

Table I: Array for Combining Outage Probabilities
Two Groups of Units: Three 15 Mw and Three 22 Mw. Outage = .03

Units	Mw	Prob- ability	Units	Mw	Prob- ability	Units	Mw	Prob- ability	Units	Mw	Prob- ability
Three 15-Mw Unit Group Separately											
0	0	.912673	1	15	.084681	2	30	.002619	3	45	.000027
Three 22-Mw Unit Group Separately											
0	0	.912673	1	22	.084681	2	44	.002619	3	66	.000027
Combined Groups											
0	0	.832972	1	22	.077286	2	44	.002390	3	66	.000025
1	15	.077286	2	37	.007171	3	59	.000222	4	81	.000002
2	30	.002390	3	52	.000222	4	74	.000007	5	96	—
3	45	.000025	4	67	.000002	5	89	—	6	111	—

or point of connection of ties? By using a common steam header for a group of units? By interconnecting two systems? By changes in load factor?

Fig. 9 shows variation of reserve needs with the number of units of equal capacity and for three values of load-loss probabilities, and an outage rate of $q = 0.03$. Fig. 10 shows the effect of interconnecting two stations with a tie. Curve *a* gives the variation of load-loss probability of each station with the tie capacity, assuming local reserve at each station remaining constant at 80% of maximum load. Curve *b*, on the other hand, gives the local reserve needed to maintain load-loss probability at 0.00046. Both curves were figured for a load-duration curve shape of Fig. 6.

Fig. 11 shows the effect of variation in daily peak-load variations for a group of 60 units equivalent to those of the Consolidated Edison system in 1938. At that time the daily maximum load ratio = (sum of daily peak loads) / (Annual peak load $\times$ 365) was of the order of 70%. For an objective reserve of, say, 320 mw the load-loss probability was 0.00042. The curve shows, for instance, that with the same reserve if the ratio had been 80% the load-loss probability would rise to 0.000658, an increase of about 60%.

For constant conditions of load factor, outage rate and unit size, the degree of service reliability should be lower with increasing number of units. A given outage in excess of reserve becomes less severe as the system grows. Consistent with this criterion, the objective reserves of the major stations of the Consolidated Edison system as of 1938 were set to correspond to an expected outage in excess of reserve of

one day every seven peak seasons. This compared with an expectancy of one day every peak season for the entire system.

Fig. 12 shows the combined effects of system growth and change in daily maximum load ratio on the load-loss probability of the Consolidated Edison system. The objective reserve for 1938 was 320 mw, corresponding to a load-loss probability of 0.00042 of 70% daily maximum load ratio. For 1968, with an expected daily maximum load ratio of 80% the reserve would be 455 mw for the same level of reliability as in 1938. Should the load ratio remain at 70% the reserve would drop to 430 mw. These figures represent contingency reserve requirements apart from considerations of overhauling.

Overhauling Units. The time available for periodic maintenance overhauls of generating units is determined by the amount of capacity represented by the difference in annual and daily peak loads, as shown by Fig. 7. Strictly speaking, the contingency reserve should be calculated, excluding the units on overhaul. For all practical purposes, considering the nature of the problem, it may usually be assumed that the contingency reserves remain constant through the year.

Regardless of the method used in calculating the reserve of a system, the final value must be checked to insure that it is sufficiently large to allow performing all extended maintenance work. Take into consideration the overhaul cycle and duration of both turbine-generators and boilers.

In 1938 the valley in the curve of daily maximum loads, Fig. 7, provided ample room for performing maintenance work. In addition, as a result of

Table II: Summary Probability of Outages for Groups of Three 15-Mw and Three 22-Mw Units

Probability of Outage: Exactly equaling indicated			Exceeding indicated		
Mw	Mw	Mw	Mw	Mw	Mw
0	.832972	.167028			
15	.077286	.089742			
22	.077286	.012456			
30	.002390	.010066			
37	.007171	.002895			
44	.002390	.000504			
45	.000025	.000480			
52	.000222	.000258			
59	.000222	.000036			
66	.000025	.000012			
67	.000002	.000009			
74	.000007	.000002			
81	.000002	—			
89	—	—			
111	—	—			

the depression, the actual reserve of the system exceeded the calculated value. During the war, and under the impact of the emergency, reserve standards were lowered and our actual reserves fell short of the value considered adequate. We are trying hard now to reestablish those standards, but because of the current shortage of materials and consequent delayed deliveries, we do not expect to do so for some time. Valley in the curve, Fig. 7, is gradually filling up so it is now anticipated that the long-range contingency reserve must be increased to fulfill overhauling requirements.

