

Advances in UHV Transmission and Distribution
Prof. B Subba Reddy
Department of High Voltage Engg (Electrical Engineering)
Indian Institute of Science, Bangalore

Lecture – 10
Basic philosophy of HV testing, tests for various HV apparatus

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Basic Philosophy of High Voltage Testing

In any electrical system/apparatus if the insulation system is intact – No failures

To achieve this- Insulation system & correspond conductor configuration must be appropriately designed.

The basic criteria are:

- (a) under all envisaged over voltage conditions, there should be no insulation failure
- (b) HV phenomena under working stresses must be below levels - **assure long life**.

So all high voltage testings have above basic philosophy.

High voltage tests are usually classified as:

- (i) Type tests -Intended to prove/check design features & quality- done on new samples
- (ii) Routine tests- to check the quality of the individual test piece and are done to ensure the reliability of the individual test objects, quality & consistency of the material used.

High Voltage tests include:

- (i) Di-electric tests with direct voltages
- (ii) Di-electric tests with a c voltages
- (iii) Di-electric tests with impulse voltages & impulse currents
- (iv) Tests with combination of above (v) Capacitance & tan δ measurements
- (vi) Pollution tests etc

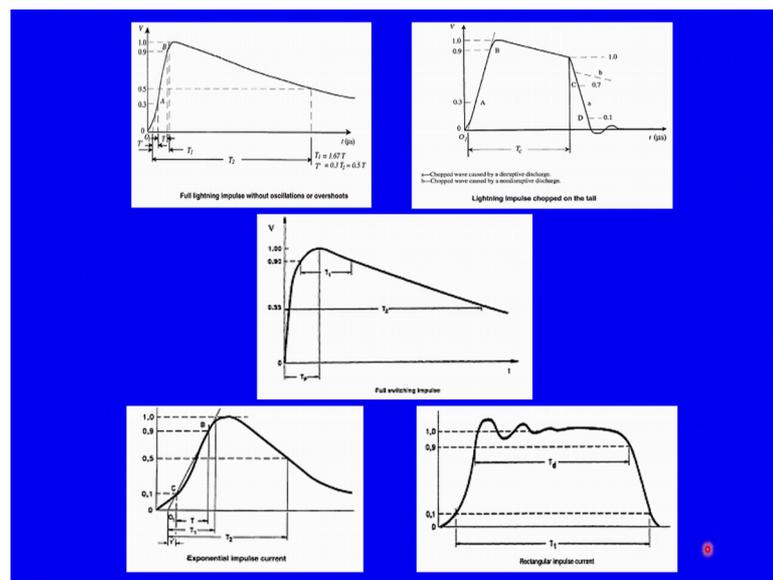
So, we have earlier looked into the basic philosophy and importance of high voltage testing's for the equipment these concerns the reliability. So, in any electrical system if insulation system is intact there should not be any failures. So, to achieve this; the insulation system and corresponding conductor configuration must be appropriately designed. So, the basic criteria being under all envisaged over voltage conditions there should be no insulation failure that is important fact to be noted here under high voltage a phenomena under working stress must be below levels though assure long life. So, that is very important the line which is designed the insulation which is designed for working stresses must be below the levels so that the life of insulation could sustain for about long period of time.

So, all high voltage tests have above basic philosophy and this as it we have try to mention about high voltage tests are usually classified as type routine and sample tests. So, the reliability of individual tests objects the quality and consistency of the material is to be done. So, high voltage or other reliability tests for the high voltage equipments I

include dielectric tests with direct voltages for d c equipment dielectric tests with A C voltages which are used for A C voltage levels of A H V or U H V dielectric tests with impulse voltage and impulse currents. So, impulse voltages could be lightning impulse or switching impulse voltages and impulse currents this could be lightning impulse currents which an a dielectric could see in the field because of the lightning activity both voltage and lightning currents are normally seen and the insulator has to withstand both the voltage and the surge currents because of the lightning.

So, these have to be test in the laboratory. So, tests with combination of above. So, apart from individual tests the combination of the tests have also been to be carried out and as discussed with capacitance (Refer Time: 02:32) measurements and pollution tests are also essential for better and long life of any insulating equipments.

