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Intelligent Support System for Power System Operators: Decision Making for Wash Timing of Polluted Insulators

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Abstract

The support or automation of various kinds of intelligent work is urged at large, integrated control centers. Given this demand, a decision making system for wash timing of polluted insulators, applying the Bayesian rule theory, has been developed in order to support maintenance work in the power system. The results of this system application revealed that exact wash timing of the insulators could be determined automatically, equivalent in precision to judgement by skilled operators, thus contributing to further work efficiency.

1. Introduction

Since 1990, the number of substations controlled by a control center for local system has increased, bringing about a more efficient power system operation and enhanced productivity. By 1995, a single large control center, called an integrated control center, was able to manage 60 to 70 substations, establishing an integrated control system. As the control range continues to expand in this way, power system operators face its limitations, finding difficulty identifying exact conditions from the huge store of information when a fault occurs, and in taking suitable countermeasures. Meanwhile, the enhanced reliability of power system components has led to decrease of faults and disorders while operators are on duty. With these achievements, demand has grown not only for automation of work planning support, restoration operations and maintenance planning, but also for upgraded support or automation of intelligence-dependent work. These include tasks that relay on the judgement and experience of skilled operators.

In this paper, we focus on the history of automated work at control centers for local system, and the description and benefits of the decision making system for wash timing of polluted insulators as a case model of automated intelligent work. In conventional decision making for wash timing of polluted insulators, power system operators ceaselessly supervised insulator pollution, deciding when to wash based on their veteran experience. This automatic wash timing system for polluted insulators is determined by analyzing past insulation pollution data, and weather data including wind velocity, wind direction and precipitation. The Bayesian rule theory of conditional probability is applied as a discriminate function for this automated system. The system, which plans and implements insulator washing work even while operators are busy with other work, has been found to contribute greatly to work efficiency. In addition, the wash timing is equivalent in precision to judgement by skilled operators, resulting in standardization of different decisions for wash timing.

In the future, power demand will increase even further with the development of an information intensive society, and a more comfortable, appliance-oriented lifestyle. This tendency will lead to the creation of more complicated, larger power networks, in conjunction with recent changes such as liberalization and deregulation within the power market. Intelligent support systems will be more sophisticated, and have better functions.

2. Intelligent Support System

Power system operation

The power system is composed of various elements: power stations, transmission lines, transformers, transformation equipment including circuit breakers, and distribution lines, as shown in Figure 1. Its system configuration varies ceaselessly as additional or new equipment are installed as demand grows.

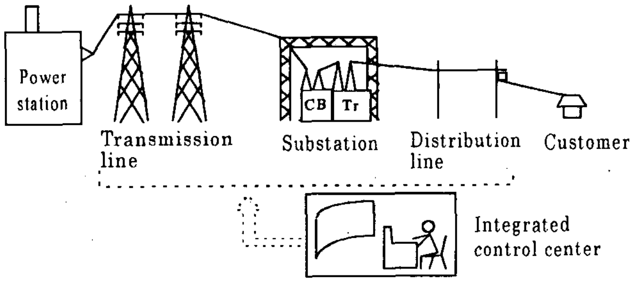

Fig. 1 Power system

The power system, which is constructed over a wide area, is comprised of ultra high voltage power facilities that facilitate efficient power delivery. It is a huge network. Because electricity cannot be stored, supply and demand occurs at the same time. Thus, in order to maintain stable system operation and supply constant, high quality power for customers, the entire power system components must be employed cost-effectively in a systematic manner. This power system structure featuring the control configuration, illustrated in Figure 2, is classified as: the central load dispatching center to control the trunk system; and the integrated control centers to control the local system.

