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DominionEnergy.com

May 7, 2026

Attention: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Serial No.:	26-105B
VCS LIC/MM:	Rev 0
Docket No.:	50-395
License No.:	NPF-12

DOMINION ENERGY SOUTH CAROLINA (DESC), INC.
VIRGIL C. SUMMER NUCLEAR STATION (VCSNS) UNIT 1
RESPONSE TO APPARENT VIOLATION; (EAF-RII-2026-0008)

By letter dated March 31, 2026 (Reference 1), the Nuclear Regulatory Commission (NRC) notified Dominion Energy South Carolina (DESC) of an Apparent Violation (AV 05000395/2025004-01) for “Inadequate Maintenance Strategy Resulting in Inoperability of the Turbine-Driven Emergency Feedwater Pump.” The NRC preliminarily determined the finding to be of low to moderate safety significance (WHITE) and provided an opportunity for DESC to submit a pre-decisional response to the AV. By letter dated April 9, 2026, DESC informed the NRC that additional information would be provided for consideration in making a final determination for the AV (Reference 2).

DESC takes this matter seriously and has thoroughly evaluated the condition and are implementing corrective actions to prevent recurrence. Based on the supplemental information provided, DESC’s perspective is that the significance of the finding is low safety significance (GREEN).

The key conclusion of the supplemental information provided is the Turbine-Driven Emergency Feedwater Pump (TDEFP) would have successfully performed its safety function and injected into the steam generators because steam generator (SG) injection conditions are inherently less challenging to turbine initial speed control than surveillance test conditions. Independent transient hydraulic analyses demonstrate that SG injection imposes substantially higher brake horsepower and steam demand, which materially slows turbine acceleration, reduces required governor valve travel, and preserves significant margin to overspeed even with the degraded governor linkage condition observed. This analytical conclusion is further reinforced by plant evidence showing a successful SG injection during the October 2025 reactor trip with no intervening maintenance or condition change. This successful injection strengthens overall confidence that the degraded condition would cause an overspeed condition in the surveillance test configuration and not during an actual SG injection event.

Attachment 1 addresses the four questions related to cause and corrective actions, which describes the direct cause of the event as governor linkage binding. Attachment 2 addresses two open concerns from the NRC preliminary White Finding Report (Reference 1). Attachment 3 provides a functionality assessment demonstrating reasonable assurance the TDEFP would have successfully performed its function during a SG injection event. The independent functionality assessment supports DESC's perspective that the significance of the finding is low safety significance (GREEN). DESC requests the NRC consider this new information when determining the final significance of the violation.

Should you have any questions regarding this submittal or require additional information, please contact Mr. Michael Moore, Manager Nuclear Station Emergency Preparedness and Licensing at (803) 345-4752.

Sincerely,

Eric S. Carr
Chief Nuclear Officer and President Nuclear Operations & Contracted Energy
Dominion Energy Services Inc.

References:

1. "Virgil C. Summer – NRC Inspection Report 05000395/2026092; Preliminary White Finding," dated March 31, 2026.
2. "Virgil C. Summer Nuclear Station (VCSNS) Unit 1 – Notification of Intended Response," dated April 9, 2026.

Attachments:

1. Response to Apparent Violation 05000395/2025004-01
2. Summary of Governor Valve Linkage Binding and Governor Valve Travel Margin
3. Evaluation of Turbine Driven Emergency Feedwater Pump November 2025 Surveillance

Commitments contained in this letter: None

cc: G. J. Lindamood – Santee Cooper
J. Lara – NRC Region II
A. Wilson – NRC Region II
G. E. Miller – NRC Project Mgr.
NRC Resident Inspector

Attachment 1

RESPONSE TO APPARENT VIOLATION 05000395/2025004-01

Dominion Energy South Carolina
Virgil C. Summer Nuclear Station Unit 1

VIRGIL C. SUMMER NUCLEAR STATION (VCSNS)
DOMINION ENERGY SOUTH CAROLINA, INC. (DESC)
RESPONSE TO APPARENT VIOLATION 05000395/2025004-01

Reason for the Violation

VCSNS failed to schedule and implement a preventive maintenance procedure appropriate to the operating conditions for the turbine-driven emergency feedwater pump (TDEFP) governor linkage. As a result, degradation of the governor valve linkage went undetected, leading to inoperability and unplanned unavailability of the pump.

During routine surveillance testing on November 12, 2025, the TDEFP turbine tripped upon initial startup. Subsequent troubleshooting identified worn and misaligned components, and some components not properly installed, such as washers, within the turbine speed governor valve assembly. These issues caused binding during operation of the governor valve. Due to this binding, the TDEFP was unable to control turbine speed within required specifications during surveillance testing and was verified to have tripped on overspeed. The governor linkage binding is intended to describe friction between surfaces during movement.

Corrective Steps That Have Been Taken and the Results Achieved

The governor linkage assembly was rebuilt and realigned with new parts as needed. As part of the troubleshooting activities, the turbine-driven emergency feedwater pump (TDEFP) governor was also replaced. The TDEFP was restored to operable status on November 16, 2025.

Also, during the recent spring refueling outage, instrumentation was installed on the TDEFP to record turbine speed and discharge flow during pump actuation. This new instrumentation provides capability for monitoring and future troubleshooting. In particular, this new instrumentation allows the direct monitoring of the margin to the overspeed trip setpoint to ensure the risk of reaching an overspeed trip is minimized.
A root cause evaluation (RCE) was performed to identify causes of the event and develop corrective actions to prevent recurrence.

Corrective Steps That Will be Taken

The primary corrective action to prevent recurrence of this issue is to revise MMP-300.015, Turbine Maintenance, Emergency Feedwater Pump TPP0008. This revision will provide detailed instructions for disassembly, inspection, and reassembly of the TDEFP governor linkage assembly and will align the procedure with preventive maintenance work instructions. Additionally, VCSNS will replace additional parts of the governor linkage assembly, that are not currently available, at the next opportunity. These additional components were not considered causal to the linkage binding issue and are being replaced to enhance the long-term reliability of the TDEFP.

Date When Full Compliance Will be Achieved

Regulatory compliance was restored on November 16, 2025, when corrective maintenance was completed on the TDEFP governor and governor linkage assembly and the equipment was returned to an operable status. Completion of programmatic corrective actions will include revision of procedure MMP-300.015, Turbine Maintenance, Emergency Feedwater Pump TPP0008, which is scheduled to be completed by June 30, 2026.

Attachment 2

Summary of Governor Valve Linkage Binding and Governor Valve Travel Margin

Dominion Energy South Carolina
Virgil C. Summer Nuclear Station Unit 1

Governor Valve Linkage Early-Stroke Binding or Stick-Slip Behavior

In NRC Inspection Report 05000395/2026092, the NRC identified there was uncertainty in the analysis presented in Report 0310-0085-RPT-001 due to the inability to characterize early-stroke binding or stick-slip behavior.

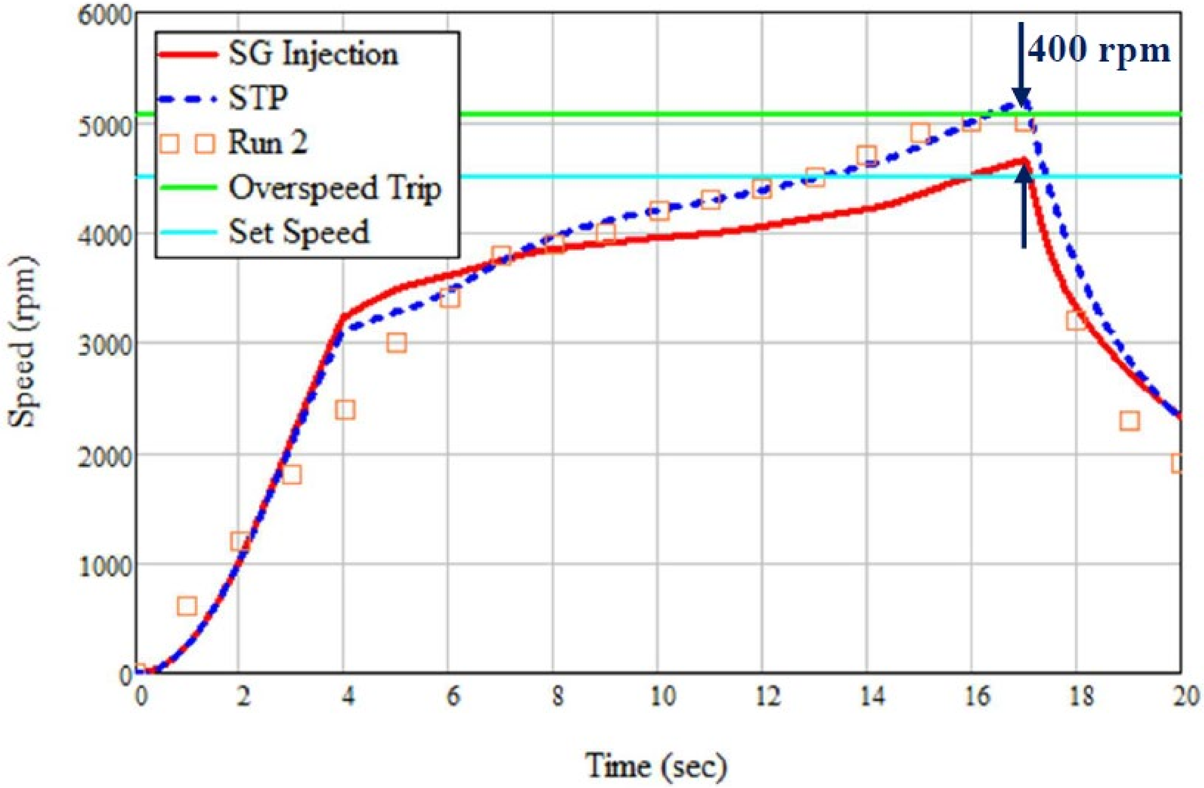
While stick-slip behavior in the governor linkage was identified, the pump startup transient behavior was repeatable in the as-found condition. Data from the failed November 12, 2025 quarterly surveillance run was compared with the following troubleshooting run, which was performed before any maintenance was performed on the pump. The data available for comparison is the emergency feedwater (EFW) pump suction pressure data, which is shown to correlate with the speed transient based on pump starts with both speed and suction pressure data available. The pump suction pressure transient during the pump starts are very similar. This indicates that in the as-found condition, the pump start transient was repeatable. This refutes concerns regarding uncertainty related to randomness that could be introduced by friction or binding. See Attachment 3, Report 0310-0085-RPT-001, Revision 2, Appendix D for data and additional discussion.

Unquantified Governor Valve Travel and Overspeed Margin

A transient analysis, included as Appendix B of Report 0310-0085-RPT-001, Revision 2, was performed to quantify governor valve travel and overspeed margin during a surveillance test procedure (STP) and a steam generator (SG) injection event. The model used for the analysis includes the steam admission and governor valves, the Terry Turbine, turbine-driven emergency feedwater pump (TDEFP), and the EFW piping. The model was used to estimate (1) the difference in the required governor valve travel between an STP and the SG injection and (2) the overspeed margin if the TDEFP had been called to respond to an SG injection event in the as-found condition from the November 2025 STP.

The governor valve starts full open and closes to a steady-state position during the turbine start transient. The analysis showed that the governor valve is roughly 13% open for a typical STP and 18% open for a typical SG injection once the steady-state turbine speed is reached. The required travel for the SG injection is less because the turbine needs higher steam flow to meet the higher power demand of the pump during an SG injection. The power demand is higher because the pump flow during an SG injection is about twice that during an STP.

The analysis also shows if the pump had been aligned for an SG injection in the November 2025 as-found condition and the initial valve response during the speed ramp was the same as in the November STP, the peak speed reached would have remained about 400 rpm below the overspeed trip setpoint (see Figure below). The significant margin to overspeed for SG injection provides reasonable assurance that the pump would have been able to start and meet its function in the as-found condition.



Conclusion

The TDEFP had degraded enough to fail the STP but not enough to fail to perform successfully during a SG injection event. The degraded TDEFP performed successfully for an SG injection event on October 14, 2025, and it appears to have nearly avoided the overspeed trip when aligned for the November 2025 surveillance tests. The pump transient behavior was repeatable in the as-found condition. The higher brake horsepower demand during a SG injection event increases the margin between the peak turbine speed and the trip speed as compared to a surveillance test. The larger margin would have allowed a successful TDEFP start since the performance was only marginally unacceptable in the more demanding STP alignment. Therefore, there is reasonable assurance the TDEFP would have started successfully in its as-found condition for an injection event between October 14, 2025 and November 11, 2025.

Attachment 3

<u>Evaluation of Turbine Driven Emergency Feedwater Pump November 2025 Surveillance</u>

Dominion Energy South Carolina
Virgil C. Summer Nuclear Station Unit 1

0310-0085-RPT-001
Revision 2

Evaluation of Turbine Driven Emergency Feedwater Pump November 2025 Surveillance

Comparison to Steam Generator Injection Event

Prepared for: V. C. Summer Nuclear Station

Preparer:	Kayleigh McNeill	E-signed by: Kayleigh McNeill on 2026-05-06 00:10:03
Reviewer:	Susan Harp	E-signed by: Susan Harp on 2026-05-06 00:23:19
Approver:	Susan Harp	E-signed by: Susan Harp on 2026-05-06 00:23:43

QA Statement of Compliance

This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of the MPR Standard Quality Program.

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MPR

Evaluation of Turbine Driven Emergency Feedwater Pump November 2025 Surveillance

Comparison to Steam Generator Injection Event

RECORD OF REVISIONS		
Revision Number	**Pages /Sections Revised**	**Revision Description**
0	All	Initial Issue
1	All	Revised to address NRC questions. Specific changes include: - Clarified the criteria used to select maintenance run data for evaluation (Section 6). - Added discussion of a transient analysis that was performed to demonstrate the effect of fluid inertia on the pump start-up transient and to illustrate performance differences between surveillance tests and SG injections (Section 7). - Expanded the discussion of the repeatability of the speed transients and the impact of linkage friction (Appendix C). - Explained why the steam admission valve opening times varied during the maintenance runs (Appendix D). - Added valve position measurements (Appendix E).
2	All	Revised to address NRC questions. Specific changes include: - Added discussion of a transient analysis that was performed to quantify governor valve travel and overspeed margin during start-up for surveillance tests and SG injections (Section 7). - Added governor valve position transient analysis (Appendix B).

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1.0 Purpose

This report evaluates the expected startup characteristics of the V.C. Summer Nuclear Station (VCS) turbine-driven emergency feedwater (TDEFW) pump to determine if the performance of the governor would be different during a surveillance test as compared to during an event that required injection into the steam generators (SG) (the safety function of the TDEFW pump). The report specifically evaluates if there is sufficient evidence to show the TDEFW pump would have started successfully for an SG injection event in the degraded condition that caused the TDEFW pump to trip during a November 2025 surveillance test.

2.0 Background

The VCS TDEFW pump experienced an overspeed trip during a surveillance test on November 12, 2025. The prior successful start and operation of the TDEFW pump occurred on October 14, 2025, at which time the pump was used to inject emergency feedwater into the SGs following a plant trip. No maintenance or adjustments were made to the TDEFW pump after the successful October start and no conditions that would have damaged the TDEFW pump during the run were identified.

Dominion asked MPR to investigate if there are differences between the surveillance test and typical events that require injection into the SGs that would explain why the pump operated satisfactorily in the October event but tripped in the November surveillance test. Dominion would like to determine if the TDEFW pump would have started successfully had it been called upon for injection between the October event and the November surveillance test.

The VCS TDEFW pump is not fully instrumented to record/monitor data during all events and surveillance tests, so a full set of data is not available for every run of the TDEFW pump. Data for injection events was particularly limited, with minimal data available for the October 14, 2025, event due to an interruption in plant computer recording. While sufficient data is available to assess the as-found pump performance when in the surveillance alignment, the performance in the injection alignment has to be predicted analytically.

Data recorded during troubleshooting runs following the November 2025 trip, with the TDEFW pump alignment consistent with the alignment for surveillance tests, are used in this report to establish the condition of the pump in the as-found condition. The performance during an injection event is then evaluated using a transient analysis that demonstrates the relative difference in performance when aligned for a surveillance test versus an SG injection event.

3.0 Key Observations and Conclusions

The following key observations were made based on review of the available data:

1. **The TDEFW pump successfully started during an SG injection event in October 2025.** No modifications or adjustments were made to the TDEFW pump or supporting components after the October 14, 2025, pump start when the TDEFW pump successfully injected into the SGs. This suggests that the difference in the line-up between a

Surveillance Test Procedure (STP) and an SG injection allowed the TDEFW pump to avoid an overspeed during the October SG injection event.

2. **The TDEFW pump nearly avoided an overspeed during the November 2025 STP.** During the November 2025 STP and subsequent troubleshooting runs, the ability of the governor to slow the acceleration of the turbine during startup to prevent an overspeed trip was impaired. In the as-found condition, the turbine speed reached very close to the 5060 rpm trip setpoint at the beginning of each run. The approach was so close to the trip setpoint, the turbine both tripped and started successfully during the troubleshooting runs that immediately followed the failed surveillance test.
3. **The TDEFW pump start transient was repeatable.** Based on available data, the pump start transient in the as-found condition was repeatable, indicating that it is reasonable to assume the behavior would have been similar in an SG injection event. (See Appendix D for additional details.)
4. **A less demanding transient for the governor valve would not have resulted in an overspeed trip.** In the troubleshooting runs following the failed surveillance test, the turbine speed held steady near the 5060 rpm trip setpoint for a couple of seconds before either tripping or ultimately decreasing to the 4500 rpm target speed. The lack of a sudden trip when approaching 5060 rpm suggests the governor was on the verge of operating successfully even in the runs in which there was a trip. Therefore, if the transient had been less demanding on the governor, the governor response would have been adequate to avoid an overspeed trip.
5. **The SG injection start transient is significantly less demanding than an STP on the governor valve in that there is greater margin to the trip speed and a shorter valve travel distance in the as found condition.**
   A. Analyses of the TDEFW pump start transient during STP and SG injection scenarios were performed (see Section 7.0). As shown in Figure 3-1, the TDEFW pump speed would not come as close to the trip speed during an SG injection pump start as compared to during an STP pump start. The reason for the difference is that the TDEFW pump's flow rate and associated required brake horsepower are larger when injecting into the SGs as compared to a surveillance test (630 gpm during SG injection versus 300 gpm during STP at the target speed). The brake horsepower and steam flow required during SG injection are approximately 135% of that for an STP at the target speed (4500 rpm) and 142% as the speed approaches the overspeed trip setpoint (5060 rpm). The lower brake horsepower required during an STP leaves more energy for the steam flow to accelerate the turbine to a higher speed during the STP pump start, which reduces the margin to the trip setpoint as compared to operation for the SG injection pump start. There was essentially no margin to the trip speed for the STP and analysis concludes that there would be approximately 400 rpm of margin for SG injection (Figure 3-1).
   B. The analyses in Section 7.0 also show that the governor valve would not have had to close as far during a typical start aligned to SG injection as compared with an STP. Based on analysis, the governor valve stem would have to travel less by 5% of the total valve stroke during a typical SG injection event as compared to a typical STP. This difference in valve position based on the TDEFW pump flow configuration is

supported by measurements of the valve stem position during surveillance testing (Appendix F). Since the governor valve was moving from full open to a more closed position as the turbine ramped in speed, the governor valve stem needed to move farther to reach its steady-state position for the STP than it would during SG injection. The steady-state governor valve position is calculated to be roughly 13% open for STP and 18% open for SG injection.

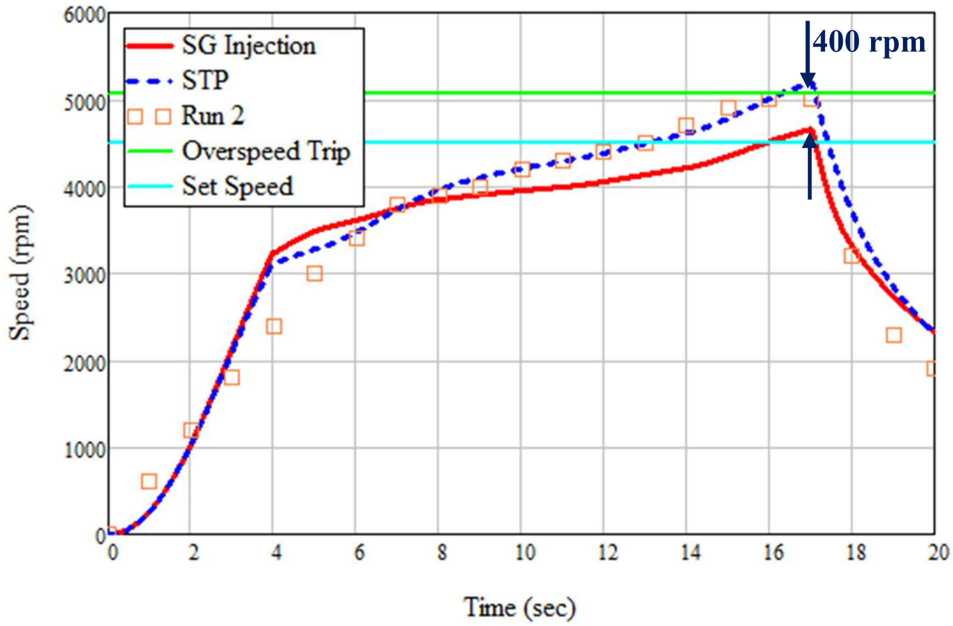

Figure 3-1. STP and SG Injection Speed Ramps with As-Found Governor Movement[1]

In conclusion, this report shows that the TDEFW pump had degraded enough to fail the STP but not enough to fail to perform successfully during an SG injection event. The degraded TDEFW pump performed successfully for an SG injection event on October 14, 2025, and it appears to have nearly avoided the overspeed trip when aligned for the November 2025 surveillance tests. The pump transient behavior was repeatable in the as-found condition. The higher brake horsepower demand during an SG injection event increases the margin between the peak turbine speed and the trip speed as compared to a surveillance test. The larger margin would have allowed a successful TDEFW pump start since the performance was only marginally unacceptable in the more demanding STP alignment. Therefore, there is reasonable assurance the TDEFW pump would have started successfully in its as-found condition for an injection event between October 14, 2025, and November 11, 2025.

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[1] The same governor valve position transient was applied to the STP (blue) and SG injection (red) analysis cases. The valve position was selected so that the STP solution reasonably matched run data (orange squares). Scoping analyses performed using different valve positions with time produced results showing similar overspeed margin for SG injection. See Section 7.3.3, including Footnote 3, for details.

4.0 Timeline of Recent TDEFW Pump Operation

The TDEFW pump actuated multiple times in 2025, both for testing and during plant trips. The pump is tested quarterly per STP-220.002 (Reference 6.A). Table 4-1 contains a timeline of key operations of the TDEFW pump in 2025 (References 1, 2, 5.C, 12).

The timeline shows the governor that was in-service at the time of the November 2025 trip was installed during the troubleshooting of the failed surveillance test in March 2025. The root causes of the failed surveillance tests in March, August, and November were reviewed to determine if there was a common cause. The review determined a separate cause for each failed test.

Table 4-1. Timeline of Key Operations of TDEFW Pump

Date	Reason for Start	Performance	Reference
2/10/2025	Plant trip	Successful pump start and operation.	5.C
3/4/2025	Surveillance test	The pump did not control within the required speed range. The cause was identified to be a cover that was not removed from the control air line, which created a vacuum in the governor. Governor was replaced as a part of troubleshooting.	12
6/9/2025	Surveillance test	Successful surveillance run of the pump	1
8/19/2025	Surveillance test	Pump overspeed mechanism tripped pump at normal running speed (~4500 rpm) due to a worn tappet nut. Tappet nut was rotated to address excessive wear.	1
10/14/2025	Plant trip	Successful pump start and operation. Note: Limited availability of computer data.	2
11/12/2025	Surveillance test	Pump tripped on overspeed (~5000 rpm).	2

The October 2025 injection occurred during a manual reactor trip due to a fire in the Main Generator Field Control Breaker. The TDEFW pump operated but most computer data was lost concurrent with the plant trip (Reference 2). Dominion was able to recover some pressure and flow data; however, data resolution is too low (10 second intervals) to observe transients.

The overspeed experienced during the November 12 surveillance run prompted several troubleshooting and STP tests performed over the following days. These runs are described further in Appendix C and in Section 6.1.

5.0 System and Component Descriptions

5.1. Flow Paths

Figure 5-1 shows the steam supply used to drive the TDEFW pump:

1. Steam is supplied from SGs B and C.

2. Steam is admitted to the turbine inlet by the steam admission valve (IFV-2030-MS). Pressure transmitter PT2032 is located just downstream of this valve and is recorded by the plant computer.
3. Steam passes through the trip/throttle valve (XVT-2865-MS), which is normally open (this valve will close if the overspeed trip mechanism is actuated).
4. The governor valve (XVM-11025-EF) varies the amount of steam admitted to the pump turbine to control speed.
5. Steam rotates the turbine to drive the pump.

Figure 5-2 shows the TDEFW pump flow path as follows:

1. Emergency feedwater is supplied to EFW pump suctions from the Condensate Storage Tank (CST). Parallel pressure transmitters PT3632 through PT3635 are located along EFW pump suction piping downstream of the CST and are recorded by the plant computer.
2. TDEFW Pump discharge
   A. **Surveillance/maintenance testing:** TDEFW pump discharge flow returns directly to CST.
   B. **SG Injection:** TDEFW pump discharge to supply lines for SGs A, B, & C where it is injected to each SG. Flow transmitters FT3561, FT3571, and FT3581 are located upstream of SG A, B, and C, respectively.

In an SG injection event, the motor driven emergency feedwater (MDEFW) pumps start before the TDEFW pump. The supply and discharge for the MDEFW pumps are the same as for the TDEFW pumps. High-range flow transmitters FT3508A and FT3518A are located on the discharge of MDEFW pumps A and B, respectively.

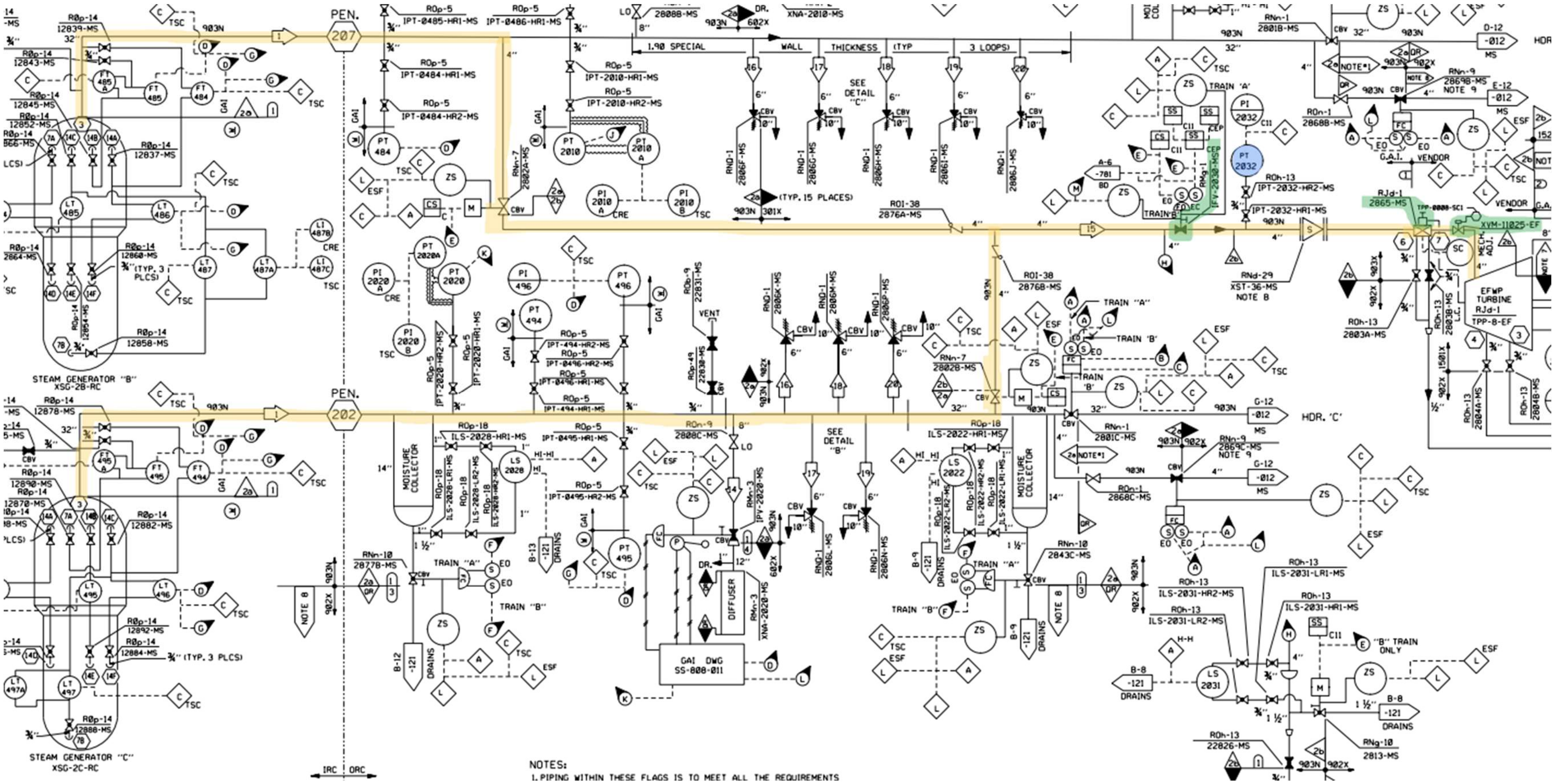

Figure 5-1. TDEFW Pump Flow Path (Steam Side) (Reference 3.A)

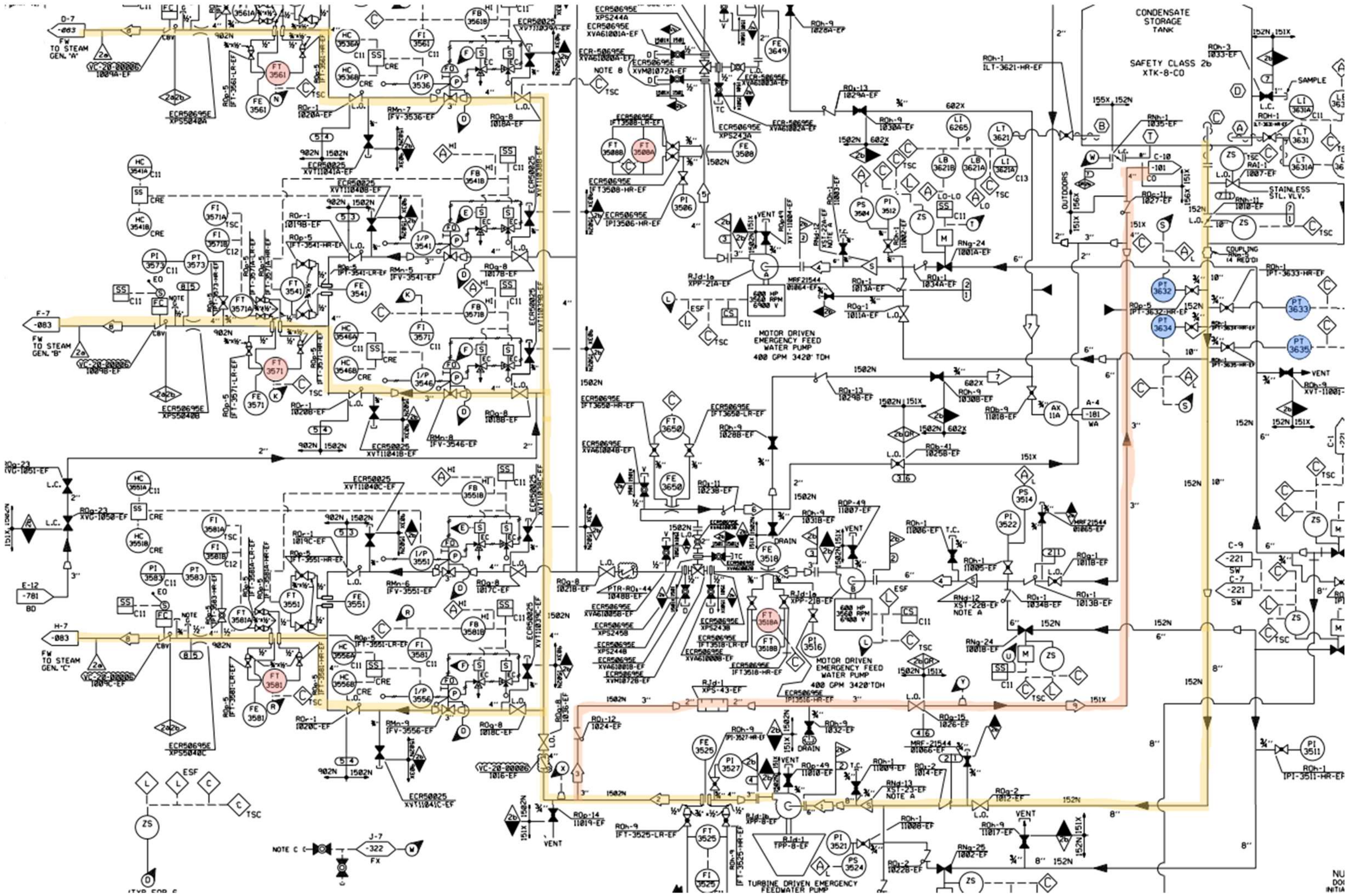

Figure 5-2. TDEFW Pump Flow Path (EFW Side) (Reference 3.B)

5.2. TDEFW Pump, Governor, and Instrumentation

Figure 5-3 shows the inlet to the TDEFW pump turbine, the trip/throttle valve, linkages to the governor, and various instrumentation. Figure 5-4 provides a clearer view of the governor valve linkages. Note the turbine speed tachometer does not have an associated computer point, so readings were taken locally by viewing the tachometer gauge.

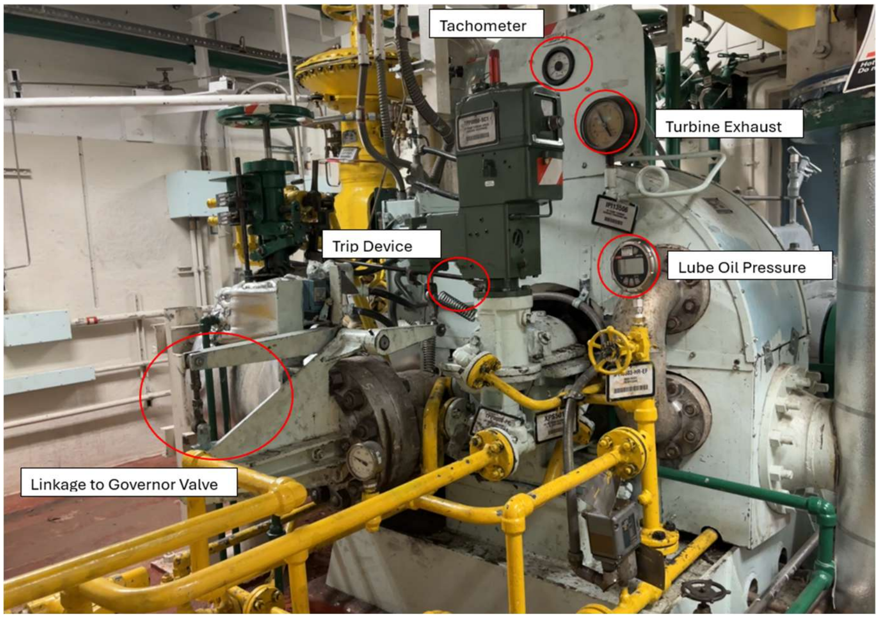

Figure 5-3. TDEFW Pump and Governor Instrumentation

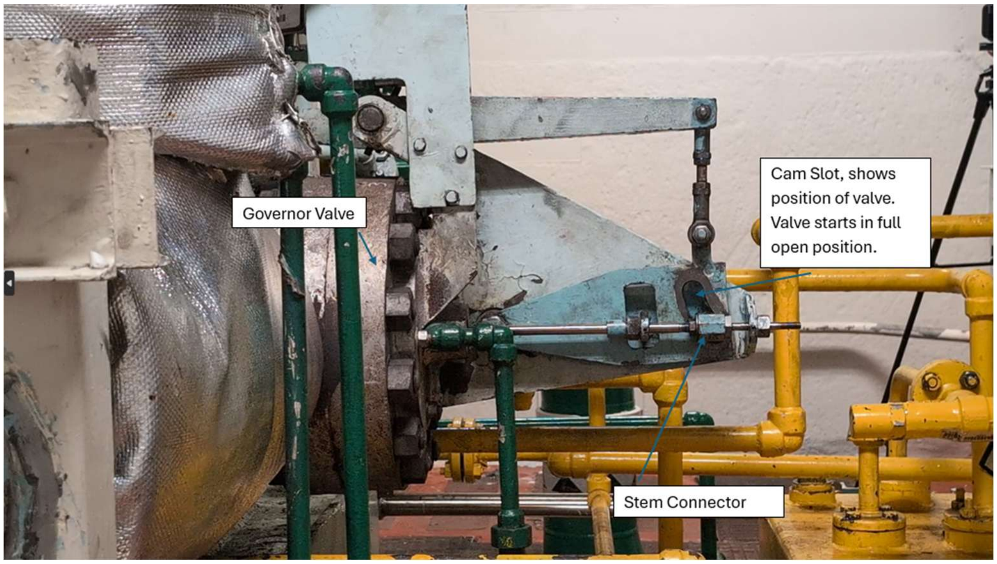

Figure 5-4. TDEFW Pump Governor Valve and Linkages

6.0 November 2025 TDEFW Pump Test Data Review

6.1. November 2025 Troubleshooting Pump Run and Maintenance Summary

MPR reviewed data from select November TDEFW pump test runs. Table 6-1 provides a summary of test parameters for all troubleshooting runs and a summary of the maintenance performed between each run. MPR tabulated tachometer readings from videos of the TDEFW pump tachometer gauge to characterize the turbine speed ramp (Figure 6-1 through Figure 6-7). No video was taken for the initial STP run on November 12, 2025, and, therefore, no speed data is available for review.

