Determination of Alarm Setpoint for Alarm System Rationalization Using Performance Evaluation

Naoki Kimura[1], Takashi Hamaguchi[2], Kazuhiro Takeda[3], and Masaru Noda[4]

[1] Department of Chemical Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395 Japan
[2] Graduate School of Engineering, Nagoya Institute of Technology, Gokiso, Showa-ku, Nagoya 466-8555, Japan
[3] Faculty of Engineering, Shizuoka University, 3-5-1 Johoku, Hamamatsu 466-8555, Japan
[4] Department of Chemical Engineering, Faculty of Engineering, Fukuoka University, 8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180 Japan
nkimura@chem-eng.kyushu-u.ac.jp

Abstract. Alarm system is one of the most important element of the plant-operator interfaces in the industrial plants. Alarm lifecycle management is very important to maintain the safety, quality, environmental and economic efficiency of the plant. In our previous study, we proposed the method to select adequate alarm variables and evaluation method in diagnostic and timely manner. In this study, we proposed a method to determine the setpoints for alarm system using three indices and the results of dynamic process simulation on the rationalization stage of the lifecycle of alarm management. And we also presented feasibility of our method by demonstration of a case study.

Keywords: Plant Alarm System, Dynamic Process Simulation, Timeliness rate.

1 Introduction

Information from sensors in the chemical plants is displayed on the console through the DCS (Distributed Control System). Plant operators can observe the plant situation by sweeping the console, and they can control the plant by sending control signals to the control elements via DCS. If any malfunction occurs in the plant, it is necessary to detect it as early as possible and to take adequate actions to bring the plant situation back to normal in order to avoid any industrial accident, quality and environmental performance degradation. Plant alarm system is one of the most important operator-plant interfaces to attract operators' attention by blinking and/or beeping in order to recognize the plant situation and to take counter measures in such a context. However consecutive and simultaneous generations of a large number of plant alarms cause congestion of information on the console or impediment of operators' recognition of the plant situation, if the each and every alarm source signals are set as alarm variables. New laws, regulations and guidelines for the plant safety have been established because of the repetition of the industrial accidents due to the alarm floods or the inadequate alarm systems.

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EEMUA[1] set a benchmark for the number of alarm generations in ten minutes following a plant upset from an ergonomics standpoint. And EEMUA also proposed the eight characteristics—which are *Relevant*, *Unique*, *Timely*, *Prioritized*, *Understandable*, *Diagnostic*, *Advisory* and *Focusing*— of a good alarm. ISA proposed the standards for the lifecycle of alarm management in SP18.2 [2]. The third stage named "*Rationalization*" was defined which consists of several steps—*Alarm validity*, *Consequences*, *Operator response*, *Response time*, *Alarm priority*, *Alarm class*, *Setpoints*, *Advanced alarm handling*— in the standards for the lifecycle of alarm management of ISA SP18.2. Thorough streamlining of alarms following the standardized design and management approaches was advocated by ISA. However the concrete methods of design, evaluation and enhancement of the alarm system have not mentioned in these guidelines and standards.

Takeda *et al.* [3] proposed the alarm variable selection method among an enormous number of alarm source signals by using two-layer cause-effect model to design the "diagnostic" plant alarm system. In their method, it is possible to systematically acquire the combinations of alarm variables, which can qualitatively and theoretically distinguish among all the assumed plant malfunctions. It is difficult to determine which combinations of alarm variables should be used, because of the large number of combinations of alarm variables by their method. In our previous studies [4,5], we proposed three indices—effective rate, recall rate and timeliness rate— to evaluate performance of plant alarm system. Therefore, we could not provide the method to enhance the performance of the plant alarm system, even though we could propose how to evaluate it. In this study, we investigate a method to determine the setpoints for alarm system using the three indices and the results of dynamic process simulation on the rationalization stage.

2 Evaluation Method for Plant Alarm System

2.1 Diagnostic Alarm Variables Derived by Two-Layer Cause-Effect Model

In our previous study[3], we proposed an alarm variable selection method based on a two-layer cause-effect model. The model represents the cause and effect relationships between the deviations of state variables, such as process variables and manipulated variables, from normal fluctuation ranges. It is represented by a directed graph, where two types of nodes are defined.

