With reference to Mr. Fernie's communication, I gather that he is of opinion that the saponification type of deterioration may (or even must) occur on any vulcanized-bitumen cable having an insulation resistance less than infinity. With every desire to leave his premises as undisturbed as possible, I am afraid I cannot agree that the current which leaks through a normal dielectric will pass to or from a wet braid at one or even a number of earthed or partially earthed points. The resistance of a wet braid, even if saturated with acidulated water, is too high for current (even from a fault passing several amperes) to be traceable on the braid a few feet away. Disregarding this fact, however, and taking up his suggestion as to the calculation of the number of coulombs which would flow through the normal dielectric in the course of two or three years, I am driven to the conclusion that Mr. Fernie could not have made the calculation himself, because the net electrolytic effect per annum per mile of cable would be the equivalent of that due to about one or two amperes flowing for one or two minutes. It is unnecessary therefore

to pursue the argument further by considering other important factors connected with electrolytic effects, such as current density, or to point out that my reference to osmotic influences had clearly no connection with the cause of faults but was simply a component of the deterioration ensuing after faulty conditions are established.

With regard to the field of utility of vulcanized-bitumen cable, I need only point to mining work as an example showing not only a splendid record in the past, but a rapidly growing demand which shows no sign of falling off. Its successful use in other directions for many years past—in fact, since the early days of electric lighting—is a matter of common knowledge.

Mr. Fernie's experience in the matter of bending tests can hardly have been shared by others, because one cannot imagine consulting engineers specifying tests which show negative results. The statement as to the improvement of the breakdown voltage by bending tests clearly points to the desirability of embodying them in the manufacturing processes.

NEWCASTLE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By P. V. HUNTER, Member.

(Address delivered 16 November, 1914.)

It is an important duty of engineers to recast their ideas sufficiently frequently for new conditions and developments to be quickly co-ordinated with existing practice. In no branch of engineering is this more necessary than in electrical power supply, owing to the rapidity of its growth. In such circumstances the retention of certain standards of method and construction, solely because they have been serviceable in the past, may lead to unsatisfactory results.

The tendency of engineering development in the production and transmission of electrical energy is in the direction of working on a large scale. As this tendency is due to economies which can only be obtained in this way, and as it persists in spite of obstacles other than engineering, it is to be expected that the size of generating plant and the radius of transmission systems will continue to increase. In the construction and operation of such large generating stations and supply systems engineering problems necessarily arise which are not apparent in smaller systems, although the only obvious difference may be that of size. One of the most interesting phenomena, and one which becomes of greater practical importance proportionately with the size of the system, is the mechanical forces experienced by circuits carrying heavy currents.

It is generally known, although not appreciated as a matter of practical interest, that any conductor carrying current experiences mechanical stress, the magnitude of the stress being proportional to the square of the current. In the case of a single straight conductor in homogeneous magnetic surroundings, so situated as not to be appreciably influenced by magnetic fields other than its own, the effect of the stress is to compress the conductor in cross-section

and extend it axially. This is known as the "Pinch" effect, and I believe it has been used to promote circulation of the molten charge in electrical furnaces.

If two conductors carrying current are brought parallel to each other they both experience mechanical stress and are either attracted or repelled according as the currents are flowing in similar or opposite directions. A single conductor arranged in the form of a ring and carrying current experiences a stress tending to increase its periphery, *i.e.* a stress similar to centrifugal force. If the conductor be formed into a helix the effect of current is both to expand the helix in diameter and to compress the turns towards each other in an axial direction.

As the magnitude of all such stresses is proportional to the square of the current, they may while quite inappreciable with normal currents be of serious moment in the event of an abnormal rush of current amounting to many times normal load. It is in my opinion very necessary to recognize and provide against the effect of such stresses throughout the electrical equipment of a modern power supply system, and no less necessary in the case of growing systems. There is no difficulty or material additional cost involved in completely guarding against these mechanical stresses. In fact, they can be said to be a danger to apparatus only when ignored.

The stresses were first experienced as a matter of practical importance in the end windings of turbo-alternators. It was found that in the event of a short-circuit occurring either at the alternator terminals or in some circuit close to the power station, the rush of current in the alternator stator windings produced mechanical forces

which had the effect of distorting and often seriously damaging the end connections. The problem was complicated by the fact that the damage largely depended on the character of the short-circuit. A growing fault allowed the armature current to demagnetize the generator field, and excessive currents were not produced in the stator windings.

