

# High voltage Engineering

# High voltage transient Voltages

- Generation of high voltages

- HIGH-VOLTAGE testing equipment is generally used for
- **Research and Testing Purposes.**
- High voltage laboratory may include equipment for different classes of tests.

## ***Generation of High -Voltages***

The routine testing is concerned with testing equipment such as transformers, switchgear, bushings and cables, etc., and is often carried out on the factory premises, and the efficiency and reliability of the product are the main factors

The high voltage equipment is equipment to study the insulation behavior under all conditions which the apparatus is likely to encounter.

Tests are also made with voltages higher than the normal working voltage to determine the factor of safety over the working conditions and to ensure that the working margin is neither too high nor too low.

# *Generation of High -Voltages*

The conventional forms of high voltage in use can be divided into the following classes:

- (a) A.C Voltage (H.V.A.C)**
- (b) Transient / Impulse voltage**
- (c) D.C Voltage (H.V.D.C)**

# H.V.A.C

## a) *Transformers in cascade*

The power frequency transformer is the most common form of high-voltage testing apparatus and forms part of almost every testing laboratory

Testing transformers of the conventional type are normally designed for operation at the same frequency as the normal working frequency of the test object

## H.V.A.C

### a) *Transformers in cascade*

From the considerations of the thermal rating, the regulation and the kVA output, the design of a high-voltage testing transformer does not differ from that of the power transformer

However, the former is often subjected to transient overvoltage due to flashover of the object under test and its insulation must therefore be designed to withstand such surges

## a) *Transformers in cascade*

Although single unit testing transformers have been used for voltages up to 750 KV, the cost of such unit's increases rapidly with voltage

Furthermore, the problems of transport and erection become severe

These difficulties may be overcome by cascading several units where the high-voltage windings of all units are, in effect, connected in series and only the low voltage winding of the first transformer is connected to the supply



## a) *Transformers in cascade*

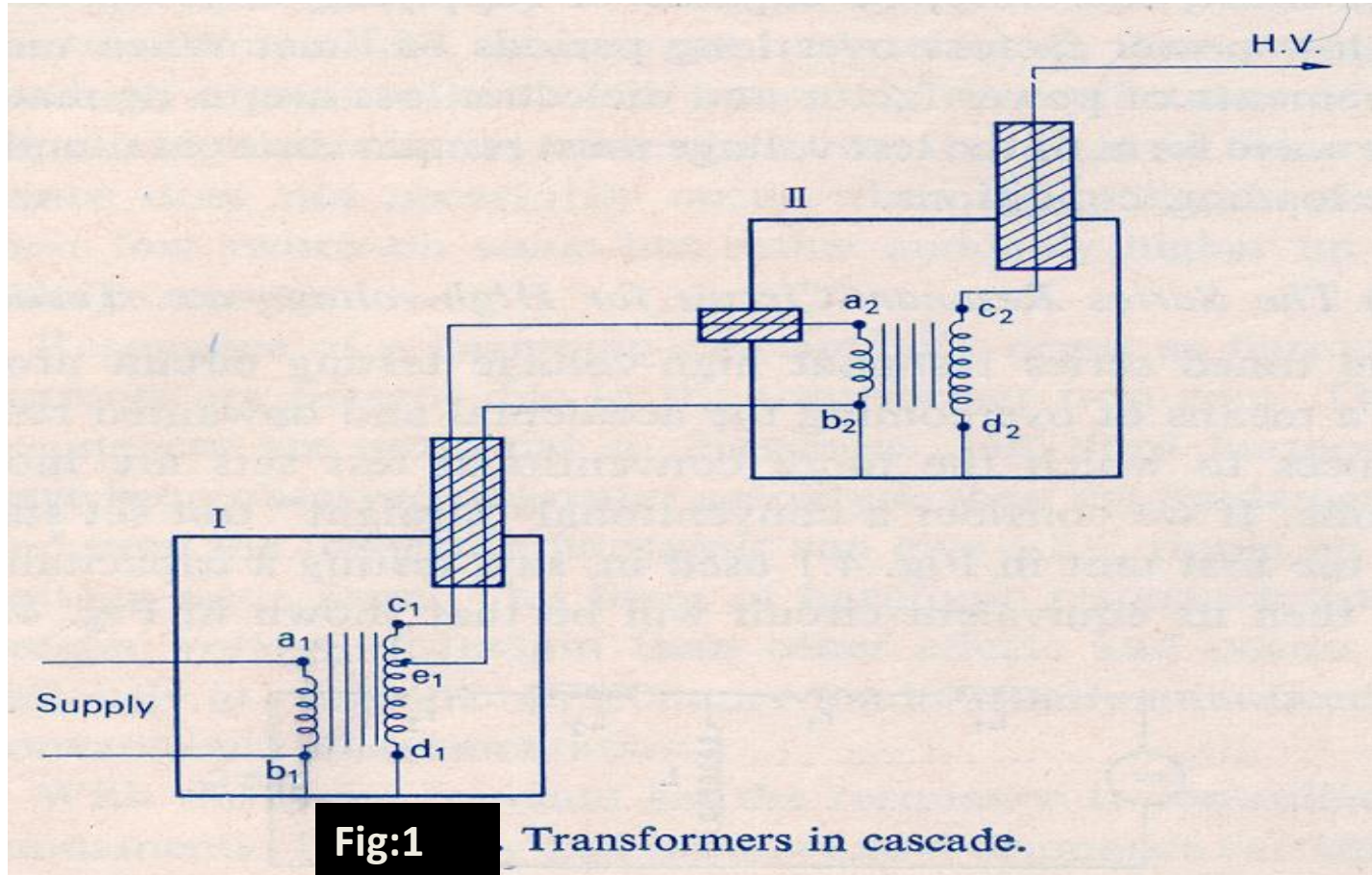
The basic scheme of connecting transformers in cascade shown in **Fig.1**

