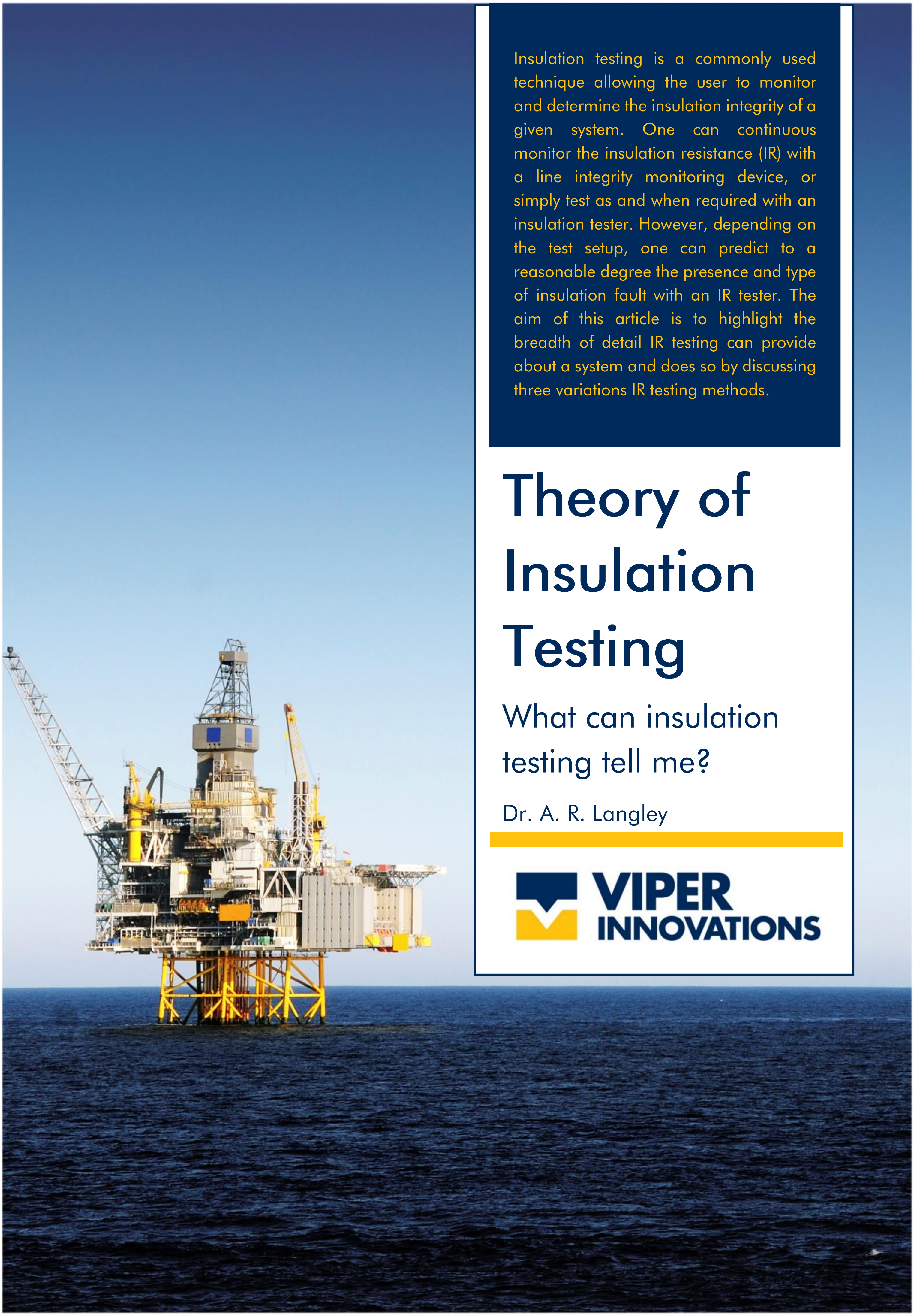


Insulation testing is a commonly used technique allowing the user to monitor and determine the insulation integrity of a given system. One can continuous monitor the insulation resistance (IR) with a line integrity monitoring device, or simply test as and when required with an insulation tester. However, depending on the test setup, one can predict to a reasonable degree the presence and type of insulation fault with an IR tester. The aim of this article is to highlight the breadth of detail IR testing can provide about a system and does so by discussing three variations IR testing methods.

