

EARTHED VERSUS INSULATED NEUTRALS IN COLLIERY INSTALLATIONS.

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A great deal of attention has recently been attracted to the question whether a 3-phase colliery installation should work with an earthed or insulated neutral, and not only are there a number of supporters of both systems, but also a number of long-standing examples of each at work both on high and medium pressures, and with current taken in some cases from a supply company and in others from their own generating plant. Conditions vary so greatly in collieries and mines that what is suitable and perhaps necessary in one case may be absolutely dangerous in another. The principal advantages of each system are as follows :—

Earthed Neutral.

1. Maximum potential to earth of any phase limited to 58 per cent. of line voltage.
2. Leakage to earth probably results in isolation of the damaged circuit.
3. Leakage tripping devices can be used which switch off the supply when an earth occurs on one phase, reducing danger of shock and explosion.

Insulated Neutral.

1. Danger of shock and explosion is reduced, as contact with earth and one phase does not complete the circuit.
2. An earth on one phase does not cause an interruption of supply, for the same reason.
3. Stress on insulation under normal circumstances is less, and liability to flash to metallic casings considerably less.
4. Only two trip coils instead of three are required to protect each circuit where an automatic switch is installed.

Power taken from a Supply Company.—As the principal consideration is the safe operation of the underground plant, it is only proposed to consider briefly how the question affects generating machinery and transmission lines. Many collieries now take their power from a supply company, and where such an installation is connected without the

intervention of a transformer, advantages 1 and 2 of the insulated system are minimised, as an earth on any part of the supply company's mains (possibly in another colliery) will have the same effect as an earth on the installation, but be beyond its control. Under such circumstances, and particularly where the voltage is high, say 5,000 or over, it is probably better to earth the neutral so that a faulty installation is isolated, and the stress to earth on healthy plants kept permanently at 58 per cent. of the line volts. In a high-tension installation the factor of safety of installation is often small, and the sudden rise of pressure produced by an earth on one part of the system may damage the insulation of another part or cause a flash-over on motors. Where the supply is transformed the colliery circuit is a separately insulated one, and the above does not apply.

Generating Plant.—As far as the generating plant is concerned (where a colliery has its own supply) the earthing or insulating of the

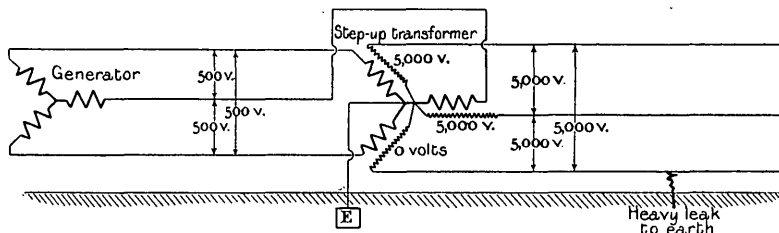


FIG. I.

1. Transformers connected star to star, neutral earthed, generator neutral unearthed.
2. Earth occurs on one phase and short-circuits it.
3. Voltage on shorted phase falls to zero, on other two rises to full-line volts, increasing stress on insulation of two phases in ratio of 58 to 100.

neutral makes very little difference, as although with alternators in parallel triple-frequency currents may give trouble with an earthed neutral, this can be got over by earthing the neutral of only one generator, or by the introduction of choking coils, and this point was discussed by J. H. Rider in a paper on the London County Council tramways.* The conditions, moreover, under which most colliery stations work are less strenuous than in those of a supply company, where interruption of the service affects a large number of concerns, so that the earthing of one generator at a time would probably work satisfactorily.

Transmission Lines.—As far as transmission is concerned, the question of earthed *versus* insulated neutral is a very open one indeed, especially on voltages under 20,000, and the President of the High Tension Committee of the American Institution of Electrical Engineers in opening the discussion on this subject put his conclusions as follows: "That some plants grounded the neutral, and its engineers considered it safe, and would never think of running in any other way, whilst the engineers of plants which did not ground the neutral would never think of doing such a thing."

* *Journal of the Institution of Electrical Engineers*, vol. 43, p. 235, 1909.

Where the neutral is earthed, it has sometimes been found possible in emergencies to keep up the supply with two lines and an earth return, while with an insulated system the supply can be maintained with an earth on one phase, if the insulation of the system has a sufficient factor of safety to withstand the full-line voltage between any part of it and earth. These points are of more importance on a supply company's system than on the average colliery installation.

