HiPDS-G

HYUNDAI HEAVY INDUSTRIES CO. LTD

Hyundai Intelligent Preventive Diagnostic System for GIS

User’s Manual
Hyundai Intelligent Preventive Diagnostic System for GIS

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1. Introduction of GIS preventive diagnostic system

1.1. Overview of GIS preventive diagnostic system

Although the reliability of GIS is very high, any internal breakdown which can occur invariably causes extensive damage with severe financial penalties and an outage of several days is needed to be repaired. To prevent these unknown breakdowns, it appears likely that improved GIS designs will be supplemented by quite extensive diagnostic monitoring as insurance of GIS. There are two main advantages of diagnostic monitoring; it will allow the user to adopt condition-based maintenance and reduce revenue expenditure, and it could lead to the ideal situation of being able to detect a developing fault in time to prevent an unplanned outage. Ideally the partial discharge (PD) monitoring techniques described here should be developed with these two objectives in mind.

If there is not appropriately connected either to the HV conductor or the chamber, corona from a sharp protrusion, free moving particles, insulation material defect, and so on, a GIS can fail dielectrically and breakdown. However, a GIS gives rise to partial discharge which indicates a change in the insulation characteristics before failure occurs. The fast rising edge of the partial discharge pulse contains frequencies with extend well above 1 GHz, and these excite the GIS chamber into various modes of ultra high frequency (UHF) resonance. The resonance persists for at least a microsecond and may be picked up by UHF PD sensors fitted in insulation barriers between GIS enclosure. The UHF signals can be amplified and displayed in real-time and their characteristic patterns reveal the nature of any defect that might be present in the GIS. With this early warning of any impending breakdown, users can take appropriate action to virtually eliminate enforced outages of GIS. This is main purpose of GIS preventive diagnostic system.

1.2. Partial discharge mechanism

There are various reasons to generate partial discharge, but the major causes of partial discharge in GIS are largely divided into four kinds. Those are free metallic particles (Particle), voids in solid insulator (Void), incomplete contact touch (Floating) and protrusions (Corona) as shown in figure 1.1. When partial discharge is generated, symptoms such as voltage and current with high-frequency, sound, light, heat, or dissolved gas, and electromagnetic wave are generated. GIS preventive diagnostic system focuses on the electromagnetic wave because other symptoms cannot be easily
detected on energized environment. Partial discharge can be described as an electrical pulse or discharge in a gas-filled void or on a dielectric surface of a solid. This pulse or discharge only partially bridges the gap between phase insulation and ground, or phase and phase insulation. The pulses occur at high frequencies; therefore they attenuate quickly as they pass to ground. The discharges are effectively small arcs occurring within the insulation system, therefore deteriorating the insulation, and can result in eventual complete insulation failure.

1.2.1. Partial discharge concepts

The first concept is the characteristic trait that partial discharges occur only during the first and third quarter of each cycle if the synchronization is fitted between GIS and data acquisition system. This is the initial rising positive signal, and the initial rising negative signal. Effectively, during the initial rising positive signal, all of the capacitive components are being charged until the partial discharge inception voltage is reached across each specific void, and partial discharges commence. When the positive wave cycle begins to decrease the positive voltage across each void is reduced, since some capacitive charge remains. Some level of charge must exist since the voltage across a capacitor cannot be changed instantaneously. During the first quarter cycle we are creating a positive charge and the resultant partial discharges. During the third quarter cycle, this positive charge is effectively reversed, resulting in a positive charge in the reverse direction, and the resultant partial discharges.

The second concept is that partial discharges are measured as voltage pulse.
- During the first quarter-cycle, a partial short-circuit, results in a negative, downward oriented pulse. This is referred to as a partial discharge with a negative polarity, and occurs during the first quarter-cycle of increasing positive voltage applied.

- During the third quarter-cycle, a partial short-circuit results in a positive, upward oriented pulse. This is referred to as a partial discharge with a positive polarity, and occurs during the third quarter-cycle of increasing negative voltage applied.

These partial discharges, which are measured as a high frequency change in the power signal in millivolts to a few volts, cannot be observed with a standard scope; therefore, they are exaggerated for illustration purposes.

1.2.2. Method for measuring partial discharge

Electrical defects inside of GIS are diverse like free metallic particle, floating electrode, bushing corona, surface corona, void in solid insulator etc as mentioned previous section. When voltage is injected in conductor of GIS, these fault sources generate the partial discharge phenomena and induced electromagnetic wave travels inside of GIS at speed of light. Electromagnetic wave transmits with mixed form of TEM, TE, TM mode and generates loss, reflection, refraction, diffraction and so on. These electromagnetic waves can be detected using antenna installed inside/outside of GIS. The frequency range of the electromagnetic wave generated by partial discharge is such a wide range from MHz (megahertz) to GHz (gigahertz). The environment of GIS substation is concentrated by some high-voltage devices, and might be corona discharge in the air. The corona discharge in the air is generally known to distribute under hundreds of MHz, so signals with higher frequency must be acquired for detecting PD generated only inside of GIS with less of an effect about such unwanted external noise. Therefore, PD sensor must be designed optimizing at the UHF (Ultra High Frequency) band for detecting electromagnetic wave effectively inside of GIS as shown in figure 1.2.
However, signals in unnecessarily high frequency band make the system be burden so it is need to limit proper frequency band. Generally, range from 500MHz to 1.5GHz as frequency band with 1GHz is chosen for signal processing.

The principle of the UHF technique is well-known worldwide after being adopted by many leading switchgear manufacturers and utilities including our company. However it may be recalled that the current pulse which forms the partial discharge has a very short risetime as shown above figure (it has high frequency components), which recent measurements have indicated can be less than 70 picoseconds. The rising edges of these pulses excite the GIS chambers into multiple resonances at frequencies up to at least some GHz. Although the duration of the current pulse is less than a few nanoseconds, the microwave resonances persist for a relatively long time, typically a few microseconds. They may readily be picked up by UHF couplers fitted either inside the GIS chambers, or over dielectric apertures in the chamber wall.

UHF PD sensor is divided into two types according to GIS working situation and installation condition; internal UHF PD sensor installed in GIS inspection window pad and external UHF PD sensor attached in surface of GIS spacer. The description of each sensor is expressed in detail in UHF PD sensor part at this manual.

The arrangement of sensor as well as the sensitivity of sensor is important for detecting without missing. When the sensitivity of sensor is high, PD signal can be detected even though the distance between sensors is wide, however, when the sensitivity of sensor is low, sensors must be arranged more closely. Because of propagation loss easily influenced by GIS appearance, there is
a limit to arrange sensors in detail like CB. Therefore, GIS structure, the sensitivity of sensor, and arrangement of sensors must be in a harmony properly. After establishing propagation loss data itemized by GIS structure, the sensitivity of sensors, the loss of signal cable, minimum input value of data acquisition system must be considered.

1.2.3. Partial discharge method using UHF

Whether internal or external sensors are used, the UHF signals can be amplified and displayed in different ways where their characteristic patterns reveal the nature of any defect that might be present in the GIS. The diagnosis of partial discharge must basically have the function which is able to estimate the causes of fault when there are faults inside of GIS. This information gives not only data for detail inspection but also possibility for becoming flashover and basic data estimating the fault location.

