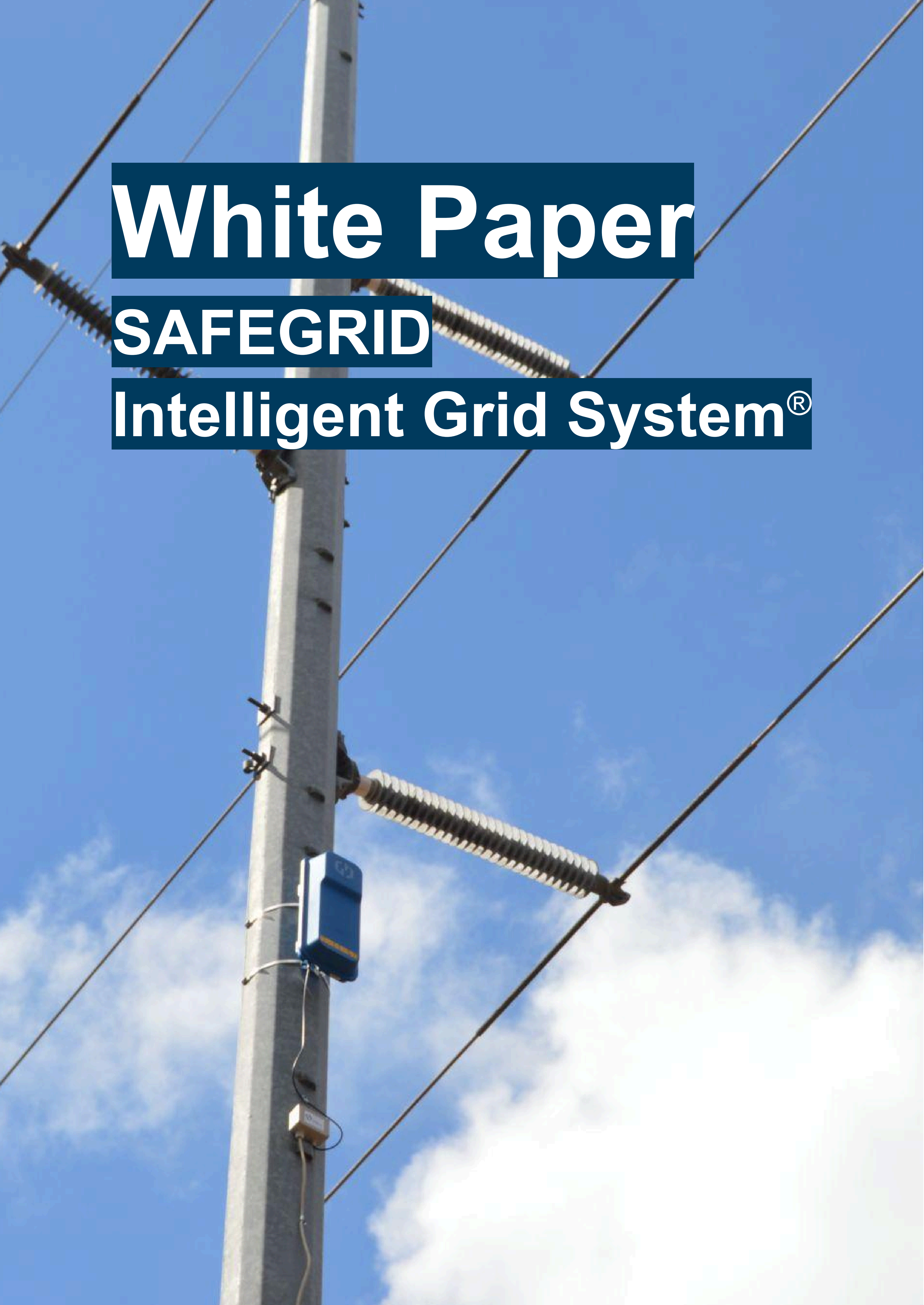
White Paper

SAFEGRID

Intelligent Grid System®



White Paper

Safegrid Intelligent Grid System®
Traveling wave-based fault location

1.Overview of power system faults and fault location

Today, the global electrical grid is a complex, interconnected network comprising some 100 million kilometers of power lines worldwide. The global grid composes the largest structure humans have ever built. While the electrical grid is the most complex construction on earth, utilities typically have had very restricted visibility to its operational state. Grid faults cause service interruptions, disturb end-customer power usage and harm the utility's operational economics. Considering the increasing electricity demand due to the on-going energy transition, reliable power supply is more critical than ever. While multiple changes are taking place in the energy industry, it cannot be overstated that the electrical grids act as the backbone which facilitates the green transformation.

Power system failures happen due to external, natural and operational causes. External causes refer to strong winds, storms, snow, wildfires, animal contacts or vegetation contacts. Natural failures refer to component and insulation breakdowns which are caused by deterioration or aging of a component. Operational problems can refer, for example, to bi-directional power flows, frequency or current/voltage fluctuations and overloading that deteriorates a component's lifetime.

Power system faults cause high currents and abnormal voltages that can jeopardize human safety, grid property and even cause disruptions to economic and social activity. Although a great effort goes into preventing and limiting damage once a fault occurs, as they inevitably do, new methods are needed to deal with grid faults. The focus of outage management is to detect, locate and remove faults.

Outage management includes the following steps

1. **Fault detection:** The ability to detect and classify a fault in all operational states.
2. **Fault location:** The ability to locate the fault as accurately as possible. Fault location enables the sectionalization of the fault area (isolating the affected area as much as possible) and eventually the fault repair by dispatching field crews to the correct location for fast service restoration.

Fault location aims to minimize outage time and the lack of service to end-customers. Accurate fault location helps to minimize field patrol labor costs together with the economic savings made via reduced outage times. Moreover, accurate fault location reduces the need for trial-and-error localization. For example, control room personnel might need to perform remote trials to sectionalize (isolate) the fault area in order to minimize affected customers.

Fault protection is done primarily via protective devices, such as fuses or protection relays and circuit-breakers, that de-energize faulty feeders in the case of a fault. They serve as the core protection devices with the function to protect human life and grid property from damage.

1.1. Power system faults

Grid faults can be categorized into two main categories: 1) short circuits, also called phase-to-phase or phase-to-neutral faults; and 2) earth faults, also called ground faults. A short circuit is a fault where two or more power system phases are in direct contact with each other or with the neutral wire. A fault event can also be any combination of the above. Short circuits characteristically have very low fault impedances, leading to large fault currents. The fault currents during short circuits are in the order of hundreds or thousands of amperes.

Earth fault refers to a fault where a power system phase comes into contact with the ground potential. This might happen, for example, via a tree, a wooden structure, or a downed conductor. The characteristic of earth faults depends heavily on the grid's primary transformer grounding method. Specifically, the connection type of transformer (delta or star) and how the neutral point of the transformer is connected to the ground. Typical grounding methods include solidly single-grounded, solidly multi-grounded, isolated, resistor-connected, or a Peterson coil grounding. Earth fault currents in other than solidly-grounded systems are typically small, in the order of few to tens of amperes. In solidly-grounded systems, the earth fault currents are almost always over 200 amperes, even thousands of amperes near the primary substation. Due to the varying grounding methods, earth fault impedances vary to a large degree, even fault-by-fault, thus affecting earth fault currents greatly. Earth faults have traditionally been the most difficult fault type to locate, and high-impedance earth faults have proven to be especially challenging to locate.

