UNIVERSITÀ DEGLI STUDI DI PADOVA

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TESI DI LAUREA

Tracking wheel test for dc polymeric insulators

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PRESENTAZIONE

Il lavoro di tesi svolto è atto ad apportare delle migliorie nel sistema di trasmissione HVDC (High Voltage Direct Current). Usualmente gli impianti di generazione forniscono potenza in tensioni e correnti a regime sinusoidale alternato e tale potenza viene trasportata ai sistemi di utilizzazione mediante linee di trasmissione trifase in corrente alternata. Nei casi in cui una quantità elevata di potenza deve essere trasportata da un centro di generazione remoto a un centro di utilizzazione che dista da esso circa 500 ÷ 600 km diventa più conveniente la trasmissione in corrente continua nonostante le spese per i centri di conversione. Questa convenienza è dovuta al fatto che l'utilizzo di linee HVDC consente di migliorare la stabilità rispetto ai transitori, riducendo le variazioni di tensione che avvengono con la trasmissione a lunghe distanze in corrente alternata e riportando tali valori entro le tolleranze imposte dalla legislazione in materia, oltre ad offrire l'opportunità di connettere due sistemi che non sono sincroni o che hanno frequenze di lavoro diverse. Altre buone ragioni che portano a intensificare gli studi su questo campo sono date dal fatto che il flusso di potenza della linea può essere invertito, consentendo alla rete elettrica di diventare più flessibile e aperta ad accogliere la generazione proveniente da fonti rinnovabili. Inoltre, mediante l'utilizzo dei convertitori, obbligatori nel HVDC, si può erogare in rete potenza reattiva in modo da aiutare ulteriormente la stabilità del sistema senza la necessità di impiegare banchi di condensatori che danno origine a transitori nel momento d'inserzione e di disinserzione.

Un elemento problematico per le linee aeree HVDC è dato dagli isolatori, questa situazione si aggrava particolarmente nel caso in cui tali linee sono installate in zone altamente inquinate o zone costiere in cui l'aria contiene elevate percentuali di sale. L'inquinamento portato dal vento a depositarsi nella superficie esterna degli isolatori fa si che si crei uno strato di materiale inquinate che, alla presenza di umidità dovuta a nebbia, brina o pioggerellina leggera, diventa altamente conduttivo. È da notarsi che in questo caso una pioggia abbondante può avere l'effetto positivo di lavare tale superficie.

La caratteristica principale degli isolatori è di essere costituiti da un buon dielettrico in grado di tenere la differenza di potenziale cui è sottoposto per sostenere il conduttore. Un materiale completamente isolante non esiste in natura ma alcuni studi sui materiali polimerici, quali le gomme siliconiche, hanno dimostrato che essi si prestano a essere utilizzati come materiale dielettrico per costruire validi isolatori. Le loro scarse proprietà meccaniche hanno fatto sì che il loro utilizzo principe sia di materiali di rivestimento per la manifattura di isolatori ibridi. La natura organica di questi materiali fa sì che essi abbiano una bassa energia superficiale che rende la loro superficie idrofoba ma che al tempo stesso li rende interessati da un rilevante processo d'invecchiamento durante il loro normale esercizio. La caratteristica della superficie dei materiali polimerici di essere idrofoba serve a limitare le correnti di dispersione che si crea in seguito alla presenza di sostanze inquinanti e umidità sulla superficie stessa in determinate condizioni di utilizzo. L'idrorepellenza della superficie fa si che non si crei un film conduttivo ma che l'umidità permanga sulla superficie sotto forma di goccioline discrete. Questo fattore riduce drasticamente l'entità della corrente di dispersione.

Dagli studi finora condotti però si è rilevato il fenomeno di una perdita d'idrofobia superficiale nel caso in cui tale superficie sia ricoperta da uno strato di materiale inquinante. La perdita di questa caratteristica porta alla formazione di uno strato conduttivo che consente alla corrente di dispersione di crescere a valori rilevanti. La corrente di dispersione ha un effetto termico che porta calore il quale, a sua volta, crea delle regioni nelle quali l'acqua, in cui sono disciolte le sostanze inquinanti, evapora. In questi canali asciutti, denominati dal gergo inglese "dry band", possono svilupparsi delle microscariche che portano alla completa scarica dell'isolatore oltre a causare dei danneggiamenti nella superficie tali da accelerare il processo di invecchiamento. È da ricordare che alcune microscariche sono tollerate poiché consentono un certo grado di auto pulizia dagli agenti inquinanti della superficie dell'isolatore, ma nel momento in cui esse diventano localizzate e intense causano l'erosione di parte della superficie nonché alla perdita progressiva di materiale. Nel lungo periodo questo fenomeno causa il fallimento completo dell'isolamento.

Lo studio sui materiali polimerici ha dimostrato che quando lo strato d'inquinamento viene rimosso alcuni materiali sono in grado di recuperare la caratteristica d'idrorepellenza.

Per ricercare materiali e forme nuove d'isolatori che si adattino bene a un utilizzo in regime continuo e a un ambiente inquinato, che si tratti d'inquinamento artificiale o naturale, sono stati sviluppati i test d'invecchiamento accelerato. Ci sono diverse tipologie di test che gli standard europei prevedono, si tratta di test fatti per sviluppare e meglio comprendere le caratteristiche legate strettamente alla composizione chimica del materiale (ad esempio "Incline Plane Test") e test che invece verificano l'affidabilità dell'intero isolatore come elemento unico finito (ad esempio il "Tracking Wheel Test"). Questi test si propongono di adottare una metodologia atta a simulare in brevi periodi una vita di servizio di trent'anni, sottoponendo passo passo il campione in prova sotto tutte le diverse tipologie di stress cui è sottoposto in esercizio. Gli standard hanno però delle lacune in materia di tensione continua in cui niente è previsto. Per questo motivo per testare gli isolatori da usare nelle linee HVDC si è deciso di far riferimento ai test ideati per la tensione alternata modificando l'alimentazione ma lasciando invariati gli altri parametri. Purtroppo la necessità di avere alimentazioni a bassa impedenza interna per svolgere test con tensione continua porta ad avere un elevato costo nelle apparecchiature da usare, a causa di ciò nella letteratura sono presenti pochi casi in cui tale test è stato eseguito con tensione continua.

Il test analizzato ed esposto nella tesi è il test d'invecchiamento che è riportato nella normativa EN 62217:2006 "Polymeric insulators for indoor and outdoor use with a nominal voltage > 1000 V – General definitions, test methods and acceptance criteria" nell'appendice A e definito come "Tracking wheel test". Con il termine "tracking" la normativa intende specificare quel fenomeno di formazione di percorsi conduttivi (tracks) che causano l'irreversibile degradamento della superficie dell'isolatore. Tali percorsi o tracce conduttive rimangono tali anche quando la superficie è asciutta e per questo investono una grande importanza nel possibile fallimento dell'isolatore.

Il test per stimare il processo d'invecchiamento dell'isolatore richiede che tali isolatori siano testati per 30 000 cicli, 1600 ore totali durante le quali sono tollerabili solo brevi interruzioni per un'ispezione visiva degli isolatori. Durante ogni ciclo l'isolatore passa attraverso quattro fasi distinte. Quattro isolatori, due tipologie di campione, possono essere testati simultaneamente. Essi sono montati in una ruota, da cui il termine wheel, a 90° l'uno dall'altro. Le fasi cui ogni isolatore è sottoposto hanno una durata di 40 s ed ogni passaggio da una fase all'altra in cui l'isolatore ruota per 90° richiede 8 s come specificato nella normativa. Tali fasi si possono riassumere come:

- Prima fase di immersione in acqua salata contenuta all'interno di un serbatoio in cui l'isolatore è completamente immerso in posizione verticale. Nell'acqua sono disciolti 1,40 kg/m^3 ± 0,06 kg/m^3 di NaCl, in questo modo si assicura che l'acqua abbia una conducibilità di circa 2,7 mS/cm.
- Seconda fase di sgocciolamento in cui l'isolatore è in posizione orizzontale per lasciare che l'acqua scivoli dalla superficie.
- Nella terza fase l'isolatore è in posizione verticale ed è sottoposto alla tensione di prova. Il valore della tensione di prova definito dagli standard è dato dal risultato ottenuto dalla divisione della distanza di dispersione (creepage distance) in mm da 28,6 e il risultato è espresso in kV. Durante il test eseguito in laboratorio per un limite di disponibilità è stata utilizzata una tensione di 10 kV benché per essere in linea con gli standard fosse necessaria una tensione di 13 kV.
- La quarta fase è quella in cui l'isolatore è di nuovo in posizione orizzontale ed è lasciato a raffreddare per dissipare il calore superficiale dovuto alla corrente di dispersione.

L'apparato costituito dalla ruota, il supporto per gli isolatori, il serbatoio e il motore elettrico atto a far girare la ruota era già stato assemblato durante il precedente lavoro svolto da Andrea Moncivì il quale l'ha ideato per testare gli isolatori con corrente alternata seguendo le direttive della normativa. Le modifiche apportate hanno riguardato l'alimentazione e il software per la registrazione dei dati.

Benché non sia richiesto dagli standard, bensì per propositi di ricerca, è stata registrata per ogni ciclo per ogni isolatore la corrente di dispersione superficiale che si è manifestata durate la fase in cui l'isolatore era sottoposto a tensione. Tali dati sono stati raccolti e registrarti in file Excel attraverso l'utilizzo del software labVIEW™ che ha permesso di campionare ed elaborare il segnale di corrente e tensione utilizzandoli per elaborare altre grandezze d'interesse quali potenza dissipata ed energia accumulata nella superficie.

La decisione di registrare la corrente di dispersione è data dal fatto che in alcune occasioni si è vista una buona correlazione tra entità di tale corrente e degradamento delle prestazioni dell'isolamento. Tuttavia in letteratura sono presenti pareri contrapposti a tale riguardo.

I risultati ottenuti dall'elaborazione di tali dati per i primi 100 cicli e riportati in appendice A della tesi sono da ritenersi in linea con i risultati ottenuti da altri ricercatori che hanno eseguito test analoghi (vedi reference 12) e non riportati poiché la qualità dell'immagine è scadente. La brevità del test, che ha avuto una durata di circa 6 ore, aggiunta al fatto che il livello di tensione era inferiore a quanto stabilito dalla normativa ha fatto si che il valore della corrente di dispersione si stabilisse intorno a valori irrilevanti. Questo trova una sua logica nel fatto che gli isolatori sono costruiti e studiati proprio per ridurre tale valore che almeno durante i primi cicli deve avere entità irrilevante. È possibile immaginare che se l'esperimento si fosse protratto per i 30 000 cicli stabiliti la corrente di dispersione sarebbe aumentata. Tale risultato è sempre confermato dall'esperimento riportano nel reference 12.

Poiché lo scopo era di comporre il set up necessario in un secondo momento per testare nuove tipologie d'isolatori aventi materiali innovativi e costruiti nel laboratorio di Alte Tensioni interno all'Università di Cardiff si considera tale scopo raggiunto portando in luce che per un test affidabile bisogna provvedere a un sistema di stop degli isolatori diverso da quello ora previsto. Infatti, nell'apparecchiatura ora disponibile la ruota è portata in rotazione da un motore elettrico in corrente continua che permette di variare la coppia modificando la corrente. Esso è comandato attraverso un impulso inviato mediante un programma sviluppato con il software labVIEW™ che usa il valore della potenza istantanea per individuare la posizione dell'isolatore. Questo modo di operare non risulta affidabile in quanto può accadere che il valore della corrente di dispersione che si manifesta nei primi cicli sia così basso da mantenersi sotto la soglia necessaria a inviare l'input di controllo del motore. Per rendere il sistema più affidabile sarebbe utile istallare una fotocellula che individui esattamente la posizione dell'isolatore e/o usare un contatto che è aperto nel momento in cui il perno dell'isolatore lo va a toccare e che passati i 40 s è riportato alla posizione chiusa e permette al motore di girare attraverso l'utilizzo di un contattore o di un software come quello menzionato.

INTRODUCTION

This project was developed during the SOCRATES - ERASMUS program done in the High Voltage Energy Systems Research Group of the school of Engineering of Cardiff University, United Kingdom from 13th September 2010 to 31st January 2011 under the supervision of Professor A. Manu Haddad.

In the first chapter there is a first and general description of the type for HVDC systems to comprise the motivations to look for better solution in this field of study. It is reported a comparison between AC system and HVDC systems with the same voltage level to understand when the DC energization is a better solution.

The second chapter presents the literature review, the description of the commercial insulators designs and then the description of polymeric insulators. It is reported a description of the advantages and disadvantages given by polymeric insulators and it is done a comparison between polymeric insulators and conventional insulators. The

Chapter third is a specific analysis of the polymeric material used for build outdoor insulators. This chapter is focalized at the method for evaluated the hydrophobicity in the surface of polymeric material because of this characteristic is the main point to understand the leakage current behavior and the ageing process.

With the chapter four is introduced the tracking wheel test like described in the standardization but with the specific modification to use with DC voltage. It is described step by step the arrangement to run the test and the program to acquire data and timing the insulators ‘cycles.

In chapter five there is the conclusion of the experiment to see the reliability of the tracking wheel test facilities. The data analyses are reported in this chapter and the comparison with other experiment is done. It is analyzed the worst case found with the four insulators tested.

CHAPTER 1

ADVANTAGES OF HVDC TECHNOLOGY

1.1 INTRODUCTION

The first electric power system was developed by Thomas Edison in September 1882, it was a DC system but already from the first applications was clearly that excessive power loss occurred when the transmission of the energy was with low voltage.

The invention of transformers, that made possible the increases of Voltage level with the Alternating Current, led to understand that HVAC transmission system is a better choice to power transmission. Around 1954 had been developed a fully-static mercury arc valve, they are the principal component in the AC/DC converters. Indeed, the electric power generation is made by a three phase synchronous generator that has features superior to the DC generator.

Since the 1960s, HVDC (High Voltage Direct Current) transmission system was developed and has played a leading role in both long distance transmission and in the interconnection of system. The first HVDC transmission system was a submarine cable between the island of Gotland and the Swedish mainland which had been exercised in 1954. The classical application of HVDC system is the transmission of bulk power. Many of these transfer power from renewable sources such as hydro and wind. The picture down (figure 1.1) explains various possible applications of an HVDC system.

It was investigated that for distance bigger than 500 ÷ 600 km is cheaper using HVDC transmission than conventional one, although these distances are reduced when it is used undersea cable, indeed there is no technical limit to the length of submarine cable connection. HVDC system ride over the limit that there are with AC, for example with the DC link is possible to connected two system that works at different frequency or that there are no synchronized. Furthermore, the power flow can be inverted. Using AC transmission in long distance there is an appreciable variation of voltage that becomes an important limit.

Using the HVDC transmission it need to use Voltage Source Converter (VSC) which can do also the regulation of active and reactive power necessary to have a variation of voltage comprise in the tolerable range to the standardizations without to spend other many to extra compensating equipment like capacitor banks.

However it is important to notice that HVDC system has also disadvantages in their use; one of this is the introduction of harmonic distortion in the grids so it is necessary to provide a good system of filters. Also the high cost of DC switches to break the short circuit current result in a limit of HVDC transmission.

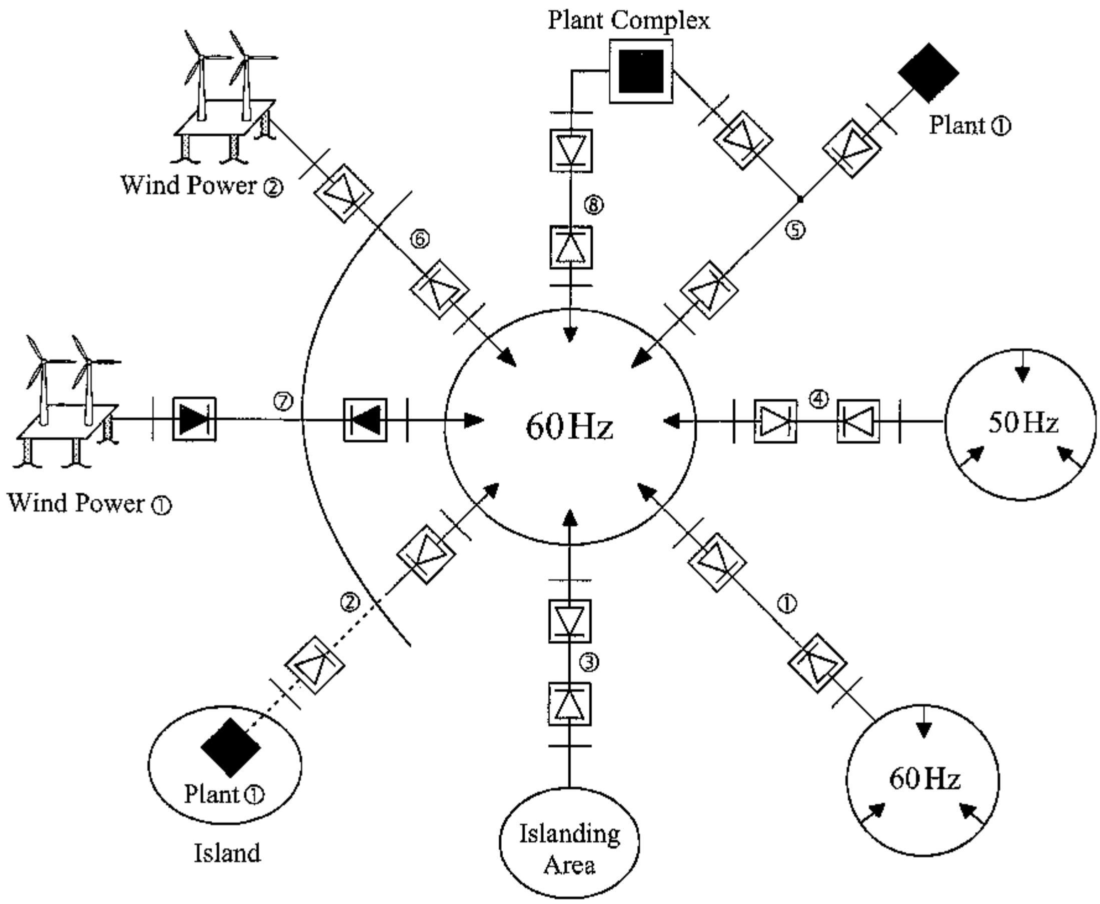


Figure 1.1: Various applications of an HVDC system [8]

The picture below may give an idea of the development of HVDC system in Europe.

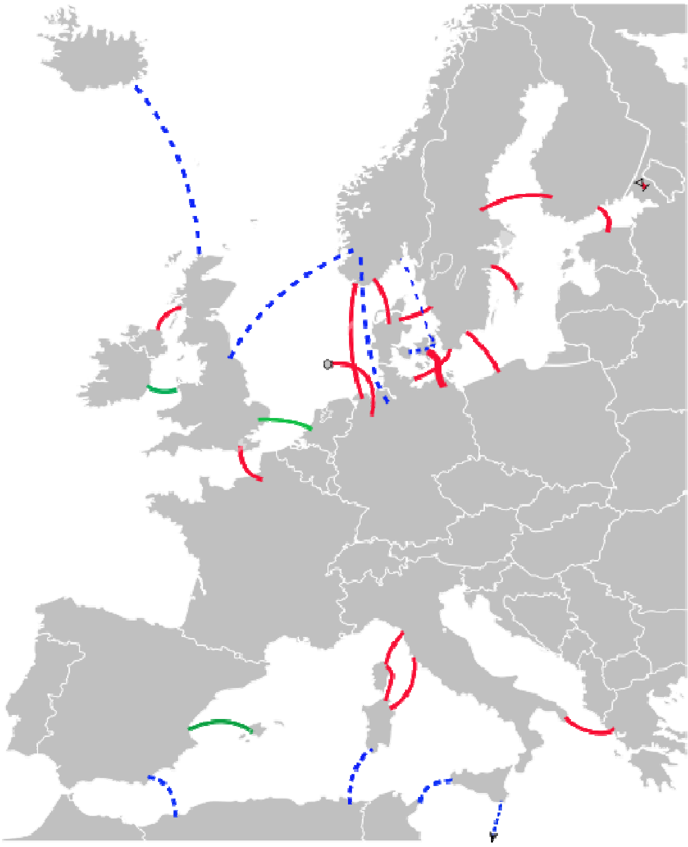


Figure 1.2: HVDC DEVELOPMENT IN EUROPE [www.wikipedia.org]

Where:

Existing links

Under construction

Proposed

A line for DC needs only two main conductors, while an AC line needs three. And the losses are lower, however the HVDC converter stations cost more than the AC terminal stations so a certain distance is required to make this use of HVDC economical. Using the following pictures is possible to compare and to understand that sometimes is very convenient to use HVDC transmission because of using this system should be save more space.

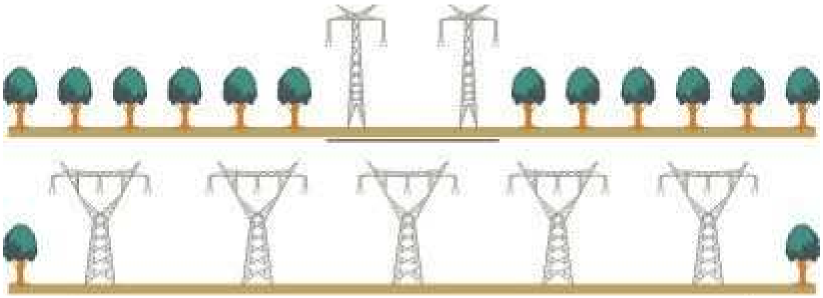


Figure 1.3: COMPARISON SAME VOLTAGE LAVEL BETWEEN HVDC TRANSMISSION AND AC SYSTEM [www.abb.com]

The figure above compares two 3000 MW HVDC lines for the Three Gorges – Shanghai transmission, China, to five 500 kV AC lines that have to be used if AC transmission had be selected, is clear that a lot of space can be save using the first solution.

To see the same concept may compare using the following figure where tower configurations for AC and DC transmission are drawn.

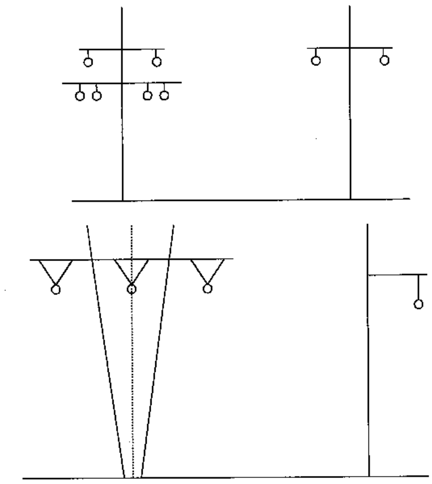


Figure 1.4: Tower configuration for AC and DC transmission [7]

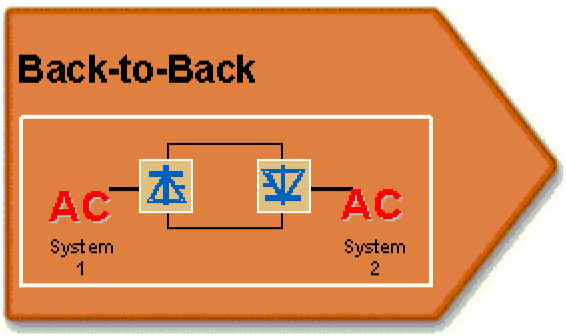
The next picture shows a HVDC overhead lines, this kind of application are found in e.g. USA, Canada, Brazil, China and India.

Figure 1.5: HVDC LINE FOR 2,000 MW IN WESTERN USA [www.abb.com]

1.2 TYPES OF UTILITY

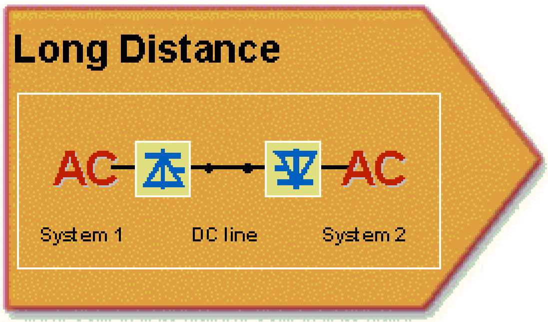
To be precise the HVDC transmission is used in two particulars ways:

- Back to back: two independent system with different electric parameters like voltage and short circuit power level, frequency are connected using the DC link like show in this block diagram.



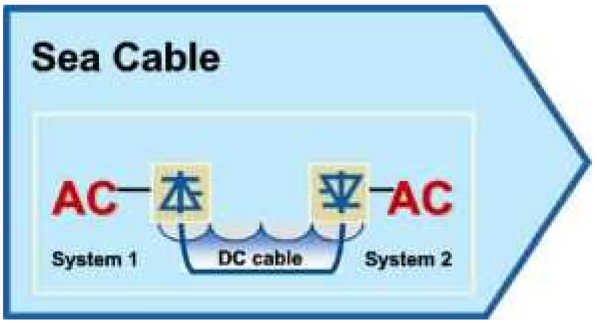
[www.energy.siemens.com]

- Long distance: this is the case where two remote AC systems with a distance from 300 to 1400 Km and more are connected. Reactive power is not transmitted over DC links so it reduces the losses. It is possible to have a completely control power flow, beyond with HVDC transmission there is the limitation of short circuit level that usually increase when new lines are built to extend AC system. In this way is easier and inexpensive to provide the switchgear apparatus.



[www.energy.siemens.com]

In this argument must be consider the case using the submarine cable to connected two different AC system separated by sea, it is very convenient because the return is done using the sea like conductor.

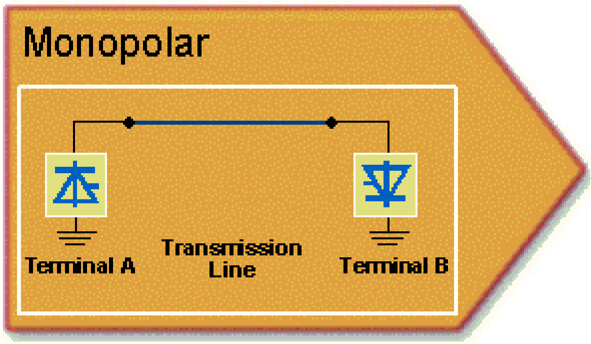


[www.energy.siemens.com]

1.3 BASIC CONFIGURATIONS COMMONLY USED

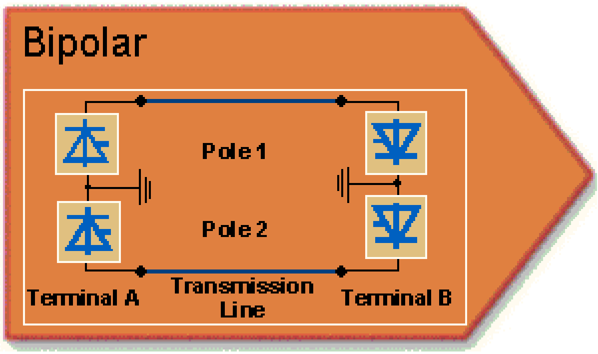
The basic configuration that is usually used can be summarizing into two cases:

- Monopolar HVDC where is used just one HV line for DC current transmission and to provide the return path can be exploits the ground. This configuration is built to rating up to 1500 MW.



[www.energy.siemens.com]

- Bipolar HVDC. This type of DC link consists of two conductors, one with positive polarity and the other with negative polarity where their neutral point is grounded. During the normally operation he current following in the grounded return is zero because of the same value of current flows into each pole. The important advance of this configuration is that the two poles may be operated separately. When one pole is out of order the other pole can transmit power by itself with the return by ground. Obviously if compare monopolar configuration with bipolar configuration is clear that in the second case the power transmitted is twice time of the power transmitted with the first configuration.



[www.energy.siemens.com]

There are different HVDC overhead lines configurations that are chosen according to economic analyses and environmental study, some of this configuration are shown in the following figure.

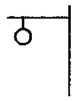
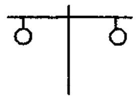
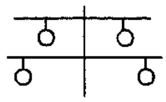
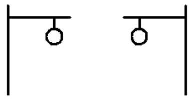
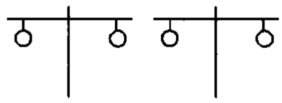
Variant	Tower configuration	Loss of one pole ground return: Permitted	Loss of one pole ground return: Not permitted	Remaining transmission capacity tower breakage	Relative cost (%)
Single monopolar line		0	0	0	85
Single bipolar line		50 (100)	0	0	100
Double bipolar line		100	100	0	114
Two monopolar lines		50 (100)	0	50 (100)	126
Two lines (bipolar or homopolar)		100	100	100	136

Figure 1.6: HVDC overhead line configurations [8]

Already after this short description it is possible to understand how is important the HVDC transmission to the development of the electrical grid in Europe and in the entire World. So it is fundamental goes on with new research to develop a very reliable HVDC system that not has outage. In this thesis is studied a specific test, originally born to AC Voltage, to found new material to build high resistance insulators that may be used under pollution condition for HVDC transmission.

CHAPTER 2

INSULATORS FOR OUTDOOR APPLICATIONS: CHARACTERISTICS AND PROBLEMS

2.1 INTRODUCTION

In general the insulators for outdoor applications have two different functions, mechanical and electrical. The biggest problem for all insulators is that it is impossible to provide an ideally nonconductive element for building it, furthermore, all insulators have external surfaces that become contaminate during the service. This contamination will carry a leakage current because in the pollution layer there are inert mineral matter, electronic-conductive dust like carbon or metal oxides, soluble salt and water. Often, the consequential problem is that of flashover occurs across this polluted surface when the leakage current exceeds a certain value.

For solve this problem have been developed a lot of type of insulators and a lot of materials have been studied. The better performance for this used are with porcelain, glass, polymer, and RBGF (resin-bonded glass fibres used in core of polymer insulator).

It is possible to affirm that all types of insulators are much more liable to flashover under DC than AC voltages in comparable conditions.

The following table explains the features of the different materials used to build electrical insulators.

MECHANICAL PROPERTIES OF THE DIELCTRIC COMPONENTS OF HIGH VOLTAGE INSULATORS					
	Units	Porcelain	Glass	Polymer	RBGF
Tensile strength	MPa	30-100	100-120	20-35	1300-1600
Compressive strength	MPa	240-820	210-300	80-170	700-750

Table 2.1: material proprieties

This kind of material has good mechanical and electrical features. The principal classes of insulator are cap and pin insulator, longrods, posts and barrels. There are some different class to classify every kind of insulators and this class are reported in the table below.

<table>
<tr><th colspan="8">HV INSULATORS</th></tr>
<tr><td colspan="5">CERAMIC INSULATORS</td><td colspan="3">POLYMERIC INSULATORS (NCI's)</td></tr>
<tr><td>GLASS</td><td colspan="4">PORCELAIN</td><td>CAST CYCLOALPHATIC EPOXY RESIN INSULATORS</td><td colspan="2">COMPOSITE INSULATORS: FIBREGLASS ROD WITH POLYMERIC SHED</td></tr>
<tr><td>CAP & PIN INSULATORS</td><td>BUSHINGS & HOLLOW CORE INSULATORS</td><td>POST TYPE &LINE POST INSULATORS</td><td>PIN-TYPE INSULATORS</td><td>LONGROD INSULATORS</td><td></td><td>EPDM RUBBER</td><td>SILICONE RUBBER</td></tr>
</table>

Table 2.2: insulators classification

2.2 TYPES OF COMMERCIAL INSULATORS

Now there are a description of all the commercial insulators comely used in AC and DC system.

2.2.1 Pin insulators

There was originally used for telephone lines and lightening conductors, have been adapted for power transmission and some variant still in use to low and medium voltage system.

The conductor is placed or on the top, in a groove, or alongside of it. The pin insulators are made in porcelain or in glass. On the bottom of the insulator there is an axial slot with thread; in the slot is cemented the pin which support the insulator. The cement has to have the same dilatation coefficient of porcelain and during the life it has not to deform. Angled sheds on the insulators for middle voltages can increase the superficial path of an eventual discharge and also interrupt the liquid path which can create on the top of its surface. The dimension of the pin insulators are showed in the following table, from the data can be notice that for more than 30 kV such insulators would result too much voluminous and could be subject to frequent building defects.

V_n kV	D Mm	H mm	F_b da N	Mass kg
10	150	112	1400	1.7
20	215	170	1900	4.3
30	225	205	2400	6.7

Table 1.3: pin insulators properties

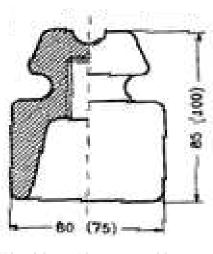


Figure 2.1: pin insulators for low voltage

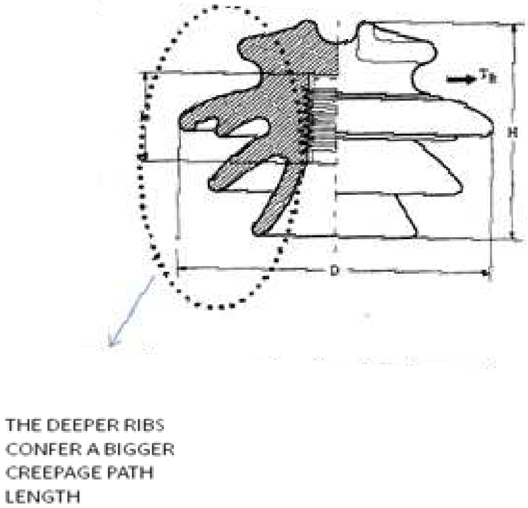


Figure 2.2: pin insulators for low medium voltage

2.2.2 Cap and pin insulators

These are manufactured from porcelain or glass and are based on the similar principle as pin-type insulators. A number of units are connected together by steel caps and pins to form an insulators sting. Just to a practical use it is possible to calculate the number of units that it is necessary to use to provided a right insulation according to the voltage applied:

$$n = \frac{U_{kV}}{15} + 1$$

Where n=number of element cap + pin to build a string at U_{kV} Voltage applied.

