System solutions: Partial discharge measurement and monitoring systems.
A potential need.

An increasing number of users consider additional tests and surveying of cable systems as part of their overall asset management. Because of this, monitoring and diagnostic systems based on partial discharge (PD) tests are in increasing demand. Brugg Cables responds to this by offering solutions for all types of PD measurements and monitoring solutions.

Why PD measurements?

Partial discharge (PD) measurements are an established measurement and diagnostic method used to assess the majority of electrical equipment in power systems. For many insulation systems, PD measurements are a useful tool for evaluating the quality of the insulation.

The correct design of cable systems is checked in type- and prequalification tests, whilst the production quality of cables and accessories is checked in routine tests according to the relevant standards. However, on-site installation poses a potential risk as far as defects are concerned. Small particles, such as dust, humidity or other tiny traces of substances, can go undetected during the installation. If they are in critical locations of the high voltage cable or accessories, they can cause possible defects. This can lead to severe insulation failures and a reduction in lifetime of the cable system. Although a final high voltage test after installation is made, the mentioned deteriorations cannot be fully excluded. In response to such difficulties, additional PD measurements can be helpful. Although PD measurements are typically used as additional measurements during after installation tests, they can also be conducted during operation.

Which type of system should be used?

Experiences show that most defects caused during installation occur in the accessories. As a result, particular focus has been given to the technological development of reliable systems for measuring PD in joints and terminations.

A PD inside a joint or termination is usually an extremely low-value signal. The cable system itself usually stands in an industrial surrounding, such as a power plant or a power station, with a harsh electrical environment. A low measurement signal combined with a harsh electrical surrounding with numerous interfering signals makes it extremely challenging to carry out reliable PD measurements.

Any kind of measurement, whether for diagnostic or monitoring reasons, must focus on detecting the appropriate signal. The technology for PD measurements in cable systems has responded to this, by developing various types of measurements.

Ultra high frequency (UHF) measurements has established itself as a typical means for PD measurements in terminations, whilst PD measurements in joints are typically done with integrated sensors in the joint or with inductive sensors in the cross-bonding box.
High quality and reliable PD measurements.

To assess the dielectric integrity of the cable system correctly, PD measurements should be highly sensitive and measure reliably. This means that considerable attention is given to produce an adequate signal to noise ratio, particularly by considering an appropriate sensor solution.

**Recommended sensors for terminations**

PD measurements with ultra high frequency (UHF) sensors have established themselves as a typical means for PD measurements in terminations. This is a reliable method as it allows measurements with low interfering signal deterioration to be detected. Another advantage of measuring with UHF sensors is that they can easily be applied after the cable system has been installed. This provides the customer with considerable flexibility when additional PD measurements on the terminations are due to be carried out.

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**Recommended sensors for joints**

In the case of PD measurements for joints, three main methods have been established. One method focuses on achieving an exact measurement of each joint; the other two on finding an optimum economic solution for the measurement process.

PD measurements with an integrated sensor provide a good and exact means of detecting potential PD. Since the capacitive current is measured with an inductive sensor, this method is called «capacitive-inductive» measurement. The capacitive-inductive sensor is directly integrated in the joint. Customers requiring this type of measurement must specify their choice before the joints are manufactured.

PD measurements using sensors in the cross-bonding box provide the customer with an economic alternative to the method with integrated sensors. Since the measuring principle is based on inductive coupling in a current transformer, it is called «inductive sensor». This method offers several advantages. The PD can be measured at a sufficiently high resolution and, in minimum configuration, only one sensor per joint-bay is required, thus making the system less expensive. Another advantage is that, the sensor can be applied after the cable system has been installed. In addition, PD measurements can also be carried out with UHF sensors in the cross-bonding box, providing the same advantages as similar measurements for terminations.

**Recommended sensors for cables**

Since the cable is tested in a final routine test and damages during laying are assessed by a sheath test, PD measurements for cables are rarely required. However, if requested, the PD in a cable can be measured with inductive sensors that are applied at the termination and/or joint.

