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General Characteristics of Gaseous Insulation

Air or other gases to some degree or other are always present in all insulation constructions. Busbars of distribution networks, conductors of transmission lines, high voltage leads of transformers and other apparatus are insulated from one another by air spaces in which air plays part of the only insulating substance. Post insulators of sub-stations, suspension insulators of transmission lines and other insulation constructions are situated in air medium. Failure of electric strength of insulators and insulating constructions can take place by way of puncture of solid di-electric from which the insulator is made or by way of development of discharge in air along the surface of the solid dielectric. Since puncture of dielectric leads to complete removal of the insulation from the system and flashover along the surface in majority of the cases does not cause appreciable harm to the insulator, the puncture voltage of the insulator is always attempted to be kept higher than the flashover voltage along the surface. In this way, the real electric strength of very large number of insulation constructions is determined by the electric strength of air, the magnitude of which acquires important significance in principle.

But air or any other gas not only has importance as a natural gaseous medium in which the insulation construction is situated as was the case in the examples given above. Gas can also be used as one of the basic insulating materials in cables, condensers and other electrical apparatus.

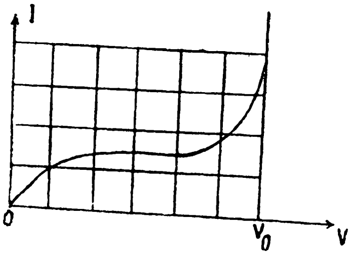

Fig. 1·1. Relationship between current in the gas and voltage between the electrodes.

The main shortcoming of gaseous insulation is its insufficient electric strength. For example, a layer of air 0·5 cm. in thickness withstands a voltage of the order of 17 KV, but a layer of pure transformer oil of the same thickness withstands about 150 KV. Therefore desirability of use of gaseous insulation is intimately related to the possibility of increase of its electric strength.

The electric strength of a gas increases with increase in pressure from atmospheric to higher values. For example, the same layer of air 0·5 cm. in thickness at a pressure of 15 atmosphere (here and later the pressure is absolute) will have a strength of about 190 KV, *i.e.* more than that of transformer oil. On the other hand, it is well known that the strength of air also greatly increases in high vacuum. Good dielectric properties of high vacuum are widely used in electronic equipments and in many other special equipments. High vacuum at present is rarely used in the industrial insulation. The fact is that gas in the insulation constructions is always used in combination with other insulating materials which, being in contact with the vacuum, give out gases, and in this manner, cause an increase of pressure and decrease of insulation strength. In such constructions, it is practically impossible to maintain vacuum and in industrial insulation increased pressures, and not high vacuum, are advantageously used for the increase of electric strength.

Gas used as an insulation must satisfy the following basic requirements :

(*i*) gas must be chemically inert and should not react with dielectrics, in combination with which it is used, and with other materials used in the construction of the apparatus ;

(*ii*) during the ionisation of the gas, which to a certain degree is always possible in high voltages apparatus, chemically active substances should, similarly, not be emitted ;

(*iii*) gas must possess a low temperature of liquefaction ; since otherwise, it will not be possible to use it at increased pressures (with the increase of pressure temperature, at which the gas changes into liquid, increases) ;

(*iv*) the gas must possess as high as possible electric strength and high heat conductivity. The last one is specially important in those cases when the gas simultaneously serves as an insulating as well as cooling medium ;

(*v*) the cost of gas must be sufficiently low, so that its use is economically justified.

Air has great advantage from the point of view of low cost ; therefore, it found some application at increased pressures in condensers, cables and other insulation constructions. But, it does not satisfy the second requirement, since ionisation of air is accompanied by emission of ozone, nitrous and nitric oxides causing intensive corrosion of all metallic parts of the apparatus and oxidation of organic insulation, which causes gradual lowering of its insulating properties. Therefore, nitrogen is often used instead of air. Nitrogen has equal electric strength, low cost and is inert.

