DEVELOPMENT OF ADVANCED DISTRIBUTION AUTOMATION SYSTEM WITH FAILURE CAUSE ESTIMATION FUNCTION

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ABSTRACT

We are planning to develop the new Advanced Distribution Automation System (ADAS) equipped with optical communication network and sectionalizer with sensor for more grid reliability and efficiency on maintenance operation. The new system is featured with the function of fault cause or damaged part estimation. The new sectionalizer captures the waveform of electrical line surge originated by fault and the system analizes the waveform for this function. This paper mainly introduces the system configuration of ADAS and an early stage examination of fault cause estimation technology.

INTRODUCTION

We have developed and operated the world-class reliable distribution system. However, we are facing variety of challenges, such as aging facilities and technicians. To keep a reliability of the system under these challenges, we are planning to introduce the new ADAS based on optical communication network [1]. In this system, measured data, such as line current / voltage, energy / power factor, and fault information (V0, I0) is used for advanced supervising and quality controls for distribution grid.

Since 2017, we have been performing field trial for the system using about 1600 sectionalizers (approximately 2% of all) installed for verification of various new functions. This paper introduces fault cause estimation function which contributes to effective maintenance operation by specifying the fault or critical fault potential to be eliminated from the grid.

ADVANCED DISTRIBUTION AUTOMATION SYSTEM (ADAS)

EFFECTIVENESS OF FAULT CAUSE ESTIMATION FUNCTION

The current DAS system has FLISR (*1) function and is widely adapted in Japan. The system can recognize fault segment by working with substation's CB reclosing process. In case of success on CB reclose, patrol inspection by field technicians is performed to all segments of feeder line to identity the cause of trip since fault segment can not be addressed. Since the non-grounded neutral distribution system of MV (6.6kV) is supported in Japan, the appearance of fault point is relatively small and sometime it is difficult to identify. If it is the case of transient contact like crow or foreign object by wind, recurrence is less concerned. However, in case of nonpermanent potential failure or damages by lightening or aging related deterioration of facility insulation, there are some cases that CB repeats trip every several days which cause severe customer compliant. Such a case, extensive inspection and preventive maintenance must be performed. The fault cause estimation can provide best possible measure to perform effective maintenance by considering the possible risk of CB trip recurrence.

Fig.1 shows the system configuration of new ADAS. Sectionalizer with sensor acquires the waveform data and transmit it to central server for analysis and estimation. Associated Information like Failure Report, Weather Data, Environmental Information are accumulated to central server. These data and real time open data (like weather at fault timing) are used for the estimation as well.

FLISR (*1): Fault Location, Isolation, Service Restoration

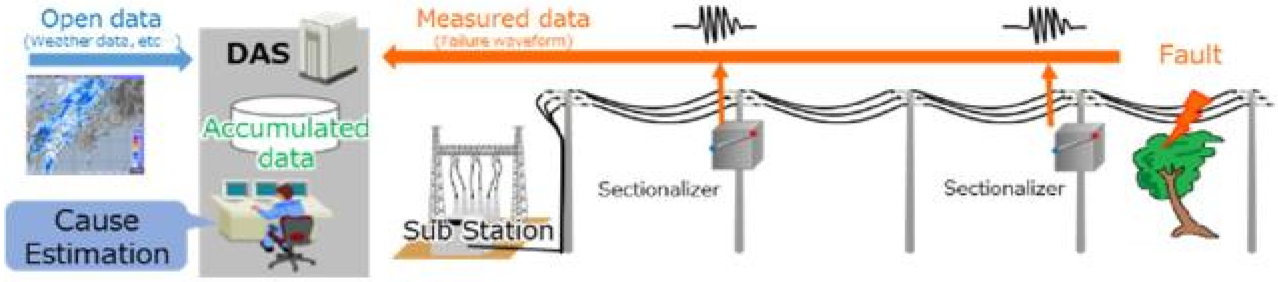


Fig.1 Cause Estimation System on Advanced Distribution Automation System (ADAS)

CAUSE ESTIMATION SYSTEM

Fault related waveforms will be accumulated and classified for machine learning of the system and these are used as teaching data for fault cause estimation.

However, followings are the issues needed to be solved.

・less availability of teaching data on system introduction stage

・some cases exist that the system can not estimate the fault cause correctly due to the similarity of waveform in different causes.

To address these issues, Associated Information for the past 10 years is studied in detail and decided to be used for improving the accuracy on estimation. Based on KANSAI corporate data base, fault cause, time, weather and regional information are carefully evaluated and rebuilt as statistical probability DB to improve failure cause estimation accuracy of waveform analysis.