Naturally, other factors affect power system faults and their characteristics as well, such as the wiring type. For example, whether a 3-wire or 4-wire distribution system is used. The latter is common in North America, where a fourth wire is used to carry the neutral conductor as consumers use predominantly single-phase supply. The low voltage connection is created by a single-phase distribution transformer, connected between the neutral wire and a phase. In contrast, a 3-phase/3-wire distribution system is a standard in Continental Europe: no neutral wire is carried in the distribution system and consumers are supplied with 3-phase power via 3-phase distribution transformers.

1.2. Traditional fault location methods

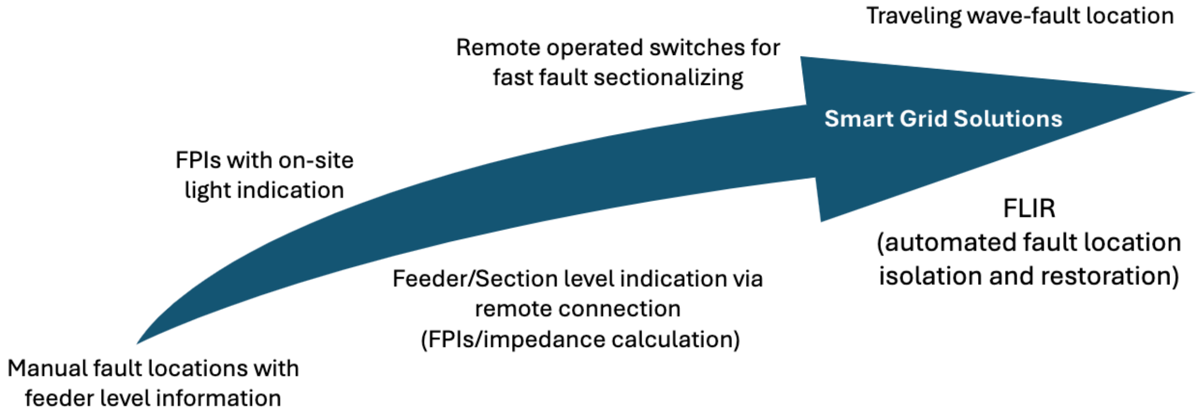
Traditional fault location methods have relied either on observational or protection device based approaches. Observational fault location refers to approaches where usually an end-user notifies the utility about a power outage or the utility detects it by themselves via other means. In this case, the technical maturity of the utility isn't usually very high; no substation automation or SCADA systems are typically used. Even if a relay has tripped, the information is not transferred to the utility as digitalization rate is low. The overall transparency to the grid and its operational state is rather limited due to the lack of remote connections.

In more modern setups, a SCADA system is used in combination with substation automation, such as microprocessor-based relays to form the core operational technology (OT) of the grid.

SCADA systems are used as the heart of the grid operations to inspect and control the grid's operational state. Grid operators can inspect tripped (faulty) feeders remotely, and depending on the automation level, control the grid via remote switches to sectionalize the affected grid areas during a fault. Additional IT systems, such as distribution management systems (DMS) or outage management systems (OMS) might be used. These software systems offer tools to manage various tasks such as switching states and outage management as a map-based automation. However, these IT systems always need some field devices, such as substation automation, remotely controllable switches, advanced metering infrastructure or fault indicators to gather the switching-state and measurement data from the grid.

For fault location, specialized devices and software have been developed for many decades for the sole purpose to detect and locate grid faults. These devices and softwares are created to complement the IT/OT systems in order to help grid operators to achieve more reliable power supply. The most common fault detection devices are fault passage indicators and impedance calculations as a software-based approach.

Figure 1. Advances in fault location



Fault Passage Indicators

The majority of fault indication devices deployed are fault passage indicators (FPIs) of various types. These devices are either installed to overhead lines or cable feeders in a substation. An FPI device detects magnetically if a fault current has passed through the indicator. If used in the substation alone, the FPI provides only the direction (downstream) information of the fault. If multiple FPIs are used on the same line, they provide a fault section between every two devices. FPIs are generally classified into two types: non-communicable and communicable. Non-communicable FPIs only provide an on-site alarm via a light indication. The field patrols then follow the light-indications to locate the fault. Communicable FPIs can provide additional remote messages to a SCADA system. The communication is typically limited in a binary fashion to notify the SCADA if the FPI has noticed a fault current. Therefore, FPIs don’t provide accurate information on the fault’s location. To achieve accurate fault locations, FPIs must be deployed at rather short intervals to achieve short sections, increasing the costs.

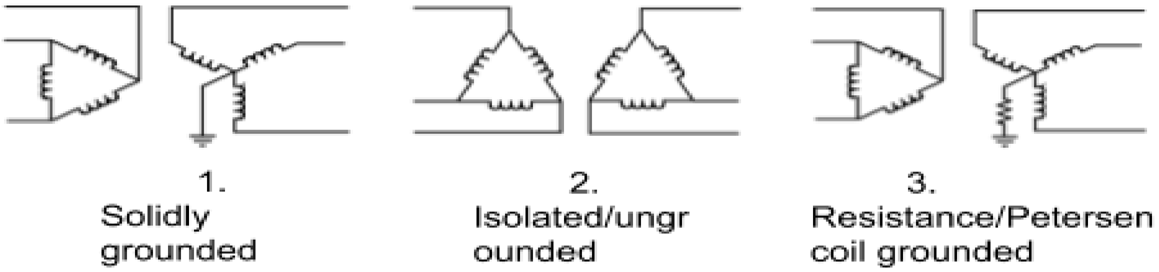
Impedance-based fault location

As modern protection relays can measure and analyze phase waveforms, the measurement data can be used to estimate the location of the faults. If the relays or the DMS system are programmed with the line parameters, such as conductor type and its cross-section, impedance per unit distances can be calculated. Once a fault occurs, an equivalent circuit for the fault is formulated using the fault current waveforms together with the line parameters to estimate a fault distance. The method works primarily with short circuit faults, given that the line data is correctly given. Uncertainties in line parameters, such as wrong conductor type or cross-section can adversely affect the calculation. Hence, the method is highly dependent on correct data input. Moreover, the same fault distance can in fact be calculated to more than one location in the grid. For example, two different branches in the same feeder can have the same impedance per unit distance. Thus, multiple fault locations are often calculated in the case of the feeder having multiple branches. This further complicates finding the fault as sectionalizing or trial patrolling must be done to find the correct location.

