The Author. taken, it would be found that there was a minimum of apparatus; there was the cable-box belonging to the alternator, the synchronizing-transformer with its fuses, the earthing-switch, two series transformers, each in a different phase for the relays, and a second set of two series transformers for the watt-hour meters, the section-switches, and bus-bars. He did not think it possible to have switch-gear simpler than that. There was no duplication of apparatus except the two sets of series transformers, and that was due to one maker having furnished the watt-hour meters and another maker the relay and other meters. It was similar with the feeder-circuit.

Correspondence.

Mr. Clothier. Mr. H. W. CLOTHIER remarked that about 5 years ago he endeavoured to classify several types of switch-gear then known,[1] and at that time it was felt, owing to the rapid advances in capacities to be dealt with and in the higher voltages used, that a change in the system was imminent. Also it was felt that some steps were necessary in order to standardize the demand for switch-gear work. The Paper was consequently of no common interest to him, being a modern treatise of greater value upon the same subject. On making a cursory comparison it was noticeable that the developments in the past had not had any tendency towards simplicity: on the contrary, for large capacities the tendency at present in England appeared to follow the practice set many years ago in America; and the apparatus once known as a switchboard was something like a warehouse containing separate floors for the storage of different commodities, with a show-room for the display of delicate instruments and appliances. The elements which constituted a power-station switchboard had multiplied, each additional element appearing to introduce a train of others, until a drawing or a diagram of connections even for a few panels, as indicated by the Paper, became almost too complex to be understood without the most careful consideration. It was time now for designers to look back upon some of the simpler designs in the past, and for a strong hand to strike out the superfluous parts and details. Obviously many improvements must be retained; but he believed the switch-gear of the future was

---

[1] "The Construction of High-Tension Central Station Switch-Gears, with a Comparison of British and Foreign Methods." Journal of the Institution of Electrical Engineers, vol. xxxi (1902), p. 1247.

destined to have features which would enable it to supersede its predecessors in safety and simplicity, and consequently effect a saving in capital, working-, and maintenance-costs; for he could not think that the apparatus described in the Paper represented finality in switch-gear construction. The detailed construction of switches was of interest, although it was, perhaps, difficult to see where any striking improvements had been made upon the switches published in American papers about 5 or 6 years ago. The double solenoid control shown in Figs. 4, Plate 1, was extremely ingenious, but it was doubtful whether the extra solenoid compensated for the complication which it introduced. Certainly a long break was obtained with comparatively light moving parts, but was the length of break necessary under oil for a 3,000-kilowatt switch at 10,000 volts? Presuming there was a clearance at the break of about 9 inches, as it was a double break there was an actual break of 18 inches through oil; but this was not at all consistent with the clearance at the side of the contacts to earth, which to scale was not more than 2 inches, or the surface insulation above the contact, which scaled only about 2½ inches. Ample clearance was an important factor in switch-design, and he believed in being well on the safe side; but he suggested that if these switches were made without the complicated double solenoid and with a shorter travel, the break would be more consistent with the clearances on the other parts of the switch. Also, retaining the same depth of tank, the length gained could be used to advantage in increasing the head of the oil above the breaking-points, which would appear to be of more service than an extra long break. Mr. Ferranti had been one of the first engineers to utilize the high insulating properties of oil, and it seemed a trifle incongruous that this experience should be used with such disregard for proportions in an apparatus which was excellent in other respects and well deserved its place in a treatise upon modern switch-gear. The maintenance of an arc through oil, despite the fact that bad oils were being used, was of very rare occurrence indeed. He had never seen an oil-switch fail from this cause. The only failures in oil-switches which had occurred to his knowledge had been due either to the absence of oil in the switch, or to an explosive effect bursting the vessels containing the oil, or else to the maintenance of an arc across parts outside the oil; and he thought that some account of the Author's experience in this direction would add to the value of the Paper. The foot-notes recalled many past works which had had a strong controlling influence over switch-gear design, but he could not agree with the remarks relating to discriminating devices, and he did not think that the maxim Mr. Clothier.