The low-voltage supply is connected to the terminals  $a_1b_1$  of transformer I, the tank of which is earthed

The end  $d_1$  of the secondary coil  $c_1d_1$  of this transformer is also earthed. The primary winding  $a_2b_2$  of transformer II is supplied from the tapping  $c_1e_1$  on the secondary winding of transformer I.

# H.V.A.C

## a) *Transformers in cascade*



## a) *Transformers in cascade*

The tapping is arranged in such a manner that the voltage between  $c_1e_1$  is equal to the voltage across the primary windings  $a_1b_1$

The end  $d_2$  of the secondary winding of transformer II is connected to its tank which is insulated from earth for the full secondary voltage of transformer I

The voltage available between the high-voltage terminal  $c_2$  and earth equals approximately the sum of the secondary voltage of the two transformers.

## **a) *Transformers in cascade***

Several such units can be arranged and the maximum insulation provided in any unit is, therefore, considerably reduced

The units generally of the core type and the insulation consists usually of bakelite barriers.

The output voltage is controlled by controlling the primary voltage of the first unit which is normally supplied through a voltage regulator

## a) *Transformers in cascade*

The characteristic requirements of a testing transformer depend upon the equipment to be tested

For tests on large transformers and generators which have a fairly high electrostatic capacitance, the testing transformer must be capable of supply large currents with good regulation

The high current rating of the transformer is not required when tests are carried out on bushings and insulator as the capacitance of the test piece in such cases is relatively small

## a) *Transformers in cascade*

Cable testing includes Long-periods in order to determine the temperature *rise* under the operating conditions

The testing transformer must therefore, be capable of supplying large currents at low power factors over long periods of time

When measurement of power factor and dielectric *loss* are to be made, the waveform of the test voltage must remain sinusoidal under all loading conditions

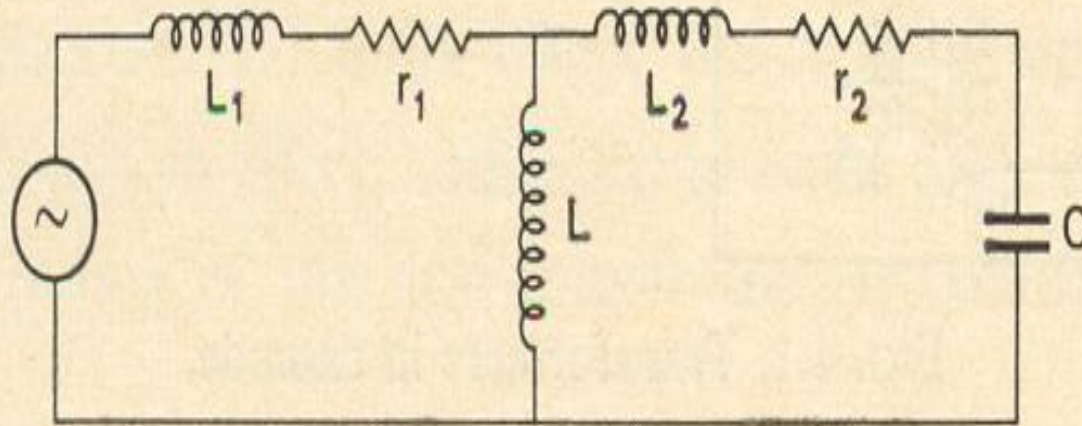
## b) The Series Resonant Circuit for High-voltage A.C Testing

