TURBINE FAST VALVING TO AID SYSTEM STABILITY: BENEFITS AND OTHER CONSIDERATIONS

Report of a panel discussion sponsored jointly by the IEEE Discrete Supplementary Controls Working Group* and the ASME/IEEE Power Plant/Electrical System Interaction Working Group

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ABSTRACT

Fast valving of steam turbines is a means of rapid reduction of mechanical power on turbine-generators to prevent rotor angle instability when a significant power-load imbalance is sensed. Fast valving and early valve actuation (EVA) are equivalent terms. It is a potentially useful aid to system stability that has not been widely applied for several reasons. The four "short note" reports describe implementations of several methods of fast valving and discuss application considerations.

INTRODUCTION

A panel discussion on turbine fast valving was presented at the 1981 Joint Power Generation Conference, with panelists from utilities who had implemented or considered implementation of fast valving. Subsequently, it was decided to condense the material into this paper. In the following sections, the individual contributions of panelists are reported.

Introductory information on fast valving and other discrete controls is presented in a Discrete Supplementary Controls Working Group paper [1]. As discussed by the individual contributions and in the references, there are a number of considerations in applying fast valving including:

- o Momentary (temporary) fast valving versus sustained fast valving.
- o Which valves (control, intercept, or both) to close, and then reopen or reposition.
- o Method of initiating fast valving.
- o Effect on boiler or steam generator safety/relief valves.
- o Effect of pressure and thermal stress on boiler/steam generator, moisture-separator, reheater, and turbine.
- o Need for boiler/steam generator control adjustment.
- o Generator tripping as an alternative to fast valving. (The Discrete Supplementary Controls Working Group has sponsored two panel discussions on generator tripping and is preparing a similar paper reporting the presentations.)
- o Methods, such as single-pole switching or neutral resistors to reduce frequency of fast valving operations. (The Discrete Supplementary Controls Working Group has also sponsored panel discussions on single-pole switching and is preparing a paper reporting the presentations.)

The presentation on sustained fast valving by Leo Edwards of Tennessee Valley Authority (TVA) is not reported in this paper. Rather, comprehensive descriptions of TVA's fast valving implementations are available in references 2, 3 and 4. References 2 and 3 include field test results to verify the power decay controls installed on a large cross-compound fossil-fired once-through unit. Reference 4 describes sustained fast valving on a large nuclear unit. TVA is applying sustained fast valving on all new large turbine-generators.

A. EARLY VALVE ACTUATION EXPERIENCE ON SOUTHERN ELECTRIC SYSTEM (J. R. Woodall and J. D. Gregory, Southern Company Services, Inc., Birmingham, AL)

The bulk of experience with EVA on Southern's system was gained from testing and operation of the Georgia Power Company Plant Harllee Branch units. The first investigation for application of EVA was initiated in 1966 for Plant Branch which has an installed capacity of approximately 1600 MW made up of four coal fired units, as summarized in Table A.1.

TABLE A.1.

PLANT BRANCH UNITS 1-4

	Unit 1	Unit 2	Unit 3	Unit 4
Generator				
Manufacturer	GE	GE	GE	W
Rating (MVA)	320	422.4	640	640
Excitation Response Ratio	0.5	1.5	1.5	1.5
Turbine				
Rating (MW)	250.8	319	480.8	490
Pressure (PSIG)	2400	2400	3500	3500
Temperature	1000/1000	1000/1000	1000/1000	1000/1000
Speed/Load Governor	MHC	MHC	MHC	EHC
Steam Generator				
Manufacturer	B&W	Riley	B&W	B&W
Type	Drum	Drum	Once Through	Once Through

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The plant is connected to the system with a 230-kV ring bus substation and nine 230-kV lines. Initial transient stability studies demonstrated that stable operation could not be maintained at the plant for a bolted three-phase fault and breaker failure. Tripping units at the plant would maintain stable operation for the postulated dual contingency; however, this solution was considered regressive and not in the best interest of system operation. State of the art stability aids were simulated on subsequent studies which range from high speed breaker failure relaying schemes to braking resistors. None of these aids would singularly satisfy the requirements.

During these initial studies, General Electric Company (G.E.) presented a paper [5] demonstrating improvements which could be realized in unit transient stability performance by momentarily closing the turbine steam valves. This concept was reviewed with G.E. and subsequently Westinghouse Electric Corporation for application on the turbine-generators at Plant Branch. The manufacturers were requested to make an indepth review of the turbine-generator designs for EVA operation and on-line field tests for the units. Preliminary stability studies were made employing the manufacturer's calculated turbine power decay EVA characteristic for each unit. These results showed considerable promise. Figures A.1 and A.2 illustrate, respectively, the calculated EVA power decay characteristics for G.E. Unit 2 and Westinghouse Unit 4.

The EVA was limited to operation of the intercept valves. This eliminated complexities of unit speed/load and plant controls associated with the governor valves. The turbine-generator manufacturers found no design limitations for EVA operation of the units and the decision was made to apply EVA controls on Plant Harllee Branch Units 2, 3, and 4.

Steam Generator EVA Limitations

During review of the turbine energy control paper [5] with G.E., Southern was advised that one primary objective of the paper was for generating discussion by the steam generator manufacturers; however none was received. Southern then requested the domestic steam generator manufacturers to review the equipment design and advise if EVA operation of the Plant Branch units had any limitations on the equipment design and operation. Several responses were not clear, although all indicated that periodic operation of EVA was acceptable. A review was made with each manufacturer to clear the issue. The basic critical issue resolved into how soon the initial steam flow would be essentially restored to the reheater. The problem was one of reheater tube heating when the steam flow was shut-off and subsequently restored during an EVA operation. For these conditions the steam generator time limitation, to essentially reestablish reheater steam flow, was obtained for both recent and approved unit additions on the Southern electric system. These are:

Babcock and Wilcox	- Once-through super critical	- 12 seconds
Foster Wheeler	- Natural circulation	- 3 seconds
Riley	- Natural circulation	- 12 seconds
Combustion Engineering	- Once-through super critical	- 10 seconds

Lifting of the steam safety valves can be expected to occur at high loads for an EVA operation. Only experience will determine if these safety valves will properly reseat. Also, the response of the steam generator controls should be investigated.