- i+: Upward deviation of state variable i from normal fluctuation range
- i-: Downward deviation of state variable i from normal fluctuation range

Figure 1 shows an example of the two-layer cause-effect model. A single direction arrow links the deviation of a state variable and its affected state variable. The letters F and L indicate flow rate and tank liquid level, respectively. In our previous study, the sets of the state variables with the directions of their deviation from the normal fluctuation ranges are derived. If the alarm setpoints are adequately configured, the derived sets are theoretically guaranteed to be able to qualitatively distinguish all the assumed malfunctions in a plant. In this study, the derived sets are referred to as the sets of the diagnostic alarm variables.

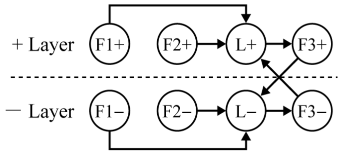

Fig. 1. Example of two-layer cause-effect model

2.2 Performance Evaluation Indices of Plant Alarm System

Three indices, "*effective rate*", "*recall rate*" and "t*imeliness rate*" have been introduced to evaluate the diagnostic characteristic and timeliness characteristics of a plant alarm system in our previous study [4,5]. Alarms are classified by diagnostic characteristic and activation status. As shown in Table 1, w is the number of actually activated distinguishable alarms, x is the number of non-activated distinguishable alarms, and y is the number of the activated non-distinguishable alarms. The effective rate (*i.e.* the percentage of actually activated distinguishable alarms to all the activated alarms) is calculated using Eq. (1). The recall rate (*i.e.* the percentage of actually activated distinguishable alarms to all the designated distinguishable alarms) is calculated using Eq. (2). High effective and recall rates indicate that the alarm system possesses strong enough characteristic to identify the root causes of assumed malfunctions of the plant. And timeliness rate is calculated using Eq. (3), for evaluating the timeliness characteristic of a plant alarm system. In Eq. (3), t_e is the elapsed time from the beginning of the malfunction till when all the alarms are activated to distinguish the malfunction and t_a is the longest available time of t_e. t_a is determined in accordance with the plant dynamics considering the time it takes for operators to respond and correct the problem. A low timeliness rate indicates that the plant alarm system generates diagnostic alarms too late for operators to respond and correct the problem in a timely manner.

$$\text{Effective rate [\%]} = w \,/\, (w + y) * 100 \tag{1}$$

$$\text{Recall rate [\%]} = w \,/\, (w + x) * 100 \tag{2}$$

$$\text{Timeliness rate [\%]} = \begin{cases} 100 & \text{if } 0 \le t_e \le t_a \\ 100\left(1 - \dfrac{t_e - t_a}{0.5 t_a}\right) & \text{if } t_a < t_e \le 1.5 t_a \\ 0 & \text{if } 1.5 t_a < t_e \end{cases} \tag{3}$$

Table 1. Criteria of diagnostic alarm system

	No. of activated alarm signals	No. of non-activated alarm signals
Number of distinguishable alarm signals	w	x
Number of non-distinguishable alarm signals	y	–

3 Case Study

3.1 Example Plant and Plant Alarm System

A case study with the two-tank system illustrated in Fig. 2 as an example plant was carried out to demonstrate the proposed method. In Fig. 2, the product is fed to Tank 1 and transferred to Tank 2. A certain amount of the product is recycled to Tank 1 from Tank 2. The letters *P*, *F*, *L*, and *V* in Fig. 2 indicate pressure, flow rate and liquid level sensors, and valve positions, respectively. In this example plant, five types of malfunctions are assumed to be distinguishable from the operation of the plant alarm system. And t_a for each malfunction is indicated below:

Mal-1: High feed pressure (t_a= 129 min.)
Mal-2: Low feed pressure (t_a = 129 min.)
Mal-3: Blockage in recycle pipe (t_a = 42 min.)
Mal-4: Wrong valve operation of V4 open (t_a = 129 min.)
Mal-5: Wrong valve operation of V4 close (t_a = 129 min.)

