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퍼지로직 알고리즘을 이용한 최대수요전력 제어기의 개발

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DEVELOPMENT OF A MAXIMUM DEMAND CONTROLLER USING FUZZY LOGIC

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Abstracts: *The predictive maximum demand controllers often bring about large number of control actions during the every integrating period and/or undesirable load-disconnecting operations during the begining stage of the integrating period. To solve these problems, a fuzzy predictive maximum demand control algorithm is proposed, which determines the sensitivity of control action by urgency of the load interrupting action along with the predicted demand reaching to the target or the time arriving at the end stage of the integrating period. A prototype controller employing the proposed algorithm also is developed and its performances are tested by PROCOM SYSTEMS Corperation of Korea.*

Keywords: *Maximum demand,Maximum demand prediction Predictive maximum demand control,Fuzzy set classification, Fuzzy logic control, Fuzzy predictive maximum demand control*

I. INTRODUCTION

The maximum demand controller(MDC) is an electrical equipment installed at the consumer side of power system, which monitors the electrical energy consumed during every integrating period and prevents the preselected target maximum demand(MD) being exceeded by disconnecting sheddable loads. It also gives the command to reconnect the loads as soon as possible. By avoiding the peak loads or MD and spreading the energy requirement the controller contributes to maximizing the utility factor of the generator systems. It results in not only saving the energy but also reducing the budget for constructing the national base facilities by keeping the number of generator plants with minimum.

The MD control on the consumer side is to maintain the MD under the preset target or to optimize the load factor, where the most favorable factors would be obtained by drawing a constant amount of energy. With such an aim the demand control equipments developed in recent years employ the predictive control algorithms which forecast the MD and control the loads in advance of the target MD beeing exceeded.

Those predictive controllers often bring about large number of control actions during the every integrating period and/or undesirable load-disconnecting operations during the begining stage of the integrating period.These become to a factor of avoiding the equipments by the consumer.To solve these problems the existing controller taken with, the controller may have performances as followings; The number of control actions must be as minimized as possible, and the control actions must be repressed for the begining stage of the integrating period. These performances can be realized by introducing a fuzzy algorithm into the decision rule. As a results, the controller employing the fuzzy predictive algorithm to be proposed in this paper is to be capable of optimizing the load-disconnecting number as well as controlling the MD, and thus they may be extensively employed by the consumer.

In this paper a fuzzy predictive MD control algorithm is proposed, which determines the sensitivity of control action by urgency of the load interrupting action along with the predicted demand reaching to the target or the time arriving at the end stage of the integrating period. A prototype controller employing the proposed algorithm also is developed and its performances are tested by PROCOM SYSTEMS Corperation of Korea.

II. FUZZY PREDICTIVE CONTROL ALGORITHM

A MD control system employing the fuzzy predictive algorithm is considered to solving the problems of the existing controller and satisfying the performance specifications as mentioned above. The fuzzy predictive MD control algorithm is developed by introducing a fuzzy algorithm into the decision rule, which determines the sensitivity of control action by urgency of the load interrupting action along with the predicted demand reaching to the target or as the time closed to the end of the integrating period. The performances of the proposed control system can be realized by minimizing the number of control actions as possible, by repressing the undesirable control actions during the begining stage of the integrating period as well as controlling the MD, and by suppressing the demand oscillations experienced by the controlled process, as regards to the simple predictor algorithms.

The proposed fuzzy predictive MD control system consists of a predictor and a fuzzy predictive MDC(fuzzy inferance engine plus a predictive load controller).

Predictor

Each time a controller based on a prediction algorithm samples the consumption of the controlled plant and computes an estimate of the mean power that would correspond to the present integrating period if the rate of the consumption did not vary. The pridicted demand, $\hat{P}(l,k)$, at kth sample of the lth integrating period defined as

$$\hat{P}(l,k) = p(k) + [\ p(k) - p(k-1)]\ (N-k) \tag{1}$$

where $p(k)$ represents the present demand, integrated over kth sample from begining of the lth integrating period, and N the number of sample points of the integrating period.