Before considering the underground plant it is interesting to note that under certain conditions it is possible to get the full-line voltage to earth in two phases of a system even with the neutral earthed on both high- and low-tension sides of the transformers, if these are connected star to star, and the generator neutral is insulated. This is due to the

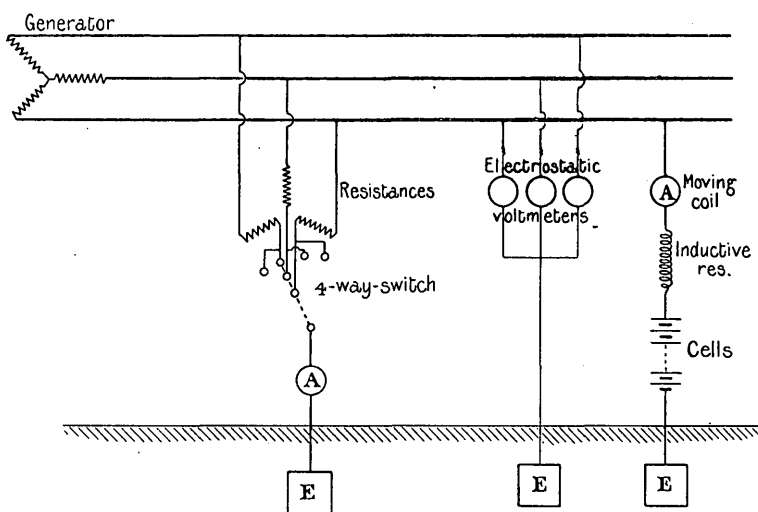


FIG. 2.—Various Types of Leakage Indicators.

instability of the neutral-point under such conditions, and is illustrated in Fig. 1. Very often the first indication of anything wrong is the arcing of the lightning arresters.

Underground Plant.—The chief considerations in the underground plant are safety as regards shock and explosion, reliability and simplicity in working, and cost both of the installation and maintenance of the same.

Danger from Shock.—Although even on a perfectly insulated system of large size, or working at high pressure, it is possible to get a severe shock from the capacity effect alone, and without any actual circuit being completed, there is no doubt that on such a system there is less danger of fatal results from accidental contact with one live phase and earth, and particularly so on medium pressure installations. It must be

noted, however, that very often on these medium-pressure systems the neutral-point is connected to earth through the resistance of the leakage indicator, the connections being as shown on Fig. 2. This resistance is generally designed to pass several hundred milliamperes, which is sufficient to give a fatal shock, and while it is, of course, much safer to get a shock in series with such a resistance which limits the current, this danger can be reduced by using the same electrostatic type of indicator usually supplied for higher voltages, or by the Nalder type of instrument which only passes a few milliamperes. Considered from this point of view there is no doubt that a system with earthed neutral presents greater dangers.

Limitation of Voltage.—With an earthed system the voltage between any point and earth cannot exceed 58 per cent. of the line pressure, but as fatal accidents have occurred with voltages as low as 150, this limiting of the voltage is not of any very great advantage, particularly in a colliery where the conditions are such as to make the men specially susceptible to the effects of electric shock.

Earthing of Metal Casings.—The best protection against the danger of shock from conducting bodies does not lie either in earthing or insulating the neutral, but in properly protecting or enclosing all live parts, and in efficiently earthing to the surrounding ground all motor frames, switch-cases, etc. The earth wire should be large enough safely to carry the load which will blow the fuses of the plant it protects, and it should be frequently tested for continuity. In a dry pit it is often difficult to get a good earth connection, and to meet this difficulty some engineers carry either a separate cable or core for earthing purposes only, but this method may possibly be a source of danger unless the system is also earthed underground, and Fig. 3 has been prepared to illustrate this. For example, on a 3-phase system with an earthed neutral, and an earthplate at the generating supply end, a leak takes place near the motor on one of the outers. This motor is at work in a more or less insulating stratum, so that the resistance from the ground to the earthplate at bank (except through the earth wire) is very high. The motor makes bad contact with the ground on which it stands, and there is a very considerable difference of potential between this ground and the motor. Any one standing on this ground and touching the motor-case will get a possibly fatal shock. If the neutral is insulated it is necessary to have a leak on one of the other phases at bank before the same conditions can apply. It may be thought that this is a rather exaggerated case, but a non-fatal shock on somewhat the same principle as outlined above, and due to variations in the resistance of the strata, occurred recently in a colliery in Scotland, and on measuring the resistance between an earthplate at bank and an earth connection at the bottom of the shaft, this was found to be 100,000 ohms. With regard to this question of earthing, Messrs. J. G. and R. G. Cunliffe* have shown that the resistance of an earthplate is often very considerable. By the kind permission of the authors

* *Journal of the Institution of Electrical Engineers*, vol. 43, p. 449, 1909.

several curves from their paper have been reproduced, and curve I. shows that quite apart from any question of the intervention of non-conducting strata (as mentioned above) the resistance between two plates each $1\frac{1}{2}$ ft. square, and arranged 200 ft. apart, may be about 30 ohms, so that a leakage current of a few amperes would cause a big drop in potential. Another very important point is that nearly 50 per cent. of this drop occurs within 3 ft. of the plates (curve II.). It appears all the more necessary, therefore, in earthing the metallic dead portions of any system to provide several earthplates distributed