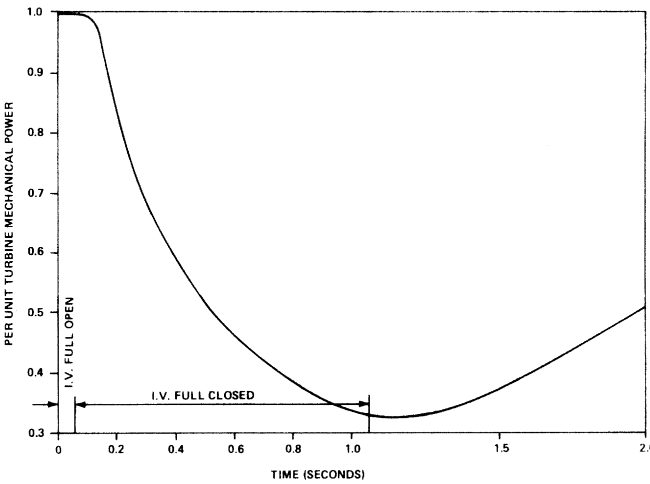

Figure A. 1 Calculated power decay supplied by General Electric for Harllee Branch Unit 2.

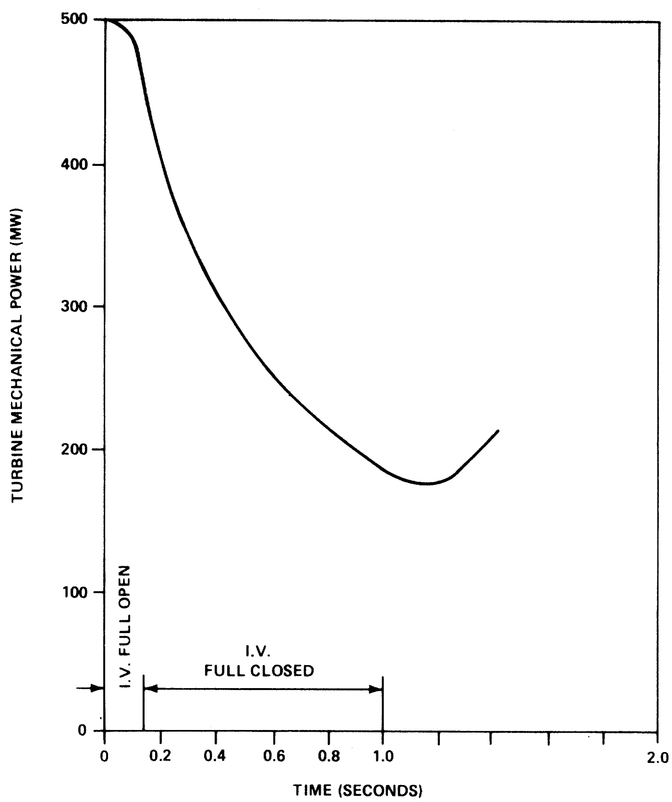

Figure A.2 Calculated power decay supplied by Westinghouse for Harllee Branch Unit 4.

EVA Control Logic Design

There were unknowns involving a U.S. Patent as to fault detection and initiation of an EVA operation. As a result, Southern had the turbine-generator manufacturer provide the detecting initiating logic as an extension of a method employed to limit overspeed due to load rejection. This logic depends on the comparison of mechanical input power and electric output power. The former is measured by reheat steam bowl pressure; the latter is monitored by a high speed power relay or transducer depending on the design of the unit speed/load control system. When the mechanical input power exceeds the output power by a set amount the intercept valves close rapidly.

The setting applied to the EVA control scheme for the tests and for initial operation allows the controls to function when the steam flow is above the 75 percent rating and the electrical output drops below 25 percent of rating. EVA operation is initiated as soon as sufficient imbalance exists between mechanical input power and electrical output power. There is no waiting period for acceleration of the unit rotor or for breaker failure to become evident. The EVA controls are not actuated by external protective relays or other devices. Each turbine-generator so equipped is individually restrained when sufficient acceleration power occurs for any reason.

This system avoids the exposure to which a common EVA logic control system is subjected at a multi-unit plant where failure or misoperation would encumber all units. The control system must be immune to electrical power backswings experienced for EVA operation initiated by a system fault. EVA operation may be experienced when not required due to any three phase fault, heavy system swings, and by the necessity of having the logic detection set with some over reach to assure coverage of the critical fault zone. The scheme is designed for detection of only a three phase fault. EVA operation is not required for faults of less severity with a failed breaker.

Field Test - General Electric Turbine-Generator Units

Units 2 and 3 were tested jointly on-line under load by engineers of the utility and G.E. Dry run tests (no steam) were made on April 5, 1970. On-line field tests were successfully made on April 10-11, 1970. For brevity only the highlights of results for tests on Unit 2 will be described, since those on Unit 3 had no significant differences.

Three tests were made on Unit 2 for the following load conditions:

Test 1 - 360 MW, 5% Over Pressure
Test 2 - 373 MW, 5% Over Pressure
Test 3 - 260 MW

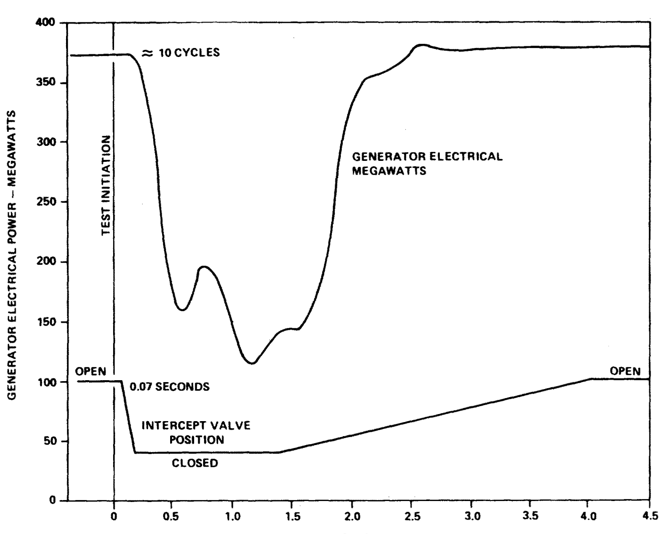

Fig. A.3 Plant Harllee Branch Unit 2 EVA Test 2. Initial load 373 MW, 5% over pressure.

The results of these tests have been reported earlier [6]. Each test was initiated by opening the generator bus potential transformer 120 volt circuits supplying the EVA watt sensing relays in the MHC control system. This simulated a three-phase fault in the critical zone.

Figure A.3 shows Unit 2 test results. Both intercept valves start to close approximately 0.07 seconds after test initiation and go through full stroke in approximately 0.11 seconds. After remaining closed for approximately 1.23 seconds, they are reopened through full stroke in approximately 2.6 seconds. This easily meets the 12 second time established by the steam generator manufacturer. The generator terminal electrical megawatt power lags the closing of the intercept valves as power is removed from the machine rotor by valves closing. Inertial electrical power oscillations are exhibited while the valves are closed followed by the power recovery back to full load as the valves are moved to the full open position. Good repeatability was obtained on each test. Figure A.4 shows comparison of the transient stability simulation results with the test results for this case. Good correlation is shown for the generator terminal megawatt output reduction.