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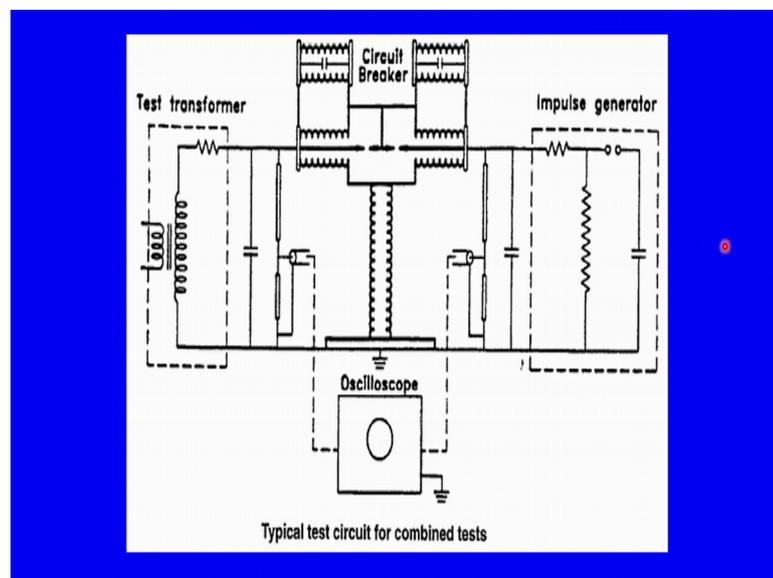


So, these surges yesterday we try to discuss surges are lightning impulse this is again a switching impulse this is a chop type of wave form these 2 curves are for the exponential impulse current. So, in lightning strikes lightning over voltages of this nature are seen that is 1.2 by 50 micro second 1.2 being different time and 50 being the real time switching surges because of opening and closing of circuit breakers you see 250 by 2500, the nature of surges could be of this in case lightning strikes I impulse currents are also to be phased by the equipment particularly like the surge arrestors or other a equipments there the exponential impulse current could be of this particular wave shape where the

front time could be 8 microseconds and tail time could be around 200 microseconds.

So, 8 by 20 is typical impulse current wave form which an equipment like a surge arrester or lightning arrester as to face apart from this surges like the rectangular type of impulses are also been seen in the on the lightning strikes this is known as rectangular type of a wave form where the magnitude could go and stabilize over a period of time and comes down. So, this may be for a few hundreds of thousand microseconds to milliseconds so this type of surges to appear in the field where the insulation material has to withstand.

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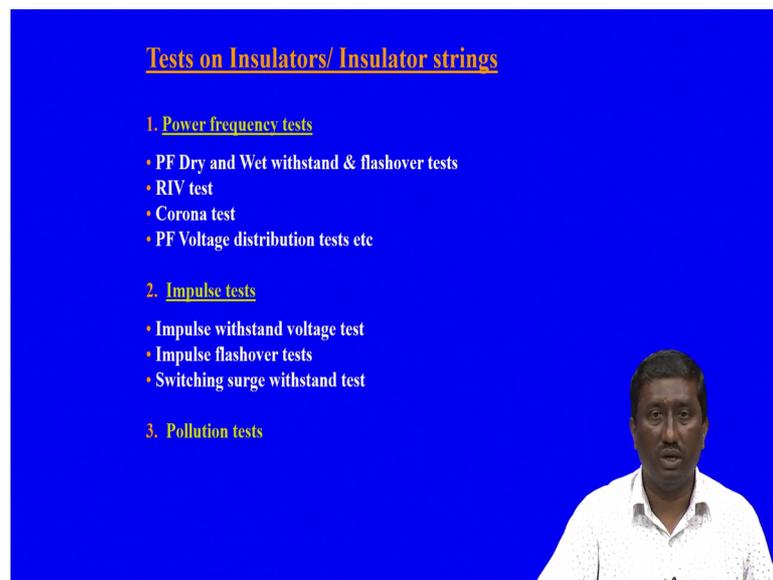


So, this is one arrangement for typical circuit for the combined tests we were talking about combined tests not only AC - DC particular tests in some of the cases we do require the combination of tests which simulates the natural conditions. So, this test is for a circuit breaker arrangement is made for circuit breaker where one side of the circuit breaker is connected to AC transformer with the measuring equipment like oscilloscope and so, on the other side is the impulse generator where the impulse voltage generator is connected.