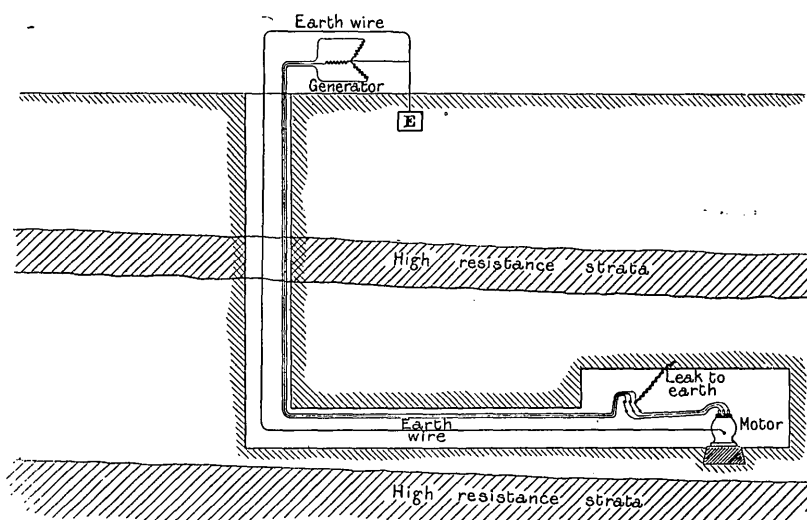


FIG. 3.

1. Motor at work in high-resistance strata, or in motor-room with such strata intervening, both above and below, between earth-plate at bank. No earth-plate underground.
2. Leakage or earth on one phase at same level as motor. Latter on concrete foundations insulated from surrounding ground, and maintained by earth-wire at same potential as earth-plate at bank.
3. Considerable difference of potential between motor and surrounding ground, with possibility of shock due to phase volts.

over the installation. Curve III. shows that there is no great advantage in making each plate more than about 4 sq. ft. in area.

Danger of Faulty Insulation.—There is, however, a possible danger of shock which cannot be guarded against in this way, and that is by coming in contact with faulty insulation, such as an unarmoured damaged cable. With an earthed system shock as before is certain, with an insulated system it is likely to be less severe. Where cables are armoured or enclosed in a metallic covering this danger cannot occur as long as the *armouring or cover are efficiently earthed and electrically continuous*. If, however, a careless jointer leaves the armouring disconnected after a hurried repair, or the armouring is eaten away

by bad water, etc., the conditions are now more dangerous than before, as an earth may cause a considerable length of armouring to be alive, any part of which will give a shock. For this reason many colliery engineers object strongly to the use of armoured cables as being likely to produce a false feeling of security.

Danger from Explosion.—It is very doubtful whether many colliery managers would instal electric plant at all in places where there is real and constant danger of inflammable gas or coal dust, as it seems fairly certain from recent experiments that an arc or flash with any moderate amount of power behind it will ignite either gas or coal dust in suspension if present in suitable proportions. With an earthed neutral failure of the insulation of one phase to earth is practically bound to produce such a flash, while with an insulated system an earth on one phase shows on the leakage indicator, and there is, at any rate, a greater chance of isolating the section before any arc occurs.

Reliability of Supply.—It is sometimes desirable to run certain plant even although it may be in a damaged condition. The stoppage of, say, a main haulage gear will disastrously affect the day's output of coal—a matter of very great importance to the colliery manager—and very possibly if the plant can be kept going for a few hours till the end of the shift, the fault can then be remedied without disorganising the working of the pit. In many such cases it may be perfectly safe and advisable to run, and as the majority of failures of colliery plant are leakages to earth, an installation with earthed neutral is likely to give more trouble than an insulated system.

If leakage trips are indiscriminately used, it is probable that unnecessary interruptions from trivial causes may be sufficiently troublesome to prejudice the manager against electricity and lead him to adopt some other motive power.

Leakage Tripping Devices.—Several very interesting devices have been recently put on the market arranged to cut off current as soon as any leakage current exceeding, say, $\frac{1}{4}$ ampere flows. They are only designed for use on a system with a neutral earthed either directly or through a resistance, and the current at which they operate can be adjusted to different values on different feeders as may be required. It is claimed that by using such switches in connection with armoured cables danger from shock and explosion is largely avoided, and Mr. Wedmore* gave the results of some very useful experiments on cables which tended to show that with such a device and armoured cables it was very unlikely that a fall of the roof could so damage the cable as to cause flashing or arcing externally. Even without the leakage trips and with only the ordinary overload devices it appeared to be generally necessary to subject the cable to "successive blows of a heavy hammer" before flame occasionally issued, and apparently also high-tension supply was safer in this respect than medium pressure. In case a

