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PS2- Future Functionalities and Applications

Development and Site Application of Intelligent Partial Discharge and Condition Assessment System for Underground Transmission Lines

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SUMMARY

Artificial intelligence and machine learning technologies have begun to be introduced in facility diagnosis and condition assessment, accelerating the intelligence, automation, and digitalization of facility operations. Meanwhile, underground transmission lines have been continuously expanded in Korea due to demands for expansion of new towns and undergrounding of power lines. Moreover, reliable diagnostic and condition evaluation technologies for the facility are increasingly required, as it is reaching 30 years after installation.

Therefore, the Research Institute developed the intelligent partial discharge and condition assessment technology and system for underground transmission lines, in which artificial intelligence technologies are incorporated. To do this, a big data system was firstly established to collect and manage data such as partial discharge measurements, line operations, and online monitoring & inspections. Second, based on machine learning techniques, a two-step automatic decision algorithm was developed and systematized to simultaneously analyze partial discharge patterns and pulse shapes. In addition, this system also includes a new method of calculating Health Index using Neural Networks. The Health index and the diagnostic results determine the condition rate of the underground transmission lines.

The intelligent partial discharge and condition assessment system for underground transmission lines named U-phas (Underground - Partial discharge and Health Index Accessment System) consists of the big data processing module, the partial discharge decision module, the Health index/condition rate module, the artificial intelligence module, and so on. It is applied to Company's actual underground transmission lines and is under operation. This system can expect that it will be able to dramatically prevent breakdowns of underground transmission lines in the future.

KEYWORDS

Partial discharge, Diagnosis, Machine learning, Health Index, Condition assessment system

1. INTRODUCTION

A few years ago, the maintenance method of power facilities was TBM (Time Based Maintenance), which determines the replacement time according to the operating period of the facility. However, the trend is changing to CBM (Condition Based Maintenance), which is known as a method of determining the replacement time by diagnosing and evaluating the condition of equipment in operation. Therefore, accurate diagnosis and condition assessment technology for facilities is required.

Partial discharge diagnosis is the only diagnostic method for underground transmission lines in operation, and it is difficult to find an alternative. The Company introduced and operated an online partial discharge diagnosis system on 345kV underground transmission lines since 2015, but the data type, format, and connection method were different for each manufacturer, resulting in poor system management and operational efficiency. However, since 2018, the online partial discharge diagnosis system application plan based on the IEC 61850 communication protocol, an international standard communication standard, has been established and is being used in 2020 through verification. The new online partial discharge diagnosis system acquires a partial discharge signal generated when an internal abnormality occurs, such as a junction box, through a detection sensor, and transmits the detected signal data to the diagnostic unit through a communication device, thereby confirming event data. These standardized systems and data became the basis for developing the intelligent partial discharge and condition assessment system for underground transmission lines named U-phas as shown Figure 1. The accuracy of the partial discharge diagnosis was increased by applying the artificial intelligence algorithm and the condition rate could be determined in real time by applying the improved Health Index.