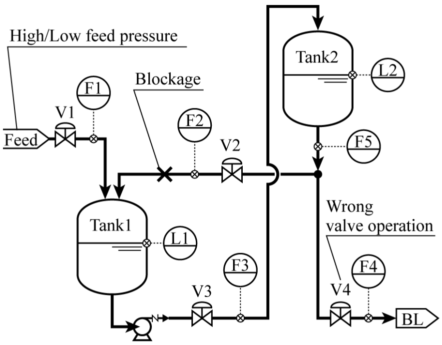

Fig. 2. Example plant of two-tank system

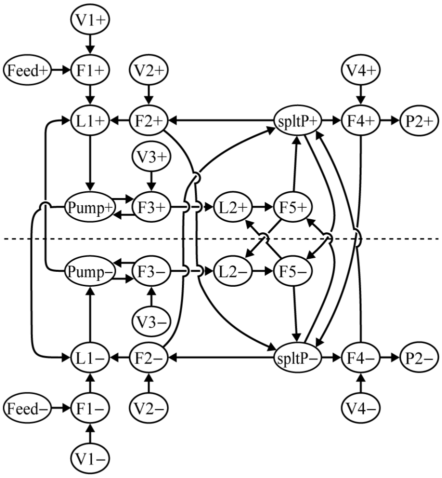

Fig. 3. Two-layer cause-effect model

Figure 3 shows the two-layer cause-effect model of the example plant. To distinguish the above 5 malfunctions, 2 types of alarm setpoints, high limit (PH) and low limit (PL), for 3 measured process variables were set as shown in Table 2. If the value of a state variable exceeds the corresponding alarm setpoint, the corresponding alarm is activated.

3.2 Results of Diagnostic Alarm Selection

All the sets of diagnostic alarms for the example plant, which can be theoretically used to distinguish all assumed malfunctions, were derived from the two-layer cause-effect model by using our previously reported diagnostic alarm selection method (Takeda *et al.*, 2010). The minimum number of sensors used as distinguishable alarm signal was three. To distinguish the five assumed malfunctions, two types of alarm signals—high limit (PH) and low limit (PL)—were adopted. Table 2 shows an example set of the minimum number of distinguishable alarm signals { F1, L1, V4 }, and the normal values, the initial setpoint values of each variables and the alarm activation patterns for each assumed malfunction.

Table 2. Alarm system and their PH/PL limits and activation patterns.

Measured variables		F1 [kg/hr]		L1 [m]		V4 [%]	
	Normal values	5603		2.20		77.7	
	Signals	PH	PL	PH	PL	PH	PL
	Initial setpoints	5883	5323	2.31	2.09	81.6	73.8
Alarm activation patterns	Mal-1	○		○			
	Mal-2		○		○		
	Mal-3				○		
	Mal-4				○	○	
	Mal-5			○			○

3.3 Evaluation Results for Each Assumed Malfunction

Table 3 shows the activated alarms, their activation times from the beginning of the malfunction—which were obtained using a dynamic plant simulator (Visual Modeler, Omega Simulation Co., Ltd.)—, t_e, and the evaluation values.

In Mal-1, F1.PH was not activated although F1.PH is a member of the alarm signal set to distinguish Mal-1. Therefore it could not be distinguished between Mal-1 and Mal-5 at the moment of only L1.PH activation. For this reason, recall rate is 50 % and timeliness rate is indeterminable.

Table 3. Alarm activation times for each assumed malfunctions in simulation.

	t_a [min.]	Alarm signals	*Activation times [min.]	t_e [min.]	Evaluations: Effective rate	Recall rate	Timeliness rate
Mal-1	129	F1.PH	Non-activated	†N.D.	100%	50 %	†N.D.
		L1.PH	106				
Mal-2	129	F1.PL	0	0	100 %	100 %	100 %
		L1.PL	100				
Mal-3	42	L1.PL	68	68	100 %	100 %	0 %
Mal-4	129	V4.PH	0	0	100 %	100 %	100 %
		L1.PL	110				
Mal-5	129	V4.PL	0	0	100 %	100 %	100 %
		L1.PH	129				

*Activation time from the beginning of the malfunction.

†N.D. means “Non-Distinguished.”

In other malfunctions, because all and the only distinguishable alarm signals are activated, both effective rates and recall rates are 100 %. In Mal-2, the activation times of F1.PL and L1.PL are 0 minute and 100 minutes respectively. If F1.PL is activated, it could be distinguished Mal-2 without L1.PL activation, because F1.PL is not a member of the other alarm signal sets to distinguish the assumed malfunctions except Mal-2. Therefore t_e for Mal-2 is determined as the activation time of F1.PL. In the same manner, t_e for Mal-4 and t_e for Mal-5 are also determined as the activation time of V4.PH and V4.PL respectively. As a result timeliness rates for Mal-2, Mal-4 and Mal-5 are 100 %. However, timeliness rate is 0 % for Mal-3, because the activation time of L1.PL was 68 minutes though t_a for Mal-3 is 42 minutes.

