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Electric Energy Demand Supervisory and Control Method Using Fuzzy Logic

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1. Preface

Problems of planning for optimum operation of electric furnaces are generally studied by a common method which is called "Simulated Annealing method"(1) that is applied in the stage of operation plan.(2) In practical operation, however, electric furnaces, especially electric melting furnaces cannot be operated as being planned because they are subject to large load variations. Therefore, electric melting furnaces have been operated according to many years of experience of substation operators.

On the other hand, conventional demand supervisory/control devices are used to control load and annunciation when useable electric energy exceeds the contract demand, by estimating the operating power within the limit of demand by the trend of the power.
But, When electric melting furnaces subject to large load variations are connected to a system, the demand supervisory/control devices cannot be used for intended demand supervision since annunciation and load are intermittently limited. Accordingly, demand supervision is performed by substation operators on the basis of their experience in load operation, which causes violations of demand contract or a surplus of useable electric energy.

This paper deals with problems of conventional demand supervisory/control methods used for equipments such as electric melting furnaces with a large variations. It also explains the fuzzy demand supervision/control method and shows the result of application to a practical systems.

2. Purpose of demand supervision and control

In general, a basic power rate is determined in proportion to contract power. Therefore, consumers who use a lot of power determine the contract power as small as possible and control a load within the contract power. If it exceeds the contract power, an additional rate is charged to the consumers.

The purpose of demand supervision and control is to control a load momentarily or predictively so as not to exceed the contract power. Excess of power is usually judged at intervals of 30 minutes, and the load is controlled at intervals of several 10 seconds to several minutes.

3. Conventional demand supervision and control

3-1 Conventional demand supervisory and control method

In the conventional demand supervisory and control method, a predictive demand (R) shown in Fig. 1 is calculated at regular time intervals according to the equation (1) and is compared with the target demand (Q), and when an alarm is emitted at $R \geq Q$, the load is controlled so that it is reclosed at $R < Q$.

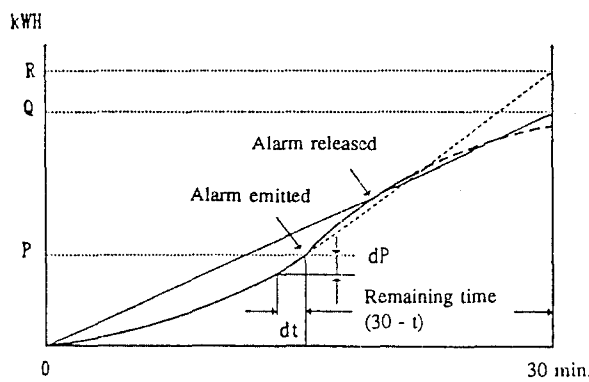
In general, the load to be controlled and the control sequence have been determined in advance.

$$R = P + dP/dt*(30-t) \quad \text{.......} (1)$$

Where R : Predictive demand
P : Actual demand
dt : Pulse integrating time
dP : Increase in demand during the time of dt
t : Time from start of demand supervision (minutes)

3-2 Problems of application to equipment with large load variations

As shown by the equation (1), the predictive demand is calculated from the differential time of load variation. In the case of equipment with large load variations, an alarm is emitted and released intermittently by the repetition of $dP/dt = \infty$ and $dP/dt = 0$, and hence the required demand supervision and control cannot be performed.



R : Predictive demand
Q : Target demand
P : Actual demand

Fig. 1 Conventional demand supervisory and control method

4. Fuzzy demand supervision and control

The fuzzy demand supervisory and control method proposed in this paper is used to obtain a result achieved by skilled substation operators using fuzzy logic for demand supervisory and control of equipment with large load variations which was not possible with conventional supervisory and control method as explained in Item 3.

In a factory using equipment subject to large load variations such as electric melting furnaces, there are additional equipment. The load of additional equipment is very small as compared with that of electric melting furnace, so the predictive demand (Rf and Ra) for the power system connected to electric melting furnace and that connected to additional equipment are obtained, and the total of these values is regarded as the predictive demand (R) of the factory. Using the predictive demand (R), target demand (Q) and remaining time (T) as input parameters, the degree of necessity of limiting the load (A) is estimated and is compared with the specified degree of necessity of limiting the load (L), and when $A \geq L$, an alarm is emitted to limit the load.

The procedure of this control is shown in the following. As a matter of course, there is a hysteresis between emission and release of alarm. Fig. 2 shows a block diagram of fuzzy demand supervision and control.

(1) Estimation of predictive demand of system connected to electric melting furnace

1) Operating method of electric melting furnace and pattern of useable electric energy

As shown in Fig. 3, electric melting furnace is used to melt materials by generating arcs between the electrode and material so its load variation is very large. In operating the electric melting furnace, it is filled with material which is to be melted. In the process of melting, the level of the melted material lowers so additional material is put in the furnace. This operation is repeated until a given weight of melted material is obtained. Fig. 4 shows the operation pattern of the electric melting furnace. The operation pattern shown in Fig. 4 is practically determined by the kind and weight of material.