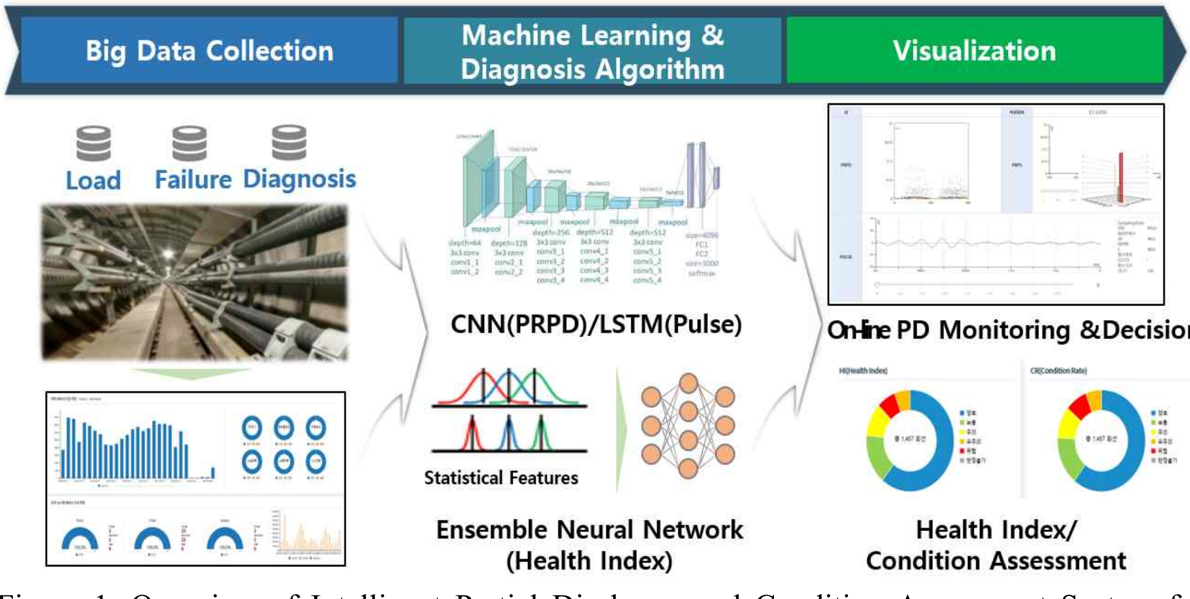

Figure 1. Overview of Intelligent Partial Discharge and Condition Assessment System for Underground Transmission Lines(U-phas)

2. SYSTEM DEVELOPMENT

2.1 Partial discharge decision algorithm

Since the new online partial discharge diagnosis system decides partial discharge by the PRPD pattern recognition, the operating personnel and experts is required for final decision.

Therefore, a two-step automatic decision algorithm was developed that distinguishes PRPD pattern and pulse using various artificial intelligence techniques as shown Figure 2. The algorithms for PRPD pattern recognition are divided into SVM (Support Vector Machine) using statistical feature extraction and CNN (Convolution Neural Network) clustering method directly using image data. The algorithms for Pulse are divided into three methods, Wavelet transform using SVM method, LSTM (Long -Short Term Memory) and CNN. Then it is finally decided as partial discharge when both PRPD and Pulse analysis results are presented partial discharge.

Experimental data and diagnostic data in the field used in the PRPD pattern recognition algorithm using CNN are converted into PRPD images through pre-processing and standard colormap. These images are created as a learning model through the transfer learning process of the VGG 19 model among the CNN techniques, and the result of verification using real data showed a high accuracy of 99.8%. The data used in the PRPD pattern recognition algorithm using SVM goes through a noise removal process and extract seven statistical features(Cross-Correlation, Positive/Negative Kurtosis, Positive/Negative Skewness, Positive/Negative Standard Deviation, ϕ-n / ϕ-$n_{(sk(q))}$ / ϕ-$q_{(Max)}$ / ϕ-$q_{(Mean)}$). As a result of verification by combining these features, it showed a high accuracy of 99.9%.

In addition, we developed an analysis algorithm for pulse data, which we thought only as a part of experts. First, each pulse was learned and verified using the t-SNE dimension reduction and clustering technique, and as a result, it was confirmed that PD and noise can be distinguished. Second, the algorithm using the LSTM analysis technique, which is useful for time series data processing, decides as partial discharge when the ratio of PD in the total converted data is 0.65 or higher. This the ratio of PD could be changed through further studies. Finally, we developed the algorithm that can decide whether the partial discharge signal is far or near through an analysis technique using wavelet feature extraction of pulse data.