Fig.2 shows the concept of combined method of waveform analysis and statistical probability for better estimation.

(1) Cause Estimation by fault waveform

The acquired waveform data is used for the cause estimation based on prepared fault cause class category. Wavelet transformation method is adapted for waveform analysis since Fault waveform is more like surge signal which has a tendency of variation with time. Fault wave signal is captured by 5kHz sampling by sectionalizer and fed to Wavelet transformation on central server. Wavelet transformation analyzes the harmonic components existence ratio up to 19th harmonic per unit time (500ms ～ 2000ms) . The wavelet transformation result is categorized by Support Vector Machine (SVM) for cause estimation. SVM is known as one of the key technologies for characteristic recognition measure of artificial intelligence technology.

In the initial introduction stage for new system, category criteria are taught by experiment result at test field. Machine learning of accumulated data by real field fault will improve the estimation accuracy over time.

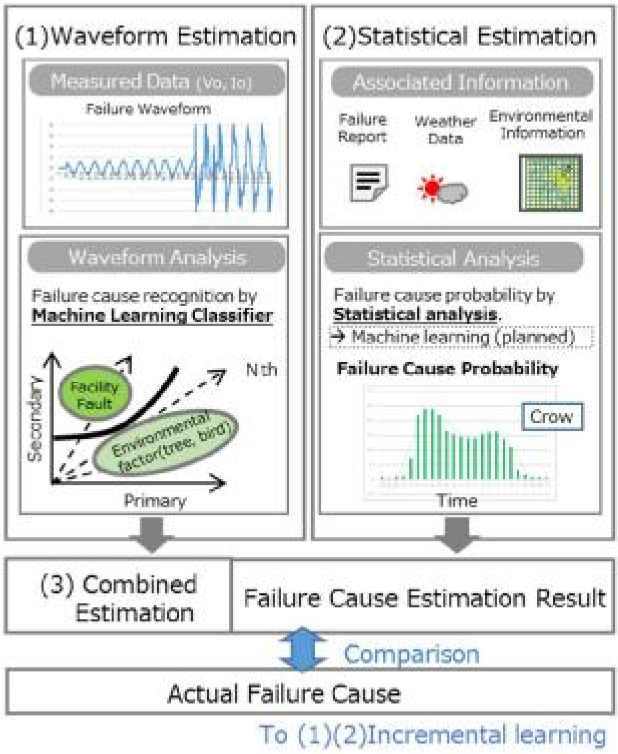


Fig.2 Advancement of Cause Estimation System

Fig.3 shows the result of wavelet transformation. Fault on cable, and animals (crow & snake) contact, both shows needle-shape waveform and resulted more existence of higher harmonic components. However, fault on vegetation shows more like sine-shape waveform and less existence of high harmonic components. By waveform analysis (Wavelet & SVM), it is easier to apart cable fault from vegetation. However, it is difficult between cable and animals. As these show that the accuracy of waveform analysis approach may not be enough for some cases.

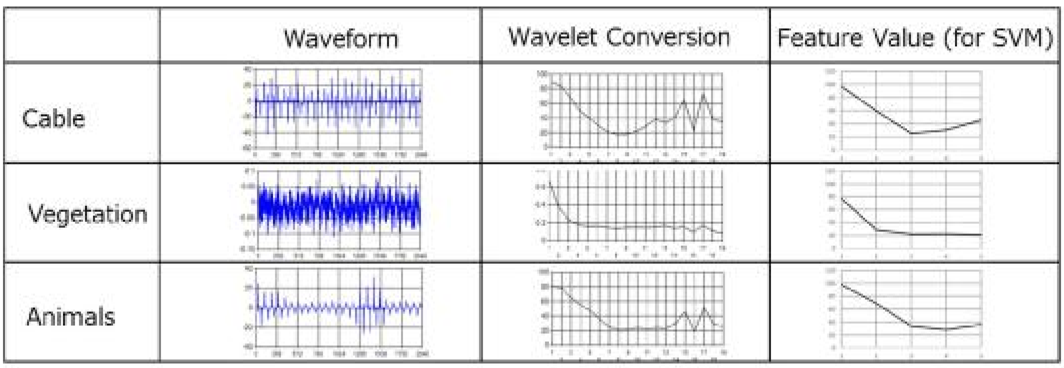


Fig.3 Waveform Analysis

(2) Cause Estimation by statistical data
Fault cause probability is calculated based on the accumulated fault data (past 10years / 32930 faults) and is prepared as statistical data. In this data, cause probability is rebuilt by condition items (time, temperature, weather, wind level, etc)
By comparing with the conditions at the timing of fault occurrence, statistical probability of fault cause can be derived. Machine learning approach will also be taken by ongoing statistical data accumulation over time.

