The Over-Loading Protecting Research Based-on the Fuzzy Control in Aero Power Supply System

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***Abstract*—when the aero-generator works in the over-loading state, the over-loading protecting module in the power supply system will cut off some loads to protect the aero-generator. In order to improve the working stability of the power supply system, decrease the disadvantage effect caused by the electrical power fluctuating to the electro-equipments, and prolong the aero-generator's working life, an anti-delay switch on/off control technique will be adopted to perform the over-loading protecting, and how to compute an appropriate delay time is a key factor in this technique. This paper will use the fuzzy control theory and method to compute the best delay time, in order to get a more intelligent and advanced over-loading protecting module in the power supply system.**

***Keywords*—Power Supply System, Over-Loading Protect, Anti-Delay, Fuzzy Control**

I. INTRODUCTION

The aero-generator is the core of the power supply system; it will supply the electrical power to all the electrical consumption equipments in the aircraft. The working reliability of the aero-generator is a key factor to insure the aircraft fly security; so it is very important to protect the aero-generator. There are two ways to protect the aero-generator, first, when the engineers design the aero-generator, they will make the aero-generator has the ability to endure a certain over-loading; the second, an over loading protection module will be adopt into the power supply system, when the load is over, the over loading protection module will cut off some loads automatically to protect the aero-generator. But, the up two ways will face some shortages, for example, when the aero-generator works in full loading state, if some interferes happen or some loads change over, the aero-generator will work in the over loading state in a very short time continually, and the over loading protection module will switch on/cut off the circuit continually too, the result is that the power supply system will work in an unstable state, the voltage will fluctuate largely, and the quality of the electrical power will become bad.

A new method that called anti-delay switch on/off control technique [1], [2] is introduced into the over loading protection module to protect the aero-generator. Because the aero-generator can endure a certain over-loading, when the load is over, the over loading protection module will cut off the circuit to protect the power supply system after some delay time, the delay time becomes a key factor to make sure the over loading protection module can work effectively or not, how to calculate the best delay time becomes the core question. This paper will introduce the fuzzy control theory and method to compute the best delay time to get a more intelligent and advanced over-loading protecting module in the power supply system.

II. THE FACTORS AFFECT THE DELAY TIME OF THE AERO-GENERATOR

By analyzing the design parameter of the aero-generator and the control relation of the power supply system, as the load is over, the factors affecting the delay time of the over loading protection module's action are: (1) the over loading carrying capacity characteristic of the aero-generator; (2) the current working state of the aero-generator.

A. The Over Loading Carrying Capacity characteristic of the Generator

As the engineers design the aero-generator, the over loading carrying capacity of the aero-generator becomes a very important parameter that they must consider, the specific data must be given. For example, the over loading carrying capacity parameter of one aero-generator used in one type of aero plane like this: when the working temperature of the aero-generator is $95\,^{\circ}C$ (the upper limit is not more than $130\,^{\circ}C$), the over loading carrying capacity characteristic data shows as table □.

TABLE I. THE OVER LOADING CARRYING CAPACITY CHARACTERISTIC DATA

Load Current (A)	Working Time (s)
600	1200
750	60
900	10
1200	2

From the up data table, the over loading carrying capacity characteristic function of the aero-generator can be get by the Lagrange's formula [3], which be denoted as follow formula:

$$y=\begin{cases}-7.6\cdot x+5760 & ,600\le x\le 750\\ -0.3333\cdot x+310 & ,750\le x\le 900\\ -0.027\cdot x+34, & 900\le x\le 1200\end{cases} \quad (1)$$

In this Lagrange's formula, x-means the load current, y-means the maximum working time that the aero-generator can work safely.

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An over loading carrying capacity characteristic cure can be drawn out too, as showing Figure.1.

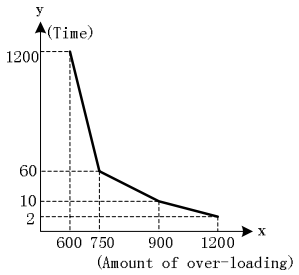


Figure 1. The over loading carrying capacity characteristic cure

By the over loading carrying capacity characteristic function and cure, the longest time that the aero-generator can work in the over loading state safely will be calculated, this time is also the delay time that the over loading protection module to switch on/cut off the output circuit of the aero-generator.

