two conditions. The maximum membership degree of the two inputs is the rule output degree. Fig. 7 illustrates the simulation of rule model of the example in ATP.

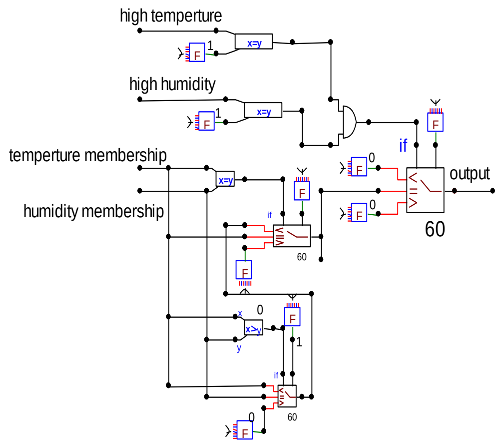


Fig. 7. The simulation of rule model example in ATP

3.3 Defuzzification

The defuzzification of COG formula, which is proposed in [17], is used to solve equation 1 as follows:

$$du(k)_{COG} = \frac{\sum_{i=1}^{k} f_i g_i - \sum_{i=1}^{m} r_i s_i}{\sum_{i=1}^{k} g_i - \sum_{i=1}^{m} s_i} \qquad (4)$$

where f_I and g_I is calculated according to the membership function shape (triangular or trapezoidal) as follows:

For triangular

$$f_1 = \frac{a+b+c}{3} \quad \& \quad g_1 = \frac{\mu_i(c-a)}{2} \qquad (5)$$

For trapezoidal

$$f_l = \frac{d^2 + c^2 + cd - a^2 - b^2 - ab}{3(d + c - a - b)}$$
$$g_l = \frac{\mu_l (d - a + c - b)}{2} \qquad (6)$$

where r_i is the COG of the overlap area of two neighboring shapes, S_i is the area size of i and m_i is the output of the rules where i = 1, . . . , m .

The COG of the triangular shape is calculated as the following procedure. In the case of m_i=1, the formula of triangular shape is used to calculate f and g. In case of m_i< 1, the shape is converted from triangular to trapezoidal, so the formula of trapezoidal shape is used to calculate f and g after calculating the new parameters w_1 and m_1. m_1 is the intersection point of the left slope of the triangular and m in x-axis. w_1 is the intersection point of the right slope of the triangular and m in x-axis.

Fig. 8 illustrates of the flow chart of the calculation of the COG method for triangular shape in ATP. Fig. 9 shows the TACS model of the COG for the triangular shape in ATP.

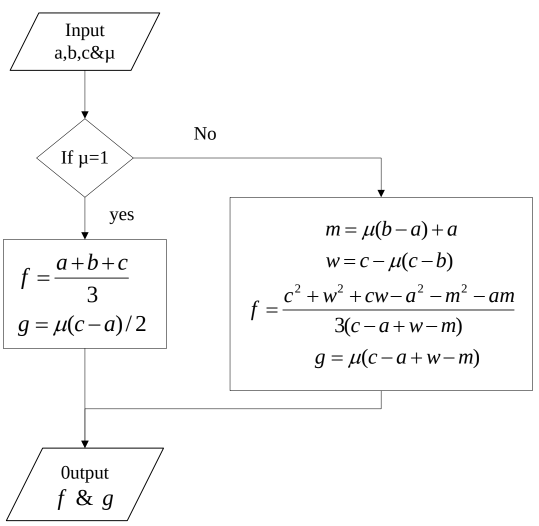


Fig. 8. The flow chart of the calculation of the COG method for triangular shape in ATP