So, the current the AC voltage is applied to the circuit breaker at its normal operating voltage or the specified voltage by the utility and the manufacturer of the rated equipment at the instant if the voltage will be applied on that voltage superimposed of the

lightning surges lightning surges could be lightning impulse from the impulse generator is applied for known applications. So, that the breaker performance is tested where during the normal functioning connected with the A C voltages in case there are surges or the impulses which are generated because of the lightning surges are applied and the verification for the circuit breaker is monitored and checked this could be withstand in the service.

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Tests on Insulators/ Insulator strings

1. Power frequency tests
 - PF Dry and Wet withstand & flashover tests
 - RIV test
 - Corona test
 - PF Voltage distribution tests etc
2. Impulse tests
 - Impulse withstand voltage test
 - Impulse flashover tests
 - Switching surge withstand test
3. Pollution tests

So, various type tests as per the international standards are being specified for different equipments which are used in high voltage and extra and ultra high voltage range. So, some of the tests include power frequency tests where these are operated at 50 hertz the power frequency dry, because for clean conditions and wet that is because of the rain which the equipment could see in the service.

So, this dry and wet conditions have to be similar to in the laboratory and the power frequency dry and withstand flash over withstand tests and the flashover. So, what is the insulation withstand with normal conditions when what is the withstand level for the wet conditions in case of the rain or the surface becoming wet and what is that flashover what is the ultimate insulation level of that equipment that is known as the flashover across that equipment.

So, these three that is the dry withstand and flashover tests are performed in case of power frequency second is radio interference voltage measurement why radio

interference voltage measurement we will discuss with the circuit the corona test which causes the visible discharges on the hardware or the corona control rings this is the creates not only the power loss, but the insulation could break down over period of time. So, corona test as to be carried out then power frequency voltage distributions.

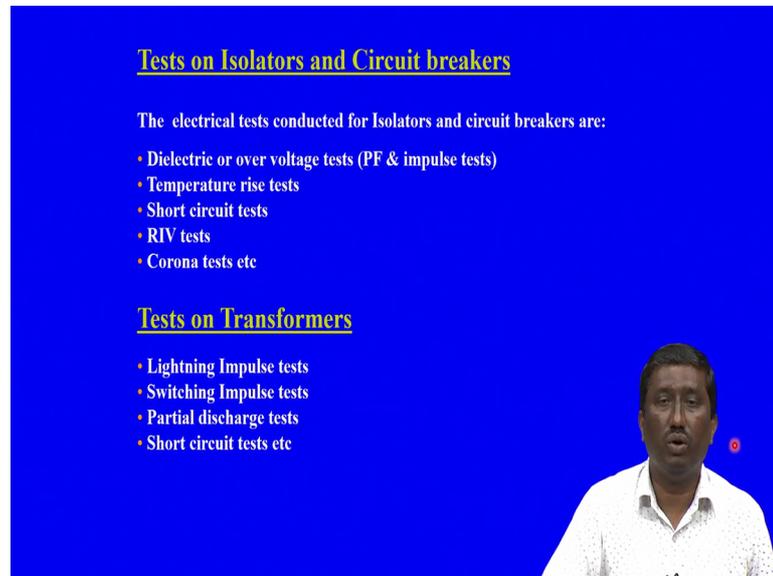
So, voltage distribution is generally carried out for the insulator strings insulator string at E H V and ultra high voltage the number of this discs which are connected on cascade will be in case 400 kV 23 to 25, in case of 765, it will be around 35 to 40 disc. So, where the distribution of potential across this insulator this have to be taking care else the insulators near the line and could feel more stress and they are the likely to have see more stress and could not may not able to sustain for a longer period of time. So, that is one of the reasons where the power frequency voltage distribution tests are to be carried out for long insulator strings that are the power frequency tests.

The second is a impulse is surge tests. So, impulse or a surge tests is again basically to see the withstand voltage level. So, for 2 20 kV what is the minimum impulse level which it has to withstand the standards of prescribed the values. So, those values as to be withstood by the equipment when a impulse of 10 application of both positive or negative or 5 applications what about the manufacture and the utility prescribe as per the standards the equipment should be able to withstand that number of applications and again impulse flashover. So, we impulse withstand all what is the voltage level is withstand when it could flashover the healthiness of a insulation when further the voltage level go on increasing. So, when is likely the flashover of that that destination also is being to be done for the severe effect in case the higher the voltage are seen by the equipment the flashover should not happen.

