following a load rejection on these units is not a reliable criterion of whether the condition is abnormal or not. If the penstock is long enough, the transient overspeed following a rejection may be as high as the sustained runaway speed. Where more than one unit is served from the same penstock, the transient overspeed depends upon whether one or more units have rejected load. In the latter case, the transient overspeed is usually very nearly as high as the sustained runaway speed.

We have tried the same type of control as applied to the more ideal units with the idea of merely accepting the nuisance of restarting the units any time the overspeed exceeds the nominal speed switch setting, but this has usually proved unsatisfactory. Consequently, for such units, duration of overspeed has been employed as the criterion to distinguish whether equipment has malfunctioned and whether the shutdown solenoid should be tripped. This is accomplished by interposing a time delay relay between the speed switch and the shutdown solenoid. If the speed switch resets before the relay has timed out, the shutdown solenoid is not tripped.

Choice of setting for the time delay relay can become quite involved. Theoretical calculation is quite possible but is lengthy and expensive; experimental determination is also expensive in terms of disturbance, manpower, and recording equipment. The approximate method shown in Fig. 5 has been satisfactory and may be of practical interest. The shape of the speed versus time curve is taken from the test usually made for other purposes on a single unit. The magnitude of overspeed when two (or more) units are rejected is taken from design calculations. The duration of overspeed to the value at which the speed switch resets is then determined as shown in the figure.

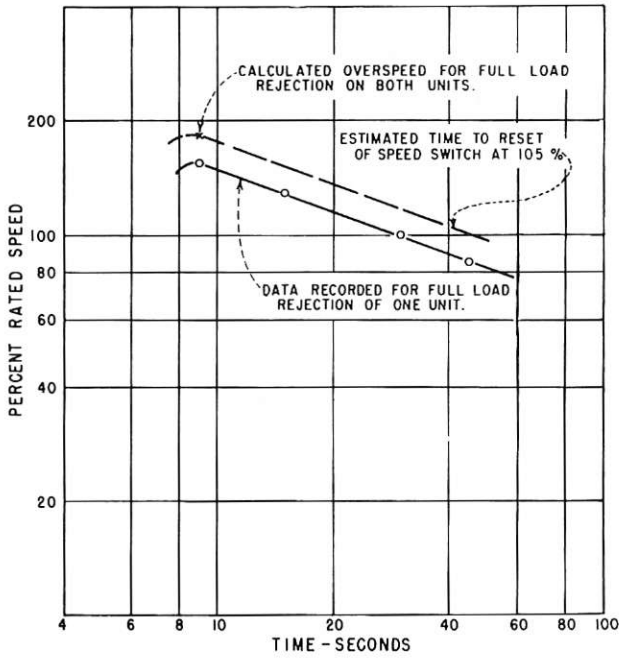

Fig. 5 Determination of duration of overspeed following rejection of two 18,950-kva units (served by common penstock 1500 feet long). Available data were 1-unit rejection test and calculated maximum speed for 2-unit rejection. Alcova Powerplant, Wyoming.

Conclusions

On small, low cost hydropower units, specification emphasis should be placed upon stability rather than upon governor sensitivity.

Solenoid control of governor dashpot bypasses is a useful device, but one which may lead to instability under system emergencies unless adjustments are made for this condition. Dependence upon manual closing of the bypasses under emergencies is undesirable.

For load rejections, dependence upon the governor ball heads as the normal gate closure actuating element with speed switch actuated shutdown solenoid for backup protection affords a simple and reliable means of control. For long penstock applications duration of overspeed is a useful criterion for effecting emergency shutdown.

The technology evolved and consolidated, mainly within the past decade, affords analysis of performance of hydrogenerating unit control, but the wide range of operating conditions from large interconnections to isolated or local area operation still affords interesting problems and occasions for exercise of ingenuity.

Acknowledgment

The calculations of speed rise and water hammer made during design by Mr. John Parmakian[3] and his technical analysis group have been a valuable practical foundation for many of the operating adjustments and control settings. Messrs. J. V. Baptist[4] and W. H. Clark[5] contributed to the overspeed control schemes described. Generous co-operation from field personnel of many projects is represented in this discussion of experience.

[3] Engineer, Division of Design, U. S. Bureau of Reclamation, Denver, Colo. Mem. ASME.

[4] Engineer, Electrical Branch, U. S. Bureau of Reclamation, Denver, Colo.

[5] Engineer, Electrical Branch, U. S. Bureau of Reclamation, Denver, Colo.

DISCUSSION

C. L. Avery[6]

The authors are to be commended for presenting a very frank and informative paper.

NEMA publication No. HT-4 recommends certain minimum values of mechanical inertia for hydro-electric generators as determined by the unit hydraulic condition. These recommendations are based on the use of standard governor designs. If the recommended values are not met, difficulties, which require special treatment, such as experienced at the Angostura Plant, may be expected.

It seems evident that the solenoid control of the governor dashpot provides a satisfactory method for quickly disarming the dashpot bypass which is convenient for automatic operation by suitable control relays and switches. In this respect it is an improvement over the mechanical bypass. Also, the solenoid operated dashpot bypass is adjustable to suit system conditions whereas the mechanical bypass requires substitution of different bypass rods for change in adjustment. Both are subject to the same limitations respecting stable control.

Overspeed switches are designed as back-up protection. If the governor does not hold the speed to normal overspeed values then the cause for malfunctioning should be determined. Otherwise, it is desirable and often imperative to get the unit back on-line as soon as possible. The use of a partial shutdown solenoid for overspeed protection seems superfluous. It may be used in the starting sequence in which case it is set above speed-no-load. It cannot be used for both purposes concurrently.

[6] Engineer, Woodward Governor Company, Rockford, Ill. Mem. ASME.

Authors' Closure

Mr. Avery's comments are all pertinent and valuable. He has wisely called attention to the fairly recent (1958) NEMA publication which conveniently indicates acceptable ranges of hydraulic and mechanical characteristics as well as the range of adjustment in the standard design governors. This should simplify implementing the first conclusion in the paper.

There is no question that the solenoid control of the dashpot is much more convenient and flexible than the mechanical bypass. It is the latter advantage that gives rise to the comments of the paper. Limiting the amount of bypassing to no more than is really needed can reduce the amount of reliance which otherwise must be placed upon means of disarming the device in emergencies.