Fig.4 shows the examples of statistical data. Cable fault shows higher probability on higher temperature and Vegetation fault shows it on windy condition. Regarding crow & snake fault, crow in daytime, snake in night time has higher probability while crow in rainy condition is low. As these show, statistical probability can compensate for the estimation accuracy by waveform analysis.

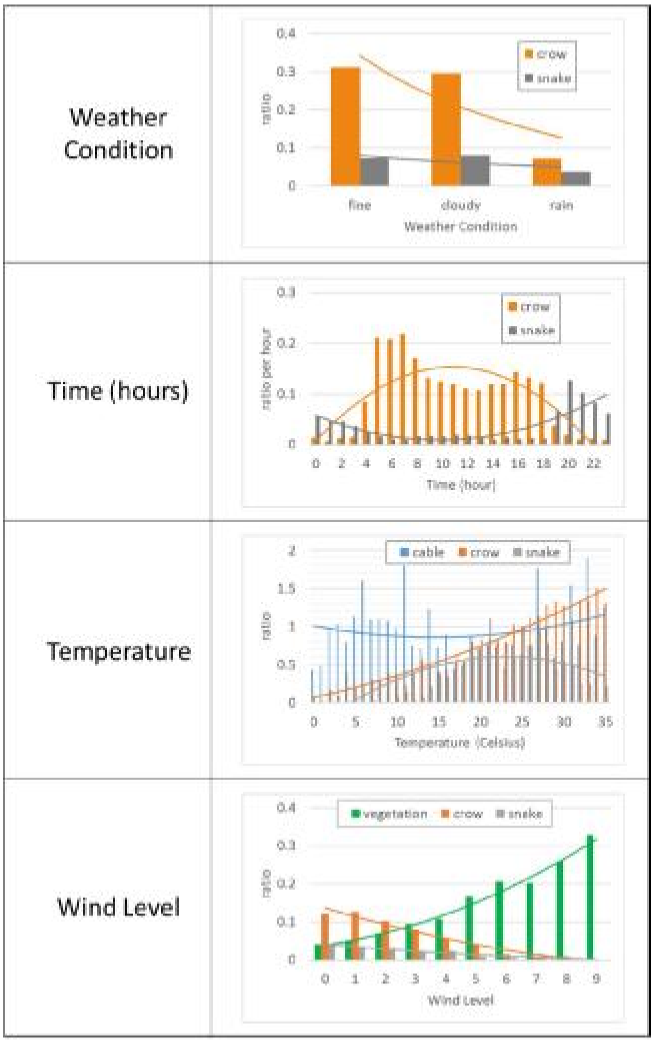


Fig.4 Statistical Analysis

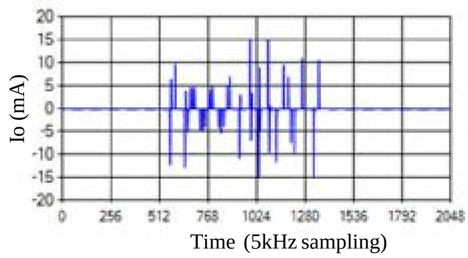
(3) Combined Estimation
As described in proceeding clause, the probability of proposed cause by waveform analysis and derived probability by statistical data are combined to improve estimation accuracy. Bayes theorem is used for connecting the proposed cause by waveform analysis with the statistical probability in terms of cause and result.
Following formula shows Bayes theorem.
Bayes theorem is well known method to revise a-priori probability w by new information, likelihood p and a-posteriori probability w' is obtained as a result.

$$w'(\theta_i|z) = \frac{w(\theta_i)p(z|\theta_i)}{\sum w(\theta_j)p(z|\theta_j)}$$

An initial value of a-priori probability w is proposed by the waveform analysis. Compensation ratio, likelihood p, is prepared based on the probability of accumulated field data. And a result value, a-posteriori probability w', is obtained by normalizing by the denominator.
The accuracy of cause estimation is improved by this combination.

FIELD TRIAL

We have installed about 1600 sectionalizers in OSAKA and KYOTO area for the initial verification of ADAS and started waveforms capturing from September 2018. At this point, no permanent fault has not been reported but some waveforms which are over the pre-determined threshold level have been captured by sectionalizers. Fig.5 shows the captured waveform and the conditions.