Earth faults are difficult in many ways

Locating earth faults has proved to be a difficult task in the modern distribution system. Earth fault levels are primarily determined by the system's grounding method, which in return is chosen by safety, asset stress and service continuity goals. For example, solid grounding with low earthing impedance provides high fault currents to drive the protection devices, but offers equal disadvantages with dangerous arcs and frequent service interruptions. Therefore, isolated or impedance-grounded systems are often used to limit the earth fault currents to lower levels. The typical grounding methods are illustrated in Figure 2.

Figure 2. Different grounding methods of the primary transformer in a distribution system



The drawback of these grounding methods is that the operative goals are achieved at the expense of earth fault detection. In high-impedance earth faults, the magnitude of the fault current is low in relation to the load current, requiring high sensitivity from the protection or fault indication device. In addition, the diverse topology options, switching states, or distributed generation along the feeder further complicates earth fault location. For example, if the switching state changes, the line capacitance changes, affecting the earth fault current. As a result, the small or even arbitrary earth fault levels have proven that FPIs or software driven calculation models often provide misleading results about earth fault locations.

Grid transformation creates additional challenges

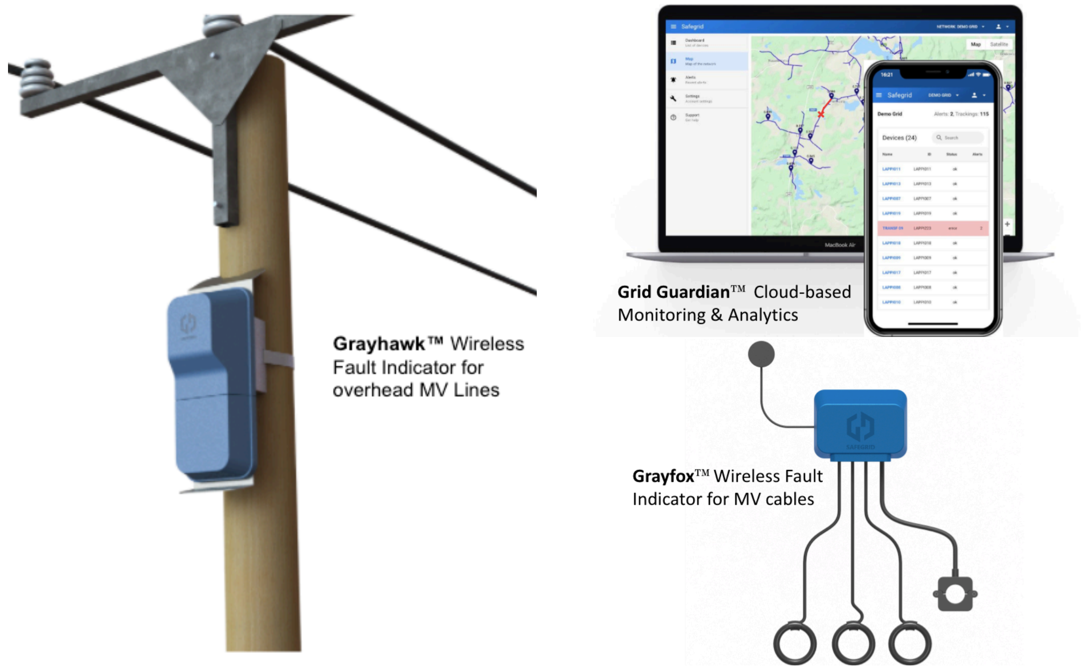
The penetration of renewable energy generation creates new problems for fault detection, especially in distribution grids. The distributed and stochastic nature of the renewable generation affects power flows and voltage levels in the grid. These changes transform the grid's operational state from the traditional top-down state to a more bi-directional state. Moreover, additional resources such as energy storages affect the grid operation. Operational changes are not limited to bi-directional power flows, but also to topology changes. The grid topology can change from a conventional radial feeder to a ring or parallel-connected feeding topology as the grids get more complex. As the switching-states and supply directions can vary, fault currents and current paths can become arbitrary. Therefore, fault location becomes even more difficult. As a result, new solutions are needed to operate in all topology, switching and feeding states to detect and locate faults reliably.

2.Safegrid Intelligent Grid System®

Safegrid's Intelligent Grid System® (IGS) employs instant-on sensors and cloud-based analytics for capturing and analyzing grid events. The system includes sensors for both overhead lines and underground cables, up to 250 kV voltage levels. The location technology is based on traveling wave-detection coupled with GPS time synchronization to triangulate the fault locations. With proprietary algorithms, the system classifies grid events by type and severity, enabling customers to identify faults, anticipate future failures and prevent them. The key benefits of the Safegrid system are:

- **Fault location with 100m accuracy:** State-of-the-art wireless and instant-on traveling wave sensors that feed data to cloud-based analytics driven by machine learning, enabling advanced grid insights
- **Fault prediction using online 24/7 partial discharge measurements:** A real-time detection and location of grid anomalies to provide proactive alerts for users to prevent future faults in advance

Figure 3. Safegrid Intelligent Grid System®

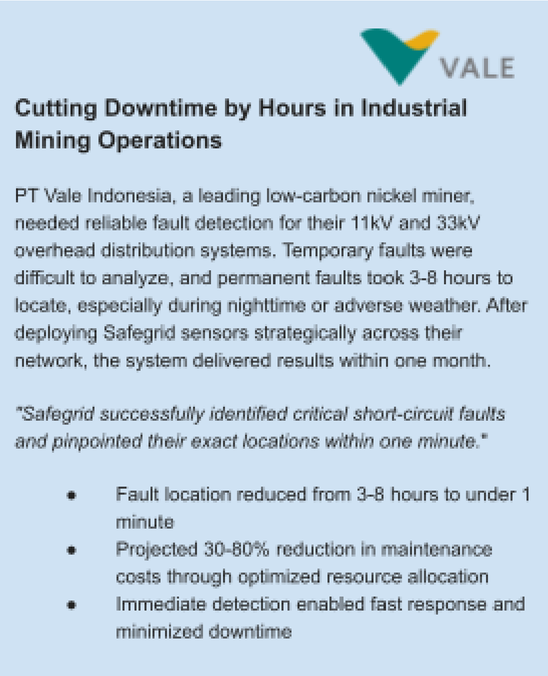


The Safegrid Intelligent Grid System® consists of the following components:

1. **GridGuardian:** A cloud-based analytics and monitoring software that gives overall transparency to the grid's operational state as well as instant actionable alerts on grid faults. The user interface is available for both desktop and mobile devices.

2. **Grayfox® Family**: A product family of sensors for cable grids that employs Rogowski-coils for non-intrusive current and voltage measurements. It is easily installed and automatically connects to GridGuardian for instant-on functionality.
3. **Grayhawk® Family:** A product family of wireless sensors for overhead lines that utilizes wireless current and voltage measurement technology. The wireless measurement enables a hot-installation as the device is non-intrusive and non-contact. It connects automatically to GridGuardian for instant-on functionality.