B. The Current Working Sate of the Aero-Generator

In fact, besides the factor of the over loading carrying capacity characteristic of the aero-generator, the current working state of the aero-generator is also an important factor to affect the delay time, such as the aero-generator's working temperature, the amount of the over loading, the output voltage of the aero-generator, the rotate speeds of the rotor, and etc. The delay time is calculated only by the factor of the over loading carrying capacity characteristic function/cure, it is not very exact, for example, when the working temperature of the aero-generator is high, and the amount of the over loading is medium, the calculated delay time is very long, it is not reasonable, and also does not meet the aero-generator's actual working need. So, to calculate the delay time, another important factor, the current working sate of the aero-generator, must be considered.

Because the relation between the current working sate of the aero-generator (for example, the temperature of the aero-generator is high or low) and the delay time cannot be expressed by the exact formula, a fuzzy control theory will be introduced into the over loading protection module to get the best delay time.

III. THE DELAY TIME CALCULATING BASED ON THE FUZZY CONTROL THEORY

A. Obtain the Input/Output Varibles in the Fuzzy Controller

Among the factors that affect the delay time in the power supply system, the over loading carrying capacity characteristic is the main, and the current working state of the aero-generator is the accessorial. To calculate the delay time, first, use the over loading carrying capacity characteristic function/cure to compute the primary delay time t_1, then consider the current working state of the aero-generator to amend the primary delay time t_1, the amending coefficient is the variable y (also called "the degree of acceptance", its range is from 0 to 1), then the actual delay time can be calculated as: $t = t_1 \cdot y$.

This paper will use the fuzzy control theory to calculate the amending coefficient y, so the output variable of the fuzzy controller is y, the working temperature of the generator x_1 and the amount of the over loading x_2 are the input variables of the fuzzy controller. The fuzzy controller is shown as figure 2.

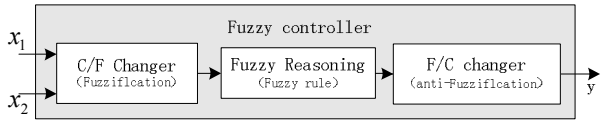


Figure 2. The fuzzy controller

B. The Input/Output Varibles Fuzziflcation

By analyzing the technical criterion and the actual working state of the aero-generator, the range of the working temperature of the aero-generator is [$95°C$,$130°C$], and the range of the amount of the over loading is [0A, 600A].

Fizzling up the input/output variables into four degree, the fuzzy language like down:

- The fuzzy set of the working temperature of the aero-generator x_1: {normal, little high, medium high, very high} = { zc, sg, jg, hg }.
- The fuzzy set of the amount of the over loading x_2: {little (over loading), medium (over loading), high (over loading), serious (over loading)} = { sd, jd, hd, yd }.
- The fuzzy set of the "degree acceptance" y: {less (accept), medium (accept), more (accept), full (accept)} = { sj, jj, hj, wj }.

The triangle linearity distributing function [4] is used to calculate the membership function of the input/output variables in this fuzzy controller; this function can be realized, calculated and regulated easily. Its curve is shown as Figure 3.

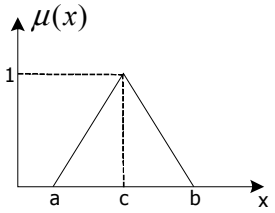
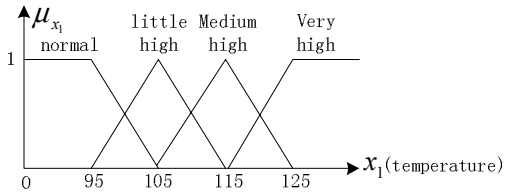


Figure 3. The triangle membership function

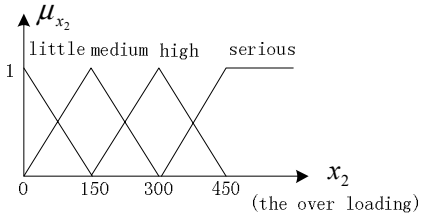
And the mathematics formula is:

$$\mu(x) = \begin{cases} (x-a)/(b-a), a < x < b \\ (x-c)/(b-c), b < x < c \end{cases} \quad (2)$$

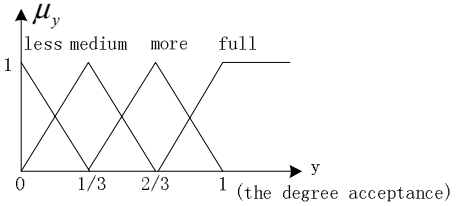
Then, the membership function cures of the input/output variables x_1, x_2, y are shown Figure 4.



a) the membership function of the working temperature x_1



b) the membership function of the amount over loading x_2



c) the membership function of the "degree acceptance" y

Figure 4. the membership function figure

C. *The Fuzzy Control Rule Selection, Reasoning and the Output varible Anti-Fuzziflcation*

The fuzzy control rule is the core content of the fuzzy control arithmetic; there are two ways to select the fuzzy control rule [5]: (1) the experience induction of the experts, (2) the synthetically reasoning.