So, but this given estimation of how the insulation flashover and what is the level which could be compared with withstand and are the flashover then switching surge this is again a switching surge withstand test this is because of some of the tests which have combination I was mentioning earlier. So, combination of the closing and circuit opening of the circuit breakers with A C which is an continuous. So, there combination tests and a switching surge for a various insulators and also after the lightning arresters have to be carried out then pollution tests again are a contamination tests this is very important above extra high voltage levels.

So, the pollution or a contamination phenomena as to be simulated in the laboratories in and for the worst conditions the insulators have to be tested or the surge arrester have to be tested for pollution and tests in the laboratory.

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Tests on Isolators and Circuit breakers

The electrical tests conducted for Isolators and circuit breakers are:

- Dielectric or over voltage tests (PF & impulse tests)
- Temperature rise tests
- Short circuit tests
- RIV tests
- Corona tests etc

Tests on Transformers

- Lightning Impulse tests
- Switching Impulse tests
- Partial discharge tests
- Short circuit tests etc

So, what are the tests which are normally carried out on isolator and circuit breakers? So, the electrical tests conducted for isolator and circuit breakers are normally classified as dielectric or voltage over voltages tests again this dielectric or over voltage tests are of power frequency and impulse tests the temperature a rise tests this is monitored by applying this suitable voltage where the circuit breaker and isolator has to be in service and the rising temperature is monitored over specified period.

Then short circuit tests the how the performance of the isolator circuit breaker in case of short circuit that amount of current is applied to the equipment and it is verified whether it could withstand the surge currents during the short circuit of the network which could be same then radio interference tests as like earlier for insulator strings the corona tests. So, these are all again specified by the standard bodies tests and transformers have to be tested for the lightning surges lightning impulse 1.2 by 50 wave forms switching surges 250 by 2500 micro seconds.

Partial discharge tests to check any voids inside the transformer where the discharges specified should not exceed prescribed value. So, partial discharge measurements have to be conducted for the transformer and short circuit as in case of the short circuit

happening outside the current which the transformer sees could be should be able to withstand over period of time. So, this again a short circuit test on each phase and the ground for the transformer is normally the secondary shorted and they try to see; what is the capability of the transformer or it could withstand over a period of time.

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Tests on Cables

- Power frequency withstand tests
- Dielectric power factor tests
- Impulse withstand tests
- Partial discharge tests
- Life expectancy tests

Tests on Surge diverters/ Lightning Arresters

<p>(a) For Capped type arresters</p> <ul style="list-style-type: none"> • Power frequency spark-over test • Impulse spark-over test • Front of wave spark-over test • Residual voltage tests • High current impulse tests • Long duration tests • Operating duty cycle test • Switching surge flashover tests • Pollution tests 	<p>(b) For gapless type arresters</p> <ul style="list-style-type: none"> • Residual voltage tests • Reference voltage measurements • High current tests • Long duration tests • Operating duty tests • Thermal Equivalency tests • Pollution tests etc
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The for the cables you have a again a power frequency withstand tests it is very important then dielectric power factor tests in impulse withstand like lightning impulse partial discharge as mentioned earlier voids could be their during manufacture of the cables or because of some discharges which are insulation getting degraded over a period of time could distort giving the discharges on the insulation and these partial discharges could bring down the insulation level of the cable. So, this has to be tested then life expectancy this how; how long the cable could be in service.

So, there are again prescribed tests for this to estimate life expectancy for the service a suitable voltage and time with the acceleration factor is normally applied and a laboratories and the life expectancy measurement are carried out. So, coming to the surge di arresters or lightning arresters; so, surge arresters are lightning arrester are very important components in the transmission network this surge arresters are the important components which protect the major equipments like the transformer surge arrester circuit breakers how many of the substation equipment and also divert the lightning surges to the ground.

So, very important component in the transmission system; so, there for surge arresters the earlier days gapped type of arresters were being employed where the blocks of the arrester elements would be placed one above the other with spark gap which are known as gapped type of arresters basically this arresters were of silicon carbide. So, initially silicon carbide materials were used for the gapped type arresters the newer once which are known as the gapless type of are surge arresters. So, gapless type of surge arresters are the elements or the non-linear elements which are being employed are of zinc oxide material. So, earlier silicon carbide was used where the gapped type arrangement.