As a result there was a difference of opinion among experienced engineers respecting the effect of short-circuits on alternators. In some cases the alternators apparently withstood short-circuits satisfactorily, and in other cases this was not so. The problem was investigated by the leading designers, and Professor Miles Walker read a valuable paper on the subject before this Institution.*

There has not to my knowledge been any later development modifying the exposition of the problem there given. The primary precaution is still to brace the end windings in a manner enabling them to withstand the mechanical forces. With the object of reducing the magnitude of the forces, reactance coils in series with the generator windings, preferably inserted at the star end of the windings, have been adopted more particularly in the United States of America. This arrangement is to be recommended where the generators are wound for the pressure of transmission. It is, however, more usual at the present day to transmit electrical energy at pressures for which generators cannot be satisfactorily wound, and in such cases a more satisfactory arrangement is to use a step-up transformer directly connected to the terminals of each generator, incorporating a substantial amount of reactance in the transformer windings. An impedance of 12 per cent at full load can be satisfactorily obtained in a transformer without extra cost and without the use of iron in the leakage paths. Such an arrangement gives a combination in which the maximum instantaneous value of the short-circuit current is six or seven times the full-load current, and the corresponding mechanical forces can be readily dealt with. Any arrangement reducing the maximum value of the short-circuit current is of material assistance, since the mechanical forces are proportional to the square of the current.

An objection to the use of reactance coils or transformers for protecting generator windings is that none of them can be said to be free from the possibility of breakdown, in which case the generator is left unprotected, and in fact such apparatus may produce the troubles which they are calculated to mitigate, namely, an instantaneous short-circuit across the generator terminals. No commercially effective proposals have to my knowledge been suggested for incorporating substantial additional reactance in the generator stator windings themselves. Professor Walker's suggestion of setting the stator windings further back from the air-gap has not, I believe, been adopted, presumably on account of the substantial path which would be provided for rotor leakage flux.

There is, however, a tendency on the part of designers to depart from windings having one bar per slot. With two conductors per slot, as compared with the same number of conductors arranged one per slot, the self-inductive flux of each cuts both conductors, with a

consequent increase of the stator reactance and a corresponding reduction of the maximum value of the short-circuit current. The reduction in the short-circuit current is, however, not in direct proportion to the number of conductors per slot. From the point of view of reliability of the winding there is little doubt that any departure from one conductor per slot is retrograde. The later arrangements have, however, the redeeming feature that each conductor is independently insulated, and as a consequence the insulation between conductors is double that between conductors and earth. This precaution largely eliminates one of the principal troubles which brought discredit on earlier windings having a number of conductors per slot, namely, failure of the insulation between conductors.

Notwithstanding the improvements in this direction there are still objections to multiplying the number of conductors per slot, the most important being the difficulty in making a really satisfactory job of the joints in conductors which are bunched together. With anything more than two conductors the jointing of the middle ones is difficult and the insulation at the joints is liable to be unsatisfactory, and it is distinctly advisable to restrict the number of conductors to two wherever possible.

On the whole it appears justifiable to express the view that with the precautions discussed above the mechanical shock on short-circuit is no serious obstacle in the construction of large generators, and it does not appear at all probable that it will in any way limit the maximum size of generator which can be satisfactorily constructed.

Serious mechanical forces accompanying the flow of current are by no means confined to the end windings of alternators. Of all electrical apparatus the transformer is that which is in a position to be subjected to the greatest mechanical stress from this cause. In making this statement I am not excluding generators. The short-circuit current of a transformer may easily be 40 times full-load current, whereas the short-circuit current of a generator rarely exceeds 20 times full-load current. Other things being equal, therefore, a transformer may experience stresses four times those of a similar generator. Fortunately, transformers are more readily braced against the mechanical stresses involved, and there is no real difficulty in constructing a transformer which will not suffer damage under short-circuit. This applies to all ordinary constructions, whether shell or core type, single-phase or 3-phase. I am glad to be able to make this statement definitely from personal observation of short-circuit tests on a number of different types and sizes of transformers supplied by various manufacturers. An oscillograph was in circuit during the tests and showed that the value of the short-circuit current checked properly with that calculated from the measured impedance of the transformer in each case, and also that the primary voltage was maintained. The values of the short-circuit currents varied in different transformers from 25 times full-load to as much as 60 times full-load current. The latter may be regarded as a somewhat extreme case, the total impedance voltage at full load being only 1.6 per cent. While it is, of course, desirable to use a transformer having as good a regulation as possible, the difference between an impedance voltage of, say, 2½ per cent and one of 1.6 per cent is for practical purposes not sufficient to warrant the additional mechani-

* M. WALKER. Short-circuiting of large electric generators and the resulting forces on armature windings. *Journal I.E.E.*, vol. 45, p. 295, 1910.

cal bracing necessary to withstand the severe stresses incurred under short-circuit conditions in the latter case.