TABLE II. THE FUZZY CONTROL RULE

the degree of acceptance y		**the working temperature of the generator x_1**			
		normal	***little high***	***medium high***	***very high***
the quantity of over loading x_2	***little***	full	full	more	medium
	medium	full	good	medium	less
	high	full	good	medium	less
	Serious	more	more	medium	less

Because the factors affected the delay time can not be established by the synthetically reasoning method. The experience induction of the experts is used in this paper, after enquiring the designers, experts, maintenance engineers and supporters to get correlative knowledge, in the same time using the power supply system drag equipment to test the aero-generator's performance, the fuzzy control rule can be get as shown in the table Ⅱ.

Any one fuzzy control rule in the table Ⅱ can be described as: "IF…AND…THEN… ", the relation between any two fuzzy control rules is "OR".

The fuzzy reasoning is obtained by the maximum-minimum operation theorem (sum-product operation theorem, introduced by Mamdani [5]), the anti-fuzziflcation of the output y adopts the average center of gravity method [6], and this method is similarly to the barycenter of the polygon. The membership function of x_1, x_2, y is $\mu_{x1}, \mu_{x2}, \mu_{x3}$. Then the exact output result formula as shown down:

$$y = \frac{\sum_i \mu_{x_1}^i \times \mu_{x_2}^i \times \mu_y^i}{\sum_i \mu_{x_1}^i \times \mu_{x_2}^i} \tag{3}$$

D. *The Calculated Result of the Relay Time*

The delay time based on the fuzzy control theory is calculated by the computer, the software is Visual Basic6.0++, and it's result is shown in the table Ⅲ.

IV. CONCLUSION

From the delay time result in the table Ⅲ, the conclusion can be get: (1) the average working temperature of the aero-generator is more high, the over loading carrying capacity of the aero-generator become more bad, the delay time become shorter; (2) the amount of the over loading is more large, the delay time become shorter. In the same time, the delay time calculated by the fuzzy control theory is more according with the actual working requirement than the result that calculated without the fuzzy control theory. For example, at one time, the working temperature of the aero-generator is 95°C, the amount of the over loading is 230A, the delay time is 33s (see the appendix table), after it has worked 25s (the working temperature is up to 115°C), some loads (about 60A) begin to stop working normally, the amount of the over loading will be decreased down to 170A, at this time, the over loading protect module will detect the new data, if the working temperature is considered (based-on the fuzzy control), the delay time is 18s, on other hand, if the working temperature is not considered, the delay time will change to be 53s, the delay time difference is 35s. By the actual working validating, the method based on the fuzzy control is introduced into the over-loading protect module, the delay time calculated is more satisfied with the actual working need of the power supply system.

REFERENCES

[1] David lazarovich, Rodney Michalko and Edwin Yue, Design and Integration of the Power Management and Generation System for the Dash/400 airplane, Allied signal Inc. Society of Automotive Engineer, Inc. SAE 1998 Transactions Journal of Aerospace Section (981273), Vol. 1,1998, pp1-107.

[2] S. D. Sudhoff, K. A. Corzine, S. F. Glover. DC Link Stabilized Field Oriented Control of Electric Propulsion System, IEEE Transaction on Energy Conversion, Vol. 13, March 1998, pp27-33.

[3] Yan qing-jing. Numerical analysis. Beijing: BUAA PRESS, February 2001, P144-199.

[4] Xun zeng-xi, Zhang zai-xing, Deng zhi-dong. Intelligent Comtrol Theroy and Technology. Beijing: TSINGHUA UNIVERSITY PRESS. September 2002, P55-70.

[5] Zhu jing. The Fuzzy Control Theory and Application. Beijing: CHINA MACIHNE PRESS, July 1995, P204-312.

[6] Zhang hua-guang, He xi-qing, The Fuzzy Adoption Control Theory and Application. Beijing: BUAA PRESS. July 2007, P38-48.