The cap and pin insulators was developed to exploited, from the mechanical viewpoint, that to ceramic and glass material have a better behaviour when they are exposed at compressive force than tensile strength. This desirable arrangement to support the axial load is obtained by the conical shape of the part of the steel pin embedded within the mortar that fixes it to a wraparound cast iron cap.

When the glass cap and pin insulators are used with DC energisation, the shattering of the glass shell occurred because of the leakage current is a unidirectional ion’s flow. However, the toughened glass has a high resistivity so it can be used in the glass cap and pin insulators for DC voltage; but to found a solution at this problem technological remedial approach that has been show to be highly successful is to improve the quality of both the raw material and the manufacturing process.

Another problem is the corrosion of electrode under DC energisation but this is a well researched problem. The positive electrode dissolves gradually into the electrolyte, produced by wetted pollution, due to the flow of leakage current. For ferrous material, such corrosion occurs through the following ionising reaction:

$$Fe \rightarrow Fe^{2+} + Fe^{-}$$

The loss of the weight W(z) of the positive electrode due to a flow of current I(z) for the duration T was found to follow approximately Faraday's Law:

$$W(z) = I(z)TZ$$

Where Z is the electrochemical equivalent (i.e. the mass of ion taken into the solution by a current of one ampere flowing for one second).

In general for this kind of insulators, the pin is the element that suffers the most, indeed when its metal is substantially reduced; the insulators string can no longer support the conductor.

This problem for the pin is very important. The method successfully developed to provide a protection of the steel pin was to use a zinc sleeve as a sacrificial electrode. The heavy sleeve of zinc is fitted around the pin, where it enters in the cement, to attack by leakage current without loss of mechanical strength in the pin.

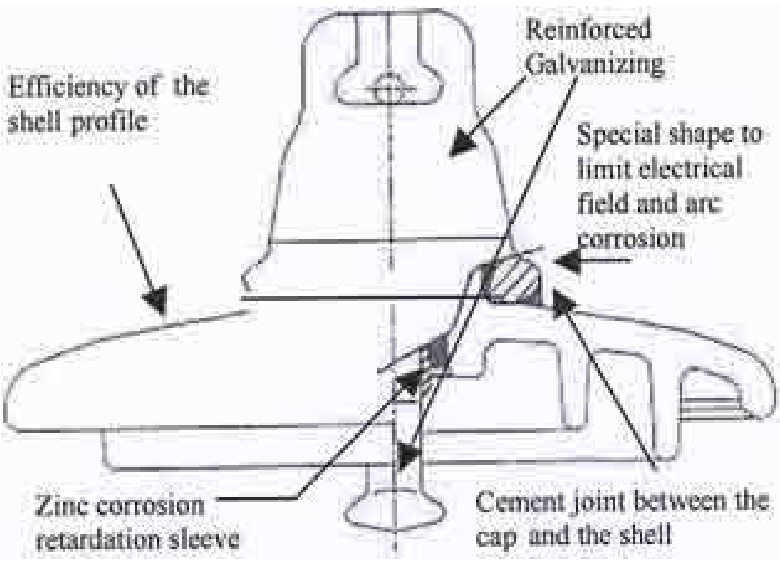


Figure 2.3: cap and pin insulator

Form some studies for glass disc on line in Africa, Scandinavia and in Italy was found that this kind of insulator has an average failure rates per annum more than ten times higher with DC voltage than the norm for AC lines. An insulation defect can occur with these insulators in HVDC, it generally begins with the failure of a first one cap-and-pin insulator, and then several insulators in a string. Such defects are difficult to detect. Glass, but also porcelain, contains mobile ions, so this mobile ions under steady stress may have a migration, for this reason probably there are more failure under DC voltages. Remedies may include reduction in ionic migration by increase in volume resistivity of the dielectric, elimination of voids and inclusion from glass (porcelain is inherently granular) and amelioration of corrosion.

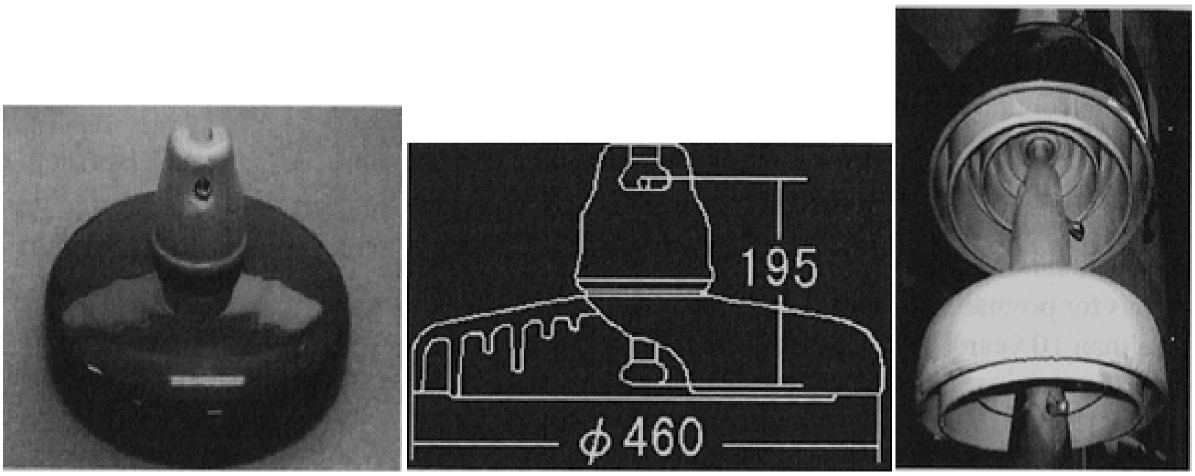


Figure 2.4: Glass cap and pin insulators for DC lines

2.2.3 *Longrods*

Longrod insulators are similar to post insulator but are lighter, it are used like a suspension insulator. The apparently advantages that longrod insulators have, if compared with cap and pin insulators, is that in this case the metal fittings exist only at the ends of insulators, it is obvious that with this kind of insulators the quantity of metal along the axial length is minimised. Longrods would be advantageous for use on DC, indeed, they are intrinsically little subject to damage from ionic migration within their dielectrics and contain no buried metal which may corrode. The problem is that they have inferior performance when used in a polluted environment. However, good results have been obtained from longrods on DC in moderate industrial pollution. The better performances to DC lines insulators have been found with Hybrid longrods.

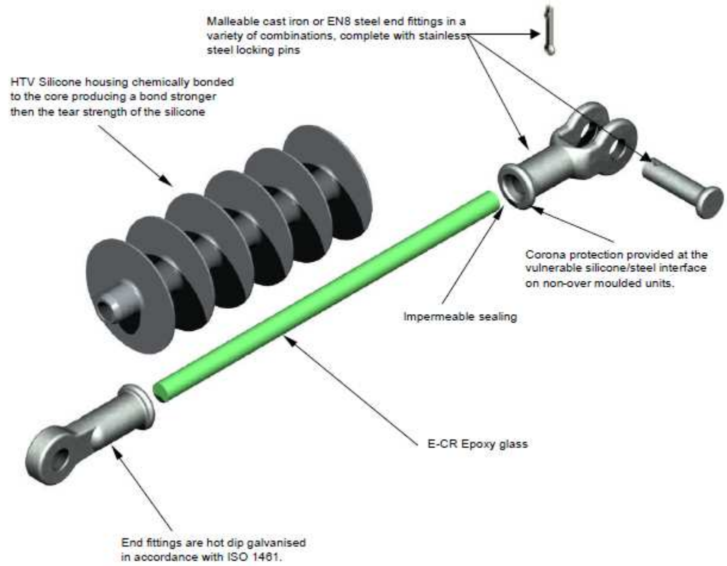


Figure 2.5: example of longrods insulator structure

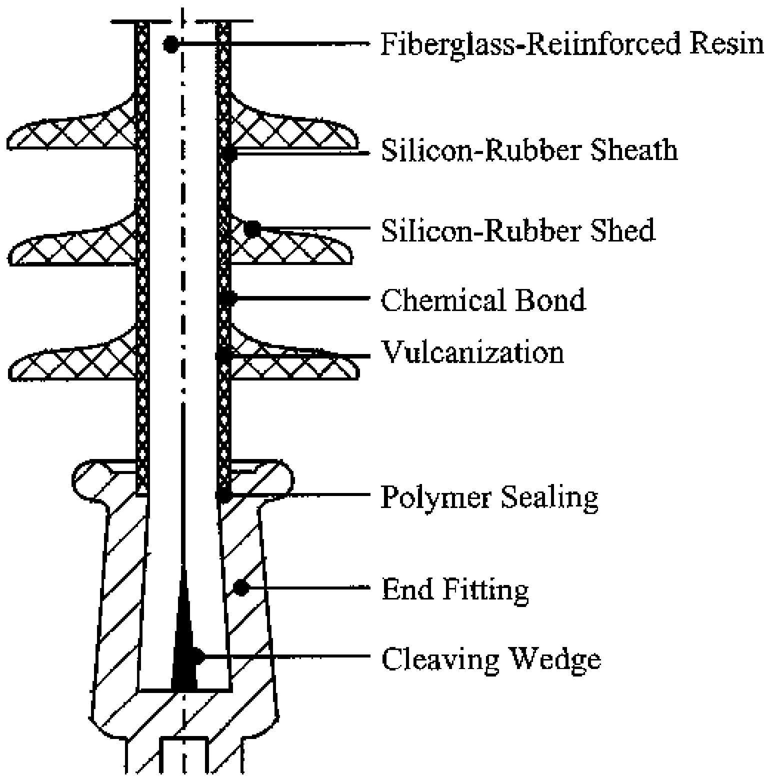


Figure 2.6: Cross-section through a composite long-rod insulator [8]

2.2.4 *Post*

They are used to support the High Voltage conductor and they are mounted on a pedestal or in the power lines cross arms. The post insulators are tall and are mainly used in substations. This kind of insulators can be made in porcelain, in glass or with polymeric materials. There are some important difference between a glass and a porcelain construction, indeed such porcelain post have developed radial cracks due to the volume growth of the mortar that bonds these cones together. The corresponding shattering of glass cones not seem to occur because the glass used is toughened glass so its tensile strength is greater than porcelain. The cracks in the porcelain surface cause a drastically reduce of path length of the leakage current. Another difference is the kind of cement that is used in porcelain and in glass post, for porcelain is used Portland cement whereas Fondu cement is employed for glass ones. To solve this problem was developed in a different way a design that avoids putting porcelain into a tensile mode.

A design of polymeric post consists in:

- A glass fibre reinforced resin core to provide the mechanical strength, while resisting the electrical stress.
- Elastomer sheds to provide the required creepage and stress reduction to withstand the stress prevailing to the system. Two commonly used material are EPDM rubber and silicone rubber.

A particular advantage of having a RBGC core lies both with its high mechanical strength and its flexibility. Both of these features enable such posts to withstand more readily than their porcelain equivalent the short circuit forces that occur under high current fault conditions and the violent vibrations that happen under seismic activity.

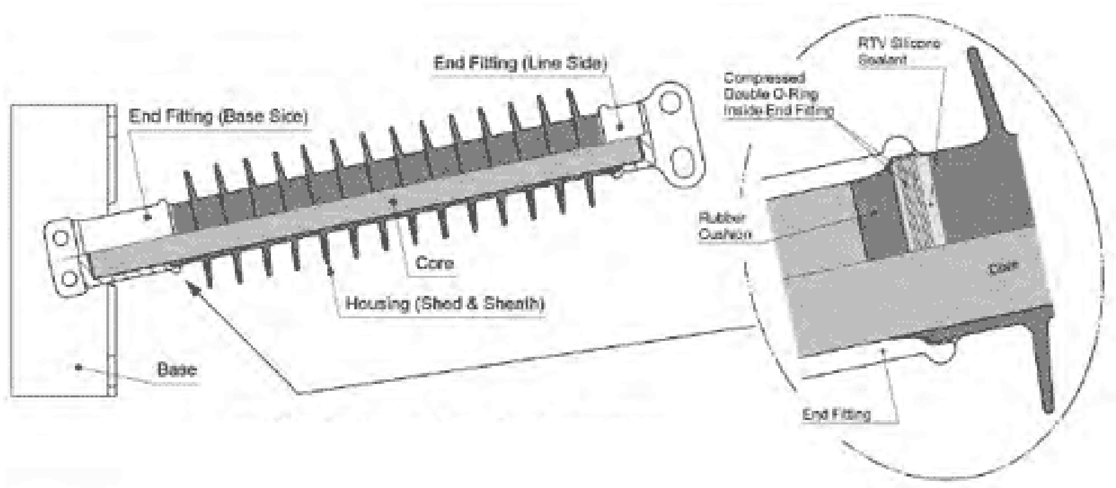


Figure 2.7: picture of post insulator [www.polymer-insulators.com]

2.2.5 *Barrels*

The important applications of the allow insulators are, for example, weather housing of bushing, surge arrester enclosures, circuit breaker interrupter heads, cable sealing ends.

In the recently times is developed the polymeric barrels insulators, especially ones having silicone rubber sheds bonded onto a glass fibre core tube.

The resin bonded glass fibre tube is constructed on a mandrel, as per standard practice. In one design of bushing manufacture the silicone rubber sheds applied to this tube. The end fittings are attached while the silicone rubber is still pliable and this complete assembly is then vulcanised in an autoclave. Final machining is carried out when this assembly has cooled down. Such hollow core insulators can currently be constructed with a maximum internal diameter of 600 mm and overall maximum length of 6 m.

The principal commercial insulators have been briefly described, now it is important explain what are their services conditions and the damage that may be occurs.

2.3 TYPES OF POLLUTION

There are two types of pollutions, natural pollution and artificial pollution. Insulators placed in the environment collect pollution by various sources.

- Coastal pollution: a layer of salt can be sprayed into the surface by the wind from the sea. In presence of humidity or fog these layer becomes conducting. Sodium chloride is the main constituent of this pollution.

- Industrial pollution: the power lines near the urban or industrial area are subject to stack from emission of the plants. These materials are used dry when deposited but with the fog they become wet and so probably they are conducting. The material will absorb moisture to different degrees, and apart from salts, acids are also deposited in the insulator.

To summarise briefly the principal sorts of contamination it is possible to find:

- Salts fog in coastal areas;
- Dust containing salt (desert or dry region);
- Agricultural deposit (fertilizers, combustion residues),

- Industrial pollution (coal mining, salt mining, cement plants, chemical industry);
- Pollution from vehicles (highways, non-electrified railways).

Wind is the instrument that causes the deposition of substance in the insulator surface but is the high humidity, fog or light rain that cause wetting of pollution layer. Can be observed that heavy rain is prone to clean the surface so is not a problem.

2.4 FAILURE MODE OF INSULATORS

The generally flashover caused by air breakdown or pollution, do not create physical damage to the insulators and the system can be restored by the mechanism of auto closing. Some other events can cause the irreparably damage to the insulators.

- Puncture

This kind of damage is common to cap and pin insulators, It is occur between the pin and either the pin or the high voltage conductor. These occurrences are usually caused by very steep impulse voltage, where the time delay for air flashover exceeds that of puncture of porcelain.

Definition by standardisation EN 62217:2006 to puncture of an insulator is:

“Permanent loss of dielectric strength due to disruptive discharge passing through the solid insulating material of an insulator”

- Shattering

Glass insulator shatter when exposed at severe arcing or puncture due to vandalism, despite that, they retain their mechanical integrity.

- Erosion

Prolongation arcing of glass insulators leads to erosion of the surface layer of the glass. Arcing and Corona over long period can cause removal of shed or sheath material in the case of polymeric insulators. Severe erosion may leads to the exposure of the glass fibre core.

Definition by standardisation EN 62217:2006 to erosion is:

“Irreversible and non-conducting degradation of the surface of the insulator that occurs by loss of material which can be uniform, localized or tree-shaped.”

- Tracking

Tracking occurs when carbonised tracks from because of arcing. These tracks are conductive. However this phenomenon only occurs in carbon-based polymers.

Definition by standardisation EN 62217:2006 to tracking is:

“Process which forms irreversible degradation by formation of conductive paths (tracks) starting and developing on the surface of an insulating material.”

- Brittle fracture

This damage may occur when water goes into the fibre glass core in case of composite insulators. The water combined with weak acids can be lead to the brittle fracture of the rod. The weak acids are produced by the combination of discharge and water; it is for this reason that the integrity of the metal/polymer or glass/polymer interface is extremely important, especially if acid-resistance glass is used.

- Crack

With the term crack is defined any internal fracture or surface fissure of depth greater than 0.1 mm according to the standardisation.

The performance of the insulators has to test according to IEC-60587 (“Electrical insulating materials used under severe ambient conditions - Test methods for evaluating resistance to tracking and erosion”), IEC-62217 (“Polymeric insulators for indoor and outdoor use with a nominal voltage>1000V-General definitions, test methods and acceptance criteria”), IEC-61302 (“Electrical insulating materials - Method to evaluate the resistance to tracking and erosion - Rotating wheel dip test”) standardisations but there are not a clear method for testing the polymeric insulator, for testing the insulators under DC voltage and for tasting the performance under snow and ice conditions. The procedure that it was decided to follow is: using the AC test method and modified apparatus to do DC tests. This way to work is the same way that may be found in the existent literature for DC tests, not just for “Tracking wheel test” but also for other kind of tests like the “Incline plane test”. These modifications are done after that a previously theoretical analyse. The critical point to provide the DC apparatus for made the test it is to provide a source of voltage of realistically low impedance. In general the number of DC test facilities for insulators and the reliability of test results have been limited by the difficulty and high cost of this kind of voltage source.

2.5 PHYSICS OF POLLUTION FLASHOVER

In general an insulation flashover can be existing for many reason, some of these are recognized in the following events:

- Direct lightning strike;
- Back flashover;
- Switching source;
- Insulator contamination;
- Insulation defect;
- Fire under the line.

Contamination flashover is a problem specifically inherent to the HVDC line. The flashover caused by pollution is critical because of it happen during normal service and so when the voltage applied is the voltage system. Therefore it is important to pay attention at individual parameters that can give an idea if the flashover is near to occur.

The probability that a contaminant flashover occurs are given by:

- Degree of insulator contaminant;
- Type of contamination;
- Non-uniformity of the contamination along the insulator string;
- Different degrees of contamination of the top and the bottom of the insulators caps;
- Kind of wetting;
- Voltage polarity.

The "Equivalent Salt Deposit Density" (ESDD) has been developed for made a unit of measure to compare different contaminate insulator surface. The ESDD is a salt coating measured in mg/cm^2 which produces the same conductivity, when completely wetted through, as the actual layer of contaminants [8]. However, usually for HVDC lines are better to use $\mu g/cm^2$.
The non-uniformity of the contamination along the insulator string is caused by the accumulation of charged particles on the top and on the bottom of the insulator string. This event is due to the field strength that is bigger in these regions.
It is important to remember that the Critical Flashover Voltage CFO is lower by several percent for negative test voltage than positive test voltage. This aspect is confirmed by many material tests done using the "Incline Plane Test Method".

Heger, Vermeulen, Holtzhausen and Vosloo have made some experiments using Inclined Plane Test method in order to determine the performance of typical power line insulation materials: RTV (Room Temperature Vulcanized) silicone rubber coated porcelain, HTV (High Temperature Vulcanized) silicone rubber and EPDM rubber. They tested these 4 kinds of materials under three voltage types: ac, positive dc and negative dc. The comparisons were done, based on the following evaluation criteria: Visual observations and sample appearance, sample mass loss, sample erosion depth, sample erosion area, average hourly rms leakage current, average dissipated power, sample hydrophobicity and chemical analysis.

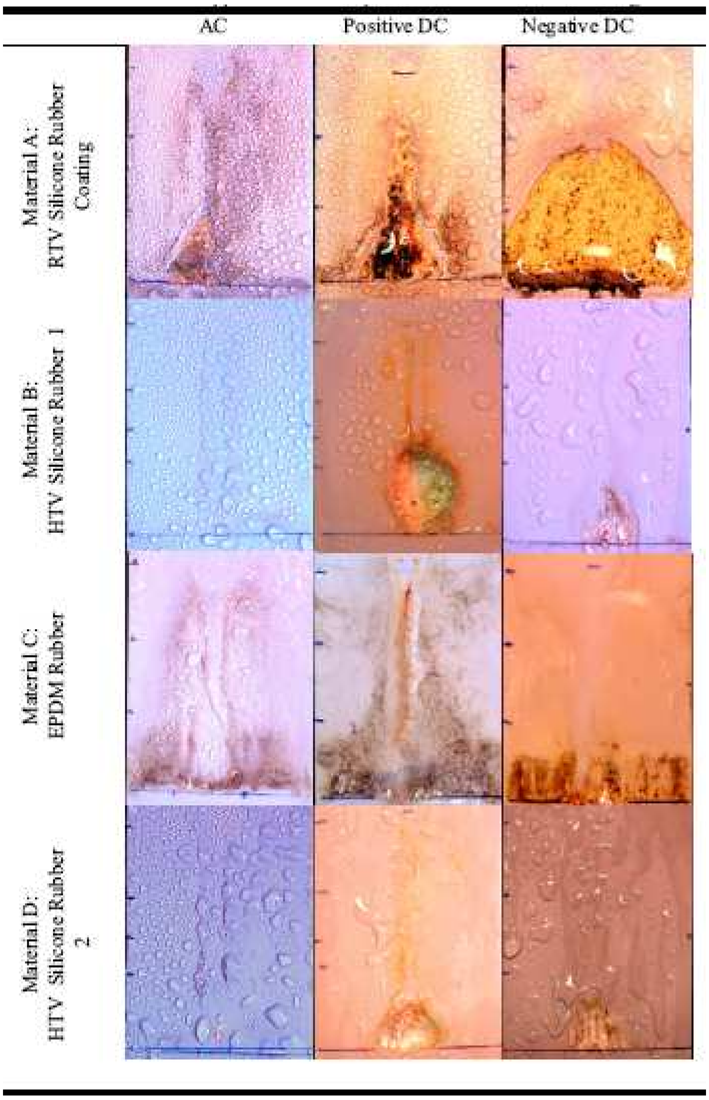


Figure 2.8: Visual appearance of samples at end of tests after washing [4]

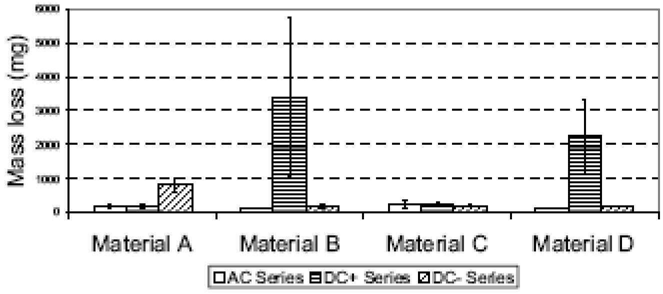


Figure 2.9: Mass loss of all samples for different voltage types [4]

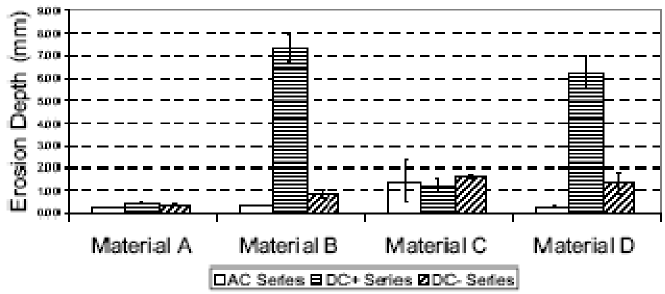


Figure 2.10: Erosion depth of all samples for different voltage types [4]

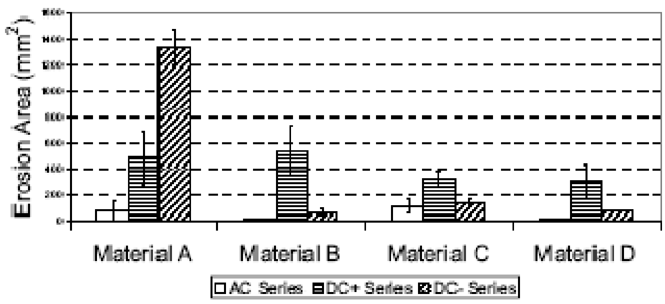


Figure 2.11: Erosion area of all samples for different voltage types [4]

The silicon rubber based materials developed only minor visual erosion during the ac series but during the positive dc series, they showed a massive increase in erosion, especially for HTV silicon rubber. The erosion of this material occurred due to the formation of holes through the entire sample thickness. EPDM materials showed more severe erosion than the other materials when energised by ac but it has a good behaviour with dc voltage. When the negative dc voltage was applied at the HTV silicon rubber we can seen that there is lower visual erosion. In contrast, the RTV silicon rubber showed extensive erosion over large areas of the sample surfaces when exposed to this voltage type. These results can be observed by the above graphs.

The measurements results for the rms leakage current for all the materials showed a no real correlation to the criteria of erosion severity, which indicated that the rms leakage current cannot be used to forecast erosion severity for polymer samples, tested using the IPT method[4].
There is also a clear polarity effect when dealing with the dc voltage, in the case of HTV rubber materials, electrolyte that flows in a direction away from the positive electrode produces arcs that are more detrimental to the insulator surface than in the case of a negative polarity, while in the case of RTV coating materials the opposite is true.

The factors that play an important role in the results obtained are:

- the effect of magnitude and polarity of the local electric field on hydrophobicity;
- the effects of UV radiation and of the different types of water droplet corona (anode or cathode) on hydrophibicityloss;
- the thermal effects of arcing, leading to chemical change.

We can see that the insulator samples are exposed to extremely harsh pollution discharge conditions when tested using the IPT method. The IPT test is a materials test, intended to evaluate the performance of electrical materials under severe ambient conditions.

Behaviour of layer of artificial pollution under electric stress was investigated by Hampton. He used strip of glass were coated with layers of kieselguhr, dextrin and salt. The voltage distribution as a function of time could be measured by capacitively couple probes that one is attached to back of glass, one behind each terminal electrode and the remaining eight distributed along the layer. The layer was wetted by water fog in a cabinet and the development of flashover from dry-band discharges was monitored.
The stage of the flashover process comprising the following step:

- uniform voltage gradient;
- development of more than one dry-band;
- dominance of one band;
- passage across band;
- development of arc;
- flashover.

The problem was: what determines whether the dry band will simply persist or whether the discharge will propagate along the surface to cause a flashover?

Hampton established that the criteria for propagation were:

E_a (stress in the arc) = E_b (stress in the layer).

The stress in the arc E_a exceeds the stress in the layer since arcs show a falling characteristic of stress against current:

$$E_a = AI^{-n}$$

Where I is the current and A,n are constants.

The arcs characteristic has a different behaviour according if it is developed in air or if there is the effect of water vapour, because of its dissociation and the large thermal conductivity of hydrogen, upon E_a. Hampton's work was never intended to comprise all the sufficient conditions for development of real flashover across a real insulator[3].

2.6 BASIC DIFFERENCE FROM AC CONDITION

The types of insulators over described can be used with AC or DC voltage but with different performance, indeed the situation is more complicity for the DC energisation.

With the DC energisation there are three important differences to AC energisation: in the mechanism of pollution and propagation of discharges to flashover, in the processes of surface erosion and corrosion of cement and metalwork and in the aging to the dielectric, especially with the ceramic matter. For DC voltage has not been done more tests because the source of voltage of realistically low impedance is very expensive.

Some difference may be deducted from first principles. The absence of voltage zeros on DC, and the polarity reversals, must favour development of primary discharges to complete a flashover. When DC voltage is applied the insulator becomes solely on resistance without capacitance and hence there is a greater frequency of primary discharge.

To compare the insulators used with AC voltage to DC voltage was defined the ratio:

$$F = \frac{Peak\ AC\ flashover}{Peak\ DC\ flashover}$$

Salt fog tests gave values of F from about 1,2 to 1,7 but were observed that with different shapes and materials may have different values of F.

The better solution is to use polymeric matters because their surface is hydrophobic, but they have the problem that when the surface is covered by pollution layer it becomes hydrophilic.

There are difference for the contaminating processes between DC energisation and AC energisation for the polymeric materials. Many airborne particles are electrically charged by triboelectirc or frictional effects, and by attachment to ions generated form cosmic rays or industries. Such particles will have an electric component of force added to their gravitational and aerodynamic ones, and will be caught when they come within range of appropriately charged DC electrodes, but will remain free in alternating fields.

Where corona activity causes large local ion flux, intense dirt deposition occurs, again on DC only, by electrostatic precipitator action. The motion on the particles having high permittivity into regions where the divergence of electric intensity is large, dielectrophoresis is a very short-range effect which is polarity independent. The force depends on the volume (v), relative permittivity (k), on the gradient of the square of the field intensity (E) according to the following law:

$$F = CONSTANT * v * \left\{ \left[\frac{k-1}{k+2} \right] gradE^{2} \right\}$$

Bird droppings, growths of moss and insect infestation have all caused flashover in special circumstances.

Dielectrophoresis is a phenomenon in which a force is exerted on a dielectric particle when it is subjected to a non-uniform electric field. This force does not require the particle to be charged. All particles exhibit dielectrophoretic activity in the presence of electric fields. However, the strength of the force depends strongly on the medium and particles' electrical properties, on the particles' shape and size, as well as on the frequency of the electric field. Since the dielectrophoresis force is not dependent of the voltage polarity its effect can be reported in AC energisation and also with DC energisation.

It is clear that a specific analysis to the polymer material using to build insulators is necessary to understand like this field can be developed.

CHAPTER 3

POLYMER OUTDOOR INSULATOR

3.1 INTRODUCTION

Polymers materials for outdoor application are in certain aspect preferable to porcelain and/or glass because of their lightweight, better resistance to vandalism and superior contaminant performance. Problems have been recorded with first generation of polymeric insulators but recently an EPRI survey has reported that 78% of utilities were satisfied with the performance of polymeric insulators, whereas only 4% report poor behaviour[6].

The principal problem that have been recognized on polymeric insulators were their long term performance. It is difficult to predict the lifetime for polymeric insulator because of they have an organic nature. This aspect can cause the unexpected degrade or age under service conditions. The stresses that the insulators have to support during their life in service are simultaneously electrical, thermal, mechanical, UV radiation. These kinds of stresses have a synergistic effect on the polymeric insulator aging and on its overall performance.

MATERIAL	PREDICTED LIFETIME (years)	OBSERVED DAMAGE
PTFE	20	Slight erosion
Silicone elastormer, Best	25	Tracks and Punctures
Silicone elastomer, Worst	2 ÷ 6	Tracks
Polyolefine, Best	5	Puncture
Polyolefine, Worst	1	Tracks

Table 3.1: Predicted lifetime of housing polymers: outdoor tests [3]

With the term “polymers” is comprise a wide range of materials different in their basic proprieties so it is difficult to comprise the long-term performance but a general valuation is reported in the table above. Heavily filled alicyclic epoxies, for example, suffering considerably loss surface properties, PTFE suffering considerably less loss of surface proprieties and silicon rubber, a know water repellent, but all these materials are called “polymers”. Another problem to evaluated the lifetime of polymer insulators it is that no same insulators are in service form 25 years because of the technology is continuously in development. From this point is possible to understand because it is so important that accelerate tests are elaborate, indeed, they have to provide good results in a relativity short time.

The most important use of polymer is in housing with which it may control external leakage current while protecting the contents against invasion by water. The surrounding polymer weathershed consisting of the sheath and skirts provides the electrical strength under all conditions that are dry, wet and contaminated. The fibber glass rod is made up of electrical grade glass fibbers bonded with either epoxy or polymer resin. Epoxy resin bonded fibber glass rod is a better solution than polyester resin bonded rods because they have higher mechanical strength. Nevertheless there are insulators with polyester resin bonded rods that are in service successfully. The rod can be cast or pultruded. The rod is attached to the aluminium or malleable iron end fittings by means of a crimp, wedge or glue but the best choice seems to be the crimped fitting[6].

It is fundamental to provide a protection for the fibber glass rod against the moisture under all conditions because of if the organic resin comes in contact with some water, it will easily carbonized in presence of electrical stress. The protection is provided by the weathershed material. Only few materials can accomplish successfully this weathershed function, they are silicone rubbers and ethylene rubbers.

About this, it have been observed that the cause of electrical failure in general can be recognised in two cases: the first is the poor bonding between the fibber reinforced rod and the housing material, and the second is the weathershed material itself, which, because of improper selection of ingredients and/or manufacturing, may be prone to erosion and tracking. Indeed, the cause for the mechanical failure can be observed when there is an inadequate attachment of the FRP rod to the end fitting.