So, basically silicon carbide or the zinc oxide are non-linear type of a resistive elements which are being stacked one above the other zinc oxide as better characteristics in compare to silicon carbide that is how the technology has been migrated the zinc oxide. So, the gap type of arresters a following tests have to be carried out there is the power frequency spark over tests how the spark over happens when the power frequency voltage and how long the current; it may be able to sustain and how it could able to quiz the arc impulse spark over is the power frequency front of wave that is a 1.2 by 50 or the wave form which is being applied when is that exactly getting spark that is the front of wave as to spark so that voltage we have to apply and find out the values then the residual voltage are residual voltage is nothing but when the lightning strikes on the system surge arresters become active and it tries to see that the voltage over voltages are diverted to the ground.

During the conduction of the surge because of the surge natural lightning happening the conduction of high currents which are of higher magnitude the voltages developed which are of higher than the normal operating voltages have to be diverted to the ground during that process of the current being diverted the voltage which is developed across the resistive element or non least element of surge arrester is known as the residual voltage. So, that residual voltage has to be measured or tested. So, high current high current impulse tests again a lightning currents you have a wave forms of 8 by 24 by a 10 micro seconds. So, 4 by 10 constitutes a high current impulse wave form. So, this high current wave forms have to be applied and monitored for the functioning of the surge arresters the long duration's tests.

So in long duration again it depends on the transmission type of a model where the inductor and capacitors surfaced and the rectangle wave form which we have discussed

the rectangle wave form simulations is being done and that rectangle wave form simulation over a period of time say it in terms of a milliseconds with a certain magnitude has to be applied and performance of the arrester as to be check then operating duty cycle tests again it is the combination of a the operating cycle like in the field operating duty cycle involves the A C voltage which is continuously applied across the arrester then a impulse current for a particular voltage level a current level the impulse current as to be applied along with a continuous operating A C cycle.

So, the operating duty the functioning of the arrester is verified similarly switching surge switching surge here again you have a impulse switching impulse which are a generated and applied to the surge arrester switching surges are basically of 30 by 60 microsecond. So, 30 being the different time and 60 microseconds being the tel times so switching surges are applied for the arrester and they are verified.

The next being the pollution tests so, similar to the insulators the pollution tests are also being conducted for the arrester blocks arrester floriated the units are full arresters for gap type of arresters these are the tests which are being used. So, residual voltage as mentioned earlier reference voltage measurements we have to check how the arrester for the normal voltage levels the current which are the arrester a seize or the delivery during the operation the reference voltage which is applied and measured then high current tests similar to the gap is long duration operating duty is applied the thermal equivalency is one thing which is not available here.

The thermal equivalency is done for the gapless arrester because there is no gaps in between each resistive elements. So, the continuous of flow of leakage current in the field will be there it will be in terms of micro amps, but the temperature could increase over a period of time this temperature could heat up the disc and it could offer a lesser resistance and where the current flow could be more so that is the reason where thermal equivalency has to be established that again is prescribed has to be carried out over period of time how this a thermal equivalency performance of an arrester.

Then the pollution a tests pollution tests are similar to the method which is being followed for the insulator strings the contamination of the solution and whether going in for spray method or dipping method IEC 507, very clearly mentions about the various

pollution techniques to adopted in the laboratory for testing insulator strings and a surge arresters.

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Number of Discs in a String ?

SYSTEM VOLTAGE	SUSPENSION STRING	DISC RATING	TENSION STRING	DISC RATING
66 kV	6	45 kN	6	70 kN
132 kV	9/10	70 kN	10	120 kN
220 kV	14/15	70/90 kN	15	120 kN
400 kV	23	120 kN	23/24	160 kN
765 kV	40/35	120 kN/210 kN	35	210 kN

So, now we have a try to see the basic information about various type tests either which are being used at the industry or a manufacturing stage are also at certification laboratories now this slide gives you the information for various voltage levels how many insulator of different ratings are being normally employed this is a very information which is essential. So, has the voltage level goes up you can see for the system voltage of 66, you can see the insulators in the field 5 to 6 insulators are being used and disc rating could be 45 kilonewtons is a mechanical strength and in case of tension string this is for suspension normally 6 are employed tension also 6. So, 5 to 6 are employed and the disc rating could be 70 kilonewtons in case of tension string.