A transformer having a full-load impedance of $2\frac{1}{2}$ per cent, and giving a voltage variation from no load to full load at ordinary power factors of approximately 2 per cent, is satisfactory from all points of view. Its voltage variation is sufficiently good for all ordinary purposes, and the stresses on short-circuit can be properly guarded against by bracing the coils, and without materially increased cost.

There is one precaution which should be remembered in connection with calculations of the short-circuit current. This current is usually deduced from a test in which the secondary of the transformer is short-circuited and sufficient voltage applied to the primary to circulate full-load current. The value of the voltage so obtained divided into the normal primary voltage will give the number of times full-load current which should be passed by the transformer under short-circuit conditions with full primary voltage maintained. This assumption is, however, only true if the leakage flux traverses a path which is air or its equivalent. If, for instance, a certain amount of iron is inserted in the leakage path in order to give higher reactance at full load, the value of the short-circuit current at full voltage deduced from the above method will be substantially too low. The method of inserting iron in the leakage paths is sometimes adopted in the case of transformers where a very bad regulation is desired.

It has also been found from experience that although a transformer may be so constructed and braced that when first installed it is fully capable of withstanding a short-circuit, it may not be in this condition after it has been in service for a few months. This particularly applies to oil-cooled transformers, where apparently there is some slight shrinkage of the insulation due to the action of hot oil. When this occurs the coils settle down, assisted no doubt by the vibration, which occurs in some degree with all transformers when in service. The settlement leaves the coils free to move, with destructive results in the event of a heavy short-circuit. It is therefore a wise precaution to examine each transformer after it has been in commission for a few months and to tighten all anchoring bolts. In some cases manufacturers provide strong springs which compensate for shrinkage of the coil. There is little doubt that this provision is of benefit, but it does not in my opinion do away with the desirability of examining the transformer and tightening everything up.

It is, I believe, a fact that the majority of transformers manufactured to-day have inadequate provision against the mechanical stresses of short-circuit. That more trouble is not experienced is no doubt almost entirely due to the fact that the generating plant is not able to maintain full primary pressure on short-circuit. This protection will disappear with the growth of the generating system.

In the case of the majority of the power-supply systems in this country it would be idle to suggest that their present development represents anything approaching their ultimate size, and there is very little doubt that transformers which are safe to-day on account of the inability of the generating plant to pass sufficient current to damage them will not be in this position later. Those who are at all dubious about the reality and magnitude of these

stresses should read a paper by Steinmetz* which was published in the *Transactions of the American Institute of Electrical Engineers*.

The above remarks are directed towards the ordinary power transformer. There is, however, little doubt that many current transformer failures if properly traced to their source are due to mechanical movement of the primary coils under a heavy rush of current. The current transformer is in the unfortunate position of not being able effectively to limit the value of the current which can be passed through it. In this it differs from generators and power transformers which put a limit to the maximum values of the currents by their own impedance. A sound mechanical construction of current-transformer windings may therefore be regarded as necessary. In this connection the soundest arrangement is decidedly that in which the primary consists simply of a bar without turns. Such transformers, it is true, do not maintain their ratio if at all heavily loaded on the secondary side, but with the exercise of a little trouble and ingenuity it is generally possible to use them almost exclusively on large switchboards. Their reliability from all points of view is so superior to that of any other type that they should undoubtedly be used wherever possible.

One curious effect of the mechanical stresses accompanying the flow of current is the tendency of knife-type disconnecting switches to open automatically under a heavy rush of current. The effect is similar to that which tends to increase the perimeter of a conductor forming a closed loop, and does not exist if the conductors above and below the switch are in line with it. It is, however, remarkable how small a deviation from a straight line is required to give this action. Fig. 1 shows a disconnecting switch which under a severe short-circuit opened automatically. If it had not been actually experienced I think one would doubt the probability of sufficient force being produced, with the arrangement shown, to open the switch, as this requires a pull of several pounds. This disconnecting switch, more than anything I have seen, brings clearly to one's mind the importance of attention to these mechanical stresses throughout the electrical equipment of a modern large power-supply system.