All measurements are current and voltage based, meaning that the Safegrid sensors not only measure phase currents and voltages on the nominal frequency (50/60Hz) but also capture the traveling waves (fast transients) up to 1MHz frequency. Respectively, the phase currents and voltages as well as the traveling waves are used to classify and locate the faults. Voltage measurements are not used by the system. Fault recordings are created from the measurements which are timestamped using a GPS receiver and sent to the cloud server using an LTE/4G-network. The system is entirely software driven as all computation is done centrally in the cloud. The sensors act as passive devices that measure and transmit data. The cloud-based approach allows to compute centrally the huge amount of high-frequency data gathered from the grid. Moreover, the gathered data is used to improve the system by training the location algorithms for better performance. The result is an evolving system that gives highly accurate and actionable alerts from various grid events and increases transparency to the grid's operational state.



VALE

Cutting Downtime by Hours in Industrial Mining Operations

PT Vale Indonesia, a leading low-carbon nickel miner, needed reliable fault detection for their 11kV and 33kV overhead distribution systems. Temporary faults were difficult to analyze, and permanent faults took 3-8 hours to locate, especially during nighttime or adverse weather. After deploying Safegrid sensors strategically across their network, the system delivered results within one month.

"Safegrid successfully identified critical short-circuit faults and pinpointed their exact locations within one minute."

- Fault location reduced from 3-8 hours to under 1 minute
- Projected 30-80% reduction in maintenance costs through optimized resource allocation
- Immediate detection enabled fast response and minimized downtime

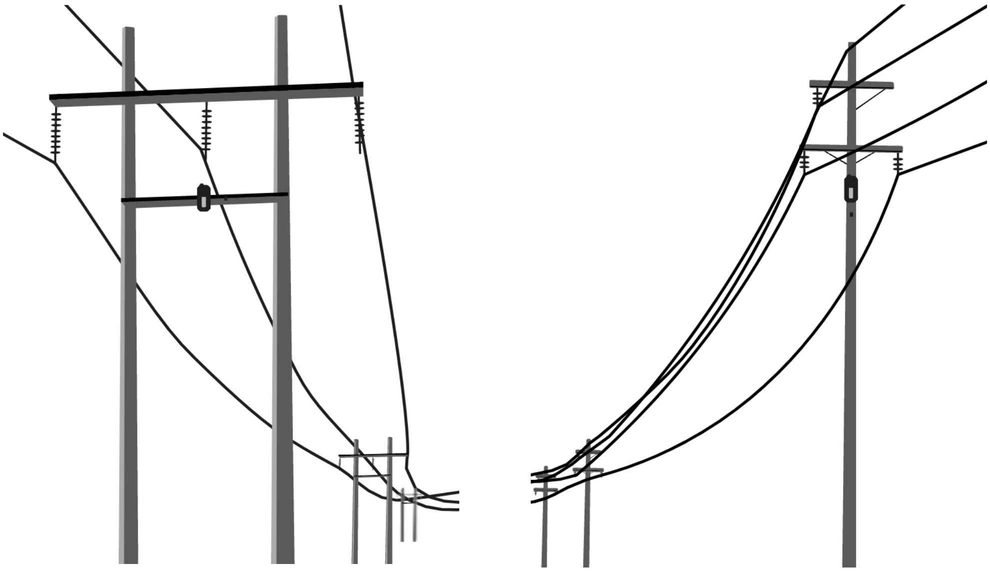
2.1. Sensor devices

The sensor devices used in the Safegrid system provide the same measurement data to the GridGuardian regardless of their type. However, as different installation methods are needed to facilitate both overhead lines and cable grids, two main sensor types have been developed.

Grayhawk® Family
The Grayhawk® Family sensors are wireless measurement devices designed for overhead lines. The device measures the magnetic field produced by the conductors using a special magnetic sensor array. As the magnetic field is a product of the current flowing in the conductor, one can deduce the phase currents by measuring the magnetic fields. The computation is done in the GridGuardian® cloud. For the phase current calculations, the GridGuardian needs only to know the geometry of the overhead line conductors in relation to the sensor.

The sensors are installed as close as possible to the wires, but within a safe distance for hot installation, according to the local safety rules. Auxiliary power is provided either from a LV line going nearby or using solar power. Alternatively, a separate instrument transformer can be installed to produce the auxiliary power. The Grayhawk® Family sensors contain an internal antenna for cellular communication and GPS reception. Installation examples are illustrated in Figure 4.

Figure 4. Grayhawk example installations

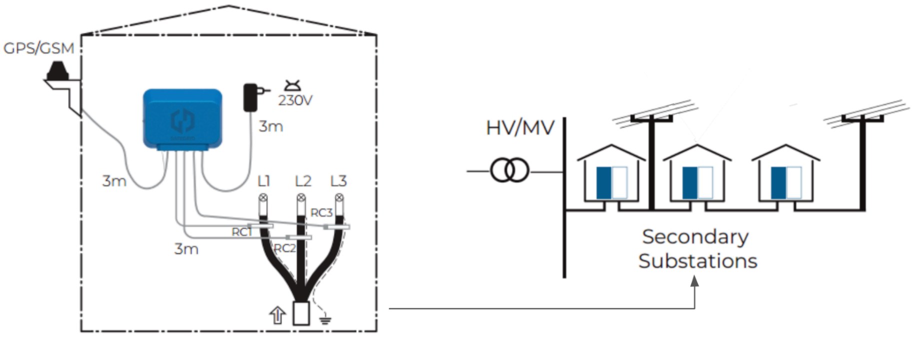


The Grayhawk® Family sensor offers easy, fast, and cost-effective installation thanks to the wireless measurement. It is important to note that the wireless measurement can expose the device to unwanted electromagnetic interference which disturbs the actual phase measurements. Such interferences might be caused by nearby or parallel power lines or other radiating devices, such as transformers. However, as the placement of the sensors have a large degree of freedom, finding a suitable installation location rarely causes issues.

Grayfox® Family

The Grayfox® Family sensor is a measuring device designed to monitor cable grids. The sensor uses traditional Rogowski-coils for the measurements, which measure the phase currents and voltages in a similar fashion as the Grayhawk® Family sensors. Grayfox® Family sensors are typically installed at main substations, secondary substations or at pole risers. Different variants exist depending on the installation location. The installation work can also be completed as a live-line work, without the need for any mains interruptions. An installation example is illustrated in Figure 5.

Figure 5. Grayfox example installation



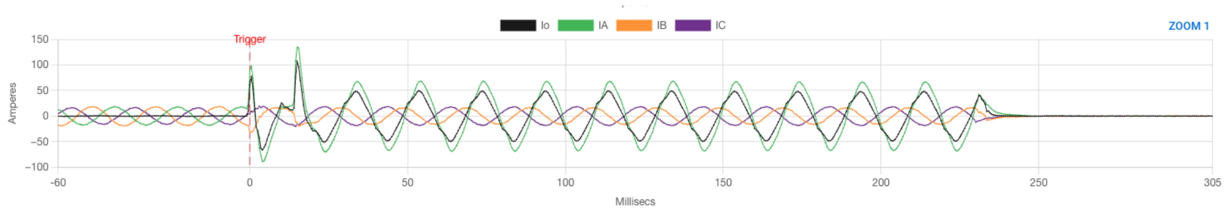
The Grayfox® Family sensors are typically placed to the inner wall of a compact substation, or into the electrical cabinet of the primary substation. The auxiliary power is usually taken from the low voltage power available from the substation. The Grayfox® Family sensors does not have an internal antenna and therefore requires external antenna mounting outside of the substation housing.

