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Conditional Event Matching Prediction of Nonlinear Phenomena of Insulator Pollution in Coastal Substations Based on Actual Database

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Abstract

A prediction method of conditional event matching prediction (EMP) for a purpose of predicting nonlinear phenomena of insulator pollution was proposed in this paper. The EMP was used if the conditional probability for increase of insulator pollution exceeded a threshold value. A performance of the EMP was strongly related to selection of database of events and a closeness function. By use of the prediction of the insulator pollution based on the conditional EMP, reliable decision making for the washing timing of the polluted insulators was evaluated based on actual data in Karatsu substation, Japan.

1. Introduction

Pollution of insulators near coastal substations has been brought by salty wind and exceeded pollution may cause flash-over of the insulators resulting serious power failures [1, 2]. To avoid these accidents, insulator washing becomes a major task and sometimes the insulators are washed frequently and unnecessarily using much amount of pure water to circumvent possible flash-overs. Thus, reliable prediction method for insulator pollution had been required to reduce unnecessary washing. A decision making for insulator washing which has enabled automation of the present decision making process was proposed by the authors [3]. Moreover, an insulator pollution model by use of weather information to achieve a reliable prediction of insulator pollution was proposed [4] and appropriate decision making of the insulator washing to reduce unnecessary washing was investigated. The proposed method brought satisfactory result of pollution estimates in normal pollution case. For rapid pollution case especially in typhoon seasons, more reliable method for estimating the insulator pollution with highly nonlinearity was required.

In this study, an innovative method for predicting insulator pollution, called a conditional event matching prediction (EMP) was proposed. The basic idea of the EMP for insulator pollution including highly nonlinearity is to make an appropriate selection of a past event among the database of past occurrences of the events. As the insulator pollutions are highly correlated to weather conditions, the database of past weather conditions and the pollution rates were used for the EMP. A reliable decision making for the washing timing of the polluted insulators was developed by use of the prediction of the insulator pollution based on the EMP. The proposed method was tested based on actual data in Karatsu substation, Kyushu in Japan, and proved to be effective and reliable in decision making of the washing timing of polluted insulators in any coastal substations.

2. Conditional Event Matching Prediction for Insulator Pollution Deposits

Conceptual explanation of conditional event matching prediction

Basic concept of the conditional event matching prediction (EMP) is to predict a state (pollution) based on past occurrence of events including the results of the state (pollution) and its circumstance (weather) if the condition of increase of pollution is fulfilled as $F(1|\boldsymbol{y}) \geq \lambda$, as seen in Fig. 1. To predict the pollution rate $\Delta p(t)$, the current surrounding weather condition is investigated first, then the closest weather condition in the past is selected in the database of the past weather information (event matching). The past pollution rate $\Delta p(k^*)$ in the selected event is chosen as the prediction of the pollution rate (prediction). The one (several) step ahead prediction of the pollution deposits can be calculated by use of the predicted pollution rate.

Algorithm conditional determination

The condition for increase of pollution is determined as follows. Select a discrete random variable x and a continuous random variable $\boldsymbol{y}$ for weather. If a pollu-