The tuned series resonant high-voltage testing circuit arose as a means of overcoming the accidental and unwanted resonances to which the more conventional test sets are more prone

If we consider a conventional "straight" test set such as the first unit in **Fig.1** used in, say, testing a capacitance  $C$ , then its equivalent circuit will be that shown in **Fig.2**.

## H.V.A.C

### b) The Series Resonant Circuit for High-voltage A.C Testing



**Fig: 2**

Equivalent circuit of straight test set consisting of a transformer and test capacitance.



## b) The Series Resonant Circuit for High-voltage A.C Testing

In this circuit  $(r_1 + j\omega L_1)$  represents the impedance of the supply, the voltage regulator and the transformer primary.

$\omega L$  represents the transformer, shunt impedance which is usually large compared with  $L_1$  and  $L_2$  and can normally be neglected.

$(r_2 + j\omega L_2)$  represents the impedance of the transformer secondary.

$1/\omega C$  represents the capacitive impedance of the load.

## b) The Series Resonant Circuit for High-voltage A.C Testing

If by chance  $\omega (L_1 + L_2) = 1/\omega C$  accidental resonance occurs

At supply frequency the effect can be extremely dangerous as the instantaneous voltage application can be of the order of 20 to 50 times the intended high voltage

This can occur and has given rise to some vicious explosions during cable testing.

## **b) The Series Resonant Circuit for High-voltage A.C Testing**

The greatest possibility of this occurring is when testing at the maximum limit of current and relatively low voltages, i.e. high capacitive load

## b) The Series Resonant Circuit for High-voltage A.C Testing

Resonance of a harmonic can similarly occur as harmonic currents are present due to the transformer iron core

These resonances are not quite so disastrous, but third harmonics have been observed of greater amplitude than the fundamental and even the thirteenth harmonic can give a 5% ripple on the voltage wave form

This form of harmonic resonance causes greater voltage distortion than other effects and occurs at particular capacitance loads usually unnoticed by conventional instrumentation.

## **b) The Series Resonant Circuit for High-voltage A.C Testing**

With the series resonant set the resonance is controlled at fundamental frequency and no unwanted resonance can therefore occur

Historically, in the period 1935-45, due to the advent of light current engineering, power engineers were increasingly aware of the potentialities of tuned circuits

## b) The Series Resonant Circuit for High-voltage A.C Testing

The cable-manufacturing industry were particularly interested from the start, as amongst other features, the circuit offers power factor correction of the large capacitive load and cable lengths were steadily increasing

This early interest influenced the development of the circuit particularly for cable testing. More general applications were appreciated as time went on

The basic circuit is shown in **Fig. 3(a)**

It comprises the load-almost pure capacitance in series with a continuously variable inductance

The equivalent circuit is included in **Fig. 3(c)**  
The inductance is varied to match the impedance of the capacitive load at the supply frequency