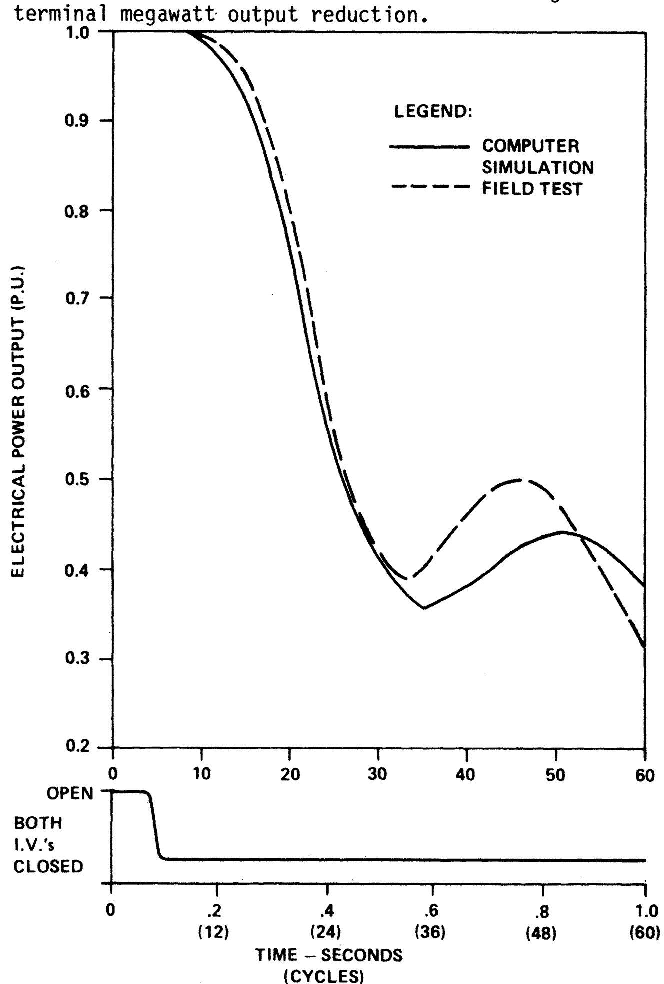

Fig. A.4 Plant Harllee Branch Unit 2 EVA Test 2--Comparison with Simulation. One per unit equals 373 MW.

There were no noticeable changes observed in unit operation (noise and vibration) by observers in the plant other than that producted by escaping steam when the reheat safety valves lifted during the tests. The safety valves lifted and reseated properly during test 1 and 2, but were not observed to function on test 3 due to less reheater pressure build-up at the lower load.

Field Test - Westinghouse Turbine-Generator Unit

Unit 4 was tested on-line under load jointly by engineers of the utility and Westinghouse on June 6, 1970. Several tests were made, with three tests for turbine-generator load conditions of 530 MW. Each test was initiated by opening the generator bus potential transformer 120 volt circuits supplying the EVA watt transducer in the Analog Electro-Hydraulic control system. This simulated a three-phase fault in the critical zone.

Figure A.5 shows Unit 4 test 2 results at 530 MW initial load. The intercept valves started to close approximately 0.18 seconds after test initiation and go through full stroke in approximately 2 seconds. After remaining closed for approximately 2 seconds, a valve on the right side started to crack open followed by the other valves on both sides. It took in excess of 27 to 28 seconds for each valve to reach the full open position. However, I.P. inlet pressure (not shown) returns to essentially the initial value in about 9 seconds due to the non-linear flow characteristic with valve position. This meets the 12 second time established by the steam generator manufacturer. Good repeatability was obtained on each test.

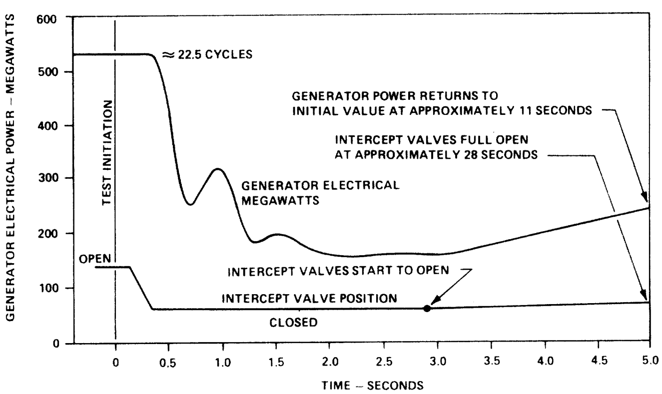

Fig. A.5 Plant Harllee Branch Unit 4 EVA Test 2. Initial load 530 MW.

In comparison with the previous tests on Units 2 and 3, tests on Unit 4 were dramatic in higher noise level and longer duration of blow down when the reheat safety valves lifted. This was due in part to the slow reopening time of the intercept valves. The reheat safety valves reseated properly during the tests. There were no other noticeable changes in unit operation.

The recorded generator terminal megawatt power has the characteristic expected for the turbine EVA tests. However, the results did not meet the predicted values calculated by Westinghouse. The intercept valves must start to close faster to meet the Westinghouse calculated EVA performance characteristic. This has an impact on the stability of Plant Branch in that, with this EVA characteristic, unstable operation would occur for a very close in three-phase fault when at full load. Southern requested Westinghouse to advise what would be done subject to their analysis of the EVA test data. The final fix list was developed after several iterations with Southern Company Services and Georgia Power Company. These items were:

1. Supply completely new servo actuators for each intercept valve.

2. Replace the present intercept valve closing spring with two closing springs.

3. Modify the spring housing by making a groove to act as a guide for the new springs.

4. Alter the intercept valve piston rings.

5. Replace the Hall effect Watt transducer and the turbine cross-over pressure transducer with three under power relays in series with the pressure switch. This is for a complete modification of the EVA control logic to eliminate 0.08 second delay.

6. Make a minor change to the Analog EHC controller.

Shipment of these components and completion of field modifications on Unit 4 have been accomplished. Since a decision had been previously made to provide EVA controls on all new unit additions and several on-line units on the Southern electric system, these modification were completed on these units also.

Conclusion

EVA tests on the Southern electric system and system simulations have proven EVA to be a practical stability aid. Although there were no adverse effects found during and after the EVA tests on Units 2, 3 and 4, EVA operation has been questioned as having the possibility of degrading unit reliability. Comments from the equipment manufacturers on this subject would be of interest.

B. APPLICATION OF NEUTRAL RESISTORS AND FAST VALVING AT THE GERALD GENTLEMEN STATION (J. H. Doudna and D. L. Osborn*, Nebraska Public Power District, Columbus, Nebraska)

The Nebraska Public Power District's (NPPD) Gerald Gentlemen Station (GGS) is located on the Sutherland Reservoir approximately 32 km (20 miles) west of North Platte. The plant consists of two 600 MW coal-fired units. The turbine-generator for Unit 1 was manufactured by Brown-Boveri, and that for Unit 2 was manufactured by General Electric Company. The boilers for Units 1 and 2 were manufactured by Foster Wheeler and Babcock & Wilcox, respectively. Both boilers are drum-type.