* *Transactions of the Institution of Mining Engineers*, vol. 38, pp. 416-430, 1910.

cable were actually suddenly severed, it seems hardly possible that a flash of sufficient energy to ignite an explosive mixture could be avoided, whether a leakage trip was installed or not, and particularly if the point of failure was comparatively near generating plant of large capacity. It must be borne in mind, however, that many cables are run in places where there is no danger of explosion or of mechanical injury. It must be also noted that these devices depend absolutely on the continuity of the armouring or earthing being maintained, and if through carelessness or other cause this is not done they afford little protection against explosion and practically none against shock. A motor standing on concrete foundations is on a very good insulator, and if the earth connection is broken or inoperative insufficient current would flow to operate the leakage trip in case of leakage to the motor frame, which would then be raised above earth potential (Fig. 4). We have previously seen that as long as earth connections are kept in good

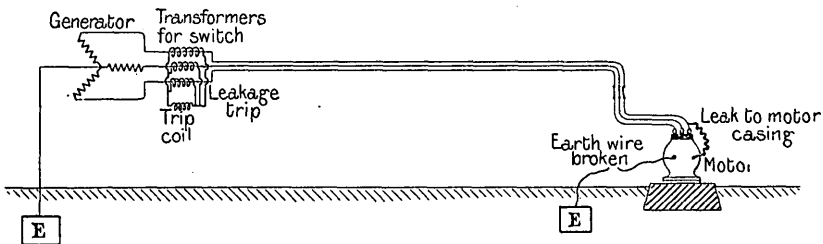


FIG. 4.

1. System with leakage tripping device, and earthed neutral.
2. Earth or leak on motor. Earth wire broken. Motor on concrete foundations, and practically insulated from earth, hence tripping device inoperative.
3. Motor frame at potential of one phase, with possibility of shock to surrounding earth due to phase voltage.

order there is no danger of shock from motor or switch casings or armouring, so that while there are undoubtedly many cases in which a leakage device may be of considerable use there are also many others where it would not justify the increased expenditure and would probably prove rather a nuisance. These devices, moreover, do not protect against shock from live terminals or from contact with a high-resistance leakage.

Simplicity of Installation.—In the author's opinion the simpler the installation can be made the more likely it is to be kept in good working order, and it has generally been found in the past that it is better to rely upon having good men to look after the plant and see that small details such as earthing, etc., are properly attended to than on automatic appliances.

Stress on Insulation.—As long as a system with insulated neutral is in good order the stress on the insulation is 16 per cent. less than on an earthed system, so that under equal conditions its factor of safety is greater. There is no doubt also that much greater clearances and

creeping distances to all metal work must be provided where the neutral is earthed, to give the same factor of safety as on insulated systems. The advantage of the earthed system is that an earth on one phase soon isolates the faulty part, and does not increase the stress on the other parts of the system, while a similar occurrence on an insulated system doubles the stress on the other places and is likely to cause further breakdowns. This point is of greater importance on extra high voltages.

Cost of Installation.—While not necessarily the first consideration, the question of cost in all engineering problems is of very great importance and one that will not be neglected by the colliery manager, whose business it is to get the best possible financial results.

Where automatic oil switches are used, three relays, one in each phase, are needed with an earthed neutral, and only two with an insulated neutral. If many switches are needed, the difference in first cost may be considerable.

The cost of armoured cable is often nearly double that of unarmoured, so that if these are run in places where there is no danger of accidental contact, damage from falls of roof or sets off the line, or of explosion, armouring is an unjustifiable expense.

The cost of maintenance is generally of greater importance than first cost, and it is here that the simplicity of the installation is of primary importance.

Conclusions.—No hard and fast rules can be laid down, and every case should be considered broadly on its own merits, but it certainly seems that generally an insulated neutral is better where permanent plant is at work and the cables are not very liable to mechanical damage. Where portable machines such as coalcutters are used, or where cables are liable to frequent hard usage, it may be worth while to use automatic devices; and in this case, if a separate transformer were used to supply this plant, its neutral could be earthed (and preferably through a resistance) without interfering with the remainder of the system. Such devices, however, will require constant inspection. There is another very important case which has not so far been considered, and that is where small lighting transformers are used. It would seem desirable to limit the secondary pressure of these to 110 volts and connect either the neutral of one side directly to earth. Finally, the author wishes to disclaim any sympathy with the present scare in regard to the use of electricity in mines. It is necessary in a paper of this sort to consider how accidents can and may occur, but the number that actually do occur is extraordinarily small considering the present widespread use of electricity and the insufficient electrical staff employed in many collieries. The average number of deaths caused by the use of electricity in mines appears to be about 1 per cent. of all the accidental deaths in such places, and many of these cases have been due simply to pure accident or carelessness which nothing could have prevented.