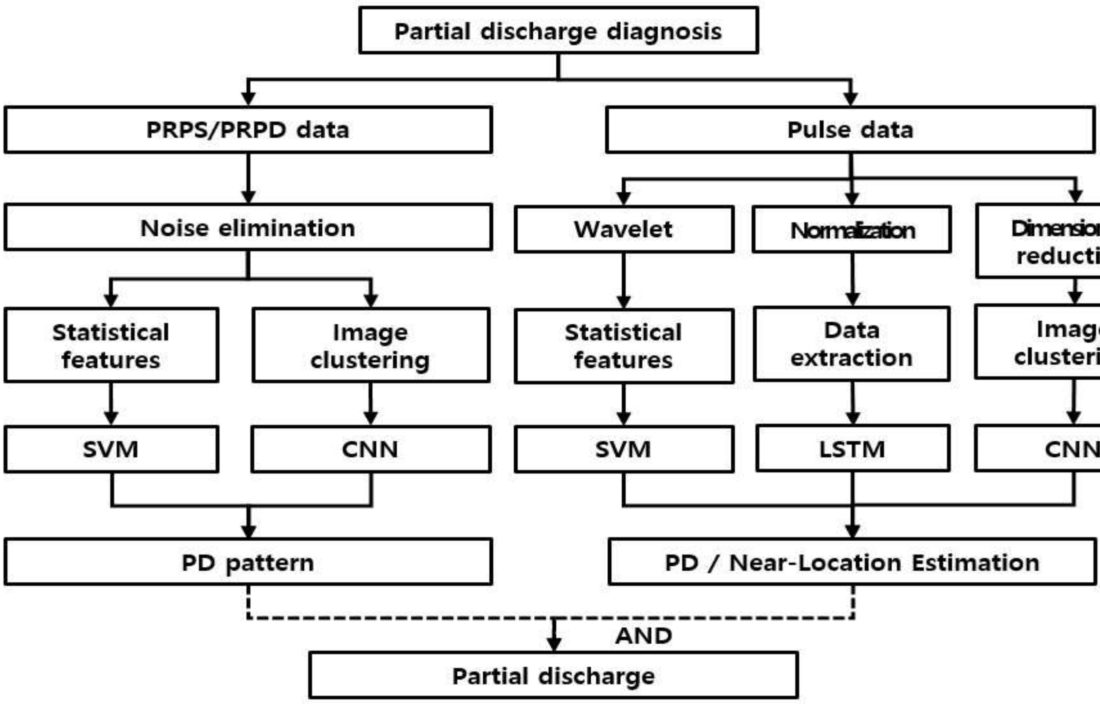

Figure 2. Two-step automatic decision process

Table 1. Construction of the dataset of the PRPD pattern recognition algorithm using CNN

CNN	Data label			
Train	Corona	Surface	Void	Noise
Experiment	272	560	669	400
On-site	-	-	-	4,164

Table 2. Verification of the PRPD pattern recognition algorithm using CNN

Verification	Error	Accuracy[%]
1,516	3	99.8

Table 3. Construction of the dataset of the PRPD pattern recognition algorithm using SVM

SVM	Data label			
Dataset	Corona	Surface	Void	Noise
Experiment	259	528	622	380

Table 4. Verification of the PRPD pattern recognition algorithm using SVM

Verification	Error	Accuracy[%]
451	1	99.9

Table 5. Verification of the Pulse decision algorithm using LSTM

Verification	Error	Accuracy[%]
300	3	99.0

2.2 Condition assessment algorithm

Statistical significance between normal and faulty lines was confirmed through the results of analysis of variance and logistic analysis of additional operating parameters as well as parameters used in the existing Heath Index. Finally, 8 parameters showing statistical significance were selected as input parameters for the new Health Index calculation algorithm. The Health index calculation algorithm were developed using 8 input parameters based on logistic regression analysis and ANOVA. This algorithm solved the problem of the lack of technical basis of the simple weighted summation method. The ensemble neural network was selected based on the results of applying various methods to solve the problem of imbalance between classes of data obtained during the development process. Finally, health index algorithm based on ensemble neural network was selected as the improved health index calculation method for this system .

A method for calculating the condition rate was proposed by integrating the improved health index(HI) and the risk index (RI) reflecting the diagnosis result as shown Figure 3. This presents the interval of inspection and diagnosis of underground transmission lines and includes action methods and replacement priorities for each condition rate. This health index is updated once every half year and will be continuously monitored. And if the life of the XLPE insulated cable is confirmed, more accurate calculation is possible.