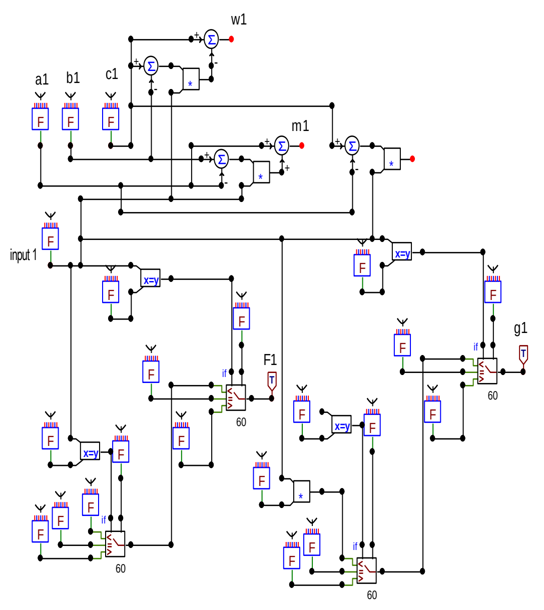


Fig. 9. TACS model of the COG for the triangular shape in ATP

The COG of the trapezoidal shape is calculated in ATP as follows; if m = 1 or m < 1, the formula of trapezoidal shape is used to calculate f and g. Fig.10 illustrates of the flow chart of the calculation of the COG method. Fig. 11 shows the TACS model of the COG for the trapezoidal shape in ATP.

r_i *and* s_i of the overlap area of the two neighboring shapes are calculated as given in the following example.

Graphical illustration of an overlap of two shapes is shown in Fig. 12. a_1, b_1, and c_1 are the parameters of the first shape.a_2, b_2, and c_2 are the parameters of the second shape, m_1 is the input of first shape, m_2 is the input of second shape, and V is the intersection point of the two shapes and α is the corresponding to V in Y-axis.

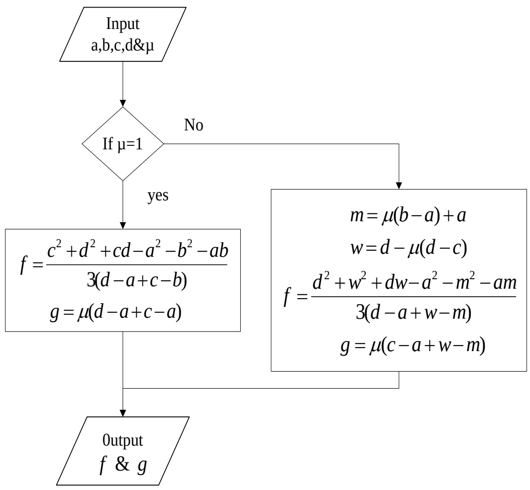


Fig. 10. The flow chart of the calculation of the COG method for trapezoidal shape in ATP

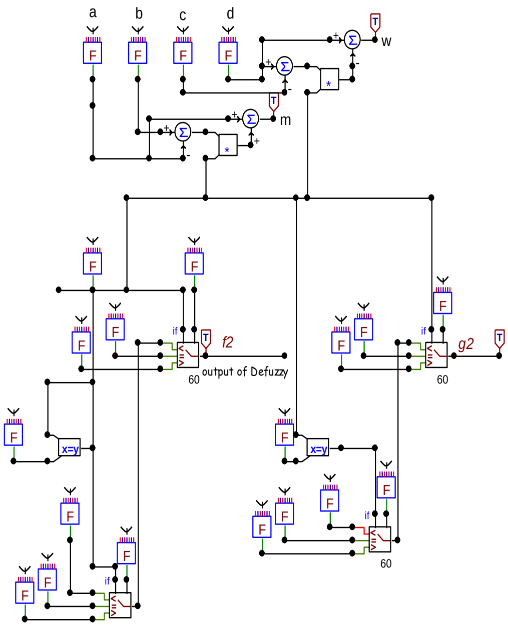


Fig. 11. TACS model of the COG for the trapezoidal shape in ATP

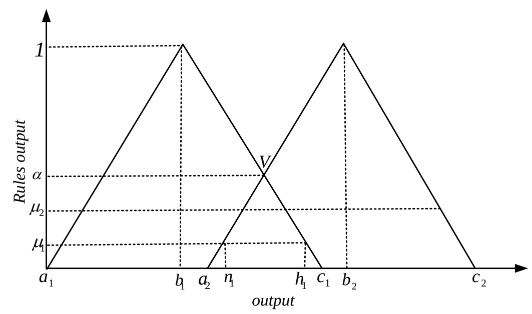


Fig. 12. Graphical illustration of an overlap of two shapes

It is observed that the shape of the overlap of two shapes is triangular when m_1 and m_2 are equal or greater than α. Otherwise, the shape of the overlap is trapezoidal. By using the formulas of f_1 and g_1, the parameters r_i *and* s_i are calculated according to the shape (triangular or trapezoidal). Fig. 13 illustrates the flow chart of the calculation method of the overlap shape in ATP. Fig. 14 shows the TACS model of the overlap in ATP.