The method to estimate the fault causes is diverse in many leading manufacturers, however, it is well known for PRPD (Phase Resolved Partial Discharge), PRPS (Phase Resolved Pulse Sequence), statistic processes, trend analysis, and artificial neural networks.

It is important to estimate the location of faults as well as the cause of faults. The method for estimating the location of faults is using the signal difference between two adjacent sensors like figure 1.3. This method cannot be adopted in application software because fast rising time of PD signal, the location is estimated by time difference between two acquired signals using high-performance oscilloscope in substation.
Information for analysing PD signals is maximum amplitude and phase data of discharge pulse, and these are made up peak detection circuit, holding circuit, and timer. The single cycle of signal is equally divided into 64 samples and circuit holds the maximum value of each division. That is the peak-hold method for UHF method and the maximum value of each division is adopted partial discharge data with representatives. The software can calculate the amplitude and the count rate of partial discharge signal measured during one second. Eliminating the external noise is also important. If the frequency response of external noise has single tone or particular frequency band, the band rejection filter can be applied. Otherwise, software method which separates noise component from mixed signal using additional noise sensor is used.
2. HiPDS-G technical specification

This chapter explains the technical specification of HiPDS-G.

2.1. General specification

2.1.1. Application scope

This chapter applies to designing, manufacturing, testing, and additional related acting of GIS preventive diagnostic system which can monitor and diagnose with real-time the partial discharge generated from defects inside of GIS.

2.1.2. Definition of terms

2.1.2.1. GIS preventive diagnostic system

GIS preventive diagnostic system (HiPDS-G: Hyundai Intelligent Preventive Diagnosis System) includes UHF PD sensor which is installed inside or outside of GIS for measuring PD, DAS(Data Acquisition System) which acquires and processes signals from multiple UHF PD sensors, CCU(Communication Control Unit) which controls data communication from multiple DAS’s and remains logging data about PD event/history and performs logic/alarm process, Application server which has HMI that monitors real-time PD signal, PD event, PD history, single-line diagram, report, diagnostic functions and so on.

2.1.2.2. UHF PD sensor

UHF PD sensor can receive the electromagnetic waves generated by the partial discharge. There are two types of UHF PD sensor; internal UHF PD sensor and external UHF PD sensor. Internal UHF PD sensor is installed in the inspection window of GIS enclosure when GIS is installed and external UHF PD sensor is installed by attaching it at the spacer of GIS. UHF PD sensors should be arranged at the proper intervals so that they can detect the UHF signals when apparent charge of minimum 5pC inside GIS will occur.

2.1.2.3. Data acquisition system

DAS is device which communicates data with CCU using fibre optical cable by acquiring, processing, and analyzing PD data from UHF PD sensor.
2.1.2.4. **Communication control unit**

CCU is intermediate device which interfaces between all DASs installed in substation and application server. It processes and saves automatically PD events data in case that PD event conditions are satisfied, and PD history data per 15 minutes for each UHF PD sensor.

2.1.2.5. **Application server**

Application server is usually installed in the control room. It is composed of optical hub and workstation PC and communicates with the CCU via an optical cable in real-time. The measured PD data are visualized and archived in application server by PD monitoring software (HiPDS-G). Also, it displays PD events data and PD history data logged in CCU, so operator can see the real-time PD activity for each UHF PD sensor and check the PD events and PD history. It has functions to monitor the communication conditions, layouts, diagrams, and system alarms. The recorded PD data are analyzed by neutral network algorithm in application server and operator can know the cause of PD occurrence easily.

2.1.3. **Performances**

2.1.3.1. **UHF PD sensor**

Partial discharge phenomenon generates electromagnetic wave which travels inside of GIS at the speed of light, and this electromagnetic wave can be detected by antenna. The frequency range of the electromagnetic wave generated by partial discharge is such a wide range from MHz (megahertz) to GHz (gigahertz). The environment of GIS substation is concentrated by some high-voltage devices, and might be corona discharge in the air. The corona discharge in the air is generally known to distribute under hundreds of MHz, so signals with higher frequency must be acquired for detecting PD generated only inside of GIS with less of an effect about such unwanted external noise. Therefore, PD sensor must be designed optimizing at the UHF (Ultra High Frequency) band for detecting electromagnetic wave effectively inside of GIS.

UHF PD sensor is divided into two types according to GIS working situation and installation condition; internal UHF PD sensor installed in GIS inspection window pad and external UHF PD sensor attached in surface of GIS spacer.
2.1.3.1.1. **Internal UHF PD sensor**

Internal UHF PD sensor is installed in GIS inspection window pad, and divided into antenna part which can PD signals and cable connection part which can connect external measuring device as shown in figure 2.1.

Because antenna part of internal UHF PD sensor is located in contact with SF₆ gas, O-ring is inserted at the connection among components so that airtight quality of SF₆ gas cannot decline. Cable connection part is equipped by N-connector with less attenuation and uses coaxial cable which is with less decrease and can connect easily to external measurement device. Also, internal UHF PD sensor has high-voltage protection equipment not to be damage from high-voltage generated when GIS works, and waterproof structure not to lead abnormality electrically/mechanically from rainfall or washing. The detail components of internal UHF PD sensor is shown in figure 2.2.
For detail measurement using portable PD monitor or oscilloscope, only coaxial cable must be removed and high-voltage protection equipment or T-connector must not be allowed to remove. This is the reason why spark from induced voltage between internal UHF sensor terminals damages device or human.

Plumbing of coaxial cable taken from sensor connects near cable duct using flexible tube or conduit considering appearance of GIS as shown in figure 2.3.

2.1.3.1.2. **External UHF PD sensor**

Internal UHF PD sensor which detection sensitivity is relatively high and effect of external noise is low is usually applied in GIS preventive diagnostic system, however, external UHF PD sensor can be applied in case that is impossible to disconnect the power in working/energizing substation. Applying external UHF PD sensor, external UHF PD sensors must be arranged denser...
than internal UHF PD sensors to detect 5pC which is PD permission standard inside of GIS, and it must be designed to reduce the effect of external noise using shielding band.

External UHF PD sensor is installed in surface of GIS spacer and removable in energizing GIS. External UHF PD sensor has two types; exposed type by epoxy insulating material shown in figure 2.4.a and metal flange type shown in figure 2.4.b.

![Figure 2.4. External UHF PD sensors](image)

(a) Epoxy exposed type
   (For 170kV GIS)

(b) Metal flange type
   (For 362kV GIS)

2.1.3.2. Data Acquisition System

DAS acquires signals with interface between UHF PD sensor, AI, DI, and RS485, processes the signals, communicates these data with CCU, and displays data on LCD screen. DAS is installed as stand type with hard outer covering or GIS panel such as LCP (Local Control Panel). Figure 2.5 shows shape of site installation of DAS.

![Figure 2.5. The shape of site installation of DAS](image)
2.1.3.2.1. Front panel

Figure 2.6 shows the front panel of DAS.

1) PD module
2) LAN module
3) Key button
4) Maker
5) Graphic LCD screen
6) Power module

2.1.3.2.2. Back panel

Figure 2.7 shows the back panel of DAS.
2.1.3.2.3. Main display

When power is on, LCD screen displays the information as shown in figure 2.8.

1) Display components
   A. Current time is displayed on the top of screen and is renewed when DAS receives time information from CCU.
   B. It displays the name of device and firmware version.
C. The homepage of Hyundai Heavy Industry is displayed on the bottom of screen.