2.2. Measurements and fault calculation

The Grayhawk® Family and Grayfox® Family sensors monitor the overhead and cable lines respectively, and when they detect a change in network currents and voltages, they will individually make a decision to send samples of measured current/voltage waveforms to the GridGuardian server. The sensors measure and sample the 50Hz/60Hz phase currents and voltages. The server then uses this information to calculate the neutral current, symmetrical components and then classifies the event into different fault categories, such as earth fault, short circuit or partial discharge. The server also analyzes the change moment of the current and provides indication on whether the fault current has passed through the sensor.

Figure 6 illustrates phase currents during an earth fault as measured by a Grayhawk® Family sensor. The event is an example from a grid with isolated-grounding where the earth fault currents typically rise to some tens of amperes due to the natural line capacitances. The phase currents I_A, I_B and I_C are calculated by the GridGuardian server using the magnetic field measurements and the configured overhead line geometry given for the Grayhawk® Family.

Figure 6. Measured phase currents by a Grayhawk sensor

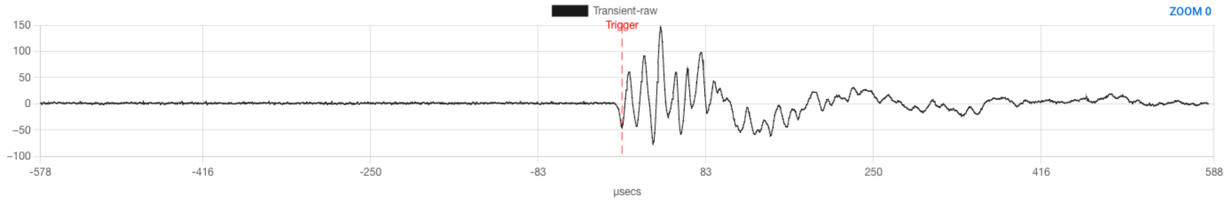


The figure demonstrates well how the steady-state currents change as the earth fault causes I_A to significantly grow as the fault current flows through phase A into ground. Finally, a relay trip and a circuit-breaker operation can be seen around 230 ms de-energizing the feeder.

Traveling wave-based fault location

In addition to the phase currents, the sensors also measure and sample high-frequency currents at or above 1MHz. These samples are analyzed by the server to find traces of fault transients. All sensors are also equipped with a GPS (Global Positioning System) receiver which provides an accurate timestamp for the fault recordings. The timestamps of the fault transients are further used by the server to calculate accurate event and fault locations.
An example of a fast transient signal measured by a Grayhawk® Family sensor is shown in Figure 7. The transient is measured from the same earth fault event as illustrated in Figure 6. When a fault occurs on the grid, a similar fast transient originates, starting to travel in all directions at the near speed of light. The actual velocity of the fast transient signals varies based on the conductor type, for example, is the medium an insulated cable or overhead line.

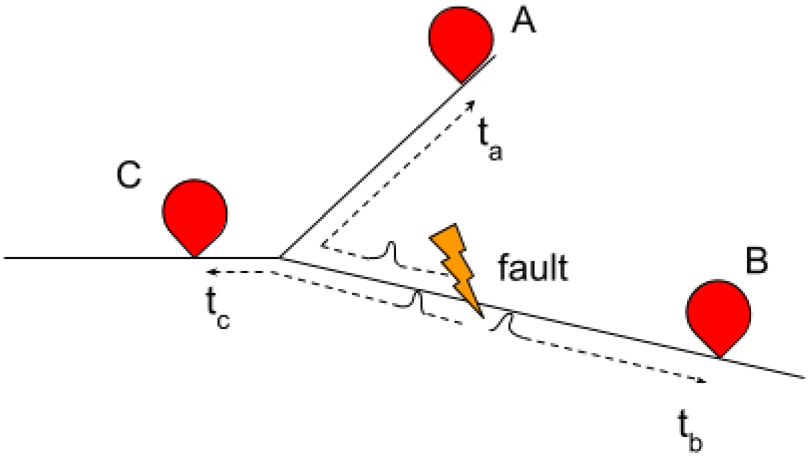
Figure 7. Measured fast transient by a Grayhawk sensor



To conclude the measurements, both the fault currents and fault transients are measured during an event by the system. However, the behavior and propagation of the high frequency transients are distinct from the fault currents. Individual fast transients are induced at the beginning of the fault, after which they start to travel throughout the grid in all directions, until they are attenuated by the line impedances. In contrast, the fault current is sustained as long as the feeder supplies current into the fault. The fault event usually lasts a few hundred milliseconds until which the relay trips and de-energizes the feeder, as illustrated in Figure 6.

The principle of utilizing fast transients for fault location is illustrated in Figure 8. In the figure, fast transients are induced by the fault (flash icon) into the grid. The sensor devices A, B and C will all measure the transients at different times due to the varying line distances. The sensors will then create fault recordings with unique timestamps (t_a, t_b and t_c) on each respective device. After creating the fault recordings, the sensors will transmit the data together with the GPS timestamp to the GridGuardian® server. Using the individual fault recordings, a single fault event is created. Finally, based on the velocity of the fast transients, the timestamps, the distance between the sensors and the grid topology, the original fault location can be computed for the event.

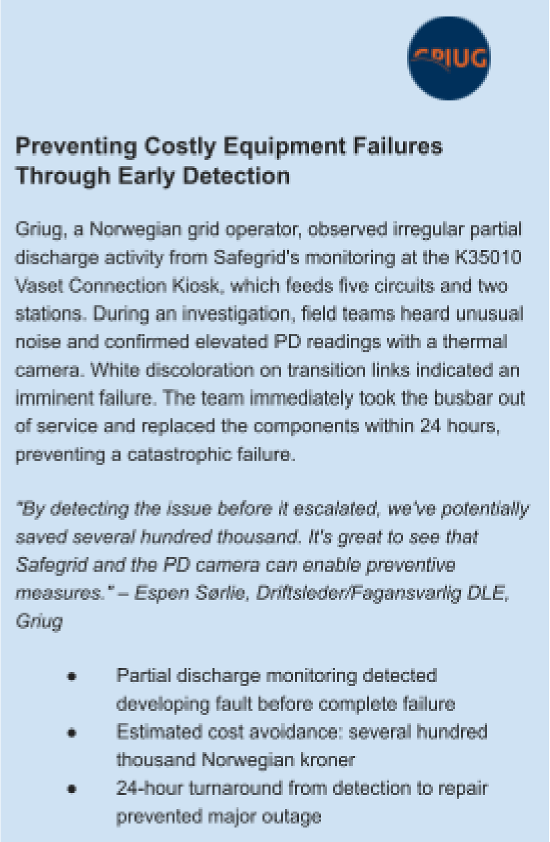
Figure 8. Traveling wave fault location-principle



A similar well-known principle is known to many to determine the distance of a lightning strike during a thunderstorm. If one counts the seconds from seeing a lightning strike to hearing the sound of thunder, one can estimate how far away the lightning struck. Only in this application, the possible path of the transient is known, its traveling speed is known, and the measurement positions are known with accurate timestamps. Combining these variables, it's possible to calculate the signal origin. More interestingly, the location accuracy is directly proportional to the resolution of the time measurement. The transients propagate near the speed of light (50-99%) depending on the medium. This averages to some 200 m/μs propagation speed. Therefore, the higher the sampling rate, the more accurate the fault locations. The Safegrid system uses a 1MHz sampling rate that enables it to locate faults at

±100m resolution on average.