**Advantages and recommendations for different sensor solutions:**

<table>
<thead>
<tr>
<th>Type and location of PD sensor</th>
<th>Signal to noise ratio</th>
<th>Costs</th>
<th>Construction effort</th>
<th>Can be applied after installation</th>
<th>Recommended application</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD measurements with UHF sensors for terminations</td>
<td>Very good</td>
<td>Medium</td>
<td>Low</td>
<td>Yes</td>
<td>For after installation tests, continuous measurements and monitoring</td>
</tr>
<tr>
<td>PD measurements with UHF sensors in cross-bonding box</td>
<td>Very good</td>
<td>Medium</td>
<td>Medium</td>
<td>Yes</td>
<td>For after installation tests, continuous measurements and monitoring</td>
</tr>
<tr>
<td>PD measurements with integrated PD sensors in joints</td>
<td>Very good</td>
<td>Medium</td>
<td>High</td>
<td>No</td>
<td>For continuous measurements and monitoring</td>
</tr>
<tr>
<td>PD measurements with inductive sensors in cross-bonding box</td>
<td>Good</td>
<td>Low</td>
<td>Low</td>
<td>Yes</td>
<td>For after installation tests, continuous measurements and monitoring</td>
</tr>
</tbody>
</table>
Focusing on reliable and economical solutions for PD systems.

Economic factors often affect users in their selection of an appropriate technical system, resulting in considerable variation in the type of solutions required. Brugg Cables and its partners respond to this wide variety of needs by providing an innovative product and service portfolio for PD measurements and monitoring.

Applications for PD measurement systems

PD measurements make a snapshot assessment of the state of a system and are usually carried out parallel to after installation tests. Customers choose between two recommended PD measurement types as shown in the diagrams below. The first measures by placing a sensor within each joint; whilst the second measures by placing a sensor in each joint bay.

- **PD measurement system with sensor in the joint**
- **PD measurements with sensor in the cross-bonding box**

Both types of PD measurements have their advantages. The former is particularly beneficial for those requiring a wide variety of detailed results. The later provides an economic solution as it allows PD detection in appropriate detail at reduced costs.

Applications for PD monitoring systems

PD monitoring systems are usually used for long-term assessments of the system. This requires durable measuring equipment. UHF sensors in terminations and integrated sensors in joints or in the cross-bonding box are recommended as the most appropriate applications responding to this demand.

Variety of systems solutions

To provide our customers with an economic solution for measuring PD, Brugg Cables and its partners have developed an innovative product and service portfolio. We are proud to say that one of our partners is Omicron, the world-wide leading company in supplying measurement, diagnostic and monitoring solutions. All PD measurement and monitoring systems can be rented. This can be applied to the whole system or to single elements, such as sensors or measuring devices. Renting the system provides a particularly economic means of conducting part-time measurements.

### Our system solutions are:

<table>
<thead>
<tr>
<th>PD measurements</th>
<th>Costs</th>
<th>Availability time of measurements</th>
<th>Effort to customer</th>
<th>Recommended application by considering measurement accuracy and costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD measurements with PD equipment and sensors rented</td>
<td>Low</td>
<td>Short</td>
<td>Low</td>
<td>For after installation tests</td>
</tr>
<tr>
<td>PD measurements with PD equipment rented and sensors purchased</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>For after installation tests and sporadic measurements (e.g. 0.5x/a)</td>
</tr>
<tr>
<td>PD measurements with PD equipment and sensors purchased</td>
<td>Medium</td>
<td>Long</td>
<td>Medium</td>
<td>For after installation tests and sporadic measurements (e.g. 1x/a)</td>
</tr>
<tr>
<td>PD monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD monitoring with equipment rented</td>
<td>Medium</td>
<td>Short</td>
<td>Medium</td>
<td>For after installation tests and a limited time after (e.g. 2 weeks)</td>
</tr>
<tr>
<td>PD monitoring with equipment purchased</td>
<td>High</td>
<td>Long</td>
<td>High</td>
<td>For monitoring over a long period for cable systems of particular importance</td>
</tr>
</tbody>
</table>
Our experiences in PD testing and monitoring.