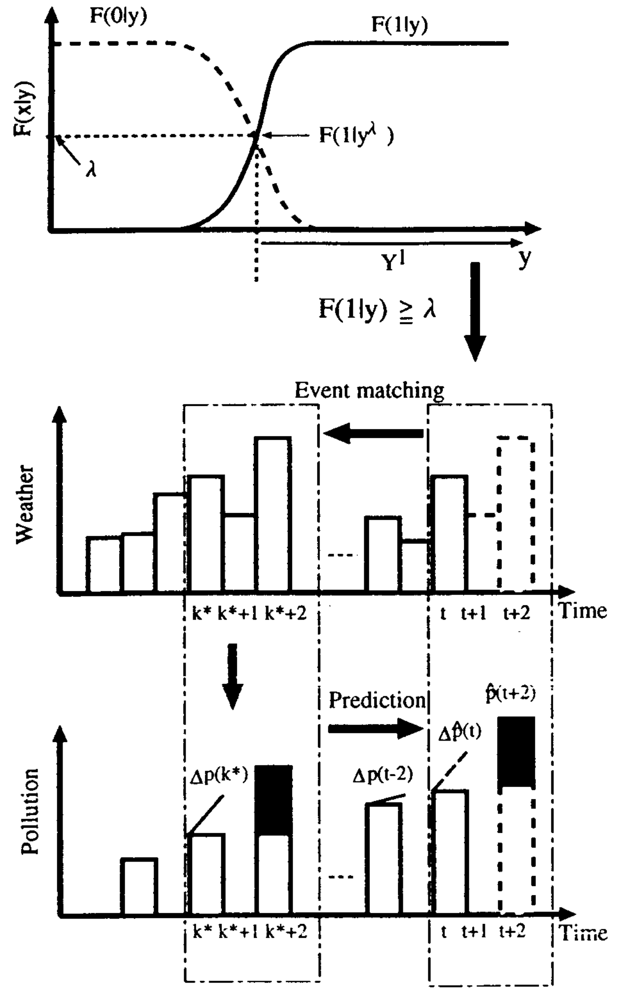

Fig. 1. Event matching prediction (EMP): (i) searching past events and selection of a specific event whose weather condition was the closest to the current condition, (ii) prediction of the pollution deposits by use of the pollution rate of the selected event.

tion rate $\Delta p(k)(= (p(k+2) - p(k))/2\Delta t)$ fulfills the condition

$$\Delta p(k) \geq 0.0005 \qquad ((\mathrm{mg/cm^2})/\mathrm{h}) \tag{1}$$

the random variable x has the value 1, otherwise $x = 0$. The conditional EMP is carried out, if the weather satisfy the following condition as

$$F(1|\boldsymbol{y}) \geq \lambda \tag{2}$$

where λ shows an indication coefficient. In this study, the value of λ is chosen as 0.5 which brings the minimum number of the summation of the false positive and the false negative. The conditional probability for occurrence $x = 1$ for a given weather condition is obtained by use of the Bayesian rule as

$$F(1|\boldsymbol{y}) = \frac{F(1)f(\boldsymbol{y}|1)}{F(0)f(\boldsymbol{y}|0) + F(1)f(\boldsymbol{y}|1)} \tag{3}$$

where $F(1)$ is the probability of the occurrence $x = 1$ and $F(0)$ is the that of $x = 0$. The probabilities $F(1)$ and $F(0)$ are calculated by

$$F(1) = M/(M+N), F(0) = N/(M+N) \tag{4}$$

where M is the number of data which satisfies the condition (1) and N is the number of data which does not satisfy it. The normalized histograms of the weather data for $x = 1$ and for $x = 0$ are approximated by gaussian distribution functions. If the equation (1) is fulfilled, the following EMP algorithm is carried out.

Algorithm of EMP

By use of the current weather information of wind velocity $v(t)$, wind direction $d(t)$ and humidity $h(t)$ and weather forecast for the next two stages $\hat{v}(t+1)$, $\hat{v}(t+2)$, $\hat{d}(t+1)$, $\hat{d}(t+2)$ and $\hat{h}(t+1)$, $\hat{h}(t+2)$, the closeness of the events $C(k,t)$ which will be explain in the next section, is calculated for all k in the database. The timing of the closest event k^* is chosen among the values of $C(k,t)$ as (event matching)

$$k^* = \{k | \min_k C(k,t)\} \tag{5}$$

and pollution rate at the selected timing k^* is chosen as

$$\Delta p(k^*) = (p(k^*+2) - p(k^*))/2\Delta t. \tag{6}$$

Two hours ahead prediction of insulator pollution deposits is obtained by use of the selected pollution rate as (prediction)

$$\hat{p}(t+2) = p(t) + 2\Delta t \Delta p(k^*). \tag{7}$$

In the conditional EMP, construction of database and selection of the criterion for measuring the closeness of the circumstances are the crucial items to be determined.

Construction of database

The weather information, wind velocity $v(\cdot)$, wind direction $d(\cdot)$ and humidity $h(\cdot)$ for the stages $k, k+1$ and $k+2$ are factors which are highly correlated to the pollution rate. The database for EMP was constructed by use of the past events from 3 Sept. '96 to 31 Jan. '97. For a final objective of the safety decision making of washing timing, only events of positive pollution rate

$$\Delta p(k) \geq 0 \tag{8}$$

are included in the database.