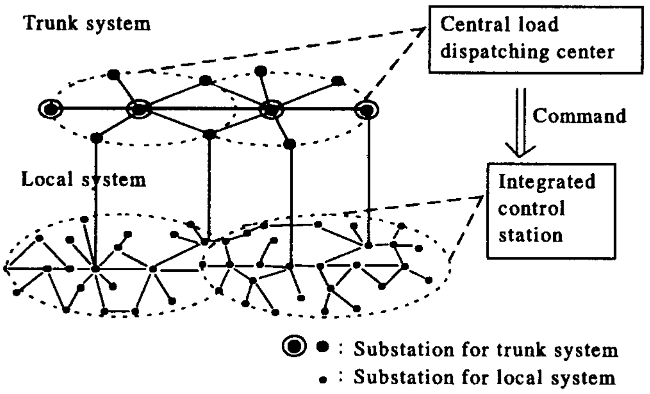

Fig. 2 Hierarchical control configuration

Changes in power system operation and automated items

The operation of integrated control centers is closely related to the range of the centralized control of substations. The centralized control of substations began in 1970, controlling two to three substations by a master substation. in order to improve operators' working conditions. Since then, with the progress of data transmission media, the number of substations controlled by a single master substation has gradually increased, as shown in Figure 3. Since a local system covers a wide area regionally, three to four control centers have been installed in each region, increasing to 30 control centers in the entire Kyushu area in 1985. Finally, for even more sophisticated operation, work efficiency, and enhanced productivity, three to four control centers, which used to be installed in one region, were comprehensively installed within integrated control centers for local system.

With the above developments, most substations have been unmanned since 1995, showing an unmanned system rate of 98%. Furthermore, the number of substations controlled by a single integrated control center increased to between 60 and 70. The number of operators necessary could be reduced by 60% of those necessary in 1970, contributing to great enhancement of productivity.

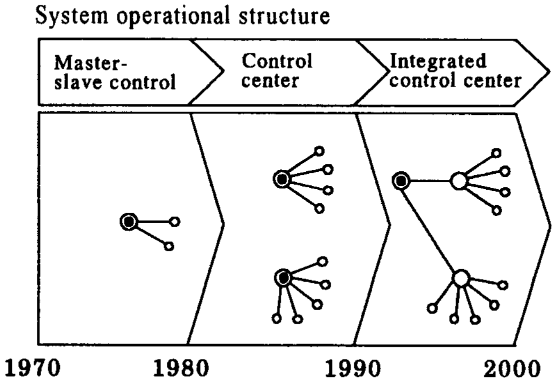

Fig. 3 Transition of the power system

During the early stages of control centralization, work automation was implemented in the recording of voltage and current at a designated time, recording the type of circuit breakers activated at a fault, and notifying these. Since then, planning work for demand forecast and dam system operation were automated, using advanced data processing equipment and new processing technology. To execute restoration work precisely, individual functions of operation and maintenance — such as detection of faulty sections and judgement of equipment disorder — were upgraded. Through these efforts, highly advancement of power system operation was achieved.

Needs for an intelligent support system, and anticipated benefits

As the number of substations to be controlled increases, the number of accidents and faults occurring within the system in a control region also increases. In addition, the volume of data, such as records of voltage, current, and equipment condition when a fault or disorder occurs, increases. On the other hand, thanks to the improved reliability of power equipment, faults and disorders encountered by workers on duty decrease. In order to facilitate these procedures, automation of various tasks such as recording, notification, and fault detection will continue to be promoted. Intelligent work, which used to be conducted by skilled operators, will require such support and automation. Expectations to automate intelligent work may result in even more effective application, where system operators can make judgements with the sophistication of an experienced veteran, and will be able to review their own methods theoretically.

3. Decision Making for Wash Timing of Polluted Insulators

Pollution and weather factors

Insulators of substations in coastal areas are vulnerable to deterioration of its performance. Insulator pollution here is attributable to surface salt deposits from salt-laden sea breezes, leading to faults, as shown in Figure 4. To prevent the worst from occurring, hot line insulator flushing is generally practiced, in which the salt deposit on insulators is washed down with water. It is commonly known that salt accumulation on the insulator surface is in proportion to a triplicate increase in wind velocity[1]. Also, the salt particles on the insulator surface will show damp from high atmospheric humidity, resulting in severe pollution. On the other hand, salt deposited on the insulator surface is washed down by rain. This is called a rain wash effect, and reports say that a rainfall of 10mm/hr or heavier would cleanse 90% of salinity[2]. It is assumed from the foregoing that weather factors affecting insulator pollution are wind velocity, wind direction, precipitation and humidity. In light of this, the insulator pollution value and wind velocity are used as factors in the decision making system.