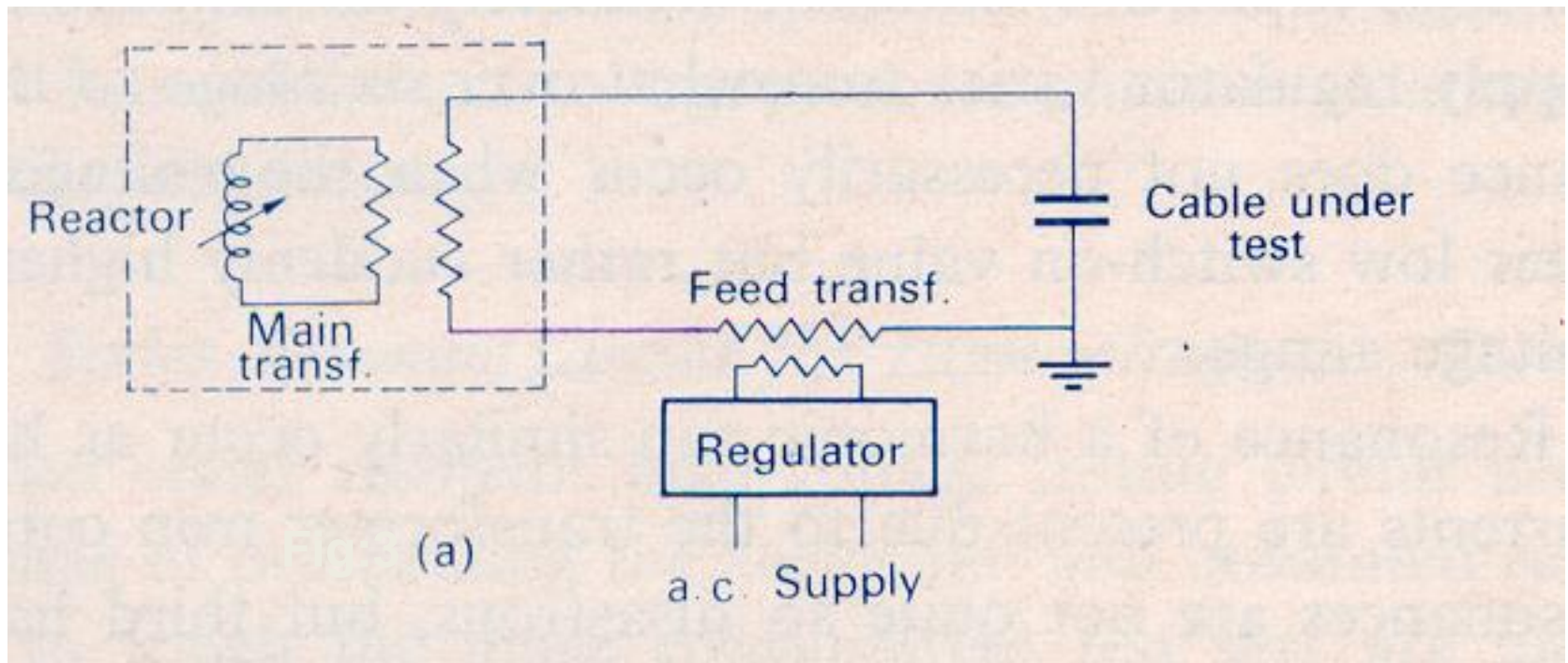
High voltages are then obtained by injecting current into the series circuit

Control of the high voltage is obtained by regulation of the supply current.