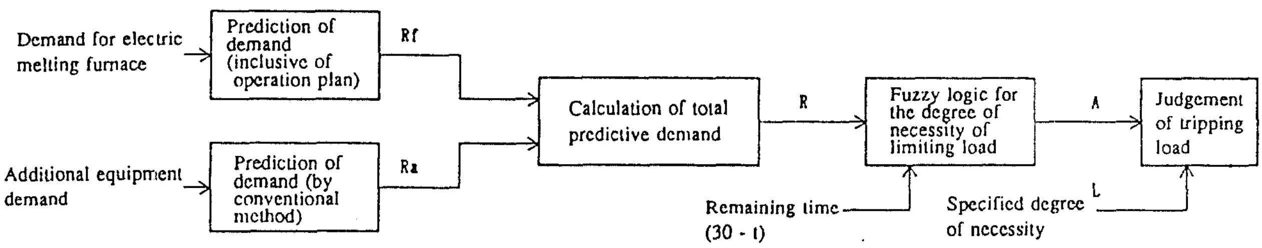


Fig. 2 Block diagram of fuzzy demand supervision and control

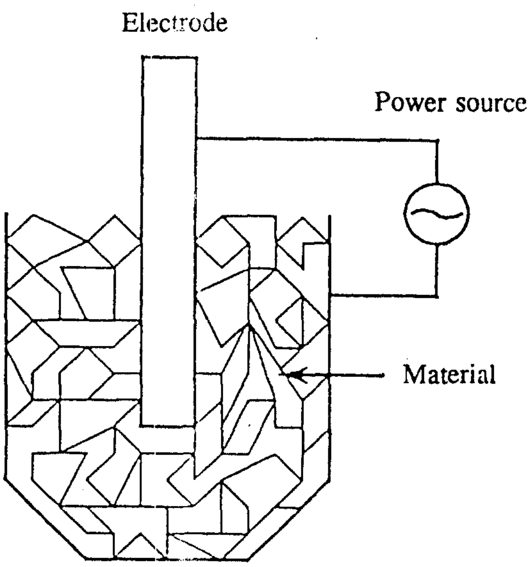
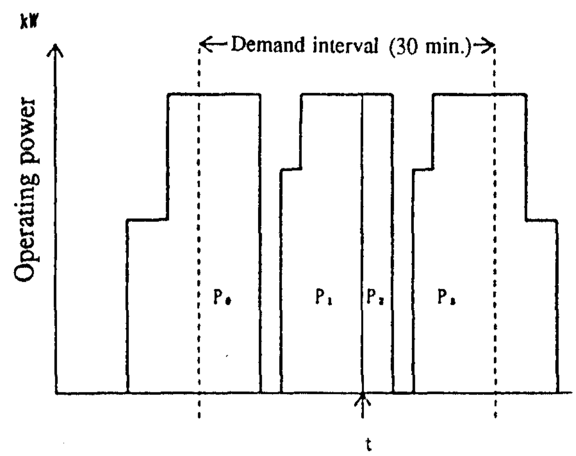


Fig. 3 Structure of electric melting furnace



$P_t = P_0 + P_1$

$P_{30-t} = P_2 + P_3$

Fig. 4 Operation pattern of electric melting furnace

2) Estimation of predictive demand (Rf)
When actual time is shown by (t) in Fig. 4, the predictive demand (Rf) can be obtained from the equation (2) where the actual demand used until the time (t) in the demand timing is (Pt) and the demand used in the remaining time (30-t) is (P30-t).

$$Rf = Pt + P30\text{-}t \quad \cdots\cdots (2)$$

(2) Estimation of predictive demand of additional equipment
Since additional equipment is small in load variations as mentioned before, the predictive demand (Ra) is estimated by conventioinal demand supervisory method shown in Item 3.1.

(3) Calculation of predictive demand (R)
Predictive demand (R) can be obtained from the equation (3).

$$R = Rf + Ra \quad \cdots\cdots (3)$$

(4) Estimation of the degree of necessity of limiting load by fuzzy logic
The degree of necessity of limiting load (A) is estimated by fuzzy logic using the knowhow of substation operators. It is judged by the operators on the basis of the following factors.

a. How much electric energy is left unused?

* Margin of electric energy is very small.
—→ Load needs to be limited.
* There is some margin in electric energy.
—→ Proceed to "b".

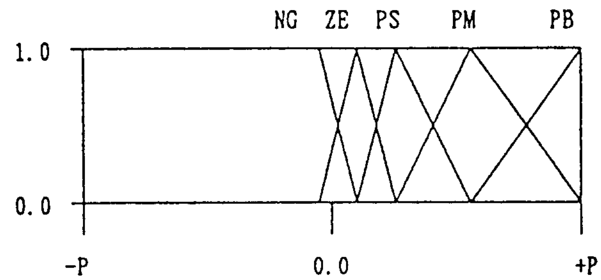
b. What is the operation schedule of electric melting furnace?

* Useable electric energy does not exceed the contract demand for the operation schedule.
—→ No measures need to be taken.
* Useable electric energy possibly exceeds the contract demand for the operation schedule.
—→ Proceed to "c".

c. When is it assumed to exceed the contract demand?