Concerning in specific the materials for the shed, the Polysil (acrylic polymer heavily loaded with sand) and NIM (new inorganic materials) are most stiff and strong so they are designed to perform the functions of mechanical support and electrical insulation but they have a problem when in their surface there are the pollution layer. Polysil and NIMS cannot be used directly to form complete insulators because of their variation in volume resistivity with humidity. In the Hybrid insulator, polymers are used solely to control the leakage current. The electrical performance of Polysil in pollution is not finally established.

The electrical aging in polymeric materials has been recognized to come from to extensive deterioration form hydrolysis and UV attack. Type of epoxies and ethylene propylene rubbers had such problems in the past but the present day materials are much improved and do not suffer like their predecessor.

The main feature of the silicone rubber surface is the hydrophobic aspect that ensure the low value of the leakage current. The initially hydrophobic state is caused by the inherently low surface energy materials. This kind of important ability is very much dependent on the polymer type and formulation. Different kind of polymeric material can be having a very different behaviour in the electrical aging so a judgment cannot be made on the insulator performance based on material family alone. Unfortunately this desirable property of polymeric materials is very much dependent of the contaminant that are present in their surface. In fact, service experience showed that polymeric materials like Teflon, EPM, EPDM, silicone rubber, cycloaliphatic resin, were prone to surface erosion when thick pollution layers were formed. Nevertheless the silicone rubber can recover its hydrophobicity quickly, despite being contaminated, and this aspect had led many to believed that the material would not age much during the expected life of insulator, but it was found that is not completely true because there was a permanent changes that are not time dependent like hydrophobicity; it was shown that silicone rubber ages, and that surface hydrophobicity are not a good indicator of aging.

Silicone rubber showed a certain advantage because of its water repellent in comparison to the other housing materials; it proved, however, to be sensitive to thick pollution layer exposure.

EPM and EPDM weathersheds materials suffered from chalking and crazing and in some cases from loss of bonding at the junction of two consecutive shed, instead those kind of damaged weren't observed in silicone rubber insulators. Deformation and reduction of hardness of the RTV silicone rubber weathersheds was observed.

The high voltage group of Chalmers University of Technology reached some important conclusions:

- EPDM and silicone rubber perform better than glass or porcelain [6],

- The aging of silicone rubber result in formation of a low molecular silicone layer on the insulator surface which preserves the good electrical insulating properties of the aged silicone rubber insulator [6],

- The EPDM insulators tend to lose their hydrophibicity by weathering after some years of exposure,

- For the RTV silicone elastomer coating the contact angle was lower than that measured on the RTV silicone rubber housing [6],

- The leakage current activity for the aged silicone rubber insulators is lower than that of EPDM insulators subjected to the same natural aging [6],

- A reduction of a contact angle in silicone rubber insulators seems to be due to an increase of the surface roughness and to an increase of the surface polarization due to hydroxyl presence, which in turn decreases the surface hydrophobicity [6].

- Leakage currents and surface degradation is different for various polymers, so that showing clearly the importance of manufacturing process for housing materials. The presently used accelerated aging tests are not suitable since they tend to show that the degradation of polymers is more a function of their inorganic filler [6].

Now, electrical discharges or electrochemical reactions cause erosion and the loss of surface material, these effect increases with density of leakage current. When the discharge of ions meets the metal terminals or end of carbon tracks, aggressive products are originated and this carries to form holes and channels. Whereas diffuse erosion usually is tolerable on the surface of housing because of thanks this phenomenon the insulator may give some degree of self-cleaning, the localised or concentrated erosion is fatal, since it allows invasion of the interior by water and contaminants.

Criteria for good housing polymer are complex and contradictory, indeed non-wetting and non-stick surface will reduce leakage current in pollution but give poor bonding to the protect substrate. The polymers that have these features are Teflon and PTFE. Instead, Epoxy, powerfully adhesive resin, will give excellent bond to the substrate but will adhere strongly dirty and water so it suffers rapid surface degradation.

During the processes of curing can be formed substance like the residues of polymerisation and catalysis so there is an undesirable salt.

It cannot be said that good correlation has been found with result based on TERT (tracking and erosion test) and similar test on housing materials. Some types of housing materials have shown characteristic advantages and disadvantages. Extreme case are the heavily filled thermoset epoxies, which generally suffer severe loss of surface proprieties causing a decline in performance, measured flashover voltage per standard severity pollution, as high as 40% from initial value in two or three years, and fluorocarbons, especially PTFE (Teflon). The rubbery materials, EPR or EPDM and the butyl rubbers have shown only fair maintenance of surface properties while some have tended to split under weathering. Elastomers having silicone rubbers as a principal constituent have often shown good maintenance of ‘non-stick’ properties, although mechanical weakness and bounding difficulties have plagued some[3].

Hence, with accelerated testing a life of 30 years may be expected on the evidence. However, predicted performances should be treated with suspicion even for single polymeric pieces but for complete assemblies (housing, core and terminations) they have to exposure the complete insulators to severe pollution under some degree of overstress. This is the sole reliable guide.

High intensities of field, in surface water-repellence of material under test, causes spreading of drops otherwise contained by surface tension. The heavy pollution is forced upon all samples by method of contamination but in real conditions of service the surface properties would catch much less than other.

Laboratory testing is made to find new components and to try new materials so they can be discussion in two separate sections:

- surface tracking and erosion testing:

  This group of test is made to study the entire characteristic of insulators, not just materials. Well-defined tests for seacoast pollution and for industrial pollution are sought.

- material tests:

This kind of test is made to study the hydrophobic behaviour of silicone rubber surface and how it is recovered after the period of dry band arcing.

3.2 EVALUATION OF THE HYDROPHOBIC AND HYDROPHILIC SURFACE

According the IEC 62073:2003 standardisation, there are three methods used to determine the degree of wetness of a surface, namely the contact angle method, the surface tension method and the spray method.

3.2.1 Contact angle method:

A good measure of wetting of an insulating material is the contact angle, θ, of a sessile water drop residing on its surface. The contact angle is defined like the angle between the edge of a single droplet of water and the surface of single solid material as show in the figure.

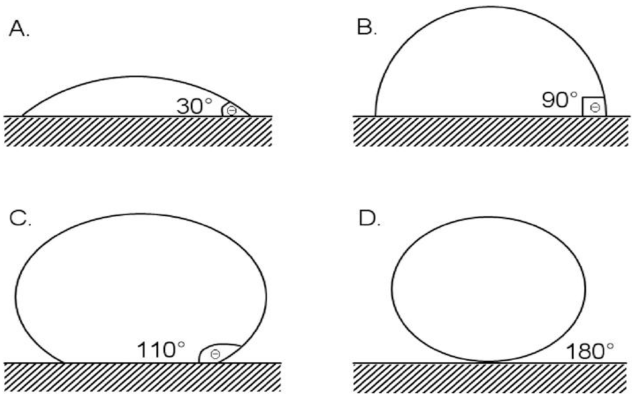


Figure 3.1: shapes of water drops

The value of the contact angle is depended from the roughness surface. Therefore the contact angle measured on a pollution surface may differ from the contact angle measured on smooth, clean and plane surface.

The following picture showed like the contact angle is measured:

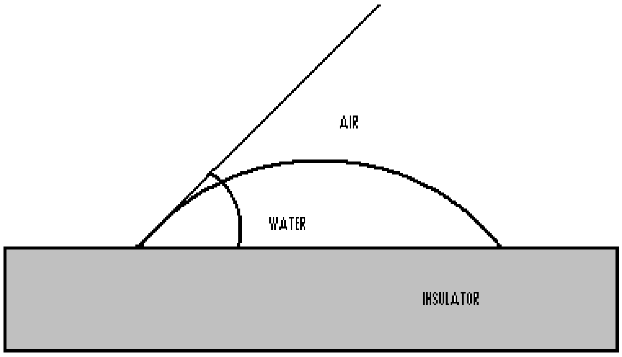


Figure 23.2: method to evaluate the contact angle

There are three coefficients of interfacial tension, λ, which controlled this angle. The equation is related by Young- Durpe:

$$\lambda_{wa} \cos \vartheta = \lambda_{ia} - \lambda_{iw}$$

Where subscripts a, i and w refer to air, insulator and water, respectively.

The value of θ change according to the surface, for clean and new ceramic surface θ is about 30° while for clean and new silicone rubber surface is about 100° but when the surface become coated with pollution layer this angle become essentially zero, some example are reported in the figure. The difference between ceramic case and silicone rubber case is that in the case of polluted surface for ceramic material θ always stays zero (i.e. the hydrophilic case) but it will, in time, return to substantial value for silicone rubber (i.e. the hydrophobic one).

3.2.2 Surface tension method

The surface tension method is based to the observation of the ability of wet the surface of insulator that droplets of a series of organic liquid mixture could have with increasing of surface tension. It is necessary to pay attention because of there are restriction when using this method for polluted insulator surfaces, the surface tension method is affected by interaction between certain types of surface pollution.

3.2.3 The spray method

To evaluated the surface with this method it need to have a visual inspection after that the samples is wetted by water mist for a short period of time.

Is possible to classify the state of surface using 6 wettability classes, namely completely hydrophobic (wettability Class 1) to completely hydrophilic (wettability Class 6). The examples of this classification are show in the follow figure:

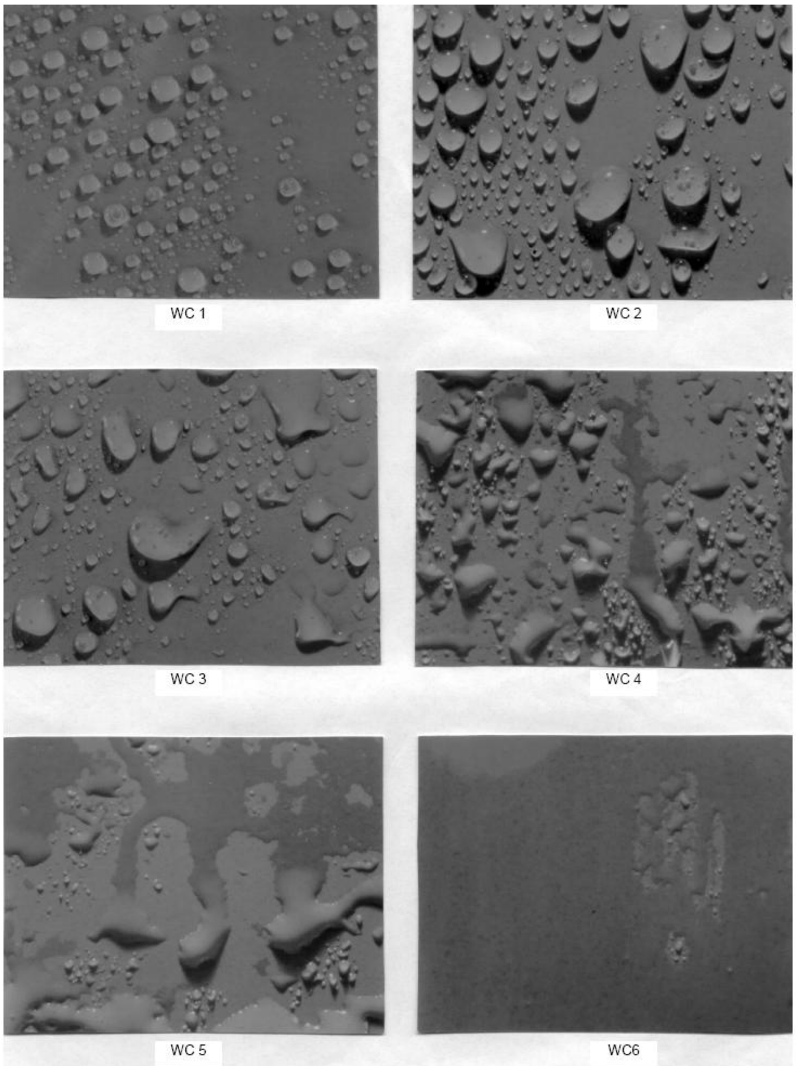


Figure 3.3:Photographs defining of wettability classes WC1 to WC6 [7]

3.3 INFLUENCE ON THE LEAKAGE CURRENT OF THE SURFACE STATE OF THE INSULATORS

3.3.1 Hydrophilic case

A leakage current is conducted in the insulator's surface when a film of polluted water covers completely this. Because of Joule heating, some of the water evaporates. Can be a region where the thickness of the water is less than a critical value or the power density (j^2 ρ) is maximum and the ρ increases with the time so also the electric field E=jρ in the electrolyte increases. The electric field in the air immediately above this area has approximately the same value. Once the ionisation level in this air reached, a discharge can occurs. This kind of region is called dry band. The discharge can be a spark, a glow or an arc according to its duration and magnitude of the current it conducts. If a pollution flashover is to take place it has to be an arc whose the roots propagate over the surface of electrolyte and along the length of the insulators. In vertically mounted sting of cap and pin insulators the value of j is maximum around the pin cavity and the value of ρ is maximum around the cap where the washing effect of rain is relevant, for this reason this two place are subjected to more discharge[2].

The voltage V and the current I relationship of an arc plus electrolyte in the insulators surface can be expressed by the Kirchoff's law as:

$$V = IR + V(e) + If(\rho) f(X)$$

Where R is the resistance of the arc; V(e) is the sum of the voltage drops at the junctions between the arc and the electrolyte (i.e. anode phenomenon, about 200 V and cathode one, about 700 V); f(ρ) is a function of ρ, the value of which varies along the length of the electrolyte and f(X) is a function of the arc length, X, the sum of the electrolyte's length plus that dry band (together L) and the effective length of the arc's root on the electrolyte's surface near the cathode and near the anode.

A value arc resistance can be calculated from Suit's arc equation:

$$R = I^{-(1+a)} \int_0^X A(x)dx$$

Where *a* is a constant and A(x) has a value at position x from the beginning of the arc that depends upon the proximity of that part of the arc to the electrolyte's surface, the amount of water on the surface and the extent that thermalisation has taken place within the arc but for the first approximation, A can be considered to have an effective value, that applies for the whole length of the arc.

The resistance of the arc decreases as its current increases and so its length extends, the criterion for the propagation of the arc's root to effect this increase in length can be stated as:

$$\frac{dI}{dX} \rangle 0$$

There are a lot of mathematical models that have been adopted to solve these equations for simple insulator shapes but for more complex insulator shapes, e.g. like the anti-fog design, the first additional aspect that need to taken into account is the form factor F. For the anti-fog insulators we need to taken into account also that not all the insulator's surface are interested by arc, in effect, the sparkover of the air gaps between sheds and the ribs of a shed can effectively shorten the arc's length. Mathematically, this can be represented by stating that the arc's length X(a) is related to the corresponding spanned length X(i) of insulator by:

$$X(a) = kX(i)$$

where k<1 for the shortening case and k>1 for lengthening one.

From the practical observation we have found that once the critical conditions have been reached, flashover is likely to occur even though an appreciable length of the insulator remains to be spanned by the arc. After this stage the resistance of the electrolyte around the arc root is much smaller than that of the rest of the electrolyte's length that still remains so be spanned and so, for all practical purposes, ρ be taken to have a constant value and f(X) can be considered to be of the form:

$$f(X) = F\left[1 - \frac{X}{L}\right]$$

The value of the flashover voltage V(FO,DC) is determinate as being:

$$V(FO, DC) \approx (\rho F)^{\frac{a}{1+a}} (kAL)^{\frac{1}{1+a}}$$

The effective quantities for the various constants can be determined by comparing the calculated values with the measured ones. Those for *a* can be obtained from simple bench-top experiments, for A we can use the data obtained with artificial pollution test made on the simple designs of post and longrod. The corresponding values for *k* are best driven from the testing of insulators that have anti-fog profile. We can assume, a=0.5, A=10 V/mm^{2}root amps and N=100 V/mm^{2}root amps. For anti-fog cap and pin insulators is found that the value of k can to vary between 0.4 and 1; it depends upon the pollution severity and whether AC or DC energised, smaller values apply to the DC case. An examination of equations that we use to calculate the flashover voltage using the parameter values quoted above, readily shows that the V(FO,DC) is much lower than V(FO,AC) for the same level of pollution severity. That is, the lack of the reignition process makes DC insulators substantially longer than those for corresponding AC case if their flashover is to be avoided. Linearity between AC flashover voltage and insulator length does not apply over the complete range of length, the pollution flashover performance under AC energisation is best to obtained by testing fullscale insulators at, or close to, the relevant operating voltage.

From the theoretical viewpoint, this restriction does not apply to the DC case, which is an aspect that needs to be considered further by experimentation [2]. To compare insulators used under AC voltage and insulators used under DC voltage to see chapter 2.6.

3.3.2 Hydrophobic case

When the water drops remain discrete the flashover path involves the intervening air gaps. The water drop plays two major roles. In one, it acts as stress enhancer, due to its much larger permittivity than that of both the surrounding air and the insulating material on which it resides. In the other, it reduces the length of the air path across the dry part of insulator. The flashover path is through the drop when the water is highly conducting or across its surface when is not so. Moreover, the electric field caused the deformability of the water drop[2].

3.4 PROBLEM ABSTRACT

In conclusion to highlight and to summarize the problem that may occur with polymer insulators used in HVDC overheads lines in service in pollution areas can be say that contamination of insulator surface in itself is not critical but became so when moisture is present. A leakage current occurs along the surface of the insulator, this current can easily be as high as several 100 mA. As a result of the heat which is generated, some areas dry out. The voltage, which was previously distributed uniformly, appears across these dry areas, resulting in partial flashovers. This effect, which also occurs with alternating current, is particularly critical with direct voltage no zero crossing to allow an extinction of arc current, like above reported. There is thus a significant hazard that a partial flashover grows into a total flashover.

CHAPTER 4

TRACKING WHEEL TEST FACILITIES

4.1 INTRODUCTION

This chapter describe the set up made to run the tracking wheel test with DC supply. In spite of there is not a specific standardisation for DC supply, it was decided to follow the standardisation EN 62217:2006 “Polymeric insulators for indoor and outdoor use with a nominal voltage > 1000 V – General definitions, test methods and acceptance criteria” for AC, but with one modification, in order to be able to test using dc voltage, the apparatus was modified by adding a rectifier to the circuit.

4.2 TRACKING WHEEL TEST FACILITIES

From the standardisation is described that with this kind of test may be tested two pairs of test specimens simultaneously but it is recommended not mixed widely differing materials on the same wheel.

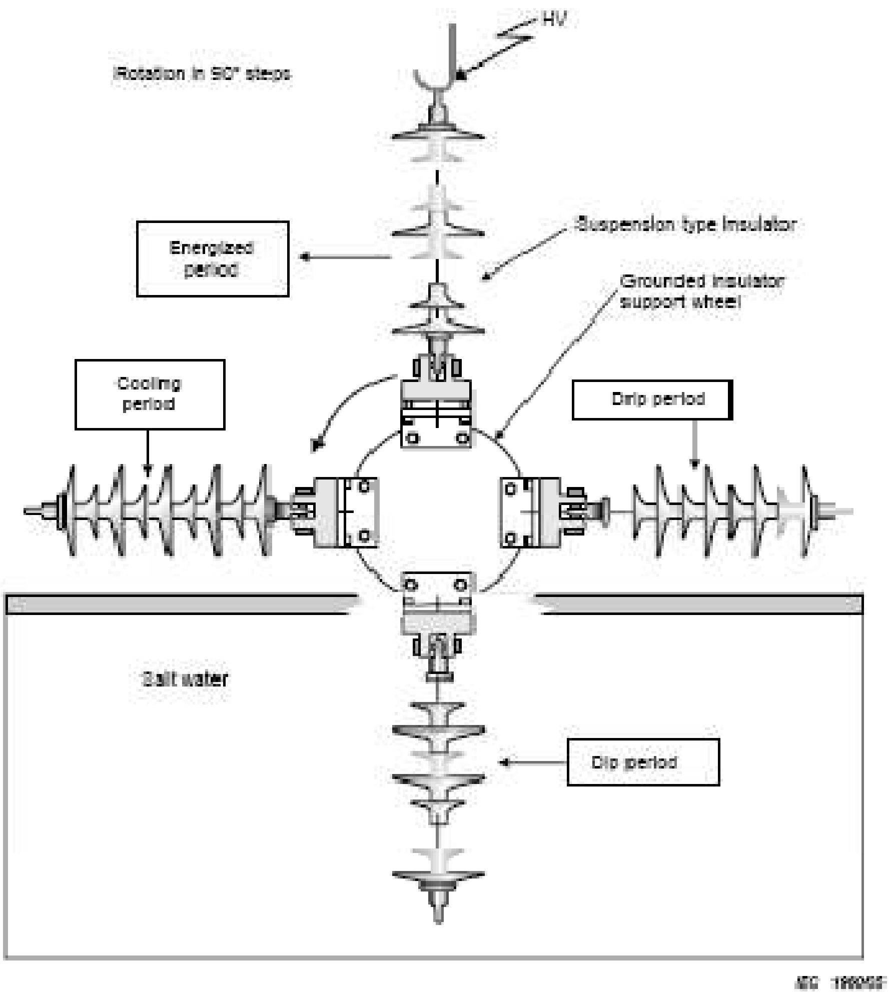


Figure 4.1: Test arrangement of tracking wheel test [EN 62217:2006]

The test apparatus of the wheel as showed in the picture above from the standardization. The insulators under test have to go through four positions in one cycle; the positions are at 0°, 90°, 180° and 270°. In every position the insulator have to be stationary for 40 s and to go between two different positions, so to make 90°, the insulators has 8 s. The different positions of the cycle may be described like:

- First position: the insulator is dipped into a saline solution;
- Second position: the insulator is left to standing of in a horizontal position to reduce the saline solution from its surface.
- Third position: the insulator is in the vertical, it touch the copper tape so it is under the voltage supply.
- Fourth position: the surface of the insulator that had been heated by the dry band sparking is allowed to cool.

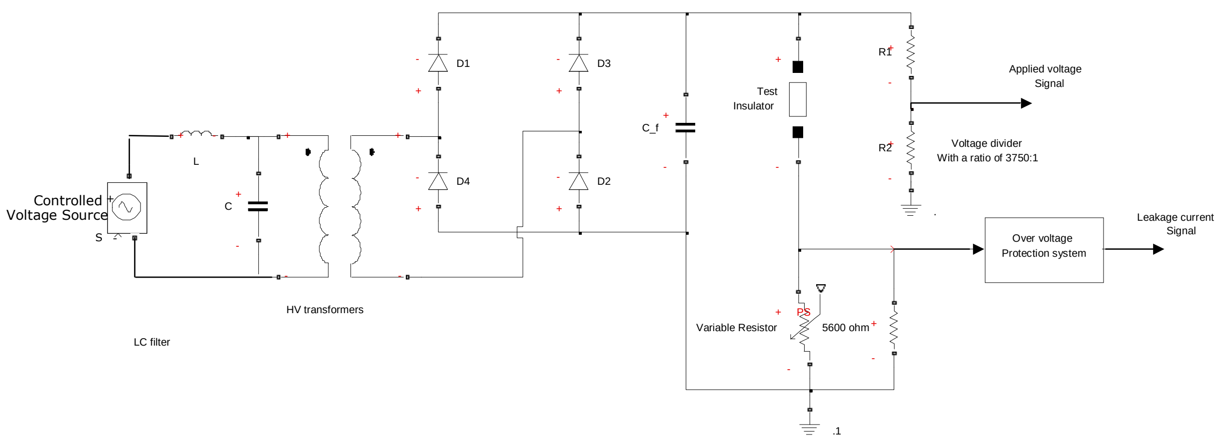


Figure 4.2: High - Voltage setup

The test circuit is composed by a 240/10 kV set up transformer that is used to generate the required test voltage, a full-bridge rectifier, a smoothing capacitor is chosen to achieve a not big ripple of the output voltage.

Figure 4.3: DC Voltage generator

The applied voltage is variable up 10 kV and it is measured using Haefely mixed resistive capacitive voltage divider with a ratio of 3750:1 because of the labVIEW signal has to have a ration voltage between -10V to 10V.

Figure 4.4: Snapshot of Voltage Divider (ratio 3750:1)

The leakage currents was monitored throughout the test using a 5,6 kΩ and was recorded using an on-line leakage current analyzer data log.

Figure 4.5: Resistor to monitored the leakage current (5,6 kΩ)

To make sure that in case of flashover the DAQ card is protect from the large voltage produced, a variable resistor was place in parallel at the leakage current signal and also with protection system. This protection system comprises:

- GDS (gas discharge tube):

It is an arrangement of electrodes in a gas within an insulating, temperature-resistance envelopment. Gas tubes are tubes whose electrical characteristic are substantially influenced by the pressure and composition of gas contained inside.

- MOV (metal-oxide varistor)

It is an electrical component with a “diode-like” nonlinear current-voltage characteristic. Varistor are often used to protect circuits against excessive transient voltages by incorporating them into the circuit such a way that, when triggered, they will shunt the current created by the high voltage away from the sensitive components.

- TVS (transient voltage suppressor)

The characteristic of a TVS requires that it responds to overvoltage faster than common overvoltage protection components such as varistor. These dispositive are chosen and placed in parallel because the TVS is faster than the MOV, that is faster than GDS, so the leakage monitoring apparatus is definitely protected.

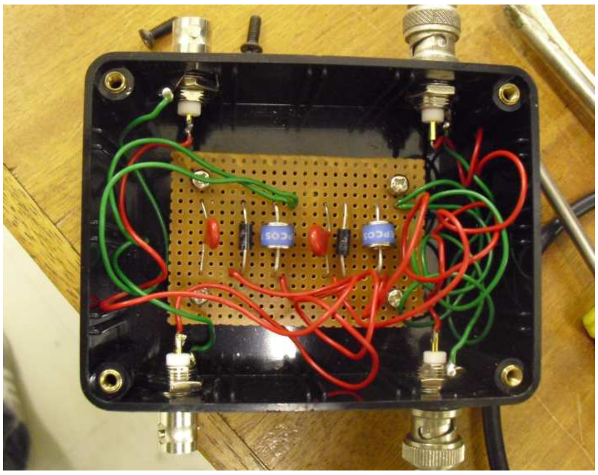


Figure 4.6: Protection system for leakage current data analyse (GDS, MOV, TVS)

To provide a good electrical contact between the aluminium wheel that support the insulators and the resistance that was used to detected the leakage current, it had been done a groove in the post where the wheel is fixed and inside the groove was placed a conductor connected with a ring. The ring is then in contact with a graphite brush which crawls to the ring during the rotation thanks to a spring placed behind it which assures a good contact. The ring is connected to the resistor which is in parallel with at the protection system and at the variable resistor.

Figure 4.7: Wheel - ring connection

The water is grounded at earth by a copper barrels fixed in the tank and linked at the zero potential point of the system. The dimension of the tank is chosen according to the insulator that can be tested, so they are 170 x 77,5 x 35 cm. The tank choice has been done in a not light and not expensive material, so was decided to use glass reinforced plastic (GRP).

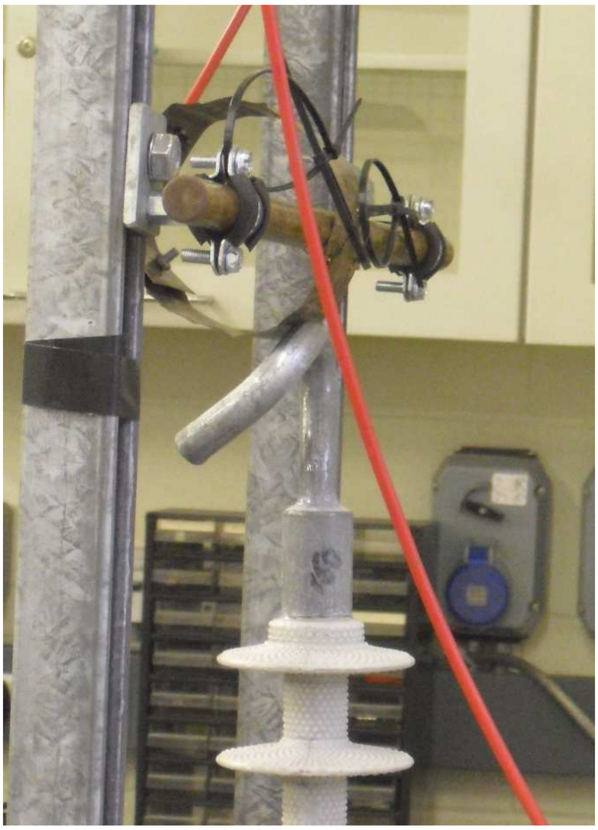


Figure 4.8: Copper tape to ensure a good contact between the Voltage Source and the insulator under energisation

It is necessarily to have a good electrical contact when the insulator is in the vertical position, so this is done using a copper tape attached in a non-conductive rod. To stopped the insulators in the right position was used the threshold value of the instantaneous power. Every time that instantaneous power was above the threshold this means that the insulator had been touched the copper tape so it is in vertical position then the rotation of the wheel had to be stopped. This kind of timing to stop the wheel it was not a good choose because of in the first cycle the surface of the insulators is not so wet to carry a high value of leakage current, in this way sometimes, especially with low voltages, the input to stopped the motor is not given in the right time and the test is failed. A better solution could be the test timing controlled by a position sensor.

The rod where is placed the copper tape can be moved up and down so the insulators tested can be with different length. Probably a better design to this electrical contact could be a rectangular copper tape fixed in the same rod along the smaller dimension because the copper tape sometimes seems to be blocked in a high position by the force given it when the prior insulator moves from the vertical position. These entire staffs are fixed in a frame with wheels so it is possible move the machine if it is necessary.

According the standardisation EN 62217, inside the tank is put salt water, the salt water where the insulators are dipped has a quantity of NaCl equal to 1,40 kg/m3, in the case here describe, in 340 l of water, 476 g are dissolved and the conductivity of the solution is 2.7 mS/cm.

To evaluate the salinity of the water inside the tank had been used a conductivity meter of “HANNA instruments” at every tests to make sure that the salt in the water is the correction value with the standardisation.

Figure 4.9: Conductivity meter of "HANNA instruments”

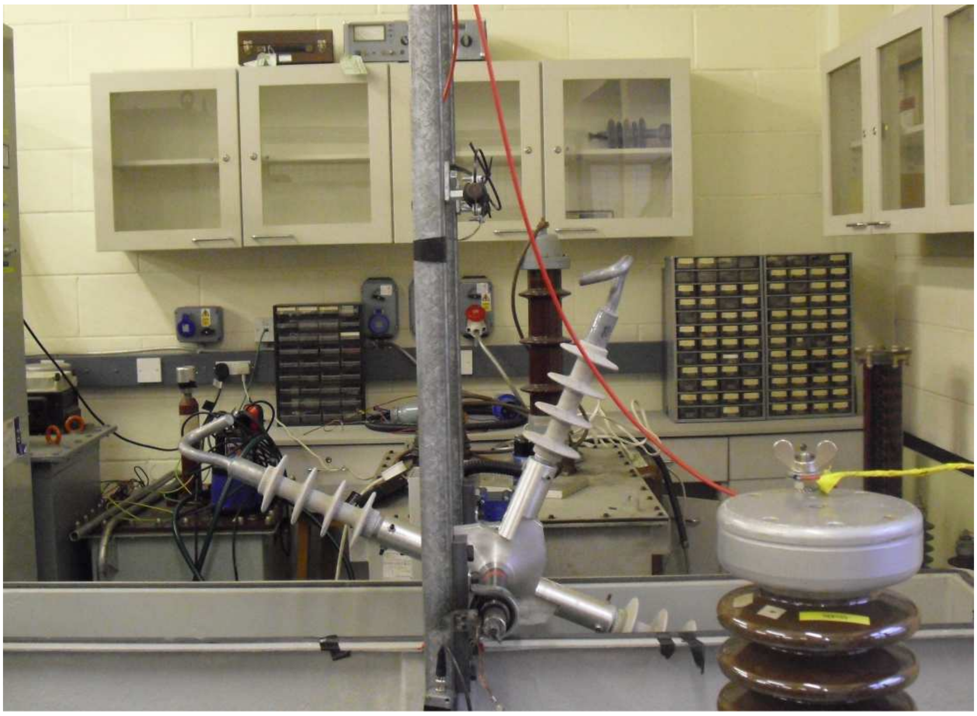


Figure 4.10: Tracking wheel test facilities

The test is considered as passed, if one both test specimens:

- no tracking occurs;
- erosion is less than 3mm;
- insulator surface is not punctured.

4.3 DATA ACQUISITION labVIEW^{TM} ENVIRONMENTAL

Although not required by the standard BS EN 62217:2006, the leakage current and the applied operation voltage was measured, processed, displayed on the PC monitor and saved onto the hard disk to research purpose. The leakage current and the applied voltage were processed using a graphical programming language called LabVIEW^{TM} that was used also to control the motor and the test timing of each of the four insulators. The LabVIEW^{TM} program communicates with the external by a peripheral device call Data Acquisition (DAQ) card. The DAQ device is normally composed by sensors that convert physical parameters to electrical signals, signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values, analog-to-digital converters, which convert conditioned sensor signals to digital values. The DAQ is connected with the personal computer.

