Ahmed Salem

Impulse Voltage Test System for Interturn and Main Insulation Testing

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Instructors	Tuomas Siltala (Quality Manager) Jani Turunen(Laboratory Engineer) Sampsa Kupari (Senior Lecturer) Jaako Virtaninen (Senior Specialist)

This thesis project describes the system for high impulse voltage testing. The devices include transformers, arresters, cables etc. The testing system generates lightning impulse voltages for very short period of time; 1.2 micro seconds according to the industrial standards such as IEC 60060-1. The purpose was to test the interturns and main insulation by impulse voltage test system. In order to test the insulation systems in ABB Insulation lab, two sample coils as named coil 1 and coil 2, identical to the coils used for the actual machine in production are manufactured and tested. The sample coils are impregnated and processed in the same conditions as the complete stator winding, for the purpose of evaluating the basic design, type of materials, manufacturing procedures and processes incorporated in the insulation system.

The impulse test system used is HAEFELY HIPOTRONICS to generate impulse voltages for testing. The system has flexibility to be used in various ways for generating different wave forms or for increasing the test voltage capabilities. Another objective of this study was to design High Voltage (HV) test Area in the facility. For testing synchronous machine and High Voltage test, certain safety distance between the HV equipment and some steel Floor is ensured because of PD (Partial Discharge). The test area design accommodated the limitations present in the facility such as space.

This thesis is presented as: First introduction to the test systems is presented. In next chapter, sample coil impulse voltage test system is explained with the requirements, in chapter three relevant standards are mentioned, in chapter four, test area design or layout is presented. The measurements and results are presented in the last chapter.

The results and measurement obtained for the two test coils fulfill the purpose of test systems. The both of the coils passed the test according to the standards IEC 60034-15 (2009) and IEC 60060-1 (1989). The result show that our test system is successful in testing the coils insulations strength and voltage.

Keywords	impulse testing, International Electrotechnical Commission, Voltage Divider, Coil, Test Voltage, Stray Capacitance, chopping lighting

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Tämä opinnäytetyö kuvaa syöksyaaltokoestusjärjestelmää. Työn tavoitteena oli suunnitella testausalue vyyhtien koestamiseen. Opinnäytetyö kuvaa syöksyaaltokoestus järjestelmää, joka sisältää laitteet kuten muuntajia, vastuksia, kaapeleita jne. Testausjärjestelmä tuottaa salaman impulssijännitteitä hyvin lyhyeksi ajaksi; 1,2 mikrosekuntia, kuten IEC 60060-1 -standardien mukaan.

Tarkoituksena oli testata kierros- ja pääeristys impulssijännitejärjestelmällä. Eristyksen testaamiseksi valmistettiin ja testattiin kaksi näytevyyhtiä nimeltään vyyhti 1 ja vyyhti 2, jotka ovat identtisiä tuotannon todellisten vyyhtien kanssa. Näytevyyhti kyllästetiin ja käsiteltiin samoissa olosuhteissa kuin staattorivyyhdet perusmallin, materiaalien tyypin, valmistusmenetelmien ja eristysjärjestelmän prosessien arvioimiseksi.

Käytetty impulssitestijärjestelmä on HAEFELY HIPOTRONICS, joka tuottaa impulssijännitteet testaukseen. Järjestelmällä on joustavuutta erilaisten aaltomuotojen muodostamiseen tai testijännitteen lisäämiseen. Tämän tutkimuksen tavoitteena oli suunnitella korkeajännitetestialue (HV) laitosalueelle. Synkronisen koneen ja korkeajännitetestien testaamisessa on varmistettava, että HV-laitteiden ja lattian teräslevyjen välillä on tietty turvaetäisyys PD:n (Partial Discharge) takia. Testialueen suunnittelu vastasi järjestelyssä esiintyviä rajoituksia, kuten tilaa.

Näiden kahden testikelan tulokset ja mittaukset täyttivät testijärjestelmien tarkoituksen. Molemmat kelat läpäisivät testin standardien IEC 60034–15 (2009) ja IEC 60060-1 (1989) mukaisesti. Tulokset osoittavat, että testijärjestelmä on kykenevä testaamaan kelojen eristyslujuuden ja jännitteen.

Avainsanat	impulssien testaus, International Electrotechnical Commission, jännitteen jakaja, käämi, koestusjännite, kapasitanssi

Contents

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Abbreviations

HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
kV	Kilo Voltage
kJ	Kilo Joule
V	Voltage
W	Watt
A	Ampere
S	Second
µs	Micro second
ns	Nano-second
C	Capacitor F
R	Resistor Ω
ID	Impulse Divider
IG	Impulse Generator
SGSA	Only named from Haefely Hipotronics
L1	Full or chopped wave
SI	Switching Impulse
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ANSI	American National Standards Institute
VDE	Visteon Dock able Entertainment
GIS	gas-insulated switchgear
SFS	Finnish Standardization Association
PD	partial discharge

1 Introduction

ABB ensures that its motors and generators are thoroughly tested in production. In certain cases the Insulation Laboratory performs extra tests such as sample coil testing. This thesis is about sample coil testing defined in IEC 60034-15. Other kind of sample coil test procedures may be agreed between ABB Motors and Generators and the customer. Sample coil testing methods include impulse voltage test of interturn insulation testing, which is very effective, test of main insulation based on power-frequency voltage testing or impulse voltage. For the purposes of testing the coils at ABB, an impulse test system called (SGSA) by Haefely Test AG Hipotronics is used. With this system, ABB is able to sell to customers motors and generators that have gone through thorough phases of testing based on international and Finnish standards of safety.

The purpose of this thesis project was to do impulse voltage test of interturn insulation of the coils at ABB by using SGSA test system. The system generates impulse voltage ranging from 10 kV to 750 kV. The system capabilities also include simulating testing switch surges. The total of the range charge voltage starts from 100 kV to 800 kV. It has energy stage range from 5 kJ to 40 kJ, this studding used SGSA 200-10 which has a max charging voltage of 200 kV and max energy of 10 kJ. Other properties of the SGSA 200-10 system are mentioned later in this document. SGSA complies with testing with ANSI/IEEE and IEC, as well as the Finnish standards. The SGSA system is quite versatile and future proof and therefore, it fulfills ABB’s testing requirements which became the base of ABB’s choice.

The SGSA system can be mounted on a trailer for better transportability. For now, ABB is using SGSA 200-10 with max charging voltage of 200 kV but in the future ABB could be using the same system for testing larger voltages up to 800 kV with little customization. Other features of the SGSA systems include protection of test objects and safety and ease of operation. The control system complies with VDE 0104.Technical, installation, and training of operating personnel is provided by Haefely Hipotronics. Deploying the system at ABB´s premises with the help of ABB and Haefely Hipotronics. The deployment of the system could involve building and installing a whole setup of the SGSA. Testing results from the system are presented later in this document.