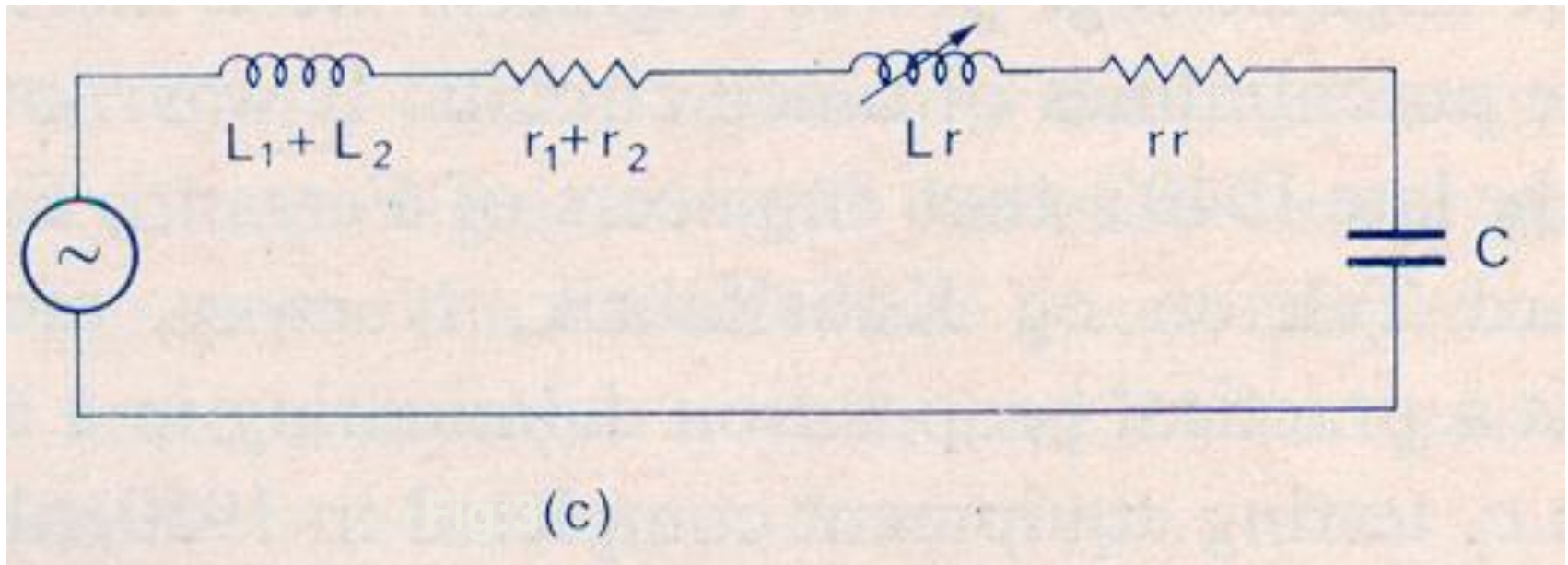
# H.V.A.C

## The Series Resonant Circuit for High-voltage A.C. Testing.



# H.V.A.C

The Series Resonant Circuit for High-voltage A.C Testing.