2) Small rectangular box which indicates the status of device is displayed in the lower right-hand corner of all displays.
   A. Four dots move to the right.
   B. First dot: It moves when data arrives from CCU.
   C. Second dot: It moves when internal Ethernet board is normal.
   D. Third dot: It moves when the first AI module is normal.
   E. Fourth dot: It moves when the second AI module is normal.

3) If there is no keystroke over three minutes, LCD backlight turns off and it turns into screen saver mode with “WWW.HHI.CO.KR” as shown in figure 2.9.

![WWW.HHI.CO.KR](image)

< Figure 2.9. Screen saver mode of DAS >

4) ESC key
   A. This is the key that moves to main display.
   B. In SET mode status, it moves to main display after saving the values on the screen

5) UP key
   A. It displays the POPUP menu, and moves cursor upward in menu.
   B. When cursor is at the top of the menu, it makes the cursor move to the bottom of the menu.
   C. If there is no keystroke over one second in position of current cursor, it moves to screen of chosen cursor.

6) DOWN key
   A. It displays the POPUP menu, and moves cursor downward in menu.
   B. When cursor is at the bottom of the menu, it makes the cursor move to the top of the menu.
C. If there is no keystroke over one second in position of current cursor, it moves to screen of chosen cursor.
D. If it is stroked over two seconds, the screen displays firmware compile time and working time of DSP.

7) SET key
   A. If it is stroked over two seconds, you can change the ID of DAS and synchronization.

8) Special key
   A. If it is stroked UP key + DOWN key over two seconds, you can calibrate the PD values, voltage, AI, DI etc.

2.1.3.2.4. POPUP menu
As mentioned above, when UP key or Down key is stroked, POPUP menu is displayed as shown in figure 2.10.

< Figure 2.10. POPUP menu of DAS >

1) It displays maximum 5 choices. (It is different from option.)
2) The item is changed using UP and DOWN key, and selected using SET key.
3) If there is no keystroke over one second, chosen item is selected.
4) PD Waveform: real time PD data display of channel #1~4 in 2D graph.
5) PD Status: real time PD maximum value display of channel #1~4 in range of 0 ~ 255.
6) AI/DI Value: AI and DI value display. (option)
7) LA Value: LA value display. (option)
8) DAS Status: Module status display of DAS.
2.1.3.2.5. **PD Waveform menu**

When PD Waveform is selected in POPUP menu, PD Waveform is displayed as shown in figure 2.11.

1) It displays one cycle waveforms of maximum four PD modules.
2) The upper left-hand corner of each waveform shows the number of PD module.
3) When noise rejection function is used by noise channel, #4 displays as N.
4) The upper right-hand corner of each waveform displays the event threshold value.
5) The event threshold value is displayed as percent converging 0~255 raw value to 0~100%.
6) “Not used” is displayed when PD module is not used or not working.
7) “No Sync” is displayed when there is no synchronization information.
8) The range of graph is from -65dBm to -20dBm.

2.1.3.2.6. **PD Status menu**

When PD Status is selected in POPUP menu, PD Status is displayed as shown in figure 2.12.
1) It displays PD module and DAS status.
2) Upper two lines show maximum value of each PD channel in range of 0~255.
3) 0 means -65dBm and 255 means -20dBm.
4) The third line displays maximum value among four event threshold value in terms of percentage.
5) The fourth line displays time information received from CCU.
6) The fifth line displays “PD DSP: OK” message and the number of packets communicated with CCU if communication status is normal.
7) The fifth line displays “PD DSP: ERROR” message and communication error duration in terms of “Day/ Hour:Minute:Second” if communication status is abnormal.

2.1.3.2.7. **AI/DI Value menu (option)**

When AI/DI Value is selected in POPUP menu, AI/DI Value is displayed as shown in figure 2.13.

![Figure 2.13. AI/DI Value menu of DAS](image)

1) It displays status and values of AI and DI module.
2) The upper section shows status and values of the first AI module and the lower section shows status and values of the second AI module.
3) Each AI module displays eight AI input values in range of 4.0 ~ 20.0 (Unit: mA).
4) If the value of AI input is out of range, it displays “-”.
5) In the middle of screen, sixteen DI input values are displayed. If input value is “1”, small black box is displayed. If input value if “0”, “-” is displayed.

2.1.3.2.8. **LA Value menu (option)**

When LA Value is selected in POPUP menu, LA Value is displayed as shown in figure 2.14.
1) It displays LA input values.
2) It displays up to six LAs.
3) If LA value is taken from AI/DI module, “A/D” is displayed in the left of screen.
4) If there are no input values, “-” is displayed.
5) If the status is normal, the results are expressed in LA number, LA working count, total leakage current, 3\textsuperscript{rd} harmonic leakage current order.

2.1.3.2.9. DAS Status menu

When DAS Status is selected in POPUP menu, DAS Status is displayed as shown in figure 2.15.

1) It expresses the normal or abnormal status of DAS.
2) Abnormal PD modules are displayed as “X” among the left four PD modules.
3) LAN box is blinking in the middle of screen, if DAS doesn’t communicate with CCU.
4) 6X2 dots are displayed under DSP letter in the middle of screen, if DAS communicates with LAs in RS485 interface.
5) Upper six dots are displayed when DAS sends data to six LAs.
6) Lower six dots are displayed when DAS receives data from six LAs.
7) There are no dots if DAS decides that RS485 line is abnormal.
8) It displays the status of #1 and #2 AI/DI modules.
9) If modules are normal, “AIDI” is displayed. If modules are abnormal, “N/A” is displayed.

2.1.3.2.10. Information menu
When DOWN key is stroked over two second in main display, Information menu of DAS is displayed as shown in figure 2.16.

![Figure 2.16. Information menu of DAS](image)

1) It displays program build time and working time.
2) “S” means SS-DSP (for LCD, AI/DI modules).
3) “P” means PD-DSP (for LAN, PD modules).
4) If ESC key is stroked, the screen turns into main display.

2.1.3.2.11. Setting menu
When SET key is stroked over two second in main display, Setting menu of DAS is displayed as shown in figure 2.17.
1) DAS number and synchronization type can be set in this menu.
2) SET key can change the item in Bay No, DAS No, Sync. order and UP/DOWN key can change the value.
3) If ESC key is stroked, values are saved and the screen turns into main display.
4) Bay No is fixed as “0”.
5) DAS No can be set from 1 to 40 and this number decides the IP of DAS.
   (DAS IP = 192.168.1.X)
6) Sync. can be set four types as follows:
   A. E50: External 50Hz synchronization
   B. E60: External 60Hz synchronization
   C. I50: Internal 50Hz synchronization (Using internal timer)
   D. I60: Internal 60Hz synchronization (Using internal timer)

2.1.3.3. Communication Control Unit
Communication control unit (CCU) is the most important part in the system, which communicates with communication server and PD server of the application server and Ethernet module of DAS, and processes PD events / histories over one year. Maximum 20 DASs can be connected per single CCU and CCU has MySQL server and FTP server for application server and remote clients. For these functions, CCU must be used workstation PD with Windows XP or Windows 2003 Server. LAN card is used one or two according to client option, the first LAN card (local network) is used to communicate with application server and DASs and the second LAN card (internet network) is used to communicate with remote clients. CCU runs without monitor but for debugging, status can be check by connecting with monitor.
2.1.3.3.1. Data communication

Figure 2.18 shows data flow of CCU. It divides into channel data and PD data for independent work of point data and PD data, and communication server handles point data and PD server handles PD data.