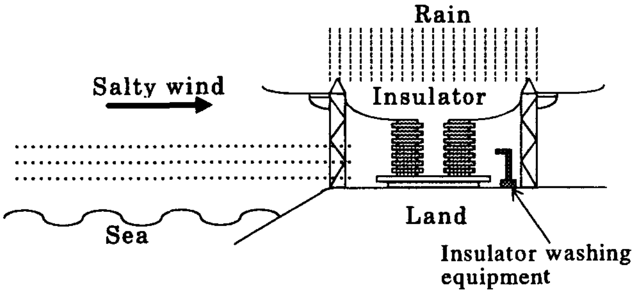

Fig. 4 Insulator pollution

Decision method for wash timing

An discriminate function to determine insulator wash timing is sought by utilizing the Bayesian rule theory, relating to conditional probability. Presuming that the probability variable x is the determinative element for execution of insulator washing under the conditions of the factor for determining insulator wash timing $y = (y_1, y_2)^T$ (y_1: insulator pollution value, y_2: wind velocity), the conditional probability density function $f(x \mid y)$ is sought. The $f(x \mid y)$ of factor y under the condition of insulator washing $x = 0, 1$, and the probability $p(x)$ for executing insulator washing can be estimated from past results of insulator washing. Based on this estimation, the $f(x \mid y)$ can be calculated by utilizing the Bayesian rule theory. The $p(x)$ for executing insulator washing can be calculated according to the frequency in past results of insulator washing, thus, it can be sought under the formula below [3]:

$$p(x) = \begin{cases} \dfrac{N-N_w}{N} & (x=0) \\ \dfrac{N_w}{N} & (x=1) \end{cases} \quad \cdots\cdots \quad (1)$$

Where;

N : number of measurement for insulator pollution
Nw : frequency of insulator washing

The conditional probability density function $f(x|y)$ of the probability variable x when the condition y is given, is calculated under the formula below by utilizing the Bayesian rule theory.

$$f(y|x) = \frac{f(y|x)((1-p(1))q(x)+p(1)q(x-1))}{(1-p(1))f(y|0)+p(1)f(y|1)} \quad \cdots\cdots \quad (2)$$

From the conditional probability density function $f(x|y)$, the probability of x=1 under the factor y is given, in other words, the conditional probability $p(1|y)$ for executing insulator washing when data of insulator pollution value and wind velocity are given, is as indicated below.

$$p(1|y) = \frac{p(1)f(y|1)}{(1-p(1))f(y|0)+p(1)f(y|1)} \quad \cdots\cdots \quad (3)$$

Insulator washing is judged to be necessary in the case where the $p(1|y)$ under this formula (3) exceeds the threshold value λ. Thus, when the factor y is given, insulator washing is to be carried out based on the conditions described below.

$$\begin{cases} \text{Washing} & p(1|y) > \lambda \\ \text{No Washing} & \text{otherwise} \end{cases} \quad \cdots\cdots \quad (4)$$

Figure 5 is a conceptual figure for determining the wash timing of polluted insulators, on the basis of the formula (4). When the factor is y_0, and in the case where the probability $p(1|y)$ for executing insulator washing obtained from past results turns out to be λ or more, insulator washing is judged to be necessary. When the threshold value λ = 0.5, the $p(1|y)$ for executing insulator washing and the $p(0|y)$ for not executing insulator washing become identical. At this moment, the probability obtained from the automatic decision making system, differing from past results - that is, the probability shown with oblique lines in the figure -becomes the minimum. It is implied here that the threshold value λ =0.5 can lead to a higher precise judgement, the nearest to past wash timing records. The larger the threshold given λ, the less frequently is insulator washing considered necessary.