Theory of Insulation Testing

What can insulation testing tell me?

Dr. A. R. Langley

VIPER INNOVATIONS

COMMON FAILURE MODES FOR SUBMERGED UMBILICALS & CABLES

The failure of submerged cables can occur due to a variety of reasons, typically involving open circuits, short circuits and electrical insulation failure. The latter is of interest in this article, where previously submerged electrical flying leads (EFL) are investigated to determine the possible cause of failure. This is attempted by performing a series of insulation resistance (IR) tests. IR testing has the capability of determining whether or not a weakness is present in the insulation and even better, has the potential to elucidate the type of fault present such as water ingress or localised weaknesses. This article aims to highlight the breadth of information that can be obtained from performing a variety of IR tests.

INSULATION RESISTANCE (IR) TESTING

Insulation resistance (IR) testing conditions are generally dictated by the system under test and any time constraints the user may have. IR testing is based on a fairly simple concept – apply a voltage between the cable conductor and earth, measure the leakage current and subsequently calculate the IR. The IR is calculated based on one of the most fundamental equations in electronics, Ohm's Law. Depending on the parameters chosen and the system under test, much more detail can be gathered about the state of insulation. This section discusses such testing methodologies and refers to the IR testing of a submerged cable.

IR Testing: How and What is Measured?

In routine testing DC voltage is normally used, as with a megohmmeter. However continuous monitoring with an IR tester, such as an insulation monitoring device (IMD), usually utilises some form of AC waveform. This is because DC measurements are susceptible to interference from noise or stray currents. The testing discussed herein predominantly concerns DC voltage testing.

When a voltage E (Volts, V) is applied, current flows through the cable insulation. This is known as leakage current I_{leak} which in turn, according to Ohm's law, provides the IR such that,

$$\text{IR} = \frac{E}{I_{\text{leak}}}$$

However, the current measured by an IR tester is the total current I_{total} which includes capacitive and absorption currents I_{cap} and I_{abs}, respectively, in addition to I_{leak} where,

$$I_{\text{total}} = I_{\text{leak}} + I_{\text{cap}} + I_{\text{abs}}$$

and,

$$\text{IR} = \frac{E}{I_{\text{total}}}$$

Capacitive and absorption currents are associated with the charging of a capacitor, which consists of two conductive mediums separated by a dielectric (insulating) material such as an insulated copper cable submerged in seawater illustrated in Fig 1. When a DC voltage is applied between the two conductors, charge carriers within the conductors move to/from the conductor surface, causing an equal and opposite charge at the facing conductor surfaces. The dielectric develops an electric field with which molecular dipoles align.

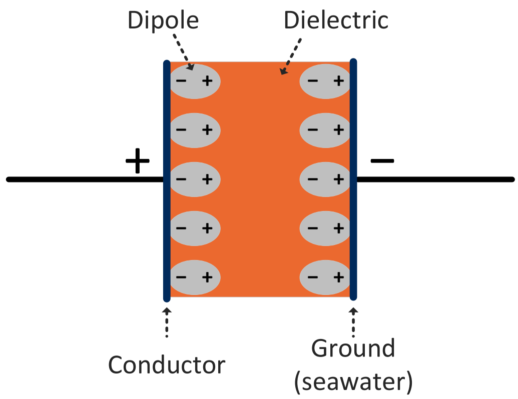


Fig 1. Illustration of a capacitor.

Capacitive current stems from the movement of charge carriers to/from the conductor surface, whereas absorption current stems from the movement of dipoles within the insulation.

So, how do capacitive and absorptive currents affect an IR test? At the start of a DC voltage IR test, capacitive, absorption and leakage currents are present. Capacitive current dominates at the start and is typically much larger than leakage and absorption currents. With time, capacitance and absorption currents will dissipate, dictated by the ability of a material to store charge (which insulators do more effectively). Capacitive current dissipates quickly compared to absorption current, shown graphically in Fig 2. The reduction in current therefore causes a continual increase in IR during an IR test. Most IR testing methods, however, take these effects into account.