![Diagram of CCU data flow]

2.1.3.3.2. PD event and history logging

CCU saves PD events / histories, and application server or remote client can interface with CCU by MySQL and FTP and show PD events / histories over one year. PD event data is saved at both file and database as much as max count set during 15 minutes base on 0 minute, 15 minutes, 30 minutes, and 45 minutes every hour when PD event condition is satisfied. For avoiding overlap of PD events, PD events are saved with uniform interval of max count set for 15 minutes.

PD history data is saved at both file and database at 0 minute, 15 minutes, 30 minutes, and 45 minutes per hour in forms of maximum amplitude, average amplitude, maximum count rate, average count rate during 15 minutes about all sensors. Therefore, 960 data is saved per single sensor of one day.

CCU has 500GB HDD for logging PD events and PD histories, this capacity is enough to save at least one-year data in the worst case.
2.1.3.4. **Application Server**

Application server must be used workstation PC with high-performance and high-confidence as like communication server and Windows XP and Windows 2003 Server is used as its O/S.

Main functions of application server are graphic based components, system alarms, trend, report and so on including database configuration, control logic and diagnosis algorithm.

### 2.1.3.4.1. Dynamic graphic edit

1) User can draw image or write text freely without stopping the system.
2) Several standard viewers like overview, group, and detail graphics are offered.
3) Several methods like color change, shape change, character/number display, meta chart, and bar graph can be used in all information about GIS.
4) Strip chart display can be used for trend graph.
5) A simple and convenient operation using keyboard or mouse is offered when running parameters are altered or changed.
6) A simple and convenient operation using clicking buttons is offered.
7) Window switching is free by clicking buttons.
8) External application program can be executed freely.

### 2.1.3.4.2. Trend

1) Trend graph about real-time data of digital or analog points is offered.
2) Maximum 8 points can be registered in single trend graph.
3) Trend period can be set like 10 seconds, 10 minutes and so on.
4) Display time range and change of a time slot are free.

### 2.1.3.4.3. System alarm

1) It handles the alarm conditions of GIS and gives the system alarms to the users quickly.
2) When system alarm is generated, system can give digital output signal (DO contact) to the ECMS using PLC. (option)

### 2.1.3.4.4. Database configuration

1) It can configure database about the application server for diagnosis.
2) It can configure database about the communication control unit for dual and decentralization configuration.
3) It can configure database about the data acquisition system for the number of sensor.
2.1.3.4.5. Report

1) User friendly report is offered.
2) Report is given in forms of Microsoft Excel.

2.1.3.5. Other Accessories

2.1.3.5.1. Coaxial Cable
Coaxial cables are used as connection cables between UHF PD sensor and DAS. Coaxial cable is stable structurally and mechanically, and its frequency characteristic is reliable and less-loss over the broadband. Cable termination is finished by using N-type plug, and cable length between UHF PD sensor and DAS should be adjusted (about less than 20m) so that loss of coaxial cable including connector is under 4dB in case of 1,000Hz. Figure 2.19 shows appearance of coaxial cable and figure 2.20 shows transmission loss test of coaxial cable.
2.1.3.5.2. Optical Fibre Cable

Optical fibre cables for duct and tunnel are used as connection cables between DASs or DAS and optical hub. Installation expense of optical fibre cable is more expensive than that of UTP cable, but optical fibre is not sensitive to electrical, magnetic or static interference so data transmission distance is over 2km and amount of data are also more than that of UTP cable. Multi-mode with 4-core optical fibre cable is usually used and its patch code is SC type. Figure 2.21 shows optical fibre cables for duct and tunnel and its patch codes.

2.1.3.5.3. Control Cable

Control cable is used to put power signal and phase synchronization signal into the DAS. A screened cable with incombustible material is usually used as control cable and color, cross section, number of cores are chosen according as cable specification of substation.

2.1.3.5.4. Optical Hub
The number of optical port and UTP port are decided by network configuration. Optical hub supports fast Ethernet with 100Mbps and has 19 inch rack-connectable type with 1U size. Figure 2.22 shows optical hub.

![Figure 2.22. Optical hub](image)

2.1.3.5.5. General Hub (option)

To access and analysis the data in your computer by communicating with GIS preventive diagnostic system installed in the main control room remotely, it must be connected with activated your intranet line, and both local server and CCU should be assigned accessible IP from your computer. General hub must be installed additionally to do remote access. Detail specification for general hub is determined after consulting with customers.

2.1.3.5.6. 19 Inch Rack

GIS preventive diagnostic system is installed at the main control room in the form of 19 inch rack, and monitor, keyboard, mouse, CCU, Server, general hub, optical hub, FDF are included. Figure 2.23 shows 19 inch rack.
< Figure 2.23. 19 inch rack >
2.2. Technical Specification

This chapter describes the technical specification of GIS preventive diagnostic system.

2.2.1. Internal UHF PD Sensor

1) Model : HiUC-D110
2) Installation : Inspection window within GIS enclosure
3) Form : Disk-loaded monopole
4) Sensitivity (5pC PD occurrence within 1M): Over -20dBm
5) Sensor arrangement basis : -65dBm
6) Detecting frequency range : 500~1,500MHz
7) Connector type : N-Type (Impedance 50Ω)
8) Over-voltage protector : Yes
9) Verification : CIGRE TF 15/33.03.05

2.2.2. External UHF PD Sensor

1) Model : HiUC-E170
2) Installation : Spacer surface
3) Form : Patch antenna
4) Sensitivity (5pC PD occurrence within 1M): Over -30dBm
5) Sensor arrangement basis : -65dBm
6) Detecting frequency range : 500~1,500MHz
7) Connector type : N-Type (Impedance 50Ω)
8) Verification : CIGRE TF 15/33.03.05

2.2.3. Data Acquisition System (DAS)

1) Type : HiDAS-1A
2) Input modules
   A. Main module
      i. DSP CPU specification : 40MHz
B. PD module
   i. Minimum pickup level  : -80dBm (in shield room)
   ii. Input signal range   : -65~—20dBm
   iii. Gain characteristic : Logarithm
   iv. External noise rejection : Noise elimination using noise sensor
   v. Number of UHF PD input : Max. 6CH
   vi. Time resolution      : 312.5us (64 samples / 1 cycle)
   vii. Rating frequency   : 50/60 Hz

C. Display module
   i. Display               : 128 X 64 dots LCD
   ii. Key button           : 4 keys (POWER/UP/DOWN/SET)

D. Synchronization signal
   i. Synchronization frequency : Internal (AC back-up voltage)
                                   : External (PT 2nd voltage)

E. Input Power
   : DC 110V ~ 220V, AC 60V ~ 220V

3) Output modules
   A. Communication port   : RJ45
      i. Protocol            : UDP/IP
      ii. Communication speed : 100Mbps
      iii. Display for communication : 2 LEDs