During the summer periods, when there is extensive use of electricity for irrigation and air conditioning purposes, the load center on NPPD's system is near Grand Island, Nebraska (274 km or 170 miles from GGS). During fall, winter, and spring, the electrical load center is near Lincoln, Nebraska (386 km or 240 miles from GGS). Because of the large distances and the high cost of transmission facilities, it was necessary to design GGS to operate with minimum of transmission system additions.

The transmission system which resulted from the studies, and which was in service at the time the first unit at GGS went in service, tied GGS to North Platte and Ogallala by 230-kV lines and to Grand Island by a new 345-kV line. Powerflow studies showed this transmission configuration to be adequate for an intact system condition for carrying the entire 600 MW output of Unit 1. However, stability simulations using this transmission system demonstrated the transient behavior of Unit 1 to be marginal. To enhance transient stability, options other than further transmission additions were investigated. These included optimizing the step-up transformer impedance, evaluating reclosing schemes, and selecting the preferred transmission voltage to which to connect the unit.

*Presently with ASEA, Inc.

After examination of the foregoing items, it was found that Unit 1 could still be unstable for three-phase and close in single line-to-ground faults which removed the GGS-Grand Island 345-kV tie from service. The unit was also unstable for nearby single line-to-ground faults, particularly in connection with a failed breaker which removed an additional transmission element. These studies also demonstrated that fast valving the turbine-generator was the most effective and least costly means of stabilizing GGS Unit 1 for these disturbances.

Since line-to-ground type faults comprise the majority of all faults, other options were investigated which would minimize the use of fast valving for severe single line-to-ground faults. Methods investigated concentrated on limiting fault currents by the insertion of a reactor or a resistor in the neutral of the generator step-up transformer. A reactor, while limiting the fault current, did not provide significant stabilizing effects on the generator. Even with a neutral reactor, the transmission lines leading away from GGS were not able to carry sufficient amounts of power due to the collapse in voltage resulting from the fault. Thus the imbalance between turbine mechanical power and net electrical power output of the generator went into the acceleration of the rotor. A neutral resistor of the same ohmic value as a reactor, however, provided a significant stabilizing effect. Although the voltage collapse still did not allow the transmission network to carry sufficient power away from GGS, the fault current flowing in the neutral resistor created real power losses and thus provided an outlet for excess electrical power which was produced by the turbine-generator during the fault. The power dissipation in the neutral resistor was significant enough to eliminate the need for fast valving for all but single line-to-ground faults which occurred in conjunction with a failed breaker and which also caused the loss of the Gentleman-Grand Island 345-kV line.

The benefits derived from the neutral resistor installed on GGS Unit 1 prompted NPPD to investigate the installation of a resistor in the neutral of the Unit 2 step-up transformer. To assure that Unit 2 would receive adequate stabilizing benefits from a neutral resistor, it was necessary to install a resistor in the neutral of its step-up transformer. Two factors dictated this: (1) there may be periods of time when Unit 1 and its associated neutral resistor are out of service; (2) GGS Units 1 and 2 step-up to different voltage levels and are isolated by a 345/230-kV autotransformer. Any ground current resulting from a line-to-ground fault and not flowing through a resistor would not cause power dissipation and thus greater rotor acceleration would result. Stability simulation for the present day system confirm the benefits derived from neutral resistors.

C. <u>TEMPORARY FAST TURBINE VALVING AT AEP's ROCKPORT PLANT</u> (B. M. Pasternack, American Electric Power Service Corporation, Columbus, Ohio)

The Rockport generating plant comprises two 1300 MW coal-fired super critical once-through units. The boilers were manufactured by Babcock and Wilcox Company and the cross-compound turbine-generators were manufactured by Brown Boveri Corporation. The first unit is scheduled for operation in September, 1984 and the second in September, 1988.

Two 765-kV outlets will be utilized to tie this plant into the AEP stations closest to Rockport. One 765-kV line will be constructed from Rockport to the existing Jefferson 765-kV station located in southeast Indiana, a distance of 180 km (112 miles). The second 765-kV line, 155 km (97 miles) in length, will be constructed from Rockport to a new station site called Sullivan, which is adjacent to the existing Breed Plant in west-central Indiana. The Sullivan station will be connected to the existing Breed 345-kV system via a 765/345-kV 3000 MVA station. In the first stage of development when Unit 1 comes in service, only the Rockport-Jefferson 765-kV line will be in service. The Rockport-Sullivan line will be placed in service by December, 1985. Therefore, there will be a period of over one year when the first 1300 MW unit will be operated on a single line.

To maximize the availability and reliability of the 765-kV outlets from the Rockport plant, single-phase switching will be installed on each line. This switching feature provides the means to isolate temporary line-to-ground faults by tripping and then reclosing only the faulted phase. The remaining two unfaulted phases remain in service to provide a path for synchronizing power from the Rockport plant during this temporary disturbance.

While the single-phase switching feature will enhance the stability performance of the Rockport units for a number of operating conditions, certain multiple transmission outage conditions involving the Rockport outlets would necessitate curtailing unit output to maintain adequate stability performance. To further enhance stability performance of the Rockport units, temporary fast turbine valving will be installed on each of the Rockport 1300 MW units. Results of simulation studies showed that the combination of the single-phase switching and fast turbine valving will enhance the operating flexibility of the 2600 MW Rockport plant and maintain the desired level of system reliability without resorting to operator-directed curtailments in anticipation of critical contingencies.

<u>Fast Turbine Valving Concept</u>

Fast turbine valving can be classified into two general categories--temporary and sustained. To accomplish either type of fast valving, the control and/or intercept valves must be closed rapidly. Both types of fast valving produce a very rapid reduction in mechanical driving power following a critical system fault. Even though the rate of reduction is not fast enough to precisely match the reduced electrical load, the accumulated effect can significantly arrest the swing of the generator, thereby improving transient stability performance.

With temporary valving, the control and/or intercept valves are permitted to reopen to their original operating position, allowing the driving power to return to the prefault value very shortly after a predetermined minimum is achieved. For sustained valving, on the other hand, after the initial closure of the control valves, the reopening of the valves is adjusted so that the post-fault driving power is reduced to a new unit load level. In addition, boiler controls must be adjusted to maintain steam pressure and temperature within acceptable limits. Sustained valving generally requires more complicated controls than temporary valving and is usually associated with long duration faults or system disturbances that result in permanent outages that significantly weaken the transmission system.