3.4 Rectification of Plant Alarm Setpoints

To enhance the performance evaluation of the plant alarm system, it is necessary to rectify the setpoints based on the operational data derived from actual plant or the simulation results of the dynamic plant simulator. Fig. 4 shows a trend graph of L1 during 80 minutes after the Mal-3 occurred. The normal value of L1 is 2.20 in a steady state, and the initial setpoint value for L1.PL is 2.09 mentioned in Table 2. The setpoint value of L1 should be set as higher than or equal to 2.09 in order to activate alarm signal L1.PL within t_a (=42 min.) against a similar magnitude of Mal-3. The following inequality is derived:

$$\text{L1.PL} \geq 2.09 \tag{4a}$$

Fig.5 also shows the trends of L1 with different 4 magnitudes of Mal-3. Mal-3a is the same with the trend in Fig.4. And the inequality constraints are derived as follows:

$$\text{L1.PL} \geq 2.06 \tag{4b}$$

$$\text{L1.PL} \geq 2.03 \tag{4c}$$

$$\text{L1.PL} \geq 2.14 \tag{4d}$$

In addition, the following inequality constraint is derived because the low limit setpoint should be smaller than the normal values.

$$\text{L1.PL} < 2.20 \tag{5}$$

As a consequence, equation (6) is derived as the allowable range, because equation (4d) is the tightest constraint between inequalities 4a–4d.

$$2.14 \leq \text{L1.PL} < 2.20 \tag{6}$$

In the same manner, the following constraints for each alarm signals are derived.

$$5603 < \text{F1.PH} \leq 5876 \tag{7a}$$

$$5315 \leq \text{F1.PL} < 5603 \tag{7b}$$

$$2.20 < \text{L1.PH} \tag{7c}$$

$$77.7 < \text{V4.PH} \leq 81.6 \tag{7d}$$

$$73.8 \leq \text{V4.PL} < 77.7 \tag{7e}$$

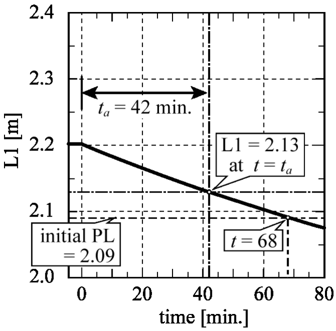

Fig. 4. Trend graph of L1 with Mal-3.

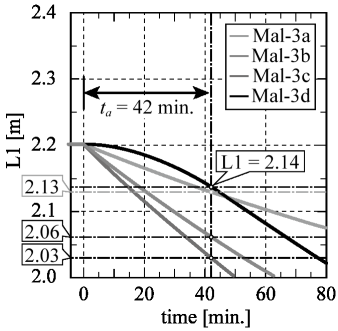

Fig. 5. Trend graph of L1 with various magnitude of Mal-3

3.5 Verification of Rectification of Plant Alarm Setpoints

Table 4 shows a set of rectified setpoints within the allowable ranges mentioned in section 3.4. The setpoints of F1.PH, F1.PL and L1.PL were changed. Table 5 shows the activation times, t_e and the evaluation values. As compared with Table 3, all of the distinguishable alarm signals have been activated within t_e for all the malfunctions. Therefore, all the performance evaluation values—effective, recall and timeliness rates— are improved to 100 %.

Table 4. Rectified alarm setpoints.

Measured variables	F1 [kg/hr]		L1 [m]		V4 [%]	
Normal values	5603		2.20		77.7	
Signals	PH	PL	PH	PL	PH	PL
Initial setpoints	*5827	*5379	2.31	*2.14	81.6	73.8

Table 5. Alarm activation times for each assumed malfuntions with rectified alarm setpoints

	t_a [min.]	Alarm signals	Activation times [min.]	t_e [min.]	Evaluations		
					Effective rate	Recall rate	Timeliness rate
Mal-1	129	F1.PH	0	0	100%	100 %	100 %
		L1.PH	104				
Mal-2	129	F1.PL	0	0	100 %	100 %	100 %
		L1.PL	55				
Mal-3	42	L1.PL	35	35	100 %	100 %	0 %
Mal-4	129	V4.PH	0	0	100 %	100 %	100 %
		L1.PL	79				
Mal-5	129	V4.PL	0	0	100 %	100 %	100 %
		L1.PH	129				

4 Conclusion

We proposed a determination method of plant alarm setpoints in accordance with the diagnostic and timely evaluations. Dynamic plant simulation results were used to demonstrate its feasibility.

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