Criterion of closeness of the event

Criterion for measuring the closeness of weather conditions affects the performance of the event matching directly. The criterion is defined by use of the weather information in product as follows:

$$C(k,t) = 1 - \frac{1}{3}(\exp_0 + \exp_1 + \exp_2) \tag{9}$$

Table 1 The proposed conditional EMP method for pollution deposits: date, weather, result and evaluation.

A Date				B Weather									C EMP			D Evaluation		
				Velocity v(m/s)			Direction d(-)			Humidity h(%)				$\times 10^{-3}$		$\times 10^{-3}$		
t	M	D	T	t	$t+1$	$t+2$	t	$t+1$	$t+2$	t	$t+1$	$t+2$	C	k^*	Δp t	$\hat{p}$ $t+2$	p $t+2$	ϵ $t+2$
2875	1	1	12	4.9	3.6	3.6	14	14	14	72	83	80	0.81	1691	0.65	3.2	2.2	1.0
2877	1	1	14	3.6	5.9	4.1	14	4	4	80	86	82	0.71	673	1.65	5.5	7.5	-2.0
2879	1	1	16	4.1	3.7	4.8	4	4	4	82	77	64	0.85	2877	2.65	12.8	13.5	-0.7

where $\exp_0$, $\exp_1$ and $\exp_2$ express the closeness of the respective weather as

$$\exp_0 = \exp\left\{-\frac{(v(k)-v(t))^2}{\sigma_v^2} - \frac{(d(k)-d(t))^2}{\sigma_d^2} - \frac{(h(k)-h(t))^2}{\sigma_h^2}\right\} \quad (10a)$$

$$\exp_1 = \exp\left\{-\frac{(v(k+1)-\hat{v}(t+1))^2}{\sigma_v^2} - \frac{(d(k+1)-\hat{d}(t+1))^2}{\sigma_d^2} - \frac{(h(k+1)-\hat{h}(t+1))^2}{\sigma_h^2}\right\} \quad (10b)$$

$$\exp_2 = \exp\left\{-\frac{(v(k+2)-\hat{v}(t+2))^2}{\sigma_v^2} - \frac{(d(k+2)-\hat{d}(t+2))^2}{\sigma_d^2} - \frac{(h(k+2)-\hat{h}(t+2))^2}{\sigma_h^2}\right\}. \quad (10c)$$

The notations $\hat{v}(t+1)$, $\hat{v}(t+2)$, $\hat{d}(t+1)$, $\hat{d}(t+2)$, $\hat{h}(t+1)$, $\hat{h}(t+2)$ are the weather forecast and σ_v^2, σ_d^2, σ_h^2 are the standard deviations of the respective weather factors. The criterion $C(k,t)$ has the value within

$$0 \leq C(k,t) \leq 1. \quad (11)$$

If the all weather conditions at t, $t+1$, $t+2$ and k, $k+1$, $k+2$ are the same, the criterion shows zero, then this value shows the closest event.

Safety decision making of washing timing

Appropriate decision making of washing timing for polluted insulator is determined so as to reduce unnecessary washing. To make a safety decision making, the two hours ahead prediction of the insulator pollution is adopted so as to choose the max value of $\Delta p(k^*)$ or $\Delta p(t-2)$ as

$$\hat{p}(t+2) = p(t) + 2\Delta t \max(\Delta p(k^*), \Delta p(t-2)). \quad (12)$$

Index for decision making of washing is defined as follows:

$$I(t+2) = \hat{p}(t+2) + \max \epsilon_-(t) \quad (13)$$

where $\max \epsilon_-(t)$ is the maximum error in the past prediction as

$$\max \epsilon_-(t) = \max_{t'<t} \epsilon_-(t'). \quad (14)$$

The insulator washing is decided if the index exceeds a hazardous level of pollution deposits P_{thr} (0.03(mg/cm^2)) as

$$I(t+2) \geq P_{thr}. \quad (15)$$

3. Evaluation of the Results of Conditional EMP and Washing Timing

Evaluation of Conditional EMP for insulator pollution

Predicted pollution by the conditional EMP was evaluated by use of prediction error defined by

$$\epsilon(t) = \hat{p}(t) - p(t) \quad (16)$$

Table 1 shows a part of the results for EMP of insulator pollution. This table includes the data (A), weather condition (B), the results of EMP (C) and evaluation of the EMP (D).