4) Certification
   A. Degree of protection : IP 54
   B. EMC compliance
      i. Electrostatic discharge immunity test : IEC61000-4-2
      ii. Electrostatic field immunity test    : IEC61000-4-3
      iii. Electrostatic fast transient immunity test : IEC61000-4-4
      iv. Surge immunity test                  : IEC61000-4-5
      v. Immunity to conducted disturbances   : IEC61000-4-6
      vi. Power frequency magnetic field immunity test : IEC61000-4-8
      vii. Voltage dips, short interruption and voltage variation immunity test : IEC61000-4-11
      viii. Insulation test for electrical relays : IEC60225-5
   C. Dynamic test
      i. Insulation resistance                : Over 10MΩ
ii. Temperature : -35~75℃

iii. Humidity : 95%

iv. Impact and variation : Pass

2.2.4. Communication Control Unit (CCU)

1) CPU : Dual Core 2GHz
2) Memory : 2GB
3) HDD : 500GB
4) Power supply : AC 60 ~ 220V
5) O/S : Windows XP
6) Database : MySQL
7) LAN : 100Mbps
8) Data auto-logging : PD Event, PD History, Trend, PRPD

2.2.5. Local Server

1) CPU : Dual Core 2GHz
2) Memory : 1GB
3) HDD : 100GB
4) Power supply : AC 60 ~ 220V
5) O/S : Windows XP
6) Monitor : 17 inch
7) LAN : 100Mbps
8) Database : SQL Server, MS-Acess
9) Additional utility : MS-Office (for report)
10) PD monitoring software : HiPDS-G
    A. Event threshold : To be adjustable
    B. Detection threshold : To be adjustable
    C. Phase shift of displayed data : To be adjustable
    D. PD pattern identification : Using by artificial neural network
        i. Free metallic particle
        ii. Floating electrode
        iii. Insulation defects (crack, contamination, etc)
iv. Protrusion of conductor/enclosure
v. Noise (cell phone noise, motor noise, etc)

E. 2D/3D PRPS(Phase Resolved Pulse Sequence) data display
F. 2D PRPD(Phase Resolved Peak Display) data display
G. Amplitude and occurrence of the PD signals

H. PD event data analysis : Min. 1 year
I. PD history data analysis : Yearly, Monthly, Daily analysis
J. PD display : in dBm

K. System alarm display when error occurs

L. Export PD data in report : Report as Microsoft Excel format
   i. PD event single report
   ii. PD event multiple report
   iii. PD event monthly report
   iv. PD history daily report
   v. PD history monthly report
   vi. System alarm report

M. Library patterns

N. Dry contact for alarm : option (DO using PLC)

O. HMI features : attached

P. Remote monitoring : option (web client)

2.2.6. Optical Hub

1) Type : SFC400-SCMXX
2) Standard : IEEE802.3U 100BaseTx / 100BaseFx
3) Optical fibre cable : Single mode (9/125um)
   : Multi mode (62.5/125um)
   : Wavelength 1300nm
4) Connector : Auto MDI-X UTP/STP (RJ-45, Cat 5.)
   : SC fibre optic connector
5) Transmission distance : UTP/STP 100Meters (Cat 5.)
   : Single mode fibre – 20km
   : Multi mode fibre – 2km
6) Transmission speed : 100Mbps
7) Lamp display: Power, Tx, Rx, Act, FDX, LINK
8) Dimension (W X D X H): 317mm X 150mm X 38mm

2.2.7. Connection Cables

1) Connection cable between UHF PD Sensor and DAS
   A. Standard: RG-8 Type
   B. Connector type: N-type plug

2) Power cable of DAS
   A. Type: FR-CVV-S
   B. Core: 2.5SQ X 4C

3) Connection cable between DASs, DAS and optical hub
   A. Type: Optical cable
   B. Core: 4 Core
   C. Mode: Multi Mode

4) Connection cable among optical hub, CCU, and local server
   A. Type: RJ45
   B. Connector type: UTP
2.3. System Configuration

Configuration of GIS preventive diagnostic system is shown in figure 2.24.

< Figure 2.24. System Configuration >
3. **HiPDS-G Program**

This chapter describes features and HMI of GIS preventive diagnostic system.

3.1.1. **Diagnosis of partial discharge**

3.1.1.1. **Real-time PD monitoring (2D/3D PRPS, 2D PRPD)**

There are maximum 6 PD modules on the DAS and each PD module can distinguish the distance input by UHF sensor signal and store the accumulated frequency as like2D-array. The meaning of a cycle signal about phase is from 0 to 360 equally divided into 64 and if the frequency synchronization is 50 or 60Hz, the signal divided equally in a second is stored within 50 or 60 cycles. In fact, 50 X 64 or 60 X 64 data is stored in a second and it is called “PRPS (Phase Resolved Pulse Sequence)” data. GIS preventive diagnostic system has the monitoring function of PRPS data in real-time, and according to the configuration, these would be described as being 2D or 3D graph. It is definitely expressed that PRPS data can be divided from -65dBm and -20dBm (256 parts 0 to 255) to easy to distinguish and the minimum value is “Yellow(-65dBm)”, the maximum value is “Red(-20dBm)”.

GIS preventive diagnostic system can also show “PRPD (Phase Resolved Peak Display)” data which is accumulated data of PRPS amplitude in every second. Due to the fact that the amplitude of PRPS is from 0 to 255, PRPD would be seen as 256 X 64 data and PRPD would be calculated per second as count of following each position of measured PRPS amplitude. The PRPD data hold information valuable for the identification and interpretation of the discharge source. Following the real time PRPD analysis, the partial discharge pattern analysis would be much easier.

3.1.1.2. **PD history**

In case if discharge signal amplitude is higher that the setting values, PD history is stored in every 15 minutes. PD history is logged in forms of amplitude (max, average) and count rate (max, average) in every 15 minutes, daily, monthly and yearly.

User can configure the parameters about PD history as follows parameters.

- Detection threshold
- Detection threshold count
The mechanism of PD history is expressed above.

### 3.1.1.3. PD event

In case if discharge signal amplitude is higher that the setting values, PD event is stored as much as max count per 15 minutes. PD event is logged in forms of index, recorded time, sensor ID and diagnostic result.

User can configure the parameters about PD event as follows parameters.

- Event threshold
- Event threshold count
- Max count

The mechanism of PD event is also expressed above.

### 3.1.1.4. Library patterns

For classification of PD patterns, standard library patterns about particle, corona, floating, void and noise are offered in graph of 2D and 3D. This makes PD signals compare with standard library patterns when user analyzes about PD events and it is very helpful for understanding analysis of PD signal.

### 3.1.1.5. Diagnosis logic

A pattern recognition system enables PD signals to be identified automatically, and with high accuracy. This diagnosis logic is especially important to utilities that may be monitoring many hundreds of UHF sensors on the GIS, since it removes the need for an expert to routinely examine the PD data patterns. The three main areas of soft computing used in pattern recognition tasks are artificial neural networks (ANNs), genetic algorithms and fuzzy logic. These approaches have been combined with more traditional statistical techniques to form a highly-effective hybrid classifier. In this system, diagnosis logic is applied all PD patterns and noises (cellular phone noise and motor noise), and the diagnostic result of PD event is displayed in HMI.
3.2. HMI (Human-Machine Interface)

3.2.1. Initial page

Initial page of HMI is as shown in figure 3.1. Initial page consist of buttons for main page, single diagram, system alarm, network status, trend, report, PD configuration, snapshot, PD event/history, real-time PD, data summary, PD library patterns, including window for displaying recent 3 alarm.