To initiate action of the control and/or intercept valves requires fast sensing of pre-defined electrical disturbances and appropriate controls to partially close the valves in the shortest possible time. The initiating signal can be developed by the same relays that detect transmission network faults or by measuring any one of several quantities, including generator acceleration or depressed bus voltage.

Temporary Fast Valving for Rockport Plant

The steam flow path for a typical 1300 MW Brown-Boveri cross-compound turbo-generator is shown in Figure C.1. The steam from the boiler enters the high pressure (HP) turbine through the main control and stop valves. The exhaust steam from the HP turbine goes to the reheater for a temperature boost and enters the intermediate pressure (IP) turbine section through the reheat, intercept, and reheat stop valves. The exhaust steam from the IP turbine goes to the low pressure (LP) turbine sections of each shaft before being exhausted to the condenser for recycling.

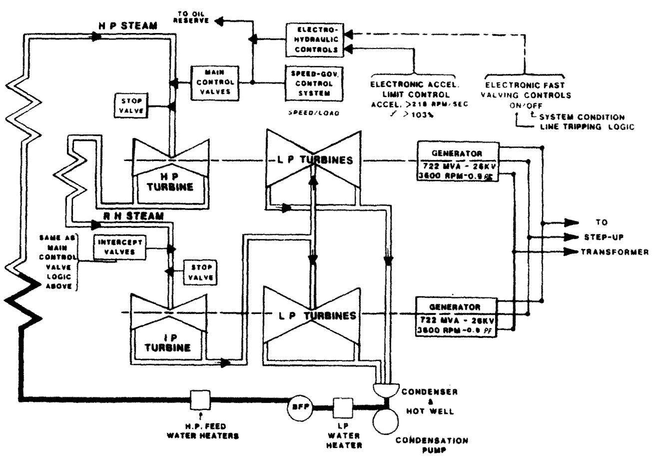

Fig. C.1 Steam Flow Path and Speed Control for a Typical BBC 1300 MW Unit.

By closing the control valves during a fast valving operation, the mechanical driving power applied to the HP turbine will be reduced rapidly, followed several seconds later by a reduction in IP and LP turbine driving power. Since the intercept valves control over 70 percent of the total unit power, the use of intercept valve stroking to supplement control valve action in the Rockport application provides significant stability benefits by causing a rapid decrease of intermediate and low pressure turbine power.

Control valve closure must be carefully analyzed to avoid imposing severe transient stresses on the boiler system as well as other problems, such as lifting of boiler safety valves and turbine stresses. In developing the turbine valving characteristic for Rockport plant, a multi-disciplinary approach involving interaction among AEP's system planners, electrical and mechanical engineers and Brown-Boveri machine designers and control experts was required. From preliminary data supplied by the turbine manufacturer, transient stability studies were run to define the acceptable range of fast valving characteristics that satisfied both the system requirements and the mechanical and thermodynamic constraints of the boiler and turbo-generator. Based upon extensive analysis, it was determined that the valve stroke characteristics should conform to certain specifications in order to meet the system performance requirements for the Rockport plant while taking into account equipment restrictions. These specifications are:

1. Control and intercept valves should close as rapidly as possible.

2. Control valve should close to 40 percent and intercept valves to 25 percent of full stroke.

3. Time delay before reopening valves should be as short as possible (0.3 seconds or less).

4. Control valves should reopen to original position in approximately six seconds, and intercept valves reopen to original position in approximately seven and one-half seconds.

Automatic reopening of both sets of valves to the pre-fault position within 8 seconds from the initiation of the fast valving is expected to minimize mechanical stresses and the possibility of lifting safety valves or causing turbine fatigue. In order to avoid thermal and pressure stresses in the boiler and turbine, the valves were allowed to immediately begin reopening after reaching the predetermined set point (25 percent for intercepts and 40 percent for control valves). This reopening occurs at the natural rate under speed-governor control. Furthermore, in order to minimize the impact of the boiler transients that follow a fast valving operation, a second operation will only be permitted after a delay period of approximately 10 minutes. The turbine fast valving characteristic is illustrated in Figure C.2.

The turbine power reduction response following the actuation of temporary fast turbine valving is inherently delayed due to the time lag involved in fault detection, conversion of the electrical signals to a hydraulic control signal and overcoming the inertia of the large valve masses. The 12-cycle time delay shown in the fast valving characteristic between fault initiation and the start of rapid driving power reduction consists of two components. The first, which cannot be reduced substantially, is due to valve inertia and hydraulic control fluid and steam transport delay. These factors account for approximately 7 to 8 cycles. The remainder of the 12-cycle interval relates to system relay and control delays, which may vary depending upon the fault conditions. In some cases, only 1 cycle of relay time may be required, whereas for evolving faults or breaker failure conditions, up to 5 cycles (or longer) may be necessary.

At the Rockport Plant, temporary fast turbine valving will be initiated using the 765-kV line protection system as the principal source of fast valving signals.

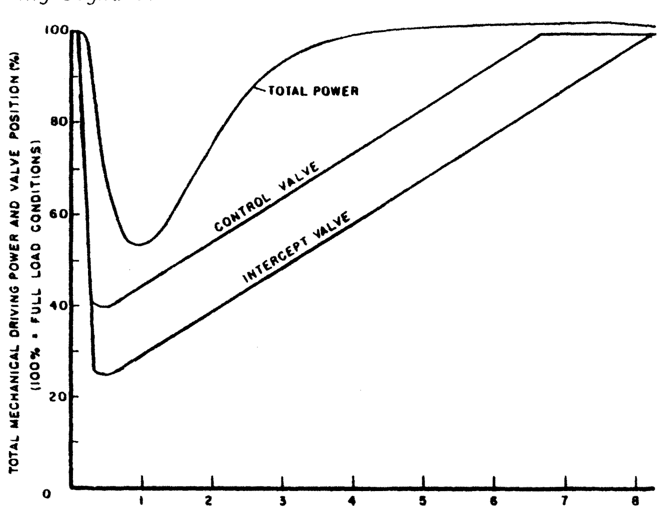

Fig. C.2 Relationship Between Mechanical Driving Power and Valve Position

Rockport Plant Transient Stability Performance

The Rockport Plant outlets are planned on the basis of double contingency criteria. These criteria require that the Rockport Plant remain stable following a disturbance, even with a critical transmission facility out prior to the disturbance. Following the permanent outage of a transmission facility, the generation on the system will be readjusted, if necessary, to insure that all facilities are operated within their normal ratings. Realistic contingencies were selected by applying the specific planning criteria outlined in Table C.1.