For more than a decade, Brugg Cables has been supervising various projects with PD systems. We have successfully installed numerous PD systems in several countries. This involved finding solutions for a variety of system designs. Our clients benefit from this wealth of knowledge.

Examples of PD measurements

Most PD measurements are made as additional measurements during after installation tests. A few examples are shown below.

*Installation of UHF sensors at a 138 kV system in Brazil*

PD measurements during after installation tests in a cross-bonding box of a 245 kV system in Qatar

Reference table of PD measurement and monitoring systems:

<table>
<thead>
<tr>
<th>Year of commissioning</th>
<th>Location of installation</th>
<th>Type of test</th>
<th>Voltage level</th>
<th>Sensors in terminations</th>
<th>Sensors in joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Switzerland</td>
<td>Measurements</td>
<td>150 kV</td>
<td>UHF</td>
<td>Integrated in joint</td>
</tr>
<tr>
<td>1999</td>
<td>China</td>
<td>Measurements</td>
<td>220 kV</td>
<td>-</td>
<td>Integrated in joint</td>
</tr>
<tr>
<td>2000</td>
<td>Liechtenstein</td>
<td>Measurements</td>
<td>110 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>110 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>Abu Dhabi</td>
<td>Measurements</td>
<td>132 kV</td>
<td>-</td>
<td>Integrated in joint</td>
</tr>
<tr>
<td>2002</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>150 kV</td>
<td>-</td>
<td>Integrated in joint</td>
</tr>
<tr>
<td>2002</td>
<td>Abu Dhabi</td>
<td>Measurements</td>
<td>132 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2002</td>
<td>Saudi Arabia</td>
<td>Measurements</td>
<td>132 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2003</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>150 kV</td>
<td>UHF</td>
<td>Integrated in joint</td>
</tr>
<tr>
<td>2003</td>
<td>Egypt</td>
<td>Measurements</td>
<td>220 kV</td>
<td>-</td>
<td>Inductive in cross-bonding box</td>
</tr>
<tr>
<td>2004</td>
<td>Saudi Arabia</td>
<td>Measurements</td>
<td>132 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2004</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>110 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2005</td>
<td>Singapore</td>
<td>Measurements</td>
<td>220 kV</td>
<td>-</td>
<td>Inductive in cross-bonding box</td>
</tr>
<tr>
<td>2006</td>
<td>England</td>
<td>After installation tests</td>
<td>400 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2006</td>
<td>Portugal</td>
<td>Measurements</td>
<td>220 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2006</td>
<td>Taiwan</td>
<td>After installation tests</td>
<td>345 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2007</td>
<td>Spain</td>
<td>Measurements</td>
<td>400 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2007</td>
<td>Taiwan</td>
<td>After installation tests</td>
<td>345 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2007</td>
<td>England</td>
<td>After installation tests</td>
<td>400 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2007</td>
<td>Germany</td>
<td>After installation tests</td>
<td>380 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>Qatar</td>
<td>After installation tests</td>
<td>220 kV</td>
<td>UHF</td>
<td>Inductive in cross-bonding box</td>
</tr>
<tr>
<td>2008</td>
<td>USA</td>
<td>After installation tests</td>
<td>345 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2008</td>
<td>USA</td>
<td>After installation tests</td>
<td>115 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>220 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Brazil</td>
<td>Measurements</td>
<td>138 kV</td>
<td>UHF</td>
<td>Inductive in cross-bonding box</td>
</tr>
<tr>
<td>2009</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>380 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Switzerland</td>
<td>After installation tests</td>
<td>110 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2009</td>
<td>Egypt</td>
<td>Monitoring</td>
<td>550 kV</td>
<td>UHF</td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>Qatar</td>
<td>After installation tests</td>
<td>132 kV</td>
<td>UHF</td>
<td>Integrated in joint</td>
</tr>
</tbody>
</table>

Examples of PD monitoring

PD monitoring solutions require more effort during the installation process. They are seldom used and only for cable systems of particular importance.

*PD monitoring of a 550 kV GIS termination in Egypt*

*Devices of the PD monitoring system in an extra box beside the terminations*
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