Fuzzy Inferance Engine

The proposed fuzzy system consists of a fuzzy rule base, a fuzzifier, a fuzzy inferance engine and a defuzzifier as shown in Fig.1. Two input signals, timing signal t and predicted demand $\hat{P}(t)$, are applied to the fuzzy system. The timing signal input is received from the internal clock or the external device for assessing the integrating period. The predicted demand signal input is came from the predictor for assessing the peak demand or MD. The output signal of the fuzzy system is a sensitivity $K(t)$ which is used to weighting the predicting demand for determining the load contol action and, thus the control activity is more sensitive as the time preceeding to the end of the integrating time.

Fuzzifier: Fuzzifier maps a crisp number into a fuzzy number. It is needed in order to activate rules which are in terms of linguistic variables, which have fuzzy sets associated with them.

The fuzzy set classifications are based on both the severity of the integrating time and the predicting demand. Three fuzzy partitions for the integrating time and three partitions for the predicting demand are considered, and linguistic variable is associated with each set as follows.

For integrating time :

TS(begining stage), *TM*(medium stage), *TB*(ending stage)

For predicting demand :

PS(small), *PM*(medium), *PB*(big)

The mebership functions for these fuzzy sets are of the triangular or the rectangular.

It should be noted that the scaling of the fuzzy sets is accomplished through the information from the frequency of load control actions and the load interrupting action during the first stage of the integrating time. A heuristic try and error procedure is needed to find an appropriate fuzzy partitioning for a desired response.

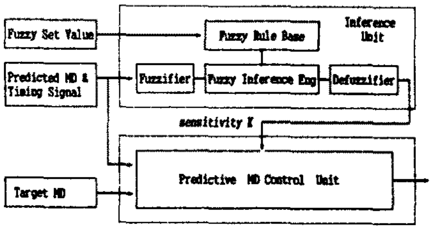

Fig. 1 Fuzzy inference unit for Predictive MD control

Rule base : *A fuzzy rule base consists of a collection of IF-THEN rules.* The commonly used way to extract rules from numerical data is to prespecify the fuzzy sets for the antecedents and consequents and then associate the data with these fuzzy sets.

The control rules are constructed based on the observations of the dynamical behaviour of the system, that is, how many the load control actions arise, and the unnecessary load interrupting action arise during the begining stage of the integrating time. The rule base consists of 9 rules as shown in Table 1.

Table 1. Rule base

Integrating time t / Predicting power $\hat{P}$	TS	TM	TB
PS	KS_S	KM_S	KB_S
PM	KS_M	KM_M	KB_M
PB	KS_B	KM_B	KB_B

The membership functions $KS_S, KM_S, KB_S, \cdots$ are of singleton.

Inference engine : Inference engine maps fuzzy sets into fuzzy sets by means of $\mu_{A\rightarrow B}(x, y)$. The Inference engine is used to combine fuzzy IH-THEN rules from the fuzzy rule base into a mapping fuzzy input sets to fuzzy output sets for determining membership grades. The rule R_1 is expressed as

$$R_1\text{: If } \hat{P} \text{ is } PS \text{ and } t \text{ is } TS, \text{ then } K \text{ is } KS_S \tag{2}$$

and the membership grade of R_1 *for the two inputs* $\hat{P}$ *and* t *is given by*

$$\mu(R_1) = \min[\, \mu_{PS}(\hat{P}\,), \mu_{TS}(t)\,] \tag{3}$$

then, the membership value for the output KS_S can be obtained as *following;*

$$\mu(KS_S) = \mu(R_1) \tag{4}$$

The other rules, R_2 to R_9 and the corresponding membership grades and membership values are given in the same fashion as Eq.(2), Eq.(3) and Eq.(4), respectively.

Defuzzifier : Defuzzifier produces a crisp output from the fuzzy set that is the output of the inference. A decision procedure must be employed in oder to determine the control value suggested by the membership value $\mu(KS_S)$ defined in Eq.(4). In this study the most widely used form of defuzzification, height defuzzifier, is used to calculating the output.