All tests followed STP-220.002 and/or used STP-220.002 lineup. MPR selected runs that would provide insight into the condition of the equipment in its as-found state, enable direct comparison with the initial overspeed event, and evaluate the effect of linkage friction and needle valve adjustments. Specifically, the following selection criteria were used:

- Fast-start runs with a target speed of 4500 rpm were selected, whereas slow-start runs in which the initial target speed was lower, or operators manually controlled the valve, were excluded.
- Runs that occurred before and after notable maintenance actions (e.g., linkage dressing, needle valve adjustment, linkage component replacement, and governor replacement) were selected to understand the impact of each action on governor performance and speed ramping.
- Redundant runs were not included.

Note that data from the October 2025 injection to the SGs was not analyzed because the only data available was collected with a 10-second time step. A 10-second time step was too long to capture transient behavior.

Table 6-1. STP Runs Analyzed (Reference 2)

Date and Time	Run Number	Overspeed Trip (Y/N)	Target Speed Setting	Time Since Last Run[1]	Selected (Y/N)
11/12/2025 01:43:00	1	Y	4500 rpm	Weeks	Y[2]
11/12/2025 18:28:00	2	Y	4500 rpm	16:05:00	Y
11/12/2025 23:22:00	3	N	2200 rpm	-	N
11/13-14/2025 Night	Linkages between governor and governor valve dressed				
11/14/2025 08:48:00	4	N	<4500 rpm; Speed manually adjusted	-	N
11/14/2025 09:42:00	5	N	4500 rpm	0:34:00	Y
11/14/2025 12:04:00	6	Y	4500 rpm	2:14:00	Y
11/14/2025 17:22:00	7	Y	4500 rpm	-	N
11/14/2025 Day	Governor needle valve adjusted from between 1/16 and 1/8 turn to 1/4 turn open				
11/14/2025 22:57:00	8	N	4500 rpm	5:35:00	Y
11/15/2025 03:13:00	9	N	4500 rpm	-	N
11/15/2025 Day	Replaced governor with spare (and set needle valve to 1/8 turn open)				
11/15/2025 13:55:00	10	N	<4500 rpm; Speed manually adjusted	-	N
11/15/2025 16:55:00	11	N	4500 rpm	1:30:00	Y
11/15-16/2025 Night	Disassembled and rebuilt governor linkages with new parts				
11/16/2025 11:48:00	12	N	<4500 rpm; Speed manually adjusted	-	N
11/16/2025 12:55:00	13	N	4500 rpm	0:19:00	Y
11/16/2025 15:23:00	14	N	4500 rpm	2:18:00	Y

Notes
1. Time since last run is only calculated for selected runs.
2. Speed data is not available. Pressure data is evaluated in Appendix D. Most recent pump start was during the October 14, 2025, injection to the SGs.

Run 2 is the first troubleshooting run and is assumed to have recreated the trip as it occurred in the initial STP run (Run 1) and shows the pump tripped due to a true overspeed, reaching approximately 5060 rpm. Stick-slip behavior was visually observed in the linkages connecting the governor and the governor valve during this first troubleshooting run (Reference 4.A). This behavior is expected to have had minimal impact on the start transient (see Appendix D).

The linkages were inspected, and excessive friction was identified due to wear on the linkage interfaces. Additionally, excessive clearances between some linkage components were identified. Spare linkage components were not available for immediate installation and an effort was initiated to obtain new linkage components. The linkages were disassembled, and maintenance personnel dressed the interfacing surfaces so that the linkages operated smoothly. After this maintenance, the pump was started using the STP-220.002 lineup inside the two-hour cooldown window required for formal STP-220.002 testing (Run 5). The pump successfully started and reached steady state operation at the target speed of 4500 rpm. An official STP was then performed (Run 6), with the expectation the test result would remain the same, however, in this instance, the pump tripped due to an overspeed.

Additional troubleshooting identified that the governor needle valve was between 1/16 and 1/8 of a turn open. Per procedural guidance, the needle valve normal setting varies between 1/16 and 1/4 of a turn open, however the valve should be as far open as possible to prevent sluggish response of the governor while closed enough to avoid hunting (Reference 6.B). Maintenance personnel opened the needle valve to 1/4 of a turn. During the next shift, the TDEFW pump was started per STP-220.002 (Run 8). The pump successfully started and reached steady state operation at the target speed of 4500 rpm.

While the governor with the new needle valve position successfully started and operated without an overspeed, the governor was found to hunt at lower speeds (see Appendix C, log entry 11/15/2025 5:42). For this reason, the governor was replaced with the VCS spare governor. After the governor replacement, the pump was tested per STP-220.002 (Run 11) and again successfully started.

New components for many of the linkages between the governor and governor valve were now available, and Dominion decided to replace those components. After maintenance was completed, the pump was started per STP-220.002 (Run 13), then retested after the two-hour cooldown period (Run 14). In both instances, the pump successfully started and reached steady state operation at the target speed of 4500 rpm.

6.2. Test Run Speed and Pressure Data

References 5.A and 5.B provide computer recorded data available from the surveillance and maintenance testing runs seen in the Appendix C timeline.

Figure 6-1 through Figure 6-7 provide transient data for the selected test runs. Speeds were recorded manually from videos of the tachometer during each run (Reference 4).

Speed data is not available for events where the TDEFW pump is called into service and injects water into the SGs. Therefore, other available parameters are reviewed to determine if they correlate with TDEFW pump speed and can provide insight into the speed ramp of the TDEFW pump during injection to the SG.

Two pressure parameters and two signals are available and plotted along with speed:

- PT2032 reads the pressure of the steam just downstream of the steam admission valve and upstream of the throttle/trip valve, the governor valve, and the turbine inlet.
- PT3635 reads the pressure measured in the common suction line to the TDEFW and MDEFW pumps near the CST.
- L4575S is the signal to the steam admission valve to begin to open.
- Y1959D is the limit switch on the steam admission valve which indicates the valve is fully open.

Due to the absence of timestamps for the speed data, the speed data must be manually aligned with the available pressure data. It is assumed that the start of the speed increase aligns with the start of the increase in the pressure downstream of the steam admission valve. The alignment of the speed data to the other data (e.g., pressures and valve signals) is provided to illustrate system behavior but is not directly used to draw conclusions. The conclusions which use plant data are based on the comparison of the TDEFW pump speed transient data across the November 2025 troubleshooting runs.

Table 6-2 compares the time between the TDEFW pump start signal and the following events for all the troubleshooting runs:

1. The steam admission valve open limit switch reached.
2. Change in the pressure downstream of the steam admission valve.
3. Speed ramp reaches 3600 rpm. 3600 rpm is the pump speed that correlates with the required pressure for TDEFW pump injection to the SGs (see Appendix A, and further discussed in Section 7.0).
4. The second speed ramp reaches 3600 rpm (if applicable).

An evaluation of the data provided in these graphs and table is provided in Sections 6.2.1 through 6.2.3.

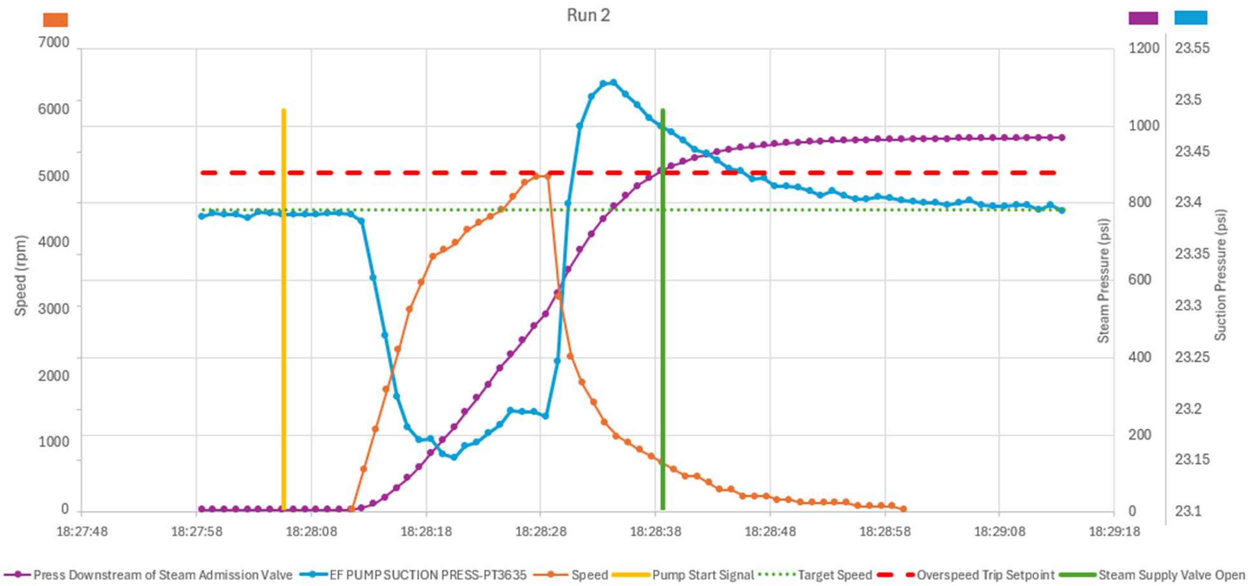

Figure 6-1. Run 2: Equivalent to initial STP (with 2-hour cooldown period)

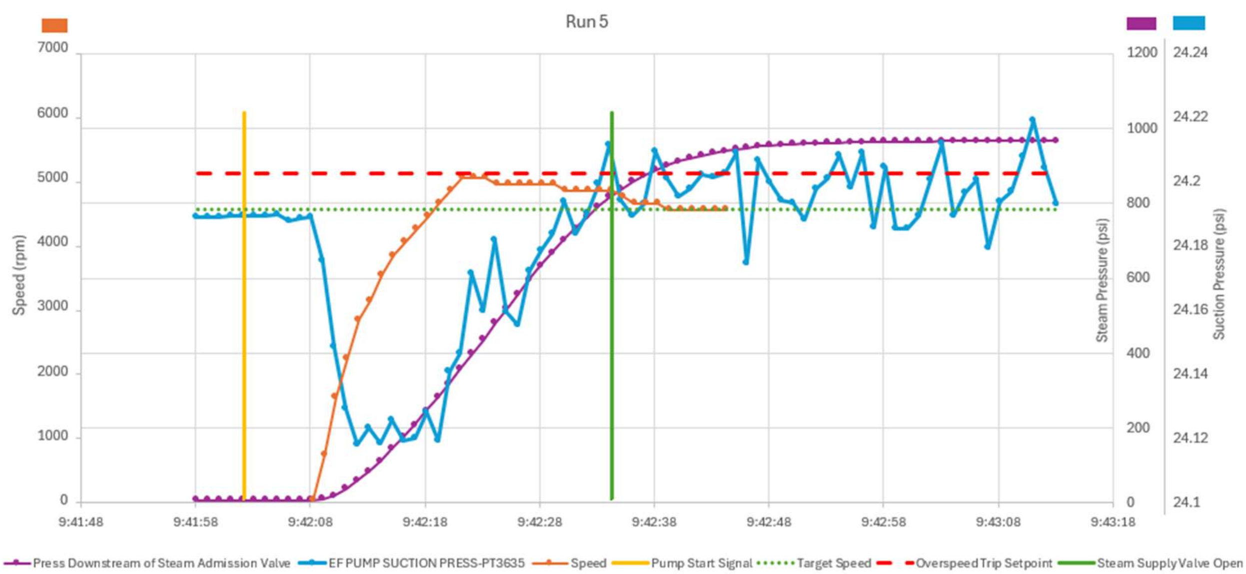

Figure 6-2. Run 5: After Governor Linkage Dressing

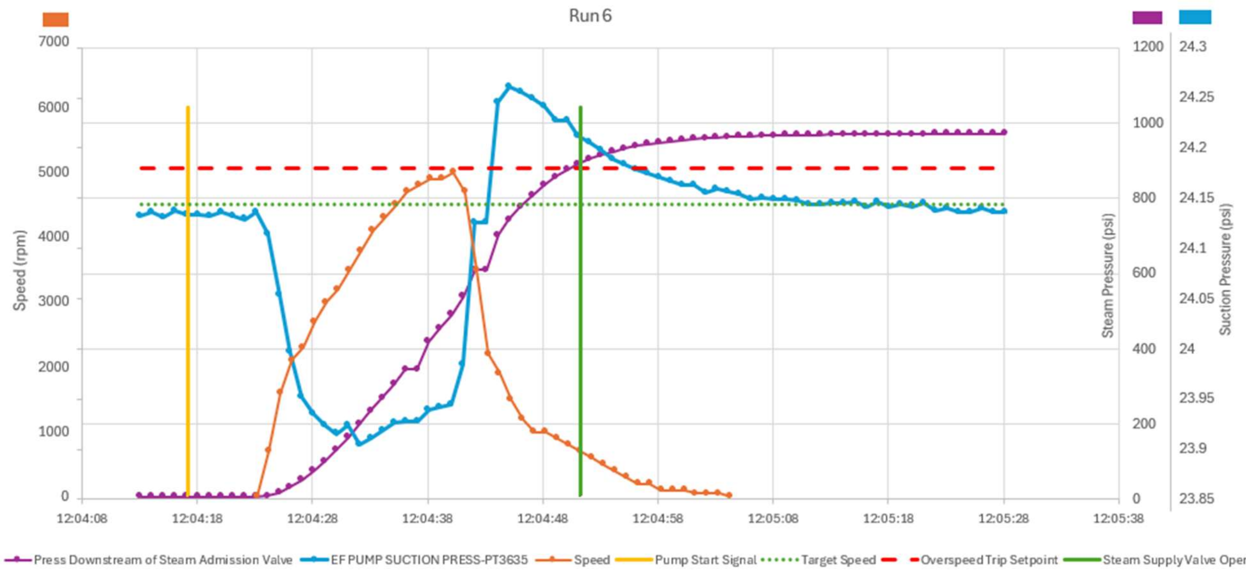

Figure 6-3. Run 6: After Governor Linkage Dressing (with 2-hour cooldown period)

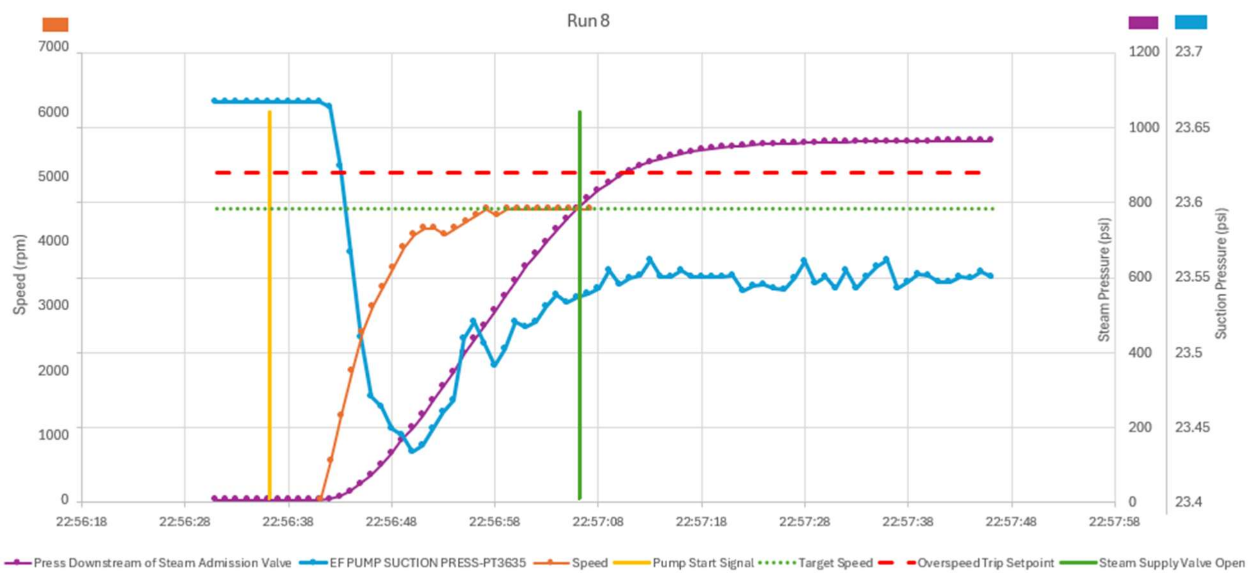

Figure 6-4. Run 8: After Needle Valve Adjustment (with 2-hour cooldown period)

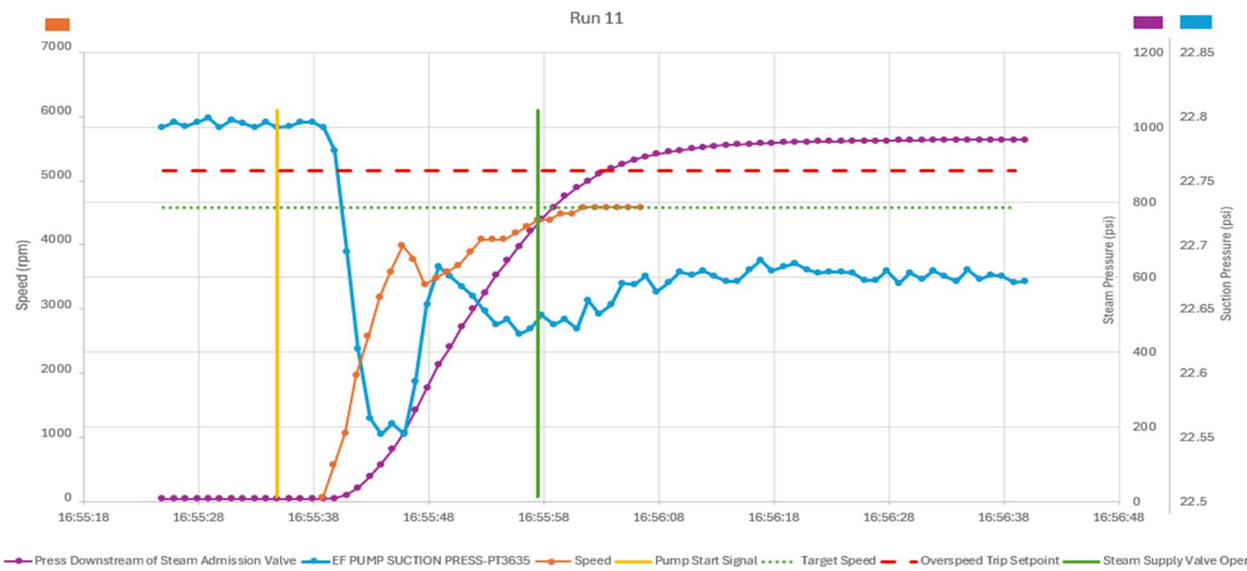

Figure 6-5. Run 11: After Governor Replacement

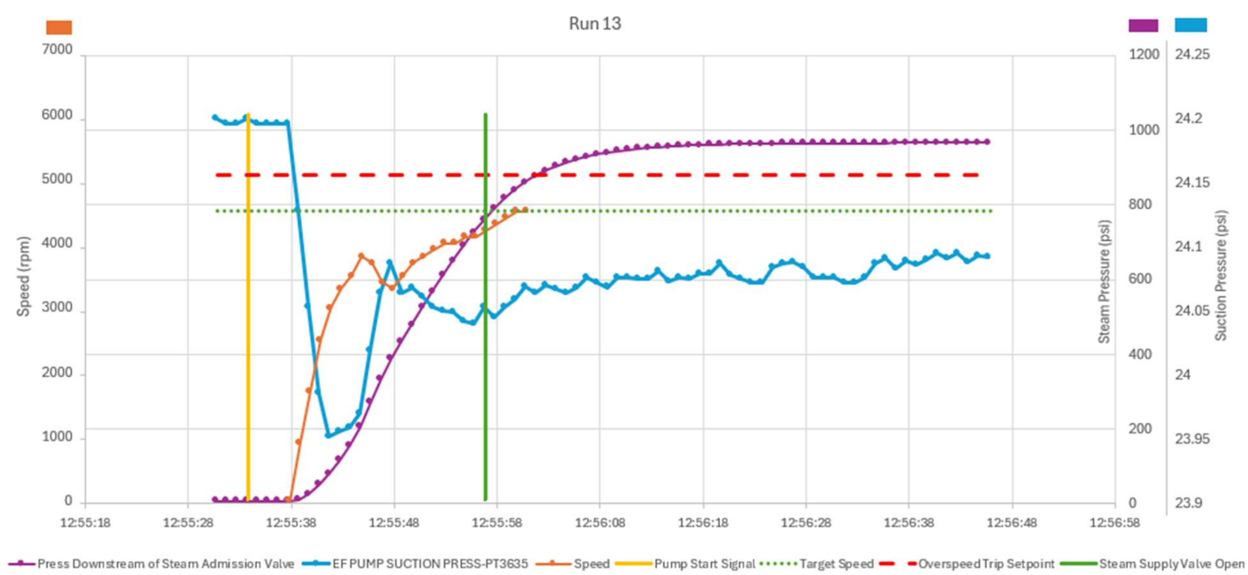

Figure 6-6. Run 13: After Governor and Linkage Replacement

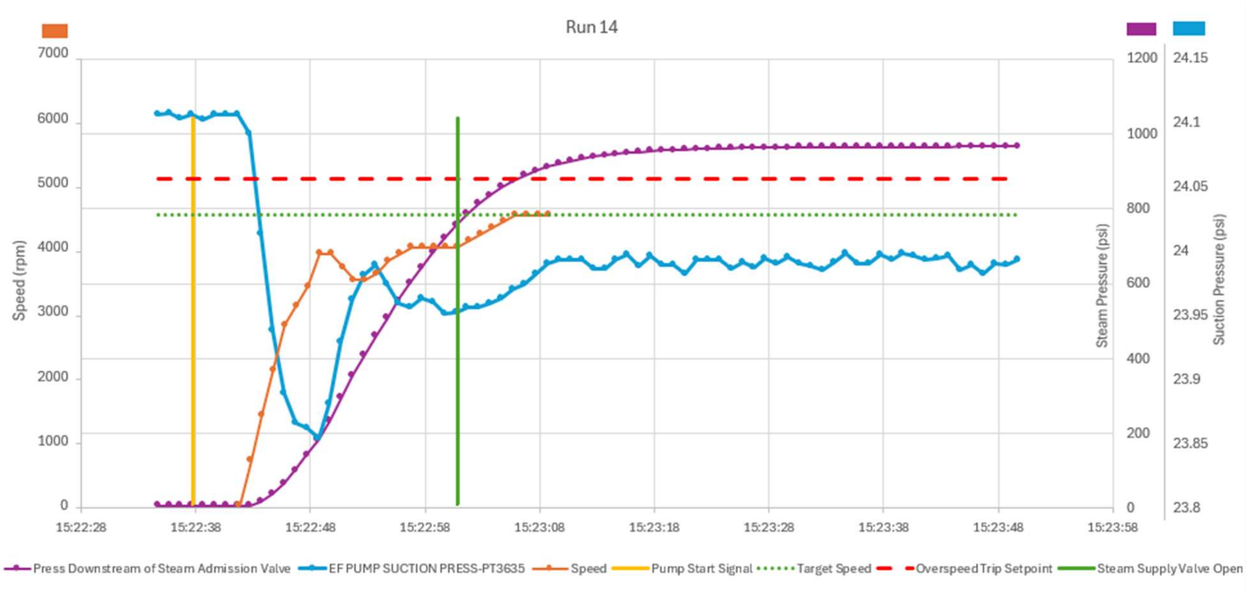

Figure 6-7. Run 14: After Governor and Linkage Replacement (with 2-hour cooldown period)

Table 6-2. Timing of TDEFW Pump Events During Testing

Date and Time	Run	Time to Open Steam Admission Valve (s)	Time from Start Signal to PT2032 Increase (s)	Time from Start Signal to 3600 rpm (Initial) (s)	Time from Start Signal to 3600 rpm (2nd Pass) (s)
11/12/2025 18:28:00	2	33	6	13	N/A
11/14/2025 9:42:00	5	32	7	13	N/A
11/14/2025 12:04:00	6	34	7	14	N/A
11/14/2025 22:57:00	8	30	6	12	N/A
11/14/2025 16:55:00	11	23	4	11	16
11/16/2025 12:55:00	13	23	4	11	16
11/16/2025 15:23:00	14	23	5	11	16

6.2.1. TDEFW Pump Speed

The speed trace for each run is evaluated below to assess the:

- As-found condition of the TDEFW pump and supporting systems, and
- Impact that maintenance actions had on the pump speed transient.

Run 2

During Run 2, the turbine speed increased linearly over the first 7 seconds to 3800 rpm, then continued to ramp at a slower rate. It reached and surpassed the target speed of 4500 rpm within 13 seconds, briefly settled at approximately 5000 rpm, then tripped on overspeed. The speed trace in Figure 6-1 shows the governor was acting to slow the turbine prior to the overspeed trip, but did not respond fast enough to avoid an overspeed. If the transient had been less severe, the governor may have been able to respond fast enough to avoid an overspeed trip.

Run 5

After the linkages between the governor and the governor valve were dressed such that the linkage could move smoothly, Run 5 was performed. Turbine speed increased linearly over the first 4 seconds to 2800 rpm, then at a slower rate to approximately 5000 rpm. As compared with Run 2, the initial linear acceleration period was shorter, and the acceleration decreased at a lower speed for Run 5. This slight change in the initial ramp may be due the removal of excess friction in the governor linkages. However, as the speed increased to and beyond the target speed, the transient looked very similar to Run 2. The turbine narrowly avoided an overspeed trip, hovering near approximately 5000 rpm for a couple of seconds before gradually decreasing to the setpoint speed for the next 17 seconds.

Note Run 5 was performed less than two hours after a slow startup of the pump was completed, and, therefore, the governor oil would have been warmer and less viscous than runs that are performed with time to cool down prior to operation. A waiting period is required prior to official STP runs to remove any potential for preconditioning prior to the test. The temperature of the oil likely improved the responsiveness of the governor during Run 5. The success of Run 5 shows slight differences in the system or transient would have allowed the pump to avoid an overspeed trip in the as-found condition.

Run 6

Run 6 was an official STP run performed after the 2-hour cool down period. Turbine speed increased linearly over the first 3 seconds to 2100 rpm, then at a slower rate to approximately 5000 rpm where it hovered for a few seconds before it tripped on overspeed. Since this test was performed 2 hours after Run 5, the oil was cooler than it was for Run 5. It is possible that cooler governor oil had some slight impact on the transient, however, both runs closely approached the overspeed setpoint as the acceleration decreased.

Run 8

Run 8 was performed after the governor needle valve position was opened from the lower end to the upper end of the normal range, hence the governor was expected to become more responsive. Speed data from Run 8 indicates the governor engaged and controlled turbine speed before reaching the target speed setpoint. Speed increased approximately linearly for the first 4 seconds until the turbine reached 2600 rpm. Acceleration decreased as the turbine approached 4200 rpm before falling slightly to 4100 rpm. Speed then resumed rising and reached 4500 rpm over the next 4 seconds, momentarily dipping below the setpoint before stabilizing. The speed data from Run 8 shows that adjustments to the governor needle valve setting improved the governor's ability to control the pump speed during a pump start.

Run 11

Run 11 was performed after the governor was replaced and the new governor needle valve was adjusted. Speed data from Run 11 indicates the new governor successfully engaged and controlled turbine speed before the setpoint. Speed increased approximately linearly to 3900 rpm. At 3900 rpm, speed dropped sharply to 3300 rpm before gradually increasing to 4500 rpm. The sharp dip after the initial ramp indicates the new governor (and needle valve position) is more responsive. Run 11 was performed 1.5 hours after a slow startup of the pump had been performed so the governor oil may have been warmer, allowing the governor to be slightly more responsive than runs performed with cooler oil.

Run 13

Run 13 was performed using the new governor after several linkages were replaced. Speed increased linearly over the first 3 seconds to 2500 rpm, then at a slower rate to 3800 rpm. The speed then fell to 3300 rpm, recovered and rose to the setpoint gradually over the next 13 seconds. This run also followed a slow pump startup, potentially affecting oil temperature and allowing the governor to be slightly more responsive than runs performed with cooler oil.

Run 14

The TDEFW pump was formally tested per STP-220.002 in Run 14, after the governor oil had cooled for the 2-hour waiting period. The pump speed increased linearly to 2800 rpm over 4 seconds before the governor engaged. Speed continued rising to 3900 rpm, then decreased to 3500 rpm before recovering and stabilizing briefly at 4000 rpm for 5 seconds. Speed then increased to the 4500 rpm setpoint over the next 5 seconds and stabilized. The 20-second interval between governor engagement and setpoint achievement indicates the replacement governor provided slower, more controlled turbine acceleration compared to the previously installed governor (Run 8).

6.2.2. Steam Admission Valve Stroke Time and Downstream Pressure

The steam admission stroke time and pressure between the steam admission valve and the turbine were reviewed to:

- Assess if a correlation between pressure and pump speed could be identified (such that pressure data could be used in instances where speed data is not available),

- Assess the cause and impact of variation in the steam admission valve stroke time, and
- Assess the impact of the timescale of the steam admission valve stroke on the pump speed transient.

Assessment of Potential for Correlation between Steam Pressure Measurement and Pump Speed

The flow rate through the turbine during the start transient is determined by the position of the steam admission valve and the governor valve and will determine the acceleration of the turbine. In Run 2, there is an inflection point in the pressure ramp within a second of the trip. The inflection point is less clearly correlated with the trip in Run 6. For runs that do not trip on overspeed, the ramp rate is more consistent. While the pressure ramp rate is expected to have some variation based on the position of the governor valve and, therefore, the speed of the TDEFW pump, the slope variation is not significant enough to derive a correlation to the pump speed during the start-up transient.

Assessment of Variation in Steam Admission Valve Stroke Time

Table 6-2 shows the time between the pump start signal and the steam admission valve open signal varied between 30 and 34 seconds during Runs 2 to 8, then decreased to 23 seconds during Runs 11 to 13. Appendix E shows a step change in opening time occurred after steam admission valve solenoid trains were swapped.

The effect of the variation in steam admission valve opening time on the TDEFW pump transient is investigated by reviewing the speed traces before and after the step change. Despite the shorter opening time, the Run 11 initial ramp rate of the speed transient is very similar to the Run 8 initial ramp rate. This initial ramp rate is expected to be independent of the governor because it occurs before the governor begins to control the turbine speed. This comparison demonstrates the steam admission valve opening time does not significantly affect the TDEFW transient.

Assessment of Impact of Steam Admission Valve Stroke Timescale on the Pump Speed Transient

The TDEFW pump startup transient occurs before the steam admission valve is fully open and before the steam supply pressure reaches steady state. The speed trace from Run 5 (Figure 6-2) shows the pump narrowly avoided tripping due to overspeed. After avoiding the overspeed, the pump speed steadily decreases to the target speed, even as the steam admission valve continues to open and the steam supply pressure continues to increase. Based on this data, it is anticipated that as long as the pump avoided an overspeed early in the transient, the governor would have adequately controlled the pump speed through the remainder of the transient as the steam admission valve continued to open and the steam supply pressure continued to rise.

6.2.3. EFW Suction Pressure

The EFW suction pressure was reviewed to:

- Assess if a correlation between suction pressure and pump speed could be identified (such that pressure data could be used in instances where speed data is not available), The start and operation of the EFW pumps is expected to cause transient and steady state changes to the EFW pump suction pressure as the flow accelerates and when it reaches a steady state velocity. Changes to the CST water level will also impact the suction pressure. During the troubleshooting runs, the CST water level is anticipated to remain constant because water is recirculated to the tank during the test. The pressure variation caused by the pumps is small and, therefore, could be easily masked by other perturbations to the system as well as instrument noise.

Suction pressure data fluctuated within less than 0.5 psi during troubleshooting runs. Despite minimal variation, suction pressure trends are found to correlate well with the speed data. For all runs, a sharp drop in suction pressure occurred as the pump speed began to increase, and a small spike in pressure coincided with the first decrease in pump acceleration when the governor engaged. Pressure recovered and stabilized at or below its original value as the pump speed reached steady state due to the velocity losses within the piping system. During runs that tripped, suction pressure increased sharply immediately following the trip. Therefore, EFW suction pressure can be used to identify pump starts and compare speed transient in plant data for transient which pump speed data is not available.

7.0 Comparison of TDEFW Pump Injection into Steam Generators to Quarterly Surveillance Test

7.1. Differences Between TDEFW Pump STP and TDEFW Injection into SGs

During an injection to the SGs, the TDEFW pump is aligned to the SGs. The pump cannot inject water until the pump speed is high enough to generate discharge pressure exceeding the pressure of the SGs. Therefore, during the TDEFW pump initial speed ramp, the pump flow is through the minimum flow line. If the pressure of the SG at the injection point is assumed to be 1080 psig (slightly above operating pressure), TDEFW pump will begin to inject water into the SGs when the pump speed has reached approximately 3600 rpm (see Appendix A for speed calculation).

Table 7-1 provides a summary of the differences between the pump start transient between an STP and an SG injection. The next two sections discuss the transient analyses that were performed to provide additional details of the transient behavior.

Table 7-1. Comparison of Parameters for a TDEFW Pump Start During an STP versus an SG Injection with Operating MDEFW Pumps

Parameter	STP	SG Injection with Operating MDEFW Pumps
Flow path during initial ramp <3600 rpm	Recirculate to CST, <300 gpm	Recirculate through minimum flow line, <100 gpm
Flow path at >3600 rpm	Recirculate to CST	Recirculate through min flow line and begin injection into SG
Flow path at 4500 rpm	Recirculate to CST, ~300 gpm (Reference 6.A)	Recirculate through min flow line (~100 gpm, Reference 6.A) and inject into SG (~530 gpm, Reference 5.C)

7.2. Transient Analysis to Compare STP and SG Injection Power Requirements and Evaluate Fluid Inertia Effects

A transient model of the portion of the TDEFW system that injects flow was developed to compare brake horsepower (BHP) requirements of the pump for STP and SG injection alignments. The model includes the TDEFW pump modeled using the head flow curve and the BHP curve, the discharge piping to the steam generators, and the mini flow and test line back to the CST. The model also includes the fluid inertia of the parallel flow paths and appropriate boundary conditions at the CST and the SGs.

7.2.1. Comparison of STP and SG Injection Power Requirements

Using this model, a transient analysis was performed to simulate a pump flow injection in each alignment using a defined speed ramp of the drive-turbine. The transient analysis (Appendix A) assesses pump flow and BHP required by the pump during the transient turbine acceleration[2] for the SG injection (Case 1) and the STP (Case 2). The analysis demonstrates that the BHP requirement depends on pump speed and pump flow. The analysis determines that the SG injection scenario is less demanding on the governor than the STP scenario.

Figure 7-1 shows the BHP required by the pump as a function of time during the pump start for the SG injection case and the STP case along with the speed ramp shown on the second vertical axis.

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[2] Speed data from Run 2 is used as the speed ramp for both the SG injection and STP cases of the transient analysis. Use of the same speed ramp for both cases is appropriate to demonstrate differences in BHP requirements for TDEFW pump start-up in each alignment.

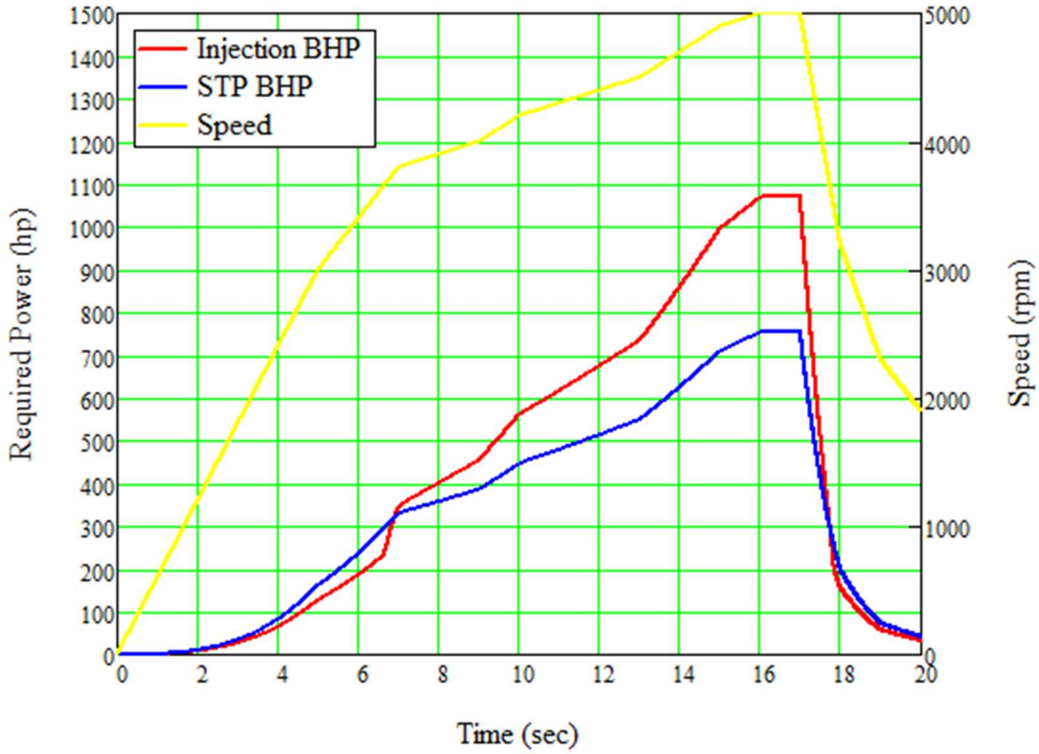

Figure 7-1. TDEFW Pump Required BHP (SG Injection and STP)

As shown in Figure 7-1, the required pump BHP is lower for the SG injection case than for the STP case at pump speeds below 3600 rpm due to the pump flow being lower. Flow to the steam generators starts when the pump discharge becomes high enough to overcome the back pressure at approximately 3600 rpm. Above 3600 rpm, the flow to the steam generators increases rapidly to values higher than the STP flow. Therefore, the pump BHP requirement for SG injection becomes higher than in the STP. The required BHP for the SG injection case is significantly higher as the pump approaches full speed.