Table C.1

ROCKPORT PLANT TRANSIENT STABILITY TESTING CRITERIA

	PRE-FAULT SYSTEM	FAULT CONDITION
I.	All facilities in service	Permanent three-phase fault on either Rockport outlet (cleared in primary time)
II.	All facilities in service	Permanent single-phase-to-ground fault on either Rockport outlet with single breaker pole failure (cleared in back-up time)
III.	One Rockport Plant transmission outlet out of service	Temporary single-phase-to-ground fault on the remaining Rockport transmission outlet (cleared by single-phase switching)
IV.	Most critical transmission facility remote from the Rockport plant out of service	Permanent single-phase-to-ground fault on either Rockport outlet

The transient stability performance was evaluated for a multi-phase fault or a slow clearing (14 cycles) single phase-to-ground fault on either Rockport outlet with all facilities in service, and for a single phase-to-ground fault on either Rockport outlet with the remaining outlet or another critical facility remote from the Rockport Plant out of service. Primary fault clearing was assumed to occur 3 cycles after fault initiation.

Table C.2 presents the results of those selected transient stability tests which illustrate the need for stability enhancements for the two-unit/two-outlet configuration. As indicated, to maintain adequate stability margins for a number of possible operating conditions, particularly when one of the two 765-kV outlets is out of service and Rockport is operating at or near its full capacity of 2600 MW, operator-directed unit curtailment of up to 500 MW would be required in anticipation of the next critical transmission contingency.

The transient stability performance of the plant was reevaluated with fast turbine valving to quantify the potential benefits. The last column of Table C.2 highlights the results of this analysis. As indicated, actuation of fast turbine valving eliminates the need for pre-fault generation curtailment in all but one case. The 100 MW operator-directed curtailment at Rockport for the case with the Rockport-Jefferson 765-kV line out of service is a reduction from the 500 MW curtailment required if no fast turbine valving were employed. This required modest curtailment is primarily due to the relatively weak 345-kV system in the Breed area, where the second 765-kV outlet from Rockport Plant is to be terminated. However, the transient stability simulations carried out for this study did not consider the effect of plant auxiliary motor load damping. The auxiliary load requirements at Rockport total about 160 MW, which has a significant damping effect on the generating units. Subsequent studies taking this auxiliary load requirement into account indicate that these dynamics will eliminate the need for even the 100 MW curtailment.

Table C.2

ROCKPORT PLANT STABILITY PERFORMANCE

PRE-FAULT CONDITION	CONTINGENCY	PRE-FAULT CURTAILMENT FOR STABLE OPERATION OF THE PLANT — TEMPORARY FAST TURBINE VALVING: NO	YES
All facilities in service	Permanent three-phase fault on Rockport-Jefferson 765-kV line	100 MW	None
All facilities in service	Permanent single-phase-to-ground fault on Rockport-Jefferson 765-kV line with breaker failure	300 MW	None
Rockport-Sullivan 765-kV line out of service	Temporary single-phase-to-ground fault on Rockport-Jefferson 765-kV line (cleared by single-phase switching)	200 MW	None
Rockport-Jefferson 765-kV line out of service	Temporary single-phase-to-ground fault on Rockport-Sullivan 765-kV line (cleared by single-phase switching)	500 MW	100 MW
Breed-Casey 345-kV line out of service	Permanent single-phase-to-ground fault on Rockport-Jefferson 765-kV line	200 MW	None

Conclusion

Temporary fast valving at the Rockport Plant will provide several benefits, including avoided unit curtailments and reduced electro-mechanical stresses resulting from system disturbances. These benefits will be achieved at minimum expense without making changes in the boiler control systems.

The development of the temporary fast valving control scheme for Rockport considered three key factors: speed, selectivity and reliability. As discussed, rapid detection of a critical system disturbance and immediate initiation of power decay is essential to derive the maximum benefit from the temporary fast valving scheme. However, while valving should be fast, unnecessary initiation should be avoided to minimize wear on the valves and transient effects on the boiler and turbine. Consequently, the relay and control system must be selective. Finally, reliability is important to insure that valving will be properly initiated and completed for those system fault conditions which could otherwise cause unit tripping.

At the Rockport Plant, speed is achieved through the use of electronic controls in the plant coupled with locating the control mechanism physically close to the valves to minimize hydraulic fluid transport delays. Further, all system fault conditions will be detected using 1-cycle line relays at the Rockport terminal.

In order to achieve selectivity, permissive checks will be included in the control logic. These checks will be of two types. First, a plant loading check will be made so that valving will only be initiated when the units are loaded beyond a pre-defined critical value. The second permissive signal, which will be required for double contingency cases, will be turned on and off by the plant operator for predefined line outages on command from the System Control Center. In addition, the fast valving control will be blocked for approximately ten minutes following each operation to permit the boiler to stabilize.

Application of fast valving improves stability margins and thereby reduces the possibility of unit trips due to system disturbances. Fast valving action does result in boiler transients. The stresses accompanying these transients are, however, judged to be acceptable compared to the system and other benefits described earlier.

D. <u>SYNOPSIS OF BALTIMORE GAS & ELECTRIC COMPANY'S EXPERIENCE WITH EARLY VALVING AT CALVERT CLIFFS</u> (W. G. Thompson, Baltimore Gas & Electric Co., Baltimore, Maryland)

In the late 1960's the Baltimore Gas and Electric Company (BG&E) committed to two nominal 850 MW nuclear units at Calvert Cliffs in Calvert County, Maryland. Unit 1 was completed in 1973 and Unit 2 was completed a year later in 1974. At that time the BG&E bulk transmission system was as depicted in Figure D.1. It will be noted that the Calvert Cliffs site is external to the BG&E franchise area and is tied into the BG&E 230-kV and 115-kV systems at Waugh Chapel Substation by two 500-kV lines 76 km (47 mi.) in length. The so-called Baltimore-Washington 500-kV loop that was to tie Calvert Cliffs to PEPCo's Chalk Point Generation Station and Waugh Chapel to the Conastone-Doubs 500-kV line was in the planning stage, but impediments to its completion were already in evidence. Because of the very real possibility that the transmission system associated with the Calvert Cliffs Nuclear Plant might be limited to two 76 km long 500-kV lines for a period of time, concern arose regarding possible generator stability problems due to transmission contingencies.

In 1969 Bechtel Corporation was commissioned to do an exhaustive transient stability study of the Calvert Cliffs plant to determine: (1) if any problem existed and (2), if so, to recommend solutions. The study and its findings were reported in an IEEE paper [7]. The study showed that, while the Calvert Cliffs units were stable for a three-phase fault on one of the 500-kV lines at Calvert Cliffs with normal clearing times of 3-cycle at Calvert Cliffs and 4.5 cycles at Waugh Chapel (Figure D.2), they would be unstable for the same fault with a stuck breaker and 7.5 cycle back-up clearing (Figure D.3). The simulated effects of various stability aids, such as fast valving, independent pole tripping, and extremely fast excitation were tested. The one aid that was most effective was fast valving, and the study recommended the use of fast valving for Units 1 and 2.