The control value is determined by using the center of gravity method as follows.

$$K = \frac{k_1 \cdot \mu(KS_S) + k_2 \cdot \mu(KS_M) + \cdots + k_9 \cdot \mu(KB_B)}{\mu(KS_S) + \mu(KS_M) + \cdots + \mu(KB_B)} \tag{5}$$

where k_i i=1,...,9 is the support of the corresponding fuzzy set.

It is very easy to use this defuzzification method because the centers of gravity of the membership function are known ahead of time. But, it only uses the center of the support, k_i, of the consequent membership function.

Predictive MDC

Each time a controller based on a predictor algorithm samples the consumption of the controlled plant it computes an estimate of the mean power that would correspond to the present integrating period if the rate of the consumption did not vary.

The weighted demand, $\overline{P}(l, k)$ at kth sample of the lth integrating period defined as

$$\overline{P}(l, k) = K(l)\ \hat{P}(l, k) \tag{6}$$

Shedding actions take place if this value is greater than the target and restorations happen in the opposite case. This may be stated as an inequality

$$\overline{P}(l, k) \le R(l) \tag{7}$$

where $R(l)$ is the maximum allowable energy consump- tion, corresponding to the target demand of the lth integrating period.

III. CONFIGURATION OF MD CONTROL SYSTEM

A prototype MDC employing the proposed algorithm is developed by PROCOM SYSTEMS Corperation of Korea. The controller provides two input ports for timing signal and demand signal, which are transmitted from the maximum demand meter or watt-hour meter.An auxiliary device of power transducer must be required if analog voltage and current signal from the external PCT only is available, instead of the demand pulse signal. Output ports via relay contacts also are provided for load switching of 8 channels and for alarm of 3 channels. LED module indicates alarms, load switching conditions, and power supply condition. LCD module displays system states such as present date-time, present demand, predicted demand and target demand. Key pad, communication port and printer port also are prepaired. The microprocessor controls the takeover of the incoming pulse signals and their processing, the load monitoring, the issuing of orders from the output module, and also the indication and signals on the digital display and the light diodes. The hardware configuration of the proposed MD control system is designed as shown in Fig.2.

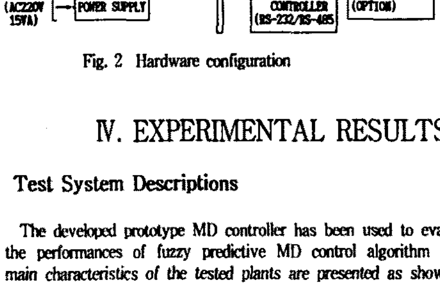

Fig. 2 Hardware configuration

IV. EXPERIMENTAL RESULTS

Test System Descriptions

The developed prototype MD controller has been used to evaluate and test the performances of fuzzy predictive MD control algorithm proposed. The main characteristics of the tested plants are presented as shown in Table 2, where all the plants has registive loads, and the load factors for each plant are set to 123%, 105% and 87%, respectively. The parameter settings of fuzzy predictive MDC are listed in Table 3, where the priority of interrupting loads is given in order of channel number, the first eligible load for shedding.

Table 2 Test Plant Model

No	Contract DM	Target DM	Load Cap	Load Fact	Load Type	Remarks
A	332 KW	315.4 KW	389 KW	123 %	Registive	Target power is 95% of contraction power Load factor is ratio of load capacity to the target power.
B	332 KW	"	332 KW	105 %	"	
C	332 KW	"	273 KW	87 %	"	

Test Results

The test results of the MDC to the plants are depicted in Fig.3, 4 and 5. In Fig.3 the demand curve shows the MD is limited to 98% of the target, and the load switching diagram depicts the four channel loads only is interrupted, in spite of the plant-A's load capacity exceeding the target demand by 23%. Fig.4 represents the efficacy of control algorithm for the plant-B with load capacity exceeding the target demand by 5%. In this case, the MD does not exceed 99% level of the target, and one time of the load switching action only takes place. Fig. 5 shows the test results for the plant-C with load capacity below the target power by 23%, where no control action arise, as expected.