Figure 7-2 shows the ratio of BHP required by the pump for the SG injection case to the STP case as a function of speed during the pump start.

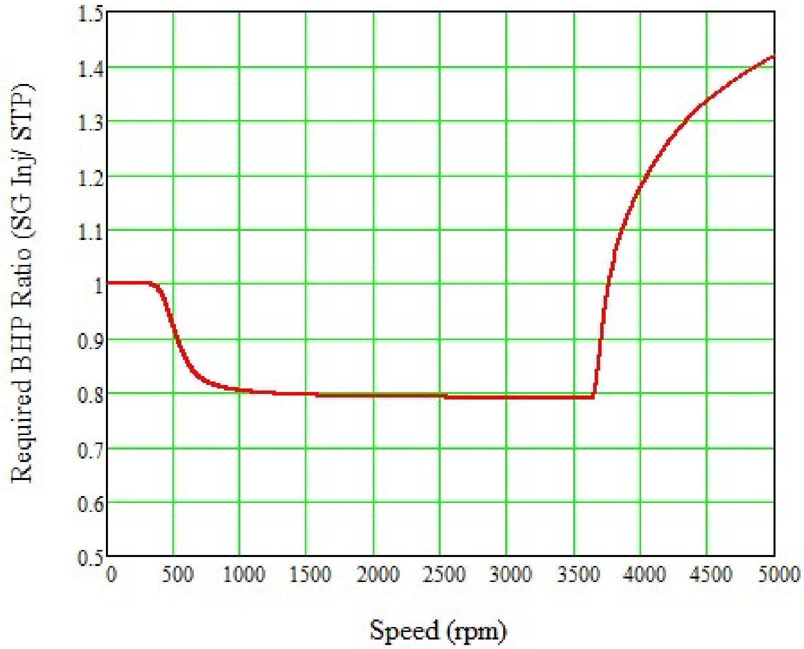

Figure 7-2. Ratio of SG Injection to STP TDEFW Pump Power Demand vs Speed

- The BHP required by the pump for the SG injection case below 3600 rpm is approximately 80% of that required for the STP case due to the flow being lower.
- Above 3600 rpm, the ratio of SG injection case to STP case BHP increases rapidly once the flow overcomes the SG pressure and begins to inject. The SG injection case BHP becomes about 42% higher than the STP case BHP at the maximum speed of 5000 rpm during the simulated transient.
- At the target speed setpoint of 4500 rpm, the BHP required by the pump for the SG injection case is approximately 134% of that required for the STP case. At 5000 rpm, the SG injection case BHP is approximately 142% of the STP case BHP. Assuming the governor valve position during the pump start is the same, the additional load from the pump will result in a lower rate of increase of the turbine speed during an SG injection as compared to an STP. Therefore, the pump is more likely to avoid an overspeed trip as speed increases during an SG injection.

The transient analysis demonstrates that the BHP required for an injection to the SGs is significantly higher than for an STP. Due to the higher required BHP for the SG injection, more steam is needed by the turbine to generate the required power. For a given valve position, the turbine will also accelerate more slowly to full speed after reaching 3600 rpm because of the higher load created by the higher BHP requirement. These factors associated with the higher BHP during the latter part of the speed transient would have allowed the TDEFW pump to avoid an overspeed during an SG injection event in the November 2025 as-found condition.

7.2.2. Fluid Inertia Effect Evaluation

The model was also used to evaluate if the fluid inertial effects are important for this transient. Figure 7-3 shows speed and transient pump flows for STP and SG injection on the same graph. The initial flow ramp is slow because the pump has not developed sufficient head to inject to the SGs. Once injection starts, the flow reaches the steady state value at nearly the same time as the speed. Since there is no substantial lag between the flow and the speed, the fluid inertial effects are negligible for the EFW system installed at VCS due relatively slow turbine acceleration.

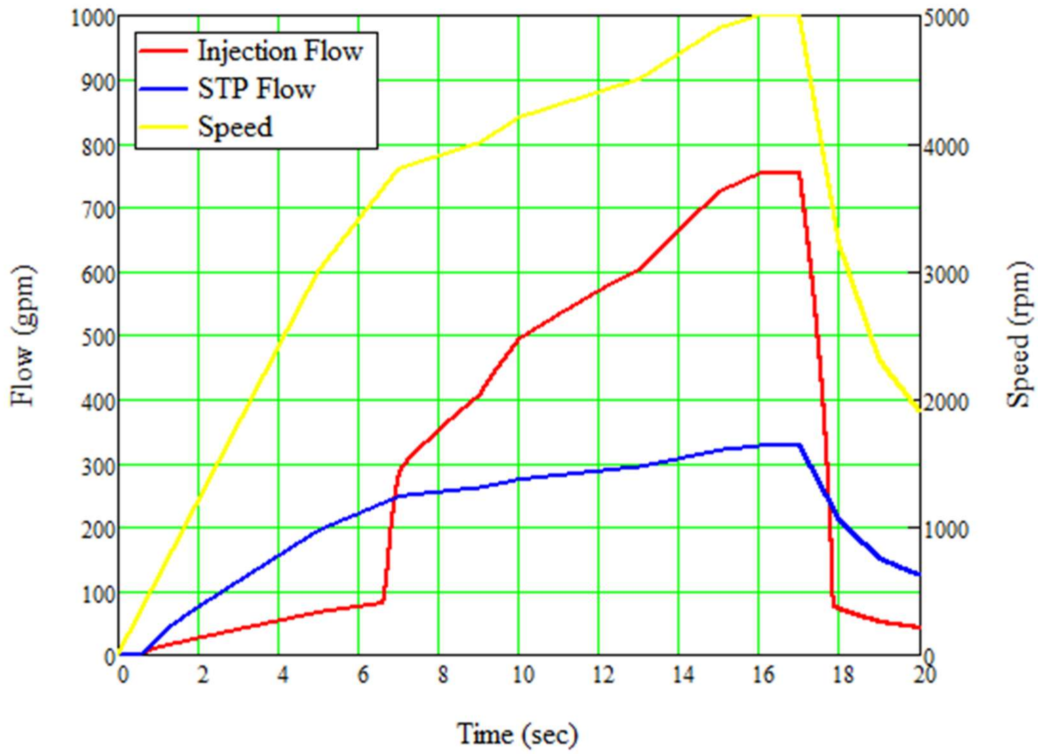

Figure 7-3. TDEFW Pump Speed and Flow Transients

7.3. *Transient Analysis to Quantify Valve Travel and Overspeed Margin*

MPR performed a transient analysis (Appendix B) to characterize the relationship between the TDEFW pump BHP requirement, steam flow, and governor valve lift and to quantify valve travel and overspeed margin in STP and SG injection conditions.

The analysis described in Section 7.2 simulated the pump start and flow injection to compare the power requirements for the SG injection and STP alignments. That analysis did not model the steam side that powers the turbine. Instead, it used a defined speed ramp to examine the BHP requirement. As a result, that analysis did not directly quantify the effect of the different BHP requirements between the SG injection and the STP cases on the steam flow demand, the governor valve required movements, and the margin to overspeed trip. Therefore, an additional analysis was performed. This analysis modeled the steam side and simulated the pump start based on steam flow provided by the steam admission valve.

7.3.1. Model

For the new analysis, a detailed model of the EFW steam supply system was developed and the model was coupled with the model of the pump and the flow injection piping discussed in Section 7.2. The completed model includes the following:

- The steam admission valve modeled using the valve opening stroke time and flow coefficient,
- the governor valve modeled using its lift curves,
- the drive-turbine modeled using the turbine performance curves and rotating inertia,
- the pump modeled using the pump performance curves and rotating inertia, and
- the EFW piping for SG injection and STP alignments modeled using the flow resistance and inertia of the fluid.

The governor is not modeled. The governor valve movements are specified as a function of time to create normal start-up and overspeed trip scenarios to compare turbine acceleration and governor valve movements for the SG injection and STP cases.

7.3.2. Analysis Cases

The following analysis cases were run using the model.

- **Case A:** This case simulates the first maintenance run (referred to as Run 2) which led to an overspeed trip. The purpose of this case is to determine if the TDEFW pump configured for an SG injection would have been successful in the November 2025 as-found condition.

  The governor valve position was adjusted in the model until the speed ramp calculated by the model matched reasonably well with the measured speed ramp of Run 2, which corresponded to an STP alignment. Next, the same governor valve position was applied to an SG injection alignment and the pump speed was calculated. The speed ramp for SG injection was compared with the speed ramp for Run 2 to assess the margin to the overseed trip setpoint.

- **Case B:** This case simulates a simplified normal start-up for an STP and the SG injection. The case was run to determine the difference in the steam flow demand and the required governor valve movement between the two scenarios.

  For each scenario, the governor valve is moved such that pump speed reaches the normal speed setpoint. The results of this case allow comparison of the power required by the pump, the steam flow required by the turbine, and the governor valve stroke needed to allow the required flow to the turbine for SG injection and STP. The case shows that the power requirement of the pump and the steam flow requirement of the turbine are higher for an SG injection during the start-up. As a result, the governor valve has to move closed less for an SG injection.

7.3.3. Analysis Results

The results of the transient analysis include the required power, steam flow rate, governor valve movement, and speed ramp for STP and SG injection.

Case A: Run 2

Figure 7-4 shows the results of the Case A analysis. The governor valve position as a function of time was specified as shown in Figure 7-5. With this position as input, the model produced a speed ramp that is close to the measured Run 2 speed ramp. When the same valve position is applied to an SG injection alignment in the model, the speed ramp shown by the red solid line is produced. The peak speed reached during SG injection is about 400 rpm less than the overspeed trip setpoint[3].

The Case B results discussed below show that the required governor valve travel for SG injection is less than the travel needed for an STP. This Case B result coupled with the speed margin results shown in Figure 7-4 indicate the following:

If the TDEFW pump had been aligned for SG injection in November 2025, then even with the degraded governor performance, the pump would have started and performed its safety function without an overspeed trip.

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[3] As shown in Figure 7-5, the valve initially closes and then re-opens slightly. This valve movement was required to match the STP speed ramp in Run 2. A review of the video of Run 2 shows that the valve was closing throughout the event. It does not appear to be re-opening. To evaluate the effect of the difference in the movement between the analysis and the video, a scoping analysis was performed with a different valve movement which includes closure to a fixed position but no re-opening. The valve travel in this scoping analysis was selected such that the STP resulted in overspeed. Next, the same valve movement was applied to SG injection and the speed ramp was calculated. The analysis showed a margin of about 500 rpm to overspeed trip for SG injection. Therefore, this scoping analysis demonstrates that the overspeed margin for SG injection is significant and is not highly dependent on the manner in which the governor valve moves.

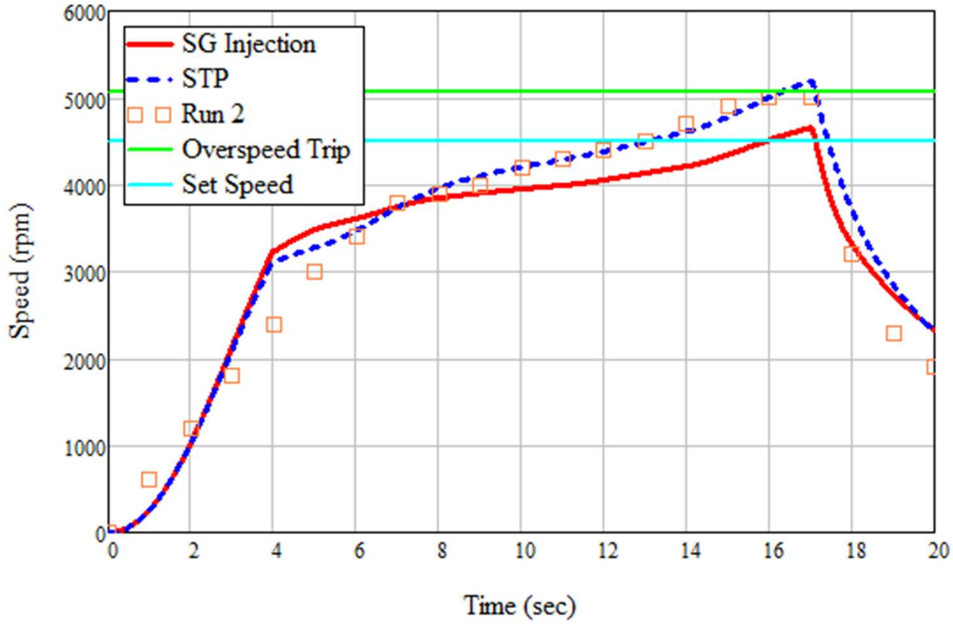

Figure 7-4. Case A: STP and SG Injection Speed Ramps

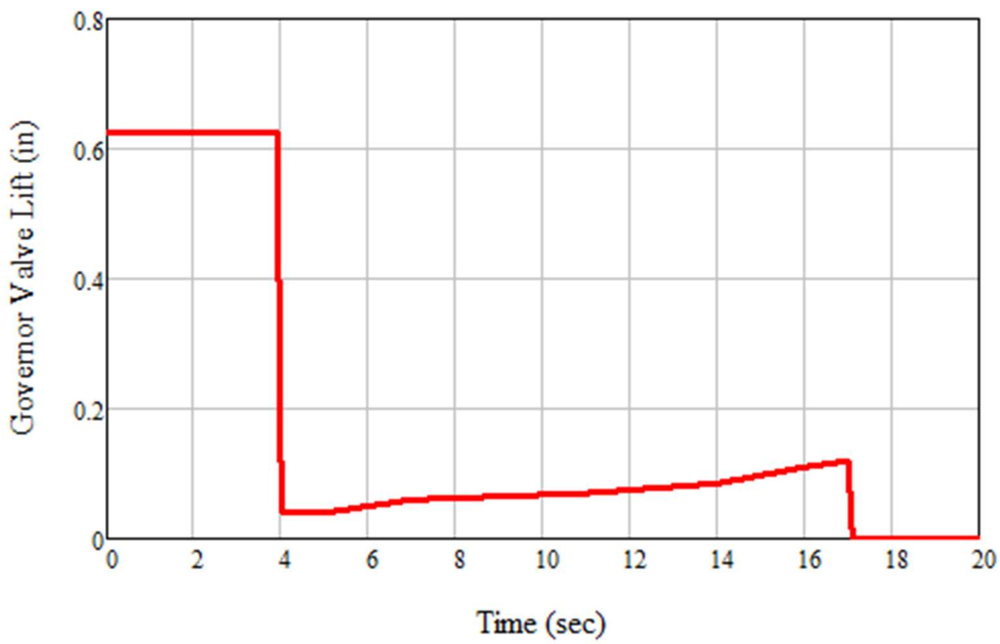

Figure 7-5. Case A: Valve Position

Case B: Simplified Normal Startup

Case B examines the differences in governor valve and turbine performance between STP and SG injection starts by considering simplified ideal start conditions. Figure 7-6 shows hypothetical identical, simplified speed ramps to the target speed for STP and SG injection cases. The speed transients were modeled after the initial part of the speed transient in Run 8.

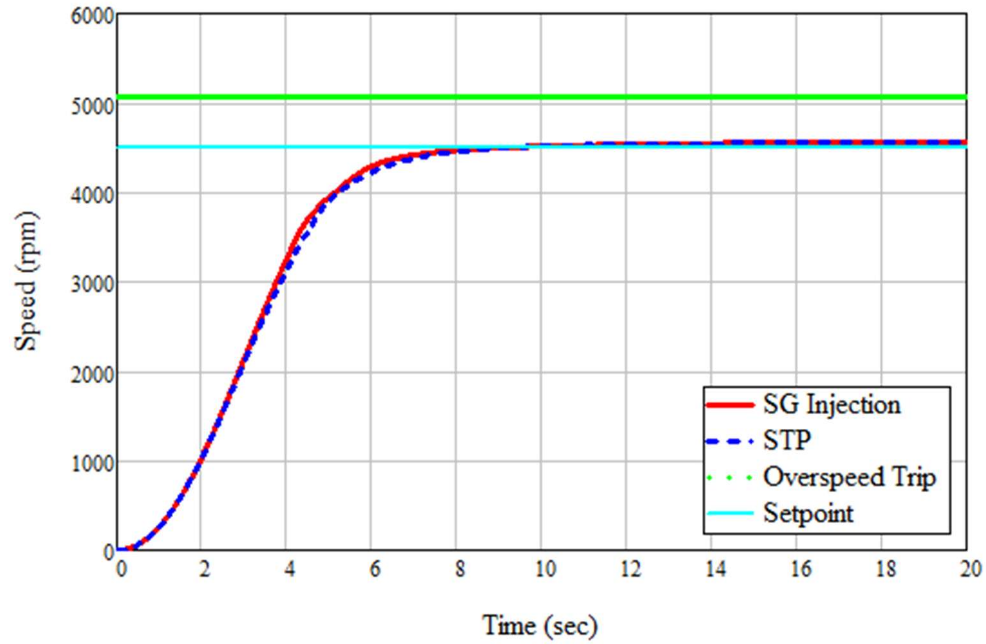

Figure 7-6. Case B: STP and SG Injection Speed Ramps to Target Speed

Figure 7-7 and Figure 7-8 show the power requirement of the pump and the steam flow requirement of the turbine for the two scenarios. The SG injection needs significantly more power. As a result, the steam flow needed by the turbine is also higher (approximately 135% of the STP case).

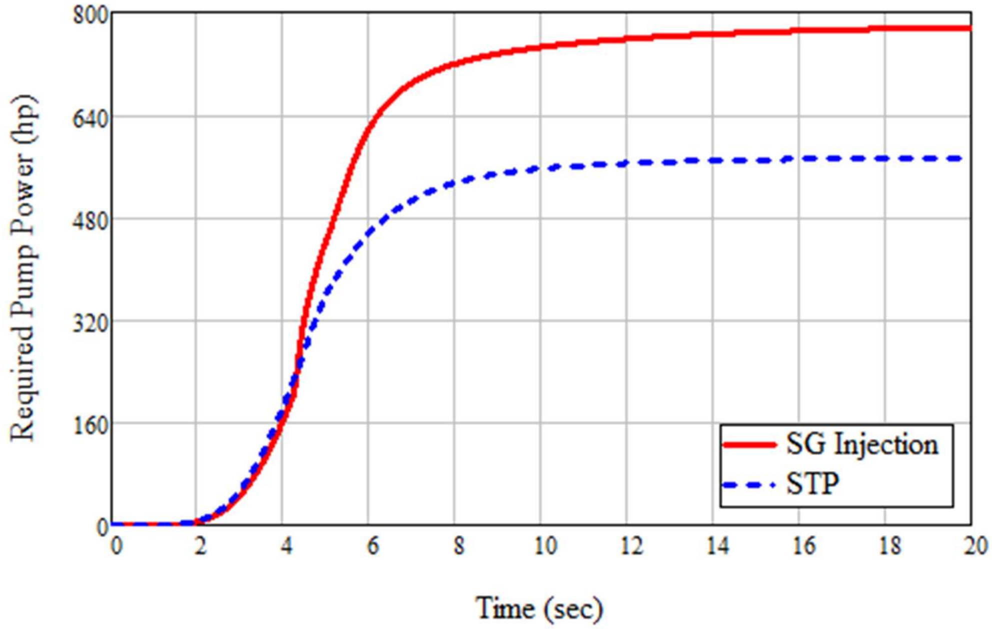

Figure 7-7. Case B: BHP Required for STP and SG Injection

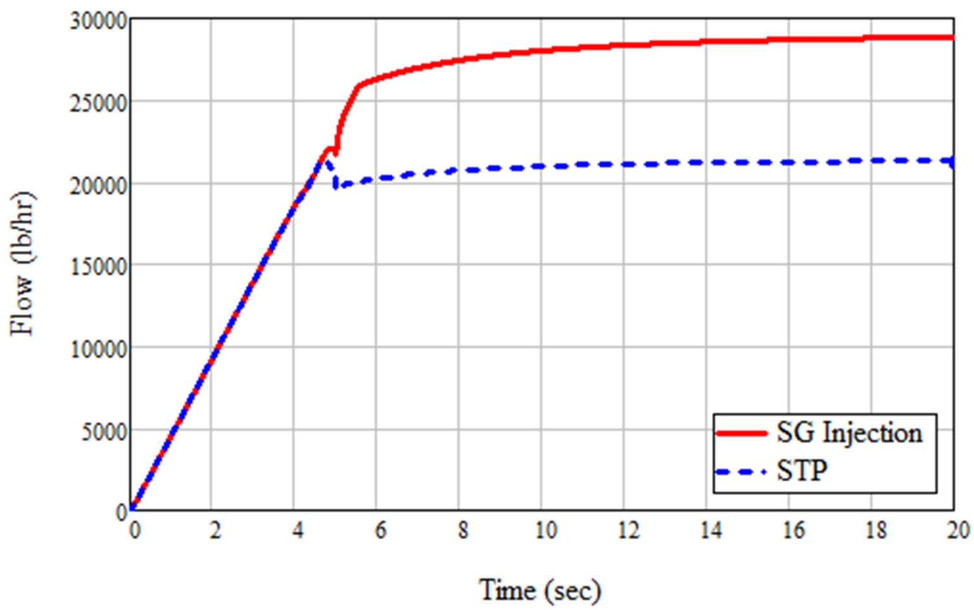

Figure 7-8. Case B: Steam Flow Required for STP and SG Injection

Figure 7-9 shows the governor valve travel needed for the two scenarios. The full stroke of the governor valve is 0.625 inches. The valve is initially full open. The valve position is more open when the turbine is at steady state speed during SG injection than during an STP. The final valve positions are 0.08 inches open for STP and 0.11 inches open for SG injection.

The difference in the governor valve position between the two configurations was measured during a comprehensive surveillance test when the TDEFW pump is configured to the CST during one test and to the SG during another test. The measurements are documented in Appendix F. While there was notable uncertainty with the measurement method used, the difference in the measured positions was 0.03 inches (5/32 inches - 1/8 inches), which is consistent with the difference between analysis results (0.11 inches – 0.08 inches = 0.03 inches).

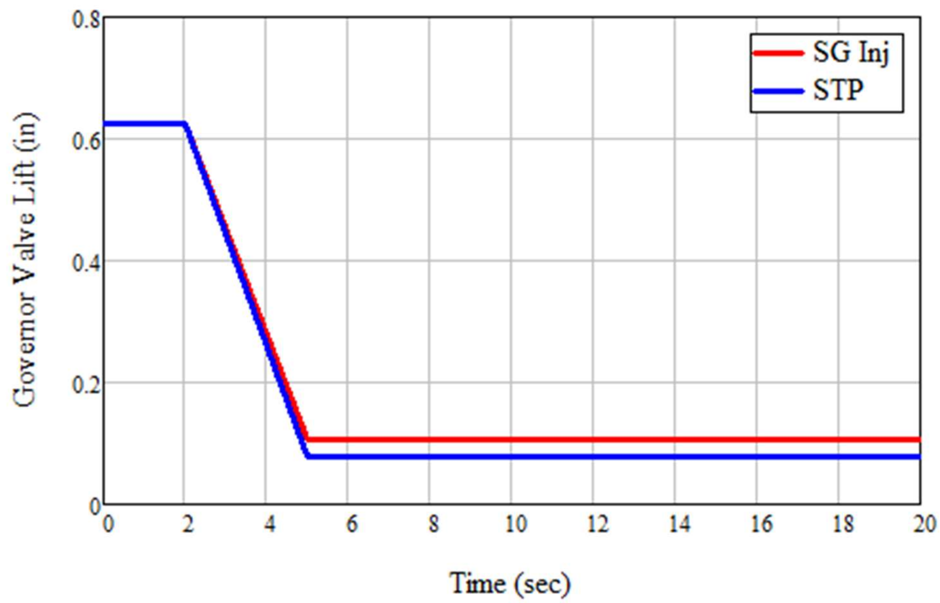

Figure 7-9. Case B: Governor Valve Travel Required for STP and SG Injection

Table 7-2 summarizes governor valve travel, steam flow rate, and power calculated to meet the 4500 rpm target speed for STP and SG injection cases. Since the pump requires 34% more power for SG injection than for STP and the steam flow rate through the governor valve varies approximately linearly with the valve travel, 34% more steam flow is required to drive the turbine to turn the pump at steady-state speed and the valve remains 35% more open (0.11 inches for SG injection versus 0.08 inches for STP).

The governor valve stem position is 18% open (0.11 inches/0.625 inches = 18%) for an SG injection and 13% open (0.08 inches/0.625 inches = 13%) for an STP when the turbine reaches full speed. This is a difference of 5% of the total valve stroke. Therefore, the total required valve stem travel from the full open position during a pump start is 82% of the total valve stroke for SG injection and 87% of the total valve stroke for STP. Hence, as the turbine starts, the governor valve stem moves a shorter distance to control the turbine speed during an SG injection as compared to during an STP.

Table 7-2. Calculated Conditions for STP and SG Injection at 4500 rpm

	STP	SG Injection	Margin for SG Injection
Governor Valve Initial Position	0.625"	0.625"	-
Governor Valve Final Position	0.08"	0.11"	35%[1]
Governor Valve Travel	0.545"	0.515"	5%[2]
Required Steam Flow	21500 lb/hr	28800 lb/hr	34%[3]
Required Power	570 hp	780 hp	34%[4]

1. Governor valve final position for SG injection is 35% more open than the position for STP.
2. Governor valve travel is 5% less with respect to the full stroke for SG injection.
3. Steam flow demand for SG injection is 34% more than the position for STP.
4. TDEFW pump power demand for SG injection is 34% more than the position for STP.

8.0 Review of Available SG Injection Flow Data

In this section, available data from a past SG injection event is reviewed to assess alignment with expected behavior.

Pressure and flow data is available from the successful TDEFW pump actuation during a plant trip on February 10, 2025 (Reference 5.C). During this event, the MDEFW pumps started several seconds before the TDEFW pump start signal. Note a different governor was installed in February 2025 than the one used in October and November 2025; however, plant data from the February SG injection transient is provided to illustrate system behavior during a startup for injection.

Figure 8-1 depicts EFW pump suction pressure, pressure downstream of the steam admission valve, the TDEFW pump start signal, and the steam supply admission valve open limit switch. The first dip in the EFW suction pressure is due to the start of the MDEFW pumps. The second two dips are caused by TDEFW pump start transient.

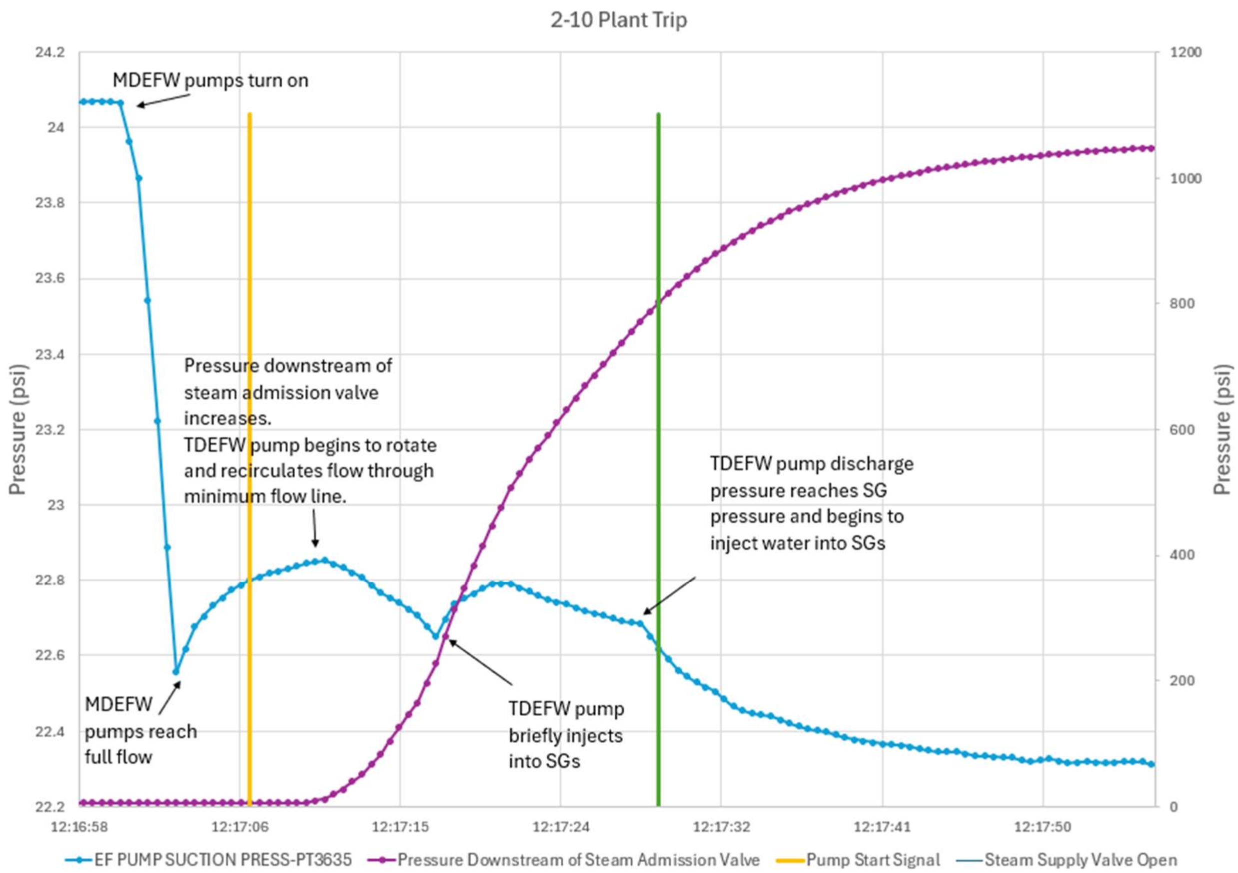

Figure 8-1. February Injection Steam and Suction Pressure Data

Flow rates are captured at the inlets to the SGs and the discharge of each MDEFW pump. Feedwater flow through the TDEFW pump is not directly captured by the computer data; however, the flow rate from the TDEFW pump to the SGs is approximately equivalent to the sum of the flow rates to all three SGs minus the sum of the discharge flow rates of both MD pumps:

$$TD = (SG_A + SG_B + SG_C) - (MD_A + MD_B)$$

Note a small portion of the discharge flow from each MD pump is recirculated to pump suction via the recirculation line while the flow rate through the main line is small, thereby reducing the actual forward flow from each MD pump. When the EFW pumps are called upon to inject to the SGs, the MDEFW pump flow rate increases rapidly such that the MDEFW pump recirculation line valve closes early in the pump start transient and prior to the TDEFW pump start signal. Due the minimal impact on the transient, the MD pump recirculation flow data is neglected for this data review.

Figure 8-2 compares EFW pump suction pressure trends with the flow rates through the MDEFW pumps, into SG A, B, and C, and the calculated TDEFW pump flow rate into the SGs. Note the gradual increase of flows into SG B and C is most likely not real and appears in the data due to averaging in data collection or storage. Flow data for SG A is expected to more accurately reflect real SG flow behavior. The artifical slow ramp in the SG B and C flow rate creates an unrealistic negative TDEFW pump flow rate to the SGs prior to the start of the TDEFW pump.

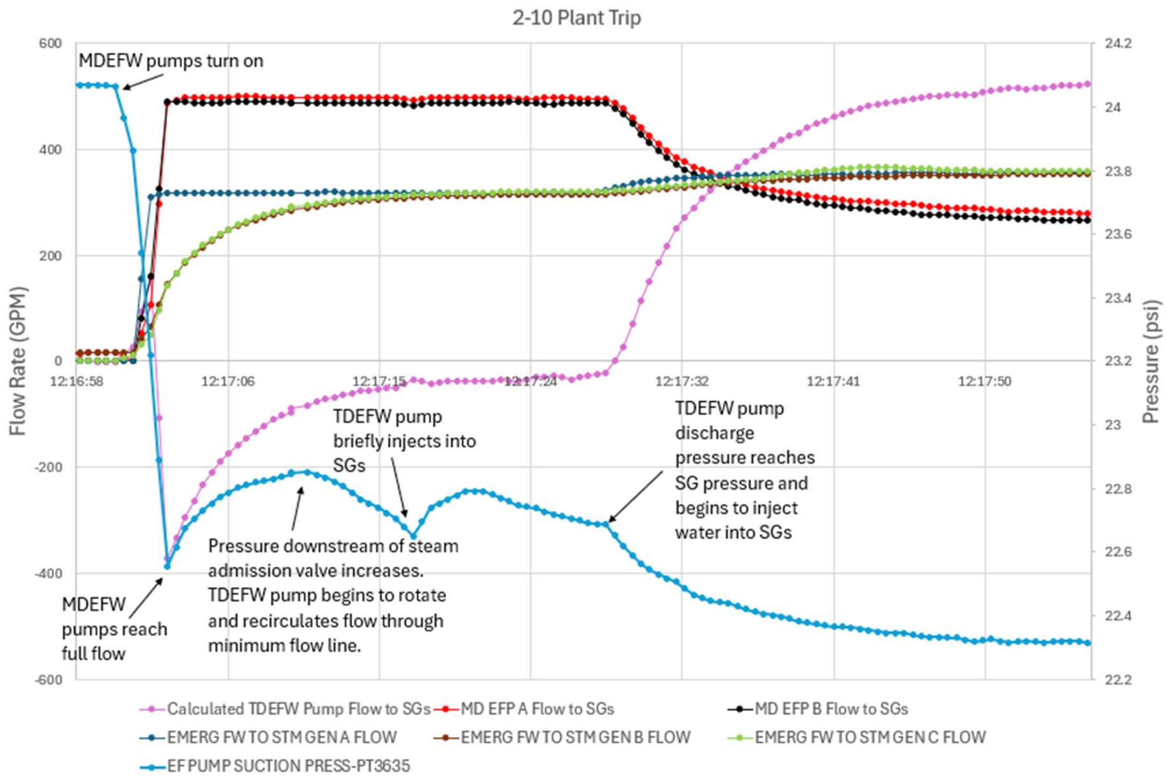

Figure 8-2. February 2025 Plant Trip EFW Pump Suction Pressure and EFW Flow Rate Data

Pump suction pressure trends correlate closely with events in the flow data. Suction pressure dropped significantly as both MDEFW pumps started and came up to full speed. Suction pressure recovered until the TDEFW pump began accelerating.

Suction pressure reached a sharp local minimum 10 seconds after the start signal was received, coinciding with a small dip in both MDEFW pump flows. This behavior indicates the TDEFW pump injected momentarily into the SGs as the turbine reached approximately 3600 rpm (calculated in Appendix A). Suction pressure subsequently increased, indicating the governor engaged to briefly slow the pump, then decreased as speed resumed ramping to the setpoint. The suction pressure then decreased sharply, indicating the start of injection after the pump increased to approximately 3600 rpm for the second time. Simultaneously, TDEFW pump flow and SG A, B, and C flows increased while MDEFW pump A and B flows decreased steadily.

This behavior is consistent with the expected behavior during an SG injection event based on the evaluations in previous sections.

9.0 References

1. MPR Letter No. 0310-0080-LTR-001 Rev. 0, “Evaluation of August 2025 TDEFW Pump Trip – Performance Deficiency and Exposure Time,” sent October 7, 2025.

2. V.C. Summer Nuclear Station, Document, “Timeline of Events,” shared by Dominion via OneDrive (modified and included as Appendix C).

3. P&IDs
   - A. V.C. Summer Nuclear Station, Drawing No. D- 302-011, “MAIN STEAM (NUCLEAR),” Revision 42.
   - B. V.C. Summer Nuclear Station, Drawing No. D-302-085, “EMERGENCY FEEDWATER (NUCLEAR),” Revision 53.

4. Videos of TDEFW STPs:
   - A. V.C. Summer Nuclear Station, “Governor Valve and Linkages_1m35s.mov,” November 12, 2025, shared by Dominion via OneDrive.
   - B. V.C. Summer Nuclear Station, “Tachometer-Oil-Trip & Throttle_1m45s.mov,” November 12, 2025, shared by Dominion via OneDrive.
   - C. V.C. Summer Nuclear Station, “Turbine Fast Start (STP)_2m30s.mov,” November 14, 2025, shared by Dominion via OneDrive.
   - D. V.C. Summer Nuclear Station, “IMG_0063_55s.mov,” November 14, 2025, shared by Dominion via OneDrive.
   - E. V.C. Summer Nuclear Station, “IMG_0064_3m00s.mov,” November 14, 2025, shared by Dominion via OneDrive.
   - F. V.C. Summer Nuclear Station, “IMG_0095_fast_start.mov,” November 16, 2025, shared by Dominion via OneDrive.
   - G. V.C. Summer Nuclear Station, “IMG_0102_1m45s.mov,” November 16, 2025, shared by Dominion via OneDrive.
   - H. V.C. Summer Nuclear Station, “IMG_0086_1m45s.MOV,” November 15, 2025, shared by Dominion via OneDrive.
   - I. V.C. Summer Nuclear Station, “IMG_3448.MOV,” February 27, 2026, shared by Dominion via OneDrive.
   - J. V.C. Summer Nuclear Station, “IMG_3449.MOV,” February 27, 2026, shared by Dominion via OneDrive.

5. Plant computer point data:
   - A. V.C. Summer Nuclear Station, “Trend Data.xlsx,” November 2025, shared by Dominion via OneDrive.
   - B. V.C. Summer Nuclear Station, “Trend Data_Added Points.xlsx,” shared via email from Derrick Neufeld on December 17, 2025.
   - C. V.C. Summer Nuclear Station, “EF Full Flow Data,” November 2025, shared by Dominion via OneDrive.

D. V.C. Summer Nuclear Station, "Trend Data February 2026," February 2026, shared by Dominion via OneDrive.

6. VCS Procedures:

A. V.C. Summer Nuclear Station, Procedure No. STP-220.002, "TURBINE DRIVEN EMERGENCY FEEDWATER PUMP AND VALVE TEST," Revision 10.