Even in the case of straight copper connections there may be considerable stress under short-circuit conditions.

As an illustration I will take the case of a line of busbars spaced at 18 in. centres, each individual bar being supported at intervals of 3 ft. In the event of a short-circuit between two adjacent bars sufficient to produce a momentary current of 100,000 amperes, each busbar support would according to theoretical calculation experience a force at right angles to its axis of some 900 lb. Now 100,000 amperes is a large but by no means impossible current; it probably represents the maximum instantaneous short-circuit current of about 50,000 kw. of generating plant at 5,000 volts. The forces are peculiarly destructive, as they are of a pulsating nature. The severity of the stress is of course increased if the conductor is at all able to move in its fastenings so that it can deliver a blow to the supports. There is one incidental precaution which

* C. P. STEINMETZ. Mechanical forces in magnetic fields. *Transactions of the American Institute of Electrical Engineers*, vol. 30, p. 367, 1911.

may be readily taken when the conductors are in the form of copper strip, and that is so to arrange them that the greatest dimension of each conductor's cross-section is in the line of the force. This gives greater rigidity and is an obvious precaution when the need for it is recognized. It is, however, quite common to see such conductors arranged differently.

In the foregoing I have attempted to show that severe mechanical stresses accompanying a heavy flow of current

FIG. 1.—Disconnecting Switch.

are not confined to any particular part of the equipment of a large generating and transmission system, and the need for precautionary measures everywhere. The precautions suggested have been in the nature of a better mechanical construction, capable of meeting the stresses without strain. It is, however, most desirable to reduce the magnitude of the forces, and there is no doubt that a great deal can be done in this direction by the use of reactance. An admirable paper on this subject was read recently before this Institution by Messrs. Peck and Faye-Hansen,* and various contributions have appeared in the technical Press and Proceedings of Societies during the last few years. In some cases the indiscriminate use of reactance has been advocated in a manner which, if adopted literally, would make commercial engineering practically impossible, and in no case has the economic condition introduced by the use of reactance been sufficiently considered.

So far as generators are concerned, the addition of even a comparatively large reactance does not materially affect either the cost of the generator or its efficiency. In the

case of reactances between busbar sections and on feeders, however, the conditions are different. With reactances between busbar sections, it is necessary to divide up the transmission system into as many separate networks as there are sections of busbar. The need for separating the transmission system into such small networks arises owing to the fact that the interconnectors between sections would short-circuit the reactance and defeat its purpose; in addition, the interconnecting cables might suffer serious damage owing to the excessive currents which would flow through them on the occurrence of a bad fault on one of the busbar sections. A limited number of interconnectors may be used if fitted with instantaneous excess current relays, but this would not relieve each section of the network from carrying a proportion of spare feeders sufficient for its own load.

The division of a high-tension network into small independent sections cannot be too strongly condemned. This will be realized when it is properly recognized that the majority of high-tension networks cannot be laid out economically because they are too small, that is to say, they do not include a sufficient number of feeders covering a sufficiently large area. As a consequence, the proportion of spare feeders is excessive. The carrying capacity of the feeders leaving the majority of the power stations in this country is from two to four times the actual maximum load carried by the power station; this is obviously an excessive amount of spare.

An amount of spare plant exceeding 25 to 30 per cent should be regarded as excessive, just as much in feeders as it is in generators. The excessive amount of spare feeder capacity which exists in general is not entirely due to the small size of network; it is probably just as much due to faulty automatic protective devices which impose on the designer the necessity for providing a network that can deal with its load with several feeders out of commission simultaneously. Notwithstanding this, however, there is little doubt that the division of a network into a number of isolated sections very materially increases the cost and must be avoided except in the case of networks so large as to require a number of separate power stations. The disadvantage of dividing a network into sections is greater the higher the diversity of the load.