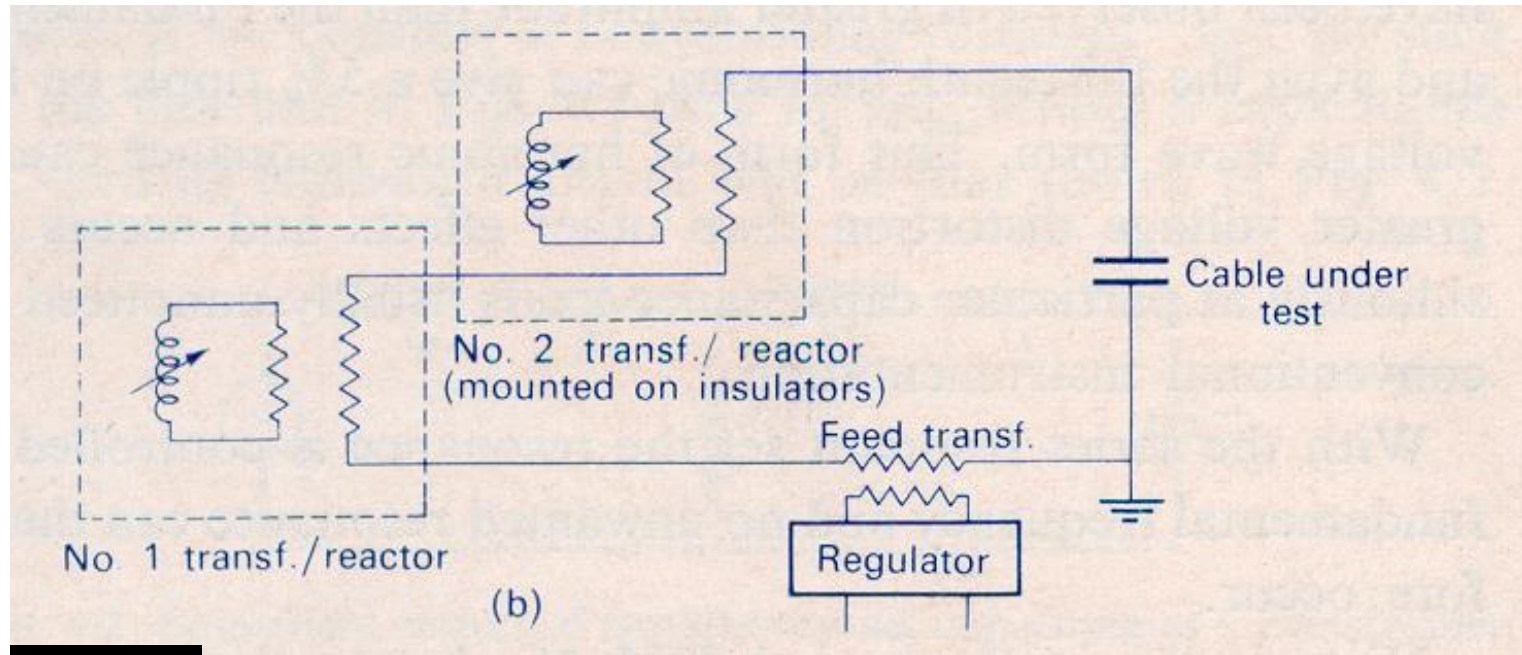
## H.V.A.C

### b) The Series Resonant Circuit for High-voltage A.C Testing

- The only modifications necessary to make this practical are those imposed by high voltage considerations, e.g. it is impossible to make a high voltage continuously variable inductance
- For this purpose Ferranti Ltd. developed a moving coil reactor which provides LV step less inductance variation with a step-up transformer incorporated in parallel to match the voltages (see diagram)
- Also the supply regulator supplies the main circuit through a feed transformer for similar reasons. To obtain very high voltage, two or more transformer/reactor units may be connected in series as shown in **Fig. 3(b)**.

# 1. H.V.A.C

## The Series Resonant Circuit for High-voltage A.C Testing



**Fig: 3** (a) Simplified diagram of series resonant circuit for single transformer/reactor unit. (b) Simplified diagram of series resonant circuit for two or more units in series. (c) Equivalent diagram of series resonant circuit.

# ***Additional Advantages of the Series Resonant Circuit***

1. The voltage wave-shape is improved not only by the elimination of unwanted resonances, but also by attenuation of harmonics already in the power supply
2. A practical figure for the amplification of the fundamental voltage amplitude on resonance is between 10 and 20 times
3. Higher harmonic voltages are divided in the series circuit with a decreasing proportion across the capacitive load
4. It is easily seen that harmonics in the supply become insignificant. Good wave shape helps accurate h.v. measurement and is very desirable for Schering Bridge work

## ***Additional Advantages of the Series Resonant Circuit***

- The power required from the supply is lower than the kV A in the main test circuit
- It represents only about 5% of the main kV A with a unity power factor.



# *Additional Advantages of the Series Resonant Circuit*

- If a failure of the test object occurs a power arc does not develop. Instead the voltage collapses immediately the load capacitance is short-circuited
- This has been of great value to the cable industry where a power arc can sometimes lead to the dangerous explosion of the cable termination
- Additionally, as the arc is self-extinguishing due to this voltage collapse, it is possible to delay the tripping of the supply circuit
- This results in a recurring flashover condition with little energy, thus making it simple to observe the path of an air flashover

# ***Additional Advantages of the Series Resonant Circuit***

- The series or parallel operation of multiple-transformer units is very simple and efficient with the series resonant circuit
- Any number of units may be put in series without the high impedance problems associated with a cascade group
- The volts across each unit are equal with equal reactor impedances unlike the similar "straight" cascade group which has considerable voltage regulation differences between units
- For heavy current testing it is possible to parallel transformers of different impedance merely by controlling each associated reactance.



## ***Additional Advantages of the Series Resonant Circuit***

- High-voltage connections are very simply made on multiple units-no heavy bus bars are needed, only a single small gauge wire to carry the h.v. current.

## ***Additional Advantages of the Series Resonant Circuit***

- The series resonant circuit has now been accepted for cable testing at all the main British manufacturers and is increasingly being used in other countries
- Many other laboratories have also adopted the circuit for general applications
- A few have adopted variations of the basic circuit to meet particular requirements, e.g. Lv. feed current with series resonance in the Lv. circuit-the transformer h.v. winding being in parallel with the load capacitance and the Lv. winding in series with the reactor.

## ***2. Transient / Impulse Voltage***

- Studies of transient disturbances on a transmission system have shown that lightning strokes and switching operations are followed by a traveling wave of a steep wave front
- When a voltage wave of this type reaches a power transformer it causes an unequal stress distribution along its windings and may lead to breakdown of the insulation system
- It has, therefore, become necessary to study the insulation behavior under impulse voltages.