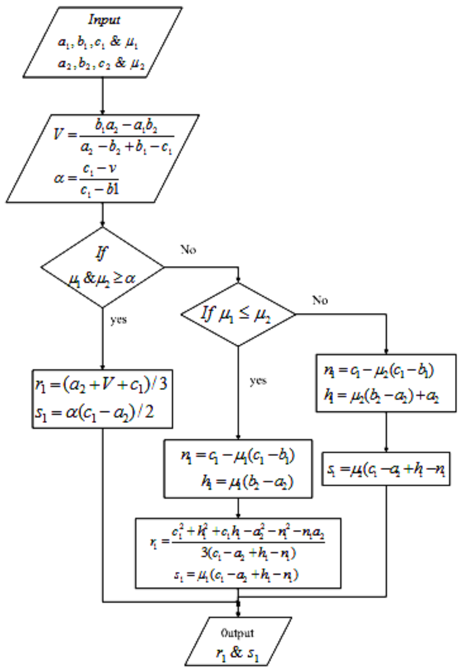


Fig. 13. Flow chart of the overlap calculations

4-Verification of the proposed model

In this section, the proposed ATP model of the fuzzy logic controller is verified using numerical examples. The first one explains the membership degree and the rules. The fuzzy rules in this example are:

R1: IF(x is negative) THEN ($y1 = e^{0.9x}$),

R2: IF(x is zero) THEN (y2 =4.2x),

R3: IF(x is positive) THEN ($y3 = e^{-0.7x}$).

The output Y is calculated in case of x = −3and x =2. From Fig. 15, it can be seen that a= -4, b=0, c=4, k1=0, m1=10, w1=-10 and d1=0.

In case of x=-3
From equation 3, μ(x) =0.25 with zero type and μ(x) =0.3 with negative type. According to the membership degree and its type, R1: y1 = 0.06720, R2: y2 = 12.6 and R3: y3 = 0 because the condition is not valid.

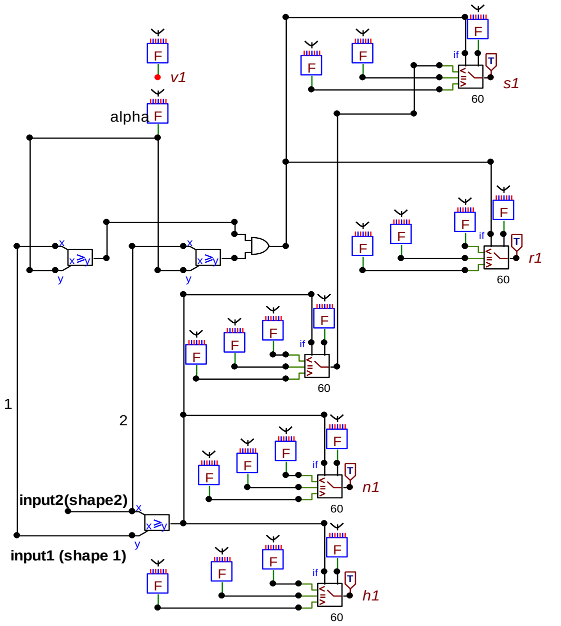


Fig. 14. TACS model of the overlap calculation in ATP

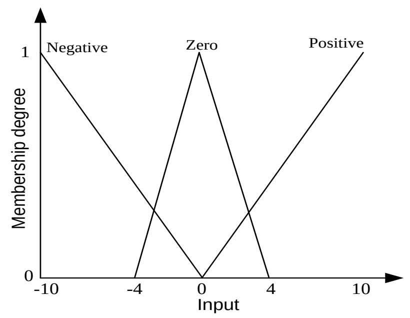


Fig. 15. Graphical illustration of the verification example

In case of x=2

From equation 3, μ(x) =0.5 with zero type and μ(x) =0.25 with positive type. According to the membership degree and its type, R1: y1 = 0 because the condition is not valid, R2: y2 = 8.4 and R3: y3 = 0.2465.

The illustrated example is tested using the proposed fuzzy logic model. Fig. 16 shows the membership functions model for the example. The output of the model for negative, zero, and positive memberships for x=-3 is 0.3, 0.25, and 0, respectively. The output of the model for negative, zero, and positive memberships for x=2 is 0, 0.5, and 0.2, respectively. Fig. 17 shows the three rules model in ATP. It is found that the numerical results satisfy the proposed model outputs.