One purpose of this thesis project was to test two sample coils, named Coil 1 and Coil 2, identical to the coils used for the actual machine. The sample coils were impregnated and processed in the same conditions as the complete stator winding, for the purpose of evaluating the basic design, type of materials, manufacturing procedures and processes incorporated in the insulation system.

2 Fundamentals of High Voltage Testing

High voltage (HV) testing is performed on electrical equipment to test the high voltage withstanding capabilities of them. There are certain test procedures followed by HV testing. HV testing uses the phenomenon generated in the electrical insulation under the electrical field presence. *"The phenomenon such as conductivity and breakdown, polarizations and dielectric losses depend on the insulating material, on electrical field generated by the test voltages and shaped by the electrodes as well as environmental influences" [1, page 17]*

High voltage testing is of two types mainly, insulating material testing and complete electrical equipment testing.

Insulating material testing includes testing samples of dielectric. The sample of dielectric testing is actually measuring the strength of the material (dielectric), permittivity measurement and per unit volume loss of dielectric. The permittivity measurement and per dielectric loss per volume is done by HV testing techniques known as HV Schering Bridge.

The tests performed on the completed electrical equipment are actually measuring the capacitance, overall dielectric loss or power factor and breakdown voltage. Only a few equipment are subjected to breakdown voltage because in many case a destructive test will also destroy or damage the equipment. However, all equipment are tested for two times of the normal operating voltages which is lower than the breakdown voltage. This ensures that the equipment can withstand certain high voltage without any damage above the normal voltage. The equipment life increase by having this capability. For example, The HV AC tests are performed on cables, transformers, and switchgears etc. The stress of insulation is tested by high voltage AC tests at operational Alternating Voltage 50 Hz in EU or 60 Hz in USA and temporary over-voltages [1].

2.1 Electric Field Insulations – (External and Internal)

The electrical insulations are classified as external and internal for the sake of HV testing. In the case of external insulation, environmental aspects are also mentioned.

2.1 1 General Definitions and Principles

Interturn and main electrical insulation are subjected into the electrical field. And, due to electric field ionization process take place between high and low electrodes causing high current flow. Due to high current flow, the dielectric loss in insulation happens leading to breakdown phenomenon. In the breakdown, insulation failure happens and zero potential difference between electrodes mean that the voltage has collapsed. The IEC 60069-1 (2010) terms breakdown as disruptive discharge [1].

External insulation is defined as outer surface of insulation which is exposed to electric field and to different weather conditions and environmental agents such as temperature, pressure and humidity etc. Self-restoring external insulation can restore its properties after breakdown contrary to internal insulation of the equipment which is destroyed under breakdown.

Internal insulation protects the components of solid, liquid or gaseous insulations from the conditions such as humidity, pollution and vermin. There are non-self-restoring, self-restoring and partly self-restoring insulations. Non-self-restoring includes solid and liquid impregnated elements. Partly self-restoring is related to gas or solid elements. For testing High Voltage, external insulation is important as it affected by environment most. For HV tests for self-restoring insulation, occurrence of breakdown may happen. Breakdown is not acceptable in case of non-self-restoring insulation during HV testing. Therefore, the test conditions should be such that ensure reproducibility and accuracy estimated results below; beneath the conditions testing. Results should be comparable to one another. The results vary because of the breakdown process and polarity dependence of the measurements and certain other factors.

3 Sample Coil Testing

3.1 General

This chapter describes the standard IEC 60034-15 sample coil test procedures in the Insulation laboratory of ABB Motor and Generator. Other kind of sample coil test procedures may be agreed with between ABB and the customer. Three sample coils are manufactured identically to coils used in corresponding stator winding. These extra coils are added to total number of coils and chosen randomly from ready coils in coil manufacturing before winding work. L-steel Profiles are assembled to chosen sample coils according to instruction ABB internal instructions and sample coils are then impregnated in a VPI process similar to VPI process for the corresponding stator. Two sample coils are used in the sample coil procedure. The extra third sample coil is used for adjusting test devices [2].

3.2 Equipment

The equipment used for test system is explained in the following sections.

3.2.1 Impulse Voltage Test System

In order to do impulse voltage tests on High voltage (HV) devices, certain systems such as Marx generators or simply Impulse voltage test systems are widely used. The power apparatus that are tested through these systems include for example, HV cables, power transformers, switchgear or generators etc. The testing mechanism is followed by the relevant international standards, for example, IEC, ANSI/IEEE and other national standards. Lightning and switching impulse are used. The requirements for preparation of test coils, carrying out tests and interpretation of results are listed in the IEC 60034-15 (2009): the impulse voltage level form wounding stator coils for rotating in Alternating Current machine and IEC 60060-1 (1989): High-voltage test techniques [8].

Voltage surge or impulse voltage is common hazardous phenomenon in electrical equipment. This may happen due to lightning. In this situation, amplitude of the voltage rises many times to the normal operating voltage of the equipment. The shape of the waveform is steep and rising in the beginning and then slowly falling. Such waveform causes problematic conditions that are not experienced by the apparatus under normal operating conditions. In order to ensure safety, it is advised to test the devices in factory under stimulated impulse voltage conditions that may likely be experienced in real scenarios.

The following Figure 1 shows Impulse Voltage generator Test System by HAEFELY HIPOTRONICS Test, AG. The system named as SGSA with max charging voltage 300 KV and max energy 15 kJ, impulse capacitance 333 nF with Charging unit LGR 100-20 in the left side of figure, Impulse Generator SGS 300 kV. 15 kJ in the middle of the figure and finally in the right, CS Divider 300 kV. This test system is used for impulse voltage test system.

Figure 1: Impulse Voltage Test System SGSA Equipment [3]

The figure 2 shows how impulse voltage generator circuit are coupling, single stage circuit is two Cs (impulse capacitance), SF (spark gap), floor of Parallel resistance and series resistance and load test object according to Haefely Hipotronics SGSA.