The traveling wave method has been known for decades, but Safegrid is the first company in the world to commercialize a working, scalable solution for both transmission and distribution grids. Previous attempts at fault location using traveling waves have failed to deliver due to the complex behavior of the transients, such as reflections and signal attenuation, topology management issues, and high frequency noise, combination of cable and overhead lines in the same feeder line. These issues have prevented successful implementations of the technology especially in distribution grids. By providing wireless and fast-to-install sensors, combined with advanced proprietary algorithms, Safegrid is the world leader in design and manufacturing of traveling wave-based fault location systems.



Preventing Costly Equipment Failures Through Early Detection

Griug, a Norwegian grid operator, observed irregular partial discharge activity from Safegrid's monitoring at the K35010 Vaset Connection Kiosk, which feeds five circuits and two stations. During an investigation, field teams heard unusual noise and confirmed elevated PD readings with a thermal camera. White discoloration on transition links indicated an imminent failure. The team immediately took the busbar out of service and replaced the components within 24 hours, preventing a catastrophic failure.

"By detecting the issue before it escalated, we've potentially saved several hundred thousand. It's great to see that Safegrid and the PD camera can enable preventive measures." – Espen Sørlie, Driftsleder/Fagansvarlig DLE, Griug

- Partial discharge monitoring detected developing fault before complete failure
- Estimated cost avoidance: several hundred thousand Norwegian kroner
- 24-hour turnaround from detection to repair prevented major outage

Sensor placement on a feeder line

The reliable operation of the Safegrid Intelligent Grid System® is based on sufficient sensor coverage and the correct placement of the sensors. The positioning of the sensors is of primary importance for accurate fault location.

As mentioned above, the fault transients are attenuated as they propagate in the grid. Signal attenuation occurs in the line impedances, but also in the form of reflections at interface points of the grid. Reflections occur at network branches or at line impedance changes, e.g., at the point where conductor type changes. Due to these physical phenomena, the accurate transient based monitoring of the power grid requires sufficient sensor coverage and the correct placement of the sensors. The number and the location of the sensors needed is based primarily on the quantity of branches and the line distances.

Figure 9. Example of a sensor placement scheme for a distribution grid

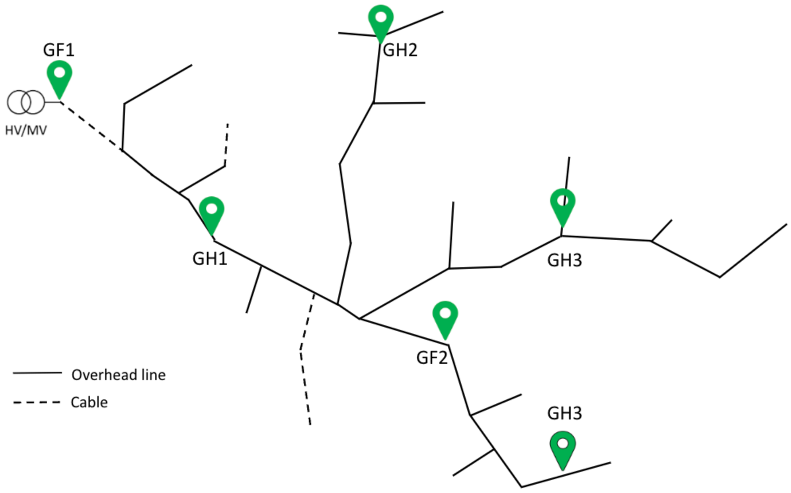


Figure 9 illustrates an example of a typical feeder line in a rural distribution grid. Often similar grids are composed of both underground cable and overhead line as a mixed network. Cables might be used near the main substation at the beginning of the feeder, but as the distance from the substation increases, the feeder is more likely to be composed of overhead lines. Usually both Grayfox® Family and Grayhawk® Family sensors are used together as a mix in the same feeder. The distance between two sensors can be long, up to 10 km or even more, depending on:

- Quantity of branches
- Quantity of MV/LV transformer on the line
- Quantity of cable-to-overhead or overhead-to-cable crossovers

As a rule of thumb, a sensor is needed every 5 - 10 kilometers of grid length in an overhead line feeder. For a cable grid, a sensor might be needed every 3 - 5 kilometers of grid length. Moreover, if the feeder is sufficiently covered with sensors, a change in the topology or the switching state is irrelevant for the performance of fault locating. The system can also locate high-impedance earth faults using the traveling waves the faults have induced into the grid.

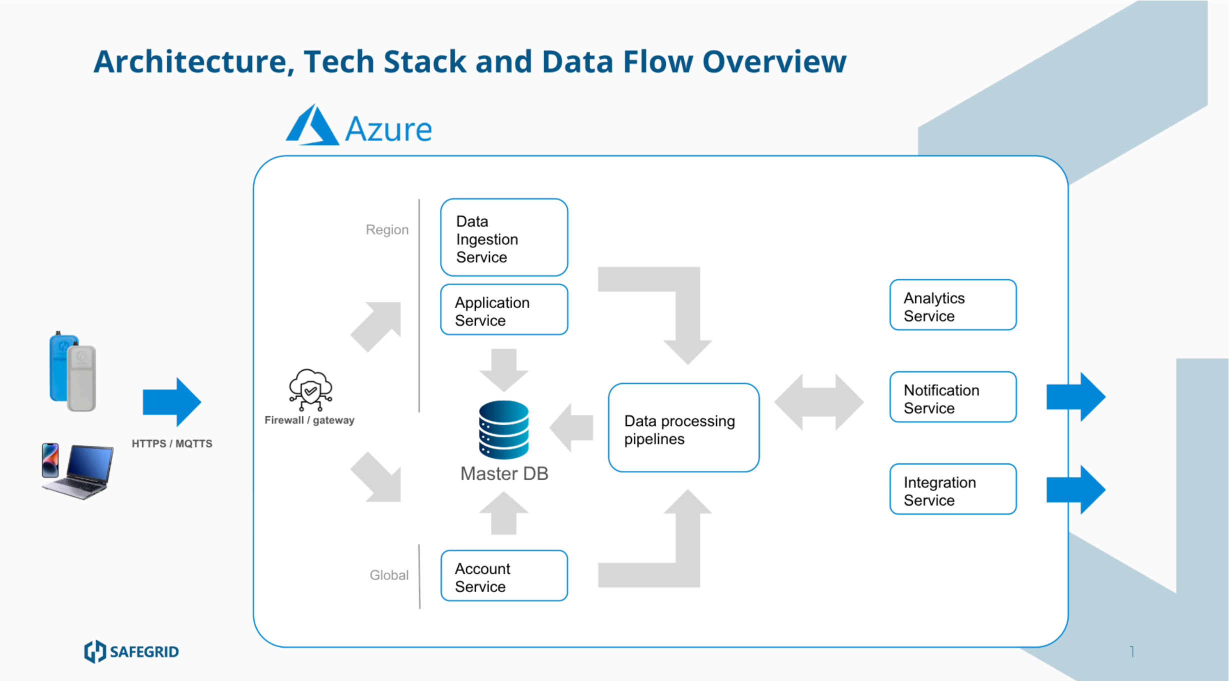
The aforementioned illustration applies to distribution grids. For transmission lines with fewer branches, the distances can be even longer. Safegrid has simulation tools to indicate the optimal locations of the sensors. The complete sensor placement and installation guide is provided to Safegrid customer utilities.