Mr. Clothier. extracted from Mr. Andrews's important work was at all self-evident or conclusive. It was comprehensive only within certain limits, because there were many branches where current might feed a bus-bar at one time, and through the same branches current might be led away from the bus-bar as the load was transferred from one part of the power-transmission system to another, such as was the case with inter-connectors between stations and ring mains. Moreover, overload-devices for generators were a very old and simple form of protection, but, he suggested, none the less effectual or reliable, provided they were set high enough. He agreed with the statement that cable-charging gears should not have the same share of attention as in the past, and he was somewhat surprised to see such prominence given to this subject in the Paper. He believed that he had originally proposed the use of water-resistances for cable-charging at a time when Mr. Ferranti's ideas on the subject took another course, and he ventured to suggest that it was due to some investigations which he had made for Mr. Ferranti that the apparatus described by the Author had found its way into practice. Even at the time the idea was promoted, it was a very debatable point whether cable-charging apparatus would be installed upon some of the larger power-schemes then under consideration; but in one case at least the decision in favour of the cable-charging gear had been encouraged because a simplification in the arrangement of the feeder-panels was rendered possible, and some extensive switch-gear had been made with no quick-break switches, but, instead, provision for breaking as well as charging a circuit either loaded or unloaded through the water-resistances. This feature, however, in favour of the use of charging-apparatus, now disappeared, because the present practice demanded circuit-breakers on the feeders, whereas at one time fuses were employed; and so it was to be expected that the switch-gear of the future would not be encumbered by cable-charging apparatus and connections thereto, with the attendant train of accessories. Great attention should be given to reducing absolutely to a minimum the duplication of parts. For example, the addition of oil-break switches near a steam-turbine was likely to be more a source of danger than of convenience: it was desirable to keep all switch-apparatus under control from the main station operating-platform, and the extra control-column containing instruments for the use of the engineer attending the machine did not appear to him to have the merits which warranted an acceptance of the Author's suggestion. All designers would agree with the Author's concluding remarks concerning the reliability of the smallest constructional details when dealing with a multiplicity of apparatus; but Mr. Clothier would add that equal importance must be attached to the reduction of apparatus in order to ensure economy in the long run, and hence to advance the electrical industry as a whole. Mr. Clothier.

Mr. G. W. PARTRIDGE considered that the arrangement of switch-gear was becoming more complicated every day, and he would strongly urge designers to pause ere they installed further complications and apparatus. In his opinion, the control of large generators should be left entirely in the hands of the switch-man in charge, who should switch them in and out when he pleased. He was much averse to the use of reverse or maximum-current circuit-breakers on generators. In the event of there being anything wrong on the system, or of a sudden overload coming on, this might cause the generators to fall slightly out of step, causing an interchange of current between them, in which case the automatic arrangements nearly always acted and made matters worse than they were before, through the machines being taken out of circuit when they were most wanted. When inspecting the switch-gear at the St. Denis station in Paris, he had noticed that the reverse-current circuit-breakers on the generators were set to go only when the voltage had fallen more than 50 per cent. of the normal; but even this arrangement was not as safe as the hand-control of large machines. He had seen a sudden short-circuit throw large alternators out of balance when they were running on a rapidly rising load; had any of these machines been switched out it would have meant practically shutting down the whole station, owing to the generating-sets being of large capacity and few in number. In this particular instance, the alternators were gradually brought in step again and the supply resumed. The same objection applied to the automatic paralleling device, which might work satisfactorily until something went wrong; and he much doubted if this device would operate if it were necessary to synchronize machines at a low voltage. From his experience it was necessary at certain times, in cases of emergency, to put machines into parallel at low voltages, and sometimes slightly out of phase. He therefore thought that simplicity of design should be the chief aim and object of switch-gear. He had often noticed in large modern stations that half the automatic apparatus was either tied up with string or wedged up with pieces of wood to prevent it from acting when it was not wanted. He had lately been shown over a large modern station, and the engineer in charge, in going over an amazing amount of switch-gear and interlocking arrangements, showed him one or two devices by which, he claimed, one man could, if he desired, shut down every machine in the station by manipu- Mr. Partridge.