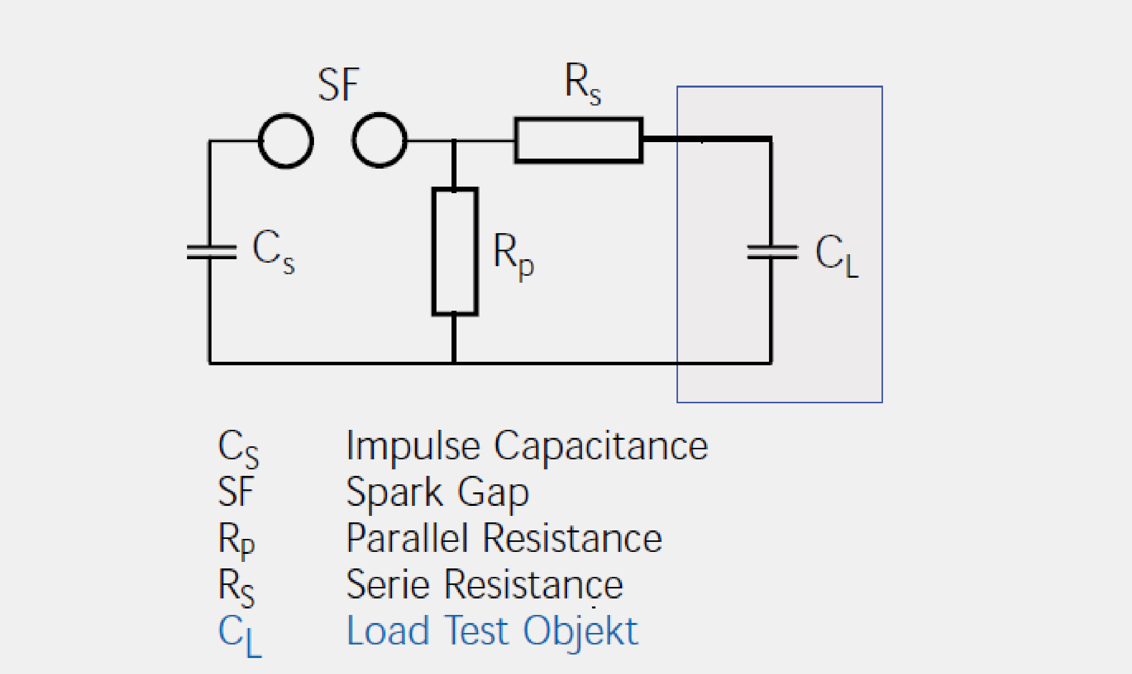

Figure 2: Impulse Voltage Generator Single Stage [3].

The Figure 3 shows the impulse voltage test system operates below; beneath the control unit and impulse measuring system getting value from charge unit and impulse generator and according to measurements testing or carve wave are impulse generator, test object, shunt (parallel and series resistors), and sphere gap.

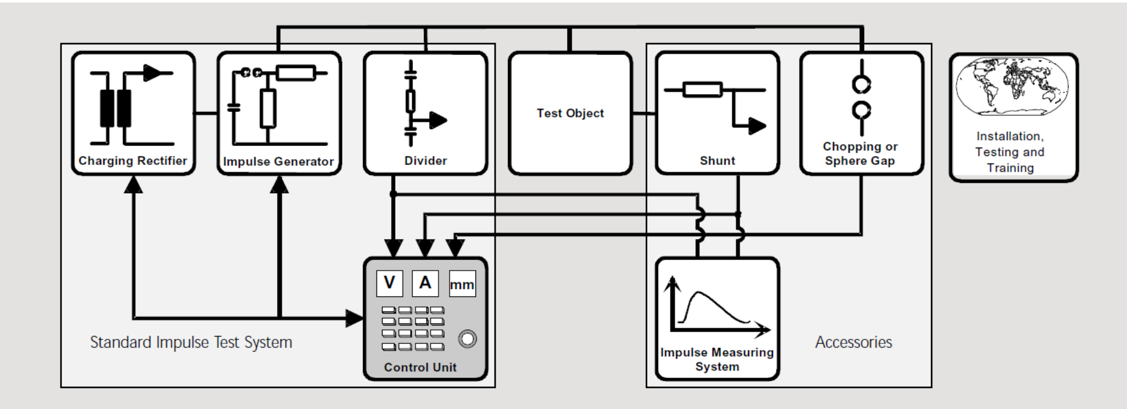

Figure 3: Function of the impulse voltage test system [3]

Figure 4 shows chopping gap before using it and after since, Figure 5 shows Spear Gaps with Impulse Surges during the test.

Figure 4: Chopping gaps

Figure 5: Spear gaps with surge during the test.

Figure 6 shows two chopping gaps connected with the Impulse Generator that work in series, the lower one starts the pulse. It is about 1.2 mm space between two balls and it is possible to control the space. The upper balls is the second unit which gives pulse to divider. The pulse travels through the impulse generator (Resistor and Capacitor] and then through chopping gaps to divider and then to test object. The spark gaps for all stages are located inside of the triangular structure. One sphere of each spark gap is rigidly attached to the stack, while the other is horizontally adjustable by a rack-and-pinion mechanism. A vertical shaft is used to adjust all the gear units at once, so that the flashover distance can be matched to the charge voltage of IG. First-stage gap has a trigger electrode, which permits controlled triggering of the first stage and thus entire IG. Insulator stack has holes with covers providing maintenance access to the spark-gap switches, as shown in Fig.6.

Figure 6: Two chopping gaps (Trigger Electrode)

Figure7 shows how divider works, when the HVDC Transformer output 150 kV 5 MA gives load to charging supply and then surges getting through to Impulse Generator through spear gaps through capacitor and resistors through divider through test object to control unit. Voltage divider shows by oscilloscope.

Figure 7: Divider 150 KV

Figure 8 shows Glaninger circuit acts, as system of IG, required when testing very small inductance such as low inductance only.

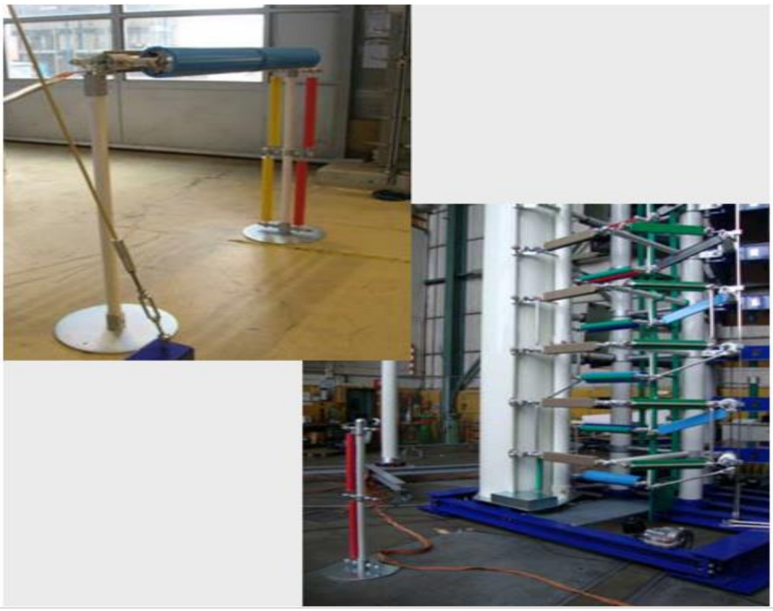

Figure 8: Glaninger[4].

