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A Fuzzy Logic Controller for the Swell and Shrink Problems of Nuclear Steam Generators

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Abstract: A Fuzzy Logic Controller for handling the swell/shrink problems of nuclear steam generators is designed, implemented and tested on the compact nuclear simulator at Korea Atomic Energy Research Institute. Its performance is found to be better than of the PI controller originally being used. In terms of the total variations for the control actions and for the flow error curve, the ones by the fuzzy controller are found to be less than one third of those by the PI controller.

1. Introduction

During the low power operations of a nuclear power plant, the steam generators experience swell and shrink problems when the steam dump valve opens or closes, i.e. the amount of steam flow through the dump valve changes rapidly. The sudden changes in the amount of the feedwater flow into the steam generators also cause some shrink effect to the water level.

The difficulty in the level control for the case of low power operations (less than 20% of the rated power) originates from the lack of the accuracy of the measured value for the steam flow out and water flow in. Their measurement error are so big that they are not usable as input to the level controllers. Thus, we are left with only one input variable, i.e. the level error to the controller.

The swell and shrink effects complicate the situation further and the control goal of maintaining the level within the predefined limits becomes very difficult to be achieved. In [1], a controller is proposed to compensate the water level measurement for the shrink and swell effects so that the unnessary control action could be eliminated.

In [2], we find a control strategy to physically suppress the sewll and shrink phenomena, i.e., to quickly open the feedwater valve as fast unloading is initiated and to quickly reduce water inventory during fast reloading. In[3], we find an actually implemented and industrially applied control scheme where they use an estimated steam flow by the turbine's first stage pressure.

In this paper, we present a fuzzy logic controller developed for the Compact Nuclear Simulator at Korea Atomic Energy Research Institute using the level error as the major input and the flow error as an indicative of how the steam flow changes.

2. Fuzzy Logic Controller

A schematic diagram of the fuzzy logic controller developed is shown in fig. 1. The inputs are the level error(LE) and the flow error(FE).

while the output being the increment of the valve position. The sign of the flow error and whether the magnitude of the flow error is big or small on the average, are used in manual operations even though the magnitude itself may not be the usable due to measurement error. Thus, in our design, the averaged flow error during a certain period of time is used by fuzzifying it into three fuzzy sets (fig.3).

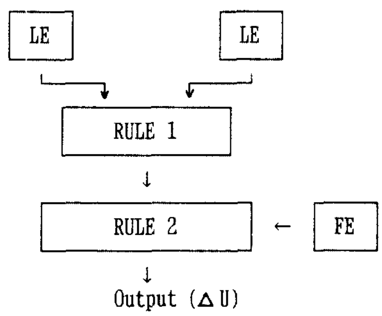

Fig.1. A Schematic Diagram for the Fuzzy Logic Controller

Note that we are using the velocity algorithm rather than the position algorithm. The input scanning period is 0.5 second (5 times the real time mode) and the average over a period of 5 seconds is used for the flow error.

The fuzzy sets for the level error and the flow error are all equally spaced spike functions, the former consisting of eleven sets as shown in fig.3 and the latter with three sets. for the change in the level error, however, we have used cubic spline functions for the thirteen fuzzy sets.

The fuzzy set intersections we have used are the product operation(Dubois & Prade with $\alpha = 1$) and the fuzzy logic implications are the Larsen's product operation rule. Other methods have been tried, but these are found to be slightly better suited to our experiements than the others.

The fuzzy rules used for the combination of the input variables, derived variables, or to generate the controller output are as shown in table 1 and 2. Note that all of the blocks are filled in the table and that we had to use eleven fuzzy sets for each variable to take a proper care of the shrink problems.

We have tuned this fuzzy controller so that the total variations of the level error and of the