Mr. Partridge. lating one switch. Mr. Partridge would have thought it better practice to make it as difficult to shut down a station as possible, and not to have such complications in use. The high-tension oil-switches now used in all switch-gear were first designed by him for the London Electric Supply Corporation in May, 1892, and some of them had been in constant use ever since. Where oil-switches were not worked continually, such as an oil-switch controlling a feeder, he had found that a thin film of oil appeared to get between the contacts, causing a slight sparking to take place, which, if left over any length of time, reduced the surface of the contact and caused heating of the various parts. If it were possible, he would like to see some mechanical means of indicating the exact position of the oil-switch itself, that was, when it was off or on, as, should anything go wrong with the porcelain insulator carrying the actual switch-arm, the man in charge had no notion whether his switch was on or off, as his pilot-lights, which were controlled by the mechanical arrangement of the switch, were lighted. Mr. Partridge had witnessed what might have been a very serious accident from this cause. In some oil-switches he had at present in use, a mechanical contrivance had been actually fitted to the metal arm carrying the current, and indicated its exact position. It might also interest engineers to know that the London Electric Supply Corporation had underground high-tension oil-switches in constant use on the high-tension feeders. By means of them the super-intendent of mains could cross-connect or switch-off lengths of feeders, which made the use of these switches invaluable for detecting faults or making joints. Some of these switches were installed in October, 1892, and were still in use and giving no trouble. Signalling arrangements in large stations were very necessary; but Mr. Partridge had not, up to the present, seen a perfect arrangement for this purpose. The oil-switches, synchronizing-lamps, etc., placed alongside the turbines in the St. Denis station formed a very good arrangement; but they should not be controlled by any relay. It gave an opportunity to the engine-driver of seeing exactly what the switch-man was doing, by looking at the instruments placed on this switch-pillar. The main discharger shown by the Author as the "Partridge system of charging," by means of transformers instead of water-resistances, when properly manipulated, caused no rise in pressure, or disturbances. The actual apparatus first designed by Mr. Partridge for the Deptford generating-station in 1892 had been in daily use for the last 14 years, and although mains 7 miles in length were every night and morning switched on and off to a single-phase system on a periodicity of 85, it was impossible to tell when a main was put on or when it was taken off: which he thought spoke for itself. Another advantage of the use of transformers would be for high pressures, say, above 10,000 volts, as it was much easier to wind a transformer for a working-pressure of, say, 15,000 volts than to make a water-resistance. The discharger in question was also arranged so that, if necessary, the two halves of the station could be synchronized and gradually put in parallel or divided up again to separate systems by its use. He had never seen this in use in any other station. He thought that series transformers should, if possible, be always placed between the generator and the main oil-switch: this was not always shown in the diagrams of the Paper. By these means, when the main switch was off, the transformer connected with the generator was made dead. Failure of a series transformer meant a very serious breakdown in the system and a possibility of the high pressure getting on to the instrument-boards. He had not seen any satisfactory means o protection against this, and he would like to know if any engineers had considered the use of high-tension fuses placed on the low-tension windings of these transformers, thereby cutting off the instruments entirely if the high-tension should get through. The use of protective devices on high-tension circuits was a very interesting subject. He had himself devised different kinds of apparatus to work in connection with it; but he had never had very satisfactory results. The use of water-jet resistances might be a way out of the difficulty if coal were cheap. In one of the large stations on the Continent, where they had been installed but abandoned, one feeder when working at a pressure of 10,000 volts would absorb 230,000 units per annum if a water-jet resistance was always connected across its terminals. As it would be necessary to put one of these resistances across each feeder it would render the use of this apparatus out of the question. Mr. Partridge.