In table 2, the standard deviations of the errors ϵ, ϵ_+, ϵ_- were compared, in which ϵ_+ stands for the standard deviation of errors of ϵ which have positive values and ϵ_- stands for the standard deviation of error of ϵ with minus values. The columns A shows the standard errors for rapid pollution $p(t) \geq 0.001$, and B shows for normal pollution $0.001 > \Delta p(t) \geq 0$. Rapid pollution occurred 25 times and small frequent pollution occurred 335. The proposed EMP was compared with a simple prediction method. The simple prediction method brings the predicted insulator pollution in two hours ahead as the same as the current pollution deposits as

$$\hat{p}(t+2) = p(t). \quad (17)$$

By comparing the values of ϵ, ϵ_- for two different methods, the proposed method brought smaller value in case

Table 2 Evaluation of the proposed EMP method by the standard deviation of the predicted pollution errors for data of Karatsu substation in January 1997.

Method	A Rapid pollution			B Normal pollution		
	ϵ	ϵ_+	ϵ_-	ϵ	ϵ_+	ϵ_-
	$10^{-3}(mg/cm^2)$			$10^{-3}(mg/cm^2)$		
Simple Prediction	2.40(25)	0	2.40(25)	0.36(335)	0.39(165)	0.33(170)
Proposed Prediction	1.52(25)	1.87(12)	1.09(13)	0.68(335)	0.80(229)	0.29(106)

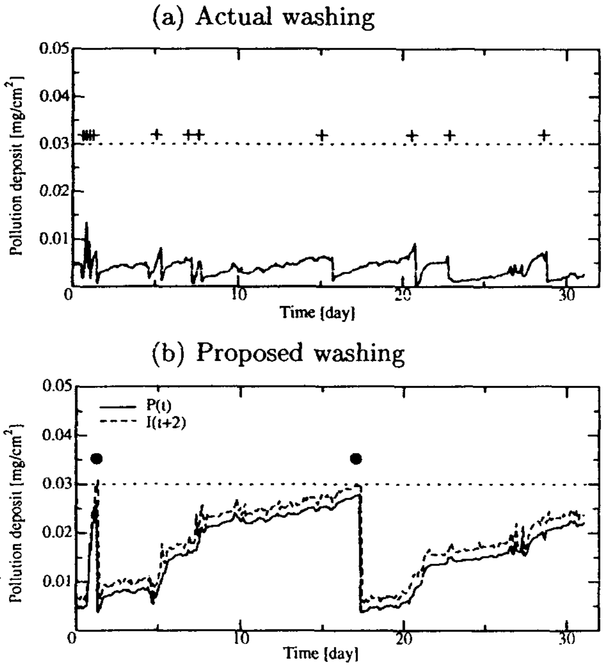

Fig. 2. Insulator pollution and washing timing (a) actual data of pollution deposits and washing timing at Karatsu substation during January in 1997, (b) proposed washing timing based on the mixture of EMP for the same data.

of rapid pollution A. The proposed prediction method is useful for safety decision making of washing timing.

Evaluation of washing timing

The proposed decision making of washing timing based on the mixture of the conditional EMP is verified by modificational usage of actual data of insulator pollution deposits. The modified data was constructed from the actual data by ignoring the effects of the actual insulator washing. Fig. 2 shows the insulator pollution and washing timing for actual case (a) and for the proposed one (b). The number of washing timing by the proposed method was reduced to be 2 with a small risk whereas the actual number was 11 in the duration of one month, in January 1997.

This results show that insulators near coastal substation are washed so frequently in the current stage because precise prediction of the insulator pollution and washing rule for safety have not been existed in actual field. Whereas, Fig. 2(b) shows that number of unnecessary washing can be reduced based on the proposed prediction of the pollution (12) and the washing rule (15). Then, the proposed method can be usable effectively and widely for insulator pollution prediction and its washing timing problems in actual field.

4. Conclusion

An innovative method for predicting nonlinear phenomena, called a conditional event matching prediction (EMP), was proposed. A prediction method for insulator prediction was constructed based on the proposed EMP. A decision making for timing of the insulator washing by use of the prediction method was evaluated based on the actual data of the Karatsu substation and proved its effectiveness in reduction of unnecessary insulator washing.

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