B. V.C. Summer Nuclear Station, Procedure No. MMP-300.015, "TURBINE MAINTENANCE, EMERGENCY FEEDWATER PUMP TPP0008", Revision 19, Change J.

7. Work Orders:

A. V.C. Summer Nuclear Station, Work Order No. STP0220.002-XPP0008 (2025-06-09; WO 88201751909), Revision 9.

8. VCS TDEFW Pump Head flow curves

A. Bingham-Willamette Co, Curve No. 35273, "Witness Test Performance Curve Sheet".

B. Bingham-Willamette Co, Curve No. 38216, "Characteristic Curve Sheet".

9. V.C. Summer Nuclear Station, Document, "Governor Valve Measurements," shared via email from Derrick Neufeld (VCS) to Erin Tindall (MPR) Thu 3/5/2026 5:41 AM (excerpts included as Appendix F, Table F-2).

10. V.C. Summer Nuclear Station, Calculation No. DC05220-091, "EF Hydraulic Analyses," Revision 4.

11. V.C. Summer Enhanced Design Basis Document, "Emergency Feedwater System (EF)," Revision 18.

12. Dominion Energy, Document No. PI-AA-300-3007 – Attachment 1, "Equipment Failure Evaluation", CA No. 13185528.

13. Email from Derrick Neufeld (VCS) to Erin Tindall (MPR) Sat 3/7/2026 5:19 AM with the subject "RE: TDEFW Pump – Additional Information Request".

14. Email from Derrick Neufeld (VCS) to Erin Tindall (MPR) Tue 2/24/2026 9:31 AM with the subject "V.C. Summer TDEFW Steam Admission Valve Stroke Times".

15. Email from Daniel Busbee (VCS) to Erin Tindall (MPR) Tue 1/6/2026 4:41 PM with the subject "TD Bypass Flow."

16. Karassik, Igor J., Messina, Joseph P., Cooper, Paul, Heald, Charles C. "Pump Handbook, Third Edition," Chapter 13 pg. 36.

17. *Nuclear Maintenance Applications Center: Terry Turbine Maintenance Guide, Auxiliary Feedwater (AFW) Application: Replaces 3002001670*. EPRI, Palo Alto, CA: 2017. 3002010629.

18. VCS Terry Steam Turbine Instruction Manual, Turbine Type:GS-2, Serial No: T-38765-A, VCS Document number 1MS-94B-425-0, dated November 13, 1979.

A MPR Calculation No. 0310-0085-CALC-001 Rev 0, "TDEFW Pump Start Transient Analysis"

0310-0085-CALC-001
Revision 0

TDEFW Pump Start Transient Analysis

Prepared for: V. C. Summer Nuclear Station

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QA Statement of Compliance

This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of the MPR Standard Quality Program.

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TDEFW Pump Start Transient Analysis

RECORD OF REVISIONS		
Revision Number	**Pages /Sections Revised**	**Revision Description**
0	All	Initial Issue

Table of Contents

1.0 Purpose and Background

1.1. Purpose

This calculation documents a transient hydraulic analysis of the Turbine-Driven Emergency Feedwater (TDEFW) pump start at V. C. Summer. The results of the analysis illustrate the hydraulic performance of the system and pump brake horsepower requirements for different system alignments. The results will be used to evaluate the consequence a pump overspeed trip during the November 2025 TDEFW pump surveillance test on the ability of the pump to inject to the steam generators had it been called into service.

1.2. Background

The Emergency Feedwater (EFW) system at V.C. Summer is a safety-related system that injects flow into the steam generators to remove decay heat under certain design basis accident scenarios. The EFW system includes two motor-driven pumps and one turbine-driven pump. These pumps take suction from the Condensate Storage Tank (CST) and inject into the feedwater lines that lead to the steam generators. Quarterly surveillance tests are performed on the EFW pumps to meet the plant licensing commitments. During these tests, the flow from the pump is recirculated back to the CST through a test line.

The TDEFW pump has a governor which controls the speed by modulating the governor valve which controls the steam flow to the turbine. A mechanical overspeed protection trip is also provided to ensure the speed does not exceed the setpoint speed and cause damage to the turbine. When performing the quarterly surveillance test procedure (STP) on the TDEFW pump in November 2025, the overspeed protection trip activated and the pump tripped. The pump had previously operated successfully during a steam injection event in October 2025. The unexpected pump trip during the STP called into question the operability of the pump for injection events between the October 2025 event and the November 2025 surveillance test.

Dominion initiated an evaluation of the cause of the trip, the impact of the failed surveillance test on the pump's safety function, and regulatory impact. As part of this effort, MPR performed a technical evaluation of the event based on the steady state flow rates through the pump when the pump was configured for an STP and for a SG injection event (Reference 10). To refine and confirm that simplified evaluation, a transient analysis of the pump start is needed to determine the following:

- If there is significant lag between the pump speed increase to rated speed and the flow increase to steady state flow due the inertia of the fluid.
- How the pump power requirements vary during the start transient for a surveillance test and steam generator injection and the impact of the difference in the power requirement on the governor speed control demand.

2.0 Summary of Results and Conclusion

A transient analysis of the TDEFW pump start was performed using a transient hydraulic model of the EFW system at V. C. Summer. The acceleration of flow after the TDEFW pump start was simulated for steam generator injection and for an STP. The power required by the pump from the turbine during the start transient to meet the hydraulic power requirement was calculated for the two cases. The results of the analysis are discussed in detail in Section 8.0. The key conclusions from the results are as follows:

- For steam generator injection, there is a time lag between the pump start and the start of flow to the steam generators. The lag is the time needed for the pump speed to increase enough to develop discharge pressure that is sufficient to overcome the steam generator pressure. This lag is not a reflection of the system hydraulic inertia.
- Once the pump has developed enough discharge pressure to overcome the steam generator pressure, there is negligible time lag between the pump reaching its rated speed and the flow reaching the steady state value for steam generator injection. The STP flow path has higher hydraulic inertia than the SG injection path. Still even for the STP case, there is negligible time lag for the flow to reach steady state. This result shows that the hydraulic inertia of the system is small regardless of the flow path. As a result, the start-up is a quasi-steady state event.
- The power required by the pump during the transient for the steam generator injection is lower than the power required during the STP only before the flow to the steam generator starts. After the flow starts, the power requirement for the steam generator injection case is significantly higher. The higher power requirement will cause slower speed acceleration of the pump for the SG injection case than is used in this analysis.
- During the start transient, the governor valve is initially open. The governor closes the valve as the pump speed increases to ensure an overspeed trip does not occur. Since the steam generator injection case has higher power demand, the governor valve will need to close less during the start-up. Thus, the steam generator injection case is less demanding on the governor than the STP case in which the valve must close farther to prevent an overspeed trip.

3.0 System Description

The TDEFW pump is normally aligned to take suction through piping that runs from the CST to the pump. The discharge piping splits into multiple flow paths. The major flow paths relevant to this analysis include the minimum flow return (mini flow) line, the line used to perform the STP, and the three lines that inject to the three steam generators through the main feed water piping. The motor-driven EFW (MDEFW) pumps also take suction from the CST and supply flow to the three steam generators through the same lines that are used by the TDEFW pump.

A simplified schematic of the piping is shown in Figure 3-1. The schematic does not show the MDEFW pumps and their connections because these were not explicitly modeled. However, the effect of the MDEFW operation on the flow and discharge pressure of the TDEFW pump was captured in the analysis.

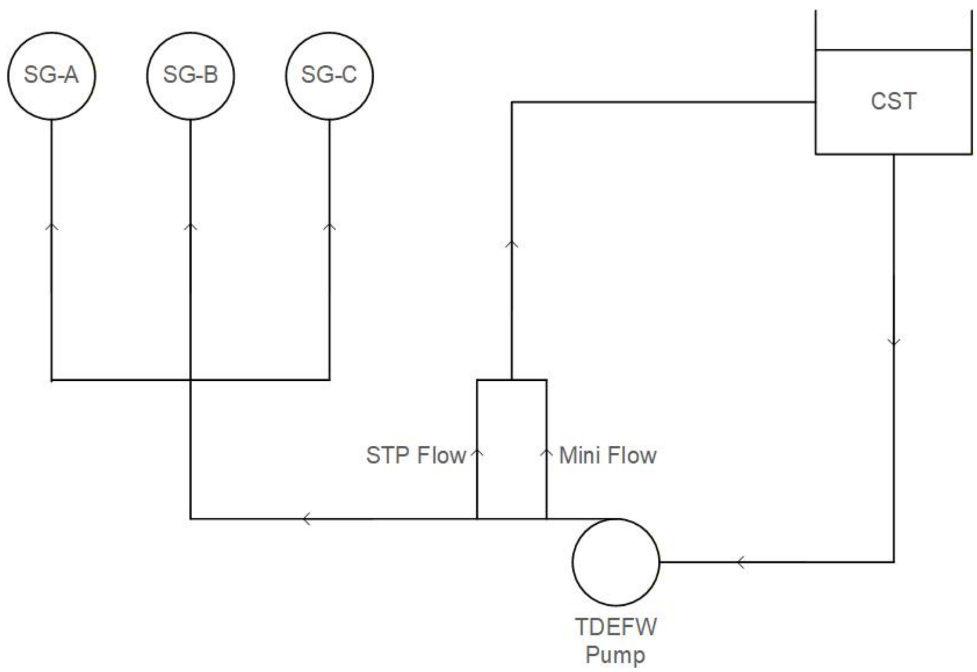


Figure 3-1. TDEFW Pump System Model - Simplified Schematic

Normally, the pump is aligned to the steam generators for injection in response to a design basis accident. The minimum flow line is open and the STP line is closed. Thus, during injection, the pump injects to the steam generators and the minimum flow line simultaneously. In most events, the MDEFW pumps will actuate before the TDEFW pump and inject into the same flow paths to the steam generators. The MDEFW pumps will reach steady state prior to the TDEFW pump start.

For an STP, the steam generators are isolated and the test line is opened. Thus, the TDEFW pump supplies flow to the test line and the minimum flow line.

The pump is powered by a Terry turbine that receives steam from the main steam system. The steam flow to the turbine is modulated using a governor valve which is controlled by the turbine speed governor. The governor controls the speed. It indirectly responds to the change in the pump power demand and steam supply conditions by modulating the lift of the governor valve.

4.0 Methodology

4.1. Overall Approach

A transient hydraulic model of the portion of the EFW system that is relevant to the TDEFW pump start was developed. The MDEFW pumps and their piping was not explicitly modeled, but the effect of these pumps running prior to the TDEFW pump start was captured. A transient analysis was performed to simulate a TDEFW pump start using a measured speed ramp of the pump as input (Reference 6). The speed ramp that was used was taken during the troubleshooting run immediately following the November 2025 surveillance test overspeed trip. The analysis was performed for two different alignments: with the pump aligned for injection to the steam generators and aligned for the STP. The transient pump flow and the required brake horsepower (BHP) were calculated from the analysis and compared to develop insights into the two items listed at the end of Section 1.2. Appendix A includes the detailed analysis for injection to the steam generators. Appendix B includes the detailed analysis for the STP.

The hydraulic model includes the following:

- The TDEFW pump is modeled using its head flow curve and BHP curve.
- The MDEFW pumps are not explicitly modeled, but their effect is indirectly captured. These pumps are expected to be running, and their flow is expected to be at steady state when the TDEFW pump starts. Since all pumps inject into the same lines to the steam generators, the operation of the MDEFW pumps increases the apparent flow resistance of the piping for the TDEFW pump and decreases its flow rate. The decreased flow rate was used to calculate the flow resistance of the piping as seen by the TDEFW pump to capture this effect.
- The TDEFW pump discharge piping and the lines to the steam generators A, B, and C are modeled using the piping flow resistance and the fluid inertia. All three lines are modeled and combined together as described in Section 3.0 and 4.2.2 depending on the analysis case.
- Appropriate boundary condition pressures are used at the steam generator and CST locations. The CST level is assumed to be the same for both analysis cases.

4.2. Equations

4.2.1. Pump TDH and Power

The pump Total Dynamic Head (TDH) at each instant in time is calculated by adjusting the pump head flow curve corresponding to the rated speed to the instantaneous speed using the pump affinity laws. The pump affinity laws state that the pump flow is linearly proportional to the speed and the pump head is proportional to the square of the speed. Therefore, the head flow curve corresponding to a given speed is determined at every time step of the simulation by:

$$H = H_{rated}\left(\frac{N_{current}}{N_{rated}}\right)^2$$

$$Q = Q_{rated}\left(\frac{N_{current}}{N_{rated}}\right)$$

where

H	is the head at the current instantaneous speed
Q	is the flow at the current instantaneous speed
H_{rated}	is the head at the rated speed
Q_{rated}	is the flow at the rated speed
$N_{current}$	is the current instantaneous speed
N_{rated}	is the rated speed corresponding to the head flow curve

The pump flow rate at each instant in time is known from the fluid dynamics calculations (see Section 4.2.2). The pump TDH is read at each time step from the new head flow curve based on the pump flow rate. The pump discharge pressure is calculated as the sum of the suction pressure and the TDH converted to pressure using the fluid density.

$$P_{discharge} = P_{suction} + (TDH)\rho g$$

where

$P_{discharge}$	is the pump discharge pressure
$P_{suction}$	is the pump suction pressure
TDH	is the pump total developed head
ρ	is the fluid density
g	is gravity

The hydraulic power required by the pump depends on the pump TDH, flow, and efficiency. The power is directly provided by the vendor at the rated speed as a function of flow. The affinity laws state that power is proportional to the cube of the speed. Similar to the head flow curve, the power curve is modified at every time step depending on the pump speed and the required power is calculated knowing the flow rate.

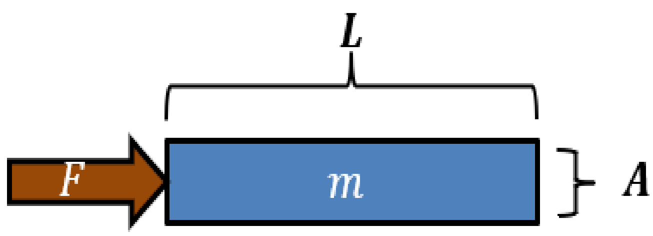
$$Pow = Pow_{rated}\left(\frac{N_{current}}{N_{rated}}\right)^3$$

where

Pow	is the power at the current speed
Pow_{rated}	is the power at the rated speed

4.2.2. Fluid Dynamics Model

The time rate of change of the flow in a given flow path depends primarily on the inertia of the fluid in the flow path. The momentum equation describes the flow behavior when an unbalanced force is applied on the fluid. The equation for fluids is derived below from the Newton's second law of motion.



4-1. Fluid Element Force

4-1 shows a segment of pipe with fluid inside. The force applied on the fluid is given by

$$F = ma$$

where

F is the force applied on the fluid
m is the mass of the fluid
a is the fluid acceleration

The equation can be written in term of the fluid pressure (P) and pipe flow area (A) as:

$$PA = \rho AL \frac{dv}{dt}$$

The force on the left-hand side is expressed as pressure times the area on which the force is applied. The mass on the right-hand side is expressed as density (ρ) times the length of the fluid segment (L) times the pipe flow area. The acceleration on the right-hand side is expressed as the time derivative of velocity (v).

The equation can be further modified as:

$$PA = \rho AL \frac{d}{dt}\left(\frac{w}{\rho A}\right)$$

In the above equation, the velocity is expressed as the mass flow rate (w) divided by the flow area and the density. The area is constant, and the density does not change with time for an incompressible fluid. Hence, they can be taken out of the derivative and cancelled. Thus,

$$\frac{L}{A}\frac{dw}{dt} = P \qquad \text{Equation 1}$$

The dw/dt is the time rate of change of flow, and the L/A is the inertial length of fluid which represents the resistance of the fluid to acceleration. The inertial length is generalized by the following equation for a flow path whose area is a variable, but smooth function of its length:

$$L_{iner} = \int_0^L \frac{dx}{A(x)}$$

For a pipe with discrete changes in areas through reducers or expanders that are short in length, the inertial length can be approximated as the summation.

$$L_{iner} = \sum_{i=1}^{N} \frac{L_i}{A_i}$$

where

N is the number of sections in the pipe with different areas.

The inertial lengths of multiple parallel flow paths can be combined to calculate an equivalent inertial length using the following equation. This equation was used to combine the inertial lengths of the three steam generator paths and the inertial lengths of the STP and mini flow line paths (Figure 3-1).

$$L_{iner.eq} = \frac{1}{\sum_{i=1}^{N} \frac{1}{L_{iner.i}}}$$

The pressure term on the right-hand side of Equation 1 is the source term that is the sum of all forces acting on the fluid element per unit area: pressure force, elevation head force, and friction force. Therefore, the momentum equation for the injection to the steam generators can be written as:

$$\frac{dw_{sg}}{dt} = \frac{1}{L_{iner.sg}}\left(P_{disch} - P_{sg} + \left(\Delta H_{sg}\rho g\right) - \frac{R_{sg} w_{sg}\left|w_{sg}\right|}{2\rho}\right)$$

where

w_{sg} is the flow to the steam generators
$L_{iner.sg}$ is the inertial length of the SG flow path
P_{disch} is the pump discharge pressure
P_{sg} is the steam generator pressure
ΔH_{sg} is the elevation head between the pump and the steam generator
ρ is the fluid density
g is the gravity acceleration
R_{sg} is the flow resistance of the steam generator flow path

Similarly, the momentum equation for the STP is given by:

$$\frac{dw_{stp}}{dt} = \frac{1}{L_{iner.stp}}\left(P_{disch} - P_{cst} + (\Delta H_{cst}\rho g) - \frac{R_{stp}w_{stp}|w_{stp}|}{2\rho}\right)$$

where

w_{stp} is the combined flow back to the CST through the test line and the mini flow line
$L_{iner.stp}$ is the inertial length of the combined flow path thru the test line and the mini flow line
P_{cst} is the CST pressure
ΔH_{cst} is the elevation head between the pump and the CST
R_{stp} is the flow resistance of the combined flow path thru the test line and the mini flow line

The momentum equation for the mini flow line path is given by:

$$\frac{dw_{min}}{dt} = \frac{1}{L_{iner.min}}\left(P_{disch} - P_{cst} + (\Delta H_{cst}\rho g) - \frac{R_{min}w_{,min}|w_{min}|}{2\rho}\right)$$

where

w_{min} is the flow back to the CST through the mini flow line
$L_{iner.min}$ is the inertial length of the flow path through the mini flow line
P_{cst} is the CST pressure
ΔH_{cst} is the elevation head between the pump and the CST
Rmin is the flow resistance of the flow path through the mini flow line

Note that the last term in the momentum equation includes the multiplication of flow (w) by its absolute value (|w|), rather than using flow squared. This approach ensures that the friction force is always in a direction opposite to flow.

After calculating the time rate of change of flow for each equation, the flow at the next time step is calculated as follows using a forward difference:

$$w_{i+1} = w_i + \frac{dw}{dt}\Delta t$$

For the SG injection case, the momentum equations for the SG flow path and the mini flow line flow path are solved. The total flow from the two equations is fed back to the pump equations to calculate the new pump discharge pressure at the next time step.

For the STP, the momentum equations for the SG flow path and the STP flow path are solved. However, the SG pressure in the SG momentum equation is increased to a value above the discharge pressure capability of the pump. This prevents the pump from injecting flow to the SG. The calculated flow from the STP momentum equation is fed back to the pump equations to calculate the new pump discharge pressure at the next time step.

5.0 Assumptions and Limitations

5.1. Assumptions with a Basis

1. The inertial length of the pump suction piping from the CST is small relative to the inertial lengths of the discharge piping based on the calculation in Appendix C. Therefore, inertial effects in the suction piping are minimal, and a separate momentum equation for the suction flow is not included in the analysis. This simplification has little impact on the results and conclusions.
2. The pump speed ramp used in the analysis (Reference 6) for both cases is a measured speed ramp when in the STP alignment. The speed ramp is appropriate for the STP case. The speed ramp will be slightly different when aligned for injection to the steam generators because the hydraulic power needed by the pump will be higher. This would cause the pump to increase speed at a slower rate. The purpose of this analysis is to determine if the fluid inertia causes the flow rate to lag behind the steady state flow rate for a given pump speed. The lag, if any, will be less for a slower speed ramp. Therefore, the use of the STP speed ramp for the SG injection case is acceptable and conservative.
3. A water density of 62.3 lb/ft^3 is used in the analysis. The actual density may vary slightly depending on the water temperature. The small variation will have no impact on the analysis results.
4. The steam generator pressure used in the analysis is taken from maximum pressure during the TDEFW pump startup in the main steam line (PT-495) from the February 2025 plant trip data.
5. Reference 3 states that the estimated flow through the minimum flow line for a configuration that closely matches the February 2025 steam generator injection event configuration is 108 gpm based on a Dominion calculation (Reference 1). A value of 100 gpm was used in this analysis for the flow rate through the minimum flow line during an STP injection event as a representative value.

5.2. Assumptions without a Basis

There are no assumptions without a basis for this calculation.

6.0 Design Inputs

The design inputs used in the analysis are listed in Table 6-1.

Table 6-1. Design Inputs and Sources

No.	Design Input	Value	Reference
1	Water density	62.3 lb/ft^3	Assumption 5.1.3
2	Pump suction pressure	23.8 psi	1
3	Pump TDH when injecting to the SGs	3900 ft	See Note a
4	Steam generator pressure	1080 psig	2 (also see Assumption 4)
5	TDEFW pump elevation	419.2 ft	1
6	Steam generator injection elevation	477.26 ft	1
7	Steady state TDEFW pump flow to the steam generators when the MDEFW pumps are also injecting flow to the steam generators	530 gpm	2
8	CST pressure at the point of return	14.7 psia	1
9	Minimum flow line flow when injecting to the steam generators	100 gpm	3 (also see Assumption 5)
10	Elevation of the return point to the CST	450.3 ft	1
11	Total pump flow during STP	300 gpm	4
12	Pump TDH during STP	4030 ft	See Note b
13	Pump rated speed	4600 rpm	5
14	Pump head flow curve	See Figure 6-1	5
15	Pump BHP Curve	See Figure 6-2	5
16	Pump speed ramp	See Figure 6-3	6 and Note c
17	Inertial length of the path to the steam generators	1326 ft^{-1}	Calculated in Appendix C based on information in Reference 7
18	Inertial length of the mini flow line path to the CST	5011 ft^{-1}	
19	Inertial length of the STP and mini flow lines to the CST	4673 ft^{-1}	

Table 6-1. Design Inputs and Sources

No.	Design Input	Value	Reference

Notes:

a) The pump TDH value was read from the head flow curve for the total flow for SG injection at 4600 rpm speed.

b) The pump TDH value was read from the head flow curve for the total flow for STP at 4600 rpm speed.

c) The speed curve was generated by observing a video of the TDEFW pump tachometer taken by Dominion during the initial troubleshooting run after the pump overspeed trip occurred during the November 2025 STP. This run is used because it is expected to be the most representative of the condition of the TDEFW pump during the November 2025 STP (for which speed data is not available).

d) The 4600 rpm speed and the corresponding pump TDH were used to estimate the flow resistances of the flow paths for the SG injection and STP. The actual speed during injection and STP is 4500 rpm. The use of 4600 rpm tends to overpredict the flow resistances. The analysis slightly underpredicts the calculated flow rates due to the use of 4600 rpm speed instead of 4500 rpm. This has no impact on the conclusions with regards to the effect of inertia and the power requirement during injection and STP.

The pump head flow curve is shown in Figure 6-1. The figure included different curves for different speeds. The curve corresponding to 4600 rpm is used as the rated speed curve.

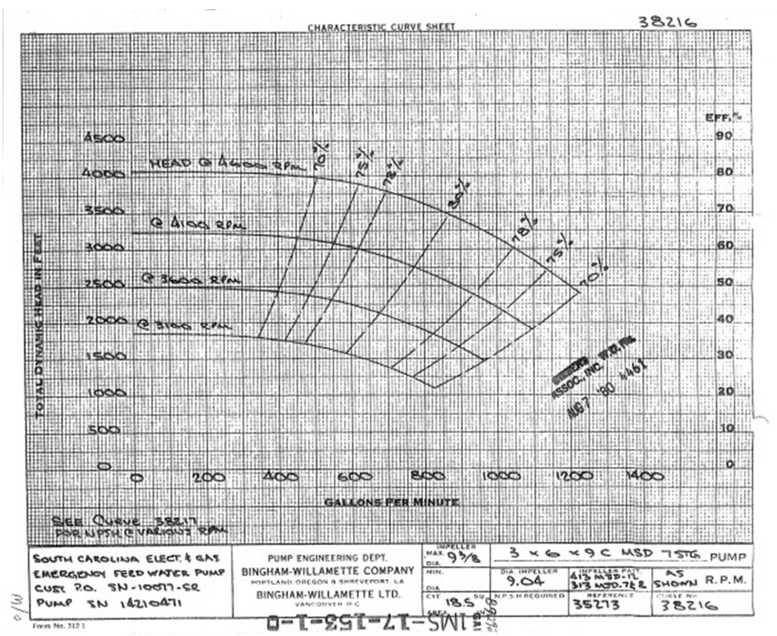


Figure 6-1. Pump Head Flow Curve

The pump BHP curve is shown in Figure 6-2. This curve corresponds to 4600 rpm pump speed.

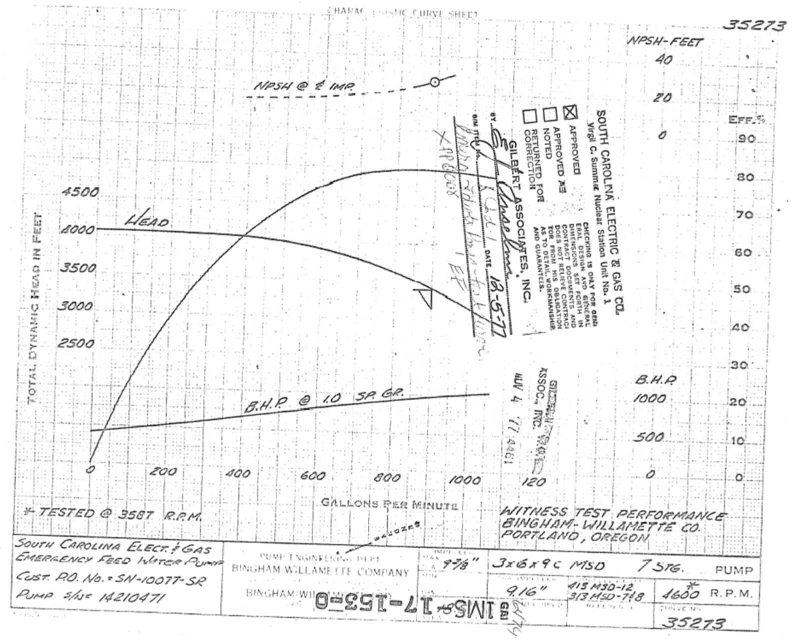


Figure 6-2. Pump BHP Curve

The speed curve is shown in Figure 6-3.

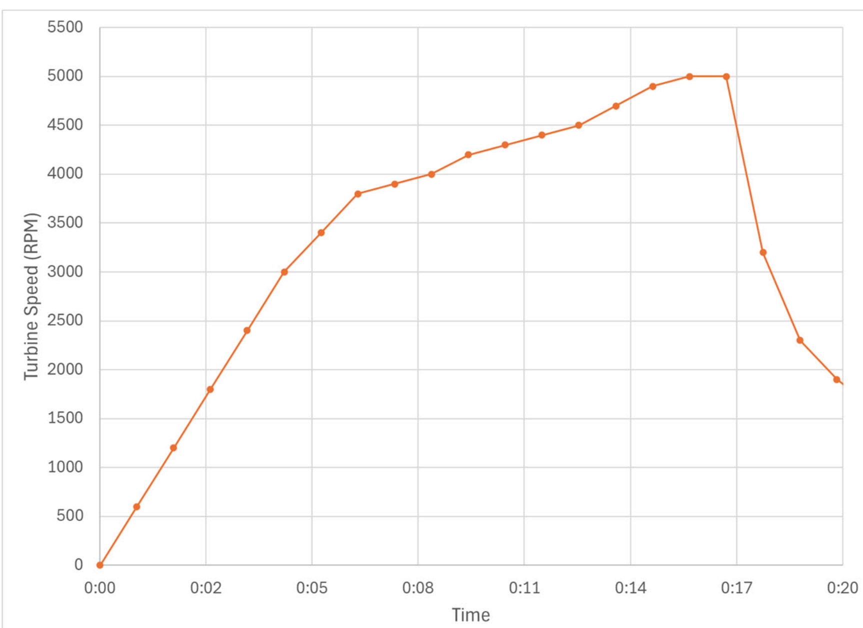


Figure 6-3. Speed Ramp Curve

7.0 Computer Codes

The analysis was performed using a computer program that was run using the Mathcad 15 software on MPR Computer 4495, running Windows 11 Pro operating system. The program is provided in Appendices A and B and in Reference 8. The program falls under the MPR Standard QA Manual (Reference 9) definition of Working Level Software. The analysis program was verified using a line-by-line review of the program functions. The validation of the analysis methodology was performed based on a review of the governing equations, their implementation, sensitivity studies, and reasonableness of the results.

The intent of the analysis is to confirm that a simple steady state approach used in MPR report 0310-0085-RPT-001 Revision 0 (Reference 10) to evaluate the ability of EFW pump to perform its function during a past degraded condition is appropriate. The analysis does not generate specific outputs that are needed to make any design or operating procedure changes in the plant. Therefore, additional validation of the analysis method is not considered necessary.

The input and output are fully contained in the Mathcad files including the plots provided in this calculation. The analysis files are listed in Table 7-1.

Table 7-1. Listing of Computer Files for an Analysis with a Single Run

Case Identifier	File Name	Input/Output	Description
Case 1	Transient Overall Rev e Inject	Both	Analysis of Injection to the steam generators
Case 2	Transient Overall Rev e STP	Both	Analysis of STP

8.0 Calculations and Results

8.1. SG Injection

Figure 8-1 shows the pump speed as function of time, which is an input to the analysis. Figure 8-2 shows the pump discharge pressure. The pressure increases over time as the speed increases, and it follows the speed closely.

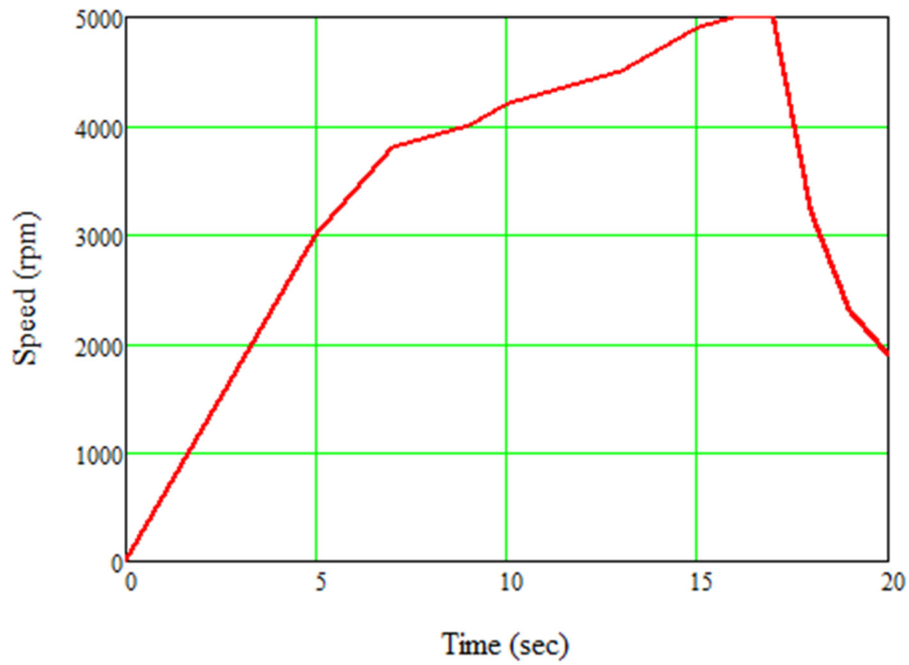


Figure 8-1. Speed Ramp Curve (SG Injection)

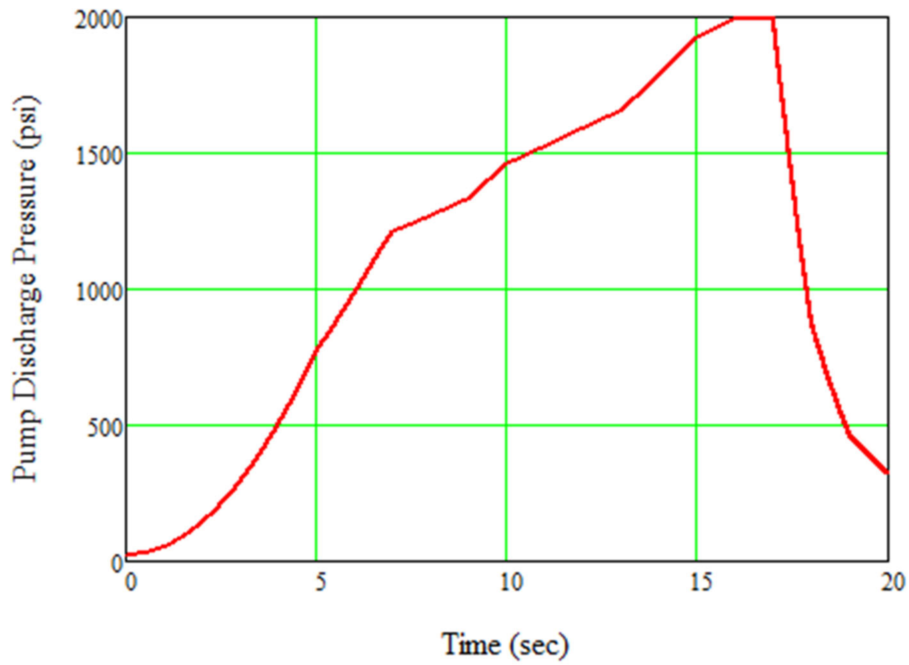


Figure 8-2. Pump Discharge Pressure (SG Injection)

Figure 8-3 shows the combined flow to the three SGs and the flow to the CST through the mini flow line. The mini flow line flow starts within 1 second after the pump start. This time delay is the time needed for the pump to overcome the elevation head of the CST. The start of the flow to the SGs is delayed because it takes longer for the pump to overcome the SG elevation head and backpressure. Once the elevation head and backpressure are exceeded (at about 3600 rpm speed), the flow to the SGs increases rapidly due to the low hydraulic resistance of the flow path. The flow follows the speed curve closely and reaches a plateau at the same time the speed reaches its plateau of 5000 rpm (Figure 8-1). This shows that the hydraulic inertia of the flow has little impact on the transient and the pump start is a quasi-steady state event.

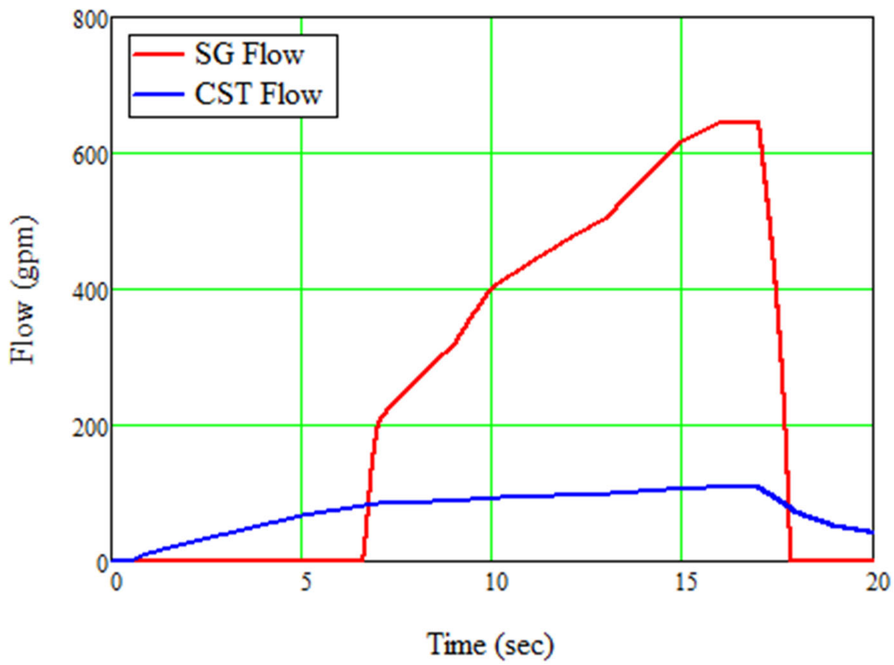


Figure 8-3. Flow Rates (SG Injection)

8.2. STP

The pump speed plot shown in Figure 8-1 is the same between the injection and STP cases. The pump discharge pressure for the STP case is shown in Figure 8-4. The peak pressure reached is higher than that in the SG injection case because the STP flow path is more restrictive than the SG injection flow path.