Mr. BERTRAND ROWE, of Pittsburg, Pa., observed that in all general features the descriptions given by the Author covered the practice followed throughout the United States in large power-installations. The difference between American and European practice lay in the details. One of the most difficult parts of such an installation was the isolating of conductors at terminals, where they connected to oil circuit-breakers and other apparatus. The best American practice for large stations provided that each lead as it left an oil circuit-breaker should be confined to a separate compartment. In many of the switches described in the Paper, the leads of the heavy-duty switches, such as were shown in Plates 1 and 2, were taken out at the top of the switch, where they were not easily isolated on account Mr. Rowe.

Mr. Rowe. of the mechanism. He was glad to learn that European practice seemed to confirm American, in that oil circuit-breakers should be designed to open rather than close by gravity. Another feature in American practice which differed from what was described as European practice, was that, in the United States, the entire control of all electrical apparatus was placed in the hands of the chief operator of a station, and there was no auxiliary control-column provided on the engine-room floor for the use of the steam-engineer, as described on p. 28. In many stations, however, a wattmeter was provided for the convenience of the steam-engineer to enable him to observe the loading of his generators, and a system of signals at each machine connected him with the chief operator. A synchroscope was often provided also, which could be observed by the steam-engineer, this synchroscope operating in parallel with another which was observed by the chief operator. As to the fire-proofing of cables, flame-proof cable was only applicable in stations where conductors could be well insulated from grounds and opposite polarities. This was necessary because the covering was liable to absorb more or less moisture, and if the covering got grounded, and was damp, it was the same as supplying the cable with a grounded sheath. This would rapidly deteriorate a rubber-insulated cable. The flame-proofing was always stripped away from cable-ends and places where the covering must be adjacent to live terminals. The section of copper in bus-bars and conductors varied with the frequency, and American custom was not as conservative as the usual practice mentioned in the Paper. While flat-bolted contact-surfaces were rated at 100 amperes per square inch, the current-density for hard drawn copper was taken at 800 amperes per square inch for a temperature-rise not exceeding 20° C. for continuous-current work. For the same conditions at 60 cycles per second the density should be about 550 amperes per square inch; while for 25 cycles the density should be about 650 amperes per square inch. For threaded contacts 200 amperes per square inch was allowable, reckoning on the cylindrical surface of the threaded portion. The foregoing current-densities would be lower than necessary if the conductor was of such a section that it presented a large radiating surface to the air and was not confined.

Mr. Vogelsang. Mr. MAX VOGELSANG, of Frankfurt-am-Main, expressed his entire concurrence with the Author's general opinions, but drew attention to a few discrepancies which he discovered in them, with special reference to German standard practice. Although the general technical considerations guiding the safe construction of high-tension switchboards were more or less international, the rapidity with which this branch of electrical engineering grew nevertheless led to certain differences in

Mr. Vogelsang.

construction in the various countries. It was not customary in Germany to provide separate oil-tanks for three-phase circuit-breakers, not even in the large sizes, so long as they were built on the well-known and simple principle of only two breaks per pole. It was customary to keep the phases separate—that was, to construct a three-phase circuit-breaker in the same way as three single-phase circuit-breakers—only in those cases where it was necessary to do so on account of exigencies in design such as were present in the case of high-tension switch-gear for 20,000–30,000 volts, and which possessed more than two breaks per pole (namely, six to ten breaks per pole). The design of a circuit-breaker with separate oil-tanks appeared to him to be unsatisfactory, inasmuch as it was certainly more troublesome to look after three oil-tanks (and perhaps empty and fill them) than one oil-tank; and, further, the use of separate oil-tanks introduced unnecessary metallic partitions between the poles, whereby, in comparison with the compactly-built apparatus, there was certainly no increase in safety, whilst, on the other hand, a large and clumsy design was the result. It was also necessary to remember that in practice, should one pole of a circuit-breaker become faulty, it made no difference, as regarded repairs, whether the poles were entirely separate or not. It was, however, very desirable to separate the poles in their common oil-tank by means of wooden or other partitions, at places where direct arcking from pole to pole could occur; but, as already stated, he did not believe that the separation of the poles in independent tanks resulted in a gain in safety. As regarded electrical switch-gear control, the Author described a system which appeared to differ from the usual push-button control so extensively employed both in the United States and in Germany. Both in Germany and in America, where the electrically-controlled high-tension circuit-breaker probably originated, it had always been usual to design the apparatus in such a way that the circuit used in closing the switch was first made by a push contact, and, after completion of the main circuit, automatically broken by the apparatus itself. In the German apparatus this circuit was worked in conjunction with that of the signal-lamps, whereby matters were further simplified in this respect. He was at a loss to discover, from the Author's description of the connections for his apparatus, any advantages compared with what might be called the well-known push-contact system. The "free-handle" system, which was usually recognized as the distinctive feature of a good modern automatic circuit-breaker, did not appear to him to be essential for these large high-tension switches, primarily because they were nearly always fitted with time-relay releases, whereby the switch could never be released the moment it was closed. The relay would therefore have