The function about each item is as follows:

1. Version
   - It displays version of HMI.

2. Time
   - It displays current date and time.

3. Buttons
   - Main page
   - Single line diagram

< Figure 3.1. Initial page of HMI >
- System alarm
- Network status
- Trend
- Report
- PD Configuration
- Snapshot
- Initial page
- Gas pressure(option)
- Lightning arrester(option)
- PD event/history
- Data summary
- Real-time PD (2D/3D PRPS, 2D PRPD)
- PD library patterns (2D/3D PRPS)
- PD history (15 min, day, month, year)

④ Login menu
- User account
- Log in / Log out

⑤ Single alarm acknowledgment and all alarms acknowledgment button
- It makes current alarm notice and stop blinking.
- ACK: acknowledgment about single alarm
- ALL ACK: acknowledgment about all alarms

⑥ Recent three alarm
- It displays recent three alarms among alarm lists.
- It renews recent one when there is new alarm.
- It displays the number of alarms that user doesn’t acknowledge.

3.2.2. Main page
When user clicks main page button among function buttons, it displays 3D GIS layout and location of UHF PD sensors as shown in figure 3.2. User can easily notice the GIS layout and UHF PD sensor that PD signal is generated.
The function about each item is as follows:

1. Location of UHF PD sensors
   - It displays the location of UHF PD sensors.
   - When user clicks the sensor, it displays the real-time 3D graph of the chosen sensor.

2. Alarm about UHF PD sensor
   - UHF PD sensor is displayed in “green” color at the normal status.
   - UHF PD sensor is displayed in “red” color at the abnormal status.
   - The condition about the abnormal status is as follows:
     i. In case that the number of PD events per 15 minutes exceed the user’s configuration.
     ii. In case that the average value of PD maximum value per 15 minutes exceed the user’s configuration.
iii. In cast that the average count rate of PD maximum count rate per 15 minutes exceed the user’s configuration.
   - When the abnormal status turns to the normal status, the color is changed from “red” color to “green” color automatically.

### 3.2.3. Single line diagram

When user clicks one-line diagram button among function buttons, it displays single line diagram of GIS and location of UHF PD sensors as shown in figure 3.3. User can easily notice the single line diagram of GIS and UHF PD sensor that PD signal is generated.

![Figure 3.3. Single line diagram of HMI](image)

### 3.2.4. System alarm

When user clicks system alarm button among function buttons, it displays system alarms as shown in figure 3.4. System alarm displays alarm lists up to 30 in one page. System is divided into two types; Current Alarm page which shows only recent alarm lists which are not
acknowledged by user as shown in figure 3.4 and History Alarm page which shows all past alarm lists which are acknowledged by user as shown in figure 3.5. When user clicks system alarm button, system alarm page is displayed and alarm which is not acknowledged by user is flickering. When user clicks “ACK” button, the most recent alarm is acknowledged and it is deleted from current alarm lists if the alarm status is clear. If the alarm status is not clear, it moves below flickering alarm lists which are not acknowledged by user, and stops flickering. Also user clicks “ALL ACK” button, all alarms are acknowledged.

1) Current Alarm page

New alarm is displayed in the top of alarm lists and flickering. When user double-clicks the alarm or clicks the “ACK”/“ALL ACK” button, alarm is acknowledged and stops flickering. Figure 3.4 shows the current alarm page.

![Figure 3.4. Current alarm page](image)

The function of each button is as follows:
① History Alarm / Current Alarm Button
This button shows the current alarm page or the history alarm page.

② Reload
Alarm lists are renewed by re-reading alarm lists stored in database.

③ Page Up / Down
It displays next page or previous page.

④ Alarm List
It is composed of 30th lines in one page.

2) History Alarm page
It displayed alarm lists which are acknowledged by user and cleared the status. Figure 3.5 shows the history alarm page.
3.2.5. **Trend**

When user clicks trend button among function buttons, it displays trend page which can analyze trend about the maximum value of PD signal as shown in figure 3.6.

![Figure 3.6. Trend page](image)

User can notice the maximum value of all PD sensors in the trend graph according to date. The trend data is stored maximum 4 weeks (28 days). When user clicks “RUN” button, the script of “RUN” button turns into “HOLD”, and analysis components are appeared. The explanations of analysis components are as follows:

- ![+](image): When graph is exaggerated on the X or Y axis, mouse pointer is magnifying glass form. It makes mouse pointer change for gripping the cursor.
- ![X](image): This button make the graph exaggerate on the X axis. When user clicks the button, the mouse pointer turns into magnifying glass form and the graph is exaggerated on the X axis by dragging the desired part to exaggerate.
- ![Y](image): This button make the graph exaggerate on the Y axis. When user clicks the button, the mouse pointer turns into magnifying glass form and the graph is exaggerated on the Y axis by dragging the desired part to exaggerate.
- ![Zoom](image): This button make the graph zoom out back again.
3.2.6. Network status

It displays the network structure of system and the status whether network is working or not. User can notice the network connection status of all DASs and CCU. If communication is normal, the LED turns into “green”. Otherwise, the LED turns into “red”. Figure 3.7 shows the network status page.

< Figure 3.7. Network status page >

3.2.7. Report

When user clicks report button among function buttons, report generation program runs. Figure 3.8 shows the initial page of report generation program.
Report generation program can handle total five items such as PD event, PD history, system alarm, PRPD history, PD trend and all reports can be exported as excel format.

### 3.2.7.1. PD event report

When user click “PD Event” button on the menu, it moves to PD event screen as shown in figure 3.9. When user selects desired month to show stored PD events, daily lists of the number of PD events are displayed in table on the left of program. When user select desired day, stored event lists about selected day are displayed in table on the middle of program. When user clicks the “Monthly Report” button, monthly report for PD event is printed and saved automatically. When user clicks the “Multiple Report” button, user can select the multiple PD events to export into excel report and report for multiple PD events is printed and saved automatically. Also when user clicks the “Single Report” button, report for single PD event is printed and saved automatically.

The directory stored as excel format is as below:

- Directory of monthly PD event report: D:\HiPDS-G\REPORT_FILE\PD_REPORT\Monthly
- Directory of multiple PD event report: D:\HiPDS-G\REPORT_FILE\PD_REPORT\Multiple
- Directory of single PD event report: D:\HiPDS-G\REPORT_FILE\PD_REPORT\Single
3.2.7.2. PD history report

When user click “PD History” button on the menu, it moves to PD history screen as shown in figure 3.10. PD history is itemized by month and sensors. When user clicks the “Monthly Report” button, monthly report for PD history is printed and saved automatically. Also when user clicks the “Daily Report” button, daily report for PD history is printed and saved automatically. The directory stored as excel format is as below:

Directory of monthly PD history report: D:\HiPDS-G\REPORT_FILE\HISTORY_REPORT\Monthly
Directory of daily PD history report: D:\HiPDS-G\REPORT_FILE\HISTORY_REPORT\Daily
3.2.7.3. System alarm report

When user click “Alarm” button on the menu, it moves to system alarm screen which can notice current alarm and history alarm as shown in figure 3.11. PD history is itemized by month and sensors. When user clicks the “Report Generation” button in this page, alarm report is printed and saved automatically. The directory stored as excel format is as below:

Directory of current alarm report: D:\HiPDS-G\REPORT_FILE\ALARM_REPORT\Alarm
Directory of history alarm report: D:\HiPDS-G\REPORT_FILE\ALARM_REPORT\History
3.2.7.4. **PRPD history report**

When user click “PRPD” button on the menu, it moves to PRPD screen which can notice the stored PRPD as shown in figure 3.12.