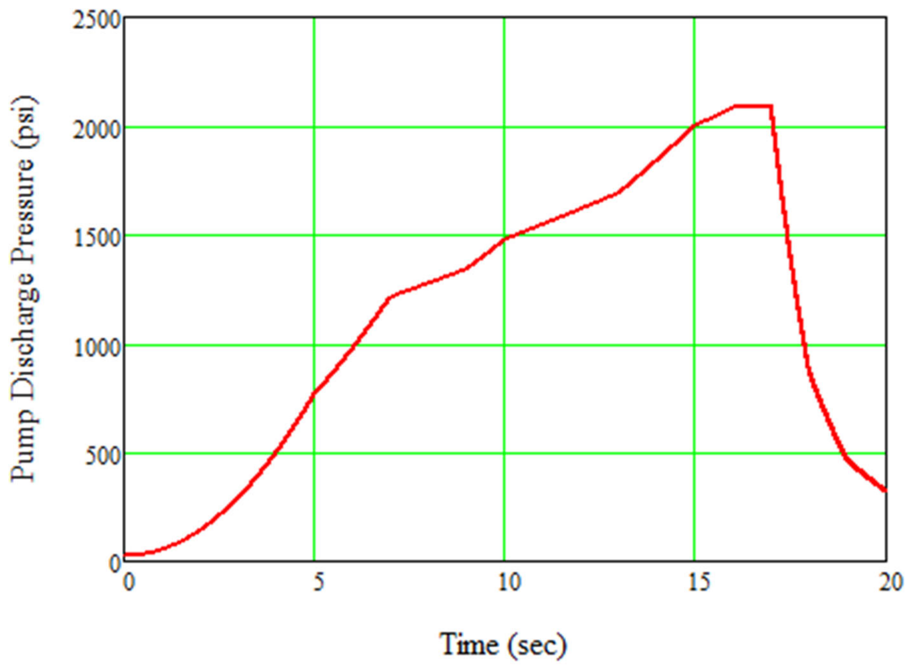


Figure 8-4. Pump Discharge Pressure (STP)

Figure 8-5 shows the flow to the CST and the flow to the SGs. The flow to the SGs is zero since the SGs are isolated during the STP. The total flow to the CST through the test line and the mini flow line is lower than the total flow to the SGs and the flow through the mini flow line for the SG injection case.

Similar to the SG injection case, the flow reaches a plateau at the same time the speed reaches the 5000 rpm plateau. Since there is no time lag, it shows that the inertia of the STP path, although higher than the inertia of the SG path, is relatively small.

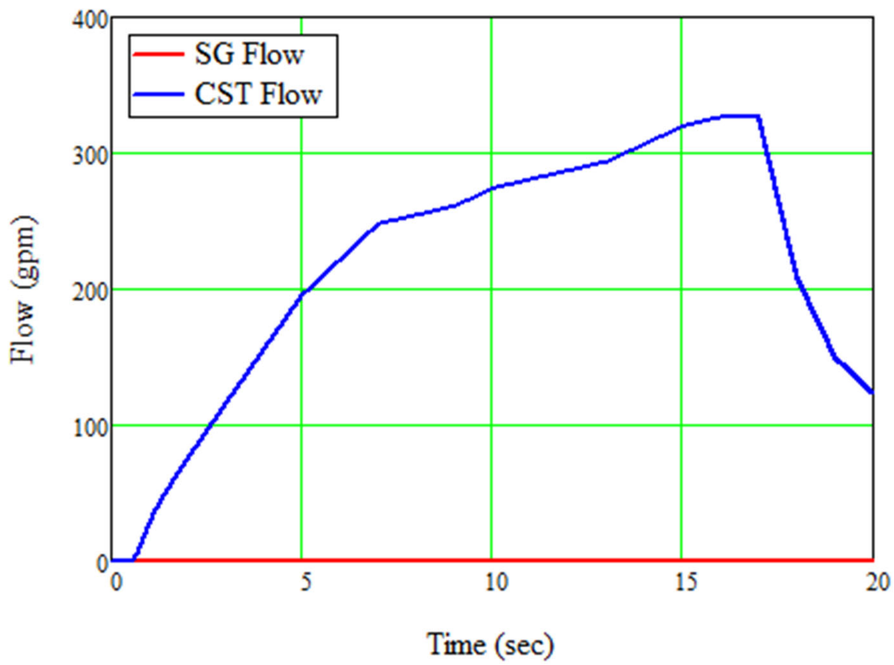


Figure 8-5. Flow Rates (STP)

8.3. Results Comparison

Figure 8-6 shows the SG injection and STP flow rates superimposed along with the speed curve. Both flows closely follow the speed curve and reach the plateau at the same time the speed reaches 5000 rpm.

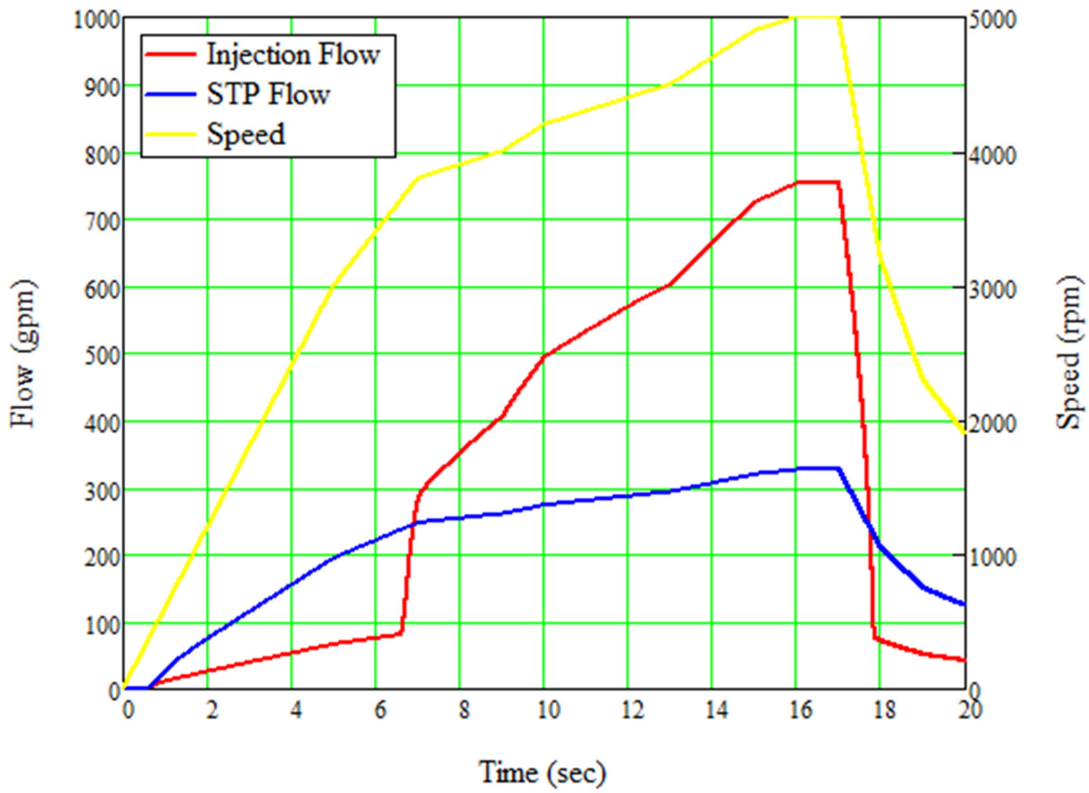


Figure 8-6. Flow Rate Comparison

Figure 8-7 shows a comparison of the pump required power during the start transient. The required BHP initially is lower for the SG injection case because the only flow is through the mini flow line, which is less than the STP flow as shown in Figure 8-6 for about 7 seconds. After 7 seconds, the SG flow starts and as a result, the pump power requirement increases to values higher than the STP. At high speeds close to or above the normal running speed, the SG injection flow needs significantly more power.

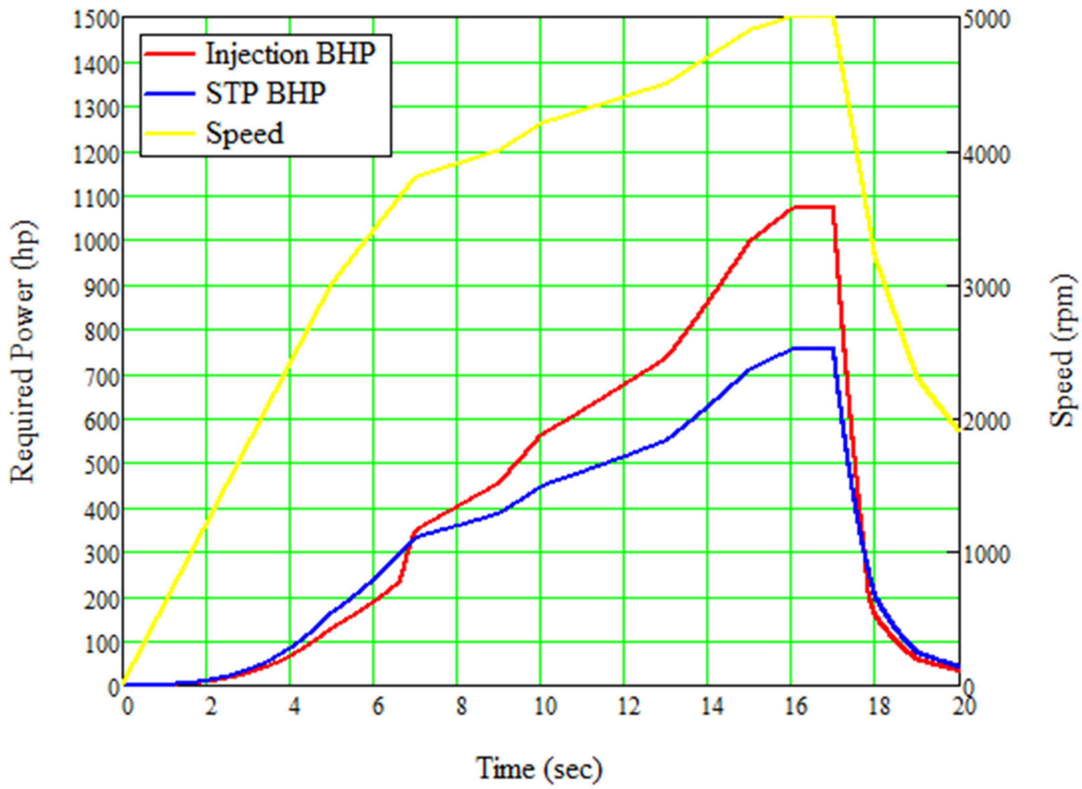


Figure 8-7. Required Power during Start-up

The speed curve used as input in the analysis cases applies to the STP case since it was measured during an STP. The higher power requirement for an SG injection case would increase the power demand on the turbine. More steam flow would be needed to meet the power demand. As a result, the speed ramp for the injection case would be slower.

9.0 References

1. V.C. Summer Nuclear Station, Calculation No. DC05220-091, “EF Hydraulic Analyses,” Revision 4.
2. V.C. Summer Nuclear Station, “EF Full Flow Data,” November 2025, shared by Dominion via OneDrive.
3. Email from Daniel Busbee (VCS) to Erin Tindall (MPR) Tue 1/6/2026 4:41 PM with the subject “TD Bypass Flow.”
4. V.C. Summer Nuclear Station, Work Order No. STP0220.002-XPP0008 (2025-06-09; WO 88201751909), Revision 9.
5. Head Flow Curve for TDEFW Pump, “South Carolina Elect. & Gas Emergency Feedwater Pump Cust P.O. SN-10077-SR Pump SN 14210471.”
6. V.C. Summer Nuclear Station, “Tachometer-Oil-Trip & Throttle_1m45s.mov,” November 12, 2025, shared by Dominion via OneDrive.
7. ProtoFlo Pipe Section Summary Report Attached to Email from Daniel Busbee (Dominion) to Erin Tindall (MPR) Dated 03/09/2026, 10:39 am, “RE: TDEFW Pump - Additional Information Request.”
8. MPR Electronic Record 0310-0085-ELEC-01, Revision 0, “Electronic File for EFW Pump Start Transient Analysis.”
9. MPR Standard Quality Assurance Manual, Revision 8 dated March 3, 2025.
10. MPR Report No. 0310-0085-RPT-001, Revision 0, “Evaluation of Turbine Driven Emergency Feedwater Pump November 2025 Surveillance.”

A SG Injection Case Analysis

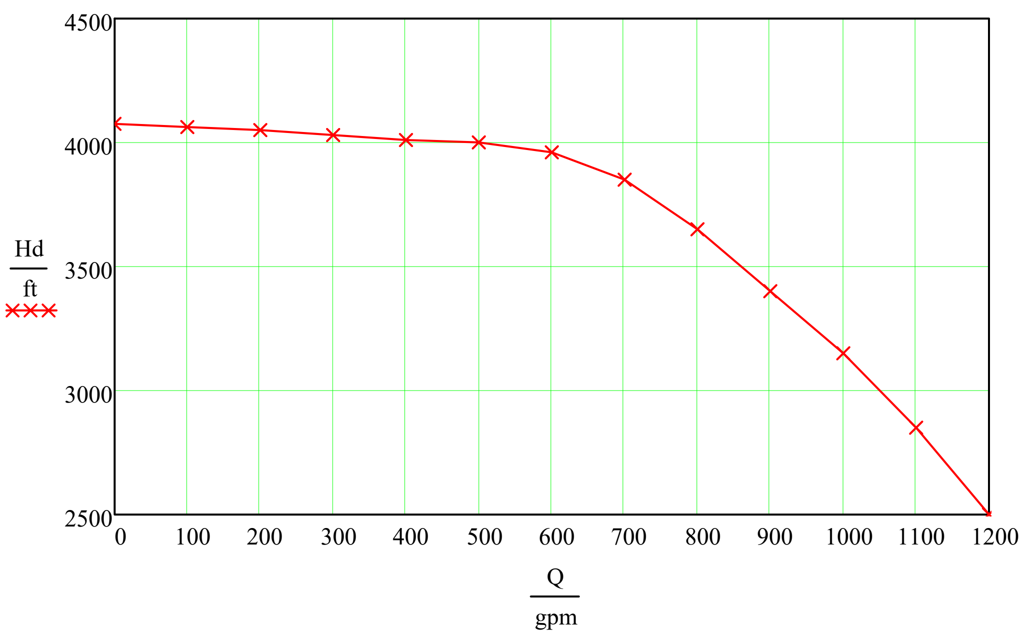
$N_{step} := 20000$	Number of time steps
$\Delta t := 0.001 \cdot sec$	Time step size
$\rho := 62.3 \cdot \frac{lb}{ft^3}$	Water density
$P_{suction} := 23.8 \cdot psi$	Pump suction pressure
$H_{inj} := 3900 \cdot ft$	Pump head when injecting to SGs at steady state
$P_{disch} := P_{suction} + H_{inj} \cdot \rho \cdot g = 1.711 \times 10^3 \cdot psi$	Discharge pressure of the pump when injecting to the SGs
$P_{sg} := (1080 + 14.7) \cdot psi = 1.095 \times 10^3 \cdot psi$	Steam generator pressure
$\Delta H_{sg} := (419.2 - 477.26) \cdot ft = -58.06\ ft$	Elevation head between the pump and the SGs
$Q_{sg} := 530 \cdot gpm$	Steady state flow to the SGs
$R_{sg} := \frac{2 \cdot \left(P_{disch} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g\right)}{\rho \cdot Q_{sg}^2} = 6.307 \times 10^4 \frac{1}{ft^4}$	Resistance of the flow path to the SGs
$P_{cst} := 14.7 \cdot psi$	Pressure of the return location in the CST
$\Delta H_{cst} := (414 - 450.3) \cdot ft$	Elevation head between the pump and the return point to the CST
$Q_{cst.mini} := 100 \cdot gpm$	Flow through the mini flow line during injection to the SGs
$Q_{cst.stp} := 300 \cdot gpm$	Flow during the STP
$H_{stp} := 4030 \cdot ft$	Pump TDH during STP at 300 gpm flow
$N_{rate} := 4600$	Rated speed

Speed ramp data (This is the speed ramp from Run 2)

$$t := \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \end{pmatrix} \cdot \mathrm{sec} \qquad Spd := \begin{pmatrix} 0 \\ 600 \\ 1200 \\ 1800 \\ 2400 \\ 3000 \\ 3400 \\ 3800 \\ 3900 \\ 4000 \\ 4200 \\ 4300 \\ 4400 \\ 4500 \\ 4700 \\ 4900 \\ 5000 \\ 5000 \\ 3200 \\ 2300 \\ 1900 \end{pmatrix} \div N_{rate}$$

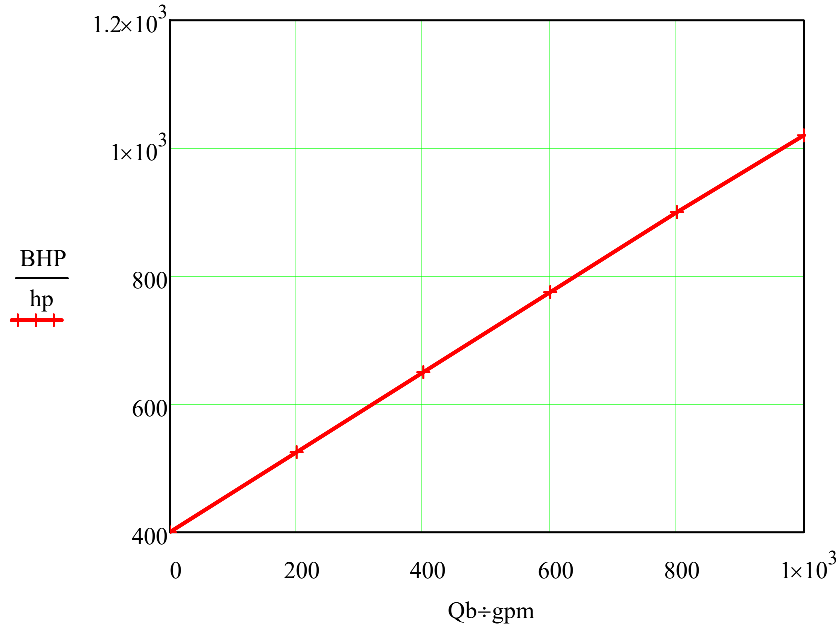
Head flow curve

$$Q := \begin{pmatrix} 0 \\ 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \\ 700 \\ 800 \\ 900 \\ 1000 \\ 1100 \\ 1200 \end{pmatrix} \cdot gpm \qquad Hd := \begin{pmatrix} 4075 \\ 4062 \\ 4050 \\ 4030 \\ 4010 \\ 4000 \\ 3960 \\ 3850 \\ 3650 \\ 3400 \\ 3150 \\ 2850 \\ 2500 \end{pmatrix} \cdot ft$$



BHP Curve

$$Qb := \begin{pmatrix} 0 \\ 200 \\ 400 \\ 600 \\ 800 \\ 1000 \end{pmatrix} \cdot gpm \qquad BHP := \begin{pmatrix} 400 \\ 525 \\ 650 \\ 775 \\ 900 \\ 1020 \end{pmatrix} \cdot hp$$



Linear interpolation function for speed

$$Speed(x) := linterp(t, Spd, x)$$

Function for determination of pump head as a function of volumetric flow (q) and speed ratio (nr)

$$Hx(n_r, q) := \left| \begin{array}{l} \text{for } i \in 1 .. rows(Q) \\ \quad \left| \begin{array}{l} Qx_i \leftarrow n_r \cdot Q_i \\ Hx_i \leftarrow n_r^2 \cdot Hd_i \end{array} \right. \\ H \leftarrow 0 \ \text{ if } n_r = 0 \\ H \leftarrow 0 \ \text{ if } H < 0 \\ H \leftarrow linterp(Qx, Hx, q) \ \text{ otherwise} \end{array} \right.$$

Function for determination of pump required BHP as a function of volumetric flow (q) and speed ratio (nr)

$$\mathrm{Power}(n_r, q) := \begin{array}{|l} \text{for } i \in 1 .. \mathrm{rows}(Qb) \\ \quad \begin{array}{|l} Qx_i \leftarrow n_r \cdot Qb_i \\ PowerX_i \leftarrow n_r^{3} \cdot BHP_i \end{array} \\ Pow \leftarrow 0 \text{ if } n_r = 0 \\ Pow \leftarrow 0 \text{ if } Pow < 0 \\ Pow \leftarrow \mathrm{linterp}(Qx, PowerX, q) \text{ otherwise} \end{array}$$

$L_{iner.sg} := 1326 \cdot ft^{-1}$ Inertial length of SG path

$L_{iner.cst} := 5011 \cdot ft^{-1}$ Inertial length of the mini flow path back to the CST

$L_{iner.stp} := 4673 \cdot ft^{-1}$ Inertial length of the test and mini flow path back to the CST

Calculate the resistance of the line to the CST based on flow and the pump head

$$\mathrm{Res}_{cst}(Hd, Q) := \begin{array}{|l} P \leftarrow P_{suction} + Hd \cdot \rho \cdot g \\ R \leftarrow \dfrac{2 \cdot \left(P - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g\right)}{\rho \cdot Q^2} \\ R \end{array}$$

$$\mathrm{Res}_{cst}(4030 \cdot ft, 300 \cdot gpm) = 5.783 \times 10^{5} \frac{1}{ft^4}$$

Determine the SG pressure, CST path inertial length and the CST path resistance depending on if it is injection or STP.

$$\text{Setup}(x) := \begin{array}{|l} \text{if } x = \text{"Inj"} \\ \quad \begin{array}{|l} P \leftarrow P_{sg} \\ L_{in} \leftarrow L_{iner.cst} \\ R \leftarrow Res_{cst}\left(H_{inj}, Q_{cst.mini}\right) \end{array} \\ \text{if } x = \text{"STP"} \\ \quad \begin{array}{|l} P \leftarrow 10000 \cdot psi \\ L_{in} \leftarrow L_{iner.stp} \\ R \leftarrow Res_{cst}\left(H_{stp}, Q_{cst.stp}\right) \end{array} \\ \text{augment}\left(\dfrac{P}{psi}, \dfrac{L_{in}}{ft^{-1}}, \dfrac{R}{ft^{-4}}\right) \end{array}$$

The SG pressure is made 10000 psi for the STP case to prevent any flow.

$$\text{Setup}(\text{"Inj"}) = \left(1.095 \times 10^{3} \quad 5.011 \times 10^{3} \quad 5.036 \times 10^{6}\right)$$

$$\text{Setup}(\text{"STP"}) = \left(1 \times 10^{4} \quad 4.673 \times 10^{3} \quad 5.783 \times 10^{5}\right)$$

Main solver

$$X(str) := \text{for } i \in ORIGIN..N_{step}$$

$$\quad \text{if } i = ORIGIN$$

$$\quad\quad t_i \leftarrow 0$$

$$\quad\quad N_{s_i} \leftarrow Speed(t_i)$$

$$\quad\quad w_{sg_i} \leftarrow 0$$

$$\quad\quad Q_{sg_i} \leftarrow 0$$

$$\quad\quad w_{cst_i} \leftarrow 0$$

$$\quad\quad Q_{cst_i} \leftarrow 0$$

$$\quad\quad Hd_i \leftarrow Hx\left(N_{s_i}, Q_{sg_i} + Q_{cst_i}\right)$$

$$\quad\quad P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g$$

$$\quad\quad Pow_i \leftarrow Power\left(N_{s_i}, Q_{sg_i} + Q_{cst_i}\right)$$

$$\quad \text{otherwise}$$

$$\quad\quad t_i \leftarrow t_{i-1} + \Delta t$$

$$\quad\quad N_{s_i} \leftarrow Speed(t_i)$$

$$\quad\quad Hd_i \leftarrow Hx\left(N_{s_i}, Q_{sg_{i-1}} + Q_{cst_{i-1}}\right)$$

$$\quad\quad P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g$$

$$\quad\quad Mx \leftarrow Setup(str)$$

$$\quad\quad P_{sg} \leftarrow Mx_{1,1} \cdot psi$$

$$\quad\quad L_{iner.cst} \leftarrow Mx_{1,2} \cdot ft^{-1}$$

$$\quad\quad R_{cst} \leftarrow Mx_{1,3} \cdot ft^{-4}$$

$$\quad\quad wdot_{sg} \leftarrow \frac{1}{L_{iner.sg}} \cdot \left(P_{disch_i} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g - \frac{R_{sg} \cdot w_{sg_{i-1}} \cdot \left|w_{sg_{i-1}}\right|}{2 \cdot \rho}\right)$$

$$\quad\quad wdot_{cst} \leftarrow \frac{1}{L_{iner.cst}} \cdot \left(P_{disch_i} - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g - \frac{R_{cst} \cdot w_{cst_{i-1}} \cdot \left|w_{cst_{i-1}}\right|}{2 \cdot \rho}\right)$$

$$\quad\quad ""$$

$$w_{sg_i} \leftarrow w_{sg_{i-1}} + wdot_{sg} \cdot \Delta t$$

$$w_{sg_i} \leftarrow 0 \quad \text{if} \quad w_{sg_i} < 0$$

$$w_{cst_i} \leftarrow w_{cst_{i-1}} + wdot_{cst} \cdot \Delta t$$

$$w_{cst_i} \leftarrow 0 \quad \text{if} \quad w_{cst_i} < 0$$

$$Q_{sg_i} \leftarrow w_{sg_i} \div \rho$$

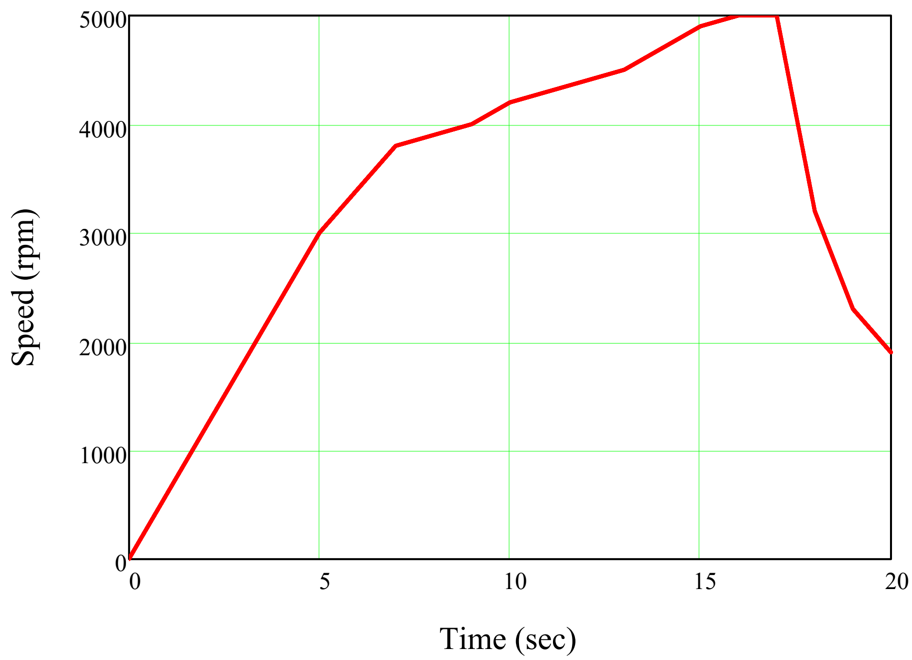
$$Q_{cst_i} \leftarrow w_{cst_i} \div \rho$$

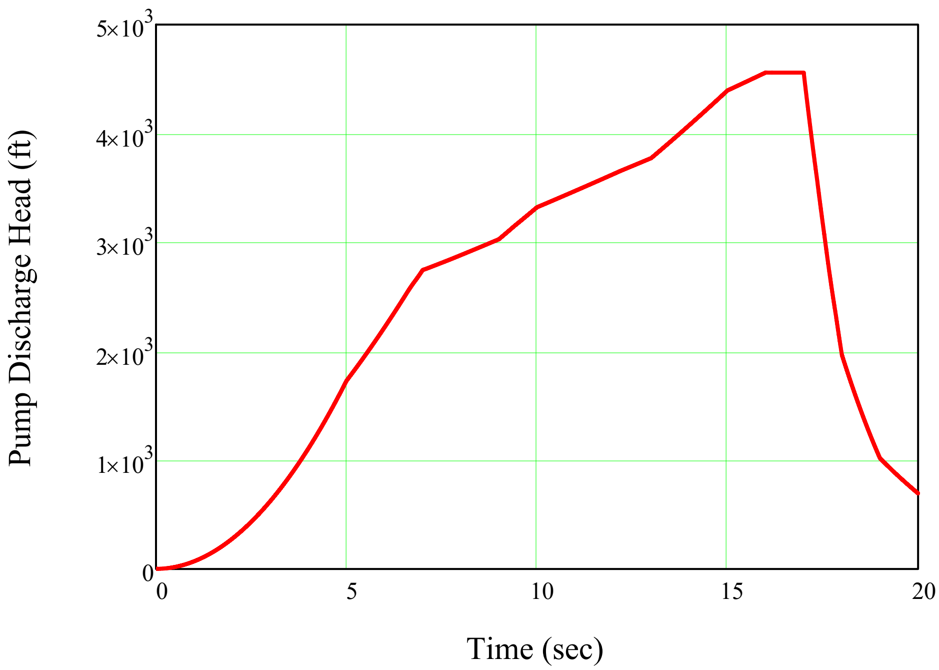
$$Pow_i \leftarrow Power\left(N_{s_i}, Q_{sg_i} + Q_{cst_i}\right)$$

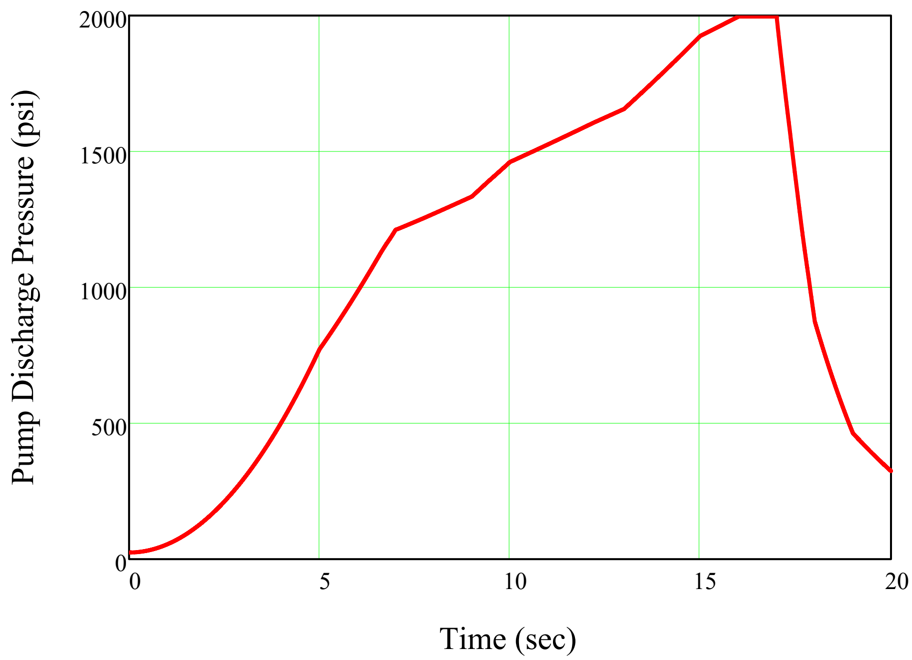
$$\text{augment}\left(\frac{t}{sec}, N_s, \frac{Hd}{ft}, \frac{P_{disch}}{psi}, \frac{Q_{sg}}{gpm}, \frac{Q_{cst}}{gpm}, \frac{Pow}{hp}\right)$$

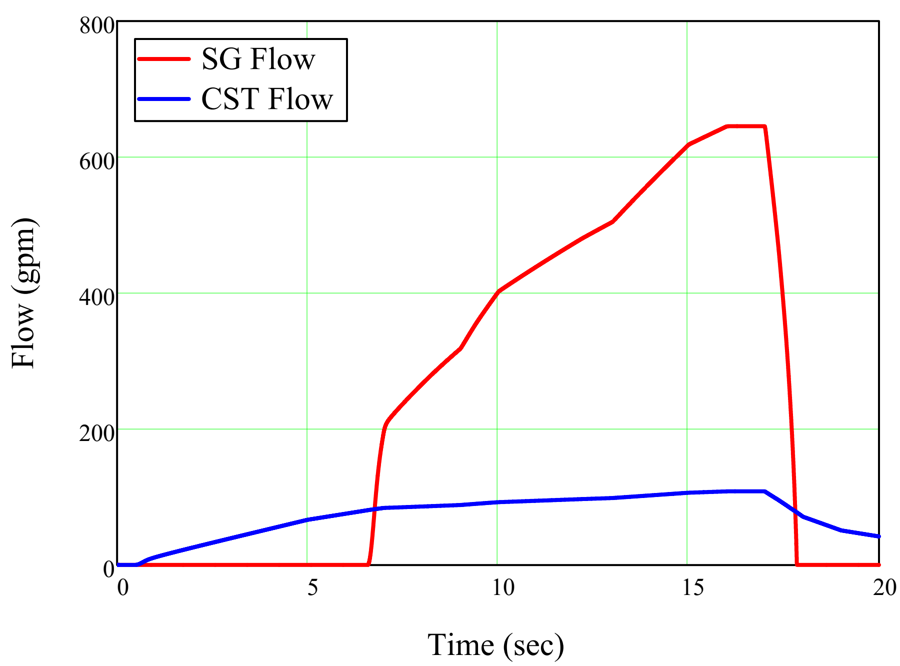
$Y := X("Inj")$

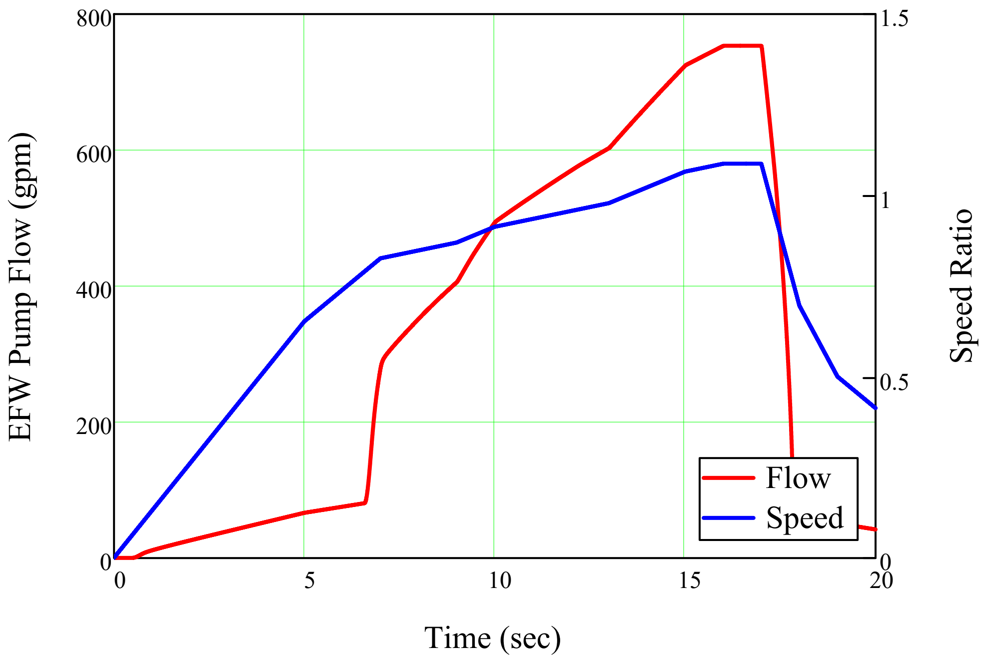
Change the Inj to STP to see the graphs for the STP





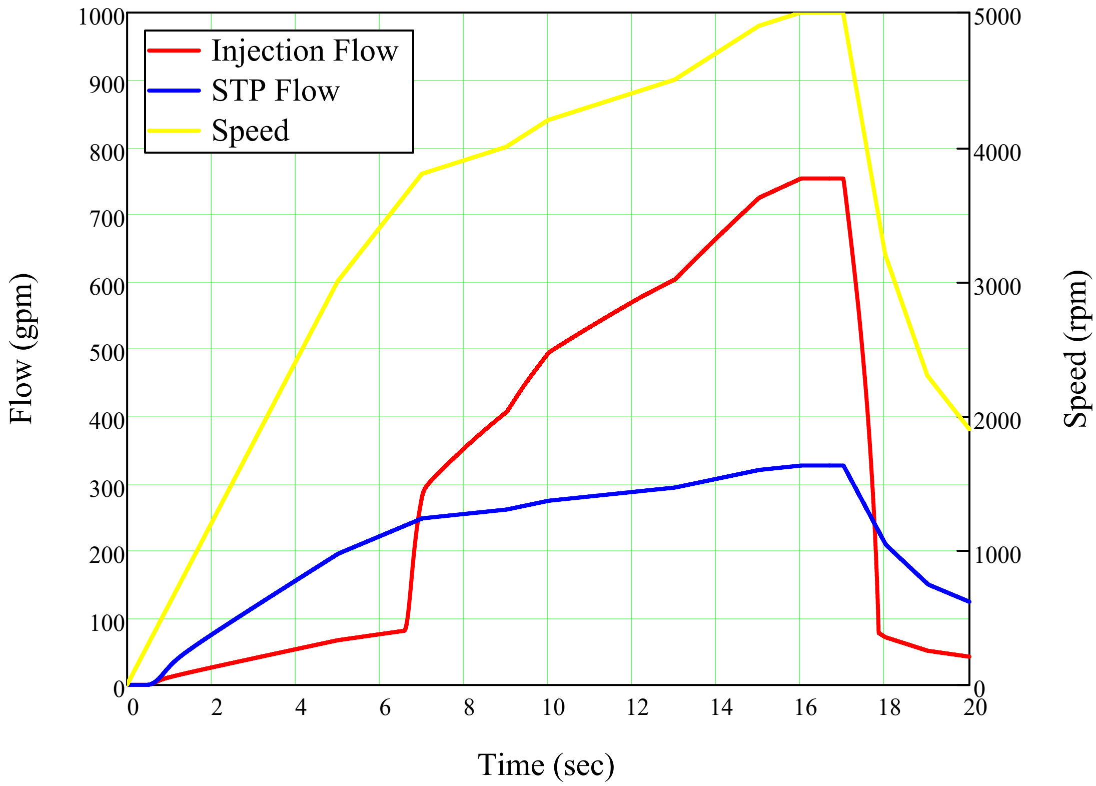

2000
1500
1000
500
0
Pump Discharge Pressure (psi)
0
5
10
15
20
Time (sec)


800
600
400
200
0
Flow (gpm)
SG Flow
CST Flow
0
5
10
15
20
Time (sec)