- LabVIEWTM

LabVIEWTM (short for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and environment for a visual programming language developed by National Instrument. LabVIEWTM has three components: a block diagram, a front panel, and a connector panel. The last is used to represent the VI in the block diagrams of other, calling VIs. The front panel is the user interface and it is quite similar to physical instruments. LabVIEWTM uses the dataflow programming language, also referred to as G. The graphical approach allows non-programmers to build program by virtual instrument which represent lab equipment that they have already used. The programming code is built in the block diagram where there are all the staffs arranged like blocks which are connected between each other by wires.

4.3.1 *Main program to acquire the data*

- FRONT PANEL

The front panel to the program that allows showing the value of Voltage applied, leakage current and their product, instantaneous power, is reported in figure.

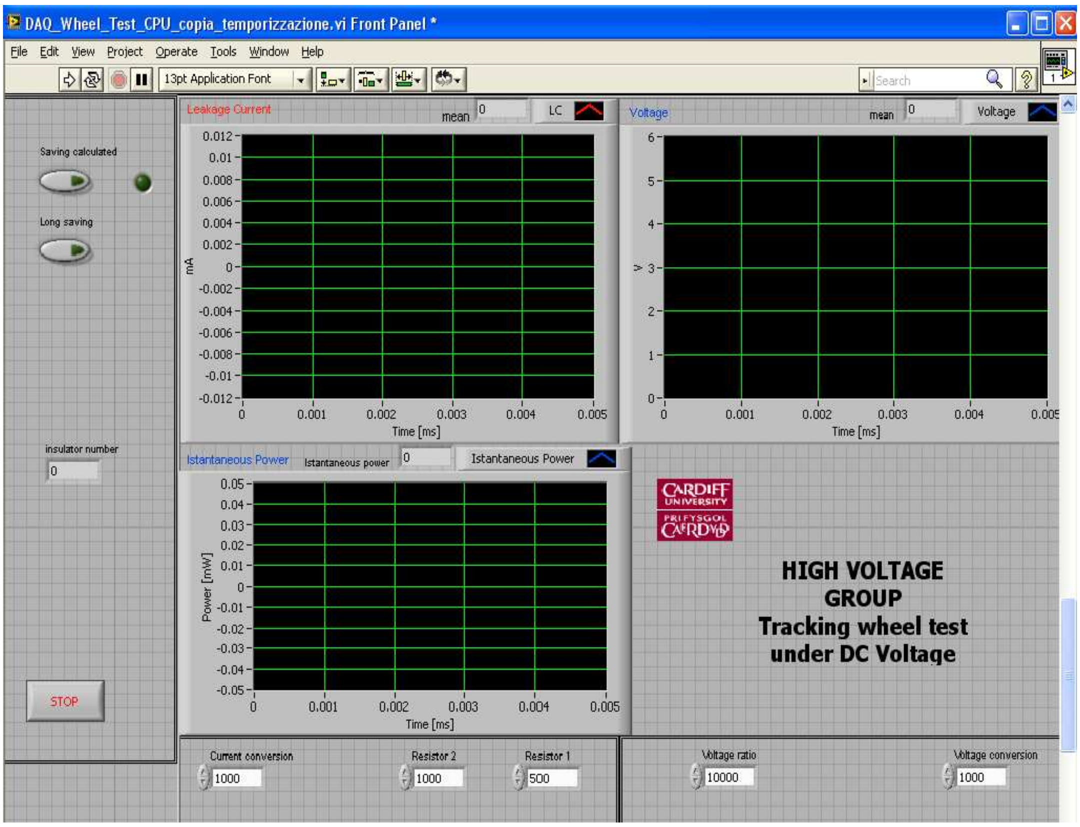


Figure 4.11: Front panel of data acquisition program

To acquire the data into the excel file is necessary to press the button Saving calculated and the insulator has to be in the vertical position, under voltage, so when both of this conditions are satisfied the green light is on and the data are stored and written in the excel sheet to 43s. The current conversion is necessary to have mA and the Resistor 1 and Resistor 2 is the value of the resistor that is placed to convert the current into voltage and so it is possible to acquire by labVIEW that can works just with voltage signals.

- BLOCK DIAGRAM

a) Current, Voltage and Instantaneous Power acquisition

The block diagram of the programme that acquire the important parameters like Leakage Current, Voltage applied and Instantaneous Power is shown in figure:

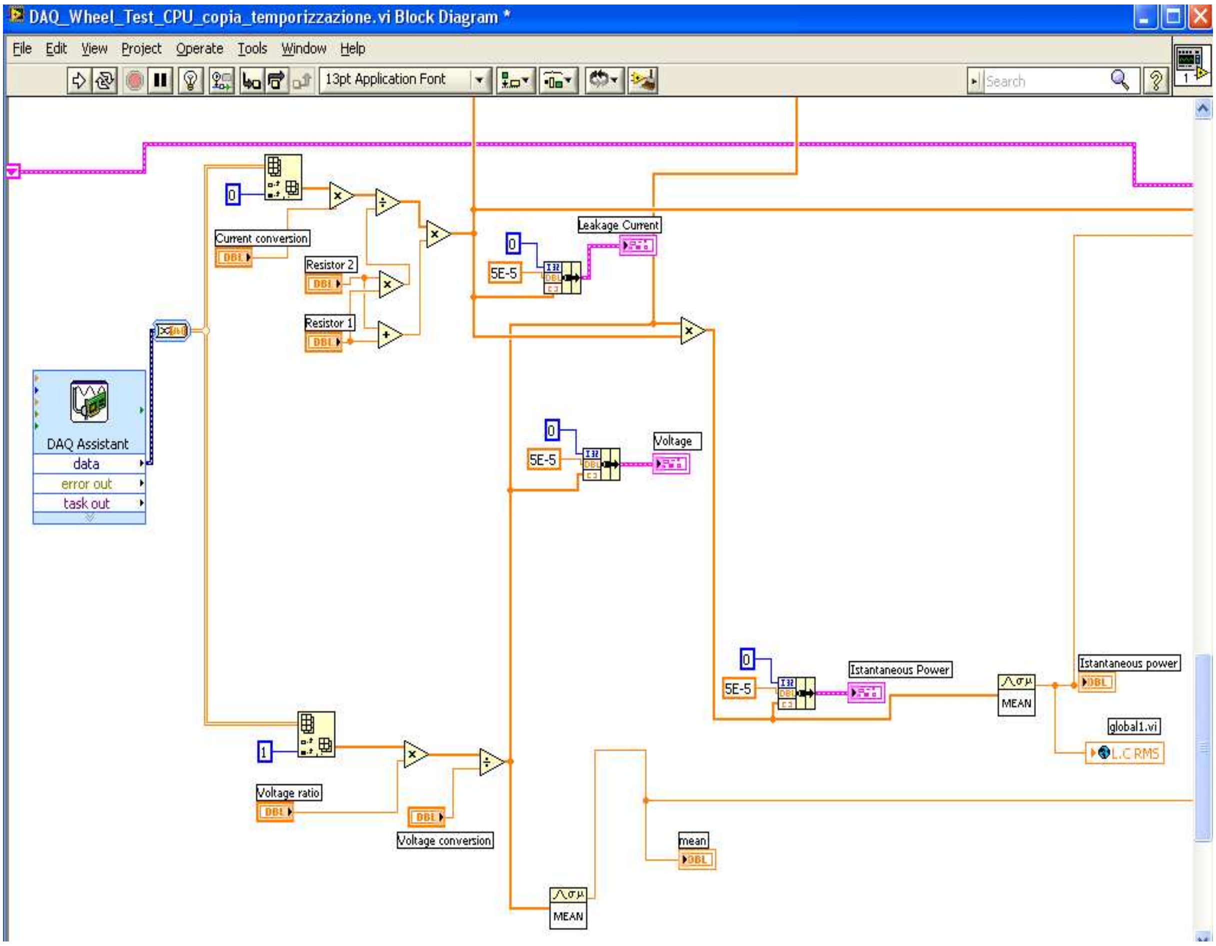


Figure 4.12: Block diagram of program to acquire voltage and leakage current

The basic of the program has been developed by Andrea Muncivì but some modification was necessary to use with direct current where is not practical to use some function like the FFT.

The leakage current is acquired by the function Mean, this function solve the follow equation:

$$I_K = \frac{1}{n} \sum_{i=0}^{n-1} x_i$$

Where n = number of sample per second.

Also the voltage is acquired by the function mean; thanks this function the dimensions of current and voltage that are array 1D are converted into scalar value to be record there.

The instantaneous power value is obtained by:

$$P_{AV} = v(t)i(t)$$

Where v(t) and i(t) are the main value of voltage and current that are calculated into the 100 samples recorded.

The data acquired are stored into four Microsoft Office Excel 2007 Files, each for insulator, for all the during of the tests. The time of sampling was the same used with AC tests because of it is not clearly what can be expected by the experiment that uses DC voltage. It has been decided to sampling with a ratio of 50 points per second. After that the data has been recorded, a data elaboration was developed to detect the behaviour of the different insulators.

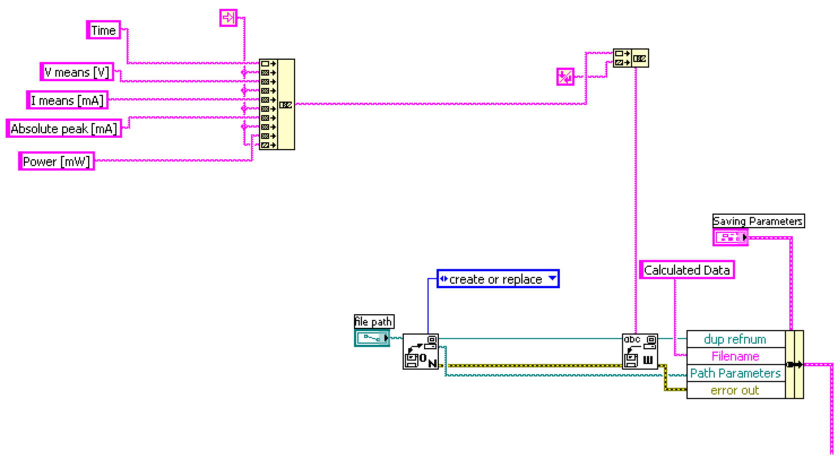


Figure 4.13: Saving function to calculated data (in the case for one of the four insulators)

In the excel file are stored the houar of the experiment (time), the voltage, the current, the absolute peak of the current and the poewr loss with the lakage current in the wetting surface of the insulator.

4.3.2 *Motor control program*

To move the wheel where are placed the four insulators has been used a DC permanent magnet motor because of with this kind of motor is possible to have simply speed control and fast response to starting and stopping. The necessity to have a simply speed control there is because the insulators tested can have different weight but the time to move from two different positions have to be the same 8 s so it is fundamental to have different torques. The torque/speed characteristic of a DC permanent magnet motor is linear and the speed can be controlled by varying the current.

- FRONT PANEL

The program to stop the motor and timing the speed of this was developed by Andrea Moncivì and not modify. To create the input to stopped the motor when one of the four insulators are in vertical position was decided to use the value of the instantaneous power that increase up a certain value when the insulator touch the copper ring that is connected to the supply because of the leakage current is present in the wetted surface, like above explained.

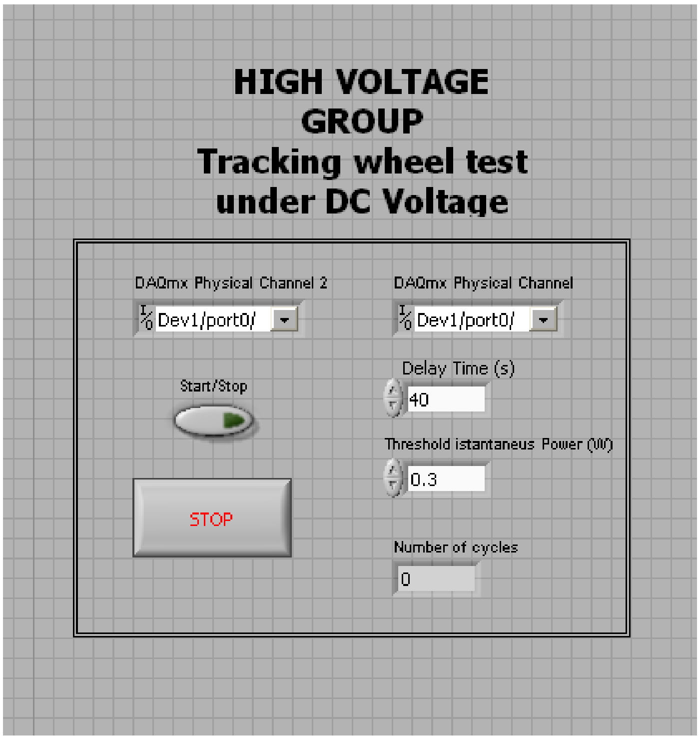


Figure 4.14: Front Panel of motor control program

Thanks to the front panel of the motor control program is possible to follow which number of cycle is running and what is the threshold instantaneous power needs to stop the wheel. It is clearly and easy program that is in communication with the main program.

- BLOCK DIAGRAM

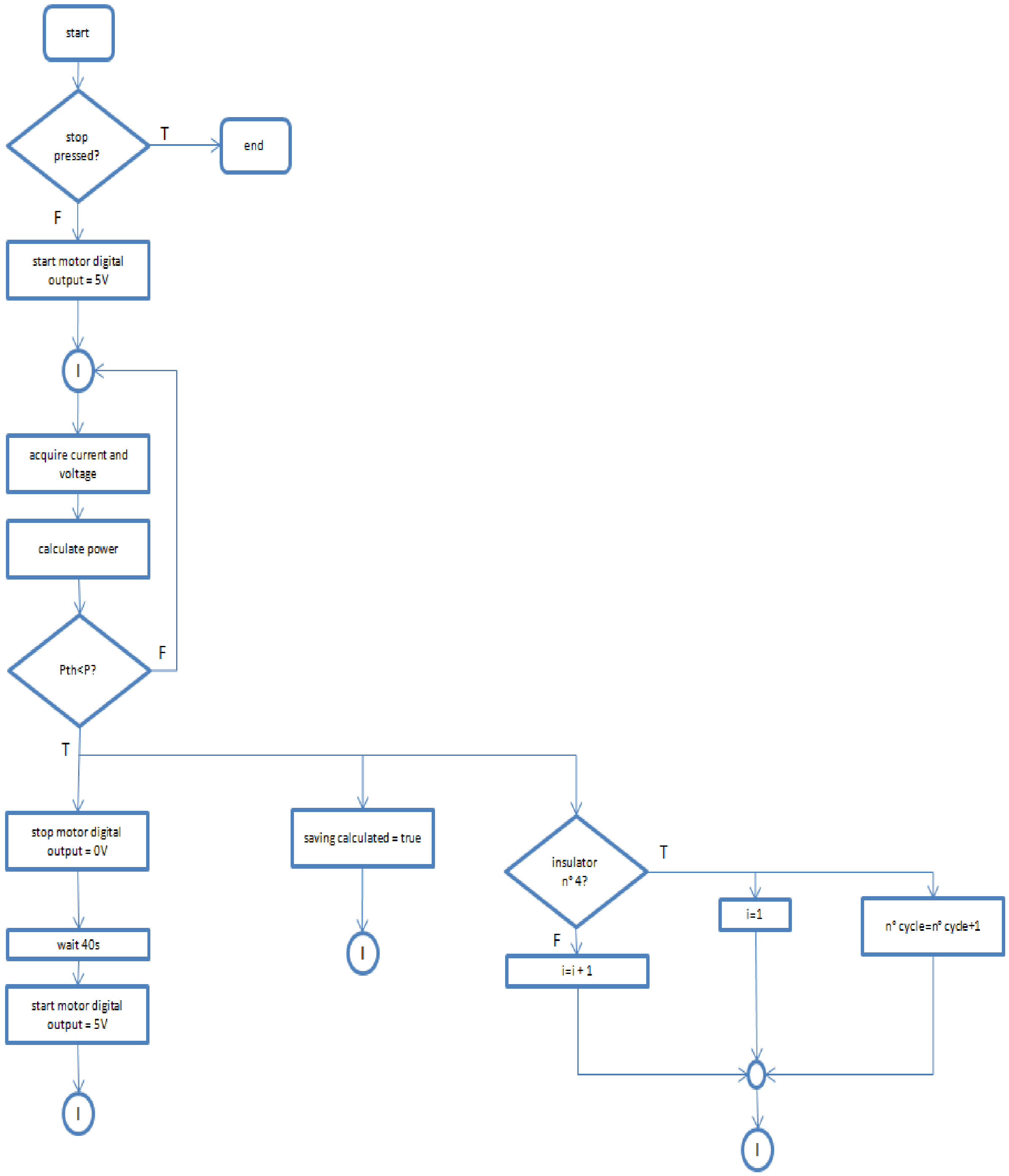


Figure 4.14: Flow chart of motor control program

The data acquisition program and the motor control program are in communication to detect the number of cycle that is running which is shown in the front panel.

The RMS value is the value of the global variabile of istanatenous power, through this value is checked if the motor has to be stopped. When the insulator run between two position the program output is a digital output of 5 V and the instantaneous power value is under the threshold value arranged in front panel while when the insulator is in vertical position the instantaneous power value exceeds the threshold value so the digital output of the program is carried down at 0 V and the motor is stopped.

Once the motor is stopped the "Saving calculated" global variable is set to true allowing the saving function to run. In the same time the routine to control the case structure to store the data in the four different excel files is run. Moreover the number of cycles elapsed are counted.

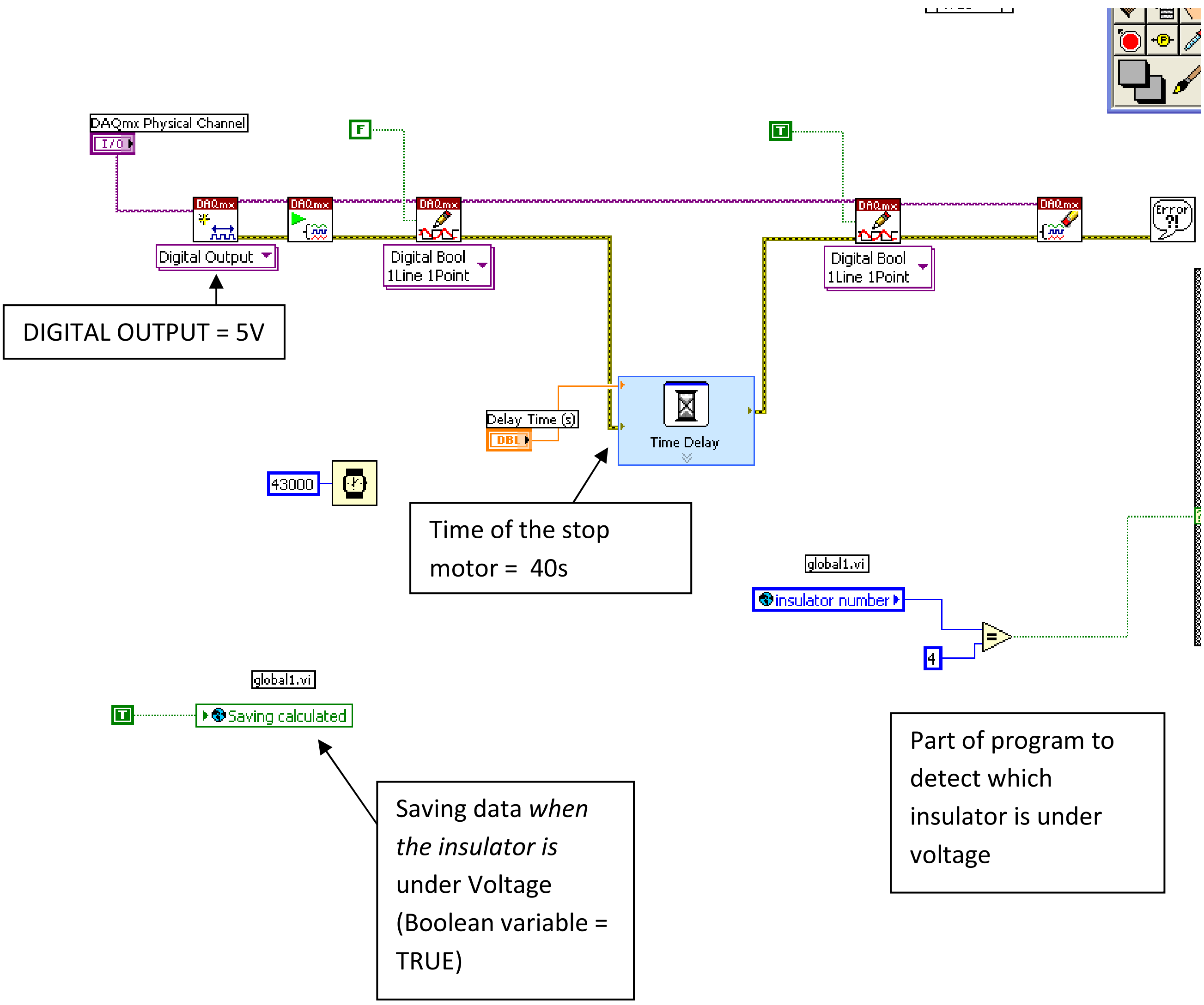


Figure 4.15: Block diagram control motor program

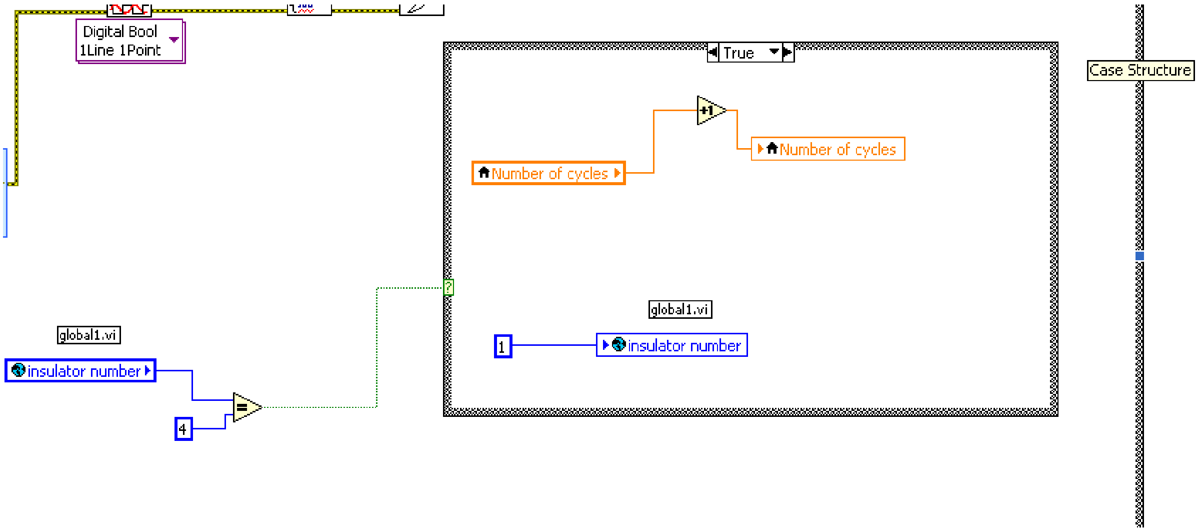


Figure 4.16: Block diagram control motor program, part of this that detect the insulator under voltage through the global variable

It is appropriate to remember that the program to stop the motor using the instantaneous power value is not the best option so it is opportune to modify the program for future tests.

CHAPTER 5

TEST RESULTS

5.1 INTRODUCTION

In this chapter is described the most interesting case of study obtained from the analysis of the data acquired to the tests.

Four silicone rubber insulators, with different designs, were tested. Two insulators were characterized by semi spherical texture, whereas the other two insulators were flat. The insulator number 4 was the texture insulator. It was a damage insulator already before to start the test. It is shown in the following picture; it is possible to see clearly the damage in the insulator surface.

The standard EN 62217:2006 specify that just two pairs of the test specimens can be test simultaneous on one wheel and it is for this reason the two types of insulators were chosen.

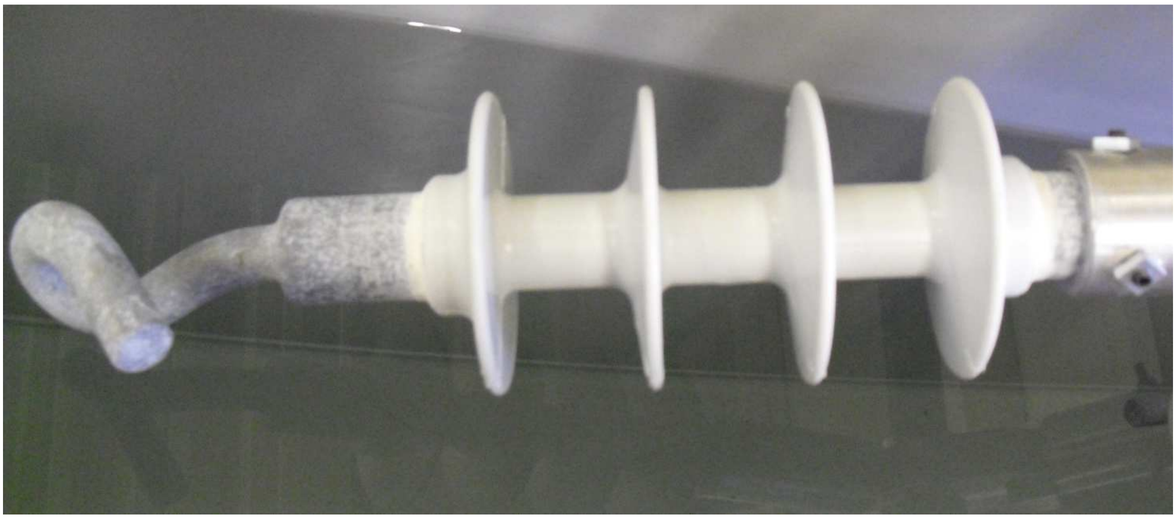


Figure 5.1: Flat insulator (insulator n°1 in the test)

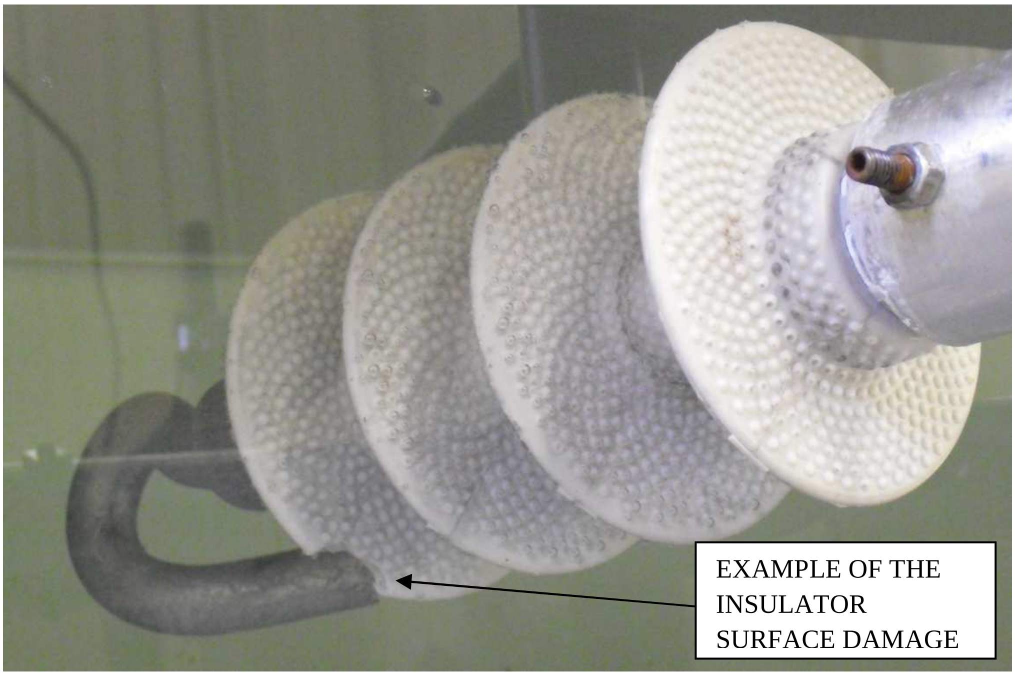


Figure 5.2: Texture insulator (insulator n°4 in the test)

According to the standardisation EN 62217:2006 the applied voltage to do the test is given by:

$$\frac{creepage\ distance\ [mm]}{28{,}6}\ [\text{kV}]$$

The specimens used in the tests had a creepage distance of 375 mm so they needs of a voltage supply of 13 kV to run an official test and the duration of the tests according to the standardisation have to be 30000 cycles, so it means 1600h or 67 days no stop (30000 cycles =[(40*4)+(8*4)*30000]= 1600h= 67days). Weekly interruptions of test for inspection purposes, each of these not exceeding 1h are permissible and one longer interruption up to 60h is allowed. The voltage generator available in the laboratory could give 10 kV like maximum positive DC value and the time to run the tests was the time that permitted to do 100 cycles so this is the case studied.

Before to start with the test the conductivity of the saline solution in the tank was measured by the conductivity meter of “HANNA instruments”. It showed that the value of the conductivity was exactly 2.7 mS/cm.

Already before to start with the test could be predicted that it is difficult to have a high value of leakage current and damage of surface visible with the inspection because of the short duration of the test and the low value of the voltage apply, different results means that the insulators tested have a poor behaviour.

To analyse the data recorded during the test was chosen to elaborate the data of the cycle test number 60, 70 , 80, 90, 100 for each of four insulators. Complete analysis are reported in the appendix A.

5.2 CASE OF STUDY

5.2.1 Analyse cycle 60 of the insulator 1

The leakage current analyse in the insulators surface has shown some particular events during the test of insulator 1, at the cycle number 60.

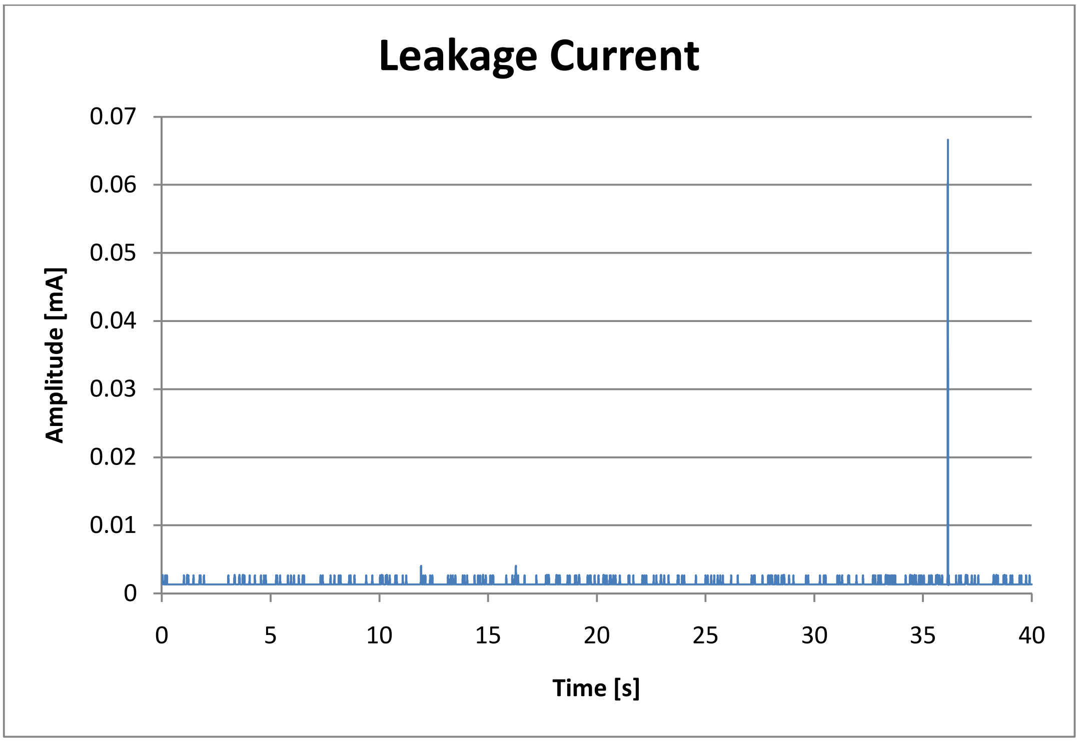


Figure 5.3: Insulator 1 cycle number 60

The value of the leakage current is very low for all the 40 seconds but around the 37th second there is a peak value. This instantaneous peak of leakage current can means that a discharge may occur in the insulator surface at this second.

To detect the normal size of leakage current in the surface of this insulator has been done another graph where not appear the peak value.