Figure 9 shows Glaninger is common when testing low voltage winding of power transformer. The glaninger circuit is connected in parallel to the series resistor. The inductance has a high impedance during the rapid rise at the impulse head. This means only the series resistor effective during impulse raise time, when slow decay, the impedance has a low impedance, which means the glaninger inductance of come into effective. The result is less damping in the resonant circuit and hence increase time to half value. The Glaninger circuit is used together with an impulse generator system. So it will be installed in the same area as the impulse generator glaninger circuit for V-Generator

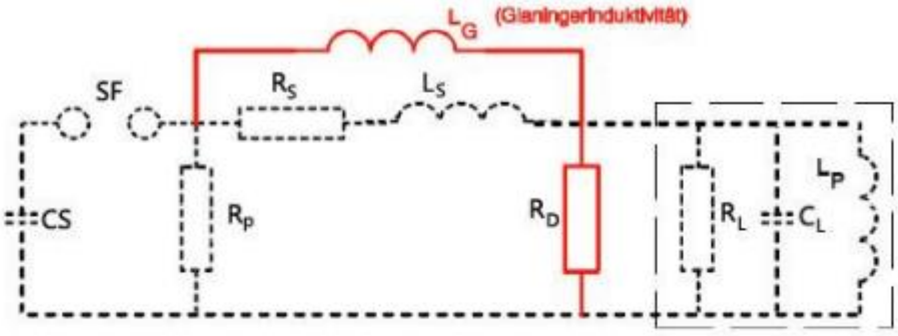

Figure 9: Impulse Generator with Glaninger Circuit [4]

Figure 10 shows the terminals for the V-type Glaninger circuit of all Glaninger elements are designed for a maximum lightning impulse voltage of 200 kV! The Glaninger circuit is only used for testing low voltage windings of transformers where the test voltage is mostly lower than 200 kV.

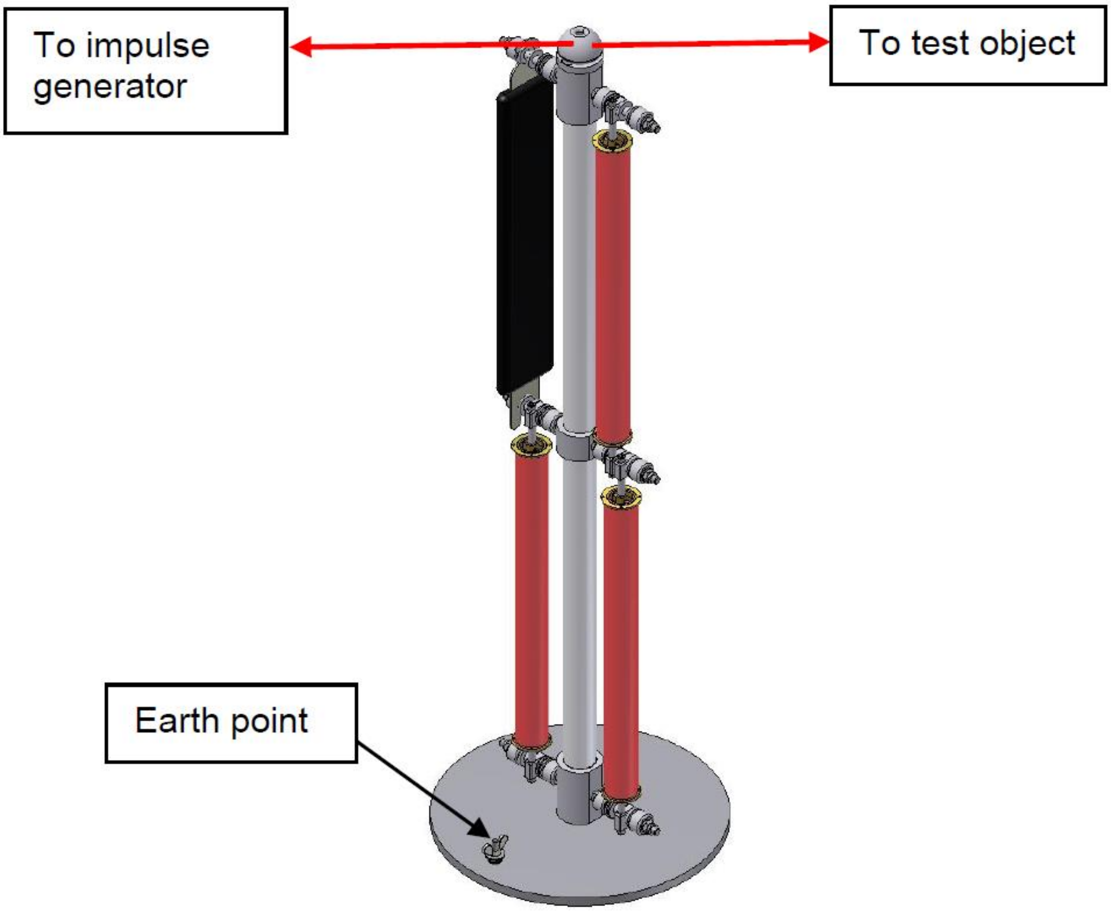

Figure 10: Terminals [4]

$$R_s \approx \frac{T_1}{2.96} * \frac{C_s + C_b}{C_s * C_b} \qquad (1)$$

With RS: total series resistance

T1: front time (0.84µs … 1.56µs)

CS: total impulse capacitance

Cb: effective test capacitance

The effective test capacitance of the transformer must be known. Otherwise a resistor value has to be estimated

Figure 11: Test Specimen: Coil

Figure 11 shows Test specimens are different on every test specimen, it can be long or short, and HV or LV. Sample coil test procedures in Insulation laboratory are explained below.

Impulse voltage test of interturn insulation is carried out by applying five consecutive test voltage impulses inside one terminal of the sample coil, the other terminal is connected to ground. Both coils were tested. Requirement for the interturn insulation withstand voltage is:

$$U_p' \geq 0.65 \times (4U_N+5)\ \text{kV} \qquad (2)$$

Where Up' is the peak voltage of the test impulse

UN is the rated line-to-line voltage of the machine in question

Impulse front rise time shall be 0.2 µs with tolerance from -0.1 µs to +0.3 µs

Impulse front rise time is calculated according to IEC 60034-15 and IEC 60060-1:

$$1.67 \times [\text{Time from } 0.3 \times U_p' \text{ to } 0.9 \times U_p'] \qquad (3)$$

Acceptance criteria: no breakdown.

IEC 60034-15 says Up’ = 0.65 x (4UN+5) kV with tolerance of ± 3 %. If this is not possible, the voltage defined in IEC 60034-15 is considered a minimum requirement. Successful test at rated voltage or higher voltage will give accepted result.

Up’ = 0.65x (4xUn+5) kV=20.42 kV, when Un = 6.6 kV.

Table 1: Example of an interturn impulse test

Test voltage requirement U/kV	Oscilloscope voltage U/V	Impulse generator settings Charge voltage spear	Coil Pulse voltage/ Breakdowns 1	2		t 28 °C RH 14 %		
		18kV 15	5/0	5/0	Coil 1 rise time / ns	Coil1 decay time / µs	Coil 2 rise time / ns	Coil 2 decay time / µs
			21,9	22,8	220,8	1,64	194	1,5
			22,6	21,2	210,2	1,5	196	1,7
			21,3	22	220,0	1,6	195	1,5
			22	22	220,0	1,5	194	1,5
			22	22	220,0	1,5	195	1,5

This table 1 shows the result from Impulse voltage test system. Main insulation is tested either with the power-frequency (50 Hz) test or with the impulse voltage test. Customer may choose the testing method. Both coils are tested as agreed with power-frequency or main insulation impulse voltage test. This thesis focuses on impulse voltage test, power frequency test is out of scope.