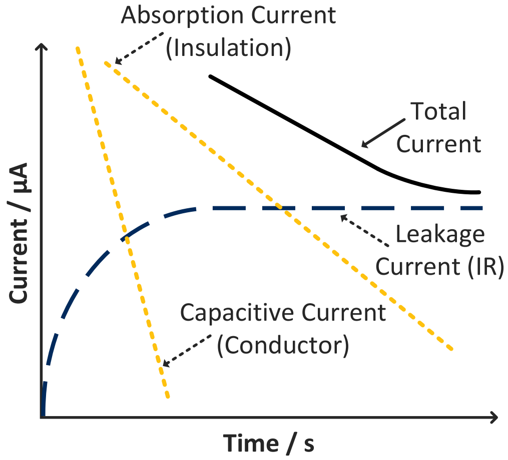


Fig 2. Capacitive, absorption, leakage and total current as a function of time during IR testing.

IR Testing Methods

IR testing serves as a useful troubleshooting tool to monitor and respond to known problems. IR testing can indicate whether an insulation fault is developing, and whether a system might need maintenance or, in some cases, replacing. It should be noted that **repeated IR testing on a single system should be performed under the same test conditions and test equipment if possible.**

The simplest form of IR test is a constant voltage test performed for a specified period and recording the IR at a set time. Choosing an ideal DC voltage and timescale depends on the system at hand, such as the cable length and withstand voltage, and time constraints the user may have.

The IR test time can be 60 s long, known as a 'Spot Test', or longer. A one-minute minimum is advised intending to avoid effects from capacitive current, illustrated in Fig 3 where the IR increases rapidly in the first instance. Indeed, absorption currents will also be present. Spot testing therefore only gives a rough idea of the insulation integrity. Increasing the test time, however, can improve accuracy, known as a 'time-resistance' test.

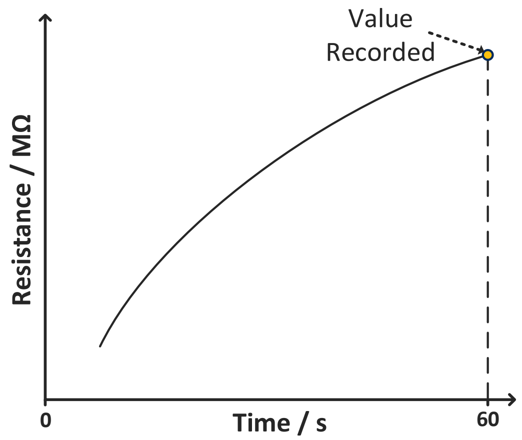


Fig 3. An 'ideal' insulation resistance (IR) value recorded at 60 s during a constant voltage IR test.

Fig 4 demonstrates a time-resistance test for 'good' insulation where the IR continues to increase due to the slow discharge of absorption current and low leakage current. For 'poor' insulation one might observe an IR decrease. For 'poor' insulation the initial absorption currents will be smaller and the leakage current higher or even increasing with time, leading to an IR decrease.

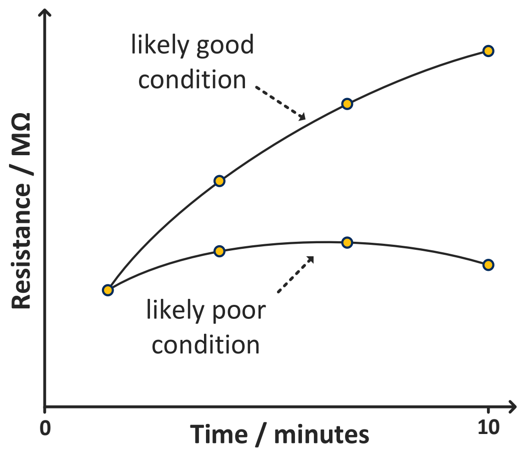


Fig 4. IR trends for 'good' and 'poor' insulation.