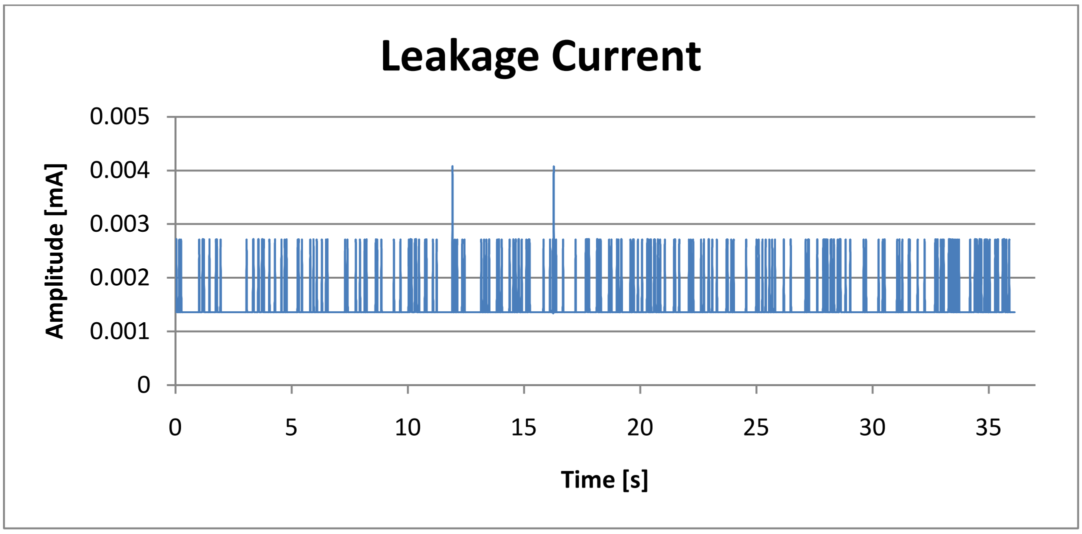


Figure 5.4: Insulators 1 cycle number 60, normal value of leakage current

It is possible to see that the average of the leakage current is around the 0.002 mA for all the forty seconds, just two values are around the 0.004 mA.

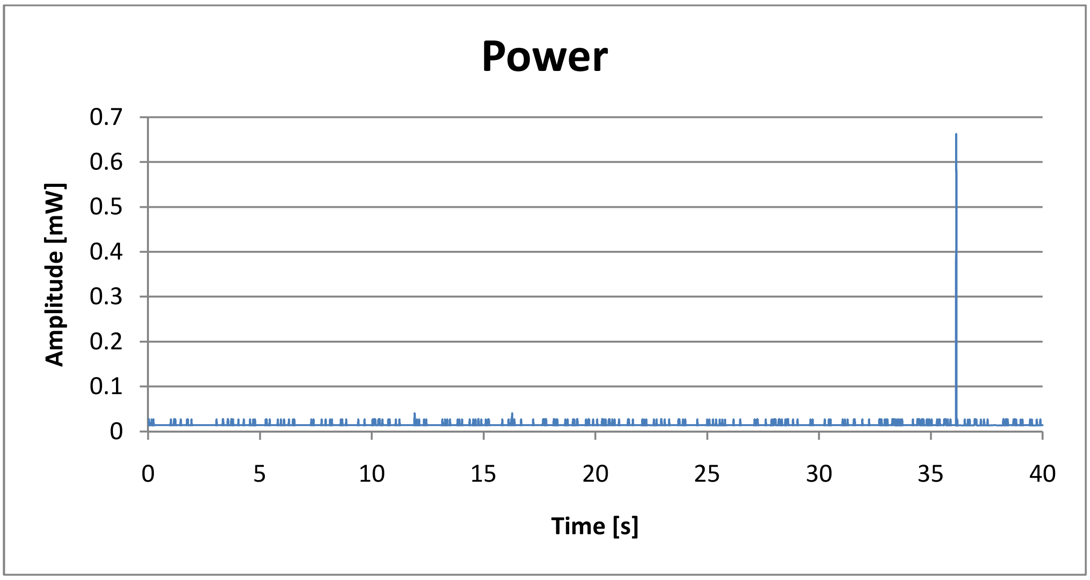


Figure 5.5: Power absorbed by the flat insulator number 1

5.2.2 Analyse cycle 60 of the insulator 4

The insulator number 4 was a texture insulator that had important damage also before to start with the test. In fact in this insulator the moisture can penetrated in its rod, like is shown in the following picture.

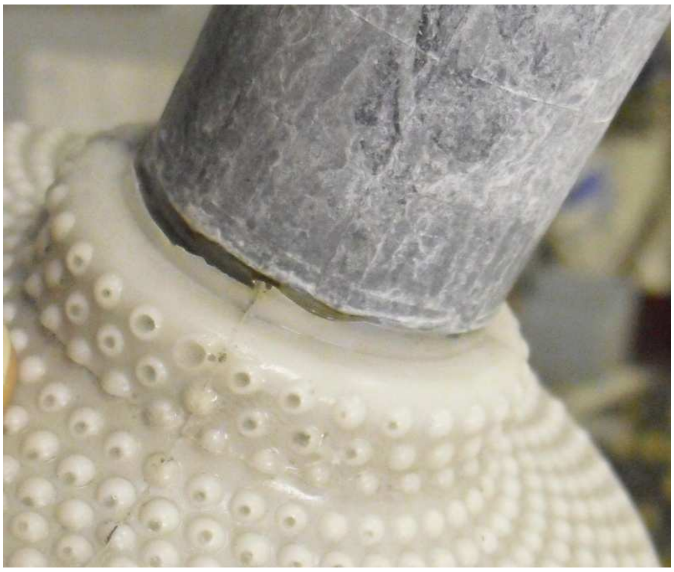


Figure 5.6: Details of insulator 4

The data analyse shown that the leakage current in this case is higher than the leakage current of the other insulators tested.

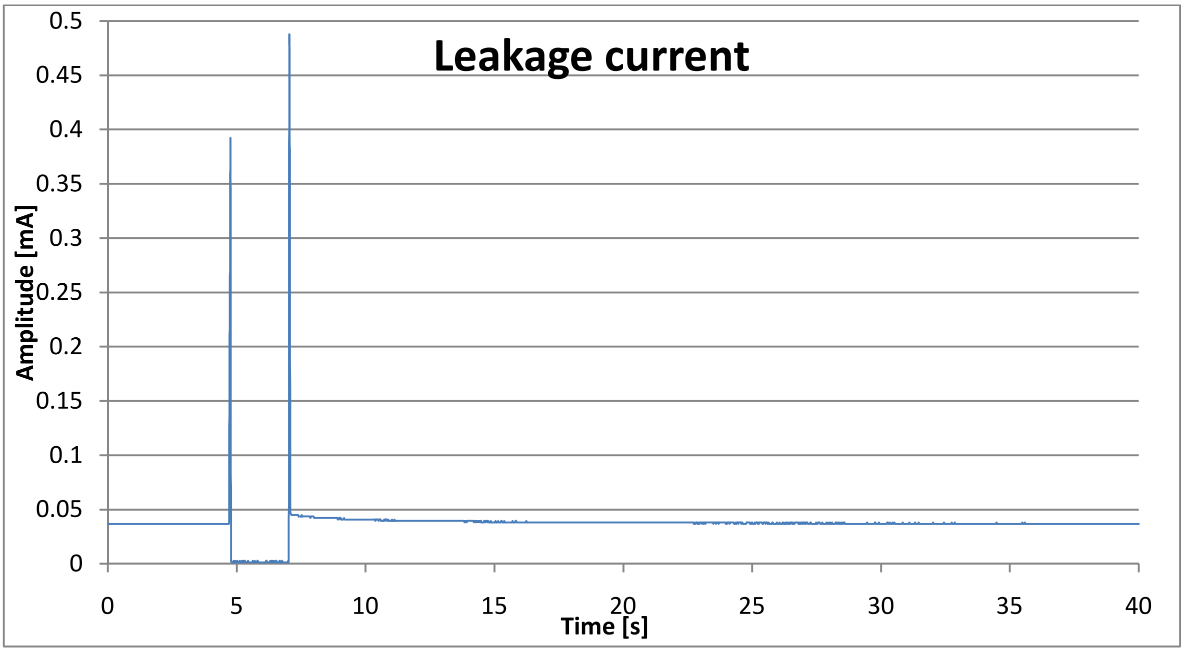


Figure 5.6: Insulator 4 cycle number 60

There are two points, during the 60th cycle, where the leakage current increase up until 0.5 mA, this value is not so high but it is high if compare with the results of the other insulators.

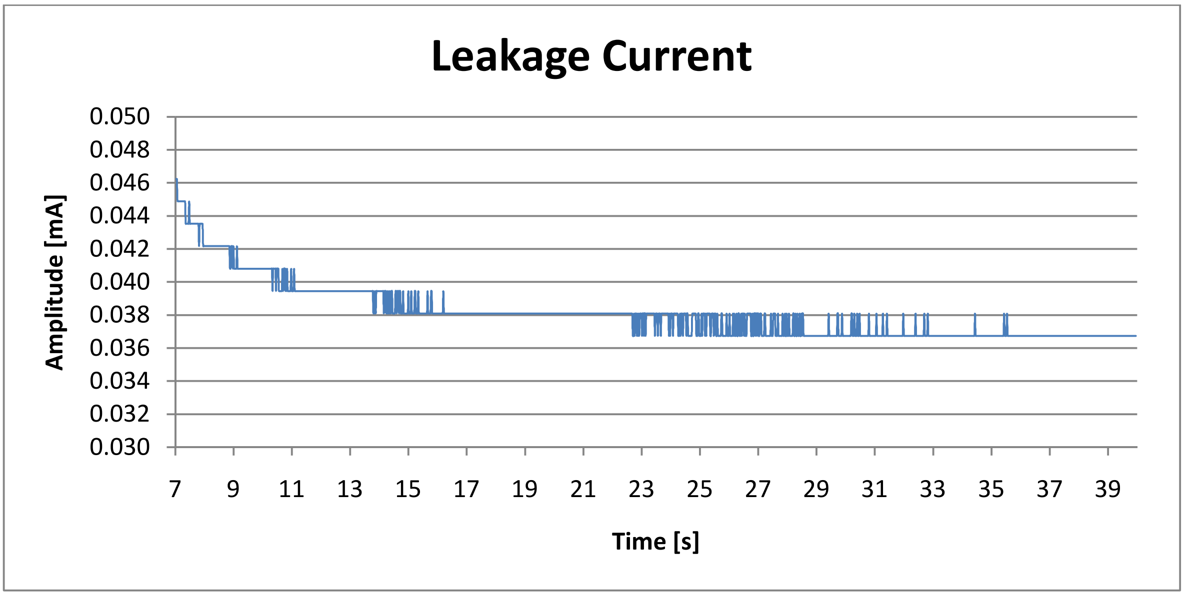


Figure 5.7: Insulators 4 cycle number 60, normal value of leakage current

Also with the analyse without the instant of peak it is possible to see that the average leakage current is around 0.04 mA and not around 0.002 mA like before.

Obviously, the power graph and the accumulated energy graph showed the same peak where probably there was a partial discharge consequent the formation of dry band zone.

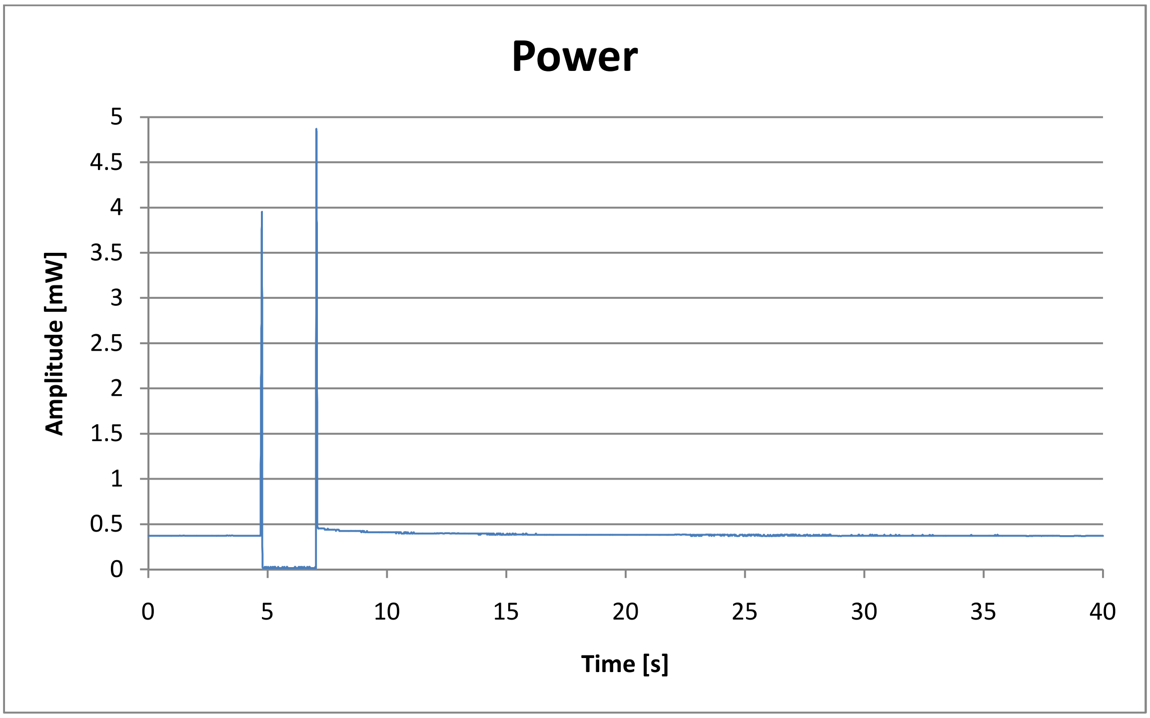


Figure 5.8: Power absorbed by texture insulator (insulator n°4)

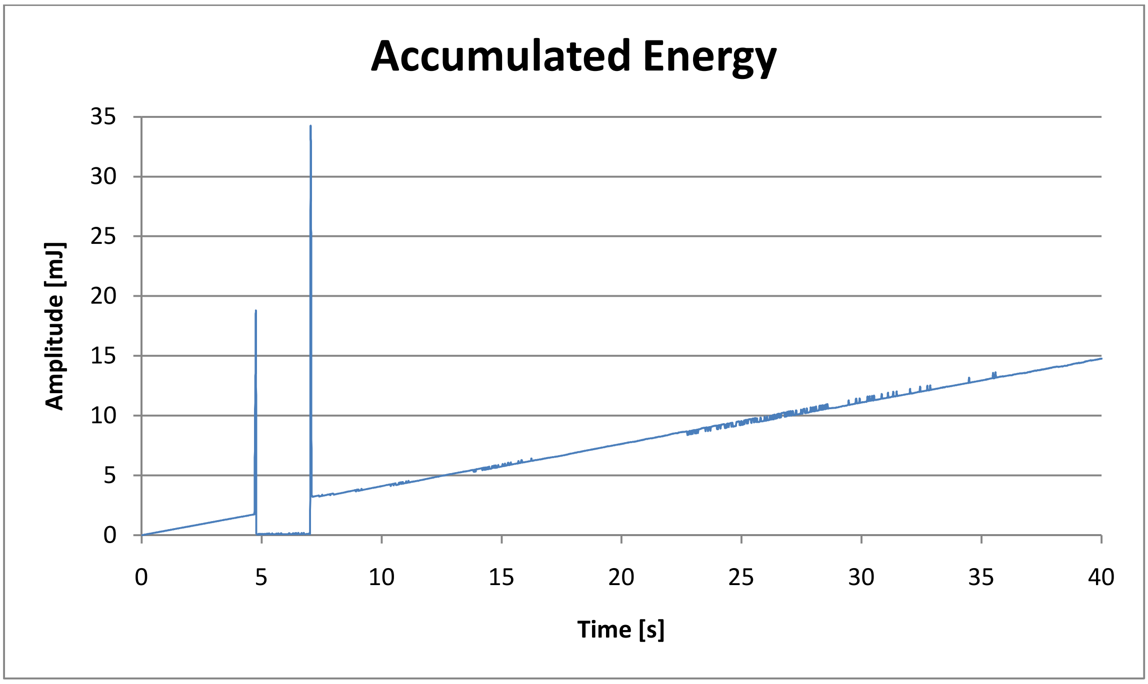


Figure 5.9: Accumulated energy by texture insulator (insulator n°4)

During the other cycles of the insulator number 4 a peak value of the leakage current was detected in the first instant, when the insulator touched the copper ring under voltage. To explain this it is reported the following graph of the cycle number 100.

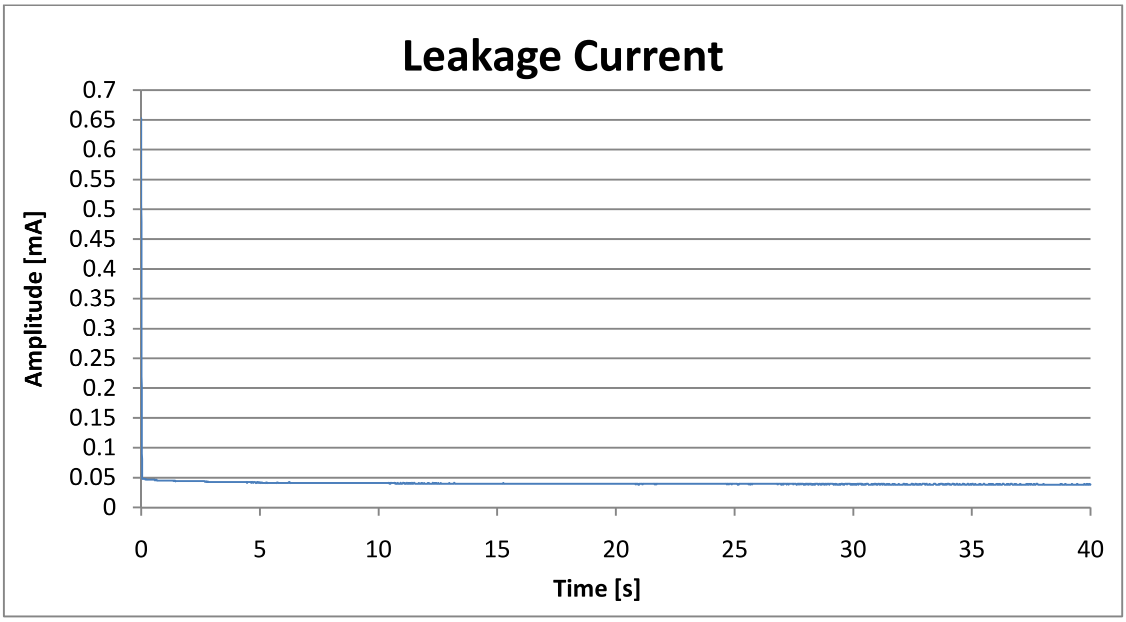


Figure5.10: Leakage current in the texture insulator number 4 during the 100th cycle

Could be interested to analyses the last ten cycles for the insulator number 4 that it is the insulator with the worst behavior. It is possible to see that, every time, when the insulator touches the ring under voltage, the leakage current increase but after this instant the leakage current value decrease rapidly (Figure 5.11).

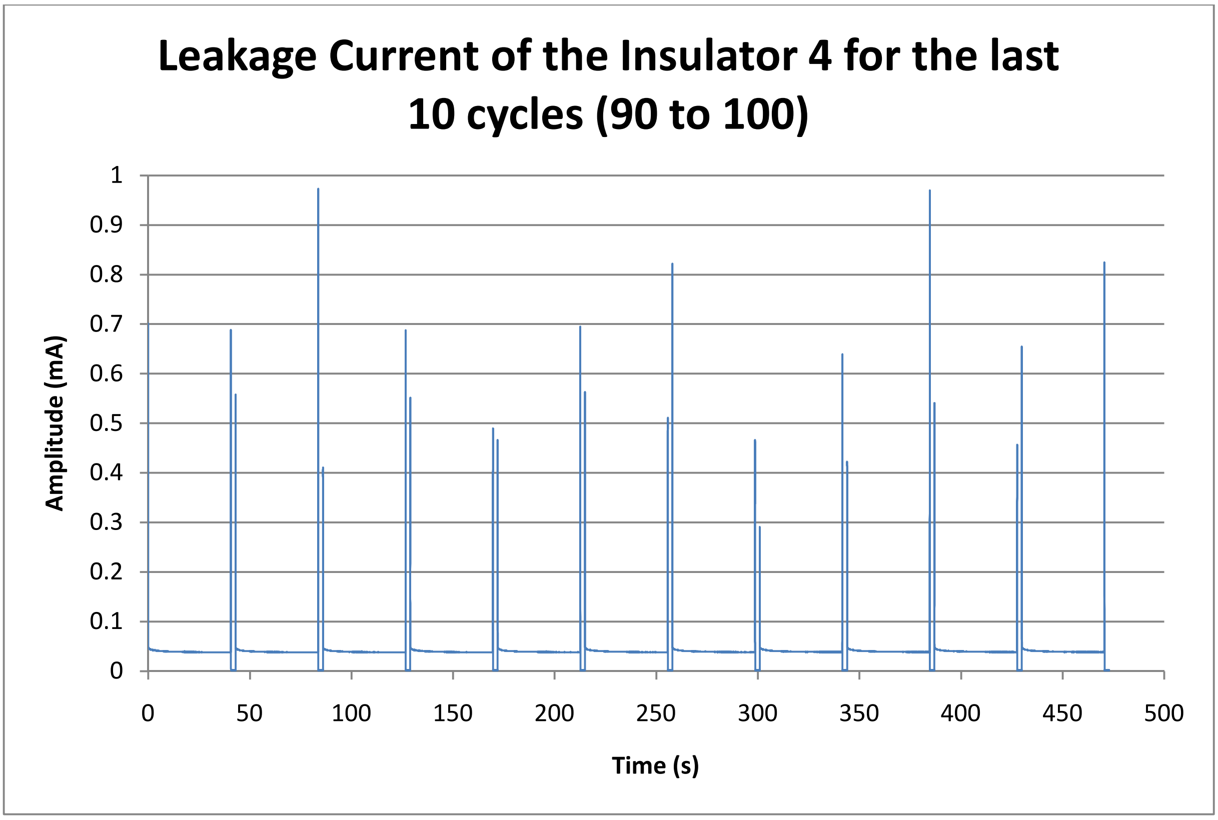


Figure 5.11: Leakage current of insulator 4 for the last 10 cycles

To justify the results obtained from the analyses it is possible to compare them with the results obtained from YinYu, Liang Xidong, Zhou Yuanxiang and Li Xuesong of Department of Electrical Engineering, Tsinghua University during their tests. They tested two kinds of composite insulators with positive DC voltage and with negative DC voltage using the Tracking Wheel Test. Both of the two kinds of insulators that they tested were liquid injection molding insulators, sample 1 was normal kind and sample 2 was the kind that, the sheath of insulator includes the front part of the end-fitting. The creepage distance for both insulators was 1020 mm so the applied voltage was 35,7 kV (=35V/mm). The duration of their test was 1000h but we can use the first period of their analyses to compare our results. They founded that for the first period, the sample kept good hydrophobicity, none corona and discharge could be observed. The leakage current was less than 1 mA. The seam result was obtained for positive and for negative DC voltage. It is interesting to notice that also during this experiment the leakage current was less than 1 mA for the first day although after 5 or 6 hours the hydrophobicity of samples became worse. Just after one day the leakage current measured was between 5 mA and 10 mA[12].

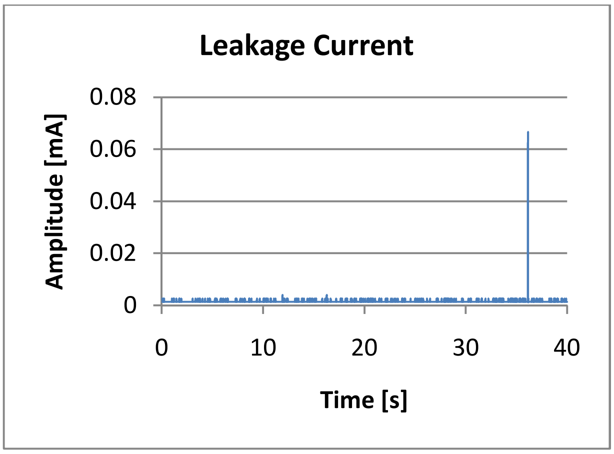
5.3 CONCLUSION

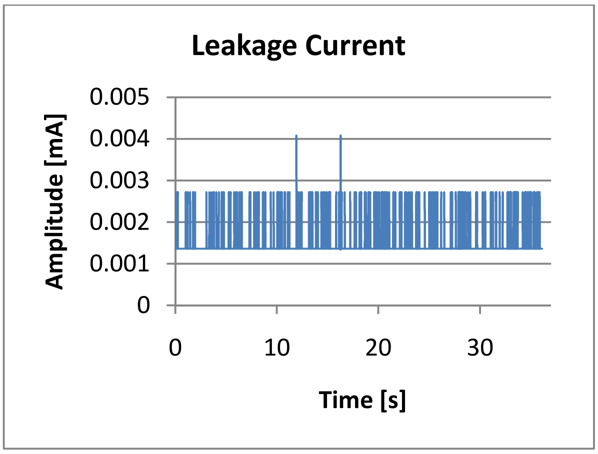
In conclusion of the data analyses it is clearly that the reliability of the electrical and mechanical system of the test-cell is reached but it must to be provided a better stop system to the insulators in vertical position. A system with an optical sensor or with a photocell to detect the insulator position can be better solutions. A cheaper solution can be to use a contact with a rod that open a contact when the insulator touch it, in this way it is sure that every cycle the insulator is stopped also the leakage current is low because of the insulator under test has a good behavior or because the pollution is not so high like can append for the first cycles.

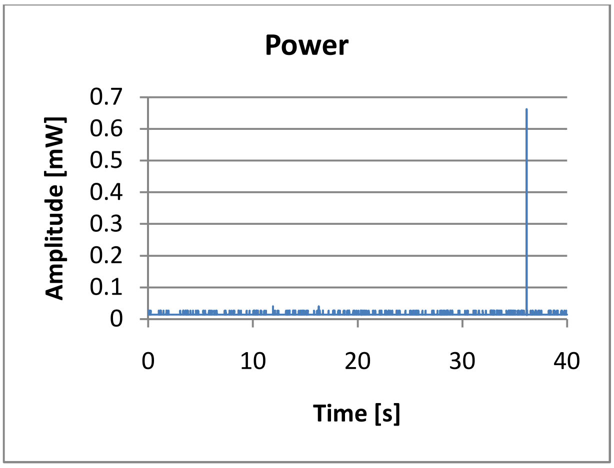
APPENDIX A:

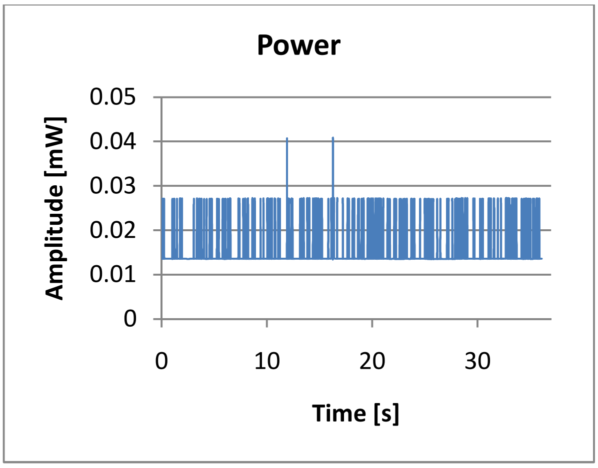
DATA ANALYSIS

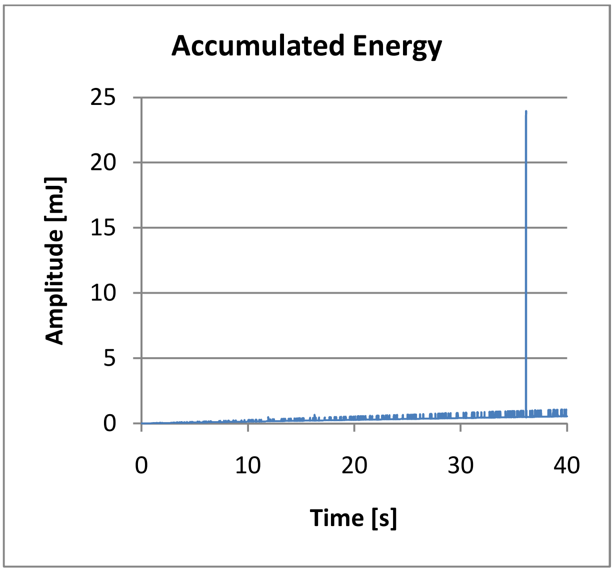
Data Analysis of Flat Insulator 1 at Cycle n° 60



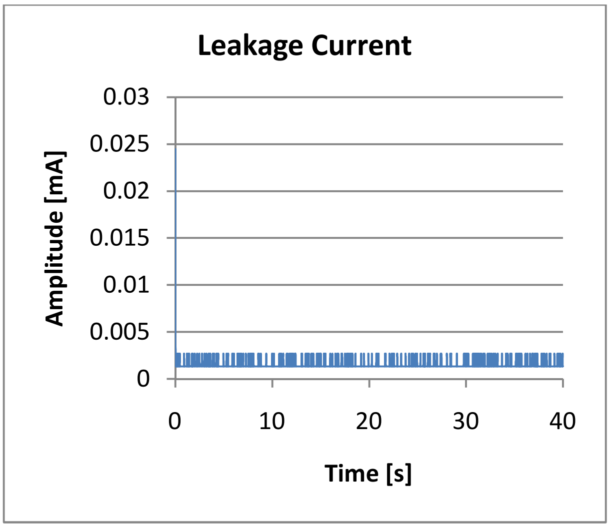


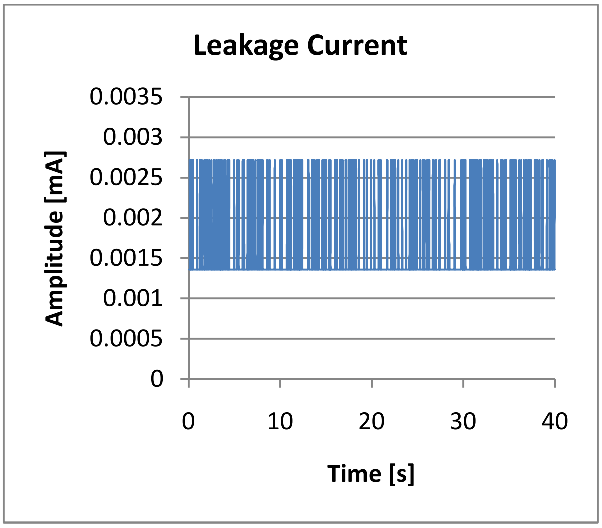


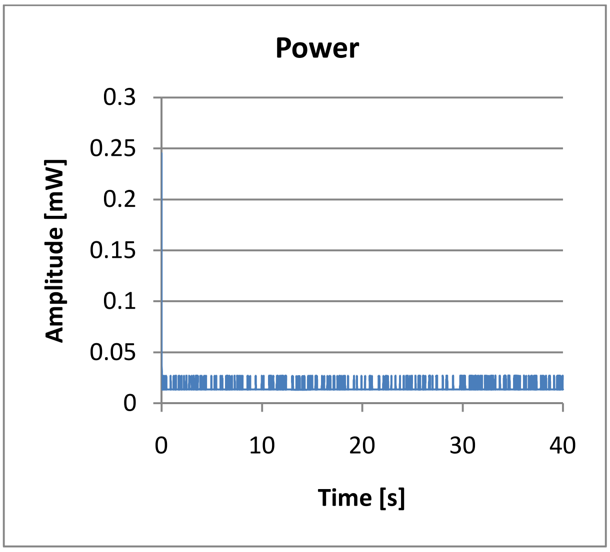


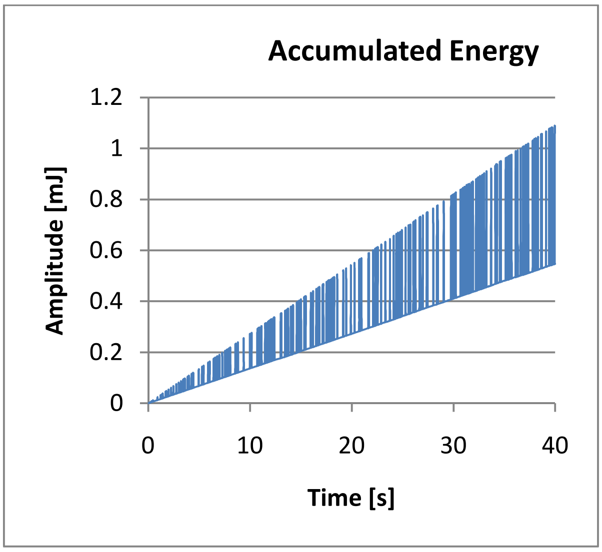


Data Analysis of Flat Insulator 1 at Cycle n° 70

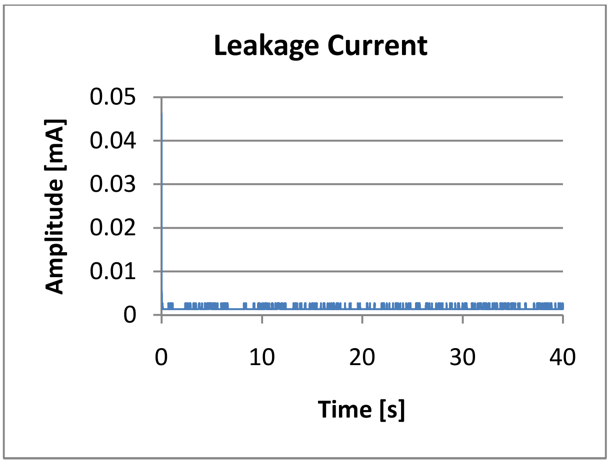


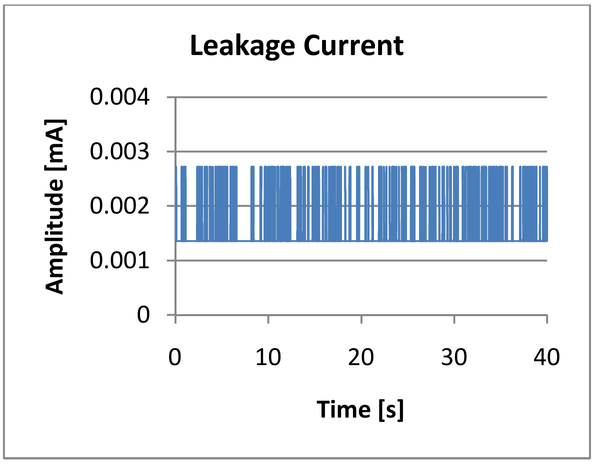


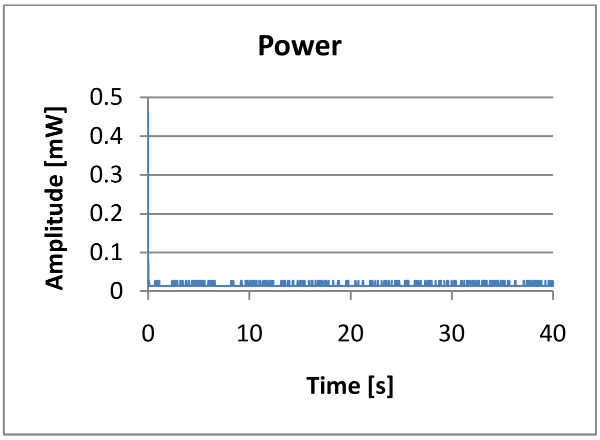


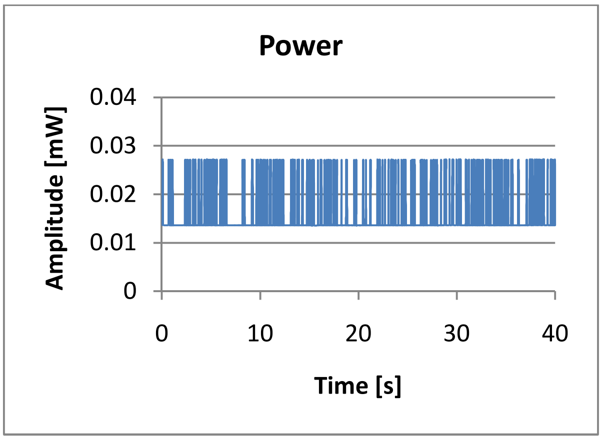


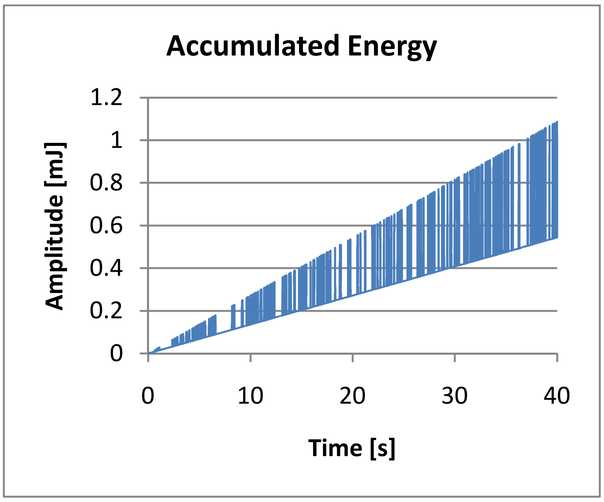
Data Analysis of Flat Insulator 1 at Cycle n° 80