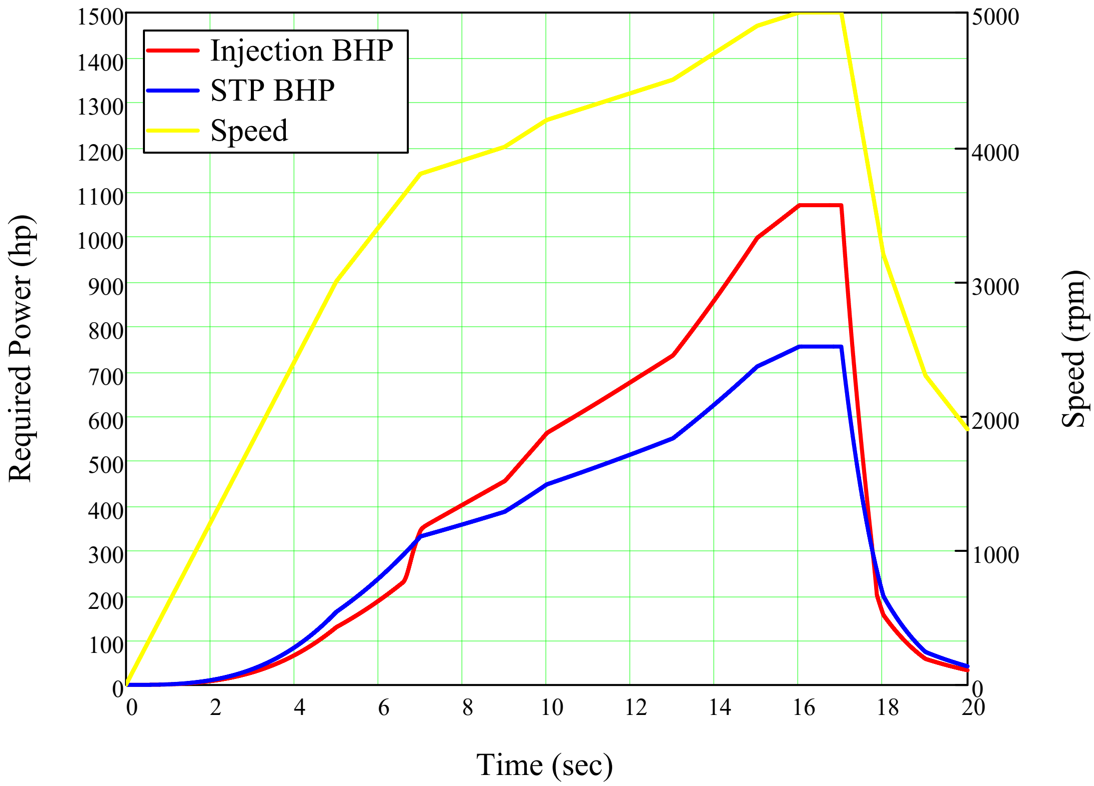

EFW Pump Flow (gpm)
Speed Ratio
Time (sec)
Flow
Speed
0
200
400
600
800
0
0.5
1
1.5
0
5
10
15
20

Superimpose parameters from the Inj and STP Cases

$$C1 := augment\left(X("Inj")^{\langle 1\rangle}, X("Inj")^{\langle 5\rangle} + X("Inj")^{\langle 6\rangle}, X("STP")^{\langle 5\rangle} + X("STP")^{\langle 6\rangle}, X("STP")^{\langle 2\rangle}\right)$$



$A1 := \text{augment}\left(X(\text{"Inj"})^{\langle 1 \rangle}, X(\text{"Inj"})^{\langle 7 \rangle}, X(\text{"STP"})^{\langle 7 \rangle}, X(\text{"STP"})^{\langle 2 \rangle}\right)$



B STP Case Analysis

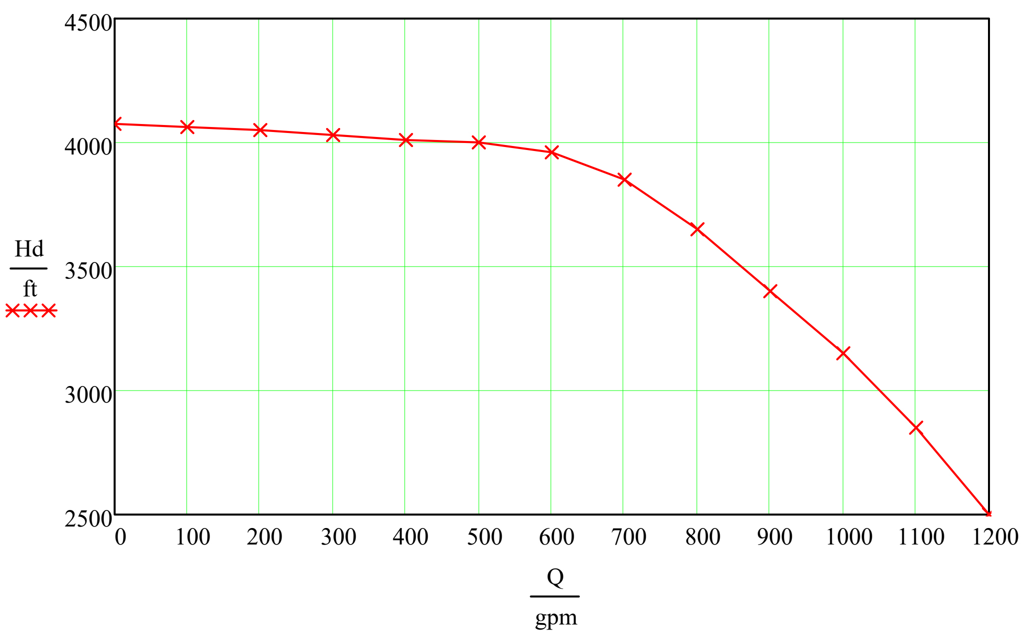
$N_{step} := 20000$	Number of time steps
$\Delta t := 0.001 \cdot sec$	Time step size
$\rho := 62.3 \cdot \frac{lb}{ft^3}$	Water density
$P_{suction} := 23.8 \cdot psi$	Pump suction pressure
$H_{inj} := 3900 \cdot ft$	Pump head when injecting to SGs at steady state
$P_{disch} := P_{suction} + H_{inj} \cdot \rho \cdot g = 1.711 \times 10^3 \cdot psi$	Discharge pressure of the pump when injecting to the SGs
$P_{sg} := (1080 + 14.7) \cdot psi = 1.095 \times 10^3 \cdot psi$	Steam generator pressure
$\Delta H_{sg} := (419.2 - 477.26) \cdot ft = -58.06\,ft$	Elevation head between the pump and the SGs
$Q_{sg} := 530 \cdot gpm$	Steady state flow to the SGs
$R_{sg} := \frac{2 \cdot \left(P_{disch} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g\right)}{\rho \cdot Q_{sg}^2} = 6.307 \times 10^4 \frac{1}{ft^4}$	Resistance of the flow path to the SGs
$P_{cst} := 14.7 \cdot psi$	Pressure of the return location in the CST
$\Delta H_{cst} := (414 - 450.3) \cdot ft$	Elevation head between the pump and the return point to the CST
$Q_{cst.mini} := 100 \cdot gpm$	Flow through the mini flow line during injection to the SGs
$Q_{cst.stp} := 300 \cdot gpm$	Flow during the STP
$H_{stp} := 4030 \cdot ft$	Pump TDH during STP at 300 gpm flow
$N_{rate} := 4600$	Rated speed

Speed ramp data (This is the speed ramp from Run 2)

$$t := \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \end{pmatrix} \cdot sec \qquad Spd := \begin{pmatrix} 0 \\ 600 \\ 1200 \\ 1800 \\ 2400 \\ 3000 \\ 3400 \\ 3800 \\ 3900 \\ 4000 \\ 4200 \\ 4300 \\ 4400 \\ 4500 \\ 4700 \\ 4900 \\ 5000 \\ 5000 \\ 3200 \\ 2300 \\ 1900 \end{pmatrix} \div N_{rate}$$

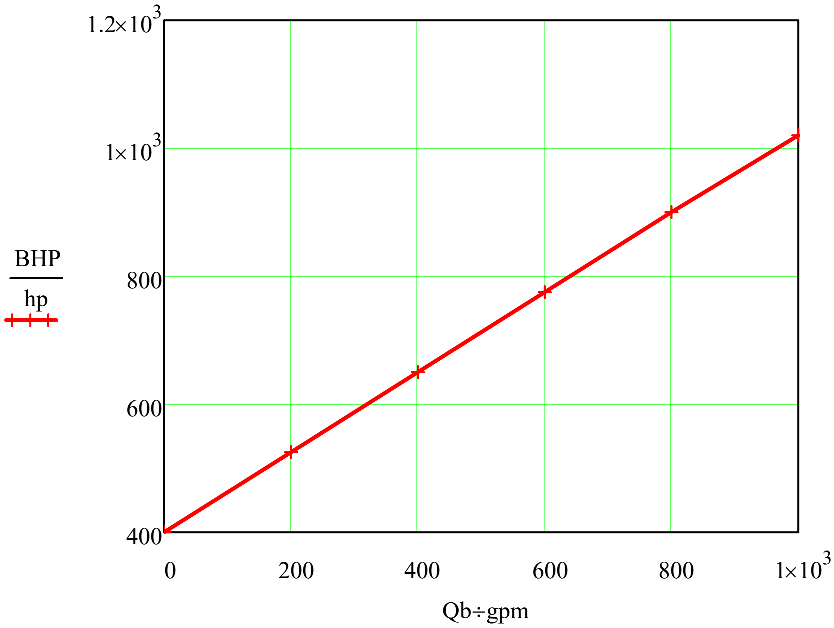
Head flow curve

$$Q := \begin{pmatrix} 0 \\ 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \\ 700 \\ 800 \\ 900 \\ 1000 \\ 1100 \\ 1200 \end{pmatrix} \cdot gpm \qquad Hd := \begin{pmatrix} 4075 \\ 4062 \\ 4050 \\ 4030 \\ 4010 \\ 4000 \\ 3960 \\ 3850 \\ 3650 \\ 3400 \\ 3150 \\ 2850 \\ 2500 \end{pmatrix} \cdot ft$$



BHP Curve

$$Qb := \begin{pmatrix} 0 \\ 200 \\ 400 \\ 600 \\ 800 \\ 1000 \end{pmatrix} \cdot gpm \qquad BHP := \begin{pmatrix} 400 \\ 525 \\ 650 \\ 775 \\ 900 \\ 1020 \end{pmatrix} \cdot hp$$



Linear interpolation function for speed

$$Speed(x) := linterp(t, Spd, x)$$

Function for determination of pump head as a function of volumetric flow (q) and speed ratio (nr)

$$Hx(n_r, q) := \left| \begin{array}{l} \text{for } i \in 1 .. rows(Q) \\ \quad \left| \begin{array}{l} Qx_i \leftarrow n_r \cdot Q_i \\ Hx_i \leftarrow n_r^2 \cdot Hd_i \end{array} \right. \\ H \leftarrow 0 \ \text{ if } n_r = 0 \\ H \leftarrow 0 \ \text{ if } H < 0 \\ H \leftarrow linterp(Qx, Hx, q) \ \text{ otherwise} \end{array} \right.$$

Function for determination of pump required BHP as a function of volumetric flow (q) and speed ratio (nr)

$$
\text{Power}(n_r, q) := \begin{array}{|l} \text{for } i \in 1 .. \text{rows}(Qb) \\ \quad \begin{array}{|l} Qx_i \leftarrow n_r \cdot Qb_i \\ \text{PowerX}_i \leftarrow {n_r}^3 \cdot BHP_i \end{array} \\ \text{Pow} \leftarrow 0 \quad \text{if } n_r = 0 \\ \text{Pow} \leftarrow 0 \quad \text{if Pow} < 0 \\ \text{Pow} \leftarrow \text{linterp}(Qx, \text{PowerX}, q) \quad \text{otherwise} \end{array}
$$

$L_{iner.sg} := 1326 \cdot ft^{-1}$ Inertial length of SG path

$L_{iner.cst} := 5011 \cdot ft^{-1}$ Inertial length of the mini flow path back to the CST

$L_{iner.stp} := 4673 \cdot ft^{-1}$ Inertial length of the test and mini flow path back to the CST

Calculate the resistance of the line to the CST based on flow and the pump head

$$
\text{Res}_{cst}(Hd, Q) := \begin{array}{|l} P \leftarrow P_{suction} + Hd \cdot \rho \cdot g \\ R \leftarrow \dfrac{2 \cdot \left(P - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g\right)}{\rho \cdot Q^2} \\ R \end{array}
$$

$$
\text{Res}_{cst}(4030 \cdot ft, 300 \cdot gpm) = 5.783 \times 10^5 \frac{1}{ft^4}
$$

Determine the SG pressure, CST path inertial length and the CST path resistance depending on if it is injection or STP.

$$\mathrm{Setup}(x) := \left| \begin{array}{l} \text{if } x = \text{"Inj"} \\ \quad \left| \begin{array}{l} P \leftarrow P_{sg} \\ L_{in} \leftarrow L_{iner.cst} \\ R \leftarrow Res_{cst}(H_{inj}, Q_{cst.mini}) \end{array} \right. \\ \text{if } x = \text{"STP"} \\ \quad \left| \begin{array}{l} P \leftarrow 10000 \cdot psi \\ L_{in} \leftarrow L_{iner.stp} \\ R \leftarrow Res_{cst}(H_{stp}, Q_{cst.stp}) \end{array} \right. \\ \mathrm{augment}\left(\dfrac{P}{psi}, \dfrac{L_{in}}{ft^{-1}}, \dfrac{R}{ft^{-4}} \right) \end{array} \right.$$

The SG pressure is made 10000 psi for the STP case to prevent any flow.

$$\mathrm{Setup}(\text{"Inj"}) = \begin{pmatrix} 1.095 \times 10^{3} & 5.011 \times 10^{3} & 5.036 \times 10^{6} \end{pmatrix}$$

$$\mathrm{Setup}(\text{"STP"}) = \begin{pmatrix} 1 \times 10^{4} & 4.673 \times 10^{3} & 5.783 \times 10^{5} \end{pmatrix}$$

Main solver

$$
X(str) := \begin{array}{|l}
\text{for } i \in ORIGIN..N_{step} \\
\quad \begin{array}{|l}
\text{if } i = ORIGIN \\
\quad \begin{array}{|l}
t_i \leftarrow 0 \\
N_{s_i} \leftarrow Speed(t_i) \\
w_{sg_i} \leftarrow 0 \\
Q_{sg_i} \leftarrow 0 \\
w_{cst_i} \leftarrow 0 \\
Q_{cst_i} \leftarrow 0 \\
Hd_i \leftarrow Hx\left(N_{s_i}, Q_{sg_i} + Q_{cst_i}\right) \\
P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g \\
Pow_i \leftarrow Power\left(N_{s_i}, Q_{sg_i} + Q_{cst_i}\right)
\end{array} \\
\text{otherwise} \\
\quad \begin{array}{|l}
t_i \leftarrow t_{i-1} + \Delta t \\
N_{s_i} \leftarrow Speed(t_i) \\
Hd_i \leftarrow Hx\left(N_{s_i}, Q_{sg_{i-1}} + Q_{cst_{i-1}}\right) \\
P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g \\
Mx \leftarrow Setup(str) \\
P_{sg} \leftarrow Mx_{1,1} \cdot psi \\
L_{iner.cst} \leftarrow Mx_{1,2} \cdot ft^{-1} \\
R_{cst} \leftarrow Mx_{1,3} \cdot ft^{-4} \\
wdot_{sg} \leftarrow \dfrac{1}{L_{iner.sg}} \cdot \left(P_{disch_i} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g - \dfrac{R_{sg} \cdot w_{sg_{i-1}} \cdot \left|w_{sg_{i-1}}\right|}{2 \cdot \rho}\right) \\
wdot_{cst} \leftarrow \dfrac{1}{L_{iner.cst}} \cdot \left(P_{disch_i} - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g - \dfrac{R_{cst} \cdot w_{cst_{i-1}} \cdot \left|w_{cst_{i-1}}\right|}{2 \cdot \rho}\right) \\
\text{""}
\end{array}
\end{array}
\end{array}
$$

$$w_{sg_i} \leftarrow w_{sg_{i-1}} + wdot_{sg} \cdot \Delta t$$

$$w_{sg_i} \leftarrow 0 \quad \text{if} \quad w_{sg_i} < 0$$

$$w_{cst_i} \leftarrow w_{cst_{i-1}} + wdot_{cst} \cdot \Delta t$$

$$w_{cst_i} \leftarrow 0 \quad \text{if} \quad w_{cst_i} < 0$$

$$Q_{sg_i} \leftarrow w_{sg_i} \div \rho$$

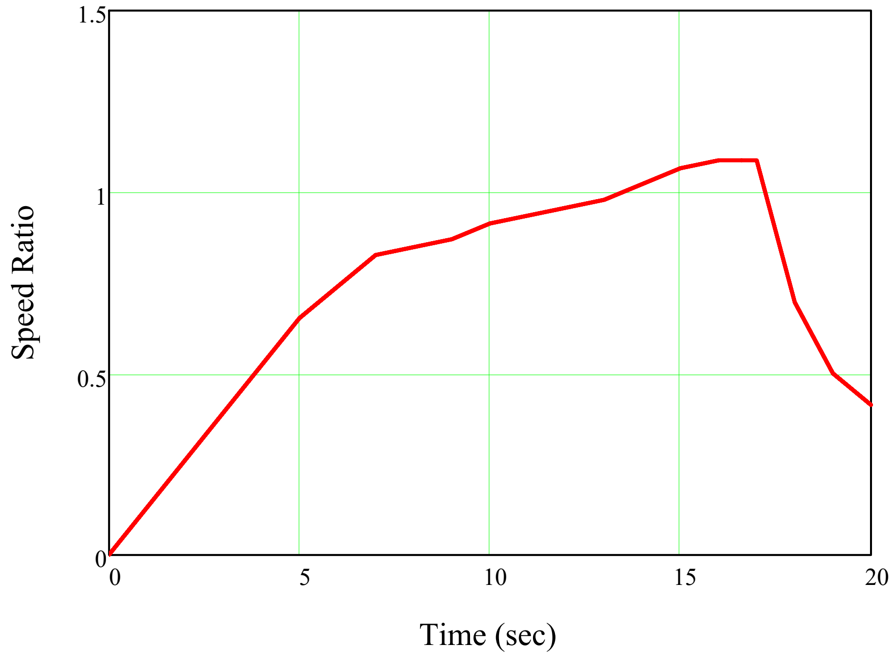
$$Q_{cst_i} \leftarrow w_{cst_i} \div \rho$$

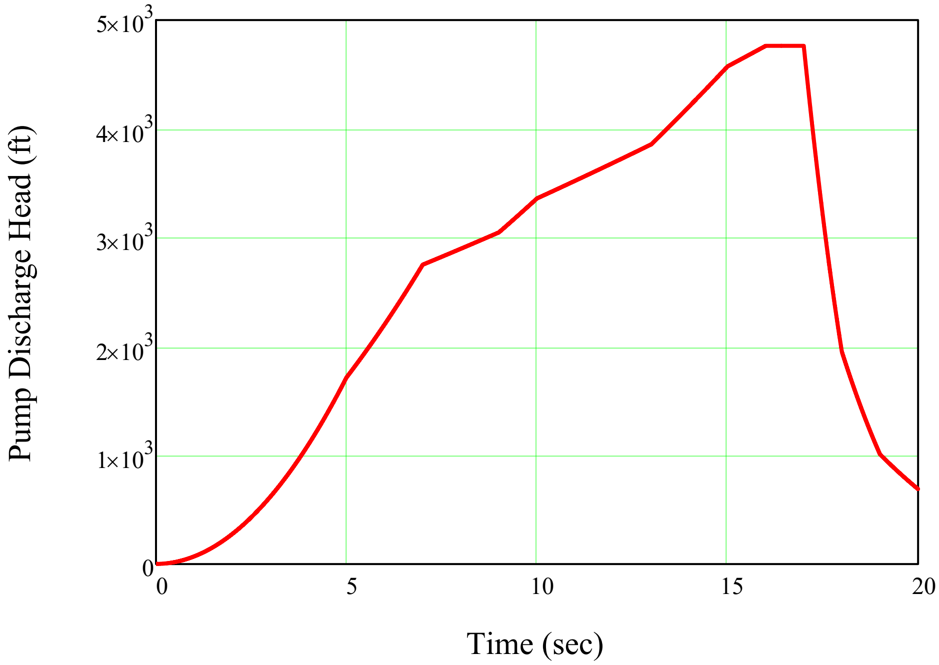
$$Pow_i \leftarrow Power\left(N_{s_i}, Q_{sg_i} + Q_{cst_i}\right)$$

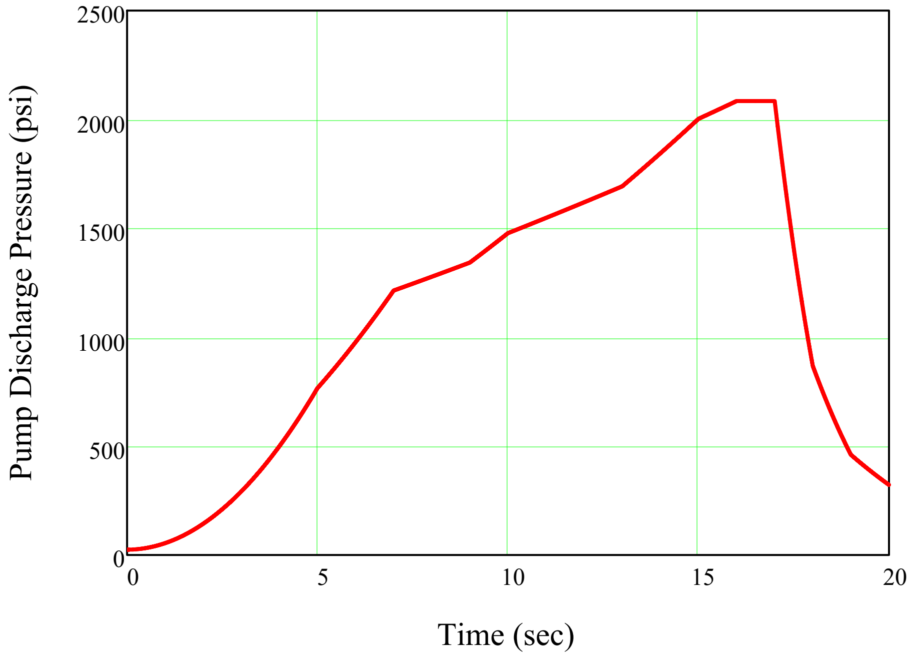
$$\text{augment}\left(\frac{t}{sec}, N_s, \frac{Hd}{ft}, \frac{P_{disch}}{psi}, \frac{Q_{sg}}{gpm}, \frac{Q_{cst}}{gpm}, \frac{Pow}{hp}\right)$$

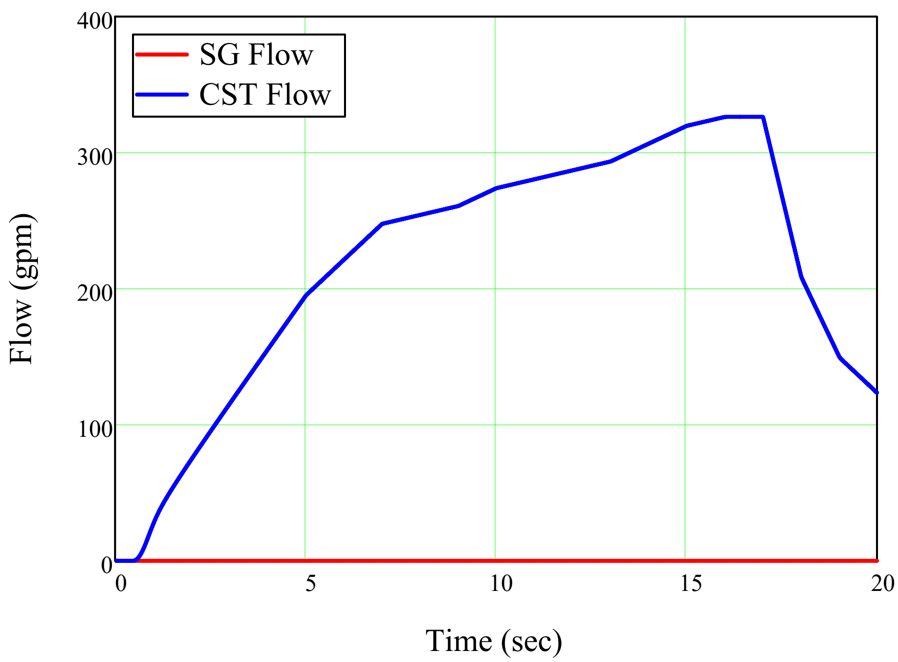
Y := X("STP")

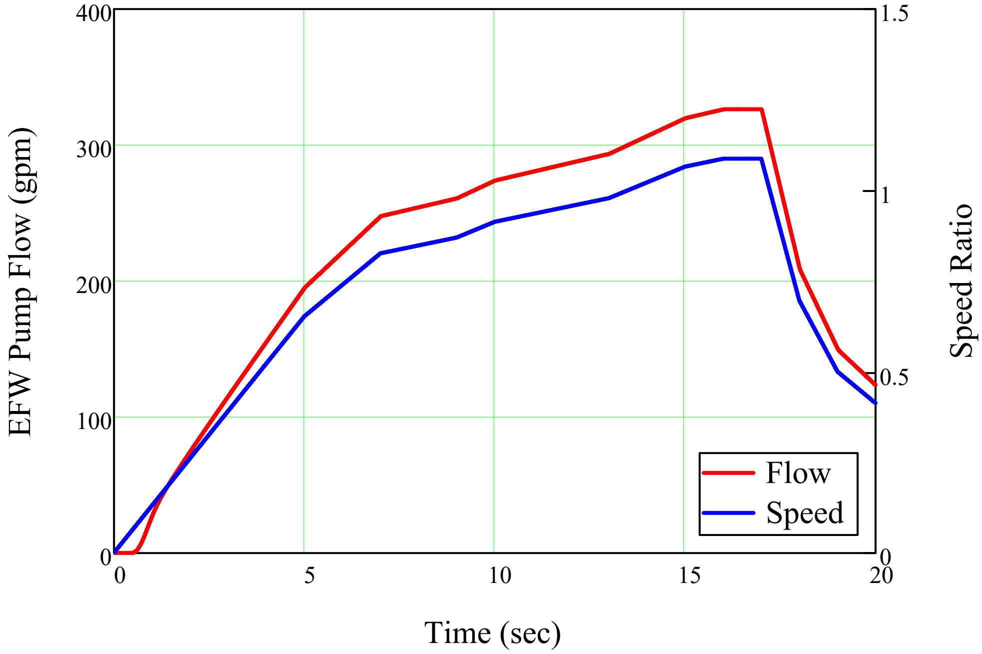
Change the Inj to STP to see the graphs for the STP





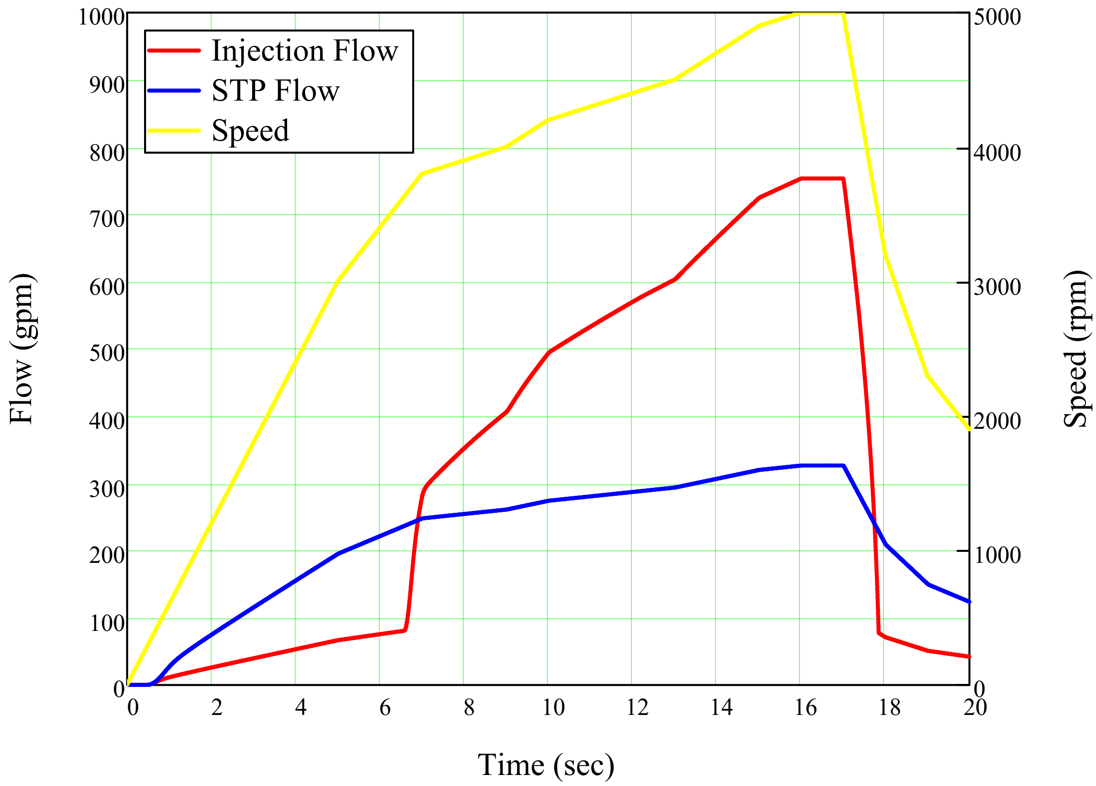

Pump Discharge Pressure (psi)
0
500
1000
1500
2000
2500
0
5
10
15
20
Time (sec)


Flow (gpm)
SG Flow
CST Flow
0
100
200
300
400
0
5
10
15
20
Time (sec)

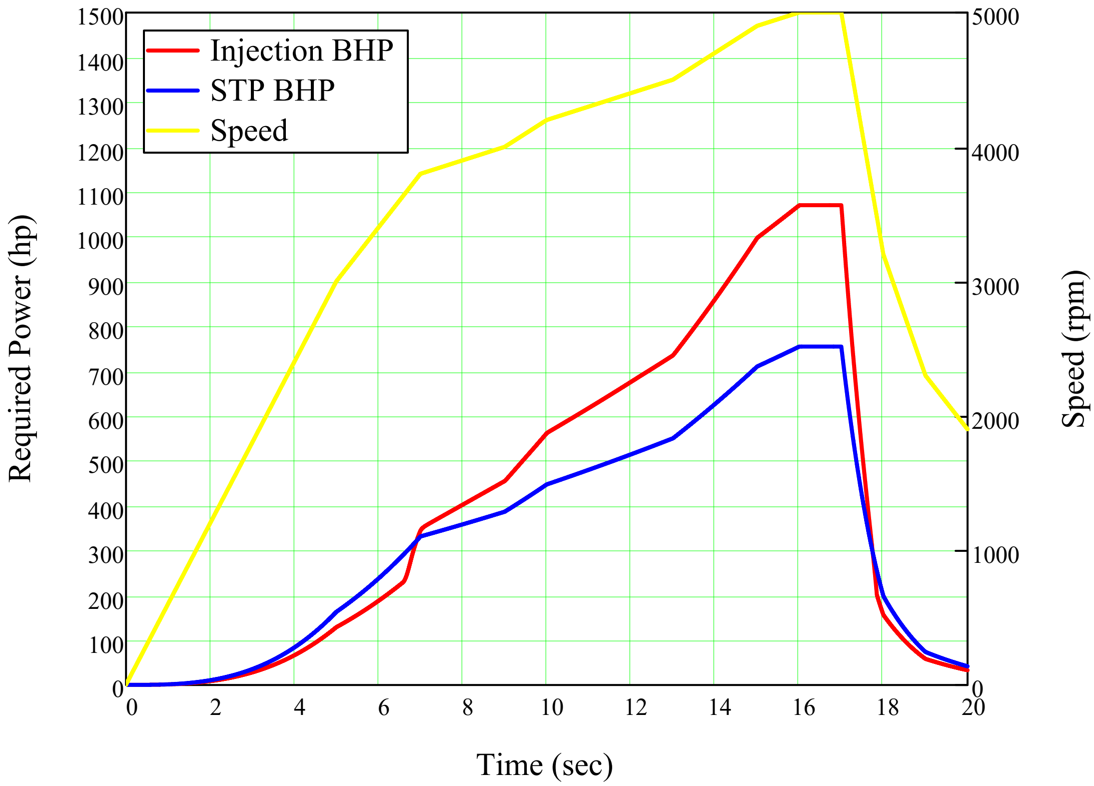

EFW Pump Flow (gpm)
Speed Ratio
Time (sec)
Flow
Speed
0
100
200
300
400
0
0.5
1
1.5
0
5
10
15
20

Superimpose parameters from the Inj and STP Cases

$$C1 := \text{augment}\left(X(\text{"Inj"})^{\langle 1\rangle}, X(\text{"Inj"})^{\langle 5\rangle} + X(\text{"Inj"})^{\langle 6\rangle}, X(\text{"STP"})^{\langle 5\rangle} + X(\text{"STP"})^{\langle 6\rangle}, X(\text{"STP"})^{\langle 2\rangle}\right)$$



$$A1 := augment\left(X("Inj")^{\langle 1\rangle}, X("Inj")^{\langle 7\rangle}, X("STP")^{\langle 7\rangle}, X("STP")^{\langle 2\rangle}\right)$$



C Calculation of Inertial Lengths

Tab Descriptions

Summary	Summarizes the intertial length calculation results from each worksheet
Min Flow	Calculates the inertial length if the only flow path is the minimum flow line
Test	Calculates the inertial length if the flow path is minflow line and test flow line operating in parallel
SG	Calculates the inertial length if the flow path is through the min flow line and the SG injection paths, all in parallel

Total Inertial Lengths 1/ft

Min Flow	5011.449	min flow line only
Test	4673.274	Test line and min flow line cominbed in parallel
SG Injection	1471.461	SG injection and min flow line combined in parallel

Inertial Lengths through Separate Legs 1/ft

Min Flow	5011.449	min flow line only
Test	4673.274	Test line and min flow line combined in parallel
SG Injection	1326.173	combine parallel SG flow paths (from tee with min flow line to SGs)

Reference for Pipe Lengths and Areas:
V.C. Summer Nuclear Station, Calculation No. DC05220-091, “EF Hydraulic Analyses,” Revision 4.