In order that the electric strength of air or nitrogen may be made comparable with that of solid or liquid dielectrics such as oil, porcelain, mica etc., the pressure in these gases should be raised to 10-15 ata. Application of such high pressures, naturally, complicates all construction and creates serious difficulties in operation. Therefore, recently serious attention is devoted to different gases having electric strength much greater than that of air or nitrogen. Some of these gases are listed in Table 1·1.

TABLE 1·1.

Relative electric strength of some gases.

Gas	*Chemical formula*	*Electric strength relative to air*	*Liquefaction temperature C°*
Air		1·0	
Hydrogon	H_2	0·6	
Nitrogen	N_2	1·0	
Sulphur-hexaflouride	SF_6	2·5	−62
Freon (Dichloro-diflouro mothane)	CCl_2F_2	2·5	−30
Trichloro-flouro methane	CCl_3F	4·5	+49
Tetrachloro methane (Carbon tetrachloride)	CCl_4	6·3	+76

Last two gases have a very high electric strength. But (CCl_4) tetrachloro methane is a gas at normal temperature and in the gaseous form, under the action of ionisation, it decomposes by emitting carbon which rms a conducting layer on the surface of solid dielectric, and chlorine which corrodes metallic parts of the construction. On account of high liquefaction temperature and chemical activeness in the presence of ionisation (CCl_3F) trichloro-flouro methane, having electric strength 4·5 times higher than that of air, also did not find application.

Two gases freon and (SF_6) sulphur hexaflouride are most widely used as insulating mediums. They have almost equal electric strength. Both these gases are chemically inert but, during ionisation, they emit a small quantity of chemical substance giving rise to corrosion. The advantage of (SF_6) sulphur-hexaflouride is its comparative lower temperature of liquefaction which permits its use at pressures upto 20 ata. while freon can be compressed upto 6 ata. But even at a pressure of 3 ata., use of which does not present appreciable technical difficulties, the withstand voltage of a 0·5 cm. thick layer of freon or (SF_6) sulphur-hexaflouride reaches a value of 140 KV, *i.e.* is of the same order as transformer oil.

The common shortcoming of both these gases is their high cost which, however, is appreciably decreased during mass production.

The ideal gas consisting only of neutral molecules does not at all conduct electric current. In actual gases, because of different external influences (ultraviolet radiations of the sun, radioactive radiations of the earth, cosmic rays etc.) a small quantity of ions and electrons which impart the gas a definite conductivity, are always present. For example, in one cubic centimetre of atmospheric air, a few tens of pairs of ions which recombine with each other after some time and again turn into neutral molecules, are created every second. If a d.c. voltage, the value of which can be varied, is applied to the gas space with plain electrodes, ions begin to move along a line of force of the field giving rise to a current I in the external circuit. As the applied voltage is increased this current increases because increasingly greater part of the ions is able to reach the electrodes without recombining in the space. After this, saturation sets in, as in electronic valves, when ions practically do not recombine in the space, and if the voltage is further increased, the current starts increasing again which testifies to the process of ionisation already started in the gas under the influence of electric field. This process develops very intensively and at a certain value of the voltage a sharp increase of current, testifying to a sudden qualitative change in the condition of the gas takes place. This voltage is called "the breakdown voltage" of the gas space and, when this voltage is reached, the gas loses its dielectric properties and turns into a conductor.

The following peculiarity of passage of current through a gas is also very important. At a voltage lower than the breakdown voltage, an indispensable condition of the passage of the current is the presence of an external ioniser which continuously produces electrons and ions in the inter electrode space. If this external ioniser is taken away, the current immediately ceases to flow in the space, and ionisation under the action of the forces of electric field, also ceases. The process is not "self-maintaining one" *i.e.* it can not maintain itself only at the expense of internal resources of the gaseous space. At a voltage equal to the breakdown voltage, the process becomes self-maintaining in character, *i.e.* it does not, any more, depend upon the help of the external ioniser. Therefore, it is often said that the condition for change over of the discharge into a self-maintaining one, is also the condition of the breakdown of the space.