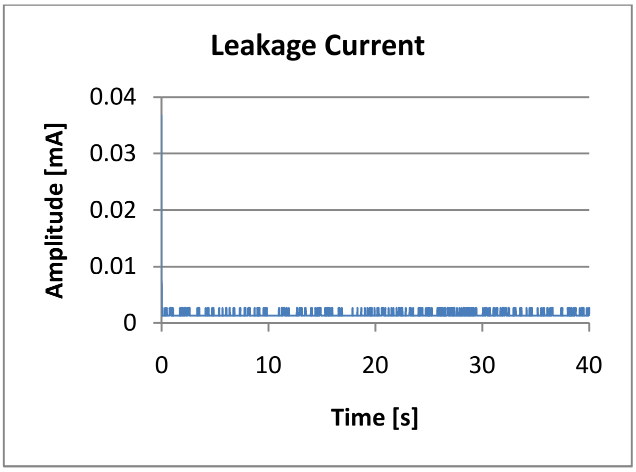


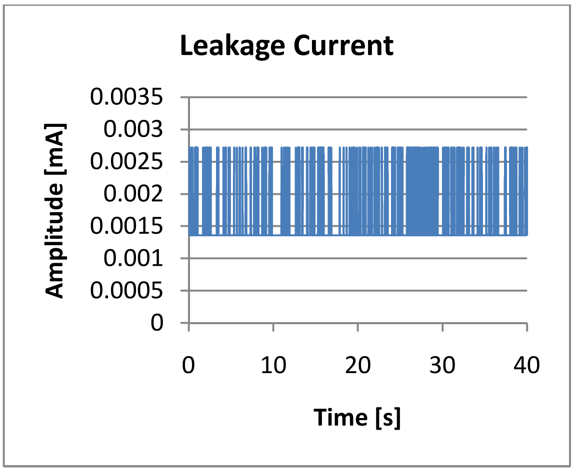


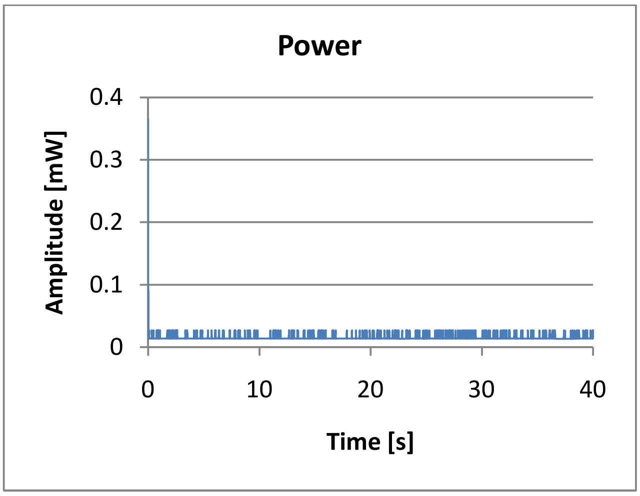


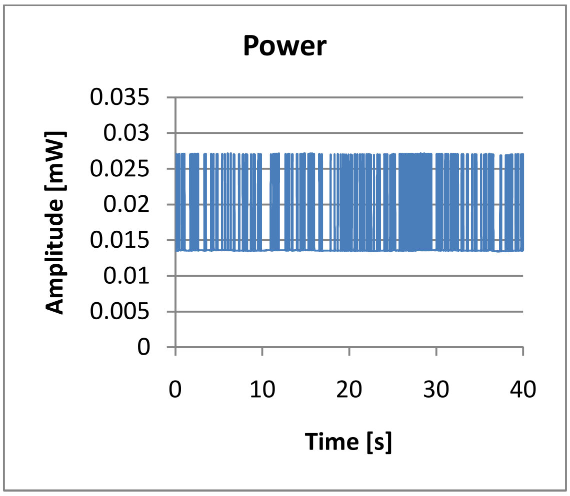


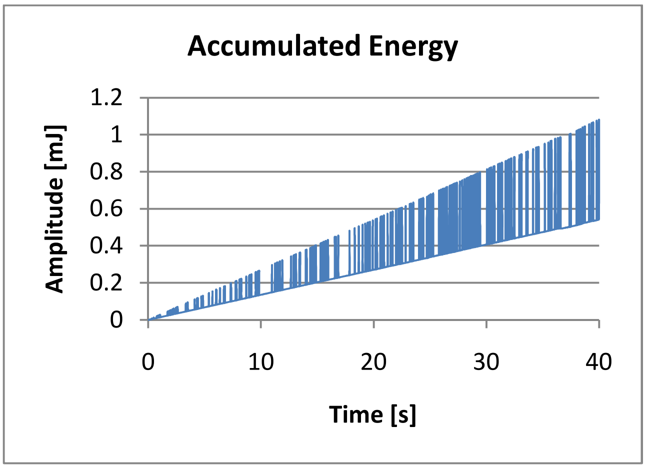
Data Analysis of Flat Insulator 1 at Cycle n° 90



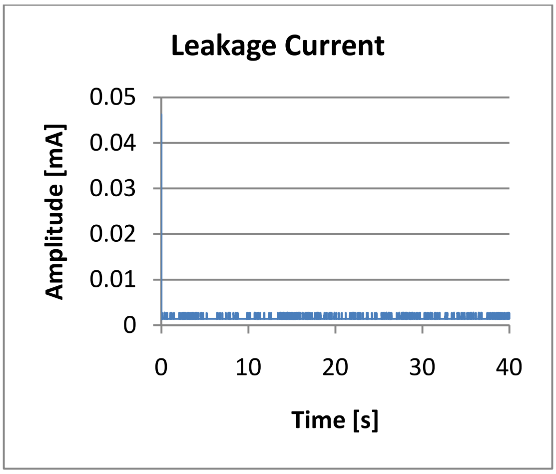


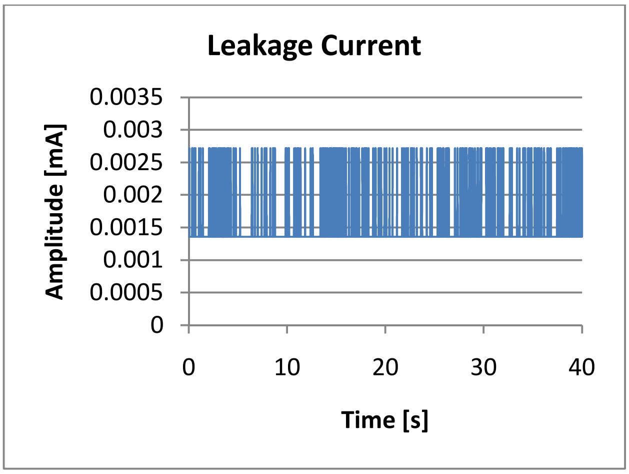


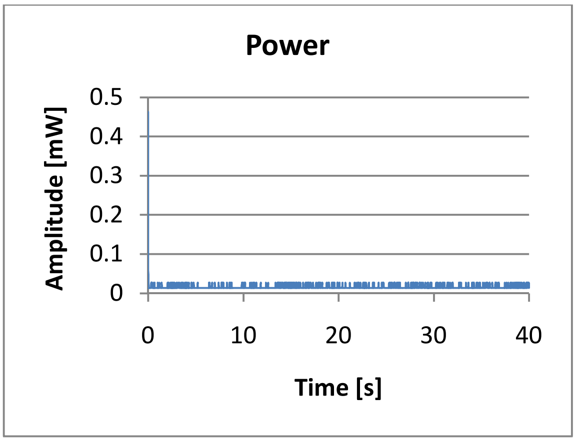


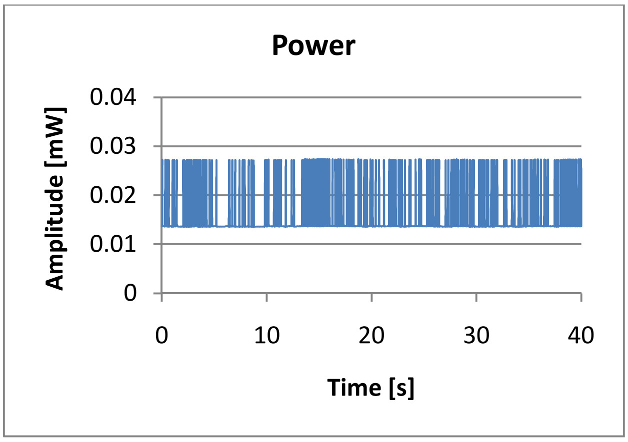


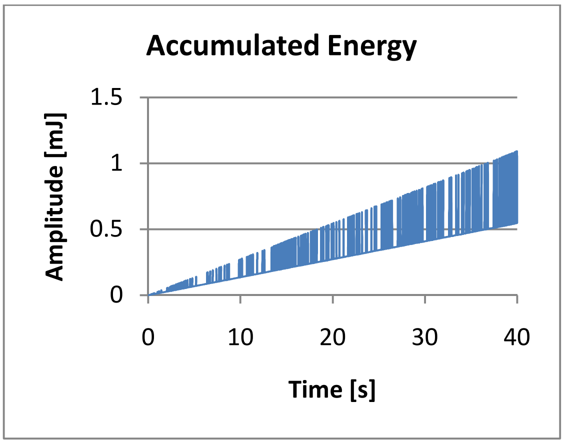
Data Analysis of Flat Insulator 1 at Cycle n° 100



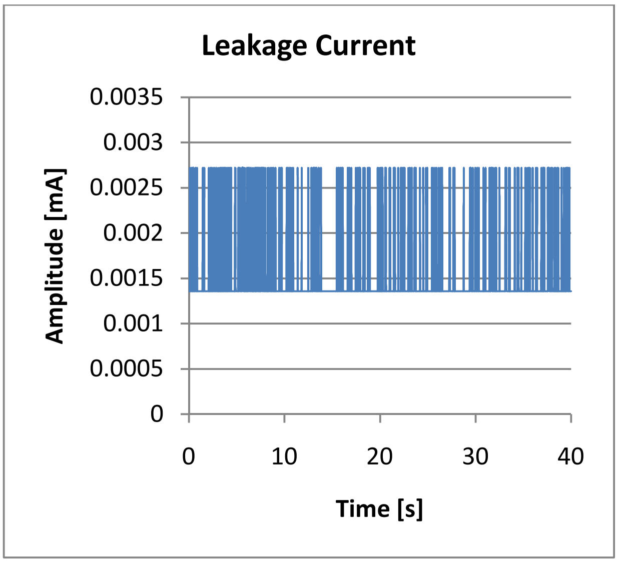


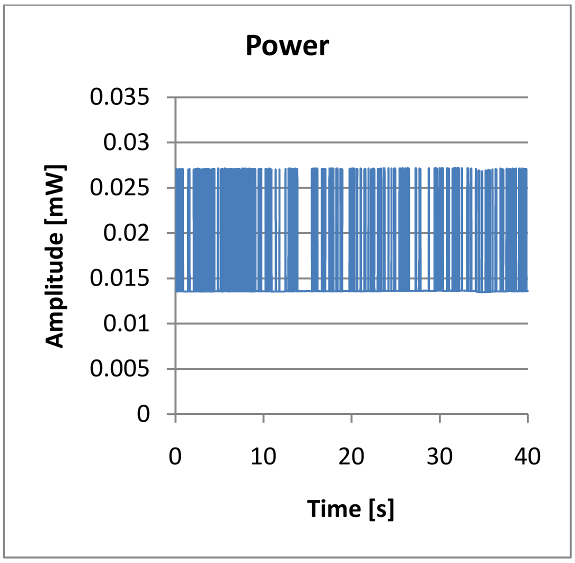


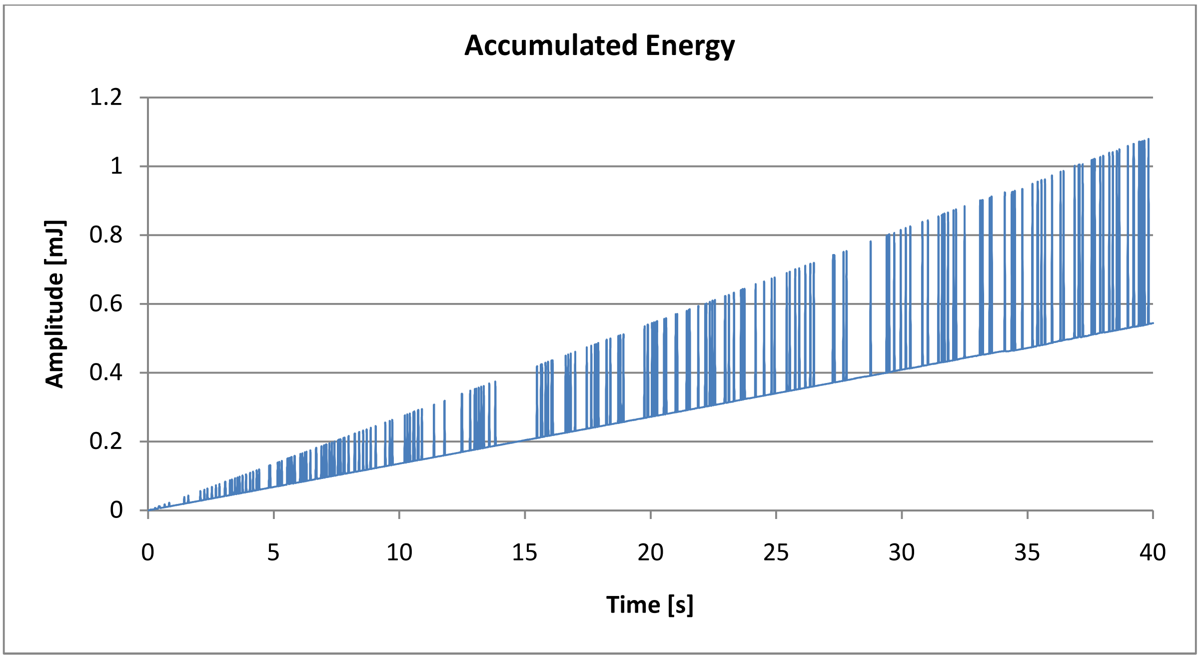




Data Analysis of Texture Insulator 2 at Cycle n° 60







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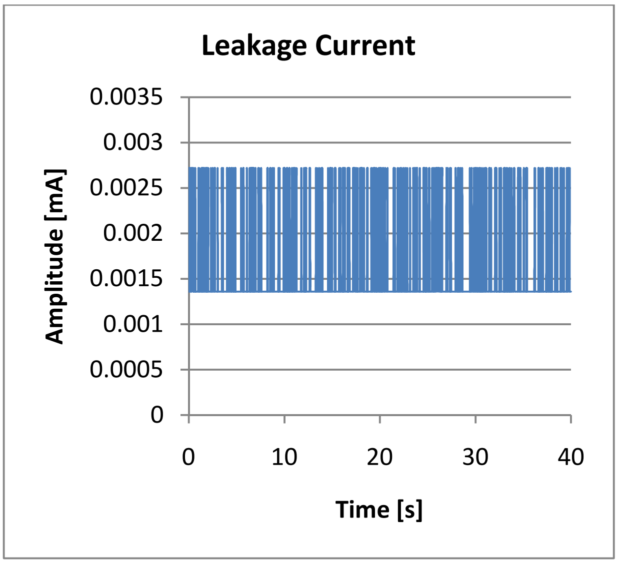

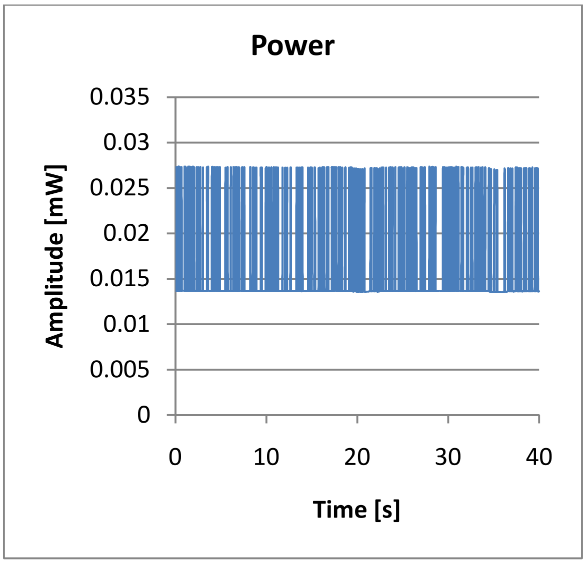

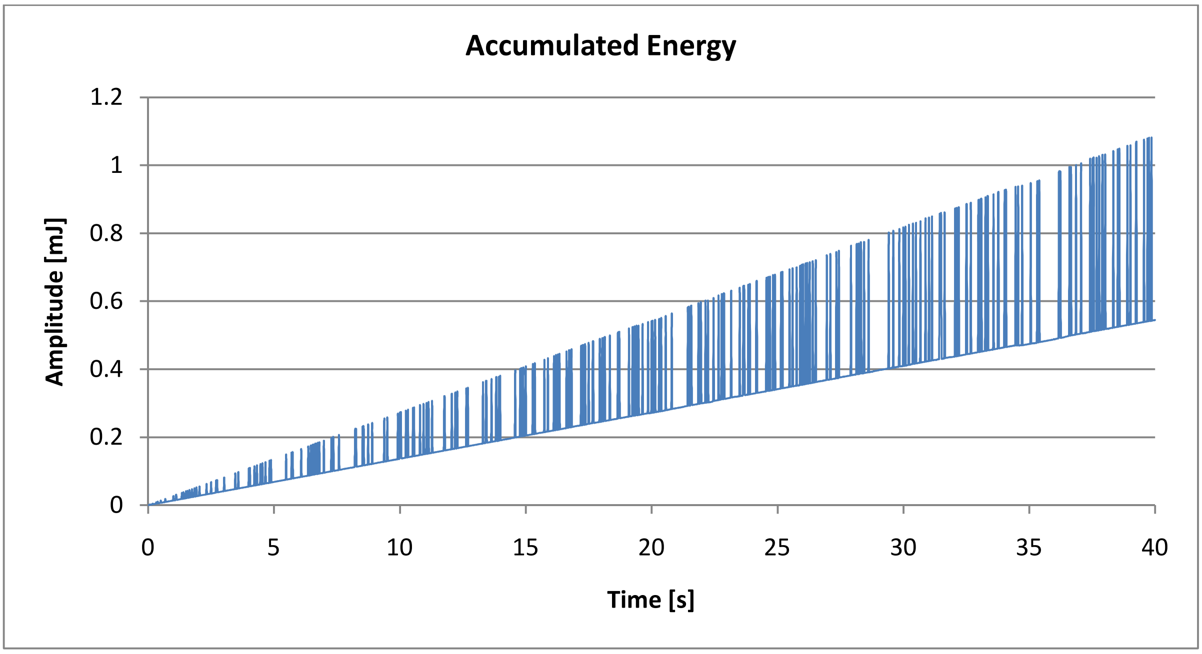

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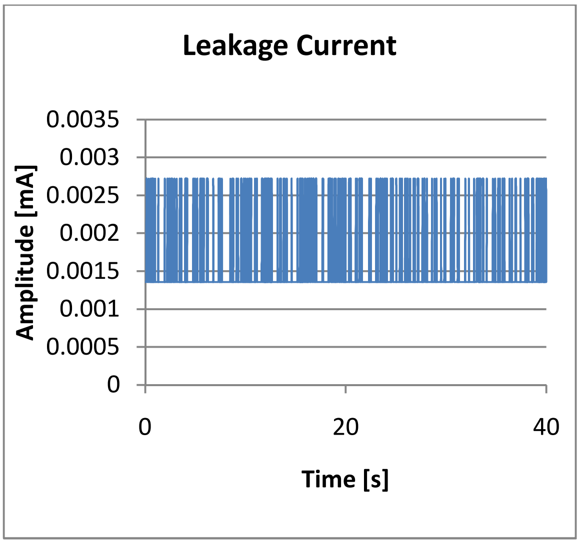

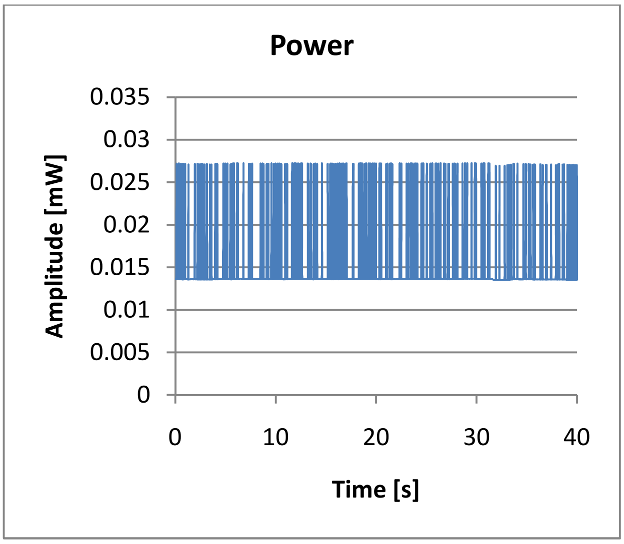

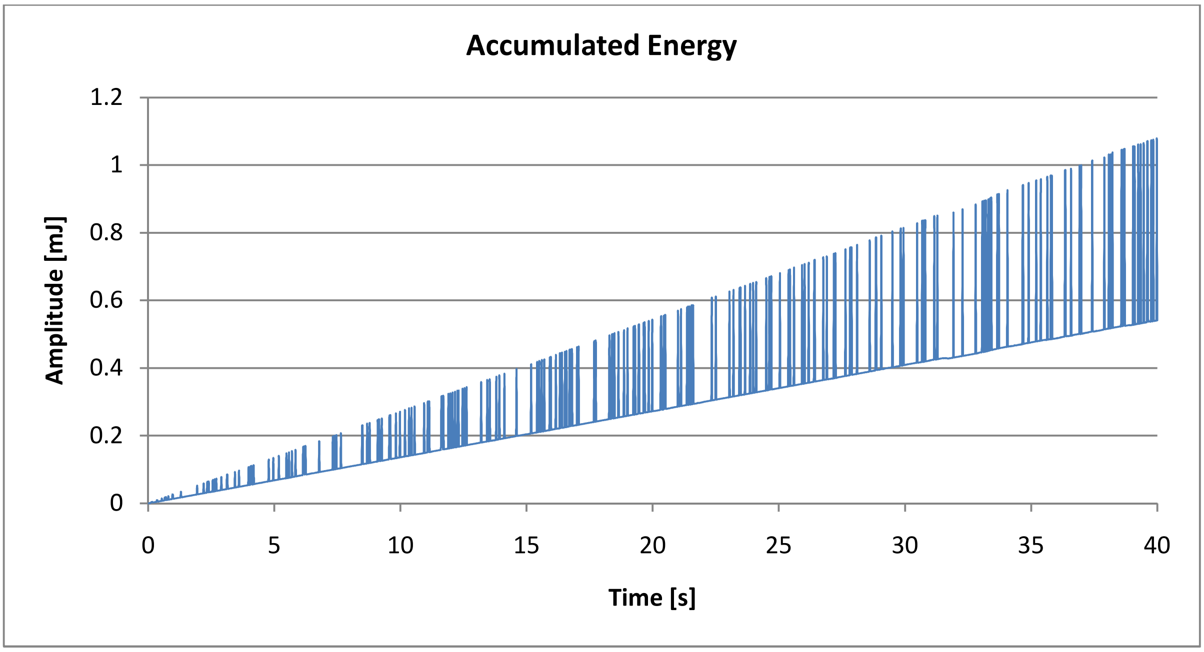

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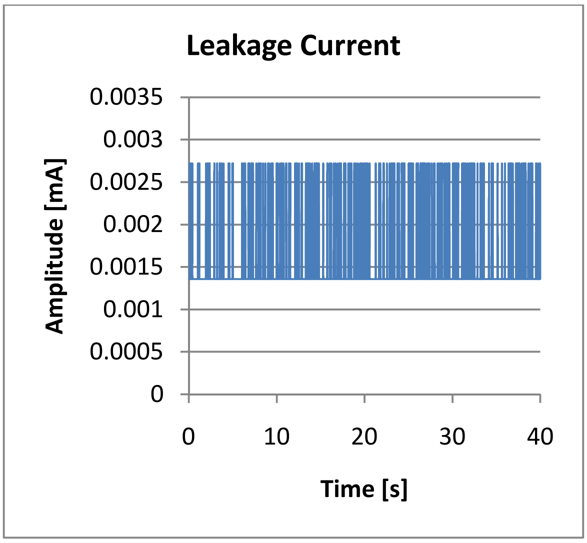