Conclusion. Though the method of probability has grown into a powerful tool for solving reserve problems, the applications made up to the present time have not exhausted its possibilities. The method can be further improved by using indexes of service reliability based on load-duration curves to include the effect of load variation. This purpose can be accomplished with little extra work by using straight-line curves and, usually, by replacing step outage-probability curves with approximate continuous ones, as in Fig. 2. The very nature of the problem entirely justifies these approximations without affecting the engineering accuracy of the results.

Consider These Factors in Specifying Mechanical-Drive Steam Turbines

Second article of a series by F S Kohl, turbine division, General Electric Co, reviews conditions that should be studied when considering installing mechanical-drive steam turbines

PROPER APPLICATION of mechanical-drive turbines requires evaluation of various turbine characteristics and the conditions under which they operate. These factors are (1) ratings (2) speeds (3) steam conditions (4) efficiency (5) governing (6) special features and (7) accessories. The principles stated here provide a good background of information for proper turbine drives.

Since standard designs offer great advantages to the user in initial cost, shipment, stocking of spare parts, etc., they should be applied whenever possible. Where standard designs are not adequate, however, modified standard units or special designs covering a great variety of requirements are available.

Ratings and Speeds. Range of horsepower and speed ratings are almost limitless. Capacities range from less than 5 to more than 25,000 hp and speeds from less than 1000 to over 12,000 rpm. Speed-reduction gears extend the lower limit to below 200 rpm, while speed-increasing gears raise the upper limit to exceed 40,000 rpm.

All ratings are not normally available at all speeds as applications do not call for all possible combinations. For example, it would be very unlikely to find a piece of driven equipment rated even 10,000 hp operating at speeds over 4000 rpm. Flexibility of turbine and gear design, however, can meet any application requirement.

The great majority of applications need less than 800 hp with speeds below 4500 rpm. Most of these can be met with standard units and almost "off-the-shelf" design. Semi-standard designs, using standardized components cover the bulk of the remainder.

Steam Conditions. Mechanical-drive turbines are built for a wide range of steam conditions.

Initial pressure, less than 50 to over 2000 psig.

Table I: Guide to Most Likely Turbine For Given Application Conditions

		CODE DESIGNATION			
		A Single-stage, small wheel		C Multistage, low efficiency	
		B Single-stage, large wheel		D Multistage, medium efficiency	
				E Multistage, high efficiency	
Rating	Load Factor	Condensing Coi of Steam High	Low	Noncondensing Coi of Steam High	Low
Less than 200 hp	Low Medium High	B A C	A B C	A B C	A B C
200-500 hp	Low Medium High	C D E	B C D	B C D or E	A B C
500-1000 hp	Low Medium High	C D E	C C D	C C D	B B C
1000-2000 hp	Low Medium High	C D E	C D E	C C D	B B C
Over 2000 hp	Low Medium High	D E E	D E E	D E E	C D E

† Larger sizes usually give higher efficiency.
‡ Low-standby service, medium—about 50%; high—base loaded.
§ Usually not a good turbine application.

Initial quality or temperature, 3% moisture to 1050 F.
Backpressure, 1 in. Hg to over 400 psig.

Standard designs are suitable for initial conditions up to 600 psig, 750 F, and with backpressures up to 75 psig. Semistandard designs range up to initial conditions of about 1200 psig, 950 F and backpressures up to 250 psig.

Efficiency. One of the most important points considered will be efficiency desired. For given horsepower, speed and steam conditions, any one of several designs can be used.

From an efficiency standpoint, the

decision on design should be based upon a cost study. But experience provides some approximate rules of thumb that can be used in the majority of cases. Table I summarizes the most usual turbine selection after cost studies for given operating conditions.

Another consideration in efficiency is the question of geared vs direct-connected drive. Speed of the driven equipment is the most important factor in this selection, although rating and steam conditions have considerable effect.

Turbines are inherently high-speed machines, low turbine speed sacrifices economy. If the driven equipment op-