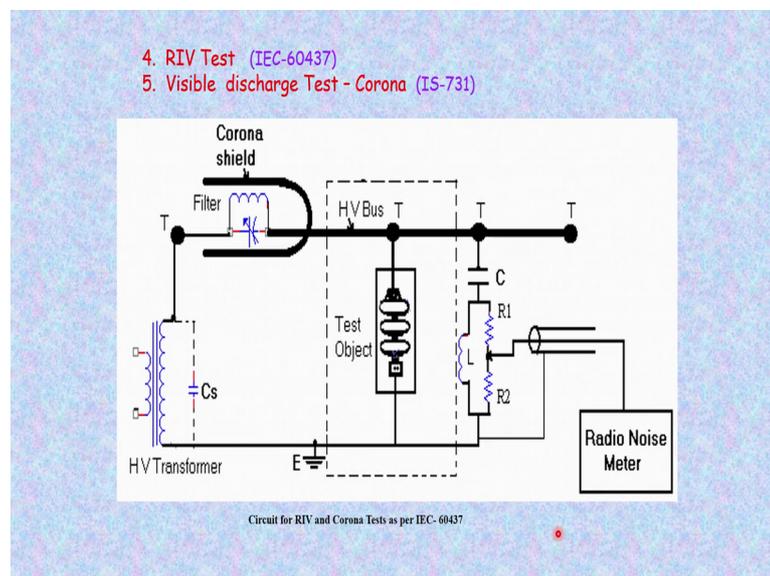
In case of suspension it could be 45 similarly for 132 kV nine or 10 discs are employed of 70 kilonewton rating and for tension 10 are employed of 120 kilonewtons. So, the mechanical strength requirement in case of tension slightly higher so, the disc employed is higher for 220 kilo volts 14 to 15 are employed in case of suspension and the mechanical strength could be of 70 kilonewtons or 90 kilonewtons and for at the tension strings for 10 to 20 kV, 15 numbers of insulators are used with 120 kilonewtons for 400 kV in a where between 23 to 25 or 24 are used depending upon the actual requirement in the area where the insulator string is used in case of suspension. So, the rating

mechanical rating will be 120 kilonewtons and for tension strings it could be 23 or 24 or sometimes 25 insulators of 160 kilonewtons, it has to carry more load in tension.

So, for 8000 kV and 765 kV depending upon the creepage of the insulators we either used 40 insulators if in case of 120 kilonewton or 160 kilonewton or 35 insulators of higher rating that is 2 hundred and 10 kilonewton or higher. So, this is how the numbers depending upon the creepage level are chosen. So, the desecrating again it could be in case if it is forty it could be 120 kilonewton or 160 or if it is 35 numbers it could be 210 kilo on and kilonewtons.

Now, some of the places where higher mechanical load is required so, they further go for 320 kilonewtons or 420 kilonewtons, in that case the number of insulators from 35 decreases to 29 or 30 numbers. So, either it could be 40, 35 or 29 to 30 depending upon the creepage and the mechanical strength of the insulators which are used. So, over tension usually if it is 210 kilonewton, 35 were used if it is 320 or 400 kilonewtons in the number gets reduced by 5 or 6.

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So, we come to the important tests which was we were earlier discussing about the radio interference a tests why this radio interference tests is very important very clearly specified in the I triple E; IEC standard international total ethnical commission standard 60437 very clearly, it will explains the importance of the radio interference measurements to be carried out for all the high voltage extra high voltage and ultra high

voltage equipments as these signals or the discharges which are happening on the surface hardware corona control rings this could travel and could create a problems with communication network.

So, very clearly the standard mentions the RIV measurements before it is being installed in the field have to be carried out anywhere between the frequency or range of 0.5 mega hertz to 2.5 mega hertz, this is the radio frequency band where the discharges could create problems to the radio networks. So, visible discharge or a corona this is described in Indian standard 731. So, where how to conduct the experiment by making the entire laboratory ambient should be complete dark the voltages is energies to the specified level of the equipment and the dischargers should be monitored on the equipment to be test.

So, in case of wherever the voltage when you are increasing the discharging inception starts it will be noted as inception of the corona discharges and the when the discharges out that known as the extension value.

So, this is the how the visible discharge experiments are carried out in the high voltage laboratory this circuit shows the radio interference measurement this is the bit similar to the partial discharge experimental setup. So, you see the high voltage transformer high voltage transformer this CS represent the stray capacitance because of the transformer from the pushing to the ground.