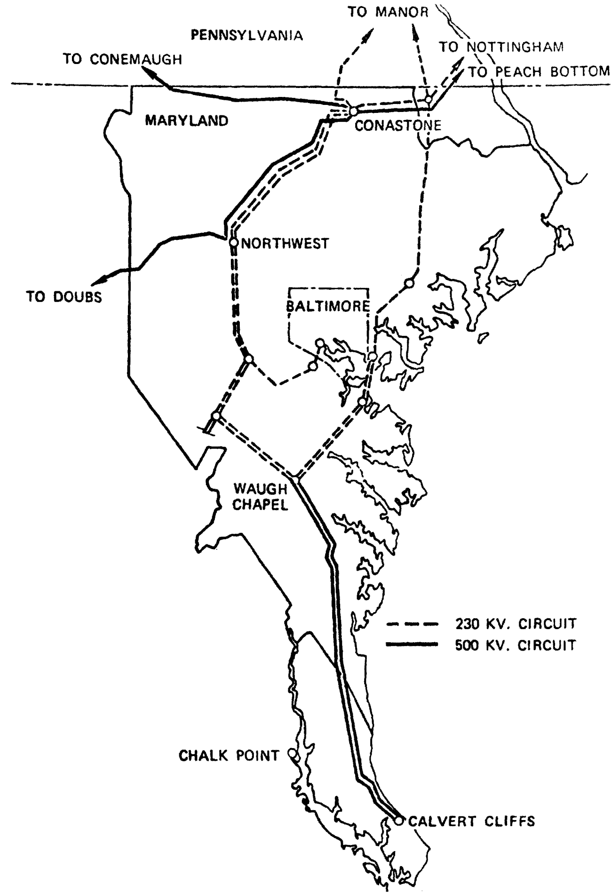

Fig. D.1 Baltimore Gas and Electric Company geographic location of 230-kV and 500-kV circuits.

To quote Bechtel: "The stability benefits from fast valving are so great for so small a cost that advantage should be taken of them. Fast valving can obviate emergency shutdowns for severe faults that would otherwise cause instability."

Theoretical benefits of fast valving can be readily shown by comparing Figures D.3 and D.4. Figure D.4 depicts the Calvert Cliffs unit swing curves for the same multiphase fault with 7.5-cycle backup clearing time as depicted in Figure D.3 but with fast valving applied. From this curve, it is readily apparent why this new tool looked so inviting. And the cost of implementing fast valving into the final unit design was to be less than $10,000.

Using the initial information on the EVA system that was furnished by General Electric and Westinghouse, a plot of input/output data was obtained for the case illustrated in Figure D.5. The mechanical power input starts to reduce at 0.12 second and reaches about one-half the generator rating at about 0.7 second. By reducing the accelerating power input shortly after the fault has occurred, the angular advance of the generator is decreased. The generator output reaches about 1.35 per unit of rating at about 0.95 second as the unit starts to pull back in angular displacement toward the system. Figure D.6 shows the turbine power response during fast valving. This curve was provided by G.E. for Unit 1. In this case, the intermediate and low pressure turbines produce 70 percent of the total turbine power and closing the intercept valves reduced the machine output to 30 percent of the initial output. This remaining output was supplied by the high pressure turbine. Figure D.6 also indicates time delays T1 and T2 before valve closure starts. T2 is fixed by the time for the solenoid to act which was stated by the manufacturer to be 0.1 second. T1 depends upon the time for the power unbalance relay to act, estimated by the manufacturers to range between 1 and 3 cycles. The study showed that changing the total time delay (T1 plus T2) from 0.12 to 0.15 second increased the angular excursions of the units by 8 to 10 degrees with all other conditions remaining the same.

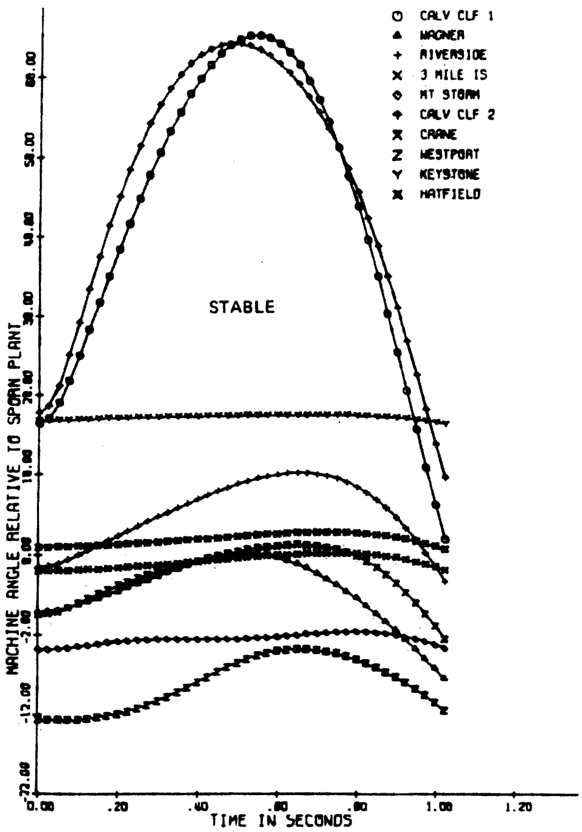

Fig. D.2 Swing Curve--three-phase fault at Calvert Cliffs 500-kV (3-Cycle clearing, no stability aids).

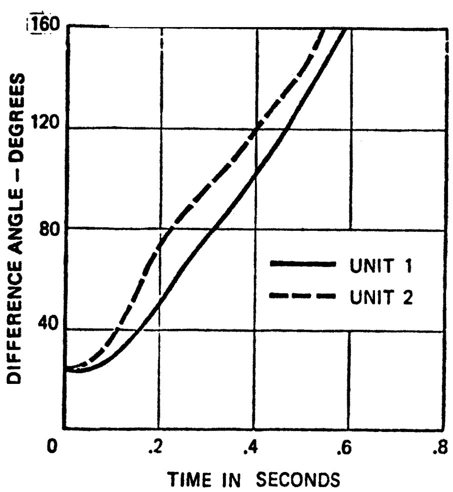

Fig. D.3 Swing Curves for three-phase fault at Calvert Cliffs on 500-kV line cleared in backup time of 7.5 cycles without stability aids.

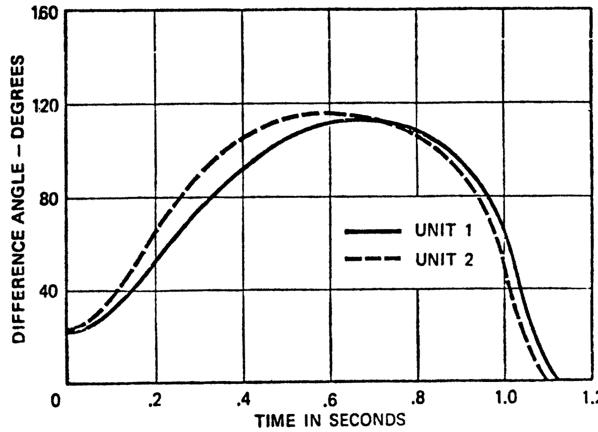

Fig. D.4 Swing Curves for same fault conditions as Fig. D.3, except with aid of fast valving.