Pump Suction Path Common to both Test and Injection

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
0.01	10.02	1	0.547599	1.826153	1.826153	Series	
11	10.02	10.53	0.547599	19.22939	8.7596142	Parallel	
12	10.02	8.81	0.547599	16.08841			12 and 12.1
13.01	10.02	149.2	0.547599	272.462	272.46203	Series	
13.02	10.02	8.46	0.547599	15.44925	15.449255	Series	
					298.49705	Total	

Pump Discharge Common Path for both Test and Injection

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
21.01	3.624	8.6	0.071631	120.059	120.05899	Series	
21.02	3.624	0	0.071631	0	0	Series	
21.03	3.624	1.8	0.071631	25.12863	25.128626	Series	
					145.18762	Total	

Mini Flow Line (to be combined in parallel with all paths)

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
20.01	1.687	5	0.015522	322.1161	322.11611	Series	
20.02	1.687	0.37	0.015522	23.83659	23.836592	Series	
20.03	1.687	0.2	0.015522	12.88464	12.884645	Series	Assumed valve length
20.05	1.687	0.37	0.015522	23.83659	23.836592	Series	
20.06	1.687	2.64	0.015522	170.0773	170.07731	Series	
20.16	3.068	5.43	0.051338	105.7698	105.76981	Series	
					658.52106	Total	

Portion of Test Line which meets the mini flow line

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
21.04	3.624	0	0.071631	0	0	Series	
20.07	2.125	0	0.024629	0	0	Series	
20.08	2.125	0	0.024629	0	0	Series	
20.1	1.687	0	0.015522	0	0	Series	
20.12	1.687	0	0.015522	0	0	Series	This length is to
20.14	2.125	0	0.024629	0	0	Series	be eliminated for
20.15	3.068	0	0.051338	0	0	Series	SG IL calculation
					0	Total	

Combine the above two length clusters in parallel (test line and min flow line)

658.52106 This is to be added in series with the lengths before and after

Meeting point of mini flow and test lines to the CST

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
26	4.026	14.46	0.088405	163.5661	163.56612	Series	
27	4.026	279.81	0.088405	3165.106	3165.1063	Series	579.81 total length of pipe is segment 27
27	10.02	300	0.547599	547.8459	547.84591	Series	rough estimate of fraction that is 10 inch
15	10.02	17.92	0.547599	32.72466	32.724662	Series	
					3909.243	Total	

5011.4487 **Total inertial length for min flow line only**

Pump Suction Path Common to both Test and Injection

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
0.01	10.02	1	0.547599	1.826153	1.826153	Series	
11	10.02	10.53	0.547599	19.22939	8.7596142	Parallel	
12	10.02	8.81	0.547599	16.08841			12 and 12.1
13.01	10.02	149.2	0.547599	272.462	272.46203	Series	
13.02	10.02	8.46	0.547599	15.44925	15.449255	Series	
					298.49705	Total	

Pump Discharge Common Path for both Test and Injection

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
21.01	3.624	8.6	0.071631	120.059	120.05899	Series	
21.02	3.624	0	0.071631	0	0	Series	
21.03	3.624	1.8	0.071631	25.12863	25.128626	Series	
					145.18762	Total	

Mini Flow Line (to be combined in parallel with all paths)

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
20.01	1.687	5	0.015522	322.1161	322.11611	Series	
20.02	1.687	0.37	0.015522	23.83659	23.836592	Series	
20.03	1.687	0.2	0.015522	12.88464	12.884645	Series	Assumed valve length
20.05	1.687	0.37	0.015522	23.83659	23.836592	Series	
20.06	1.687	2.64	0.015522	170.0773	170.07731	Series	
20.16	3.068	5.43	0.051338	105.7698	105.76981	Series	
					658.52106	Total	

Portion of Test Line which meets the mini flow line

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
21.04	3.624	4.36	0.071631	60.86712	60.867116	Series	
20.07	2.125	5.82	0.024629	236.3076	236.30762	Series	
20.08	2.125	0.13	0.024629	5.278349	5.2783489	Series	
20.1	1.687	0.13	0.015522	8.375019	8.3750189	Series	
20.12	1.687	0.31	0.015522	19.9712	19.971199	Series	This length is to
20.14	2.125	2.75	0.024629	111.6574	111.65738	Series	be eliminated for
20.15	3.068	9.31	0.051338	181.3475	181.3475	Series	SG IL calculation
					623.80419	Total	

Combine the above two length clusters in parallel (test line and min flow line)

320.34634	This is to be added in series with the lengths before and after

Meeting point of mini flow and test lines to the CST

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
26	4.026	14.46	0.088405	163.5661	163.56612	Series	
27	4.026	279.81	0.088405	3165.106	3165.1063	Series	579.81 total length of pipe is segment 27
27	10.02	300	0.547599	547.8459	547.84591	Series	rough estimate of fraction that is 10 inch
15	10.02	17.92	0.547599	32.72466	32.724662	Series	
					3909.243	Total	

4673.274	**Total inertial length for Flow test line**
4567.7641	For SG injection, this has to be combined in parallel with the equivalent of Susan's spreadsheet
443.68467	After combining, add this number to it
1575.0558	

Common SG Path

Pipe ID	Dia (in)	Length (ft)	Area (ft2)	Inertial Length (1/ft)	Equivalent Inertial Length (1/ft)	Comment	Note
22	3.624	30.85	0.071631	430.6767	430.6767	Series	
21.04	3.624	4.36	0.071631	60.86712	60.86712	Series	
					491.5438	Total	
Path to SG-C							This is in series with SGA and SGB flow paths
24.31	3.624	0.55	0.071631	7.678191	7.678191	Series	
24.32	3.624	0.2	0.071631	2.79207	2.79207	Series	no pipe length given, so assume a value of 1.o
24.33	3.624	0.51	0.071631	7.119777	7.119777	Series	
25.03	3.624	54.6	0.071631	762.235	762.235	Series	
9.31	3.862	29.424	0.081349	361.7011	361.7011	Series	
9.32	3.862	0.2	0.081349	2.458544	2.458544	Series	orifice plate, no length given
9.34	3.862	21.87	0.081349	268.8418	268.8418	Series	
9.35	3.862	0.5	0.081349	6.146361	6.146361	Series	
9.38	3.862	0.2	0.081349	2.458544	2.458544	Series	no length provided. assumed this is the main feedwater control vlave. Did not model bypass flowpath.
9.33	3.826	112.96	0.079839	1414.84	1414.84	Series	diameter 3.826 to 5.761
10.03	5.761	1.56	0.181019	8.6179	8.6179	Series	diameter 5.761 to 5.501
					2844.889	Total	
Common SGA and SG-B							
23	3.624	3.82	0.071631	53.32853	53.32853	paralell and series	
Path to SGB							
24.21	3.624	5.61	0.071631	78.31755	78.31755	Series	
24.22	3.624	0.2	0.071631	2.79207	2.79207	Series	no length given
24.23	3.624	0.55	0.071631	7.678191	7.678191	Series	
25.02	3.624	21	0.071631	293.1673	293.1673	Series	
9.21	3.862	5.121	0.081349	62.95103	62.95103	Series	
9.22	3.862	0.2	0.081349	2.458544	2.458544	Series	no length given
9.24	3.862	8.42	0.081349	103.5047	103.5047	Series	
9.25	3.862	0.92	0.081349	11.3093	11.3093	Series	
9.28	3.862	0.2	0.081349	2.458544	2.458544	Series	no length given
9.23	3.826	104.89	0.079839	1313.762	1313.762	Series	diameter 3.826 to 5.761
10.02	5.761	1.19	0.181019	6.573911	6.573911	Series	
					1884.973	Total	
Path to SGA							
24.11	3.624	1.76	0.071631	24.57021	24.57021	Series	
24.12	3.624	0.2	0.071631	2.79207	2.79207	Series	no length given
24.13	3.624	0.5	0.071631	6.980174	6.980174	Series	
25.01	3.624	10	0.071631	139.6035	139.6035	Series	
9.11	3.862	96.15	0.081349	1181.945	1181.945	Series	
9.12	3.862	0.2	0.081349	2.458544	2.458544	Series	no length given
9.14	3.862	10.42	0.081349	128.0902	128.0902	Series	
9.15	3.862	1.5	0.081349	18.43908	18.43908	Series	
9.18	3.862	0.2	0.081349	2.458544	2.458544	Series	no length given
9.13	3.862	133.05	0.081349	1635.547	1635.547	Series	diameter 3.826 to 5.761
10.01	5.761	3.71	0.181019	20.49513	20.49513	Series	diameter 5.761 to 5.501
					3163.379	Total	

1326.173	**combined inertial lengths of SG paths from min flow line to SGs**
1027.776	combine min flow line with SG paths
1471.461	**add in pipe from pump discharge to min flow line**

B MPR Calculation No. 0310-0085-CALC-002 Rev 0, "TDEFW Pump Start Transient Analysis – With Detailed Model"

0310-0085-CALC-002
Revision 0

TDEFW Pump Start Transient Analysis – With Detailed Model

Prepared for: V. C. Summer Nuclear Station

Preparer:	Amol Limaye	E-signed by: Amol Limaye on 2026-05-05 22:49:30
Checker:	Kayleigh McNeill	E-signed by: Kayleigh McNeill on 2026-05-05 23:05:30
Reviewer:	Susan Harp	E-signed by: Susan Harp on 2026-05-05 22:54:40
Approver:	Susan Harp	E-signed by: Susan Harp on 2026-05-05 23:11:08

QA Statement of Compliance

This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of the MPR Standard Quality Program.

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TDEFW Pump Start Transient Analysis – With Detailed Model

RECORD OF REVISIONS		
Revision Number	**Pages /Sections Revised**	**Revision Description**
0	All	Initial Issue

Table of Contents

1.0 Purpose and Background

1.1. Purpose

This calculation documents a transient analysis of the Turbine-Driven Emergency Feedwater (TDEFW) pump start at V.C. Summer.

During the November 2025 TDEFW pump Surveillance Test Procedure (STP), the pump tripped on overspeed due to a degraded condition in the governor valve control system. This analysis quantifies the margin to an overspeed trip that would have been available if the pump was aligned for Steam Generator (SG) injection at the time instead of the STP alignment that returns the pump flow to the Condensate Storage Tank (CST).

1.2. Background

The Emergency Feedwater (EFW) system at V.C. Summer is a safety-related system that injects flow into the steam generators to remove decay heat under certain design basis accident scenarios. The EFW system includes two motor-driven pumps and one turbine-driven pump. These pumps take suction from the Condensate Storage Tank (CST) and inject into the feedwater lines that lead to the steam generators. Quarterly STPs are performed on the EFW pumps to meet the plant licensing commitments. During these tests, the flow from the pump is recirculated back to the CST through a test line.

The TDEFW pump has a governor which controls the speed by modulating the governor valve that controls the rate of steam flow to the turbine. A mechanical overspeed protection trip is also provided to ensure that the speed does not exceed the trip setpoint speed and cause damage to the turbine.

When performing the quarterly STP on the TDEFW pump in November 2025, the overspeed protection trip activated and the pump tripped. The pump had previously operated successfully during a steam injection event in October 2025. The unexpected pump trip during the STP called into question the ability of the pump to meet its safety function for SG injection events between the October 2025 event and the November 2025 surveillance test.

Dominion initiated an evaluation of the cause of the trip, the impact of the failed STP on the pump's safety function, and regulatory impact. As part of this effort, MPR performed a technical evaluation of the event based on the steady state flow rates through the pump when the pump was configured for an STP and for an SG injection event. The evaluation concluded based on steady state flow rates of the TDEFW pump during the two alignments that the power requirement would be greater for an SG injection. As a result, the governor would be less challenged.

To further evaluate the results of the simplified evaluation, a transient analysis was performed (Reference 1) to determine the power requirement of the pump during a start-up for an STP and SG injection. The analysis calculated the power requirements for the two alignments over time and confirmed that the power requirement would be higher during the start-up for SG injection. However, that analysis did not explicitly determine the steam flow demand and amount by which the governor valve needs to move to control the turbine speed for the two alignments during the start-up.

The analysis documented in this calculation models the steam system which supplies steam flow to the turbine and combines this model with the model of the pump and the flow supply system to the SGs and to the CST to perform a full transient analysis. The analysis calculates the turbine steam flow demand and the governor valve movement for each alignment during start-up and confirms the results presented in the Reference 1 analysis.

2.0 Summary of Results and Conclusion

A transient analysis of the TDEFW pump start was performed using a model of the EFW system at V.C. Summer. The key findings from the analysis are as follows:

- During an SG injection, the TDEFW pump power requirement is higher than during an STP due to the higher pump flow during an SG injection. The power requirement is higher by 34%.
- The steam flow needed by the turbine to meet the power requirement during SG injection is higher than the steam flow needed during an STP. The steam flow requirement is higher by 34%.
- The governor valve is initially open and closes during the start-up to control the speed. The valve is required to close less for an SG injection to allow the additional steam flow. The valve is required to close by about 5% less in terms of the total valve stroke.
- The smaller valve travel makes the SG injection less demanding on the governor relative to an STP. The reduction in travel distance makes it more likely that the governor will be able to control the turbine speed before reaching the overspeed trip setpoint.

An analysis that replicated the first troubleshooting run, Run 2, which caused an overspeed trip, was performed using the model. The valve displacement was tuned to make the speed trace closely match the Run 2 speed ramp and overspeed trip. The same valve displacement was then used to simulate a start-up for SG injection under the assumption that the governor valve response would be reasonably similar during an SG injection event. The results showed that the peak speed reached during the start-up for SG injection remained below the overspeed trip setpoint by approximately 400 rpm.

The model results and comparison with the speed data from the November 2025 STP are shown in Figure 2-1. The blue dashed line is the calculated speed ramp for the Run 2 STP which reasonably matches the measured speed shown by the orange squares. The red solid line shows the speed ramp for an SG injection which stops increasing 400 rpm short of the overspeed trip setpoint.

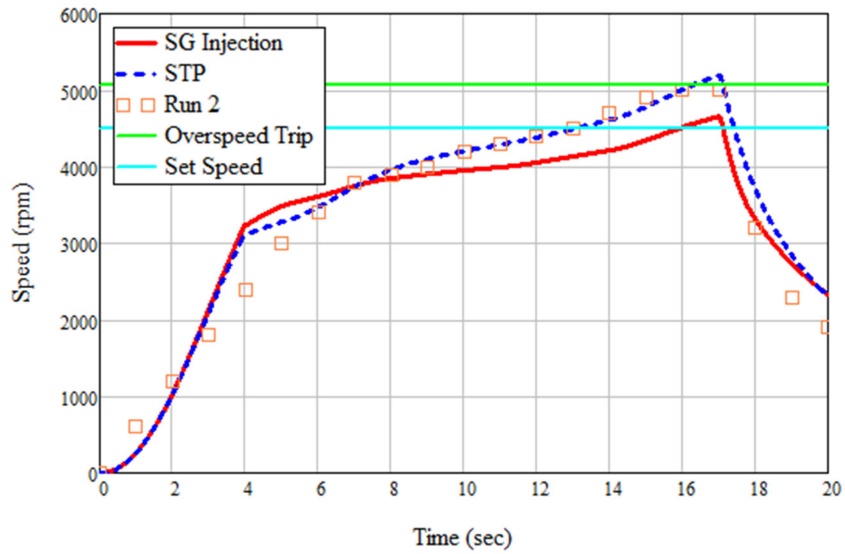


Figure 2-1. Calculated and Measured Speeds

Based on the smaller valve travel and the substantial margin to overspeed trip for an SG injection, MPR has the following conclusion:

- If the TDEFW pump had been lined-up for SG injection in November 2025, then even with the degraded governor valve control system performance, the pump would have started and performed its safety function without an overspeed trip.

3.0 System Description

The TDEFW pump is normally aligned to take suction through piping that runs from the CST to the pump. The discharge piping splits into multiple flow paths. The major flow paths relevant to this analysis include the minimum flow return (mini flow) line, the line used to perform the STP, and the three lines that inject to the three steam generators through the main feed water piping. The motor-driven EFW (MDEFW) pumps also take suction from the CST and supply flow to the three steam generators through the same lines that are used by the TDEFW pump.

A simplified schematic of the piping is shown in Figure 3-1. The schematic does not show the MDEFW pumps and their connections because these were not explicitly modeled. However, the effect of the MDEFW operation on the flow and discharge pressure of the TDEFW pump was captured in the analysis.

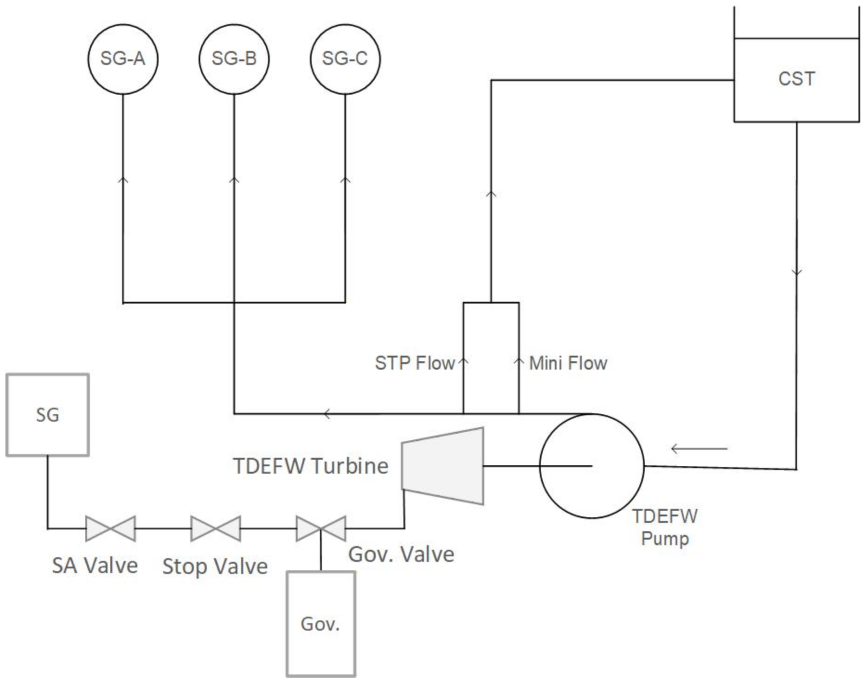


Figure 3-1. TDEFW System Model - Simplified Schematic

Normally, the pump is aligned to the SGs for injection in response to a design basis accident. The mini flow line is open and the STP line is closed. Thus, during injection, the pump injects to the SGs and the mini flow line simultaneously. In most events, the MDEFW pumps will actuate before the TDEFW pump and inject into the same flow paths to the SGs. The MDEFW pumps will reach steady state prior to the TDEFW pump start. For an STP, the SGs are isolated, and the test line is opened. Thus, the TDEFW pump supplies flow to the test line and the mini flow line.

The pump is powered by a Terry turbine that receives steam from the SGs. The turbine is normally isolated by a closed steam admission valve. The turbine stop valve and governor valve are downstream of the steam admission valve and are normally open. To start the turbine, the steam admission valve is opened. The steam flows through the stop and governor valve and the turbine nozzles to power the turbine. As the steam admission valve continues to open, the turbine speeds increases. As the speed increases, the shaft-driven mechanical/hydraulic governor develops sufficient oil pressure to start moving the governor valve. The governor partially closes the governor valve to limit the steam flow to the turbine and controls the speed to the speed setpoint.

The governor has a mechanical overspeed trip mechanism which closes the stop valve if the speed increases past the normal setpoint and reaches the trip setpoint.

4.0 Methodology

4.1. Overall Approach

Reference 1 developed a transient model of the TDEFW pump and the piping that supplies flow to the steam generators for injection and to the CST during an STP. The model was used to perform analysis of the flow injection side of the TDEFW system. Using the model, the differences between an STP and an SG injection in terms of the flow and the power required by the pump were studied.

That model was used as-is in this detailed analysis effort documented in this calculation. The detailed analysis effort created a model of the steam side of the TDEFW system including the steam admission valve, governor valve, and the turbine and combined it with the flow injection side model to create a full model.

A transient analysis was performed using the full model to simulate a TDEFW pump start, the speed increase over time, and the required governor valve movement were determined for the STP and SG injection scenarios. Appendices A and B include the files that contain the detailed analysis.

The steam system model includes the following:

- The steam generator conditions are modeled using constant steam pressure and enthalpy.
- The steam admission valve is modeled using the valve stroke time, flow coefficient, and area variation with position. The valve is opened over time to initiate the start-up.
- The piping between the steam admission valve and the governor valve is modeled as a control volume whose pressure changes over time due to mass and energy conservation.
- The governor valve and the steam nozzles are modeled using the lift curves which provide the mass flow through the valve and the nozzles as a function of upstream pressure and valve lift.
- The turbine is modeled using the turbine performance curves which provide the turbine power output as a function of the steam flow and speed.

The hydraulic model on the pump side is discussed in Reference 1 and has the following elements:

- The TDEFW pump is modeled using its head flow curve and BHP curve.

- The MDEFW pumps are not explicitly modeled, but their effect is indirectly captured. These pumps are expected to be running, and their flow is expected to be at steady state when the TDEFW pump starts. Since all pumps inject into the same lines to the steam generators, the operation of the MDEFW pumps increases the apparent flow resistance of the piping for the TDEFW pump and decreases its flow rate. The decreased flow rate was used to calculate the flow resistance of the piping as seen by the TDEFW pump to capture this effect.
- The TDEFW pump discharge piping and the lines to the steam generators A, B, and C are modeled using the piping flow resistance and the fluid inertia. All three lines are modeled and combined as described in Appendix C of Reference 1.
- Appropriate boundary condition pressures are used at the steam generator and CST locations. The CST level is assumed to be the same for both analysis cases.

4.2. Equations

The steam flow through the governor valve is governed by the momentum equation:

$$\frac{dw_s}{dt} = \frac{1}{Ls_{iner}}\left(P_{sg} - P_d - \frac{R_{sa}w_s^2}{2\rho_s}\right)$$

where

W_s is the steam flow
Ls_{iner} is the inertial length of the fluid
P_{sg} is the steam generator pressure
P_d is the pressure in the steam volume downstream of the steam admission valve
R_{sa} is the steam admission valve flow resistance
ρ_s is the density of steam

Sine the inertia of steam is low due to its low density compared to water, the inertial effects are minor and can be neglected. Therefore, the steam flow is calculated from the steady state Darcy equation:

$$w_s = \sqrt{\frac{2(P_{sg} - P_d)\rho_s}{R_{sa}}}$$

The above equation is applicable if the flow through the steam admission valve is not choked. The flow is calculated using the above equation and then compared with the critical flow. If the flow is higher than critical flow, then the flow is limited to the critical flow. The critical mass flux is calculated using the Moody equations and multiplied with the open area of the valve to calculate the critical flow.

The steam pressure in the pipe volume between the steam admission valve and the governor valve is a function of the mass and energy in the volume. The time rate of change of pressure is given by:

$$\frac{dP}{dt} = \frac{\partial P}{\partial m}\frac{dm}{dt} + \frac{\partial P}{\partial U}\frac{dU}{dt}$$

where

m us the mass of steam in the volume
U is the energy in the volume

The partial derivatives of the pressure with respect to mass and energy are based on steam table properties. The time rate of change of mass in the volume is given by:

$$\frac{dm}{dt} = w_s - w_g$$

where

w_g is the flow through the governor valve

The time rate of change of energy in the volume is given by:

$$\frac{dU}{dt} = h_{sg}w_s - h_{vol}w_g$$

where

h_{sg} is the enthalpy of steam from the steam generators
h_{vol} is the enthalpy of steam in the volume between the steam admission valve and the governor valve

The flow through the governor valve is not calculated from first principles. It is calculated based on the lift curves. The lift curves are developed in Reference 12. Similarly, the power produced by the turbine is obtained from the turbine performance curves using the steam flow through the governor valve and the turbine speed. The torque applied by the turbine is the power produced divided by the turbine speed.

The power and torque required by the pump are calculated from the pump model that is documented in Reference 1. The pump model includes the pump performance and the hydraulic resistance and fluid inertia.

The angular acceleration of the rotor is calculated from the torques as follows:

$$\alpha = \frac{T_{turb} - T_{pump}}{I}$$

where

α	is the angular acceleration
T_{turb}	is the turbine applied torque
T_{pump}	is the pump required torque
I	is the rotary inertia of the rotor

The new speed is calculated from the angular acceleration as:

$$N_{rotor.new} = N_{rotor.old} + \alpha\Delta t$$

5.0 Assumptions and Limitations

5.1. Assumptions with a Basis

All assumptions documented in Reference 1 are applicable to this analysis except Assumption 2. This assumption is removed. The speed is not an input. It is a calculated parameter.

1. The steam admission valve opening stroke is assumed to be linear with time, flow area is assumed to be linear with position, and the flow coefficient is assumed to be linear with position. The last two items are confirmed to be reasonable based on a review of similar valves by Fisher. These assumptions do not have an impact on the analysis since the analysis is not intended to be exact. It is intended to be comparative in nature between the STP and SG injection, and the valve properties described above are identical for both analysis cases.
2. The inertia of the pump is available, but the turbine inertia is not available. The overall inertia of the rotor was adjusted to reasonably match the coastdown results following the overspeed trip from Run 2.

5.2. Assumptions without a Basis

There are no assumptions without a basis for this calculation.

6.0 Design Inputs

The design inputs used for the steam side model are listed in Table 6-1. All inputs listed in Table 6-1 of Reference 1 are applicable except those noted in Table 6-1 below. Additionally, Item 16 in Table 6-1 of Reference 1, the specified speed ramp, is no longer an input in the new analysis.

Table 6-1. Design Inputs and Sources

No.	Design Input	Value	Reference
1	Steam generator pressure	1000 psia	Note a
2	Steam admission valve flow coefficient	155 gpm/psi$^{0.5}$	Reference 4
3	Steam admission valve flow area	3 in^2	Note b
4	Steam admission valve stroke time	32 seconds	Reference 3
5	Length of the steam piping between the steam admission valve and the governor valve	3.5 ft	Reference 5
6	Nominal diameter and schedule of the steam piping between the steam admission valve and the governor valve	4 inch nominal, schedule 80	References 6 and 7
7	Governor valve lift curves	Figure 6-1	Developed in Reference 12
8	Turbine rated power	990 hp	Reference 8
9	Turbine required mass flow per unit power	37 lb/hr/hp	Reference 8
10	Turbine performance curves	Figure 6-2	Reference 9
11	Inertia of the rotor	120 lb-ft^2	Assumption 2
12	Turbine setpoint speed	4500 rpm	Reference 10
13	Turbine overspeed trip setpoint	5060 rpm	Reference 10
14	Governor valve lift when open	5/8"	Reference 11

Notes:

a) The steam pressure of 1000 psia was used for both STP and SG injection cases. The actual value of the pressure can vary depending on the steam generator pressure at the time of the event. The use of the same pressure for the two scenarios is important. The actual value is of less importance for this comparative analysis

b) The area is not directly provided. It was estimated from the available details on Reference 2.

The governor valve lift curves developed in Reference 12 are shown in Figure 6-1. These curves provide the mass flow of steam through the valve as a function of the upstream pressure and the valve lift.

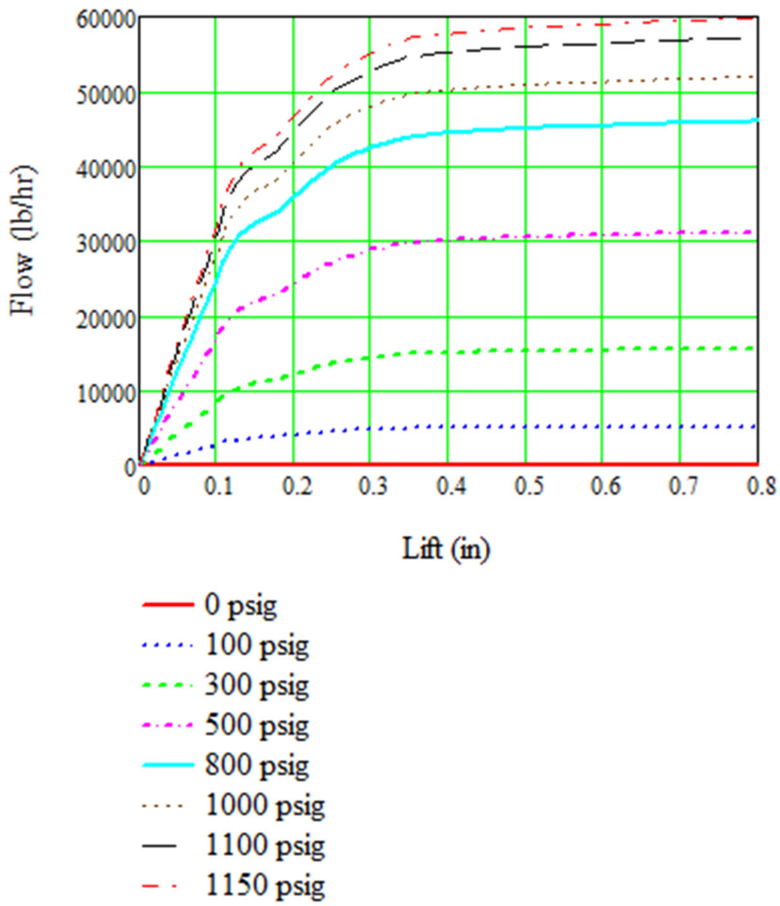


Figure 6-1. Governor Valve Lift Curves

The turbine performance curves are shown in Figure 6-2. These curves provide the power generated by the turbine as a function of the steam mass flow at a given speed.

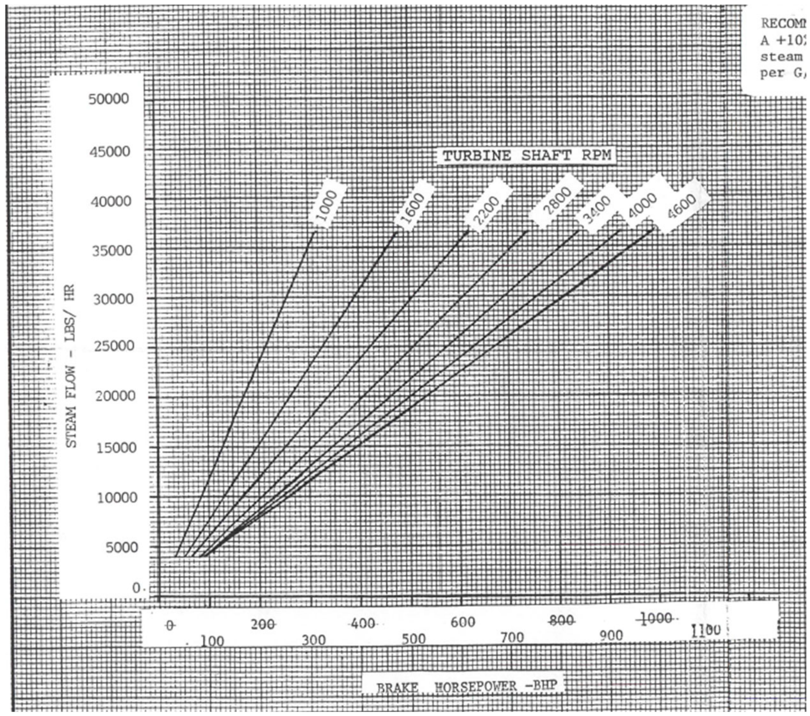


Figure 6-2. Turbine Performance Curves

7.0 Case Definition

Two analysis cases were run to compare the steam flow requirement of the turbine and the required governor valve position between an STP and an SG injection during the pump start transient. The cases are as follows:

- **Case A:** This case simulates the first troubleshooting run (referred to as Run 2) that led to an overspeed trip. The governor valve position was adjusted in the model until the speed ramp calculated by the model matched reasonably with the measured speed ramp of Run 2. Next, the same governor valve position was applied to an SG injection alignment, and the pump speed was calculated. The speed ramp was compared with the calculated speed ramp for Run 2 to assess the margin to the overseed trip setpoint.
- **Case B:** This case simulates a normal start-up for an STP and an SG injection. For each scenario, the governor valve is moved from full open to a closed position in a way that causes the pump speed to reach the normal speed setpoint. The results of this case allow comparison of the power required by the pump, the steam flow required by the turbine, and the governor valve stroke needed to allow the required flow to the turbine for SG injection and STP scenarios.

8.0 Computer Codes

The analysis was performed using a computer program that was run using the Mathcad 15 software on MPR Computer 4495, running Windows 11 Pro operating system. The program is provided in Appendices A and B and in Reference 14. The program falls under the MPR Standard QA Manual (Reference 13) definition of Working Level Software. The analysis program was verified using a line-by-line review of the program functions. The validation of the analysis methodology was performed based on a review of the governing equations, their implementation, sensitivity studies, and reasonableness of the results.

The intent of the analysis is to quantify the difference in valve travel and margin to overspeed for an STP and an SG injection. The analysis does not generate specific outputs that are needed to make any design or operating procedure changes in the plant. Therefore, additional validation of the analysis method is not considered necessary.

The input and output are fully contained in the Mathcad files including the plots provided in this calculation. The analysis files are listed in Table 8-1.

Table 8-1. Listing of Computer Files for an Analysis with a Single Run

Case Identifier	File Name	Input/Output	Description
Case A	"Full Transient Analysis Case A.xmcd"	Both	Simulation of STP Run 2 overspeed and Comparison with SG injection
Case B	"Full Transient Analysis Case B.xmcd"	Both	Simulation of normal STP and SG injection
Lift Curves	"LiftCurveR1.xlsx"	Input for Cases A and B	Lift curves in Excel Format

9.0 Calculations and Results

9.1. Case A

Case A first uses the Run 2 data for the STP alignment to estimate the governor valve position as a function of time in the as-found condition. This is necessary because the position of the governor valve during Run 2 was not measured. The valve position transient was adjusted so the pump speed matched the values measured during the Run 2 STP (Figure 9-1). The governor valve position as a function of time that was input to the model is shown in Figure 9-2. Figure 9-1 shows that the model matches the speed transient during Run 2 reasonably well.

The same valve position transient was then applied to a model created for SG injection. The valve movement is likely similar for an STP and SG injection with the exception that the pump would take longer to reach full speed because more of the energy that is available from the steam would go into rotating the pump than accelerating the turbine in the latter part of the speed transient.

The response of the governor to these differences has not been fully explored since the model does not include the governor logic. However, these differences are not likely to cause a more severe transient and so it is reasonable to apply the valve position transient from the STP to the SG injection model to assess differences in the speed transients.

Figure 9-1 shows the measured pump speed for Run 2 (orange squares), the calculated pump speed from the model for Run 2 and the calculated pump speed from the model for an SG injection. Applying the same valve position to the SG injection scenario results in a peak speed slightly above the target speed setpoint, but well below the overspeed trip setpoint.

If the valve movement were similar to that shown in Figure 9-2, an overspeed trip would not have occurred during an injection event while in the as-found condition. Based on the large margin to the trip setpoint of about 400 rpm as shown in Figure 9-1 and the success of other STP runs, it is unlikely that a trip would have occurred for an SG injection.

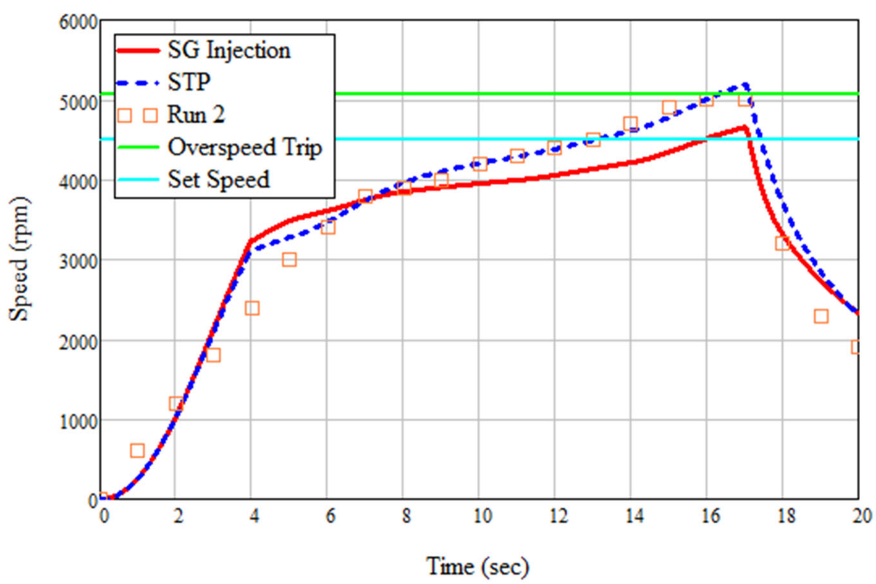


Figure 9-1. Calculated and Measured Speeds

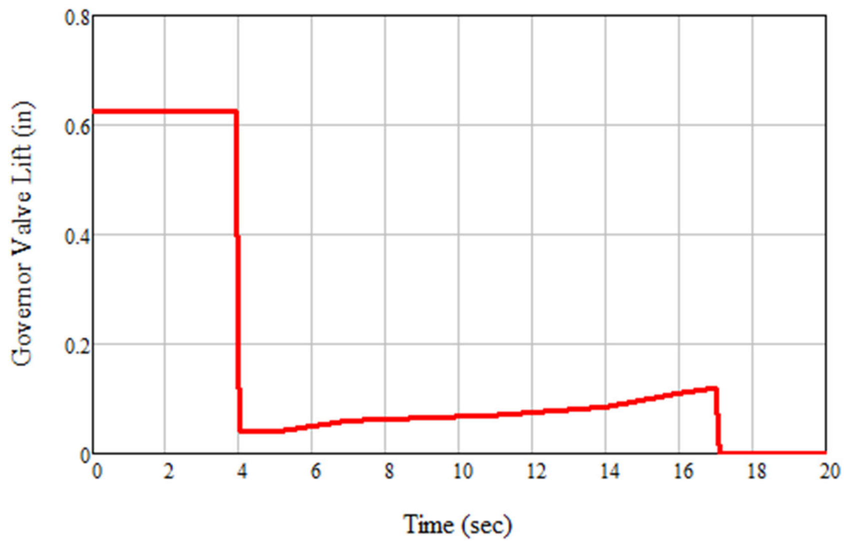


Figure 9-2. Governor Valve Position

9.2. Case B

Figure 9-3 shows the speeds for an STP and an SG injection. The speed ramps are essentially the same and both reach the set speed. The governor valve movements needed for the two cases are different, as shown in Figure 9-4, since the SG injection needs more steam flow to meet the higher power demand of the pump. The initial slopes of the curves are assumed to be the same, but the final valve position is more open for the SG injection case.

The steam flow to the turbine is shown in Figure 9-5. The steam flow demand to the turbine is higher to the turbine for and SG injection than during an STP near the end of the transient. The power requirement of the pump is shown in Figure 9-6. The power requirement is higher for SG injection due to higher flow.

These results demonstrate that due to the higher steam flow demand of the turbine to meet the higher pump power requirement during an SG injection, the governor valve must remain more open. As a result, the challenge on the governor to prevent overspeed is less during an SG injection.