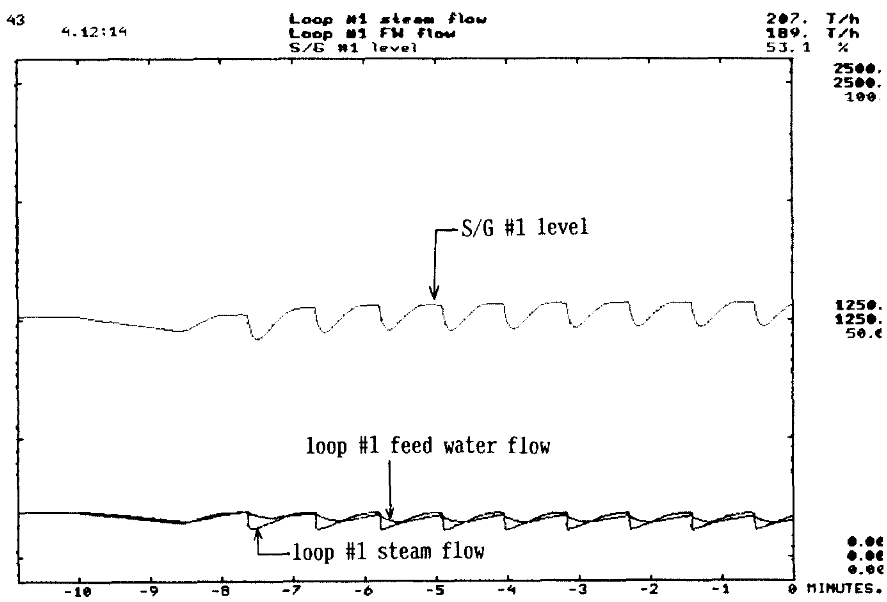

Fig.2. A Simulation Result for 100MWe to 50MWe Power Decrease

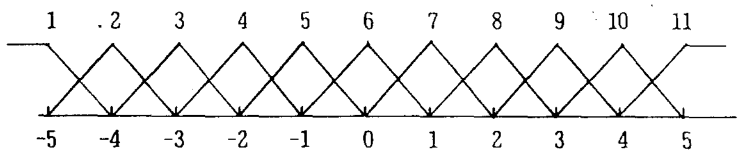

Fig.3. Fuzzy Sets for the Level Error

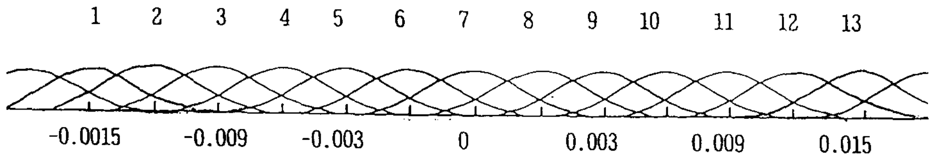

Fig.4. Fuzzy Sets for ΔLE(Cubic Spline)

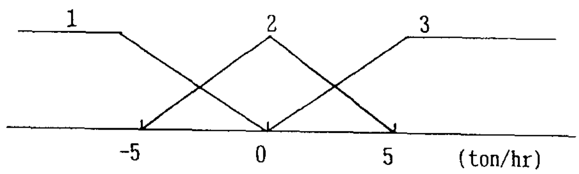

Fig.5. Fuzzy Sets for Flow Error

		ΔLE												
		1	2	3	4	5	6	7	8	9	10	11	12	13
LE	1	1	1	1	1	1	1	1	2	3	4	5	6	7
	2	1	1	1	1	1	1	2	3	4	5	6	7	8
	3	1	1	1	1	1	2	3	4	5	6	7	8	9
	4	1	1	1	1	2	3	4	5	6	7	8	9	10
	5	1	1	1	2	3	4	5	6	7	8	9	10	11
	6	1	1	2	3	4	5	6	7	8	9	10	11	11
	7	1	2	3	4	5	6	7	8	9	10	11	11	11
	8	2	3	4	5	6	7	8	9	10	11	11	11	11
	9	3	4	5	6	7	8	9	10	11	11	11	11	11
	10	4	5	6	7	8	9	10	11	11	11	11	11	11
	11	5	6	7	8	9	10	11	11	11	11	11	11	11

Table 1. Fuzzy Combination Rules (RULE 1)

		FE		
		1	2	3
LE + ΔLE	1	11	11	9
	2	11	10	8
	3	11	9	7
	4	10	8	6
	5	9	7	5
	6	8	6	4
	7	7	5	3
	8	6	4	2
	9	5	3	1
	10	4	2	1
	11	3	1	1

Table 2. Fuzzy Control Rules (RULE 2)

resulting flow error are minimized. where the total variation of a function is defined to be the integral of the absolute derivative of the function.

The computed controller output is averaged over a period of 2 seconds i.e. 4 sampling periods to eliminate the unnecessary bumps brought in to the derivative of the level error(LE).

3. Simulation Results

We have used two sets of simulation experiments to test the fuzzy logic contoller developed through this work. One is the simulation for reducing the generator power from 100MWe to 50MWe while the nuclear power is held at 16.8%, so that the steam dump valve opens and closes periodically.

The other is the simulation for increasing the generator power from zero to 100MWe while the nuclear power is held at 12% the swell and shrink effects occur in this case also.

Generator Power Change	Set Point	Controller	Control Action	Level Error	Flow Error
100MWe	Constant	Fuzzy PI	0.577 1.928	1.006 0.956	355 1881
to 50MWe	Variable	Fuzzy PI	0.572 2.024	0.987 1.022	368 1915
0MWe	Constant	Fuzzy PI	0.631 2,936	1.480 1.467	574 2927
to 100MWe	Variable	Fuzzy PI	0.617 2,923	1.441 1.464	593 2904

Table 3. Comparison of Total Variation of Curves

For each of the two simulations, we have run a pair of experiments; one with a constant set point at 50% and the other with the variable set point that varies linearly from 40% to 50% as the generator power increases from 0% to 20%.

In table 3, we see the simulation results where 'PI' represents the original PI controller being used, while 'Fuzzy' is for the fuzzy logic controller developed. Note that in all four cases, the total variations of the level error and the flow error are less than one third of the PI controller's.

references

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