So, this is the connector you have a filter with a corona shield the filter is again a tuned to a certain frequency which has to be measured you have a high voltage bus the bus has which is shown as t is the termination are high voltage bus what we have shown here the high voltage connection should be enough to see that the discharges do not come the high volt from this conductor. So, which should not be communicated that to the radio noise meter, it should be sufficient enough where the discharges should not be when test object could be circuit breaker insulator string or any of these things.

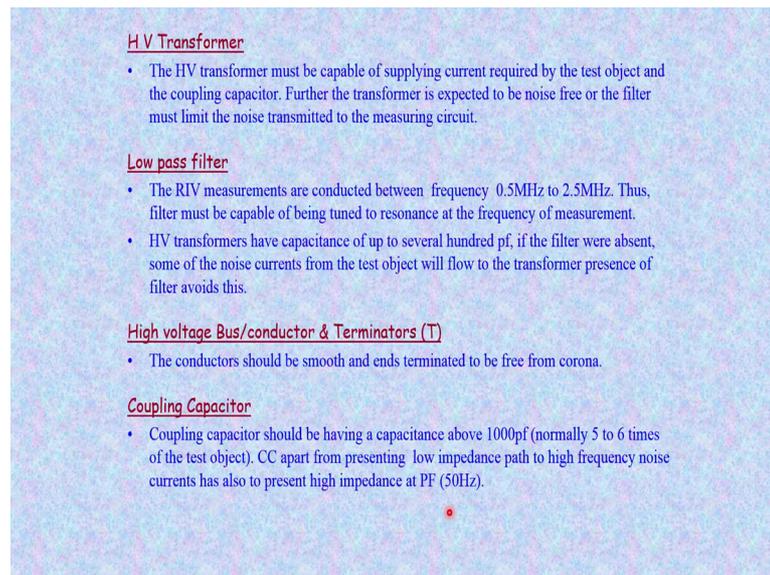
So, it is connected between the high voltage bus and the ground then you have a coupling capacitor again the coupling capacitor the requirements or a we will be discussing about that you have a coupling capacitor this coupling capacitor offers very high impedance at during power frequency voltages and at higher frequencies this will allow the discharges which are a being to be measure like the string which it is under tests or the equipment under tests the discharges which are being generated are communicated from this

through the capacitor and through the measuring impedance. So, measuring impedance have we have 2 arms R 1 and R 2 and this signal is being communicated to the radio noise meter which could measure radio noise in terms of decibels or in terms of micro volts.

So, this is a basic measuring circuit for RIV and a similar arrangement is made for the corona where in case of corona the entire laboratory is made dark and ambient that know ambient light is available then the voltage level is increased from lower value to the inception of the discharges on the sample and the extension also is noted. So, this is how the visible discharge is being done.

So, what are the important components of the circuit which we have shown here why what is importance and how the component should be tuned for other dis RIV test?

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H.V Transformer

- The HV transformer must be capable of supplying current required by the test object and the coupling capacitor. Further the transformer is expected to be noise free or the filter must limit the noise transmitted to the measuring circuit.

Low pass filter

- The RIV measurements are conducted between frequency 0.5MHz to 2.5MHz. Thus, filter must be capable of being tuned to resonance at the frequency of measurement.
- HV transformers have capacitance of up to several hundred pf, if the filter were absent, some of the noise currents from the test object will flow to the transformer presence of filter avoids this.

High voltage Bus/conductor & Terminators (T)

- The conductors should be smooth and ends terminated to be free from corona.

Coupling Capacitor

- Coupling capacitor should be having a capacitance above 1000pf (normally 5 to 6 times of the test object). CC apart from presenting low impedance path to high frequency noise currents has also to present high impedance at PF (50Hz).

So, high voltage transformer must be capable of supplying current which is required by the tests object and the coupling capacitor that is very important further the transformer is expected to be noise free. So, that is important if the transformer starts giving or a discharges or a noise this will be communicated to the tests equipment and further that would be next start with the signal which is measured. So, this should not happen it is should be noise say basically that is one of the reason where the filter is available in the circuit where this filter will limit the noise which is being transmitted to the measuring circuit.