2.3. Cloud service

GridGuardian is a cloud-based system that monitors the grid in real-time, which is accessible through both web and mobile interfaces. It uses mapping tools and grid topology data to quickly notify about grid faults. Various reporting and sensor management tools are available for the system operators. Additionally, instant SMS and email alerts are supported to provide immediate information about fault types and locations. GridGuardian supports integration to existing IT/OT systems such DMS via a standard REST-API interface. The system is hosted in Microsoft Azure in the EU and US.

The system gathers data from the Grayhawk® Family and Grayfox® Family sensors for the core monitoring functionalities. Additional data imports from 3rd party data sources, such as weather services or other measurement devices like protection relays are also supported. The GridGuardian® cloud architecture is presented in Figure 10.

Figure 10. GridGuardian cloud architecture



Architecture, Tech Stack and Data Flow Overview

Azure

HTTPS / MQTTS

Firewall / gateway

Region

Data Ingestion Service

Application Service

Master DB

Data processing pipelines

Global

Account Service

Analytics Service

Notification Service

Integration Service

SAFEGRID

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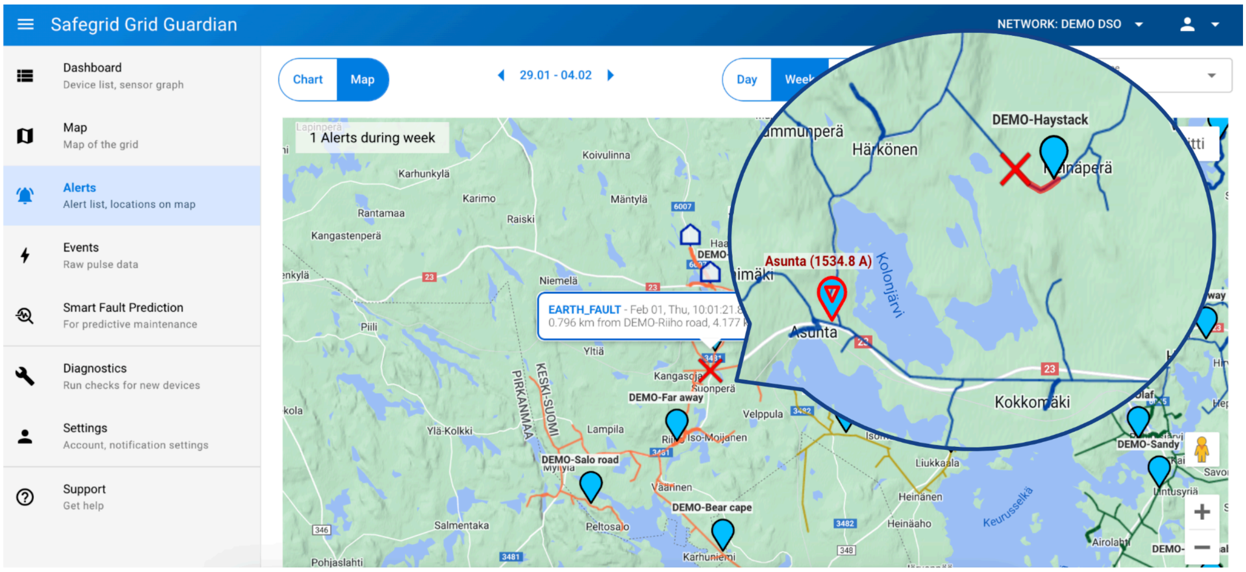
The GridGuardian user interface has various modules to manage the sensors, inspect grid events, and view the operational state of the grid. The two main modules are the Smart Fault Location and Smart Fault Prediction tools. An example view from the Smart Fault Location functionality is seen in Figure 11.

Figure 11. Accurate fault locations



EARTH_FAULT - Feb 01, Thu, 10:01:21
0.796 km from DEMO-Riiho road, 4.177

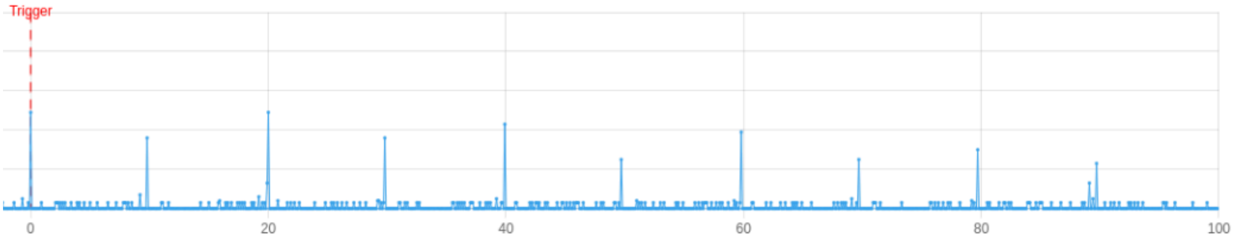
In the Smart Fault Location tool, various grid events and faults are provided in a map view with coordinate data. Event locations are indicated with the red cross icon. Moreover, the system also provides fault passage information in the fashion of a traditional FPI for short circuits. This can be seen in Figure 11 from the highlighted “Asunta” sensor which shows that a fault current has passed through the device in the downstream direction.

Detection of partial discharges for predictive maintenance

Partial discharge signals are known to emerge from frequencies approximately of 500kHz up to 1GHz or even higher. Special, rather expensive equipment made for offline measurements have been available traditionally for the measurement of partial discharge signals locally.

