If generators are to be run at high average load for a considerable portion of the time, and the price of fuel is high, then care should be taken to obtain units of highest efficiency. If the machine is to be used for only a few days throughout the year and fuel is cheap, then reliable machinery of lower efficiency and of lower first cost will reduce the fixed charges and may result in a lower cost per k.w. hour generated.

In determining the capacity of the generator units in hydraulic plants the water condition becomes a factor, for it is desirable to have at least one unit which will be equal to the minimum k.w. output of the stream during periods of low water. Here again, it is advantageous to have all units of an equal capacity, but in low heads, with streams of highly variable flow, this is often impossible. If all units are of equal capacity it makes them interchangeable and facilitates running. When, however, the average flow of a stream would not develop over 500 k.w., it is at once apparent that a 2,000 k.w. machine would give poor service during the low stage period, for a machine works best when nearly loaded to its rated normal capacity. These points merely tend to emphasize the fact that hydraulic and electric features must be considered together.

A general figure for voltage to be used is 1,000 volts per mile of transmission line up to the limiting potentials now in use, say, 60,000 volts. The actual voltage selected should correspond to the values outlined by the A.I.E.E.

The voltage to be selected for the generators depends on several conditions. Generally, if the power is to be distributed at a voltage of 10,000 or less, the voltage of the generators should be the same as that used for distribution. If the line voltage does not exceed 15,000, generators may be purchased that will give this potential without the use of a step-up transformer, but such generators are expensive on account of the insulation required, and they are more liable to injury from lightning if the system is exposed to these disturbances than generators using transformers to step-up the voltage for the line. Where transformers are used it is usually not desirable to generate at potentials lower than 2,200, and the voltage serves for small and moderate size machines, while 6,600 may be used for large units.

(3) Of the standard frequencies, 25 and 60 each has its advantages and disadvantages. A frequency of 60 cycles is preferred for lamps and 25 cycles for motors. While some incandescent lighting is done at 25 cycles, arc lamps do not give satisfactory results at frequencies much below 40. For transmission purposes a frequency of 25 cycles is preferred on account of better line regulation and the operation of synchronous converters is generally conceded to be better at this frequency. Transformers and other apparatus, aside from switching and control devices, cost more at the lower frequencies. On a mixed system of railway and lighting, if the railway load does not exceed one-third of the total, a 60 cycle system should probably be installed. But this is a local question in nearly every case.

In regard to the use of the different phases, single-phase systems are limited to small plants, where the motor load is very small, and to single-phase railways. Since lighting and railway systems may be fed from polyphase lines and a three-phase generator may be loaded to 80 per cent. of its three-phase output, when operated single phase it is difficult to see why single-phase machines should be installed in any station where there is a demand for transmission to any distance, or a possible demand for polyphase motors.

There seems to be no good reason why two-phase should be chosen aside from the fact that in a two-phase, four-wire system we have a near approximation to a single-phase system for lighting service, and we are still supplied with a polyphase system which may be readily changed to a three or six-phase where desired. Three-phase would, of course, be used for transmission, even though the voltage be generated two-phase.

(3) Standard Handbook, p. 604.

(4) As to direct versus independently driven exciters, the most salient points are again economy and reliability. As far as economy goes, there are three ways of driving the exciters. One is to connect it directly to the generator shaft; a second is to drive it by a separate prime mover. The third is to drive it by a motor driven by the prime mover. These methods differ in economy as much as the main prime mover differs from the auxiliary prime mover. As far as reliability goes, one point is that of regulation. On that point the motor-driven and the direct-connected exciters are at a disadvantage, because any variation in speed of the main plant is reproduced in the exciter, which alters the voltage of the exciter in a ratio faster than the speed alters the main generator. This causes a variation in the voltage of the main plant considerably greater than the original speed variation.

Exciters for alternating current generators are usually compound wound, flat compounded, and rated at 125-150 volts. It is especially desirable that they be stable if direct-connected to the shaft of the alternator, as is sometimes done. Standard D.C. machines of good design and of the desired rating are used where the exciters are separately driven, and separately driven exciters are preferable for most plants on account of the fact that the system is much more flexible. Any drop in the speed of the alternator does not cause a corresponding drop in the exciter voltage, and the regulation of the plant as a whole is improved. The use of exciters directly connected to the alternators mounted on the same bed-plate and belt-driven from the alternator shaft is not as common as it once was, due to the increase in the size of individual units.

In all cases it is necessary that there should be sufficient reserve capacity. As an example of the amount of reserve capacity that is sometimes installed, we have the first power plant of the Niagara Falls Power Company, in which four exciters are installed, each one having sufficient capacity to excite the entire plant, and each driven by its own turbine, fed by a separate penstock. General figures for the capacity of an exciter for any machine run from 2.5 per cent. of the capacity of the alternator for any moderate speeds and small sizes to 5 per cent. of the alternating capacity, or a trifle less, for large, high-speed turbine units. Two per cent. is a figure often used in the absence of definite data. This is too low in a very few cases. But more often the error is on the safe side.

(5) The exciter units should be of sufficient capacity to run the whole station with but one exciter. Motor generation sets of electric-driven exciters give good regulation and are economical, as, after the station is in operation, the water-driven exciters in hydraulic plants can be shut down, thus effecting a slight saving of water. Of course, it is an absolute necessity that there be a water-driven exciter, or else the station cannot be started up. Possible failure of this exciter must also be allowed for, so that we have to have at least two water-driven exciters in any hydraulic plant. It is possible to carry an exciter on the man shaft of the generator, usually on the outer end. In some cases each machine may carry its own exciter, or one or two machines only may carry exciting units of sufficient capacity for the entire station. Belted exciters are sometimes used, but rarely in any but very small plants is this method advisable. An exciter driven by a larger unit necessitates the wasting of power. If for any reason the larger generator is unable to carry its portion of the load—and all machines require attention and repairs—the arrangement of each generator carrying its own exciter is a poor one, for if the water-wheel speed is affected, or the generator load is momentarily changed by load fluctuations, then the exciter voltage follows the change. Frequently the very opposite effect from the desired one is the result.

With regard to the position of the exciters in the general station plan, it is primarily essential that they should be in direct communication with the switchboard operator. Their position is then determined by the switchboard, as

(4) P. M. Lincoln, A.I.E.E., February, 1906.
(5) F. Osgood, A.I.E.E., April, 1907.