As is well known, a gas can have high conductivity only, in a special condition called "plasma" when greater part of molecules of the gas is ionised; besides, the conductivity of the plasma increases in proportion to the increase in the number of ions, contained in a unit volume. The quantity of positive and negative charges in a unit volume of plasma is practically the same, ions being the carriers of positive charges and ions and electrons those of negative charges. The electrons contained in the plasma, by themselves, ensure its conductivity, nature of which is, thus, very similar to the nature of the conductivity of metals. The chief difference between a gas in the condition of plasma and metallic conductor is that in the plasma, charges of different signs are getting recombined with each other all the time, therefore, in the volume filled with plasma, process of ionisation maintaining a constant level of charges, should go on continuously. If it were not so, the gas will gradually return to its normal neutral condition. One of the basic mechanisms of ionisation in the plasma is thermal ionisation, produced on account of its high temperature which, in turn, is produced due to continuous collision of electrons moving under the action of field with molecules and ions of plasma. Larger the number of moving electrons, *i.e.* greater the current passing through the plasma, greater is its temperature, and consequently, conductivity also.

Thus, discharge in a gas is accompanied by conversion of all the interelectrode space or a part of it in the condition of plasma. The regime established during this can acquire different qualities depending upon the field (electric) configuration, power of the source and the gas pressure. The following types of gaseous discharges can be named.

"Decay discharge" occurs in the gap at small gas pressures, when the gas cannot acquire a high conductivity even with a high degree of ionisation because of insufficient number of gas molecules in a unit volume. Therefore, the absolute value of current passing in the gas cannot be very large ; the mutual action between the individual ions situated in the space is similarly not large. The decay discharge usually occupies all the space between the electrodes. Decay discharge, used in gas-light tubes and day light lamps and other devices are typical examples of this type of discharge.

"Spark-discharge" is formed in the gap at sufficiently large pressures p of the gas and distance S between the electrodes ($p \times S >$ 1000 cm. mm. of mercury column) in case the power of the source of supply is not large or the voltage is applied to the gap for a very short time. At high gas pressures, the discharge does not occupy all the crossed-section of the gap, but develops in the form of a narrow canal. The concentration of ions, in the plasma filling this narrow canal, can reach high values, therefore, sufficient current could pass through the canal, but its value is limited by the power of the source. On account of this, intensity of thermal ionisation in the canal can be insufficient for the maintenance of its conductivity and the canal of discharge collapses. This, for example, takes place with alternating voltage, when the discharge in the gaseous space occurs in the form of intermittent sparks, appearing one after another between the electrodes.

"Arc discharge" happens to be next stage of the spark discharge if power of the source is large. In this case, a large current promoting heating of the canal. increase of its conductivity and further increase of current can pass through the canal. Finally, a condition of equilibrium will be reached when heat losses from the canal stop further increase of temperature. This process is lengthy as a consequence of which, the spark-discharge does not pass into the arc discharge in the case of application of voltage for a very short time. The arc-discharge canal is, consequently, characterised by high temperatures and appreciable degree of ionisation of the gas.

"Corona discharge" is a discharge of its own kind characteristic of sharply non-uniform fields, when ionisation takes place only in a very small region of space in the neighbourhood of an electrode. Here electrode to electrode conducting canal is not formed between the electrodes of the gap. This eliminates the possibility of passage of a large current irrespective of gas pressure and power of the source. Thus, formation of corona discharge does not mean full loss of insulating properties by the gaseous space, however, formation of corona discharge in insulation constructions is not desirable. Formation of discharge in all gases takes place almost in an identical manner, although there are important differences in the details of the development of the process. In the following chapters, treatment is given mainly with respect to the most common gas, that is air ; but in chapter 6, experimental data for other gases will also be given.