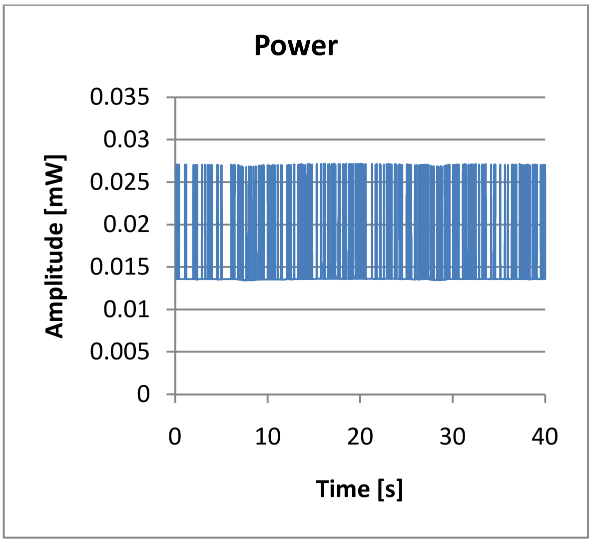

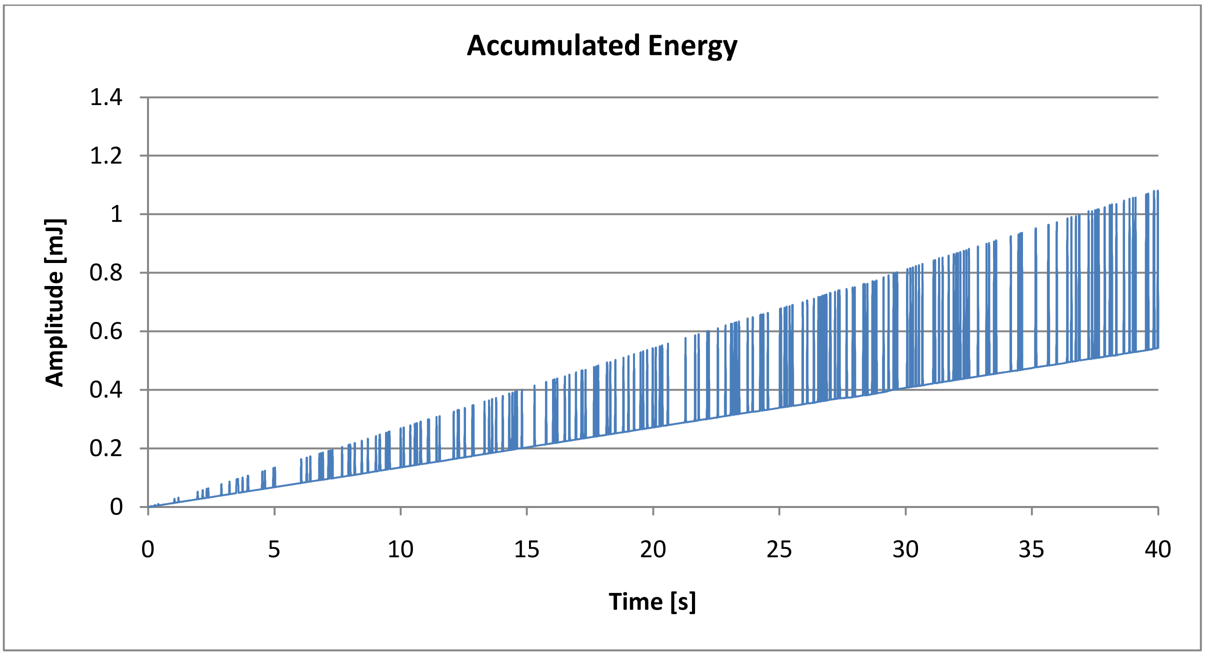

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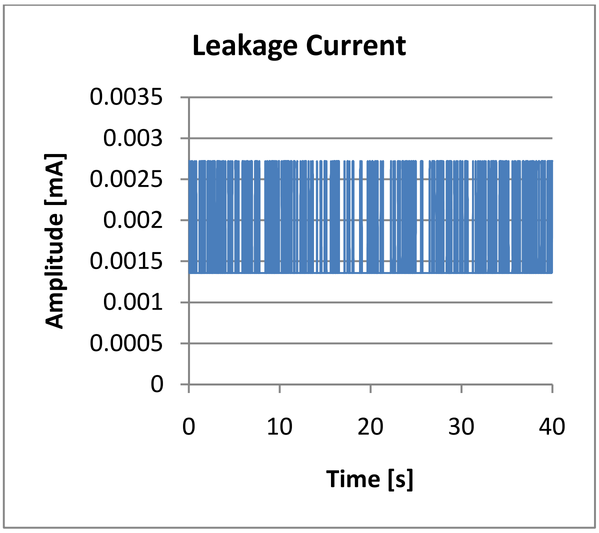
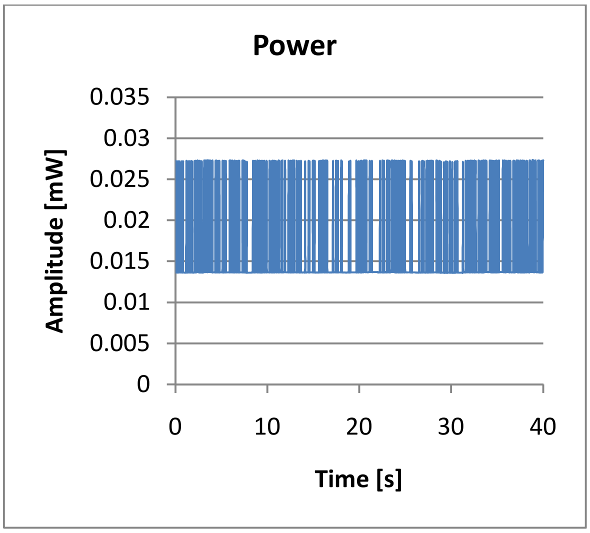
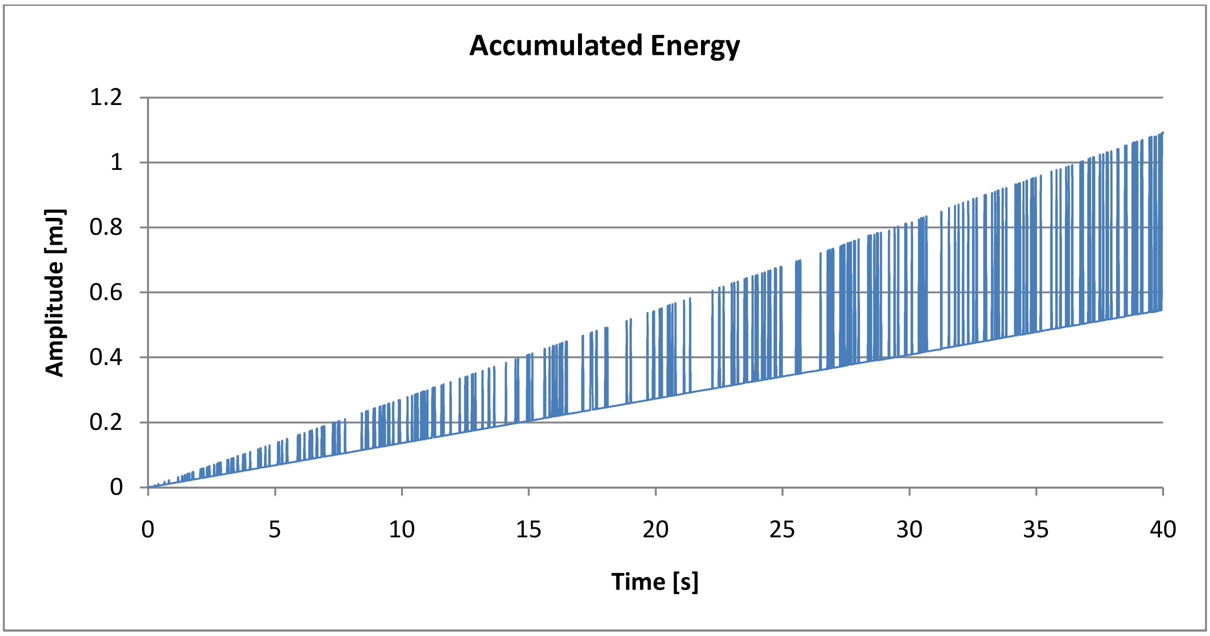
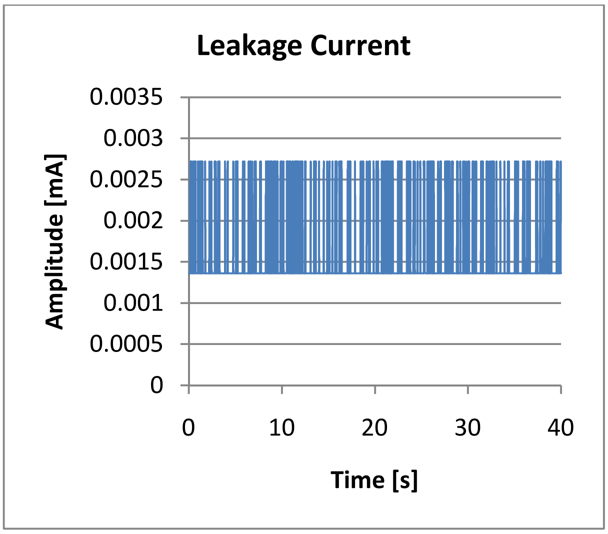
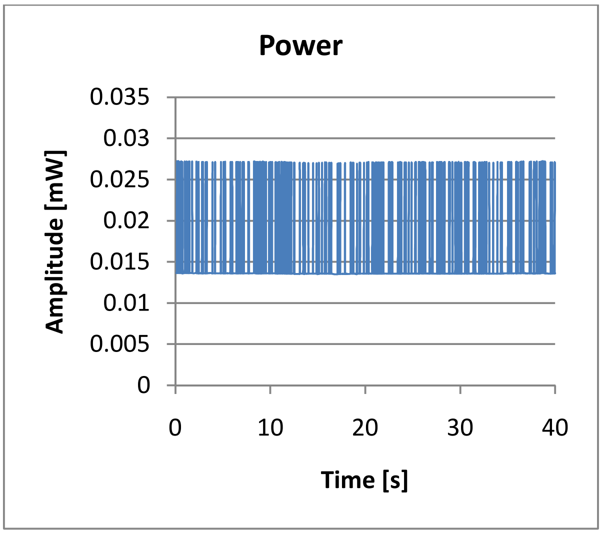


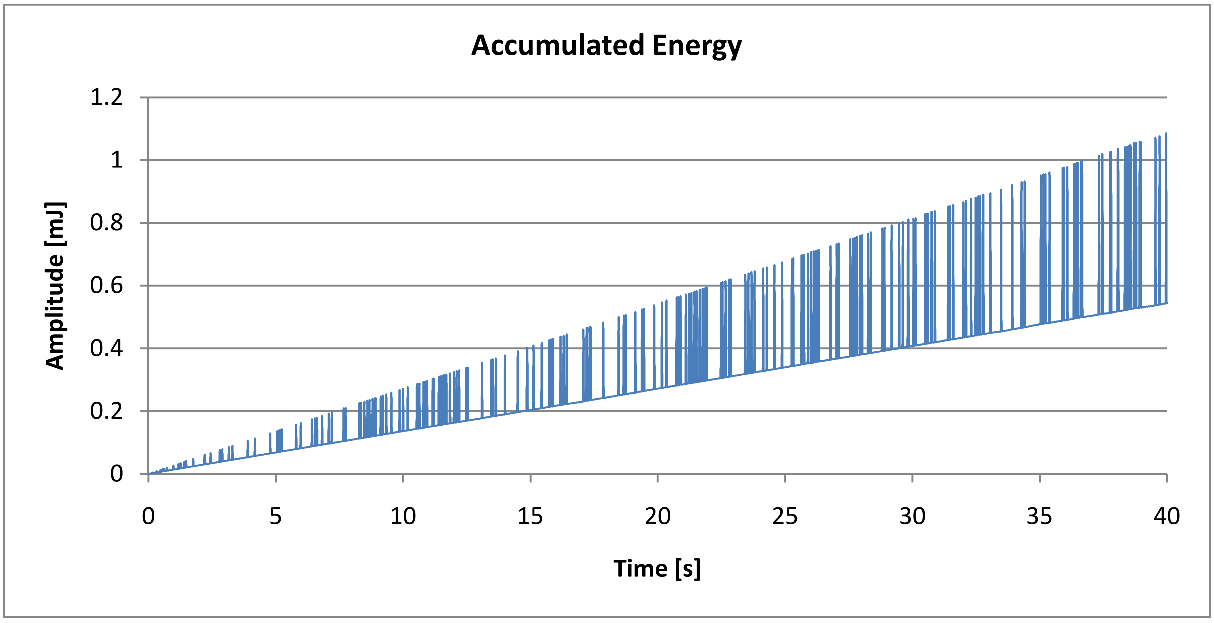




Data Analysis of Flat Insulator 3 at Cycle n° 60







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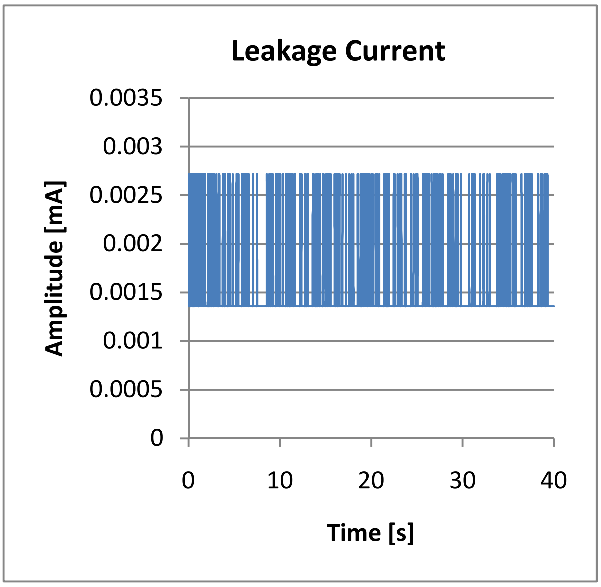

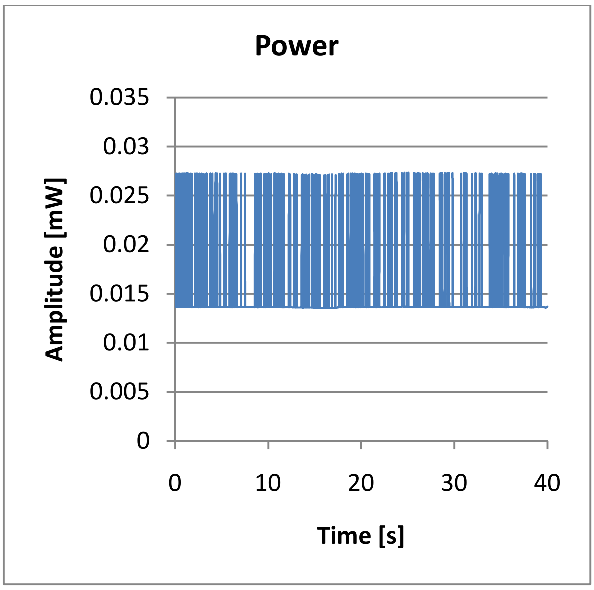

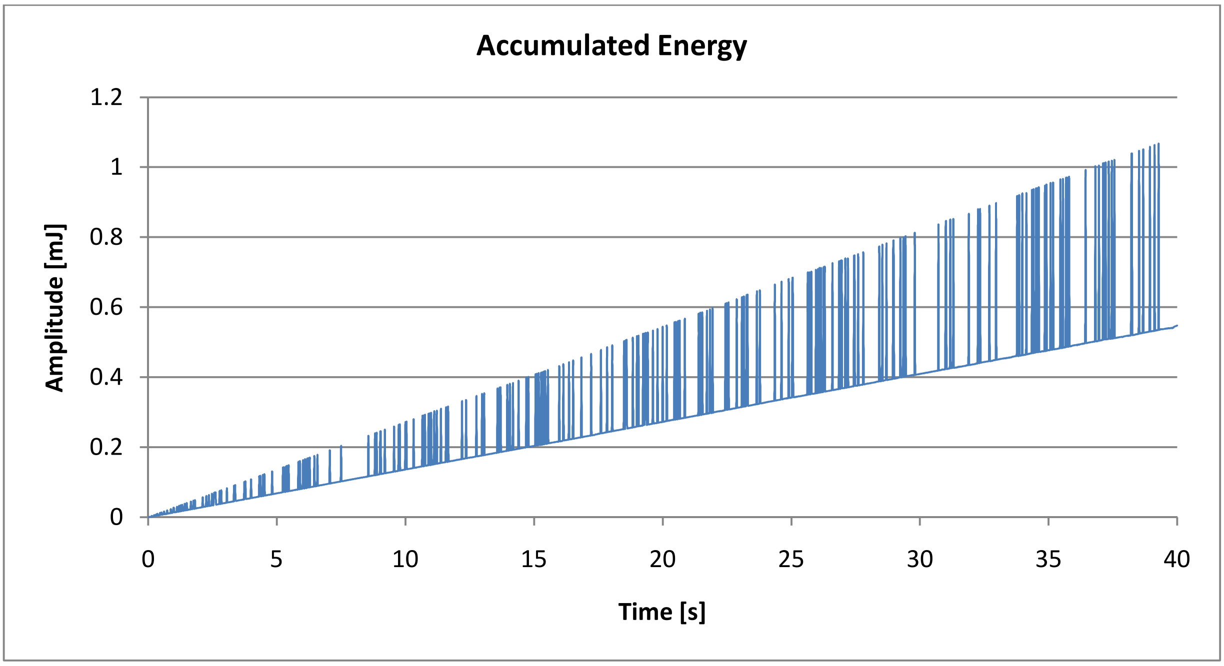

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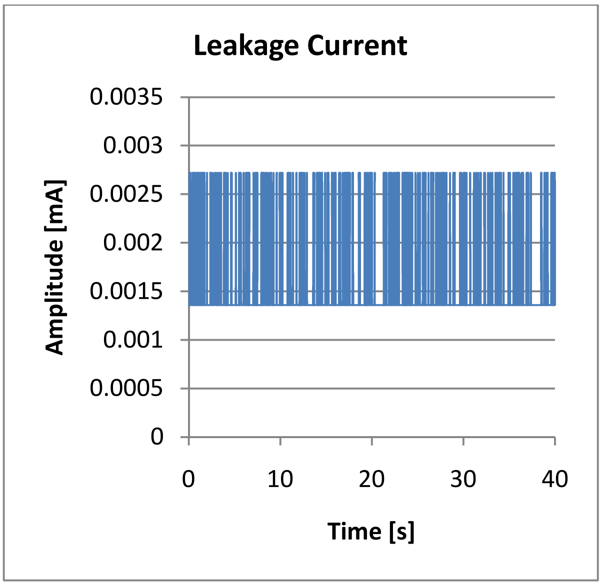

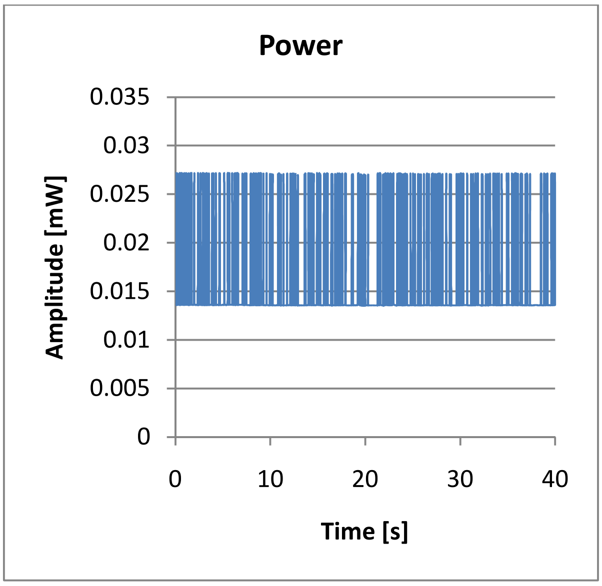

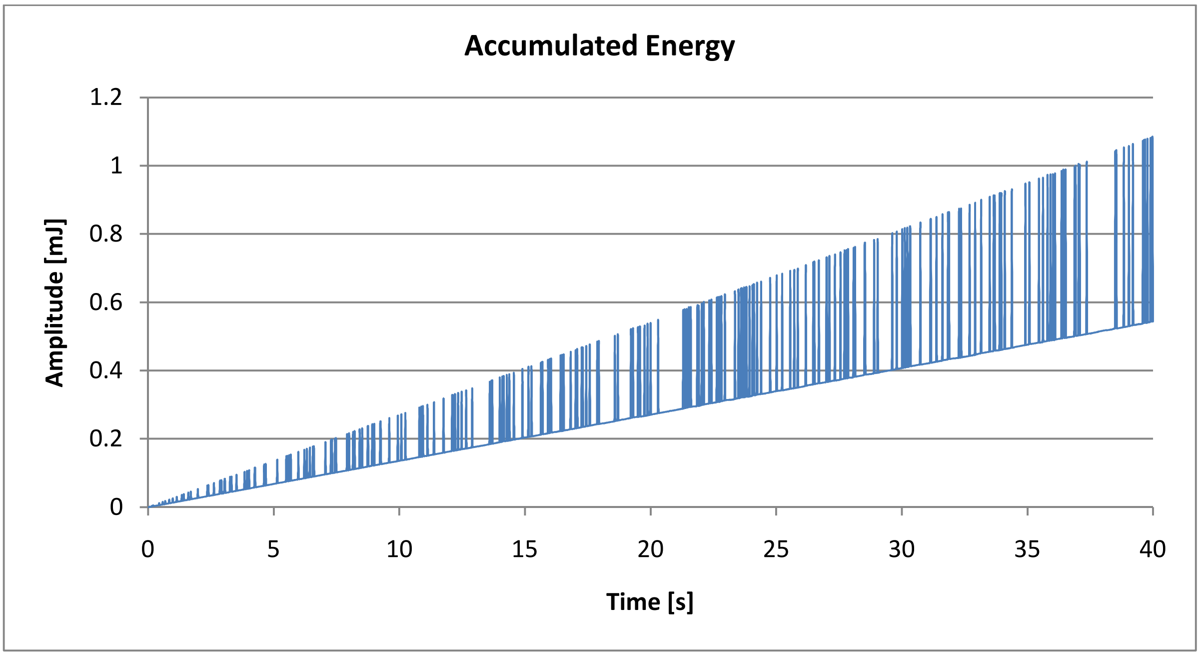

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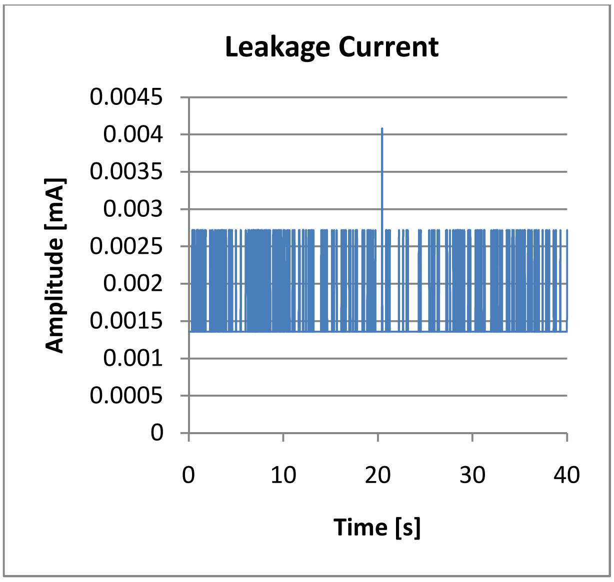
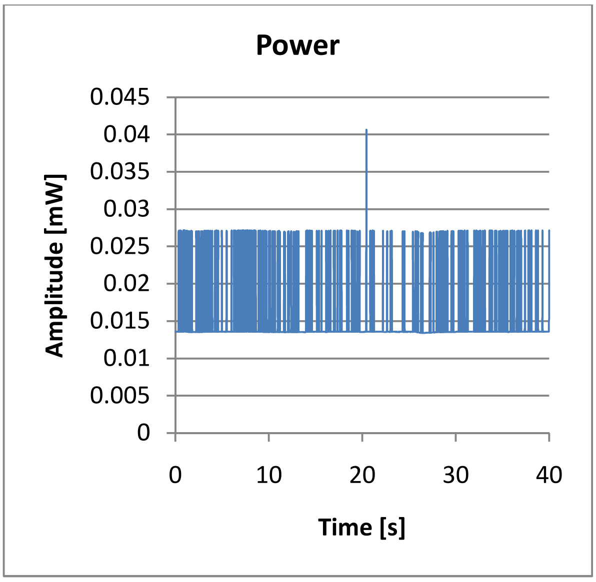
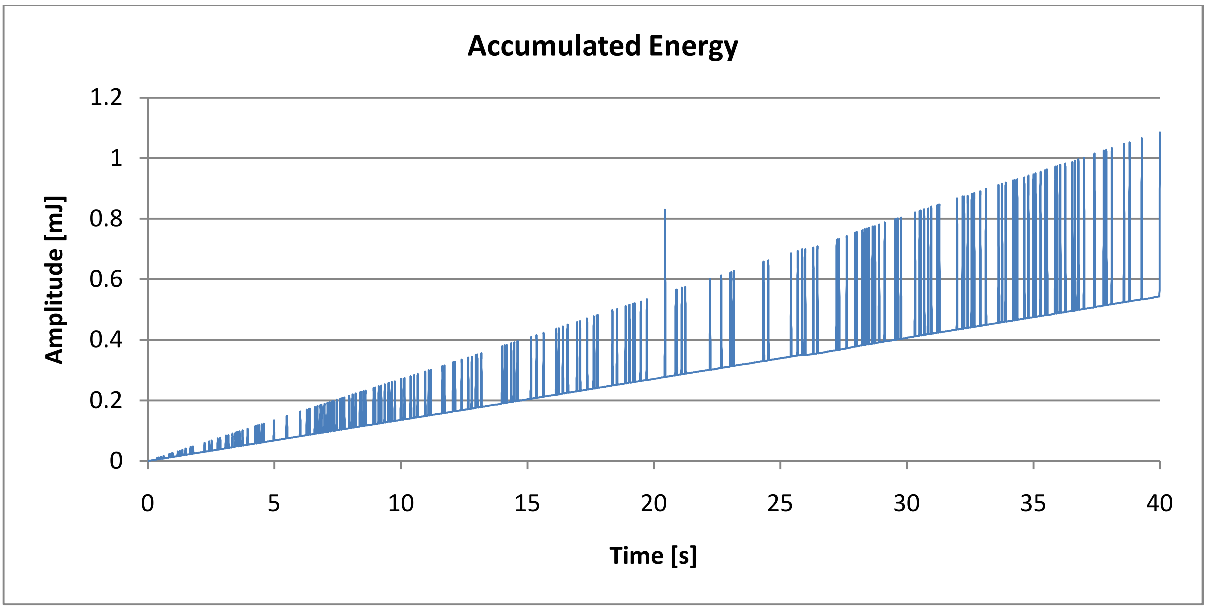
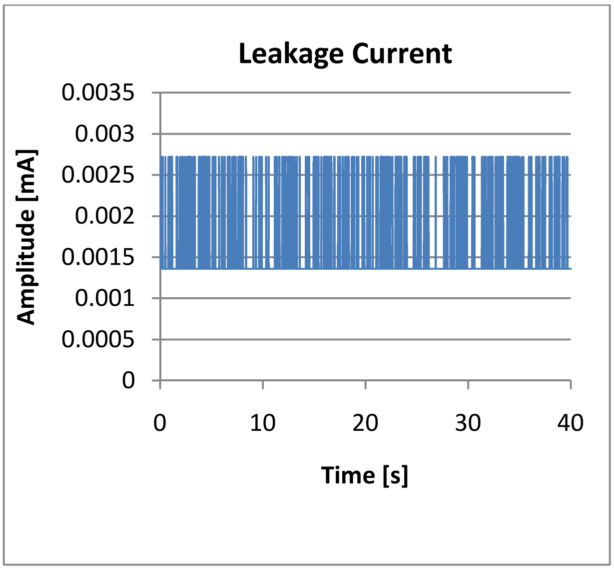
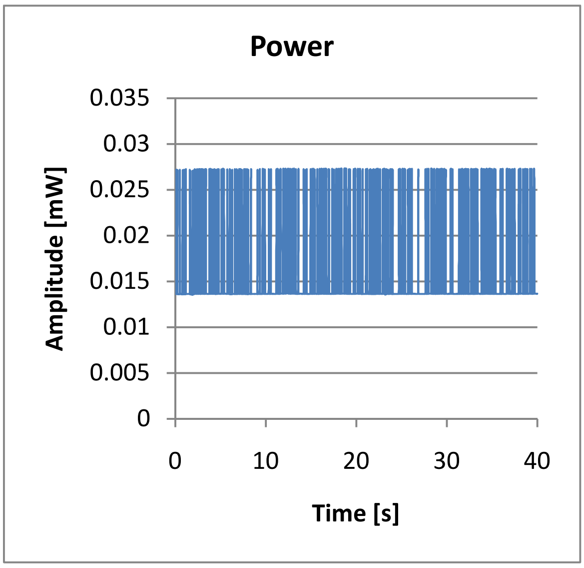


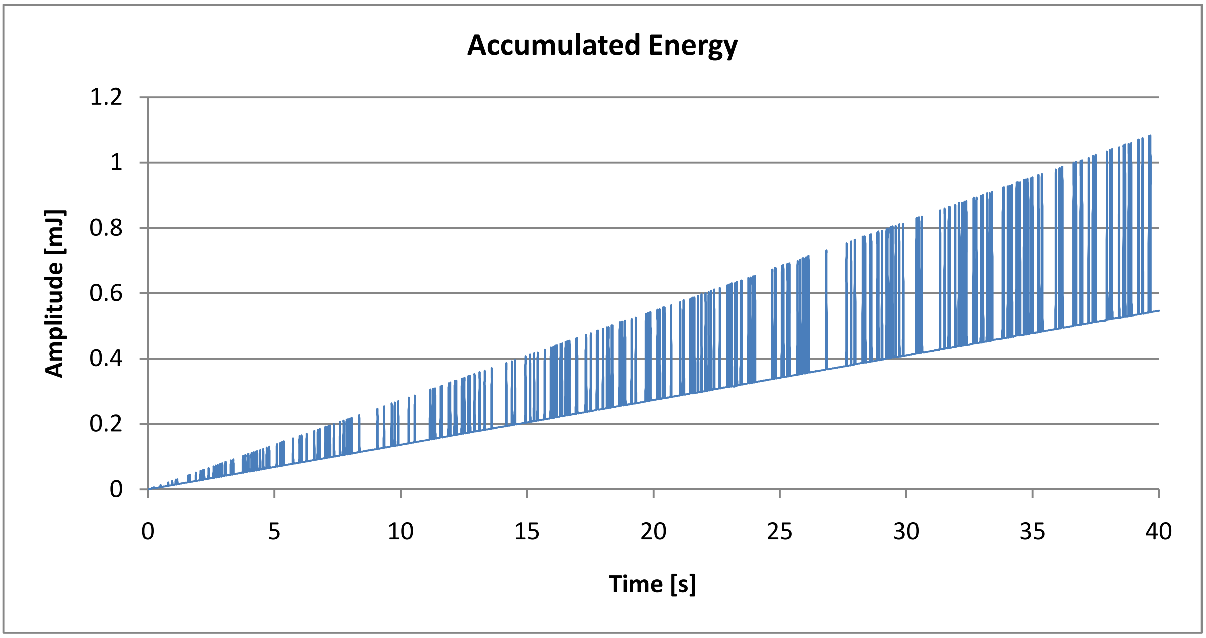




Data Analysis of Flat Insulator 3 at Cycle n° 100







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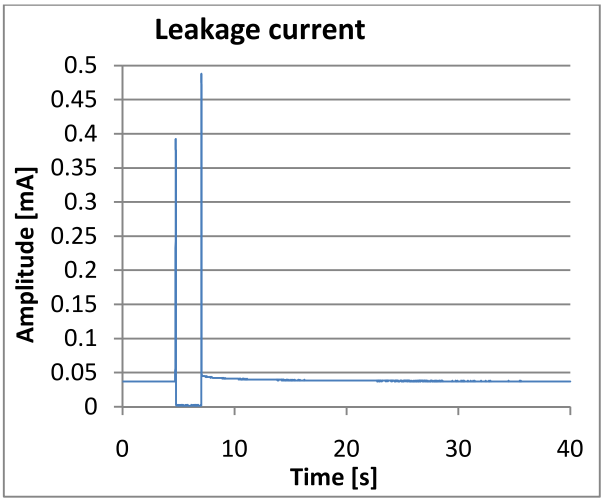

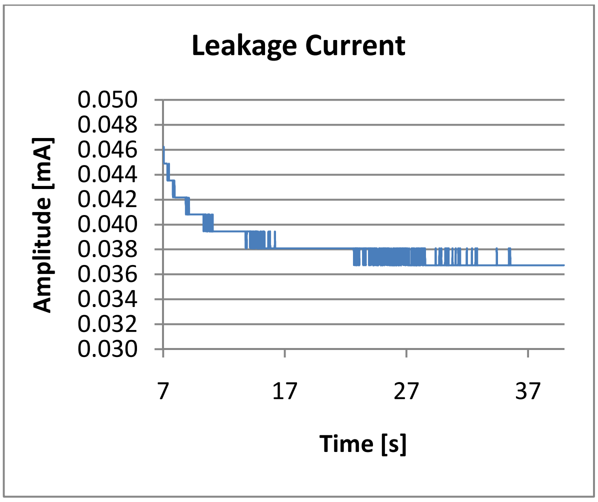

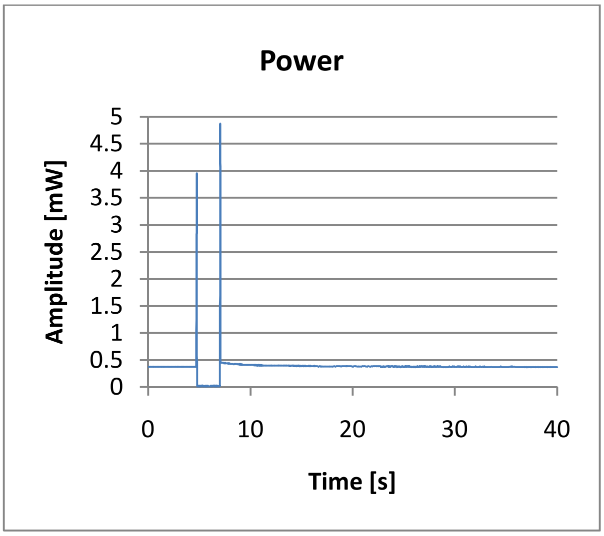

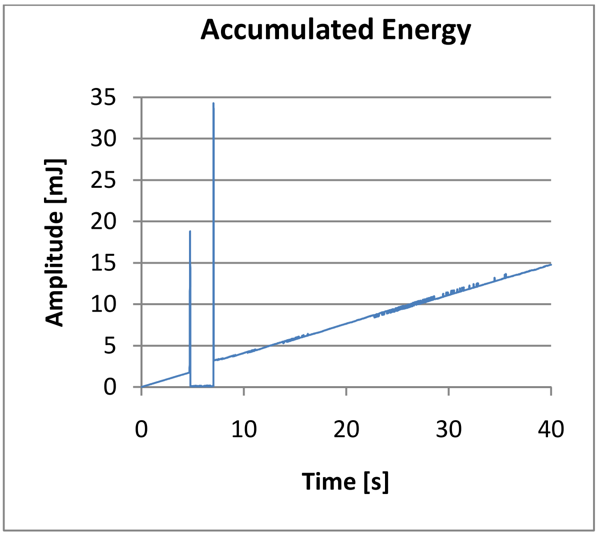

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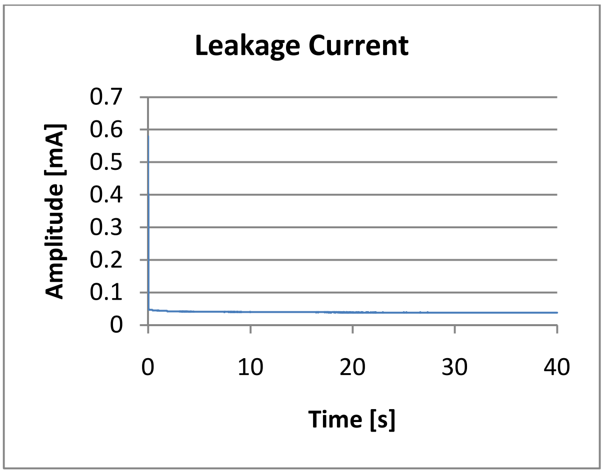