The objection to the use of reactance at the power-station end of feeders is the increased effective voltage drop incurred. This depends on the power factor of the load. On unity-power-factor loads the reactance does not appreciably increase the voltage drop of the feeder, as the reactance voltage is at right angles to the current, which, at unity power factor, is in phase with the supply voltage. The condition of unity power factor in general obtains in the United States where feeder reactance coils have found their most general application. The majority of electricity supplies are there given as low-tension continuous current through synchronous converting plant, in which the power factor is under control. In such conditions feeder reactance has no objection other than cost, and where it has been used I have no doubt that it is amply justified by the security given. The tendency in this country is, however, to supply alternating current without conversion, and the power factor of the load on individual feeders in general varies from 0.6 to 0.8. In such circumstances reactance has a material effect on the voltage drop. In order to

* J. S. PECK and K. M. FAYE-HANSEN. Current-limiting reactances on large power systems. *Journal I.E.E.*, vol. 52, p. 511, 1914.

make this a little clearer I show in Fig. 2 the variation in effective voltage drop of a feeder due to a 5 per cent

FIG. 2.

reactance, the resistance drop of the feeder at full load being assumed as 5 per cent.

It is obvious that on low power factors the permissible length of feeder must be reduced, as this is settled by the voltage drop. The simplest way out of the difficulty is to provide in addition to the reactance coil a voltage regulator on each feeder, which can be adjusted to maintain the voltage constant at the far end of the feeder under any normal condition of loading. In cases where it is necessary to use feeder reactance this appears to be the most satisfactory solution, particularly if the necessary reactance can be incorporated in the regulator. The transmission system can be more economically designed with a regulator on each feeder, as it is possible to make the feeders share the load more evenly than they would do normally. In any case those who are considering the adoption of feeder reactance are faced with the problem that, unless the power factor of the load is exceptionally good, either additional feeders or feeder regulators will be rendered necessary sooner or later.

On the whole it is desirable that the expense and difficulties introduced by the use of reactance should be avoided as far as possible, and for dealing with mechanical stresses it is first of all desirable to have the apparatus throughout so mechanically constructed as to offer the greatest resistance to damage. Having done this, the aid of reactance should be called in discreetly, using generator reactance as freely as necessary, feeder reactance only when really essential for safety, and reactance between busbar sections not at all, or only in exceptional circumstances on large networks.

INTERNATIONAL SYMBOLS.

REPORT ISSUED BY THE INTERNATIONAL ELECTROTECHNICAL COMMISSION.*

INTRODUCTORY REMARKS ON THE STANDARDIZATION OF SYMBOLS.

In so far as electrotechnics alone are concerned, it would seem possible to standardize symbols, and the following principles have served as the basis in the attainment of this object:—

The symbols must be clearly distinguishable one from another when writing with a pen on paper, with chalk on a blackboard, or with a typewriter. In the printed text, it is advisable to use a different type for the symbols from that of the text. It is desirable also that in ordinary handwriting one should not be obliged to add distinctive signs to symbols to specify the type to be employed. It should be possible to spell out the symbols when writing them on the blackboard. Finally, preference should be given to those symbols already in common use. From this it will be seen that it is impossible to make a distinction, in ordinary handwriting, between Roman letters and italics, and that small roundhand letters, being too difficult to differentiate from the above, cannot be used. It is generally agreed to abandon Gothic type, as requiring too long a time in writing. Finally, many of the Greek capitals are identical with Roman capitals. Taking the above points into account, there remain about one hundred symbols

available in Roman, Script, and Greek type, of which several are already used for mathematical symbols and which are necessary for the purposes of the electrician. A list of symbols most frequently needed in electrotechnics is appended herewith. Taking into account certain symbols which are occasionally made use of, it is obvious that there will be none left for purely physical or mechanical quantities. Thus, in the same formula, electrotechnical symbols may occur in conjunction with other symbols used in mechanics and physics generally; this is especially the case in equations containing mass, moment of inertia, speed, density, temperature, quantity of heat, etc. The International Electrotechnical Commission recommends, therefore, that in such cases, for physical and mechanical quantities, the symbol habitually used by physicists and mechanical engineers should be employed, if this symbol does not already exist in the formula as an electrotechnical symbol. If, on the contrary, it already exists in the formula, it is desirable that it be accompanied by a distinctive sign or that the notation be changed.

RULES FOR QUANTITIES.

(a) Instantaneous values of electrical quantities which vary with the time to be represented by small letters. In case of ambiguity, they may be followed by the subscript "t."

* Official copies of this Report, in pamphlet form, can be obtained from the Central Office of the International Electrotechnical Commission, 28 Victoria-street, Westminster, S.W.