Impulse voltage test of main insulation: This test method is alternative to the power-frequency voltage test of the main insulation, and it is done only if the power-frequency voltage test of the main insulation is not performed. Test voltage impulses are applied between both terminals of the coil and ground electrodes on the slot portion of the coil (both coil sides). Five consecutive test voltage impulses are used. Requirement for the main insulation withstands voltage: Up’ = (4UN+5) kV (4)

Where,
Up’ is the peak voltage of the test impulse
UN is the rated line-to-line voltage of the machine in question

Impulse front rise time should be 1.2 µs with tolerance of ±30 % and impulse front rise time is calculated according to IEC 60034-15 and IEC 60060-1:

1.67 x [Time from 0.3 x Up’ to 0.9 x Up’] (5)

Time to half value should be 50 µs with tolerance of ±20 %

Time to half value is calculated according to IEC 60060-1.

IEC 60034-15 tell that Up’ = (4UN+5) kV with tolerance of ± 3 %. If this is not possible, the voltage defined in IEC 60034-15 is considered a minimum requirement. Successful test at rated voltage or higher voltage will give accepted result.

Up’ = (4xUn+5) kV=31,40 kV, when Un = 6.6 Kg

Table 2: Example of an impulse voltage test of main insulation

Test voltage requirement U/kV	Oscilloscope voltage U/V	Impulse generator settings Charge spear volte	Coil Pulse voltage/ Breakdowns 1	2		t 28 °C RH 14 %		
		18kV 15	5/0	5/0	Coil 1 rise time / ns	Coil1 decay time / µs	Coil 2 rise time / ns	Coil 2 decay time / µs
			33,7	34.7	762,5	52	772	50,24
			33,5	34,18	764,7	51,7	768	50,89
			33,6	34,5	798,7	51	766	50,08
			34,5	34,16	778,4	50	767	51,06
			34,2	34,57	786,5	50,98	767	50,47

This table 2 shows the result of five time impulse

The figure 12 shows the result seen in Oscilloscope. As we see, coil 1 pulses are from one time to five times coils1 tr/ns for example 762,5 tr/ns

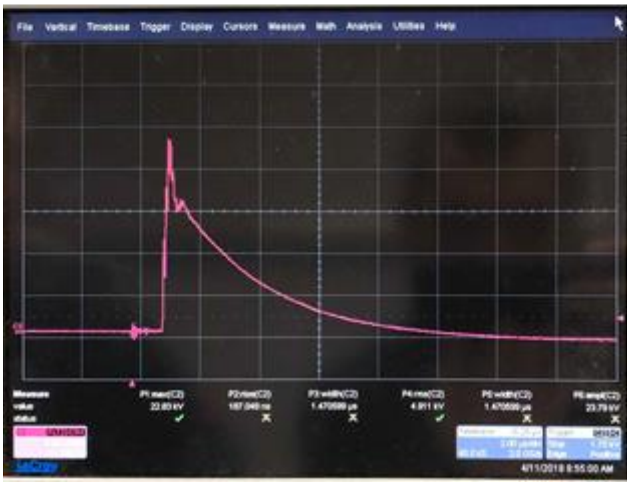

Figure 12: Oscilloscope result.

Figure 13 shows the impulse generator which is the main part in this system. System has the front time from resistors (800 ohms) and tail time from resistors (2500 ohms). Front time resistors, connected in parallel, are connected in series with the tail time resistors, connected in parallel.

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Figure 13: Impulse Generator

Figure 14 shows impulse generator as well but kind of new from HAEFELY HIPOTRONICS, 3 stage only

Figure 14: Impulse Generator [3]

Stage voltage:		20-30 kV
Stage energy:		5kJ
LI:	1.2±30%μs/50±20%μs,	efficient ≥90%
SI:	250±20%μs/2500±60%μs,	efficient ≥80%
CI:	2~6μs,	efficient ≥85%

Impulse voltage test systems can be used to generate standard lightning impulse (LI), full or chopped waves, switching impulse (SI) wave, impulse voltage ranges from 10 kV to 7200 kV energy from 2.5 kJ to 40 kJ. Also it can be used to carry out steeping and oscillating impulse test by adding some extra equipment

Figure 15 shows T1: Front resistor = 800 Ω and T2: Tail resistor = 2500 Ω. It is connected in series, and it must be 3300 Ω for impulse voltage test system to work in 20 kV.

Figure 15: Air resistor.

Figure 16: shows HV transformer output max 20 kV 5 MA.

Figure 16: HV Transformer

4 Test Area

4.1 Electrical Safety

Test area

The impulse voltage generator and all other live high-voltage parts must be arranged in a delimited test area that renders impossible any dangerous approach to parts carrying high voltage. Therefore the test area must be surrounded by a shielded safety loop (interlock) configured so that the test area can be entered only by interrupting the safety loop. In the case of permanently installed test rooms, all doors must be equipped with door contacts that break the safety loop when the doors are opened in the case of movable partitions in the form of metal mesh screens, a line along each mesh screen and plug-connectable to the adjacent mesh screen must be such that it is impossible to pass between the mesh screens without breaking the safety loop.

The design of a high voltage test area will need to comply with the requirements to perform partial Discharge (PD) measurements according to IEC, AEIC, UL and other high voltage standards. In all executed laboratory work, there were two red emergency lamps, which should be one green when test area is okay to work and the red one which means that test are in progress and you can´t get inside the area

4.1.1 Standards

SFS 6002 aims to ensure the best quality test area for the application according to SFS 6002 standard and other safety standard as well.

4.2 Disturbance for Equipment or for Measuring

How an error or a disturbance is indicated, is strongly depending on the used control unit. The corresponding information is therefore primary to be looked up in the manual of the control unit. Basic trouble shooting in case of an error disturbance, the error indication on the control unit should be regarded first. The interpretation of it and the resultant actions have to be taken from the manual of the control unit.

If overvoltage occurs at the power injection point, they can be reduced by the following actions: Route power cables along ground lines so that they do not combine with the ground conductors to form loops around the Impulse voltage generator (chiefly when grounding conditions are poor). Use shielded power cables. Use extra surge arresters in the injection.

4.3 PD Measurement Equipment

PD measurement equipment is a complement to high voltage testing and is an integral part of routine and type testing of numerous electrical devices. One of the most important non-destructive methods to detect insulation faults or defects in electrical devices. The breakdown of insulating material generally occurs at an internal weak point that has already previously shown partial discharge activity. For this reason it is an asset to be able to measure partial discharges in order to avoid costly damage. PD measurement is therefore used in quality assurance checks and diagnostics at the factory as well as during on-site testing of cables, GIS, power transformers and instrument transformers, or in rotating machines and their components[9].