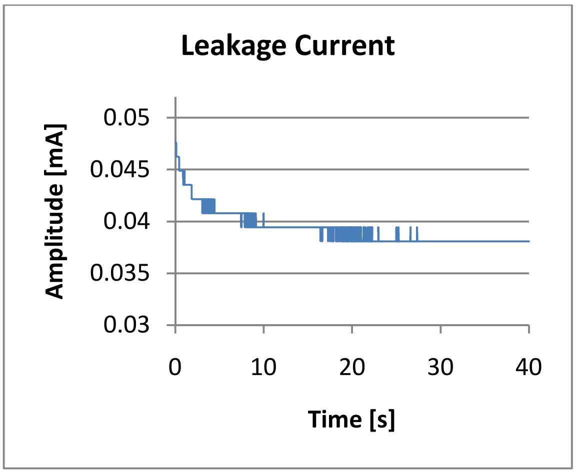

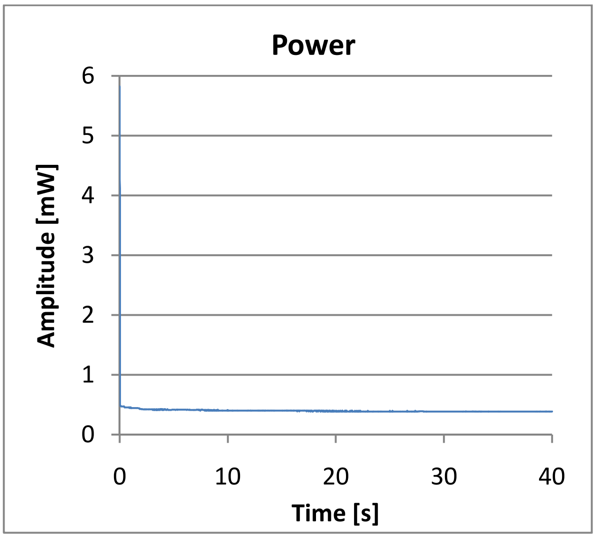

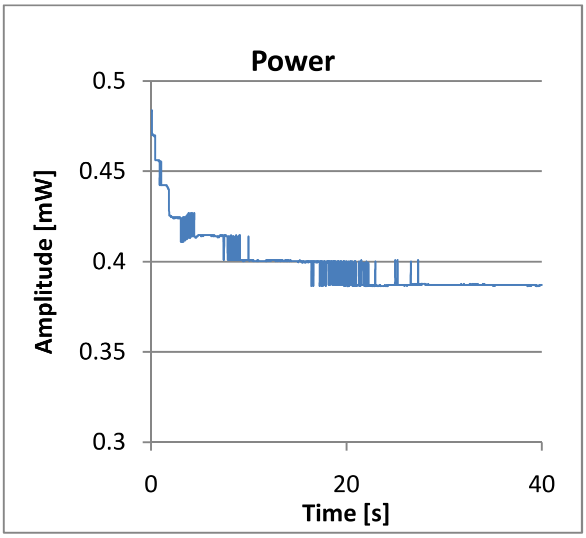

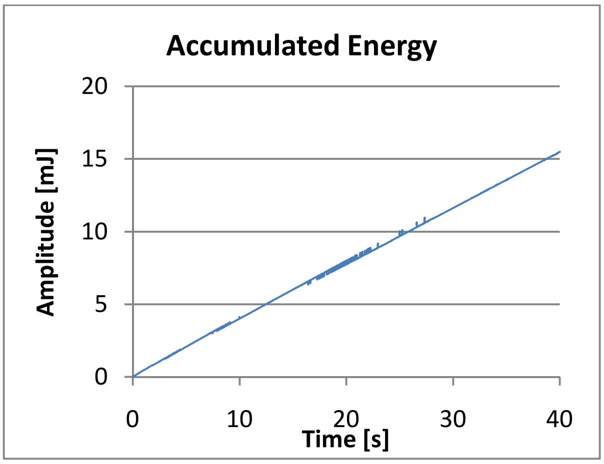

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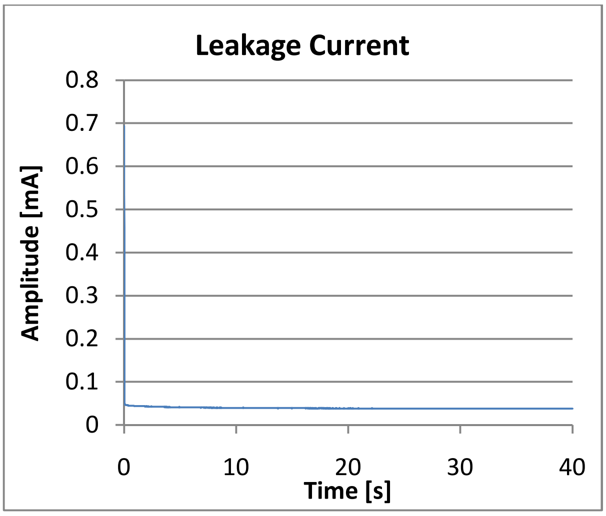

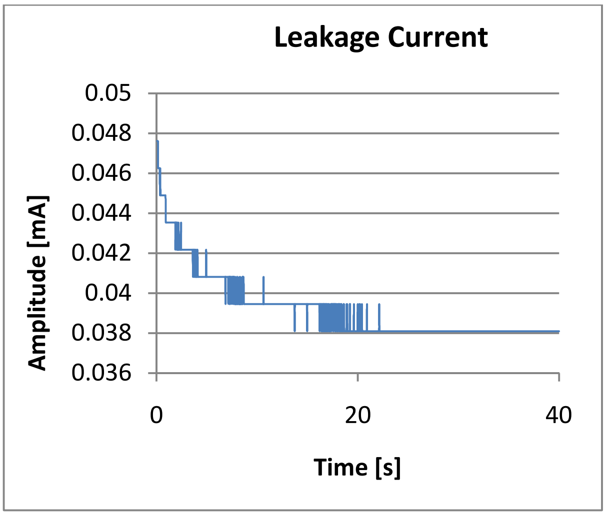

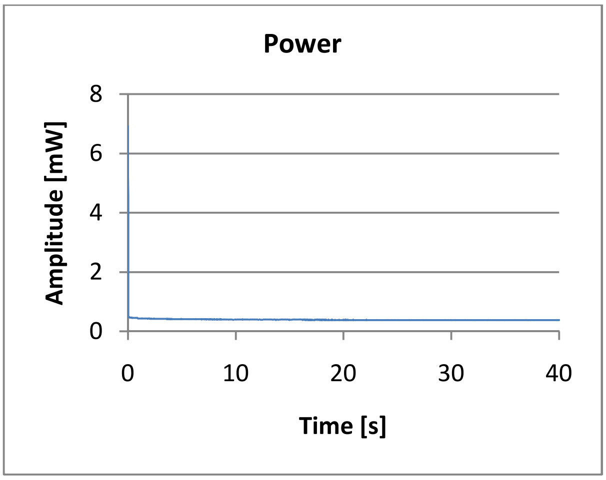

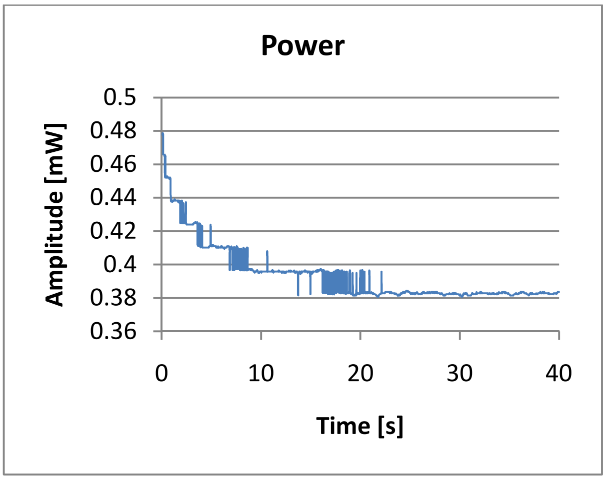

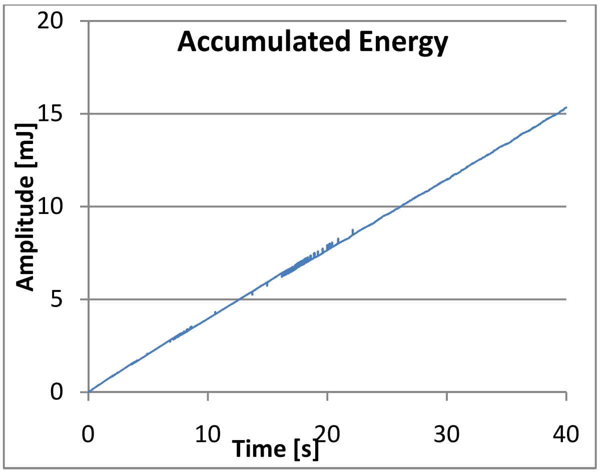

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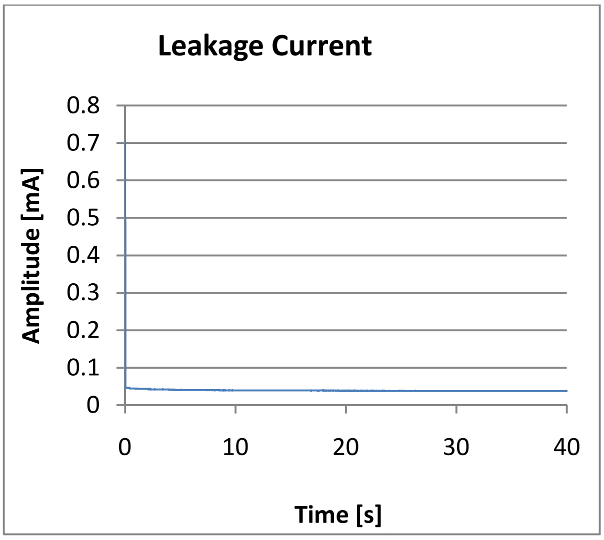

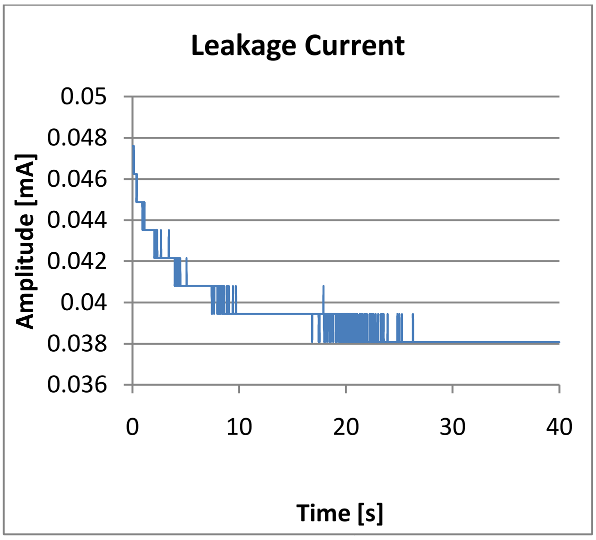

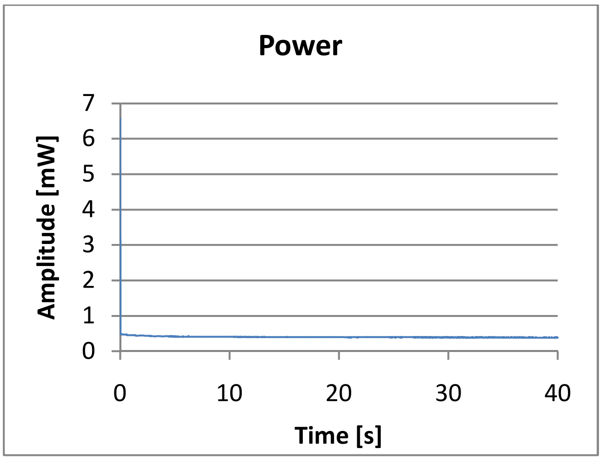

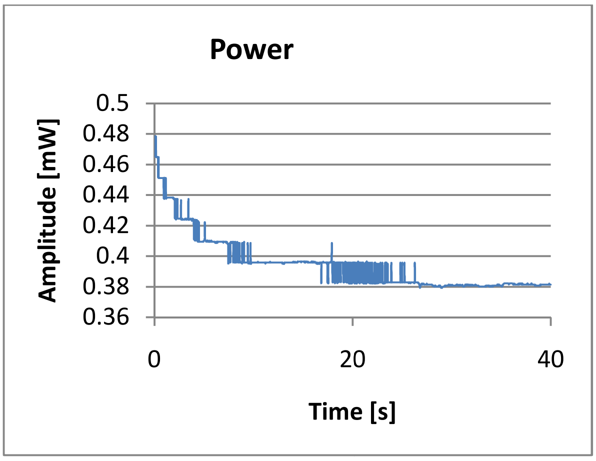

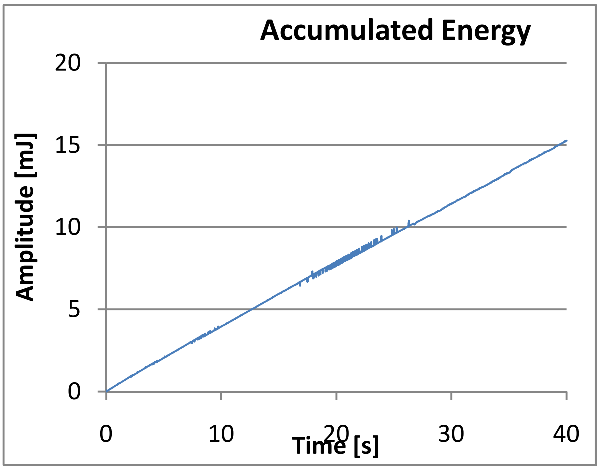

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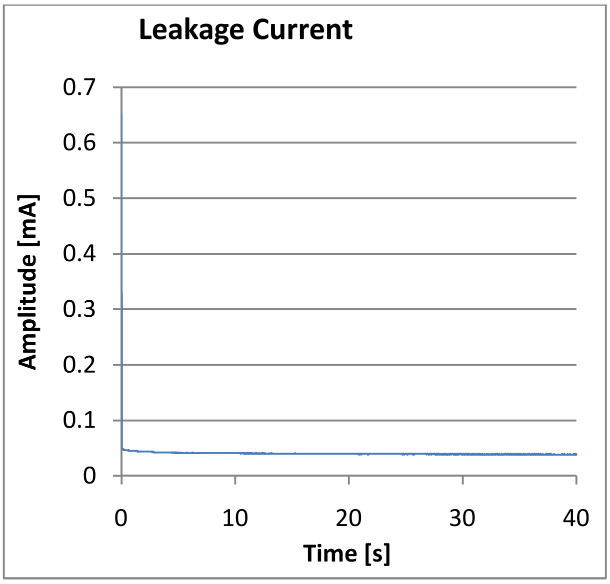

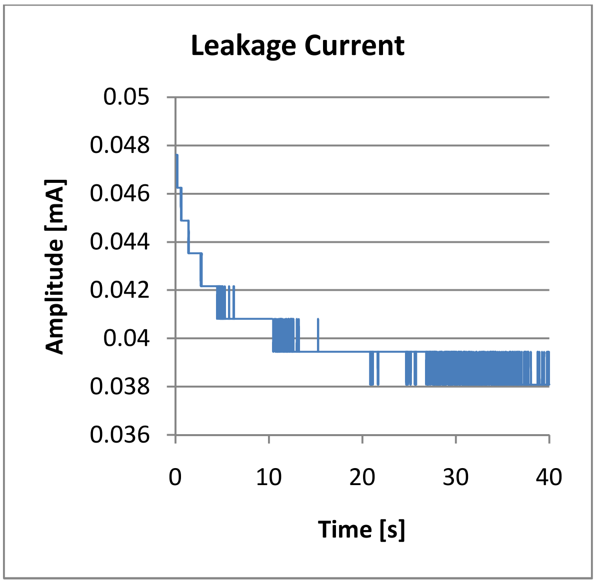

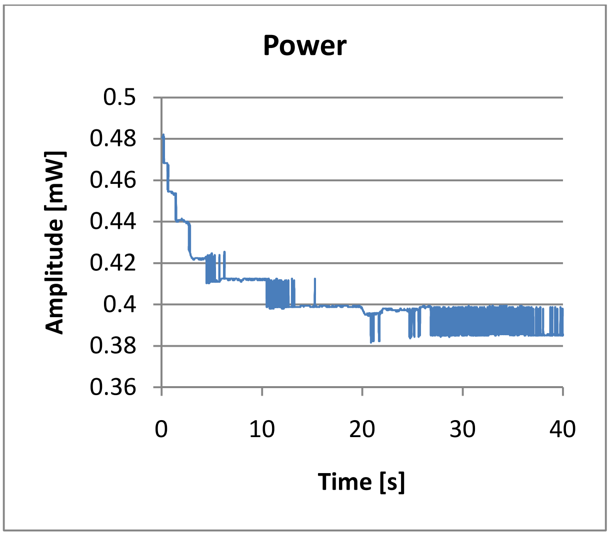

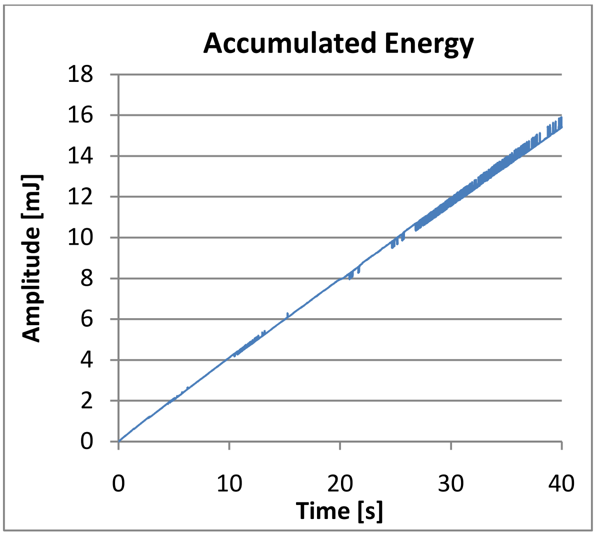

APPENDIX B:

Abstract of EN 62217:2006

BRITISH STANDARD

BS EN 62217:2006

Incorporating corrigendum no. 1

Polymeric insulators for indoor and outdoor use with a nominal voltage > 1 000 V — General definitions, test methods and acceptance criteria

The European Standard EN 62217:2006 has the status of a British Standard

ICS 29.080.10

British Standards

POLYMERIC INSULATORS FOR INDOOR AND OUTDOOR USE WITH A NOMINAL VOLTAGE >1 000 V – GENERAL DEFINITIONS, TEST METHODS AND ACCEPTANCE CRITERIA

1 Scope and object

This International Standard is applicable to polymeric insulators whose insulating body consists of one or various organic materials. Polymeric insulators covered by this standard include both solid core and hollow insulators. They are intended for use on overhead lines and in indoor and outdoor equipment with a rated voltage greater than 1 000 V.

The object of this standard is

- to define the common terms used for polymeric insulators,
- to prescribe common test methods for design tests on polymeric insulators,
- to prescribe acceptance or failure criteria, if applicable,
- to give recommendations for polymeric insulator test standards or product standards, complemented by specific requirements as needed.

These tests, criteria and recommendations are intended to ensure a satisfactory life-time under normal operating and environmental conditions (see Clause 5).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-2-11, *Basic environmental testing procedures – Part 2: Tests, Test KA: Salt mist*

IEC 60507, *Artificial pollution tests on high-voltage insulators to be used on a.c. systems*

IEC 60695-11-10, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 60721-1, *Classification of environmental conditions – Part 1: Environmental parameters and their severities*

IEC 60815, *Guide for the selection of insulators in respect of polluted conditions*

IEC Guide 111, *Electrical high-voltage equipment in high-voltage substations – Common recommendations for product standards*

ISO 868, *Plastics and ebonite – Determination of indentation hardness by means of a durometer (Shore hardness)*

ISO 4287, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters*

ISO 4892-1, *Plastics – Methods of exposure to laboratory light sources – Part 1: General Guidance*

ISO 4892-2, *Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc sources*

ISO 4892-3, *Plastics – Methods of exposure to laboratory light sources – Part 3: Fluorescent UV lamps*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
polymeric insulator
insulator whose insulating body consists of at least one organic based material.

NOTE Coupling devices may be attached to the ends of the insulating body

NOTE Polymeric insulators are also known as non-ceramic insulators.

[IEV 471-01-13]

3.2
resin insulator
polymeric insulator whose insulating body consists of a solid shank and sheds protruding from the shank made from only one organic based housing material (e.g. cycloaliphatic epoxy)

3.3
composite insulator
insulator made of at least two insulating parts, namely a core and a housing equipped with metal fittings

NOTE Composite insulators, for example, can consist either of individual sheds mounted on the core, with or without an intermediate sheath, or alternatively, of a housing directly moulded or cast in one or several pieces on to the core.

[IEV 471-01-02]

3.4
core (of an insulator)
central insulating part of an insulator which provides the mechanical characteristics

NOTE The housing and sheds are not part of the core.

[IEV 471-01-03]

3.5
insulator trunk
central insulating part of an insulator from which the sheds project.

NOTE Also known as shank on smaller insulators.

[IEV 471-01-11]

3.6
housing
external insulating part of composite insulator providing necessary creepage distance and protecting core from environment

NOTE An intermediate sheath made of insulating material may be part of the housing.

[IEV 471-01-09]

3.7
shed (of an insulator)
insulating part, projecting from the insulator trunk, intended to increase the creepage distance. The shed can be with or without ribs

[IEV 471-01-15]

3.8
creepage distance
shortest distance or the sum of the shortest distances along the surface on an insulator between two conductive parts which normally have the operating voltage between them

NOTE 1 The surface of cement or of any other non-insulating jointing material is not considered as forming part of the creepage distance.

NOTE 2 If a high resistance coating is applied to parts of the insulating part of an insulator, such parts are considered to be effective insulating surfaces and the distance over them is included in the creepage distance.

[IEV 471-01-04]

3.9
arcing distance
shortest distance in air external to the insulator between the metallic parts which normally have the operating voltage between them

[IEV 471-01-01]

3.10
interfaces
surface between the different materials

NOTE Various interfaces occur in most composite insulators, e.g.

- between housing and end fittings,
- between various parts of the housing, e.g. between sheds, or between sheath and sheds,
- between core and housing.

3.11
end fitting
integral component or formed part of an insulator intended to connect it to a supporting structure, or to a conductor, or to an item of equipment, or to another insulator

NOTE Where the end fitting is metallic, the term "metal fitting" is normally used.

[IEV 471-01-06, modified]

3.12
connection zone
zone where the mechanical load is transmitted between the insulating body and the end fitting

3.13
coupling (of an insulator)
part of the end fitting which transmits load to the hardware external to the insulator

3.14
tracking
process which forms irreversible degradation by formation of conductive paths (tracks) starting and developing on the surface of an insulating material

NOTE These paths are conductive even under dry conditions.

3.15
erosion
irreversible and non-conducting degradation of the surface of the insulator that occurs by loss of material which can be uniform, localized or tree-shaped

NOTE Light surface traces, commonly tree-shaped, can occur on composite insulators as on ceramic insulators, after partial flashover. These traces are not considered to be objectionable as long as they are non-conductive. When they are conductive they are classified as tracking

3.16
crack
any internal fracture or surface fissure of depth greater than 0,1 mm

3.17
puncture (of an insulator)
permanent loss of dielectric strength due to a disruptive discharge passing through the solid insulating material of an insulator

[IEV 471-01-14]

4 Identification

The manufacturer's drawing shall show the relevant dimensions and information necessary for identifying and testing the insulator in accordance with this standard and the applicable IEC product standard(s). The drawing shall also show applicable manufacturing tolerances.

Each insulator shall be marked with the name or trade mark of the manufacturer and the year of manufacture. In addition, each insulator shall be marked with the rated characteristics specified in the relevant IEC product standards. These markings shall be legible, indelible and their fixings (if any) weather- and corrosion-proof.

5 Environmental conditions

The normal environmental conditions to which insulators are submitted in service are defined according to Table 1.

When special environmental conditions prevail at the location where insulators are to be put in service, they shall be specified by the user by reference to IEC 60721-1.

Table 1 – Normal environmental conditions

Condition	Indoor insulation	Outdoor insulation
Maximum ambient air temperature	Does not exceed 40 °C and its average value measured over a period of 24 h does not exceed 35 °C	
Minimum ambient air temperature	–25 °C	–40 °C
Vibration	Negligible vibration due to causes external to the insulators or to earth tremors [a]	
Solar radiation [b]	To be neglected	Up to a level of 1 000 W/m^2
Pollution of the ambient air	No significant pollution by dust, smoke, corrosive and/or flammable gases, vapours, or salt	Pollution by dust, smoke, corrosive gases, vapours or salt may occur. Pollution does not exceed "heavy" as defined in IEC 60815
Humidity	The average value of the relative humidity, measured over a period of 24 h, does not exceed 95 %; measured over a period of one month, does not exceed 95 %. For these conditions, condensation may occasionally occur	

[a] Vibration due to external causes can be dealt with in accordance to IEC 60721-1.

[b] Details of solar radiation are given in IEC 60721-1.

Annex A
(normative)

Wheel test

A.1 Test specimens

Two test insulators of identical design with a creepage distance between 500 mm and 800 mm shall be taken from the production line. If such insulators cannot be taken from the production line, special test specimens shall be made from other insulators so that the creepage distance falls between the given values. These special test specimens shall be fitted with standard production end fittings.

Up to two pairs of test specimens can be tested simultaneously on one wheel. It is recommended not to mix widely differing materials on the same wheel.

A.2 Procedure

The test specimens shall be cleaned with de-ionized water before starting the test. The test specimens are mounted on the wheel as shown in Figure A.1 below. They go through four positions in one cycle. Each test specimen remains stationary for about 40 s in each of the four positions. The 90° rotation from one position to the next takes about 8 s. In the first part of the cycle the insulator is dipped into a saline solution. The second part of the test cycle permits the excess saline solution to drip off the specimen ensuring that the light wetting of the surface gives rise to sparking across dry bands that will form during the third part of the cycle. In that part the specimen is submitted to a power frequency voltage. In the last part of the cycle the surface of the specimen that had been heated by the dry band sparking is allowed to cool.

The test voltage is supplied by a test transformer. When loaded with a resistive current of 250 mA on the high voltage side the test circuit shall exhibit a maximum drop of 5 % in its output voltage.

The salt solution shall be replaced weekly. Weekly interruptions of the test for inspection purposes, each of these not exceeding 1 h are permissible. Interruption periods will not be counted in the test duration. One longer interruption up to 60 h is allowed. An additional testing time of three times the duration of the interruption period shall be added. The final test report shall include details of all interruptions.

A.3 Test conditions

Electrical stress:	The power frequency test voltage in kV is determined by dividing the actual creepage distance in millimetres by 28,6.
NaCl content of de-ionized water:	1,40 kg/m^3 ± 0,06 kg/m^3
Ambient temperature:	20 °C ± 5 K
Test duration:	30 000 cycles

A.4 Acceptance criteria

The test specimens of identical design shall be assessed together. Pairs of test specimens of different design shall be assessed separately. The numbers of flashovers and trip-outs shall be recorded and noted in the test report.

The test is regarded as passed, if on both test specimens:

- no tracking occurs, (a megohmmeter shall be applied along any suspect path, using 1 kV DC or higher. The probes shall be between 5 mm to 10 mm apart. A resistance of less than 2 MΩ shall constitute failure);
- for composite insulators: erosion depth is less than 3 mm and does not reach the core, if applicable;
- for resin insulators: erosion depth is less than 3 mm;
- no shed, housing or interface is punctured.

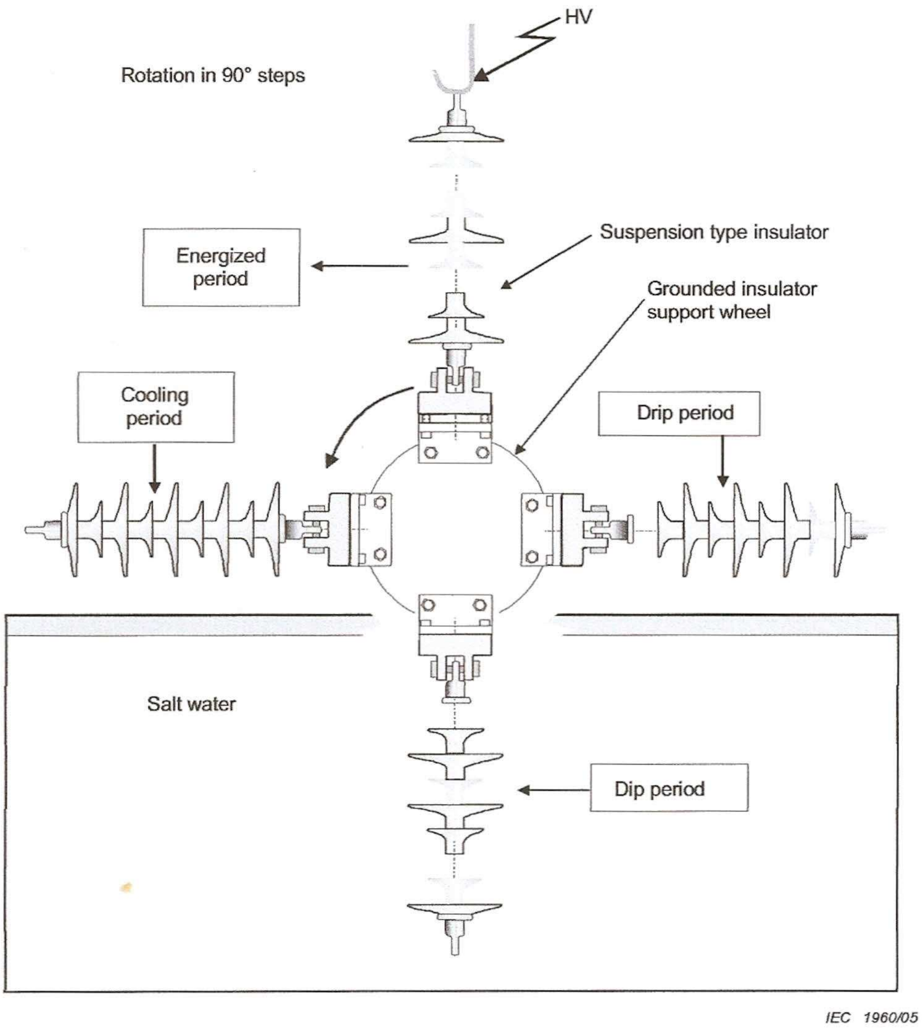

Figure A.1 – Test arrangement of the tracking wheel test

REFERENCES

[1] Crespo, J. , Sandovad. Ph.D. Thesis, “Conduction Monitoring of Outdoor Insulator Working Artificial Intelligent Techniques”, Cardiff 2005.

[2] Haddad, A., Warne, D. , “Advances in High Voltage Engineering”, IEE Power & Energy, Series, No.40, The Institution of Electrical Engineers, 2004.

[3] Looms, J. S. T. , “Insulators for High Voltages”, IEE Power & Energy, Series, No.7, Peter Peregrinus Ltd. , 1988.

[4] Heger, G. , Vermeulen, H. J. , Holtzhausen, J. P. , and Vosloo, W. L. , “A Comparative Study of Insulator Materials Exposed to High Voltage AC and DC Surface Discharges”, IEEE Transaction on Dielectrics and Electrical Insulation, Vol. 17, No.2, April 2010.

[5] Bruce, G. P. , Rowland, S. M. , and Krivda, A. , “Performance of Silicone Rubber in DC inclined Plane Tracking Tests”, IEEE Transaction on Dielectrics and Electrical Insulation, Vol. 17, No.2, April 2010.

[6] Danikas, G.M., “Polymer Outdoor Insulators”, ACTA ELETROTEHNICA NAPOCENSIS, Volume 40, Number 1, 1999.

[7] Limbo, B.S., “Insulator Ageing Tests with HVAC and HVDC Excitation Using the Tracking Wheel Tester.”, December 2009.

[8] Kim, C.K., Sood, V.K., Jang, G.S., Lim, S.J. and Lee, S.J., “HVDC Transmission, Power Conversion Applications in Power System”, Singapore, John Wiley & Sons (Asia) Pte Ltd, 2009.

[9] Bruce, G.P., Rowland, S.M. and Krivda, A., “DC inclined-plane testing of silicone rubber formulations”, IEEE Annual Report Conference on Electrical Insulation Dielectric Phenomena, 2008.

[11] Moreno, V.M. and Gorur, R.S., “Ac and dc Performance of Polymeric Housing Materials for HV Outdoor Insulators, IEEE Transaction on Dielectrics and Electrical Insulation, Vol.6, No.3, June 1999.

[12] Yin Yu, Liang Xidong, Zhou Yuanixiang and Li Xuesong, “Study of Tracking Wheel Test Method under DC Voltage”, Proceedings of the 7th International Conference on Properties And Applications of Dielectric Materials, June 1-5 2003, Nagoya.

[13] Holtzhausen, J. P., Vermeulen, H. J., Pieterse, P.J., and Limbo, S., “Insulator Aging Tests with HVAC and HVDC Excitation using the Tracking Wheel Tester”, IEEE Transaction on Dielectrics and Electrical Insulation, 2010.

[14] Hirsch, F., Rheinaben, H.V., Sormes, R., “Flashovers of Insulators Under Natural Pollution and HVDC”, IEEE transmission & distribution Committee of the IEEE Power Engineering Society for presentation at IEEE PES Summer Meeting & Energy Resources Conf., Anaheim, Cal., July 14-19, 1974.

[15] Muncivì, A., Haddad, A., “Tracking Wheel test facilities”, High voltage System Group, Scholl of Engineering, Cardiff University, U.K.

[16] EN 62217:2006, “Polymeric Insulators for indoor and outdoor use with a normal voltage > 1000V – General definitions, test methods and acceptance criteria”.

[17] IEC 61302, “Electrical Insulating Materials-Method to Evaluate the Resistance to Tracking and Erosion-Rotating Wheel Dip Test”, 1995.

[18] IEC 60587:2007, “Electrical insulating materials used under severe ambient conditions- Test method for evaluating resistance to tracking and erosion”.

[19] IEC 1245:1993 BS 7744:1994, “Artificial pollution tests on high voltage insulators to be used on d. c. systems”.

[20] Kiessling, F., Nefzger, P. Nolasco, J.F., Kaintzyk, U., “Overhead Power Lines. Planning, Design, Construction”, Springer-Verlag Berlin Heidelberg 2003, printed in Germany.