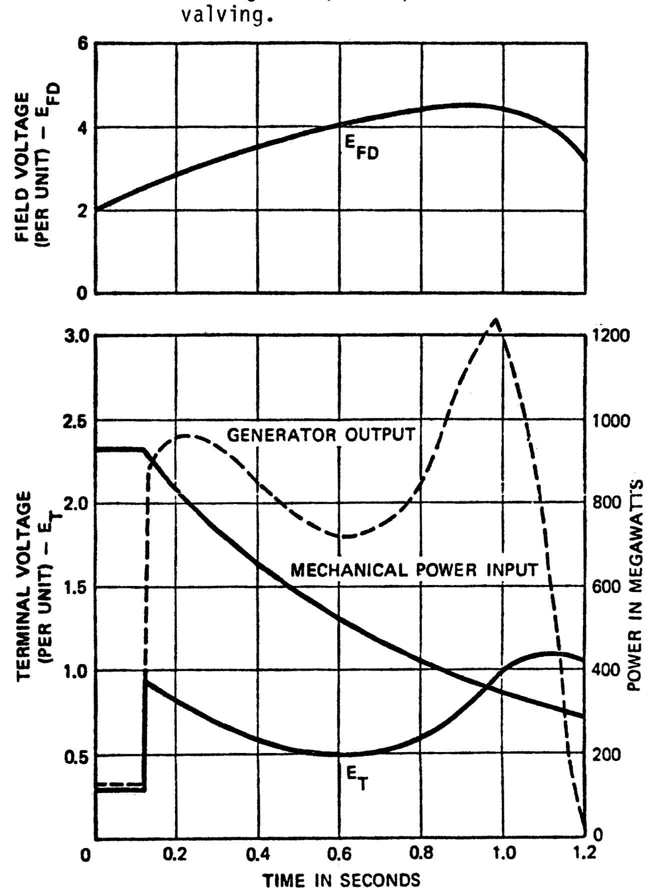

Fig. D.5 Response of Unit 1 field voltage with conventional excitation response ration of 1.0, mechanical power input, generator output and terminal voltage for same case as Fig. D.3 showing effect of fast valving.

As the benefits of fast valving looked most promising, BG&E pursued the matter further with the plant equipment suppliers, namely General Electric, the turbine-generator supplier for Unit 1; Westinghouse, the turbine-generator supplier for Unit 2; and Combustion Engineering, the nuclear steam system supplier for both units. Initially, none of the suppliers indicated any potential problems. Later, and with respect to the turbine-generator only, General Electric expressed some concern over the increased duty placed upon their plug type intercept valves, since these valves must open against full pressure differential. It should be noted that these valves

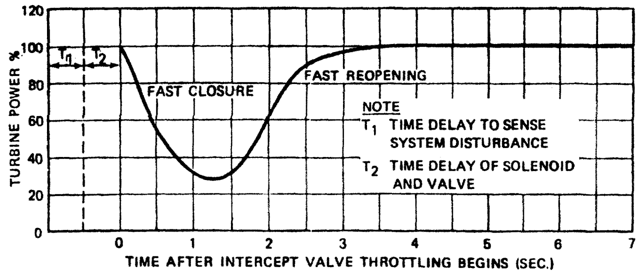

Fig. D.6 Power Response to fast (early) valving for Calvert Cliffs Unit 1, intercept valve application, only. Curve for Unit 2 is similar.

are designed to operate in this fashion to relieve the pressure bottled up in the reheat system such that loss of load does not result in an overspeed trip. However, in that case the intercept valves are only called upon to throttle a relatively low steam flow, whereas they must pass full steam flow in a matter of seconds in case of fast valving. Westinghouse, with their butterfly type intercept valves, did not see any problems.

Potential problems were foreseen in the steam supply system. Even though Combustion Engineering was of the opinion that the magnitude and duration of the pressure excursion experienced by the steam generator on fast valving would not create any operating problems with their equipment, Westinghouse expressed some concern. Westinghouse thought that the severe transients caused by fast valving could adversely affect the systems within the steam supply portion of the plant. Systems such as the feedwater heater extraction and drain systems, moisture separator reheater drains from both the shell side and the reheater tube side, and the steam generator controls were of concern. Westinghouse's experience up to that time was that these systems could be marginal for even normal transients, such as those associated with start-up.

Additionally, Westinghouse felt that the effect of water flashing into vapor due to rapid pressure decays, and the effect of bubble collapse or implosion upstream of the valves due to pressure rises would be difficult to evaluate. The low pressure extraction system can be subject to swell associated with flashing which is then collapsed by the pressure rise when the valves reopen. There was some thought that on nuclear units the bubble collapse upstream of the valves may induce a significant shock in the system.

Finally, Westinghouse expressed concern with false trips. Up to that time, several false trips had been experienced as a result of the fast valving system. Considering that fast valving is employed to operate only for low probability fault conditions, false operation as well as its inability to distinguish among the type of fault, raised questions as to the application of this technique. In light of the foregoing, potential disadvantages of fast valving were felt to far outweigh its potential advantages and it was not employed at Calvert Cliffs.

Regarding BG&E's solution to the Calvert Cliff stability problems, the actual electrical impedances of the unit transformers at Calvert Cliffs and the step-down transformers at Waugh Chapel were considerably less than the predicted values used in the study. The actual system performance was therefore more stable than initially predicted. The combination of this with independent pole tripping on the 500-kV breakers and an excitation response ratio of 1 was enough to eliminate the need for fast valving for a three-phase stuck breaker fault on the 500-kV line at Calvert Cliffs. Completion of the aforementioned Baltimore-Washington 500-kV loop will further increase the stability margin.

SUMMARY OF PANEL DISCUSSION

Depending on system characteristics, either momentary or sustained fast valving can be an effective method of stability improvement. Reliable methods of fast valving that do not compromise steam supply system and turbine availability would usually be preferred over the unit tripping alternatives.

There are methods to reduce the frequency of fast valving operations. Single-pole switching, independent pole operation, and insertion of neutral resistors can eliminate need for fast valving for the more common single-phase faults.

Implementation of fast valving is, however, relatively complex involving all system components--the steam supply system, the turbine-generator, and the electric network. Close coordination among electrical and mechanical engineers of the vendors and the utility are necessary. We hope that this paper, along with discussions, will contribute to an understanding of the benefits and limitations of the various methods of fast valving.

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