4.4 Design /Layout

Layout

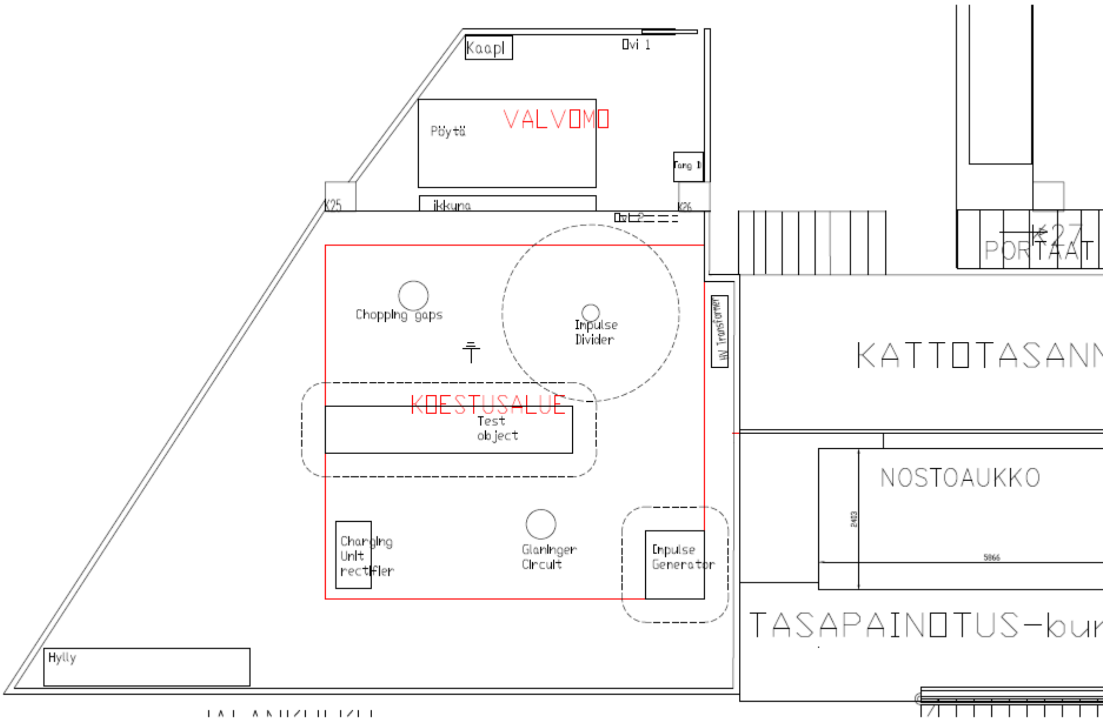

Figure 17: Layout of test area

Figure 17 shows ABB Test Area (Koestusalue in Finnish language in the layout drawing) and Control Room (Valvomo in Finnish language in the layout drawing) have not enough space to test impulse voltage test system equipment at the moment and the role to find out the best way to design the Test Area.

Before designing test area, cable ducts are put under the floor, check the incoming power, and factory earth are close to HV transformer and IG charger. Perhaps swap place for IG divider to be closer to HV transformer. The divider is the best start point for the grounding system and is better to be close to test object, and HV AC system. Moving IG and charger to the left side of the test area or right does not matter[3], the only requirement is to be far away from the wall. Regarding floor, prefer steel flower when possible. This is the best, low inductive, and floor. It also reduces PD interference. Otherwise it could use any painted/epoxy floor and make a visible and effective earthing system on the floor with copper bands, supplied with IG system. The risk is that the bands get damaged after some time and must be replaced. The fence around test area is only for safety and it will stop all electrical fields to only be in test area. Height of 2.5 m, 3.5 m, or even more is enough.

Make sure that the test area, temporary or forever, will have enough space, how tall is the wall and how long. When design Test Area wall for safety 3.5 m, and for safety distance as SFS 6001 defines 0.4 m from the wall. Test area designed for impulse voltage test system by HAEFELY HIPOTRONICS HV Transformer should be close to income power of factory, impulse divider and chopping gaps the first thing to plane it should be 1.5 m far away from the wall and same safety distance between divider, specimen and chopping gaps 1.8 m. 1.8 m safety distance for impulse generator 1.5 m. Impulse generator safety distance tall must be 0.5 m from the wall all material are movement. Design control room 2 door about 1 m (outside + inside), window glass about 3 m, all impulse voltage test system are connected tighter to get lightning impulse voltage. Insulation area: The floor of the test location must be prepared in a way that there is no sag under the load of the heaviest component. The impulse voltage generator is designed for indoor operation. The room must be clean, dry and must ensure an environment temperature between 5° and 45° C. The description that follows applies to indoor test facilities. If the equipment is de-signed for outdoor service with an insulating tower, the statements here must be modified appropriately with "test room" replaced by "test area”.

The ideal location for such a test system is a roofed space dedicated to the operation of this equipment and containing a permanently partitioned operator booth. The control area and test area should be accessible through separate entries and acoustically isolated from each other. The impulse voltage generator and the object under test must be visible from both areas.

If an enclosed room is available, the entry door must be monitored by a normally closed switch integrated into the safety loop of the impulse voltage generator control system so as to prevent the equipment being operated when the door is open. If no such space is available, one should be created by erecting mobile grounded partitions at least 1.8 m high. The partitions should have suitable electrical provisions, such as pluggable shielded two-wire cables acting in the same way as the door switch if the set of partitions is not closed or if gaps are present. If metal-mesh partitions are used, the mesh should have a clear opening of at most 40 mm.

If the impulse voltage generator is not permanently installed; it should be set up to provide the required wall standoffs W so as to prevent flashovers to walls or ceilings. In the case of lightning voltage, a rough calculation can be done based on a breakdown field strength of 5 kV/cm for the inhomogeneous field:

$$W = 002.0_{Max} \qquad (6)$$

Where W is in m and $U_{Max}$is in kV.[1]

Figure 18 shows the needed clearances around the impulse voltage generator. Because the voltage distribution is linear over the impulse voltage generator, the wall standoff W must be provided in the top area of the impulse voltage generator

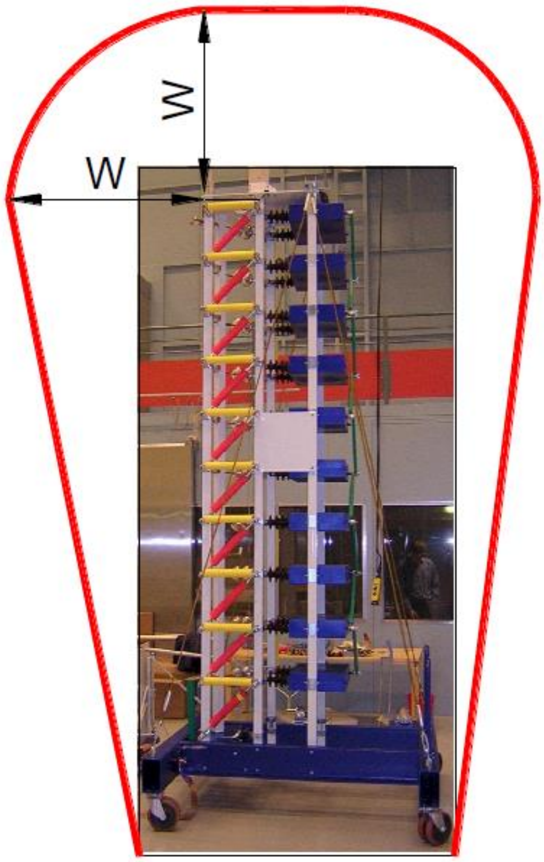

Figure 18: Minimum wall clearance[3]

For switching voltages up to 700 kV the recommended clearance can be calculated with field strength of 2.5 kV/cm.

