LIMITATIONS IN MANUAL
AND
AUTOMATIC SYNCHRONIZING
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In nearly all applications of automatic synchronizers, unnecessarily conservative settings have limited the usefulness of the synchronizer, and sometimes manual synchronizing can be improved.

The angular error at the instant of breaker contact closing produces mechanical shock and is therefore more serious than equal power swings from frequency difference alone. When synchronizing manually, since it becomes difficult to accurately allow for breaker closing time at the higher frequency differences, manual synchronizing is ordinarily limited to one slip cycle in 8 seconds or more. If the circuit breaker closing time is slow, erratic, or unknown, or if the operator is unfamiliar with the equipment, a very slow moving needle must be chosen. To realize the full benefit of an automatic synchronizer, it must perform faster, more accurately, and more consistently than can be expected of manual synchronizing. This is feasible for several reasons:

- The synchronizer automatically anticipates the proper closing instant, up to the preset cutoff frequency difference, eliminating personal error.

- Most synchronizers are equipped to automatically change the advance time to suit the circuit breaker selected, personal error due to unfamiliarity with equipment is eliminated.

The only limitation then, is error from magnitude of power swings because of frequency difference. The highest, reasonably possible, rate of control within this limitation is desirable, to reduce synchronizing delay during emergencies. The cutoff frequency difference of one-fourth hertz (one slip cycle in 4 seconds) accommodates the governors of most units without delay and will keep power swings, due to synchronizing, within conservative limits. (The automatic synchronizer can still be used to perform a smoother operation when desired, by releasing control of the circuit breaker to the synchronizer only when the frequency difference is as low as desired).

The following will help determine when automatic synchronizers have unnecessarily conservative settings, or when manual synchronizing can be improved. Some synchronizing operations produce neither power swings nor sound; some produce power swings but no sound; and some produce both power swings and sound:

THE FIRST CASE. - A slow perfect shot requires no illustration. (Slight sound may be produced by otherwise perfect synchronizing, if the running and incoming machine voltages are not equal. This is of no importance if the voltages differ by no more than 10 percent.)

THE SECOND CASE. - This operation is acceptable, as the power swings due to initial frequency difference are too slow to produce mechanical shock (fig. 1, QUIET). Damage from this source is unlikely although, for smooth system operation it is desirable to limit the swings well below nameplate rating.

THE THIRD CASE. - This represents a mechanical shock and a vibration to the machine which could be severe and damaging (fig. 1, MECHANICAL SHOCK). Limiting this shock by reasonably accurate synchronizing is very important.

Closings the circuit breaker with voltages 15 degrees out of phase (fig. 1, MECHANICAL SHOCK), even with very small difference in frequency, produces power swings as great as closing the circuit breaker exactly at synchronism when the synchroscope is making one revolution in 2 seconds (fig. 1, QUIET). Fifteen degrees is a very small angle on a synchroscope dial, while one revolution in 2 seconds is a greater frequency difference than one ordinarily attempts to synchronize manually.
Thus, closing the circuit breaker contacts at the proper instant is more important than having a very low-frequency difference. The two limitations go together to prevent accurate manual synchronizing with high-frequency differences due to the difficulty of estimating the required advance, plus the mental reaction error.

Synchronizing power-swing plots of several Bureau generators (fig. 2) represent circuit breaker contact closure exactly synchronized, with the synchroscope rotating at one revolution in 4 seconds. The maximum power swings are all within 15 to 22 percent of the nameplate rating of the respective generator. Thus, the same tolerance applies satisfactorily to many sizes of synchronizing hydropower generators.

Each power-swing curve (fig. 2) is approximately one-half of what it would be if each generator were synchronized to an infinitely large generator instead of one of identical size, assuming the same frequency difference. Effectively this is the condition when a generator is synchronized to a large number of generators in the same plant. Then, although the unit wattmeter makes a visible swing, it and the currents and stresses are still well within normal range. The swing is largely confined to within the plant, and only a small percent of it reaches the transmission lines.

Usually, after an interruption, the generators are individually synchronized to the transmission line, except in plants with units too small to absorb the charging current of the transmission line. Then, two or more units on one bus may be synchronized to the line. The maximum power swing is shown (fig. 3) which would be obtained if a 75000 kW plant were synchronized to a 240-km (149-mi) 230-kV transmission line. The corresponding swing is only 9.5 degrees (20 MW). A swing of the same magnitude would be produced by closing the switch with no frequency difference but with the voltages 9.5 degrees out of phase. The first case would be quiet, but in the later case a slight sound would be produced because the power was changed abruptly from 0 to 20 MW. In either
Figure 2. - Typical calculated power swings

Figure 3. - Calculated power swing

Calculated power swings for synchronizing similar units on the high voltage bus with frequency difference of 1 cycle in 4 seconds. Circuit breaker contacts close at instant of synchronism.

Calculated Power Swing for synchronizing Keswick Powerplant (75 000 kW) to 240-km (149-mi) Elverta 230-kV line. Breaker closed at instant of synchronism with frequency difference of 1 cycle in 4 seconds.
case, the final generator loading after the swings stopped, would be of some very small value corresponding to the speed level adjustment.

In spite of a popular notion that the incoming generator frequency should be slightly "fast" when being synchronized to a heavily loaded system, actually this is not true of the usual system. The transmission-line load, swings nearer to the stability limit if an incoming generator is synchronized with the synchroscope rotating in the FAST direction than if it were rotating at the same speed in the SLOW direction. The difference depends upon the rate of decay of the power swings (fig. 4). The rate of decay of the swings is from actual measurements on a Reclamation system. This influence is negligible compared with the influence of angular error and frequency difference. If angular error and frequency difference are held within recommended limits, no time need be wasted obtaining synchroscope rotation in a particular direction. Synchronizing will be satisfactory for either direction.

Figure 4. - Power swings of incoming machine.