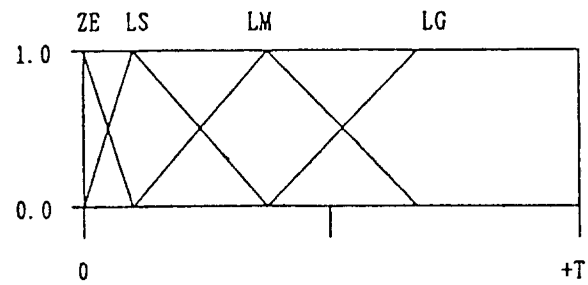
* There is much margin in electric energy.
—→ No measures need to be taken.
* There is some margin in electric energy.
—→ It needs to be supervised carefully.
* There is little margin in electric energy.
—→ Load needs to be limited.

The above items are arranged according to the rule of fuzzy logic to estimate the degree of necessity of limiting load (A). An example of membership function of the remaining electric energy, remaining time and the degree of necessity of limiting load is shown in Fig. 5 through Fig. 7.



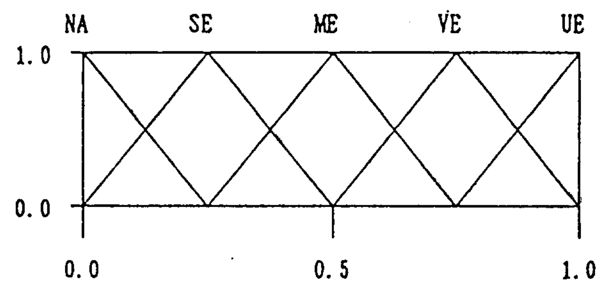
PB : Fairly enough margin
PM : Enough margin
PS : Some margin
ZE : Little margin
NG : Exceeds contract demand

Fig. 5 Example of membership function of remaining electric energy (P30-t)



LG : Fairly far ahead
LM : Far ahead
LS : A little ahead
ZE : Quite near

Fig. 6 Example of membership function of remaining time (T)



UE : Very high
VE : Fairly high
ME : High
SE : A little high
NA : None

Fig. 7 Example of membership function of the degree of necessity of limiting load (A)

Table 1 Result of application to practical system

Demand timing	At emission of furnace stop command			At termination of demand timing		
	Furnace No. stopped	Time	Used electric energy	Used electric energy	Set value of electric energy	Contract demand
1	1 2	-10 -2	21120 27720	28240	28100	28400
2	2 1	-1 0	27260 28100	28120	28100	28400
3				26540	28100	28400
4				26660	28100	28400
5	2 1	-3 0	25520 27720	28040	28100	28400
6				26640	28100	28400
7				27960	28100	28400
8				27000	28100	28400
9	1	-1	27380	27880	28100	28400

5. Result of application to practiced system

Table 1 shows the result of application of the fuzzy demand supervisory and control method proposed in this paper to a practical system. The object of application is a steel reinforcement manufacturing factory equipped with two electric melting furnaces. In this factory, conventional demand supervisory and control system was used to merely indicate a rough trend of use of electric energy, while practical judgements were performed by the operator, thereby resulting in violations of contract demand and less power consumption.

In Table 1, the demand timing shows that the demand is supervised at intervals of 30 minutes. The furnace No. which stops at emission of a stop command shows the electric furnace that has tripped a load, while the time is the difference between the time when the furnace has stopped and the time of termination of demand timing, for example, "-5" is the time from 5 minutes and 59 seconds to 5 minutes and 00 second prior to the stop of the furnace. On the other hand, the used electric energy is the power which was used until the furnace has stopped. The electric energy up to the termination of the demand timing is the power used till the end of the demand supervision, i.e., the power used in 30 minutes. The power has been set in consideration of estimated increase in the useable power of a common load which is not tripped (in this example, it is set to 300kWH), i.e., it is a target value of used electric energy at the termination of the demand timing. The contract demand is the amount of power under contact with the electric power company.

Referring to Table 1, the demand timing for limiting load was No. 1, No. 2, No. 5 and No. 9. In other demand timing, there was no necessity of limiting load. The result of control with the demand timing used to limit the load was that the electric energy used in 30 minutes was in the vicinity of the set power and was less than the contract demand.

Especially, in the No. 1 demand timing, the need for limiting load is predicted 10 minutes earlier by fuzzy logic to stop the No. 2 electric melting furnace, despite of the fact that the actual demand is 21120kWH. Also, the need for limiting load again is predicted 2 minutes before the actual demand of 27720kWH to stop the No. 2 electric melting furnace. As a result, the electric energy which was used at the termination of the demand timing was 28240 kWH.

6. Conclusion

Hitherto, a demand supervisory and control device used for a system connected to equipment with large load variations, such as electric melting furnaces, was not available, so the fuzzy demand supervisory and control method proposed in this paper cannot be compared with conventional methods. But, the fuzzy demand supervisory and control method has revealed very effective for such equipment, for example, the total electric energy used in the demand timing for limiting load was 112280kWH as against 113600kWH of total contract demand, indicating a high efficiency (98.8%) in operation.

Reference documents

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