Mr. Vogelsang. to be disconnected at the moment of making the circuit, which could be effected by arranging the switch-gear accordingly. Perhaps the Author had this in view in the case of the apparatus described. As regarded special cable-charging gear he would like to know whether such apparatus was of sufficient practical value to justify the additional complication which its use in a high-tension system must entail. The Author mentioned two such devices, one with Ferranti liquid-resistances, and the other with transformers. Mr. Vogelsang believed that it would be difficult to prove that either of these fundamentally different systems was necessary or of value, since the theoretical reasons for the adoption of such appliances were, so far, rather deficient. The electrical phenomena which took place when a current was suddenly sent into a dead three-core cable appeared to him to be so complicated as almost to defy theoretical explanation. Practical experience seemed to show conclusively that, provided the cable and the switch-gear were in order, dangerous phenomena did not occur. If, however, the cable or the switch-gear were not in order, he thought that neither theoretical considerations nor cable-charging gear would be of any use. From the Author's description he gathered that the charging-gear could only be used under normal conditions of make and break. Only slight rises of pressure could occur during these relatively simple and harmless operations, and he thought that everybody with experience in high-tension work would concur with him in saying that an element of danger was only introduced if something extraordinary or abnormal occurred. As the Author rightly said in a foot-note, the introduction of modern oil switch-gear minimized to a very large extent the dangers of abnormal rises of pressure as compared with the earlier system of high-tension fuses and exposed cut-outs. The formation of a high-tension arc, whether in switches, fuses, or lightning-arresters, was almost invariably conducive to abnormal rises of pressure, these being most pronounced in the oft-recurring case where the fuses in the several phases did not melt at the same time but one after the other, when the resulting phenomena might be of the most serious description on account of oscillations set up by the arcs, and the destruction of electrical balance in the cables. In his opinion, therefore, oil-switches were the best, as producing the smallest possible arc, and moreover, he considered it desirable to make their action as rapid as possible, and not to waste time in manipulating liquid resistances, etc., as he feared that, for instance, a resistance of this description, from which, owing to faulty handling, half the water had evaporated, would actually be a much more dangerous piece of apparatus than an oil-switch pure and simple. Moreover, when it was realized that these beautiful devices were not permitted to act at a time when, theoretically at least, they were most urgently required, namely, when a circuit-breaker acted automatically on a short-circuit, he really could not understand why an installation should be encumbered with apparatus of this description under normal working-conditions. It being desirable to bring about standardization in certain apparently minor details, he would plead this cause in the case of exciter-voltages to firms engaged in the construction of dynamo-electric machinery. This was sometimes really very annoying when generators in the same power-station were built by a number of different firms. One generator might be built for an exciter-pressure of 110 volts, another for 80 volts, and perhaps yet another for 50 volts. True, the choice of a different exciter-voltage might present some advantages as regarded the winding of the generator, but these were really of very little consequence. It was desirable that greater harmony should exist as regarded exciter-voltages, and he would submit that an entire departure from the practice of direct-coupling exciters would be advantageous, this system being adopted by manufacturers partly from mere commercial considerations, and partly in view of the above-mentioned benefits in winding the generators. He had never been enthusiastic about this arrangement, chiefly on account of the obvious fact that the whole generator-set, consisting of exciter, generator, and steam-engine, would be put out of action if anything went wrong with the exciter. For these reasons he considered it advisable to avoid the use of direct-coupled exciters, and, in order to simplify the co-operation of various types of generators, to recommend the adoption of a standard exciter-voltage. The most suitable would probably be 110 volts. The best method would probably be that advocated by the Author, of obtaining the exciter-voltage from rotary converters, and providing accumulators as a stand-by. The lighting-load of the station should then also be taken from the exciter-mains in order to safeguard completely the illumination of the building in case of a serious breakdown. In reviewing the beautiful safety-arrangements for high-tension switch-gear described in the Paper, he would supplement the Author's views by indicating that safety-arrangements for the measuring-instrument transformers were perhaps somewhat neglected. There could be no doubt that, compared with the solicitude with which, for instance, the bus-bars were usually insulated (these consisting merely of a few stout copper rods resting on insulators, and being more or less innocuous) the benefits of precautionary measures were unfairly Mr. Vogelsang.