TABLE III. THE OUT PUT DELAY TIME BASED ON THE FUZZY THEORY IN THE OVER-LOADING PROTECTING MODULE

The output delay time based on the fuzzy theory in the over-loading protecting module

Delay time

The amount of the over loading \ The working temperature of the aero-generator	90.0	92.5	95.0	97.5	100.0	102.5	105.0	107.5	110.0	112.5	115.0	117.5	120.0	122.5	125.0
10	1124.0	1124.0	1124.0	1102.0	1102.0	1102.0	1100.6	975.2	892.6	809.9	725.9	600.6	517.9	435.3	351.3
30	972.0	972.0	972.0	925.7	925.7	925.7	918.0	775.3	717.4	659.6	594.0	451.3	393.4	335.6	270.0
50	820.0	820.0	820.0	776.8	765.3	762.5	751.7	633.0	574.0	532.3	478.3	359.6	300.7	258.9	205.0
70	668.0	668.0	668.0	635.6	614.3	607.5	597.2	510.2	449.2	417.2	374.5	287.5	226.5	194.6	151.8
90	516.0	516.0	516.0	492.8	473.0	460.2	451.5	390.5	344.0	311.5	279.5	218.5	172.0	139.5	107.5
110	364.0	364.0	364.0	348.7	333.7	319.1	312.7	273.3	242.7	213.1	191.3	151.9	121.3	91.8	70.0
130	212.0	212.0	212.0	203.2	194.3	185.5	179.2	159.0	141.3	123.7	108.5	88.3	70.7	53.0	37.9
150	60.0	60.0	60.0	57.5	55.0	52.5	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0
170	53.3	53.3	53.3	48.0	44.4	40.9	35.6	30.2	26.7	23.2	17.8	12.4	8.9	5.4	5.4
190	46.7	46.7	46.7	41.5	38.9	36.3	31.1	25.9	23.3	20.7	15.6	10.4	7.8	5.2	5.2
210	40.0	40.0	40.0	35.6	33.3	31.1	26.7	22.2	20.0	17.8	13.3	8.9	6.7	4.4	4.4
230	33.3	33.3	33.3	29.6	27.8	25.9	22.2	18.5	16.7	14.8	11.1	7.4	5.6	3.7	3.7
250	26.7	26.7	26.7	23.7	22.2	20.7	17.8	14.8	13.3	11.9	8.9	5.9	4.4	3.0	3.0
270	20.0	20.0	20.0	17.9	16.7	15.5	13.3	11.2	11.2	8.8	6.7	4.5	3.3	2.1	2.1
290	13.3	13.3	13.3	12.1	11.1	10.1	8.9	7.6	6.7	5.7	4.4	3.2	2.2	1.2	1.2
310	9.5	9.5	9.5	8.4	7.7	7.0	6.3	5.4	4.7	4.0	3.2	2.3	1.6	0.9	0.9
330	8.6	8.6	8.6	7.3	6.8	6.2	5.5	4.7	4.2	3.6	3.1	2.1	1.5	1.0	1.0
350	7.7	7.7	7.7	6.6	6.1	5.6	4.8	4.2	3.8	3.4	2.9	1.9	1.4	1.0	1.0
370	6.9	6.9	6.9	5.9	5.5	5.0	4.2	3.7	3.4	3.2	2.7	1.8	1.4	0.9	0.9
390	6.1	6.1	6.1	5.3	4.9	4.5	3.5	3.2	3.1	3.0	2.5	1.7	1.3	0.8	0.8
410	5.3	5.3	5.3	4.7	4.4	4.0	3.0	2.8	2.8	2.7	2.4	1.6	1.2	0.8	0.8
430	4.6	4.6	4.6	4.2	3.7	3.3	2.5	2.4	2.4	2.4	2.2	1.5	1.1	0.7	0.7
450	4.0	4.0	4.0	3.5	3.0	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.0	0.5	0.5
470	3.6	3.6	3.6	3.2	2.7	2.3	1.8	1.8	1.8	1.8	1.8	1.4	0.9	0.5	0.5
490	3.3	3.3	3.3	2.9	2.5	2.1	1.6	1.6	1.6	1.6	1.6	1.2	0.8	0.4	0.4
510	2.9	2.9	2.9	2.6	2.2	1.8	1.5	1.5	1.5	1.5	1.5	1.1	0.7	0.4	0.4
530	2.6	2.6	2.6	2.3	1.9	1.6	1.3	1.3	1.3	1.3	1.3	1.0	0.6	0.3	0.3
550	2.2	2.2	2.2	1.9	1.7	1.4	1.1	1.1	1.1	1.1	1.1	0.8	0.6	0.3	0.3
570	1.9	1.9	1.9	1.6	1.4	1.2	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.2	0.2
590	1.5	1.5	1.5	1.3	1.1	0.9	0.8	0.8	0.8	0.8	0.8	0.6	0.4	0.2	0.2
610	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Return