![Image of PRPD history report](image-url)
PRPD is saved automatically per 15 minutes about all PD sensors and user can search all PRPD data about all PD sensors for 1 month and generate the report. When user clicks “→” button after selecting PRPD data, selected PRPD is inserted in the table up to 10. For removing the selected PRPD from the table, user needs to click “←” button. When user clicks the “PRPD Report” button in this page, PRPD report is printed and saved automatically. The directory stored as excel format is as below:

Directory of PRPD history report: D:\HiPDS-G\REPORT_FILE\PRPD_REPORT

3.2.7.5. Trend report

When user click “Trend” button on the menu, it moves to PD trend screen which can notice the stored PD trend as shown in figure 3.13. This is same as trend graph in HMI and when user clicks the “Trend Report” button in this page, trend report is printed and saved automatically. The directory stored as excel format is as below:

Directory of PD trend report: D:\HiPDS-G\REPORT_FILE\TRED_REPORT\PD_TREND

< Figure 3.13. Report – TREND >

3.2.8. Configuration of PD sensors

PD configuration is able to configure the parameters of CCU and DASs. If user makes a mistake about configuration parameters about partial discharge and system alarms, system alarm about
PD cannot be happen when PD is generated, or PD event and PD history functions can be worked abnormally. Therefore, authority of this function limits only administrator about the system. Figure 3.14 shows the page about configuration of PD sensors.

< Figure 3.14. Configuration of PD sensors >

The explanations of menu are as follows:

1. LDAS status
   i. LDAS IP
      The IP (network) of DAS can be set. The IP can be set like 192.168.1.X. (X must match with the number of DAS)
   ii. LDAS ON
       This check button sets the presence of DAS. For example, when the number of DAS is six, LDAS ON of #1~#6 DAS must be set and the others must not be set.
   iii. LDAS ID
       This informs the caption of DAS.
   iv. LA ON (option)
       This check button sets the presence of LA (Lightning arrester).
   v. PD sensor ID
When user changes PD sensor ID, sensor status about selected PD sensor is displayed in the right side.

vi. The number of PD sensor
User can set the number of PD sensor about selected DAS. Maximum six PD sensors per DAS can be set.

② PD sensor status
i. Increase mode
If increase mode is checked, when PD event status is satisfied, PD event is stored and base event level is increased to 10%. So, next PD event occurs in case of higher base event level. And increased base event level is reset after 15 minutes. If increase mode is not checked, the base event level is fixed whatever PD event occurs or not.

ii. Base event level
It is available to set up with the minimum partial discharge event and any partial signal is detected, events are stored only in case if the setting value is higher that base event level. For example, when base event level is set up with -50dBm, the events are stored only in case if the discharge signal is more that -50dBm.

iii. Base event level count
In case if discharge signal amplitude is higher than base event level and the number of higher samples than base event level is more than base event level count, system make this signal PD event and partial discharge event is stored. In fact, it is determined to be event occurred or not in terms of the above ii and iii AND condition. For example, if base event level is set up with -50dBm and base event level count is set up with 10, the partial discharge event is regarded as event and it is stored when the discharge signal is over -50dBm and samples over -50dBm are more than 10.

iv. Max count
It can determine the number of PD events during 15 minutes. The number of PD events does not exceed max count about continuous PD event status during 15 minutes. For example, when max count is set as 10, maximum 10 PD events are stored even if PD event status is satisfied continuously for 15 minutes.

v. Detection threshold level
It is available to set up with the minimum partial discharge history and any partial signal is detected, history is stored only in case if the setting value is higher that detection threshold level.

vi. Detection threshold level count

In case if discharge signal amplitude is higher than detection threshold level and the number of higher samples than detection threshold level is more that detection threshold level count, partial discharge history is stored. This mechanism is same as PD event.

vii. Phase shift

This can set the phase shift of each PD sensor.

Buttons

i. Apply all
   Current setting values can be applied to all sensors equally.

ii. Initialization
   All setting values are initialized as default value.

iii. Save
   This saves the setting values.

iv. Apply
   The PD configuration program downloads the setting parameters to the CCU.

v. Information
   This shows the all setting values in the text.

vi. Exit

3.2.9. Snapshot

When user clicks snapshot button among function buttons, it saves current page in file as shown in figure 3.15.
3.2.10. PD event / history

PD event / history page shows stored PD events and PD histories. Figure 3.16 shows the PD event / history.
3.2.10.1. PD event
In case if discharge signal amplitude is higher that the setting values, PD event is stored as much as max count per 15 minutes. PD event is logged in forms of index, recorded time, sensor ID and diagnostic result. The recorded event is displayed in 2D or 3D graph and diagnosis algorism gives the diagnostic result in text automatically.

The explanation of each item is as follows:

① Date
User can choose desired date to show list of PD events.

② PD events list
List of PD events of chosen date is displayed in forms of index, recorded time, sensor ID and diagnostic result. When user clicks the column header of PD events list, PD events are sorted in selected column. When user selects one PD event among the recorded PD events, 3D/2D PRPS graph of selected PD event is displayed in the below.

③ 3D/2D PRPS graph
3d/2d PRPS graph of select PD event is displayed. 3D/2D conversion is possible by click 3D/2D button.

④ PD analysis
When user selects one PD event among the recorded PD event, diagnosis result about selected PD event is displayed in text in the below. Diagnosis result is also included in PD events list, however, because diagnosis result can change by moving cutting position, it reflects the change of cutting position. Rate of concordance about diagnosis result is displayed by converting into a percentage.

3.2.10.2. PD history summary
User can search amplitude and count rate of PD history rapidly and easily by selecting date and sensor ID.

The explanation of each item is as follows:

① Date
User can choose desired date to show PD history.

② sensor ID
User can choose desired sensor ID to show PD history.

③ Maximum amplitude
It displays maximum amplitude of PD history.

④ Maximum count rate
   It displays maximum count rate of PD history

⑤ Average amplitude
   It displays average amplitude of PD history.

⑥ Average count rate
   It displays average count rate of PD history.

3.2.11. Real-time PD

When user clicks 2D, 3D, PRPD in real-time PD of the menu, 2D PRPS, 3D PRPS, and 2D PRPD graph is displayed. Figure 3.17 shows the select window when user clicks 2D, 3D, PRPD button. Because the detail explanations of 2D PRPS, 3D PRPS and 2D PRPD are mentioned above, this chapter skips them.

3.2.11.1. 2D PRPS

It displays online real-time PD signal in 2D graph. Figure 3.18 shows 2D PRPS graph.
3.2.11.2. 3D PRPS
It displays online real-time PD signal in 3D graph. Figure 3.19 shows 3D PRPS graph.

3.2.11.3. PRPD
It displays online real-time accumulated PD signal in 2D graph. Figure 3.20 shows 2D PRPD graph.
3.2.12. Library patterns

Diagnosis software of HiPDS-G divides PD events into particle, floating, corona, void, and noise patterns. With standard library patterns of PD signal, user can compare PD event with library pattern and analysis easily.