The second example illustrates the COG method. The defuzzified value is calculated for the shape which is shown in Fig. 18 when m_1 = 0.3 and m_2 = 0.6.
As shown in Fig. 13 v and α are calculated; v = 8 and α=o.5. Because m_1 and m_2 aren't ≥ α, so the overlap of two shapes is trapezoidal. According to (9) and (10); r_1=8 and s_1=0.42.

According to (9) and (10); f_1=6.14117, g_1=1.53, f_2=10.8615 and g_2=3.9. Finally from (6), the output=9.6599. By using a triangular model for first shape, trapezoidal model for the second shape and the model of the overlap shape, the example is modeled in ATP. The parameters of each shape, m_1 = 0.3 andm_2 = 0.6 are entered. The results of ATP are the same of the mathematically solution.

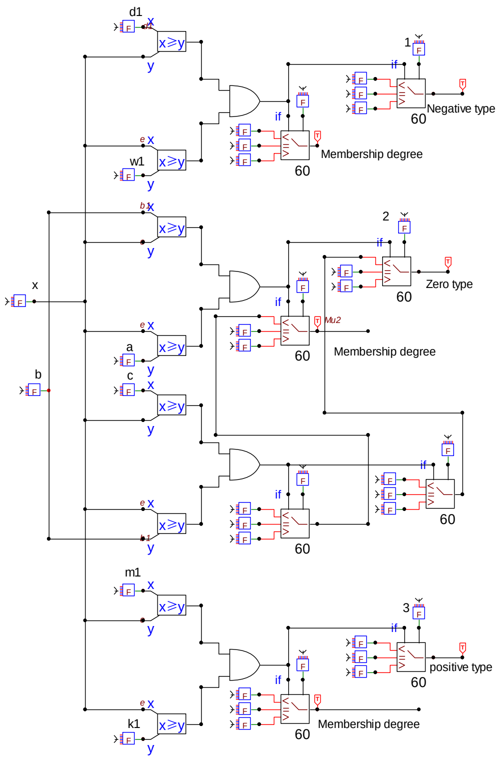


Fig. 16. Membership functions model of the verification example

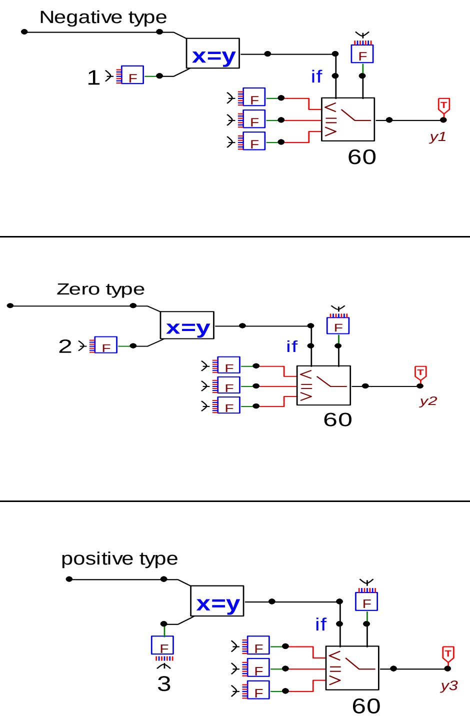


Fig. 17. The three rules model of the verification example

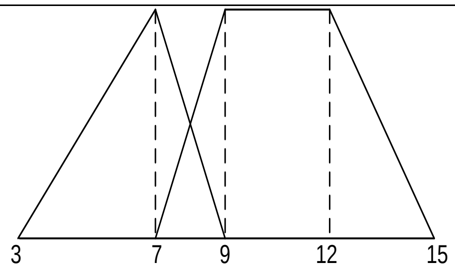


Fig. 18. The COG illustrative example

5. Conclusions

In this paper, an ATP-based fuzzy logic controller model is presented. The proposed model is the first one for fuzzy logic in ATP. Thus, it has the capability for studying the electromagnetic transients in power systems. The proposed model consists of three parts; membership functions, inference & rules and defuzzification “centre of gravity Method”. The model is built in ATP, where TACS is used to simulate all the model parts. So, the model can be used as a benchmark model for electromagnetic transients' studies of power system using the ATP. The introduced model is verified using numerical examples. The membership degree, the rules, and the defuzzification are calculated using both numerical calculation and the proposed model. The introduced model verification shows acceptable and promising results. The use of the proposed model in power system applications will be implemented in the future work.

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