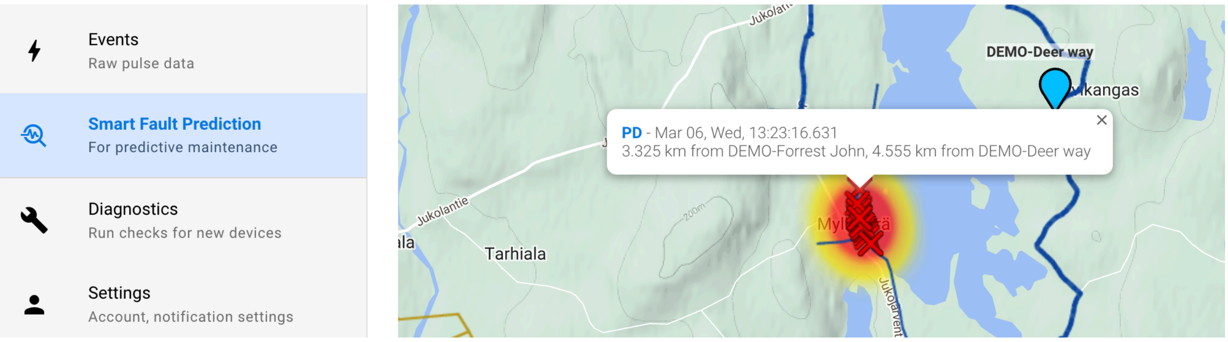
Safegrid’s approach is to provide a 24/7 online measurement tool focusing on providing a qualitative view of the grid as a whole. The aim is to alert the grid operators about potential failures prior to a component’s breakdown. Considering that the very high frequency partial discharges do not propagate far, while also taking into account that branches, terminations, joints and LV transformers attenuate the same high frequency signals the most, aiming to measure them online is not viable. However, one can benefit from the inherent property of the branches and varying impedances in the grid as the reflections of the high frequency partial discharge signals cause new reflected signals, measurable also at lower frequencies. Both the Grayfox® Family and Grayhawk® Family sensors are able to detect partial discharge signals, typically occurring in the range of 100 kHz to 10 MHz, which can originate from higher frequencies.

Figure 12. Measured partial discharges



Safegrid has developed a special approach to analyze partial discharge signals, shown in Figure 12. This enables an easy way to visualize and use the data with AI algorithms. One can notice from the figure, that a spark occurs every 10ms, which is the result from small insulation breakdowns, i.e., partial discharges which occur on the positive and negative half of a 50Hz signal. This is a consequence of the electric field as it reaches its peak value twice per cycle, reaching high enough value to cause temporary breakthroughs in the insulation. Eventually the partial discharges will deteriorate the insulation material completely, causing an outage.

Figure 13. Measured partial discharges on a heatmap



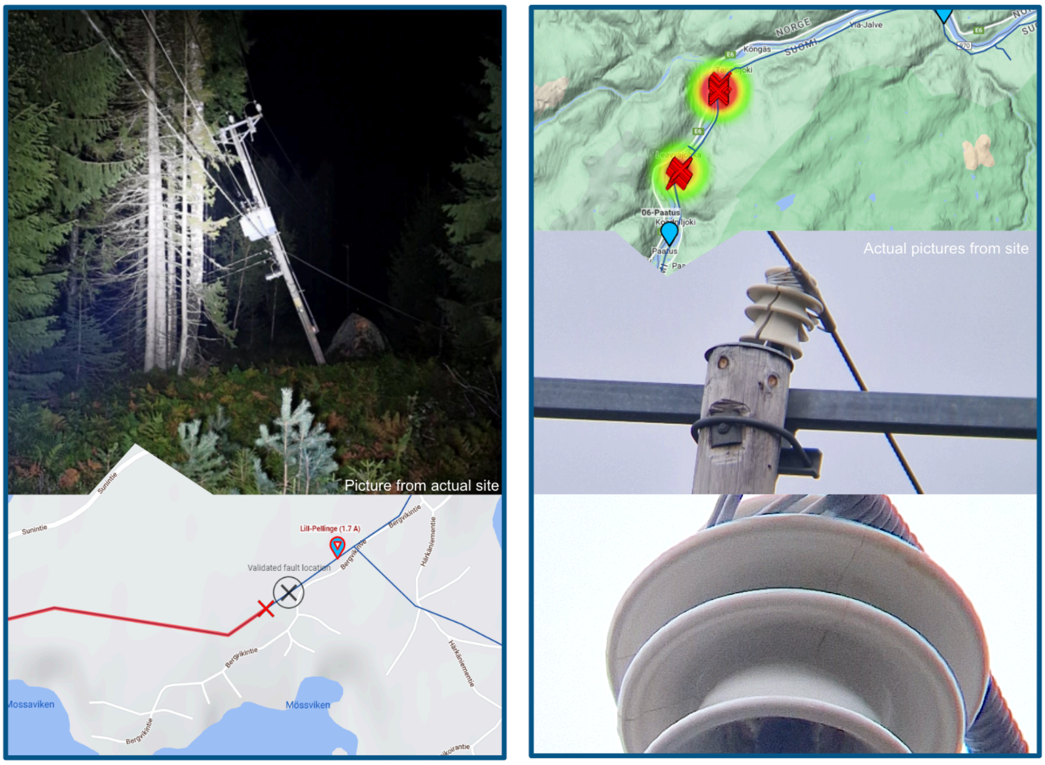
PD - Mar 06, Wed, 13:23:16.631
3.325 km from DEMO-Forrest John, 4.555 km from DEMO-Deer way

The partial discharge locations are plotted in GridGuardian as heatmaps to easily visualize cumulative hotspots for potential failures. A heatmap example is illustrated in Figure 13 from the Smart Fault Prediction tool. Email or text message alerts are also supported to inform grid operators about a potential failure.

Finally, two real life examples are presented from both the Smart Fault Location and Smart Fault Prediction tools in Figure 14. On the left side, a grid fault example can be seen where a pole broke in half due to a strong storm, causing an outage. The fault was located within a confirmed 100m accuracy, helping the utility to find and repair the fault quickly. The black cross icon, which can be seen near to the indicated location, is the customer-validated fault location. Safegrid uses the validation data to improve the location algorithm on a continuous basis.

In the second case, a real-life example can be seen from the fault prediction functionality on the right side. In this particular case, two broken insulators started to cause strong partial discharge signals, shown with the heatmaps. Once the indicated locations were inspected on-site, the broken insulators were easily found. The components were then replaced during a controlled outage, preventing the soon-to-come failure from ever happening.

Figure 14. Real-life examples from accurate fault location and fault prediction cases



Continuously improving system

The Grayhawk® Family and Grayfox® Family sensors, as well as the GridGuardian algorithms, are all updatable over-the-air. Safegrid continuously improves the sensor software and server algorithms to benefit the customer utilities using the validated data sets. In addition, the Safegrid Intelligent Grid System® continuously collects data from utility networks for algorithm training, enabling both improved accuracy and new features, making the system increasingly effective over time. Safegrid is an industry leader in collecting high frequency current/voltage and transient data and transforming them into new grid insights for the customer utilities.

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