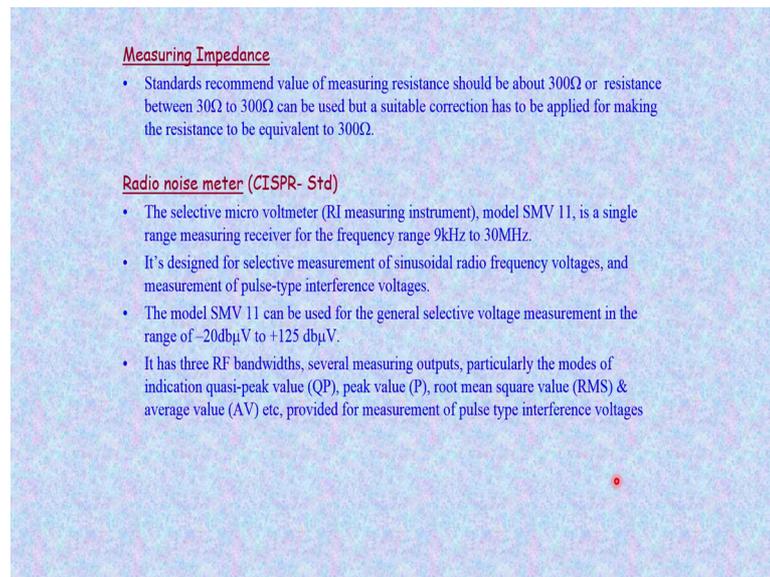
Then second comes after the transformer is a low pass filter which is being tuned the r I v measurement are conducted between as mentioned earlier frequencies between 0.5 to 2.5 mega hertz this is prescribed in the standard 437 as mentioned this filter must be capable of being tuned to resonance at the frequency of measurement.

So, the high voltage we know that transformers have capacitance up to several hundred picofarads. In case of filter were absent suppose some of the noise currents that is the noise generated by the transformer could be passed on to the test object and this will flow to the transformer the filter presents of this avoids the noise signals which are being communicated that is very very important and high voltage a bus conductor or terminators where are the t was mentioned in the circuit the conductor should be smooth there should no scratchers or no projections or no. So, that that itself should not be giving the discharges that is one of the reason where the conductor should be smooth and the ends properly terminated all the ends connecting ends should be properly terminated you cannot expose ends here and it should be where the discharges are likely to the happen. So, this ends or termination points have to be properly enclosed with the suitable shielding arrangement made.

So, coupling capacitor should be having capacitance above 1000 PF. So, whatever the coupling capacitor which is operating at one mega hertz or 2.5 mega hertz for the measurement the signals which are being generating that frequencies we should offer a low impedance and the signal should be transmitted the requirement is minimum it should be having a thousand of picofarad value it is normally 5 to 6 times of the tests objects. So, tests object in if it is in case of insulator string how many insulators are there in the; for 400 kV there are 23 to 25 insulators. So, each insulator typically around the 42 to 60 PF each case each insulator.

So, the capacitance which is measured the total capacitance of the insulator is taken in to consideration and 5 to 6 times of the capacitance of test object should be the coupling capacitor value that is the important point to be noted apart coupling capacitor apart from presenting a low impedance path to high frequency as mentioned it also present high impedance at power frequency. So, any power frequency is signals which are trying to come through the coupling capacitor will be blocked, because this offers very high impedance for power frequency signals. So, it should only operate for the higher frequency not at the power frequency.

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The measuring impedance which has been shown 2 different resistive elements the standards recommend the value of resistance this should be around 300 ohms, because the surge impedance of the transmission line is around 300 ohms that is the reason where the resistance or the impedance should be the measuring impedance should be 300 ohms, but it is again the standards allow the measurement could be made anywhere between 30 ohms to 300 ohms and suitable correction has to be applied for making equivalent to 300 ohms. So, this is clearly mentioned in the IEC 60437 standard.

The measuring equipment the radio noise meter which is being used for the measurements it as to be international standard as per the CIS per CIS PR is the international standard for radio signal measurements or a communication measurements. So, it as to adder through that particular requirement the radio interference measuring unit I should have a various arranges for the frequencies is in case. If it is required and various modules are available to be measured and here the options of measuring at peak quasi peak average several of these things are described to see that any changes or useful information could be obtained. So, the radio noise meter also to be international standard requirement for the measurement. We will stop.

Thank you.