$$F = A \frac{\partial}{\partial t} \int_{\ell_1}^{\ell_2} \rho(x, t), V(x, t)\, dx$$

The variation of $V(x, t)$ and $\rho(x, t)$ for the crossover piping system were calculated using a one-dimensional unsteady flow computerized calculation technique. The time varying boundary conditions were obtained from the cycle simulation results. The results of this analysis indicated that with the valve strokes used these forces do not require changes to the original piping design.

Conclusions

This paper presents the results of a complete evaluation of a sustained fast valving transient. The major conclusions to be drawn from the material presented are as follows:

1 The control system presently used can, with modification, achieve the desired governor and interceptor valve motions within the required time frame.

2 The reheater safety valves are not expected to lift during the transient.

3 The rate of depressurization of the moisture separator is not a problem since the calculated depressurization for fast valving is not as fast as the calculated depressurization for rapid load run back.

4 No decrease in unit reliability will be experienced because of sustained fast valving.

5 Care must be exercised when developing the model for transient simulation because significant errors can result in the omission of significant energy sources. For example, the case of ignoring the large sources of energy in the low pressure heaters in the cycle studied.

6 Results of investigations have demonstrated that a form of sustained fast valving can be applied to large generating units served by PWR steam supply systems.

7 When other forms of sustained fast valving are investigated and effectively applied to nuclear and fossil units, systems planners will have other alternatives to improve system stability.

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DISCUSSION

R. H. Park[3]

As the November 9th, 1965 blackout made clear, in the event of infrequently occurring severe contingencies it is possible for cascading shutdowns of generating stations to take place unless due precautions are taken.

One precaution is to electrically provide so that severe bulk power transmission system faults occurring close to generating stations will fail to cause loss of synchronism of the station's generators.

However, this approach can, and, as a rule, does, call for construction of more transmission circuits that would be needed if the problem of avoiding loss of synchronism did not exist.

An effective way to minimize need to construct transmission lines that would only be needed to prevent loss of synchronism is to provide to very rapidly bring into effect a sustained reduction of turbine driving power as a response to the occurrence of line faults.

The type of control that is being provided at Watts Bar has been designed to,

1 bring about a preprogrammed reduction in turbine driving power from full load to something under 60 percent, largely effected within 0.3 s, hence rapidly enough to favorably influence the ability of the generators to retain synchronism with TVA's system despite delay in clearance of three phase transmission system faults occurring close to the station, and,

2 thereafter hold driving power in the range of 65–75 percent as a way to avoid chance of loss of synchronism subsequent to the generator rotor first swing,

while, also, these favorable results have been accomplished in spite of the fact that the only fast valve closure technique available was dumping of valve actuator oil (mainly to the piston rod side of the piston).

The key control techniques utilized comprise:

(*a*) closing two out of four control valves at top speed by means of valve actuator oil dumping; and

(*b*) following full closure, rapidly reopening intercept valves part way, and thereafter slowly fully opening.

These key control features render it possible to usefully avoid other than a limited and brief undershoot of driving power below the sustained 65–75 percent range, and also eliminates development of a rise in reheat steam pressure sufficient to cause discharge of steam through reheat pressure safety valves, such as would take place in absence of their use.

The Westinghouse organization at Lester, Pa., has responded well to TVA's call on it to employ the skills of its steam turbine valve and control system designers to provide the needed hardware, which, in the form of fast reclosing valve actuator oil dump valves, and, as it appears, rugged, as well as fast closing butterfly type intercept valves fortunately was already partly available.

Also, the Lester organization, where necessary in cooperation with East Pittsburgh and Monroeville, took the useful precaution of establishing a fast valving task force which systematically examined all facets of the response of the Watts Bar installation, including the nuclear steam supply source, to initiation of fast valving, and found, among other things, that the effect of backflow of steam from feed water heaters was far from minor.

The fact that, in this instance, a thoroughgoing study of the response of an entire station to fast steam inlet valve repositioning has been carried through, deserves to be recognized as an important forward step.

While, as at Watts Bar, employing changes in turbine control systems as a way to allow avoiding a need to construct, as it works out, 105 miles of 500 kV line costing, today, around 265,000 dollars per mile, hence in excess of 27 million dollars, can be readily understood to represent a worthwhile objective, there appears to be a useful byproduct as well.

[3] President Fast Load Control Inc., Brewster, Mass.

[4] Number in brackets designate Additional References at end of discussion.

This relates to the fact that, if the control system is arranged to come into effect in response to a sudden preset increase, either in unit speed, or frequency, it becomes a way of limiting the extent of increases in speed that can cause boiler trip-offs, and also can harmfully affect turbine blading, that can take place when an area of an interconnected group of power systems becomes electrically detached from the balance as a result of a system disturbance, and as a consequence, experiences a partial loss of load due to the opening of tie lines that were exporting power.

While there is already provision for GE and Westinghouse turbines to respond to partial loss of load, the response to large load losses consists in full closure of both control and intercept valves, effected at top speed, after which at first intercept, and next control, valves, begin to open, typically at rate of between 5 and 20 s full stroke, the point applies that, as experience has demonstrated, this currently provided control scheme fails to result in the type of control action that is needed to allow providing so that boiler trips will not take place.

Also even when the extent of sudden load loss is less than enough to cause fast full valve closure, with the present control schemes turbine speed will temporarily overshoot the increase that would take place were the load change to occur slowly, while, also, overshoot of this type, occurring under load, can, in worst cases, cause damage to turbine blading.

One way to solve these problems would be to provide for the positioning of both control and intercept valves with use of servo valves that would be chosen large enough to cause position changes to take place more rapidly than is feasible with presently employed servos, and, at the same time, in accordance with European practice provide to initiate rapidly effected partial closure of intercept valves as a supplement to partial control valve closure, when speed increase exceeds a preset value, [5].[4] This European scheme has, indeed, clear cut advantages.

However, an alternate approach would be to bring into effect sustained type fast valving of the Watts Bar station type in response to a preset increase in either unit speed or frequency, coupled with provision for appropriate rapid response of steam generators, whether accomplished via bypassing of steam, as would be employed in the case of PWR and BWR nuclear installations, or via at once initiated fed-forward type changes in the fuel, air and feedwater input to fossil fuel type steam generators [6].

This type of response to partial loss of the load of an islanded area of a system could be used to progressively bring into effect a series of step type reductions of area generation in a manner dependent on the extent of frequency increase, as a parallel to the present practice of providing to progressively shed load when frequency decreases.

Additional References

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Authors' Closure

The authors wish to thank Dr. Robert H. Park for his discussion and his suggested potential application of the fast valving concept to other types of system disturbances. Dr. Park mentioned the European practice of partial closure of interceptor valves for control of speed or frequency during certain system transient conditions. Westinghouse has supplied modulating interceptor valves on some units manufactured for European customers. In line with Dr. Park's discussion, we would like to point out that as in the case of "Sustained Fast Valving," we will respond to the needs of industry as these needs become better defined and as we are requested to do so.