Further to observing IR trends, quantitative measures can be obtained to determine the possible condition of the insulation. The dielectric absorption ratio (DAR) is one of them, which describes the ratio of two time-resistance values,

$$\mathrm{DAR} = \frac{\mathrm{IR\ @\ 1\ minute}}{\mathrm{IR\ @\ 30\ seconds}}$$

A DAR < 1 indicates that the IR at a larger timescale is smaller than that at a shorter timescale. This means that absorption current is masked by leakage current in turn indicating poor insulation. The higher the DAR the better the insulation integrity due to a high absorption current. Similar to Spot Tests, DAR values offer a rough indication of insulation integrity. Some would argue that retrieving a DAR at 10 mins:1 min would be more accurate, also known as the polarisation index (PI),

$$\mathrm{PI} = \frac{\mathrm{IR\ @\ 10\ minutes}}{\mathrm{IR\ @\ 1\ minute}}$$

Typical PI values corresponding to certain degrees of insulation integrity are given in Table 1. Information gathered from DAR and PI tests depends on the system tested. A PI value between 1-2 could be ‘satisfactory’ for short sections of house wiring, but ‘questionable’ for long offshore cables. All the same, these are useful measures which help to determine whether to intervene or investigate problems further. In addition, more than one test type should be performed to ensure accuracy and consistent outcomes.

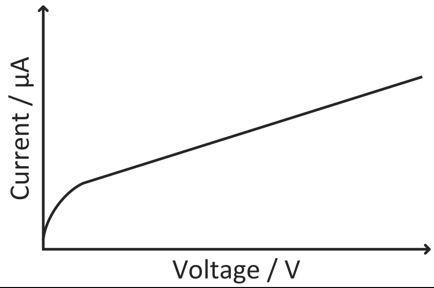
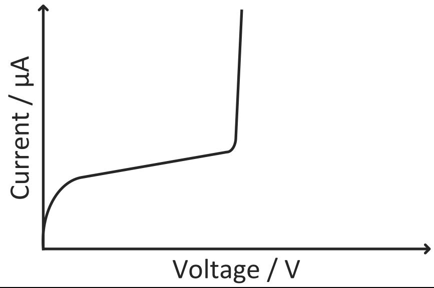
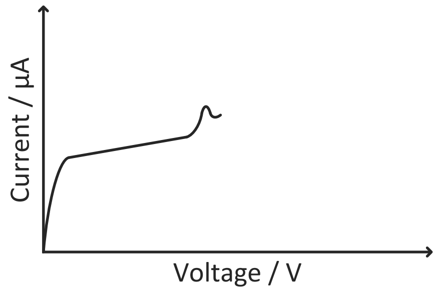
Table 1. PI values and insulation condition.

PI Value	Insulation Condition
< 1	Poor
1-2	Questionable
2-4	Okay
> 4	Good

Another useful IR testing method is ‘Ramp Testing’ where the voltage is continually increased at a constant rate to a specified voltage, e.g. a sweep rate of 100 V minute^{-1} up to 500 V. It is advised that spot and time-resistance testing is performed prior to ramp testing and should be taken into account when deciding on ramp testing conditions.

The response of insulation to a ramp test provides detail on the condition of the system and can allow the user to detect small defects in the insulation. For this test, the leakage current is plotted as a function of voltage. Certain voltage-current trends can indicate ingress and localised faults, with some common trends summarised in Table 2.

Table 2. Insulation condition and corresponding voltage-current relationship during a ramp test.

Condition	Voltage-Current relationship
Good	
Moisture Ingress	
Localised Weakness	

A smooth almost linear increase in current with voltage is expected for ‘good’ insulation condition. The increase comes from capacitive and absorption current which do not dissipate due to the continually changing voltage. When the behaviour deviates from this ‘ideal’ behaviour, this warns that the test is tending towards insulation breakdown. If a large spike in current is observed (see Table 2), this could indicate water/moisture ingress. If small ‘blips’ in current are observed, this could indicate local weaknesses in the insulation.

Overall, it is evident that these IR testing methods can provide the user information not only on the insulation integrity of the given system, but also the type of faults (if any) that are present.