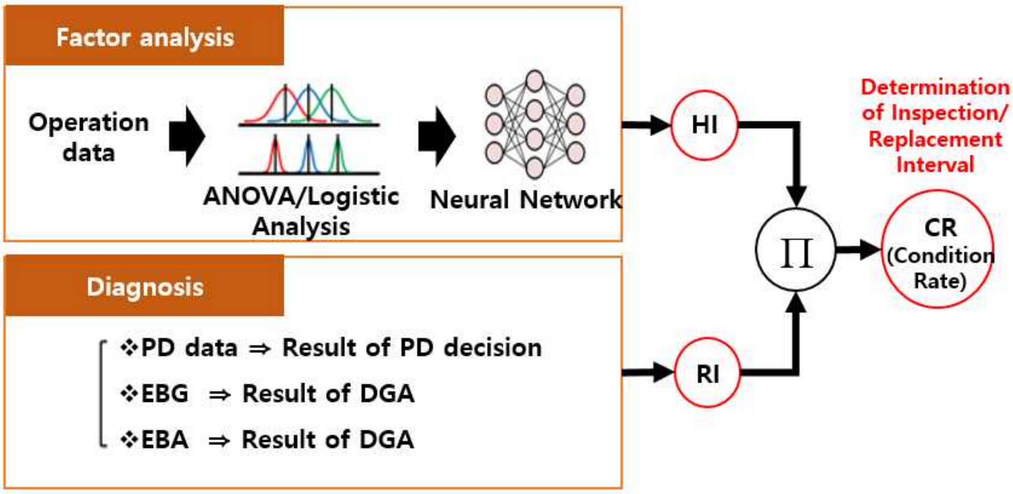

Figure 3. Calculation process of Condition Rate(CR)

2.3 System structure

U-phas uses the headquarters' data connection server for diagnosis/operation data connection and the network is configured to collect data from the development server. All diagnostic and operational data linked to the system can be inquired, analyzed, and managed through the big data cluster. The AI cluster capable of re-learning and learning model development was built, and the decision results were presented and visualized by applying various AI algorithms. The UI of the system is divided into general status, condition assessment, partial discharge decision, big data, artificial intelligence platform, and system management. (Figure 5 to Figure 8)