$W = 0.004 \times U_{Max}$

Where W is in m and U_{Max} is in kV.

For higher switching impulse voltages the required clearance may not be calculated by using a mean field strength (as done above) but by the maximum field strength which may not exceed a critical value, which depends from the maximal voltage.[1]

4.5 Material Flow

The best options to flow material without any losses that we have to design special shelf for the coil has been tested and the new coils has arrive. The best place is next to the main door that is easy for income and outcome and build a wool to cover the coils only in the back and in the front that is for coils (Test specimen) and about the High Voltage test equipment i.e. HV Transformer. It is going to be in the same lace next to income power and about the “impulse voltage test system” equipment: charging unit, impulse generator, impulse divider Glaninger, and chopping gaps. The equipment is packed in wooden cases, electronic instruments are with a separate packing inside of the cases. The packing material have to be disposed of under consideration of the national ecological laws.

For cleaning, because the individual components are made by different materials, there can’t be given any general information about detergents and interval. Before any cleaning, the concerning instructions in the component manual have to be studied.

For training, before a person works with or on a system or its components, it is absolutely necessary to instruct him/her by a trained person. Education, if the system is operated irregularly, periodic training helps to prevent user faults and increases user security visibly.

5 Measurements and Results

Circuit design of impulse generators for the lighting impulse voltage testing of transformer. National and international standard stipulate a lightning impulse voltage of 1.2/50 µs when impulse voltage testing electrical equipment [5]. Small inductive load which are often experienced in practice when testing low-voltage windings of generator transformers, or when testing distribution transformers or reactors and HF Line traps often result in a time to half-value of 50 µs ± 10 µs according to standards being unobtainable with the conventional Marx impulse voltage circuit.

For this reasons, the regulations [7] provide that for earthling no connected winding across resistance of not more than 400 Ω, when testing transformers, with the result that impedance of the equipment under test and consequently, time to half-value, are increased. The resistance does, however, also influence the voltage distribution in the transformer.

The limitations of the impulse voltage circuit currently most widely used for obtaining the standard impulse voltages in inductive

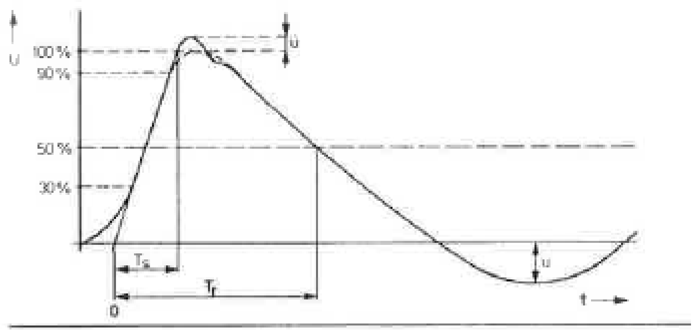

Figure 19: Definitions of 1.2/50 lighting impulse voltage [3]

T_S Front time | u Overshoot

T_r Time to half-value | U Undershoot

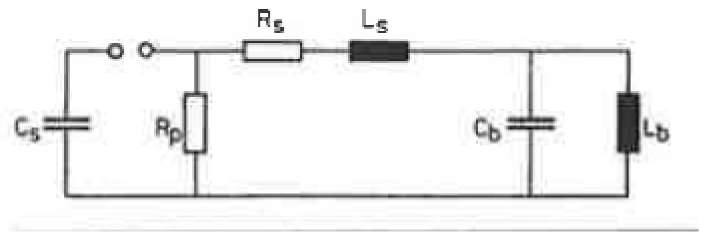

Figure 20: Single-stage equivalent circuit of a multi-stage impulse voltage generator [3]

C_S Surge (impulse) capacitance

R_P Parallel resistance

R_S Series resistance

L_s Stray inductance of generator circuit

$C_{b,}$ Capacitive loading, incl, capacitances of test object and voltage divider

$L_{b,}$ Inductive loading

Limits of Marx circuit for impulse voltage testing low-inductance equipment in compliance with international standards for lightning impulse voltage testing of transformers stipulate a 1.2/50 wave shapes, with the flowing permissible tolerance (Fig. 19),

Front time:	T_S = 1.2 µs ± 30%
Time to half-value:	T_r= 50 µs ± 20%
Overshoot:	u = < 5%
Undershoot:	u = < 50%

The mode of connection currently most commonly used for production of this wave shape is the familiar Marx multiplier circuit. The simple equivalent circuit shown in Fig. 20 is a sufficiently accurate representation for the purposes of this demonstrations [5].

Test object and measuring equipment are included in the values for inductive and capacitive loading L_b and $C_{b.}$ The characteristic values for lightning impulse voltage $T_{S,}$ T_r, u and u are a function of loading values C_b and L_b and circuit conditions L_S, R_S, R_p and C_S. For purely capacitive loading, keeping the time to half-value within permissible limits poses no problem. Discharge resistance R_p is chosen according to the capacitance C_S and C_b where by T_R ~R_p. (C_b+ C_S), and thus R_p allows keeping the time to half-value within the specified Limits for a corresponding range of C_b.Fig.21 shows an example of a range of capacitive loads Cb inside which the time to half-value is kept within standard tolerance for a given impulse capacitance Cs. In practice impulse capacitance is known. The discharge resistance R_P is chosen such that the time to half value is kept within standard tolerance for a given impulse capacitance C_S[6]. One ohmic value is sufficient for most practical applications.The time to half-value can be kept within permissible tolerance for practically any capacitive load C_b by means of additional parallel resistors.

Maintaining the front time, however, does pose a problem with purely capacitive test objects ($T_S \sim R_S. .C_b$). Beyond a certain capacitive load, the value of the resistance R_S has to be small that the resulting overshoot at the peak of the impulse would 5%. This means that the range of values of capacitive loads for which it is possible to obtain to obtain a permissible wave shape is limited by the stray inductance Ls, Which depends on the construction of the generator.