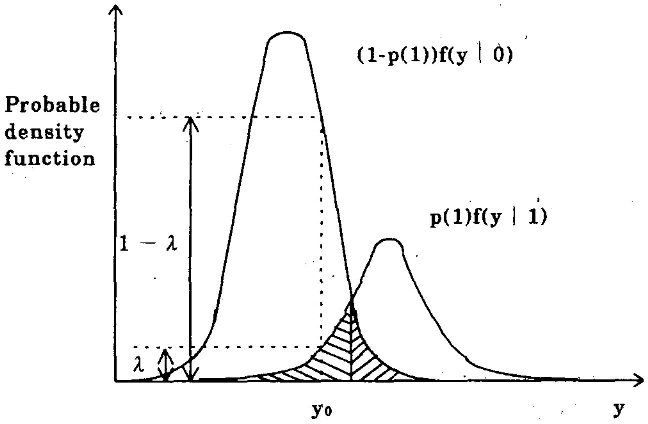

Fig. 5 Decision making concept for wash timing of polluted insulators using conditional probability

Results

The pre-set insulator pollution value changes to post-washing data when insulator washing is executed. In order to seek the pollution value when insulator washing was not been executed, its determinative element must be corrected or processed. The value is obtained by means of seeking the difference between the pollution value measured last time and that measured this time, and then adding it to the pollution value corrected. Figure 6 shows the evaluation result of the automatic decision making system for wash timing of polluted insulators, based on data measured by Karatsu Substation in September, 1996. In this case, the threshold value $\lambda = 0.5$ is given to the formula (4). By raising the threshold value, it is possible to reduce the frequency of washing while maintaining reliability corresponding to the threshold value.

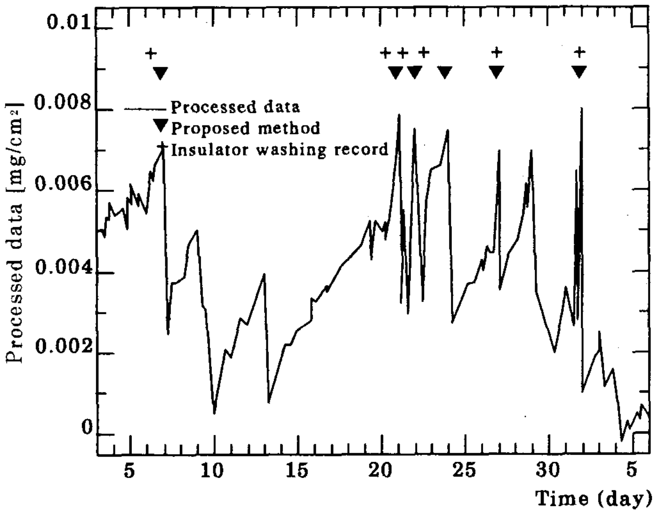

Fig. 6 Automatic decision making record based on the processed data

4. Conclusion

In the above paragraphs, evaluation was made on the effects of introducing a support system for intelligent work, taking the automatic decision making system for wash timing of polluted insulators as an example of the functions of large, integrated control centers. Dependence on electric energy is predicted to continue growing, in step with the advance of an information-oriented society and the diversification of personal lifestyles. These social needs will bring about a larger and more complicated power system. Various kinds of intelligent work that currently fall under judgement of field experts; specifically, work planning and adjustment, restoration operations, and decision making for facility maintenance timing, will continue to be automated or supported at a fast pace in the future. For the time being, however, it is necessary to effectively utilize existing equipment from a cost-effective point of view. Given this situation, such systems will be specifically introduced to the marginal supervision of transmission lines, and the inspection and diagnosis of transformation equipment will assist reviewing of current operational procedures.

In establishing this kind of intelligent support system, it is necessary to analyze data gathered in the past, clarify a rule for judgement criteria, apply an accurate method and make verifications for an extended period. Additionally, it will be necessary to establish a database from information relating to the equipment being used, which organically links a large amount of data on system operation, weather, and environment. The last, but not least, important factor in the development of the systems is that it needs to be simple and user-friendly [4].

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