Conditions:

[Date Time]	2018/9/30 22:40
[Weather]	Light Rain
[Temp]	24.7℃
[Wind]	5.2m/s
[Area]	Rural area

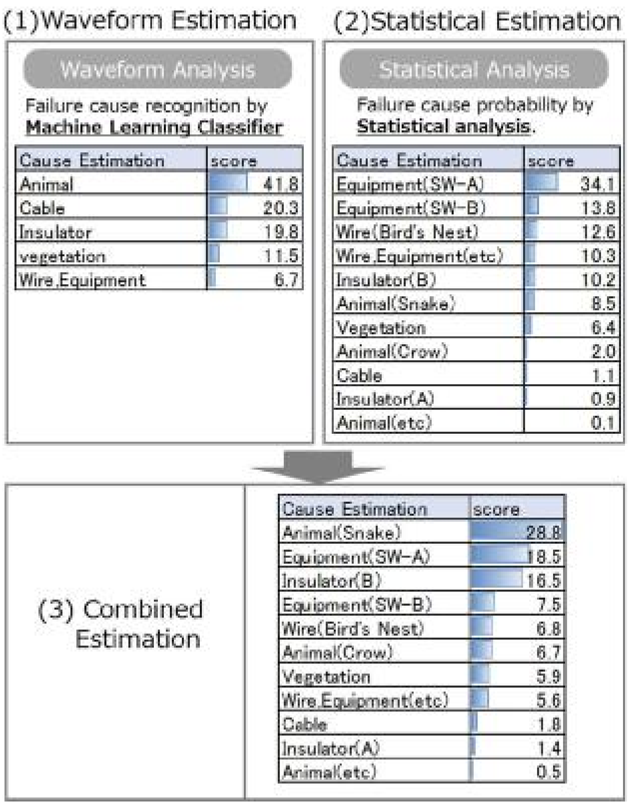
Fig.5 Captured Waveform of Failure & Conditions

Fig.6 shows the results of fault estimation of the captured waveforms processed as follows.

(1) Cause Estimation by fault waveform
Waveform analysis suggests that animals and cable could be the cause of the captured waveform since it has needle-type shape.
(2) Cause Estimation by statistical data
On the other hand, statistical analysis suggests that Equipment (SW-A) could be the most relevant cause on this condition.
(3) Cause Estimation by combined method
According to the score of combined estimation, we have concluded that the animals, especially snake, is the most probable cause.

We have not confirmed the cause by patrol inspection since it was a transient fault without CB trip and recurrence is less concerned on snake contact. However, if it repeats, deterioration of Equipment (SW-A) or Insulator (B) can be addressed as a possible cause and corrective maintenance action will be taken by intensive inspection.

In this trial, it is understood that the combined estimation can be the practical approach to perform effective maintenance considering inspection priority by knowing the possible cause hierarchy.



Cause Estimation	score
Animal	41.8
Cable	20.3
Insulator	19.8
vegetation	11.5
Wire,Equipment	6.7

Cause Estimation	score
Equipment(SW-A)	34.1
Equipment(SW-B)	13.8
Wire(Bird's Nest)	12.6
Wire,Equipment(etc)	10.3
Insulator(B)	10.2
Animal(Snake)	8.5
Vegetation	6.4
Animal(Crow)	2.0
Cable	1.1
Insulator(A)	0.9
Animal(etc)	0.1

Cause Estimation	score
Animal(Snake)	28.8
Equipment(SW-A)	18.5
Insulator(B)	16.5
Equipment(SW-B)	7.5
Wire(Bird's Nest)	6.8
Animal(Crow)	6.7
Vegetation	5.9
Wire,Equipment(etc)	5.6
Cable	1.8
Insulator(A)	1.4
Animal(etc)	0.5

Fig.6 Cause Estimation Results

CONCLUSION

We introduced the new Advanced Distribution Automation System (ADAS) equipped with optical communication network and sectionalizer. We proposed fault estimation technology combining waveform analysis and statistical analysis for ADAS. We have verified the procedure of estimation method through field trial and going to expand the trial area to improve the procedure of estimation method for more accuracy.
Proposed method has utilized the advanced technology like machine learning and artificial intelligence. Classifier category of waveform analysis will also be refined and detailed based on accumulated data reflected various failure mode at field. Fault cause estimation technology will provide the most effective approach to address nonpermanent failure issues.

KANSAI has been engaging in research and development of fault point locating technology [2] for years as well. Fault point locating and fault cause estimation will lead to minimize the time of fault restoring work and to perform effective maintenance against critical fault potential. With these technologies, we are going to maximize the service quality, and going to challenge for aging facilities and technicians' issues surrounding distribution network.

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