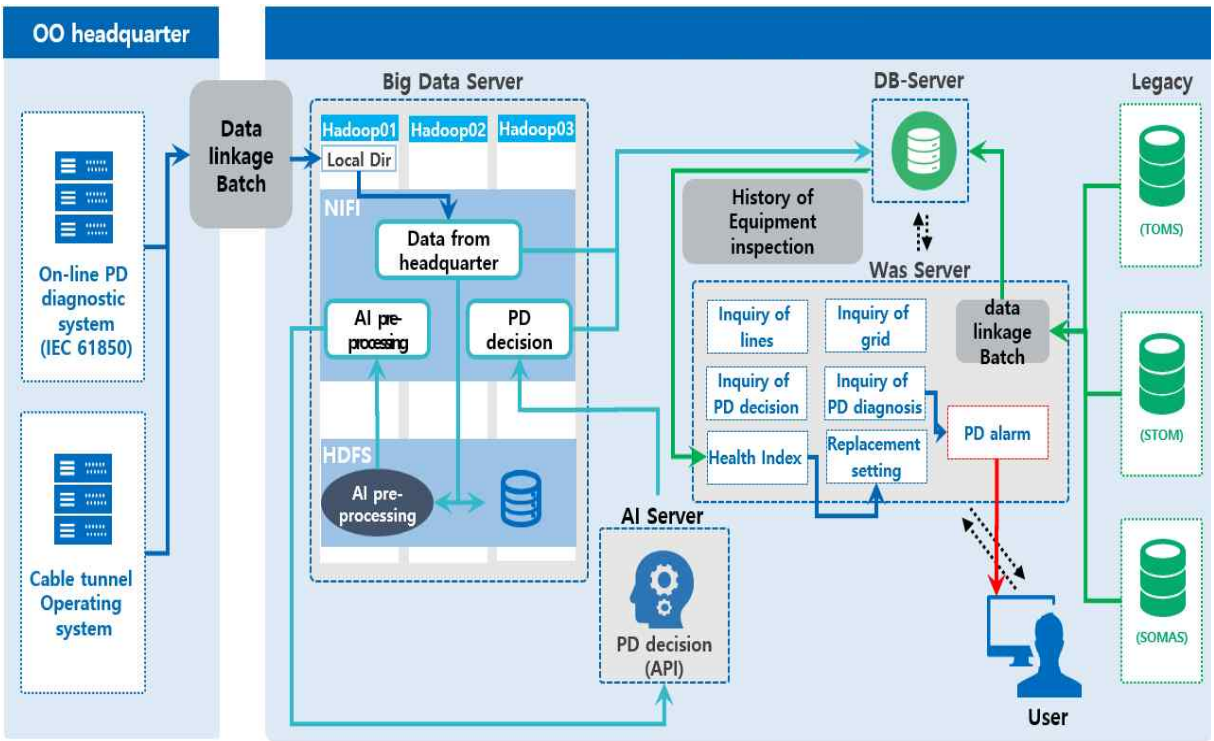

Figure 4. Configuration of U-phas

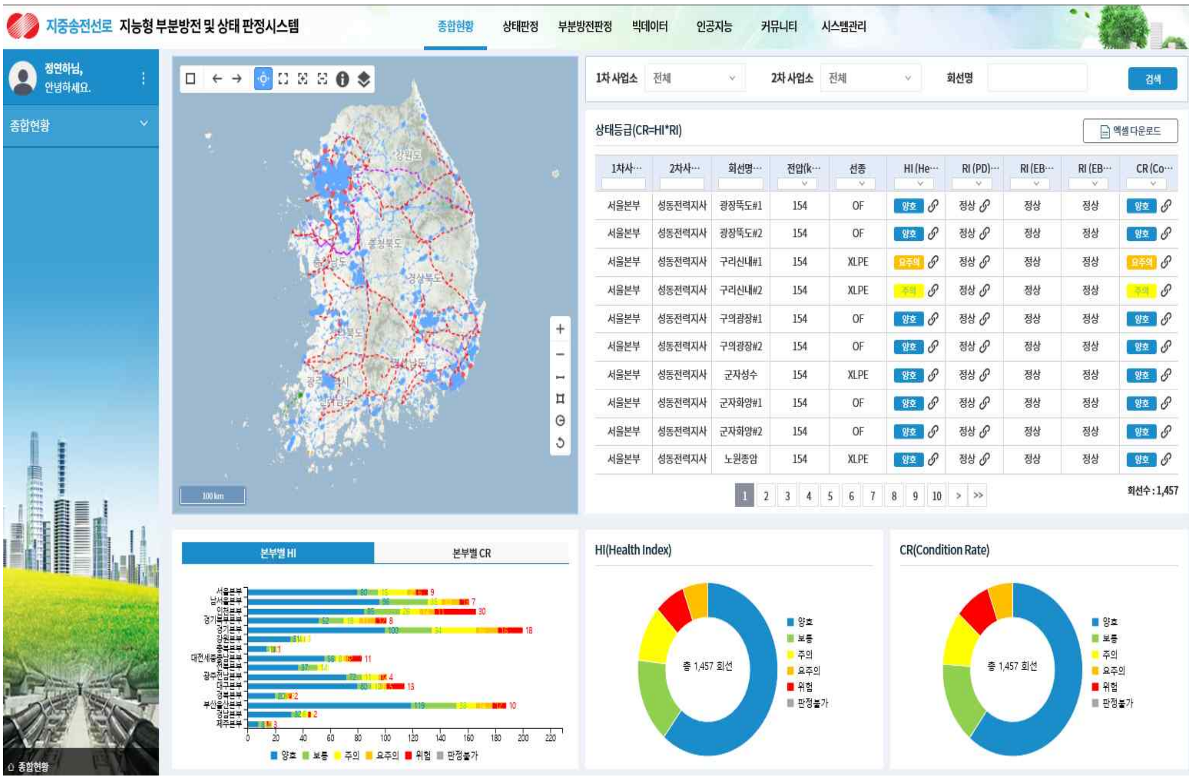

Figure 5. General status of Health index(HI) and Condition rate(CR) in U-phas

Figure 6. Big data Management in U-phas

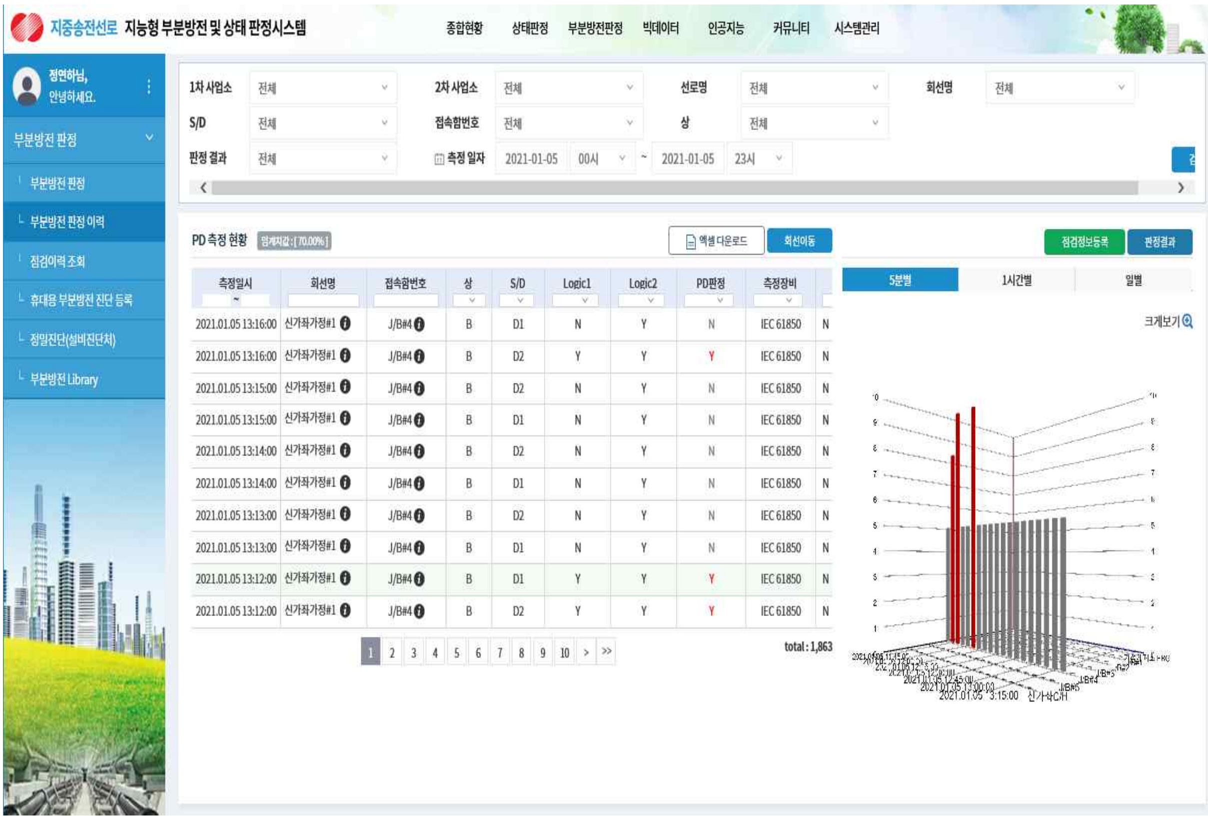

Figure 7. Partial Discharge decision for each line in U-phas

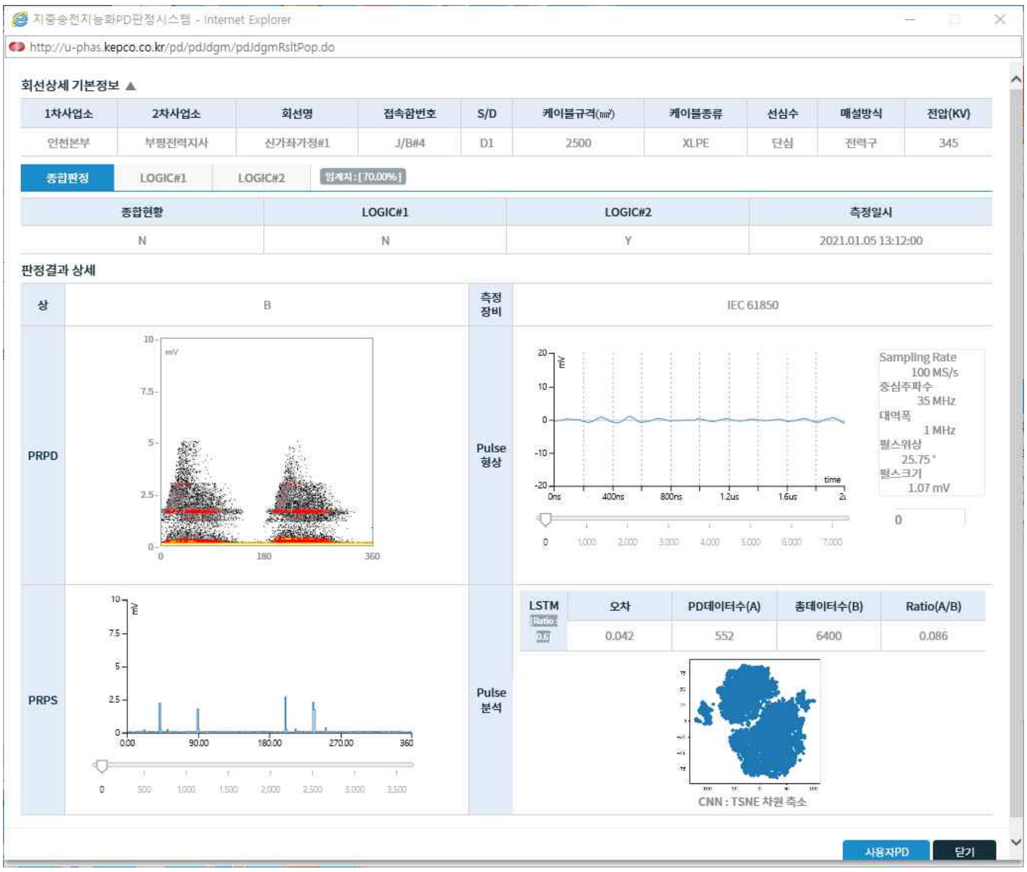

Figure 8. Result of PD analysis using AI algorithm in U-phas

2.4 Application

U-phas was applied to 23 undergroun transmission lines in the field. 14 lines to which the new online partial discharge diagnosis system was applied provide pulse data, so the decision result can be checked with a two-step automatic decision algorithm. On the other side the accuracy of algorithm is low because 9 lines to which the existing system is applied is decided only with PRPD data. This existing systems will be improved soon.

Figure 9. Application of Company's actual underground transmission lines

3. CONCLUSIONS

The intelligent partial discharge and condition assessment system for underground transmission lines named U-phas comprehensively collects and manages diagnostic and operation data scattered in individual systems in the field. It is analyzed in real time and the results can be visually confirmed through algorithms using artificial intelligence techniques. Although it is currently applied to only one headquarters, it will be used in connection with all headquarters in 2022. And an advanced partial discharge decision algorithm is being developed by continuously collecting and analyzing on-site diagnostic data.

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