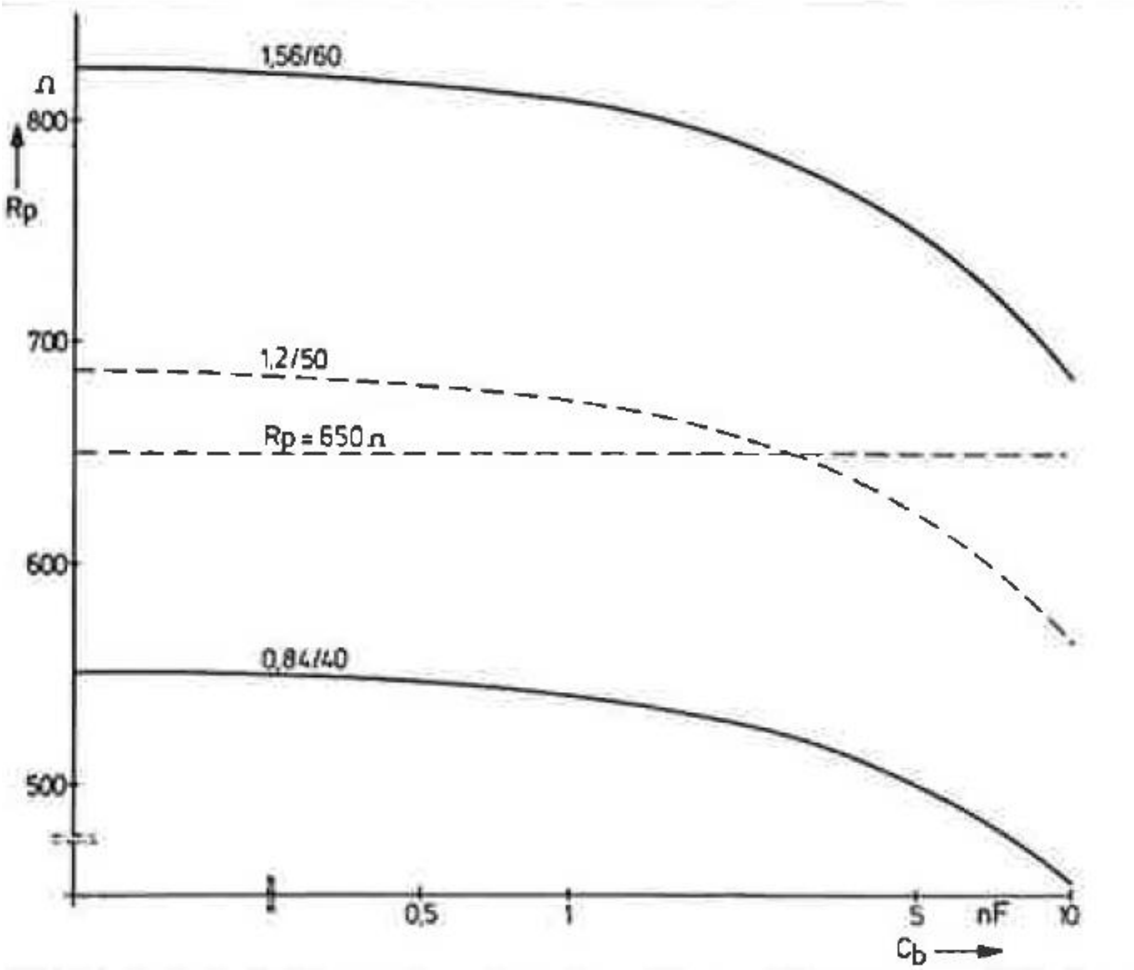

Figure 21: Tolerance limits of time to half-value for given values of paralel resistance R_p per stage as a functions of capacitive load C_b[3]

Example: 2 MV generator, 400 kWs, C_s = 100 Nf.

In this test applying 18 kV set of value of charge voltage of test interturn insulation 15 kV of the ball spark is applying five consecutive test voltage impulses between the two terminals of the sample coil, getting rise time 195tr/ms 1,5 tr/ns of coil 1 with tolerance from -0.1 ms to +0.3 ms and rise time is calculated according to IEC 60034-15 and with main insulations rise time 796,5 ns and half time around 50 μs.

6 Conclusions

Both the theoretical analysis and practical experiments have shown that generator circuit modified as per Fig. 22 (a) and (b) can deliver a lightning impulse within the permissible tolerances even under low inductive load conditions. Lightning impulse voltages can therefore be adapted for testing transformers with extreme characteristics to the recommended standards IEC 60010-10. The additional components needed to modify any modern impulse generator in this way are obtainable at low cost. The advantage of enabling of suggesting circuit offers the use of low-energy every stage generators of standard tests on transformers. The significance from practical and economic standpoint; generators could be optimally adapted to the energy requirements on the basis characteristics of the HV windings. Number of stages needed in parallel for testing low-voltage windings can also be reduced.

The SGSA is a complete system for Impulse voltage testing. It is not any high technology. Principle is a capacitor bank for voltage and energy. It is a package with resistors. When testing capacitive or inductive objects, it is needed to make make the RLC circuit to get correct wave shape according to IEC. Front time is adjusted with the front resistors, non-inductive with two layers contra wounded. It is mainly the test object and resistors to calculate. Tail time is adjusted with the tail resistors and it is mostly the SGSA capacitance that determine the tail. The HIAS is a sophisticated measuring system to fulfill all relevant standards and it communicates with SGSA controls to give exact voltage output.

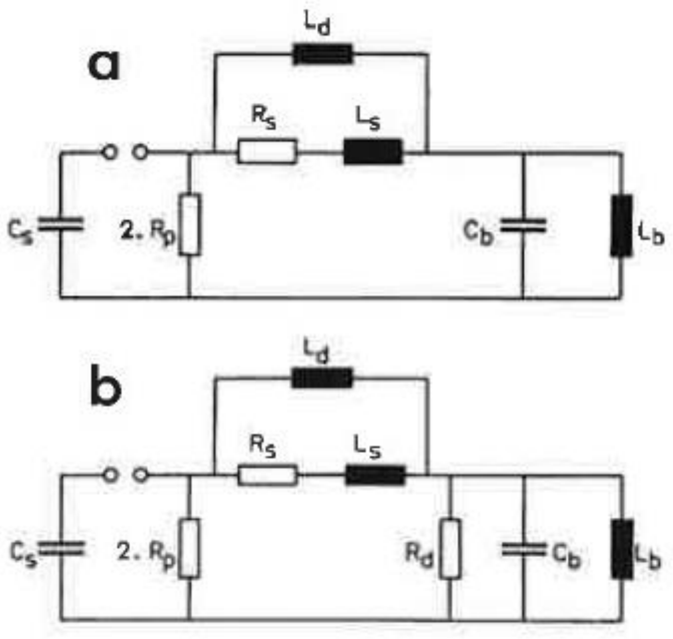

Figure 22: Single-stage equivalent circuits of a multiple stage impulse generator for standard lightning impulse voltage [3]

a Extended circuit for inductive loads of 4 mH<L_b< 15 mH

b Extended circuit for extremely small inductive loads of 0,4 mH<L_b< 4mH

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