Though the effects of proposed algorithm for minimizing the number of control actions and suppressing the demand oscillations can not be written as compared with those of the conventional algorithms, it is expected, judging from experiance with the conventional ones, that the proposed algorithm performs satisfactory. It can be observed that the undesirable control actions during the begining stage of the integrating period are repressed as well as controlling the MD. These results appreciates the worth of the proposed fuzzy predictive MD control algorithm, which determines the sensitivity of control action by urgency of the load interrupting action along with the predicted demand reaching to the target or as the time closed to the end of the integrating period. The most significant results of the tests are presented in Table 4.

Table 3 Settings of the MDC

Items		PLANT- A	PLANT- B	PLANT- C
Synchronization		Built-in Clock		
Interrupt. Order		Preferential		
Target Demand		95%(315.4KW)		
Contracting Pow		332 KW		
Limit Power		98%(325.4)		
Initial Power		10%(33.2KW)		
Demand Period		15 MIN		
Data-updating		1 MIN		
Demand Pulse Gain		100 Pulse/KWh		
LOAD CAPACITIES	CH 1	28 KW	28 KW	28 KW
	CH 2	28 KW	28 KW	28 KW
	CH 3	28 KW	28 KW	28 KW
	CH 4	94 KW	94 KW	94 KW
	CH 5	95 KW	95 KW	95 KW
	CH 6	59 KW	59 KW	0 KW
	CH 7	57 KW	0 KW	0 KW
	CH 8	-	-	-

Table 4 Test Results

No	Target DM	Load Cap.	Actual DM	Load Switching Action
A	315.4 KW	389 KW	310 (98%)	4 times after 6 min.
B	"	332 KW	312 (99%)	1 time at 14 min.
C	"	273 KW	273 (87%)	no action arise

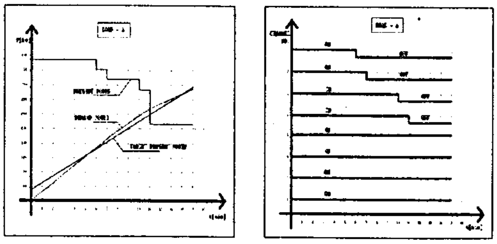

Fig. 3 Test Results with the plant-A

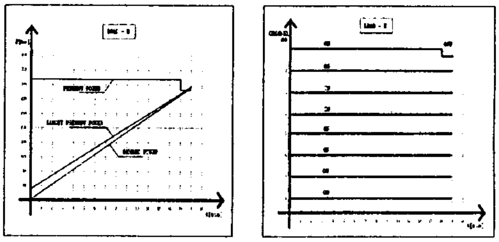

Fig. 4 Test Results with the plant-B

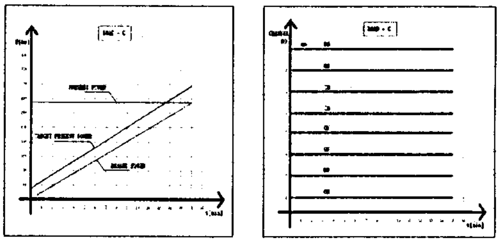

Fig. 5 Test Results with the plant-C

V. CONCLUSIONS

A fuzzy predictive MD control algorithm has been proposed in this work. The existing predictive MDCs often bring about large number of control actions during the every integrating period and/or undesirable load-disconnecting operations during the begining stage of the integrating period.These problems mainly due to the fact that appropriate methematical models for the maximum demand control can be hardly established.Those problems can be solved as describing the control object by linguistic expressions, representing the decision rules by fuzzy logics, and determining the sensitivity of control action by urgency of the load interrupting action along with the predicted demand reaching to the target or the time arriving at the end stage of the integrating period.

A prototype controller employing the proposed algorithm has been developed, and its performances also have been tested with the appropriately parameterized three plants at PROCOM SYSTEMS Corperation of Korea. It can be observed that the undesirable control actions during the begining stage of the integrating period are repressed as well as controlling the MD.These results appreciates the worth of the proposed fuzzy predictive MD control algorithm. Though the effects of proposed algorithm for minimizing the number of control actions and suppressing the demand oscillations can not compare with those of the conventional algorithms, it is expected, judging from experiance with the conventional ones, that the proposed algorithm perform satisfactory.

More research is needed in order to estabilish the stability and reliability and to improve the performances of the developed fuzzy predictive MD control algorithm.

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