Mr. Vogelsang. distributed, as regarded the fixing of measuring-instrument transformers, which, as the Author stated, were relatively more liable to breakdowns.

The Author. The AUTHOR, in reply, entirely sympathized with Mr. Clothier's remark as to the necessity of a strong hand to strike out the superfluous parts and details in switch-gear. There was certainly in many modern stations duplication and even triplication of certain apparatus, and also many instruments that might as well be left out. But the strong hand would have to be that of the engineer who drew up the specification, and not that of the designer who, in many cases, had no voice in the matter, and was often hampered by conditions with which he was entirely at variance. With the object of eliciting a decisive opinion on the practical utility of cable-charging gear, prominence was given to this subject in the Paper. It was of some importance to eliminate, if possible, this cumbersome and costly apparatus, and the objections raised by Mr. Clothier, who first introduced the principle of charging feeder-cables, and Mr. Vogelsang, could give only satisfaction to all who desired the simplification of switch-gear. The views expressed confirmed those put forward by Mr. J. P. Gregory[1] in 1904, and also seemed to confirm general modern practice. In reply to Mr. Partridge, the oil-switches placed near the machines were not controlled by relays. They were non-automatic, but could be released electrically by the operator at the switchboard for reasons stated on p. 29. Contrary to Mr. Rowe's supposition, the apparatus placed alongside the machines was not provided for the purpose of giving the control of the alternators into the hands of the engine-driver under normal working-conditions, but it served the purposes indicated on p. 28, and, as Mr. Partridge observed, was to enable the engine-driver to see what the operator was doing. With regard to the water-jet resistances, these were usually connected with the main bus-bars, and thus only one or two sets per station were required, and the number of units absorbed in comparison with the total output of the station would be insignificant. The main reason for fitting the various poles of large-capacity circuit-breakers with separate tanks was to safeguard against short-circuits. A design of switch on the lines of those shown in Figs. 15, Plate 2, gave, in the opinion of the Author, a very much greater margin of security than one with a tank common to the several poles, which latter arrangement, according to Mr. Vogelsang, appeared to be the German practice even for large sizes.

[1] Minutes of Proceedings Inst. C.E., vol. clix, p. 246.

The free handle was necessary in circuit-breakers in spite of their being supplied with time-limit devices, as the latter might cause the switch to open while the operator still had his hand on the lever. Besides, it was just with large circuit-breakers, such as those shown in Figs. 6, Plate 1, and *Fig. 18* (p. 46), that the application of the principle became imperative. The heavy levers must be rendered independent of the opening mechanism, as otherwise, on operation of the circuit-breakers, they would be thrown over into the open position, and so constitute a certain danger to any person standing near by. The Author.