3.2.12.1. Particle

A conducting particle located on the inner surface of a GIS enclosure will be charged by the electric field of the applied voltage. Due to the influence of this charge and the electric field, a force acts on the particle. If the component of this force, which acts in the direction of the inner conductor and exceeds the gravitational force, the particle gets lifted. Depending on the amplitude and frequency of the applied voltage, the conducting particle will reach the inner conductor where it assumes a charge of opposite polarity and falls down again. The particle will normally bounce on the enclosure until it either comes to a critical position, where a gas breakdown is initiated or until it reaches a low field region where it comes to rest. The bouncing on the enclosure generates discharges to the grounded outer electrode in the form of small sparks. This bouncing and sparking status results in rather high electrical signal emissions. The moving is random, however, the amplitude of PD signal is relatively high in 90 and 270 degree which induced AC voltage is maximum state. Figure 3.21 shows PRPS library pattern of particle discharge.
3.2.12.2. Floating

A conducting particle on a spacer surface has an undetermined (floating) potential. It shortens the potential difference equivalent to its length in the direction of the undisturbed electric field. The resulting discharge process is similar to that caused by a fixed protrusion. Due to the electric field, the particle will move giving rise to discharge processes which will cause surface discharge on the nearby spacer resulting in a field in-homogeneity and thus, a higher probability of surface breakdown. Therefore, horizontal spacers are avoided in GIS so that the probability of particles resting on spacer surfaces is reduced. Also, floating particles give discharges that are similar to those caused by fixed protrusions, i.e., displacement currents.

Metallic components inside the GIS with no or poor electrical contact may cause problems also. Electric forces create mechanical vibrations at twice the power frequency and the resultant potential differences between the metallic component and the electrode system may cause sparking with electric discharges.

Loose parts that are sticking to the main electrodes may also be subjected to mechanical vibrations, and are usually accompanied by acoustic emission. The probability of the floating particles being present in a GIS depends on the design and assembly procedures.

In the floating discharge, discharge signal is generated with very high amplitude over 100pC and displayed in the first quadrant and third quadrant of the phase. Figure 3.22 shows PRPS library pattern of floating discharge.
3.2.12.3. Corona

A sharp protrusion fixed on an electrode causes a local electric field enhancement. If the local field stress on the protrusion tip exceeds the critical value of about 89kV/cm-bar in SF₆, a corona discharge takes place, which does not cause an immediate gas breakdown. Protrusions located on the inner conductor of a coaxial system are normally more severe since the macroscopic electric field stress usually is higher at these protrusions than at other locations. A protrusion fixed on the outer electrode (enclosure) of a GIS will not reach the critical value because of the lower field surrounding it.

This system can detect the displacement current caused by the corona discharge. DAS can acquire shock waves emerging from local heating around the tip of the protrusion. Fixed protrusions are extremely rare with cast enclosures and extruded conductors. Figure 3.23 shows PRPS library pattern of corona discharge.
3.2.12.4. Void

Voids or cracks in spacers are usually filled with gas. A local field enhancement may occur reaching the critical breakdown value for the gas. If free electrons are present, a discharge process is initiated causing a displacement current on the spacer surface or sparking between the electrode and the spacer. Both processes can be detected. Discharge processes in epoxy spacers may also lead to treeing and breakdown. Voids can be virtually eliminated by appropriate design of the spacers and by using optimized production processes.

In the void discharge, discharge signal is displayed maximally in the third quadrant of the phase. Figure 3.24 shows PRPS library pattern of void discharge.

![Figure 3.24. PRPS library pattern of void discharge](image)

3.2.12.5. Noise

In the noise, discharge signal is displayed independent of phase. Figure 3.25 and 3.26 show PRPS library patterns of cellular phone noise and motor noise.

![Figure 3.25. PRPS library pattern of cellular phone noise](image)
3.2.13. PD history

PD history displays basically today’s PD history, and it is possible to search the past PD history by using daily, monthly and yearly button. User can analysis the amplitude and count rate change of PD signals and PD history is displayed in forms of maximum and average values of amplitude and count rate.

3.2.13.1. Today PD history

Figure 3.27 is select window when user clicks “Today” button in the menu.

< Figure 3.27. Select window of today PD history >
User can select maximum value or average value about PD history, and it displays today’s PD history data of selected sensor ID. X axis of graph stands for time (24 hours) and Y axis means amplitude (green color graph in upper side) and count rate (yellow color graph in lower side). The single bar means maximum or average history data during 15 minutes and this data is saved and displayed per 15 minutes. When user clicks the single bar, the date and time of selected bar is displayed in the title bar. When user double-clicks the single bar, accumulated 15-minutes graph of the selected bar is displayed. Figure 3.28 shows the today PD history graph.

![Graph showing PD history](image)

< Figure 3.28. Today PD history graph >

### 3.2.13.2. Daily PD history

Figure 3.29 is select window when user clicks “Daily” button in the menu.
The graph of daily PD history is same with that of today PD history and user can select the desired date.

3.2.13.3. Monthly PD history

Figure 3.30 is select window when user clicks “Monthly” button in the menu.

User can select maximum value or average value about PD history, and it displays monthly PD history data of selected sensor ID. X axis of graph stands for day (31 days) and Y axis means amplitude (green color graph in upper side) and count rate (yellow color graph in lower side).
The single bar means maximum or average history data during 1 day. When user clicks the single bar, the date of selected bar is displayed in the title bar. When user double-clicks the single bar, daily PD history graph of the selected bar is displayed. Figure 3.31 shows the monthly PD history graph.

3.2.13.4. Yearly PD history

Figure 3.32 is select window when user clicks “Yearly” button in the menu.
User can select maximum value or average value about PD history, and it displays yearly PD history data of selected sensor ID. X axis of graph stands for month (12 month) and Y axis means amplitude (green color graph in upper side) and count rate (yellow color graph in lower side). The single bar means maximum or average history data during 1 month. When user clicks the single bar, the month of selected bar is displayed in the title bar. When user double-clicks the single bar, monthly PD history graph of the selected bar is displayed. Figure 3.33 shows the yearly PD history graph.
< Figure 3.33. Yearly PD history graph >
4. Countermeasures

4.1. In case of PD occurrence

In case that system alarm arises and PD events are recorded because of PD occurrence, check the following documents for detail analysis.

- Recent PD event report of sensors which PD events are recorded.
- Recent PD history report of sensors which PD events are recorded.
- The characteristic of PD patterns (particle, corona, floating, void)
- The durability of PD patterns (continuous, intermittent)
- Current energized condition (powered feeder and no-powered feeder)
- PD events status of adjacent sensors (patterns and amplitudes)
- Recent CB, DS operation
- Recent maintenance of GIS (motor operation, welding and so on)

After reviewing above documents in detail, in case of doubtful PD inside of GIS, the location of PD can be estimated using portable PD monitor, external sensor, oscilloscope etc. Based on the content estimated in the site, opinion of our company about estimated causes and location of PD will be reported.

4.2. In case of system fault

Our system has watchdog function for periodic inspection of system and auto reset function when software problems occur. However, in case of hardware problems, check the following status for detail analysis.

1) Data acquisition system (DAS)
   1. Power fault
      - MCB “TRIP” check => When MCB is “TRIP”, return “ON”
      - Fuse status check => When the fuse had gone, change the fuse.
   2. Communication fault
      - LED check of optical hub =>When LED is “OFF” status, check the cable connection status.
2) Communication control unit (CCU) and application server
   1. Power fault
      -. Check the input power
   2. Communication fault
      -. LED check of optical hub => When LED is “OFF” status, check the cable connection status.