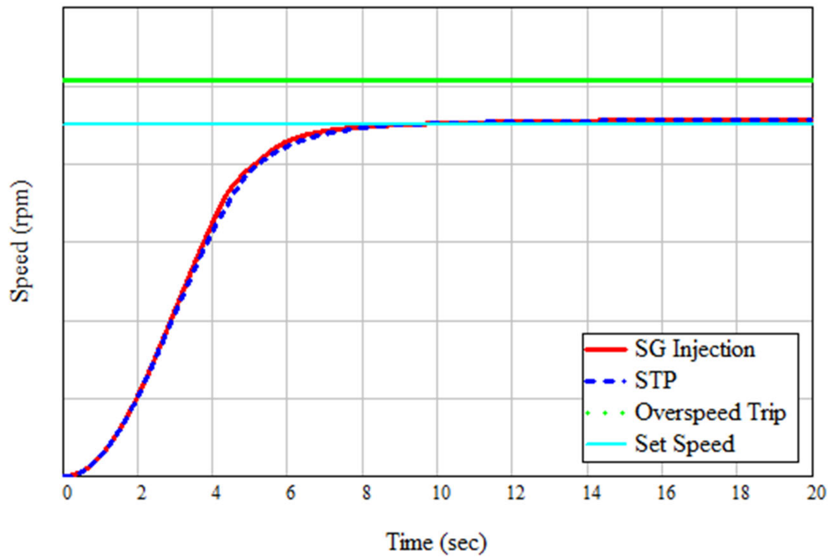


Figure 9-3. Speed Ramps

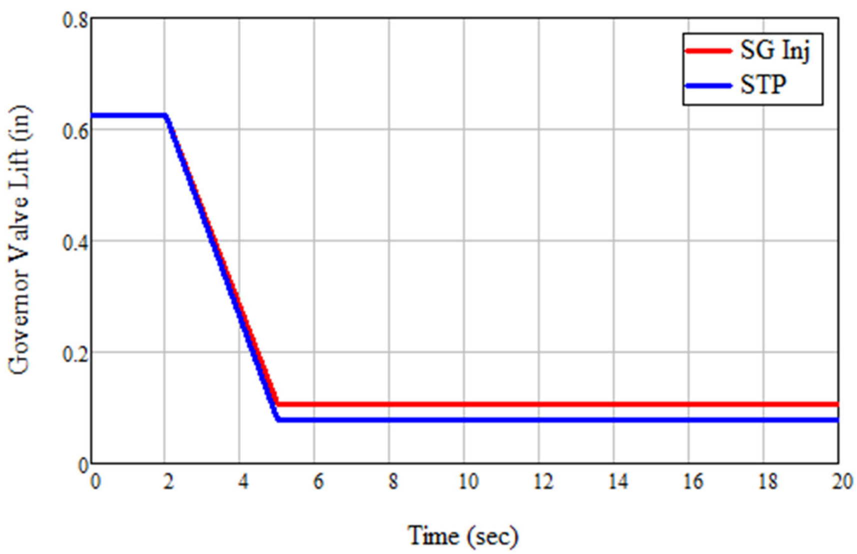


Figure 9-4. Governor Valve Position

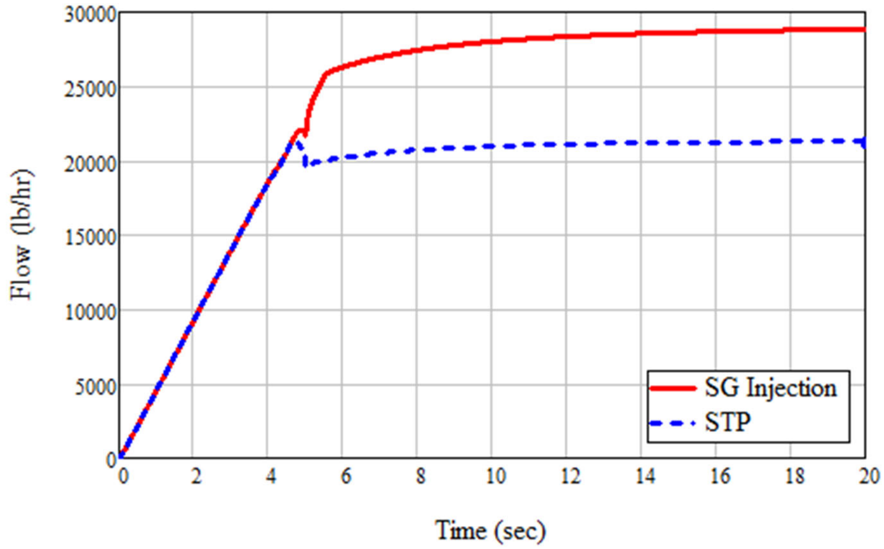


Figure 9-5. TDEFW Pump Turbine Steam Flow

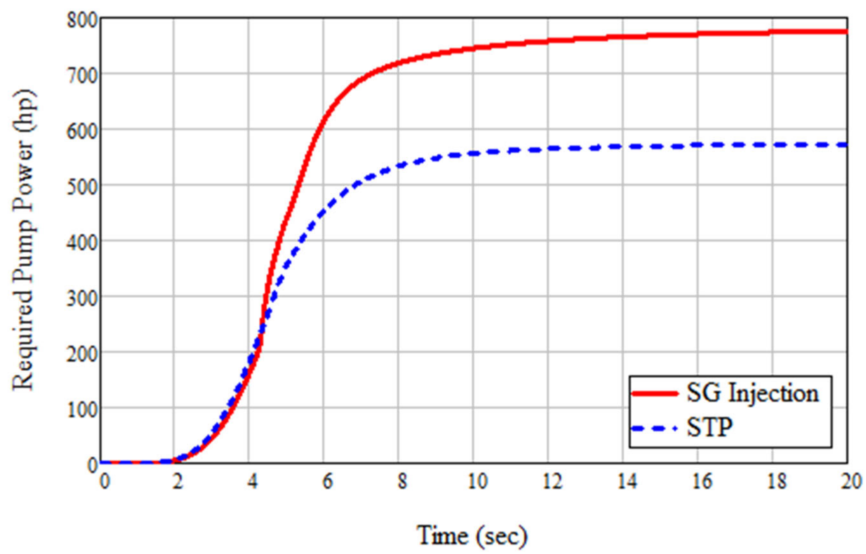


Figure 9-6. TDEFW Pump Required Power

10.0 References

1. MPR Calculation No. 0310-0085-CALC-001, Revision 0, "TDEFW Pump Start Transient Analysis."

2. V.C. Summer Nuclear Station, Drawing No. 1MS-50-105 Sh. 001, "EMERG. FDWTR. PMP. TURB CONT. VALVE," Revision 10.

3. V.C. Summer Enhanced Design Basis Document, "Emergency Feedwater System (EF)," Revision 18.

4. V.C. Summer Nuclear Station, Bill of Material No. CONSREC-000-716253BC Sh. G1-1A, "Control Valves and Accessories – ASME III Class 3 Virgil C. Summer Nuclear Station – Unit 1".

5. V.C. Summer Nuclear Station, Drawing No. C-314-011 Sh. 008, "MAIN STEAM – STEAM SUPPLY TO EMERGENCY FEEDWATER PUMP XPP-8-EF," Revision 4.

6. V.C. Summer Nuclear Station, Drawing No. D-302-011 Sh. 001, "MAIN STEAM (NUCLEAR)," Revision 42.

7. V.C. Summer Nuclear Station, Specification No. SP-0545, "PIPE LINE SPECIFICATION FOR NUCLEAR SAFETY CLASS PIPING," Revision 14.

8. VCS Terry Steam Turbine Instruction Manual, Turbine Type:GS-2, Serial No: T-38765-A, VCS Document number 1MS-94B-425-0, dated November 13, 1979.

9. VCS Terry Turbine Performance Curves, Dresser-Rand Drawing No. K-15270.

10. V.C. Summer Nuclear Station, Procedure No. MMP-300.015, "TURBINE MAINTENANCE, EMERGENCY FEEDWATER PUMP TPP0008", Revision 19, Change J.

11. *Nuclear Maintenance Applications Center: Terry Turbine Maintenance Guide, Auxiliary Feedwater (AFW) Application: Replaces 3002001670*. EPRI, Palo Alto, CA: 2017. 3002010629.

12. MPR Calculation No. 0310-0085-CALC-003, Revision 0, "Development of Lift Curves for V. C. Summer EFW Turbine Governor Valve."

13. MPR Standard Quality Assurance Manual, Revision 8 dated March 3, 2025.

14. Electronic File No. 0310-0085-ELEC-002, Revision 0, "Electronic Files for Calculation 0310-0085-CALC-002."

A Case A Analysis

$N_{step} := 8000$	Number of time steps
$\Delta t := 0.0025 \cdot sec$	Time step size
$\rho := 62.3 \cdot \frac{lb}{ft^3}$	Water density
$L_{iner.sg} := 1326 \cdot ft^{-1}$	Inertial length of SG path
$L_{iner.cst} := 5011 \cdot ft^{-1}$	Inertial length of the mini flow path back to the CST
$L_{iner.stp} := 4673 \cdot ft^{-1}$	Inertial length of the test and mini flow path back to the CST
$P_{suction} := 23.8 \cdot psi$	Pump suction pressure
$H_{inj} := 3900 \cdot ft$	Pump head when injecting to SGs at steady state
$P_{disch} := P_{suction} + H_{inj} \cdot \rho \cdot g = 1.711 \times 10^3 \cdot psi$	Discharge pressure of the pump when injection to the SGs
$P_{sg} := (985 + 14.7) \cdot psi = 999.7 \cdot psi$	Steam generator pressure
$\Delta H_{sg} := (419.2 - 477.26) \cdot ft = -58.06\ ft$	Elevation head between the pump and the SGs
$Q_{sg} := 530 \cdot gpm$	Steady state flow to the SGs
$R_{sg} := \frac{2 \cdot \left(P_{disch} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g\right)}{\rho \cdot Q_{sg}^{2}} = 7.32 \times 10^4 \frac{1}{ft^4}$	Resistance of the flow path to the SGs
$P_{cst} := 14.7 \cdot psi$	Pressure of the return location in the CST
$\Delta H_{cst} := (414 - 450.3) \cdot ft$	Elevation head between the pump and the return point to the CST
$Q_{cst.mini} := 100 \cdot gpm$	Flow through the mini flow line during injection to the SGs
$Q_{cst.stp} := 300 \cdot gpm$	Flow during the STP

$H_{stp} := 4030 \cdot ft$ — Pump TDH during STP at 300 gpm flow

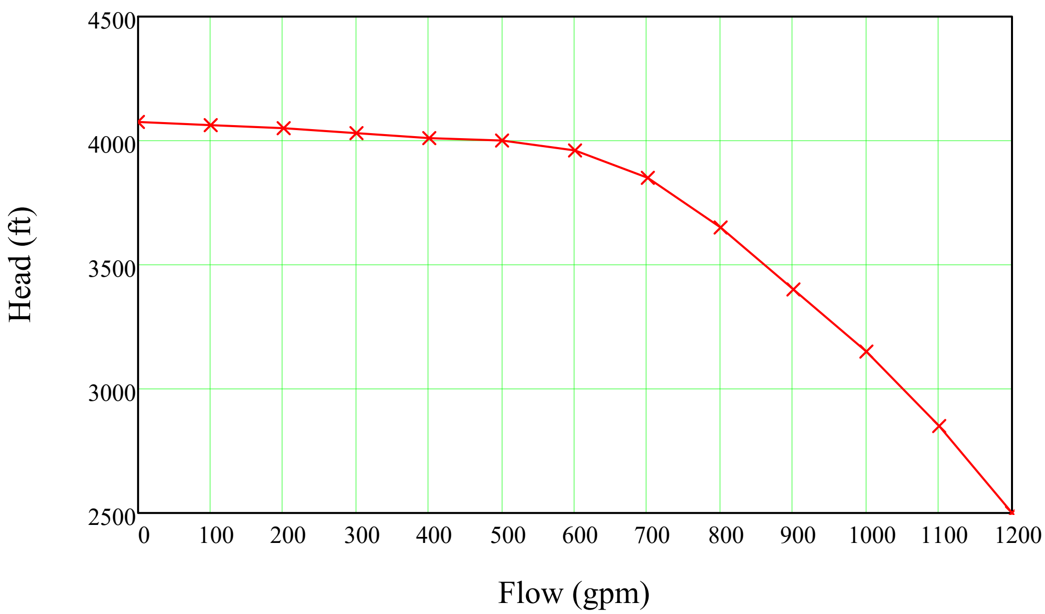
$N_{rate} := 4600$ — Rated speed

Speed ramp data (This is the speed ramp from Run 2)

$$t := \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \end{pmatrix} \cdot sec \qquad Spd := \begin{pmatrix} 0 \\ 600 \\ 1200 \\ 1800 \\ 2400 \\ 3000 \\ 3400 \\ 3800 \\ 3900 \\ 4000 \\ 4200 \\ 4300 \\ 4400 \\ 4500 \\ 4700 \\ 4900 \\ 5000 \\ 5000 \\ 3200 \\ 2300 \\ 1900 \end{pmatrix} \div N_{rate}$$

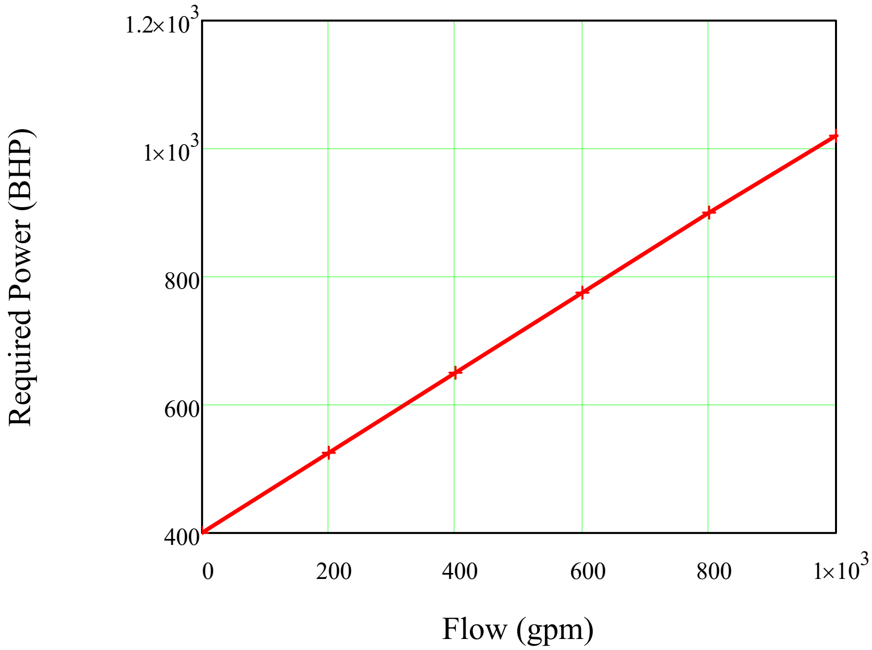
Head flow curve

$$Q_p := \begin{pmatrix} 0 \\ 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \\ 700 \\ 800 \\ 900 \\ 1000 \\ 1100 \\ 1200 \end{pmatrix} \cdot gpm \qquad Hd := \begin{pmatrix} 4075 \\ 4062 \\ 4050 \\ 4030 \\ 4010 \\ 4000 \\ 3960 \\ 3850 \\ 3650 \\ 3400 \\ 3150 \\ 2850 \\ 2500 \end{pmatrix} \cdot ft$$



BHP Curve

$$Qb := \begin{pmatrix} 0 \\ 200 \\ 400 \\ 600 \\ 800 \\ 1000 \end{pmatrix} \cdot gpm \qquad BHP := \begin{pmatrix} 400 \\ 525 \\ 650 \\ 775 \\ 900 \\ 1020 \end{pmatrix} \cdot hp$$



$d_{pipe} := 3.826 \cdot in$	Steam supply piping ID
$L_{pipe} := 3.508 \cdot ft$	Steam supply piping length
$P_{down} := 14.7 \cdot psi$	Pressure downstream of the nozzles
$Cv_{sa} := \frac{155 \cdot gpm}{\sqrt{psi}}$	Steam admission valve flow coefficient
$A_{sa} := 3 \cdot in^2$	Steam admission valve flow area
$t_{stroke.sa} := 32$	Steam admission valve stroke time

$Pow := 990 \cdot hp$ — Rated power of the turbine

$w_{pow} := 37 \cdot \frac{lb}{hr \cdot hp}$ — Steam flow per unit power

$w_{rated} := Pow \cdot w_{pow} = 3.663 \times 10^{4} \cdot \frac{lb}{hr}$ — Rated flow

Turbine performance curve (The data for 4600 rpm is actual turbine specific data. Other points are approximated from another turbine curve).

$$N_{speed} := \begin{pmatrix} 1000 \\ 1600 \\ 2200 \\ 2800 \\ 3400 \\ 4000 \\ 4600 \end{pmatrix} \cdot rpm \qquad Power := \begin{pmatrix} 310 \\ 480 \\ 620 \\ 740 \\ 840 \\ 920 \\ 990 \end{pmatrix} \cdot hp \qquad Torque := \frac{Power}{N_{speed}} = \begin{pmatrix} 1628.2 \\ 1575.6 \\ 1480.1 \\ 1388.1 \\ 1297.6 \\ 1208 \\ 1130.3 \end{pmatrix} \cdot ft \cdot lbf$$

$$Torq_{rate} := \frac{Torque}{w_{rated}} = \begin{pmatrix} 0.044 \\ 0.043 \\ 0.04 \\ 0.038 \\ 0.035 \\ 0.033 \\ 0.031 \end{pmatrix} \cdot \frac{lbf \cdot ft}{lb \div hr}$$

$N_{ost} := 5060 \cdot rpm$ — Overspeed trip setpoint

$N_{set} := 4500 \cdot rpm$ — Speed setpoint

$Lift_{open} := \frac{5}{8} \cdot in$ — Initial (full open) lift of the valve

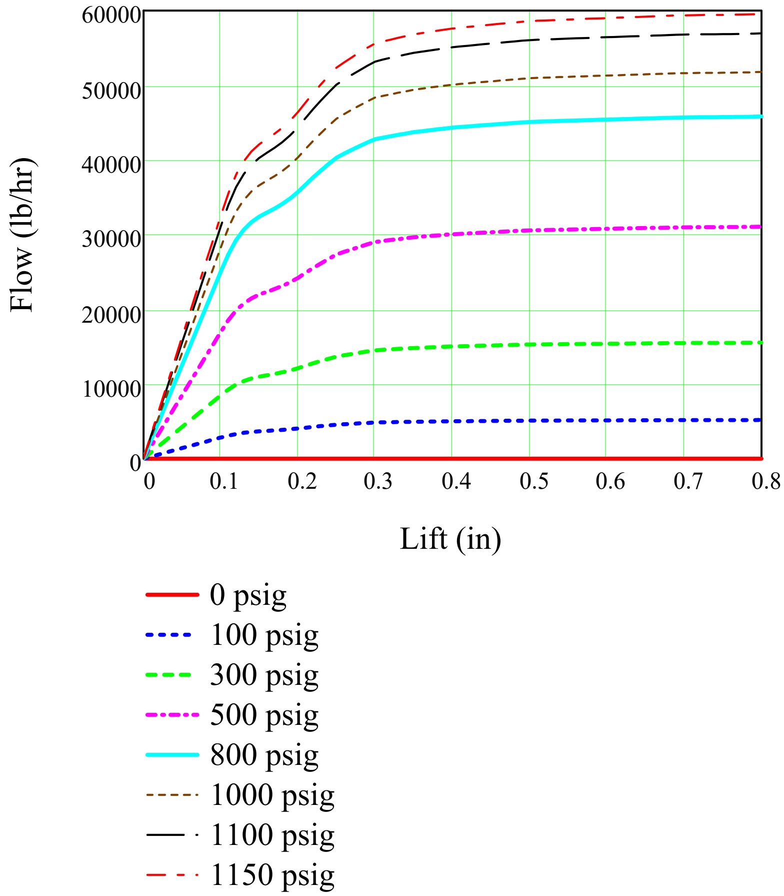
$Lift_{close} := 0.09 \cdot in$

$$t2 := \begin{pmatrix} 0 \\ 3.9 \\ 4 \\ 5 \\ 6 \\ 7 \\ 11 \\ 14 \\ 16 \\ 17 \\ 17.1 \\ 20 \end{pmatrix} \cdot sec \qquad Lift_{govern} := \begin{pmatrix} Lift_{open} \\ Lift_{open} \\ 0.04 \cdot in \\ 0.04 \cdot in \\ 0.05 \cdot in \\ 0.06 \cdot in \\ 0.07 \cdot in \\ 0.085 \cdot in \\ 0.11 \cdot in \\ 0.12 \cdot in \\ 0 \cdot in \\ 0 \cdot in \end{pmatrix}$$

$Gov_{val.lift} := READEXCEL(\text{"LIftCurveR1.xlsx"})$ — Read lift curves from excel file

$P_{vec} := (0 \;\; 100 \;\; 300 \;\; 600 \;\; 885 \;\; 1000 \;\; 1100 \;\; 1150)$ — $Title := \text{"Lift/P"}$

$B := stack(augment(Title, P_{vec}), Gov_{val.lift})$ — Create a table of lift curves with pressure



$Pos := \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ $\quad Cv := \begin{pmatrix} 0 \\ Cv_{sa} \end{pmatrix}$ Cv vs position for steam admission valve

$tx := \begin{pmatrix} 0 \\ t_{stroke.sa} \\ 100 \\ 1000 \end{pmatrix} \cdot sec$ $\quad Pos_{sa} := \begin{pmatrix} 0 \\ 1 \\ 1 \\ 1 \end{pmatrix}$ Time vs position for steam admission valve

$I_{rot} := 120 \cdot lb \cdot ft^2$ Pump and turbine rotary inertia

Linear interpolation function for speed

$Speed(x) := linterp(t, Spd, x)$

Function for determination of pump head as a function of volumetric flow (q) and speed ratio (nr)

$$Hx(n_r, q) := \begin{array}{|l} \text{for } i \in 1 .. \text{rows}(Q_p) \\ \quad \begin{array}{|l} Qx_i \leftarrow n_r \cdot Q_{p_i} \\ Hx_i \leftarrow n_r^2 \cdot Hd_i \end{array} \\ H \leftarrow 0 \quad \text{if } n_r = 0 \\ H \leftarrow 0 \quad \text{if } H < 0 \\ H \leftarrow \text{linterp}(Qx, Hx, q) \quad \text{otherwise} \end{array}$$

Function for determination of pump required BHP as a function of volumetric flow (q) and speed ratio (nr)

$$BHP_{req}(n_r, q) := \begin{array}{|l} \text{for } i \in 1 .. \text{rows}(Qb) \\ \quad \begin{array}{|l} Qx_i \leftarrow n_r \cdot Qb_i \\ PowerX_i \leftarrow n_r^3 \cdot BHP_i \end{array} \\ Pow \leftarrow 0 \quad \text{if } n_r = 0 \\ Pow \leftarrow 0 \quad \text{if } Pow < 0 \\ Pow \leftarrow \text{linterp}(Qx, PowerX, q) \quad \text{otherwise} \end{array}$$

Calculate the resistance of the line to the CST based on flow and the pump head

$$Res_{cst}(Hd, Q) := \begin{array}{|l} P \leftarrow P_{suction} + Hd \cdot \rho \cdot g \\ R \leftarrow \dfrac{2 \cdot \left(P - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g\right)}{\rho \cdot Q^2} \\ R \end{array}$$

$$Res_{cst}(4030 \cdot ft, 300 \cdot gpm) = 5.783 \times 10^5 \frac{1}{ft^4}$$

Determine the SG pressure, CST path inertial length and the CST path resistance depending on if it is injection or STP.

$$\mathrm{Setup}(x) := \begin{array}{|l} \text{if } x = \text{"Inj"} \\ \quad \begin{array}{|l} P \leftarrow P_{sg} \\ L_{in} \leftarrow L_{iner.cst} \\ R \leftarrow Res_{cst}\left(H_{inj}, Q_{cst.mini}\right) \end{array} \\ \text{if } x = \text{"STP"} \\ \quad \begin{array}{|l} P \leftarrow 10000 \cdot psi \\ L_{in} \leftarrow L_{iner.stp} \\ R \leftarrow Res_{cst}\left(H_{stp}, Q_{cst.stp}\right) \end{array} \\ \mathrm{augment}\left(\frac{P}{psi}, \frac{L_{in}}{ft^{-1}}, \frac{R}{ft^{-4}}\right) \end{array}$$

The SG pressure is made 10000 psi for the STP case to prevent any flow.

$$Vol_{stm} := \frac{\pi}{4} \cdot d_{pipe}{}^{2} \cdot L_{pipe} = 0.28 \cdot ft^{3}$$

Volume of steam between admission and governor valves

$$\rho_{sg} := \mathrm{StmPQV}\left(\frac{P_{sg}}{psi}, 1, 0\right)^{-1} \cdot \frac{lb}{ft^{3}} = 2.241 \, \frac{lb}{ft^{3}}$$

Steam density

$$h_{sg} := \mathrm{StmPQH}\left(\frac{P_{sg}}{psi}, 1, 0\right) \cdot \frac{BTU}{lb}$$

Steam enthalpy

$$Cv_{fn}(x) := \mathrm{linterp}(Pos, Cv, x)$$

Admission valve Cv as a function of position

$$\mathrm{Lift\_Gov}(x) := \mathrm{linterp}\left(t2, Lift_{govern}, x\right)$$

Governor valve lift as a function of time

$$A_{val}(Pos) := Pos \cdot A_{sa}$$

Steam admission valve flow area as a function of position

$$\mathrm{Vpos}(t) := \mathrm{linterp}\left(tx, Pos_{sa}, t\right)$$

Valve position as a function of time

$$T_{rate}(x) := \begin{array}{|l} a \leftarrow \mathrm{linterp}\left(N_{speed}, Torq_{rate}, x\right) \\ a \leftarrow 0 \quad \text{if } a < 0 \\ a \end{array}$$

Torque per unit flow as a function of speed

$$\mathrm{Torq}(Nx, w) := T_{rate}(Nx) \cdot w$$

Torque as a function of flow and turbine speed

$$\mathrm{Torq}\left(0, 68 \cdot \frac{lb}{hr}\right) = 3.185 \cdot lbf \cdot ft$$

Test

Double interpolation function that returns the flow through the governor valve, given the pressure upstream of the valve and the valve lift

```
Fun_Interp(Pr, Lift) := | Error ← "Inputs out of range"
                        | if [Lift < 0 ∨ Lift > (B^⟨1⟩)_rows(B)]
                        |    | Error
                        |    | break
                        | if (Pr < 0 ∨ Pr > Pvec_1,cols(Pvec))
                        |    | Error
                        |    | break
                        | otherwise
                        |    | for i ∈ 2 .. cols(B) − 1
                        |    |    | if Pr ≥ (B^⟨i⟩)_1,1 ∧ Pr ≤ (B^⟨i+1⟩)_1,1
                        |    |    |    | A ← submatrix(B^⟨i⟩, 2, rows(B^⟨i⟩), 1, cols(B^⟨i⟩))
                        |    |    |    | C ← submatrix(B^⟨i+1⟩, 2, rows(B^⟨i+1⟩), 1, cols(B^⟨i+1⟩))
                        |    |    |    | HX1 ← (B^⟨i⟩)_1,1
                        |    |    |    | HX2 ← (B^⟨i+1⟩)_1,1
                        |    |    | ""
                        |    | for j ∈ 1 .. rows(B) − 1
                        |    |    Column_new_j ← (Pr − HX1)/(HX2 − HX1) · (C_j − A_j) + A_j
                        |    | P_new ← submatrix(B^⟨1⟩, 2, rows(B^⟨1⟩), 1, 1)
                        |    | Value(x) ← linterp(P_new, Column_new, x)
                        |    | Output ← Value(Lift) · lb/hr
                        | Output
```

Function for critical mass flux as a function of stagnation pressure and enthalpy

$$s\_fun(po, ho) := StmPHS\left(\frac{po}{psi}, \frac{ho}{BTU \div lbm}, 0\right)\cdot\frac{BTU}{lbm\cdot R}$$

$$\rho\_fun(p, po, ho) := StmPSV\left[\frac{p}{psi}, \frac{s\_fun(po, ho)}{BTU \div (lbm\cdot R)}, 0\right]^{-1} \frac{lbm}{ft^3}$$

$$h\_fun(p, po, ho) := StmPSH\left[\frac{p}{psi}, \frac{s\_fun(po, ho)}{BTU \div (lbm\cdot R)}, 0\right]\frac{BTU}{lbm}$$

$$g\_fun(p, po, ho) := \rho\_fun(p, po, ho)\cdot\sqrt{2\cdot(ho - h\_fun(p, po, ho))}$$

$$PCRIT(po, ho, p) := Maximize(g\_fun, p)$$

$$GCRIT_{guess}(po, ho, pguess) := g\_fun(PCRIT(po, ho, pguess), po, ho)$$

$$GCRIT(po, ho) := GCRIT_{guess}\left(po, ho, \frac{po}{2}\right)$$

$$Flux := \left| \begin{array}{l} h \leftarrow StmPQH\left(\frac{P_{sg}}{psi}, 1, 0\right)\cdot\frac{BTU}{lb} \\ f_{crit} \leftarrow GCRIT\left(P_{sg}, h\right) \end{array} \right. = 2.011 \times 10^3 \frac{lb}{s\cdot ft^2}$$

Critical mass flux for the SG steam conditions

Pressure as a function of density and enthalpy

Given

$$\rho = StmPHV\left(\frac{P_{guess}}{psi}, \frac{h}{\frac{BTU}{lb}}, 0\right)^{-1}\cdot\frac{lb}{ft^3}$$

$$PState\left(P_{guess}, \rho, h\right) := Find\left(P_{guess}\right)$$

Steam admission valve resistance as a function of position

$$R_{stm.adm}(pos) := \begin{array}{|l} Q \leftarrow Cv_{fn}(pos) \\ Rx \leftarrow 100000000 \cdot ft^{-4} \quad \text{if } Q = 0 \\ Rx \leftarrow \dfrac{2}{\rho \cdot Q^2} \quad \text{otherwise} \end{array}$$

Function for steam flow calculation (calculates both choked and non-choked flows and selects the lower of the two)

$$Stm_{Flow}(P_d, t, mass) := \begin{array}{|l} vpos \leftarrow Vpos(t) \\ Rx \leftarrow R_{stm.adm}(vpos) \\ \rho_d \leftarrow mass \div Vol_{stm} \\ w_{noncrit} \leftarrow \sqrt{\dfrac{2 \cdot (P_{sg} - P_d) \cdot mean(\rho_{sg}, \rho_d)}{Rx}} \quad \text{if } P_d \le P_{sg} \\ w_{noncrit} \leftarrow 0 \quad \text{otherwise} \\ Area_{val} \leftarrow A_{val}(vpos) \\ w_{crit} \leftarrow Flux \cdot Area_{val} \\ w \leftarrow w_{crit} \quad \text{if } w_{crit} < w_{noncrit} \\ w \leftarrow w_{noncrit} \quad \text{otherwise} \\ w \end{array}$$

Mass and energy calculation for steam volume between the admission valve and governor valve (Used to set initial conditions)

$$Stm_{m.U}(P, Vol) := \begin{array}{|l} v \leftarrow StmPQV(P \div psi, 1, 0) \cdot \dfrac{ft^3}{lb} \\ h \leftarrow StmPQH(P \div psi, 1, 0) \cdot \dfrac{BTU}{lb} \\ m \leftarrow Vol \div v \\ e \leftarrow h - P \cdot v \\ U \leftarrow e \cdot m \\ augment\left(\dfrac{m}{lb}, \dfrac{U}{BTU}\right) \end{array}$$

Steam pressure calculation function for the volume between the admission valve and governor valve (calculates pressure based on mass, energy and volume of steam)

$$Stm_P(m, U, Vol, P) := \left| \begin{array}{l} \rho \leftarrow m \div Vol \\ e \leftarrow U \div m \\ h \leftarrow e + \dfrac{P}{\rho} \\ Px \leftarrow PState(P, \rho, h) \end{array} \right.$$

Main solver (solves the differential equations for STP or SG injection alignments)

The solves need a string, either "STP" or "Inj".

$$X(str) := \left| \begin{array}{l} \text{for } i \in ORIGIN..N_{step} \\ \quad \left| \begin{array}{l} \text{if } i = ORIGIN \\ \quad \left| \begin{array}{l} t_i \leftarrow 0 \\ Pos_{sa_i} \leftarrow Vpos(t_i) \\ N_{turb_i} \leftarrow 0 \\ Torq_{tb_i} \leftarrow 0 \\ w_{s_i} \leftarrow 0 \\ P_{pipe_i} \leftarrow P_{down} \\ w_{gv_i} \leftarrow 0 \\ Lift_{gv_i} \leftarrow Lift\_Gov(t_i) \\ m_{stm_i} \leftarrow Stm_{m.U}(P_{pipe_i}, Vol_{stm})_{1,1} \cdot lb \\ U_{stm_i} \leftarrow Stm_{m.U}(P_{pipe_i}, Vol_{stm})_{1,2} \cdot BTU \\ e_{stm_i} \leftarrow U_{stm_i} \div m_{stm_i} \\ v_{stm_i} \leftarrow Vol_{stm} \div m_{stm_i} \\ h_{stm_i} \leftarrow StmPQH\left(\dfrac{P_{pipe_i}}{psi}, 1, 0\right) \cdot \dfrac{BTU}{lb} \\ w_{sg_i} \leftarrow 0 \end{array} \right. \end{array} \right. \end{array} \right.$$

$Q_{sg_i} \leftarrow 0$

$w_{cst_i} \leftarrow 0$

$Q_{cst_i} \leftarrow 0$

$Hd_i \leftarrow 0$

$P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g$

$Pow_{pmp_i} \leftarrow 0$

$Spd_{r2_i} \leftarrow Speed(t_i) \cdot N_{rate}$

$N_{o_i} \leftarrow N_{ost}$

$N_{s_i} \leftarrow N_{set}$

otherwise

$t_i \leftarrow t_{i-1} + \Delta t$

$Pos_{sa_i} \leftarrow Vpos(t_i)$

$Lift_{gv_i} \leftarrow Lift\_Gov(t_i)$

$w_{s_i} \leftarrow Stm_{Flow}\left(P_{pipe_{i-1}}, t_i, m_{stm_{i-1}}\right)$

$m_{stm_i} \leftarrow m_{stm_{i-1}} + w_{s_i} \cdot \Delta t - w_{gv_{i-1}} \cdot \Delta t$

$U_{stm_i} \leftarrow U_{stm_{i-1}} + w_{s_i} \cdot h_{sg} \cdot \Delta t - h_{stm_{i-1}} \cdot \left(w_{gv_{i-1}} \cdot \Delta t\right)$

$e_{stm_i} \leftarrow U_{stm_i} \div m_{stm_i}$

$v_{stm_i} \leftarrow Vol_{stm} \div m_{stm_i}$

$h_{stm_i} \leftarrow e_{stm_i} + P_{pipe_{i-1}} \cdot v_{stm_i}$

$$P_{pipe_i} \leftarrow PState\left(P_{pipe_{i-1}}, \frac{1}{v_{stm_i}}, h_{stm_i}\right)$$

$$w_{gv_i} \leftarrow Fun\_Interp\left(\frac{P_{pipe_i}}{psi} - 14.7, \frac{Lift_{gv_i}}{in}\right)$$

$Torq_{tb_i} \leftarrow Torq\left(N_{turb_{i-1}}, w_{gv_i}\right)$

$$Hd_i \leftarrow Hx\left(\frac{N_{turb_{i-1}}}{N_{rate} \cdot rpm}, Q_{sg_{i-1}} + Q_{cst_{i-1}}\right)$$

""

$$Pow_{pmp_i} \leftarrow BHP_{req}\left(\frac{N_{turb_{i-1}}}{N_{rate} \cdot rpm}, Q_{sg_{i-1}} + Q_{cst_{i-1}}\right)$$

$$P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g$$

$$Mx \leftarrow Setup(str)$$

$$P_{sg} \leftarrow Mx_{1,1} \cdot psi$$

$$L_{iner.cst} \leftarrow Mx_{1,2} \cdot ft^{-1}$$

$$R_{cst} \leftarrow Mx_{1,3} \cdot ft^{-4}$$

$$wdot_{sg} \leftarrow \frac{1}{L_{iner.sg}} \cdot \left(P_{disch_i} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g - \frac{R_{sg} \cdot w_{sg_{i-1}} \cdot \left|w_{sg_{i-1}}\right|}{2 \cdot \rho}\right)$$

$$wdot_{cst} \leftarrow \frac{1}{L_{iner.cst}} \cdot \left(P_{disch_i} - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g - \frac{R_{cst} \cdot w_{cst_{i-1}} \cdot \left|w_{cst_{i-1}}\right|}{2 \cdot \rho}\right)$$

$$w_{sg_i} \leftarrow w_{sg_{i-1}} + wdot_{sg} \cdot \Delta t$$

$$w_{sg_i} \leftarrow 0 \quad \text{if} \quad w_{sg_i} < 0$$

$$w_{cst_i} \leftarrow w_{cst_{i-1}} + wdot_{cst} \cdot \Delta t$$

$$w_{cst_i} \leftarrow 0 \quad \text{if} \quad w_{cst_i} < 0$$

$$Q_{sg_i} \leftarrow w_{sg_i} \div \rho$$

$$Q_{cst_i} \leftarrow w_{cst_i} \div \rho$$

$$Torq_{pmp_i} \leftarrow 0 \quad \text{if} \quad N_{turb_{i-1}} = 0$$

$$Torq_{pmp_i} \leftarrow Pow_{pmp_i} \div N_{turb_{i-1}} \quad \text{otherwise}$$

$$N_{turb_i} \leftarrow N_{turb_{i-1}} + \frac{\left(Torq_{tb_i} - Torq_{pmp_i}\right) \cdot \Delta t}{I_{rot}}$$

$$Spd_{r2_i} \leftarrow Speed\left(t_i\right) \cdot N_{rate}$$

$$N_{o_i} \leftarrow N_{ost}$$

$$N_{s_i} \leftarrow N_{set}$$

$$A \leftarrow augment\left(\frac{t}{sec}, Pos_{sa}, \frac{P_{pipe}}{psi}, \frac{w_s}{\frac{lb}{hr}}, \frac{w_{gv}}{\frac{lb}{hr}}, \frac{Torq_{tb}}{lbf \cdot ft}, \frac{N_{turb}}{rpm}, \frac{Torq_{pmp}}{lbf \cdot ft}, Spd_{r2}, \frac{N_o}{rpm}, \frac{N_s}{rpm}\right)$$

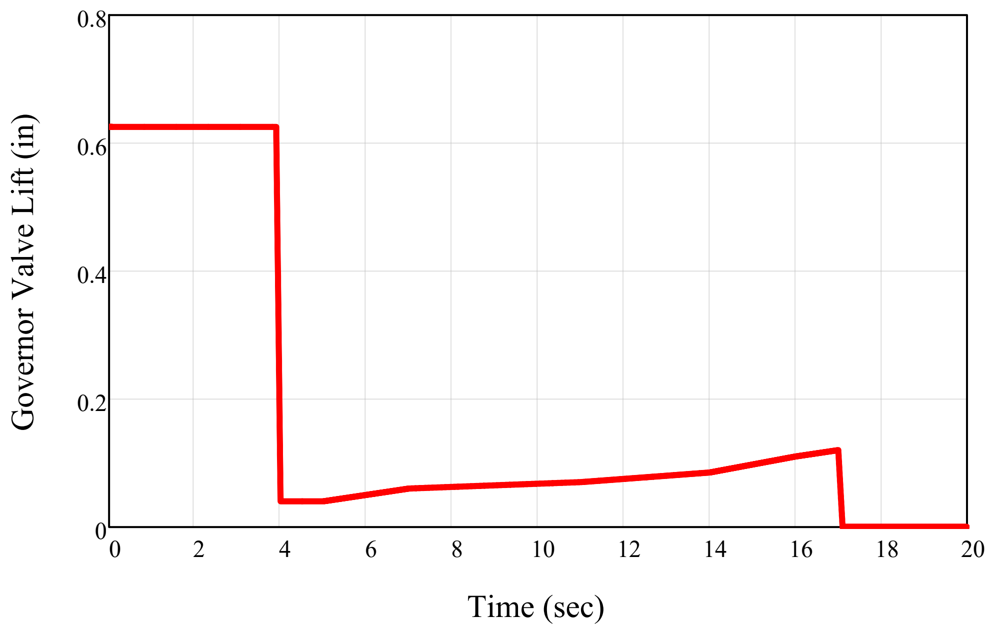
""

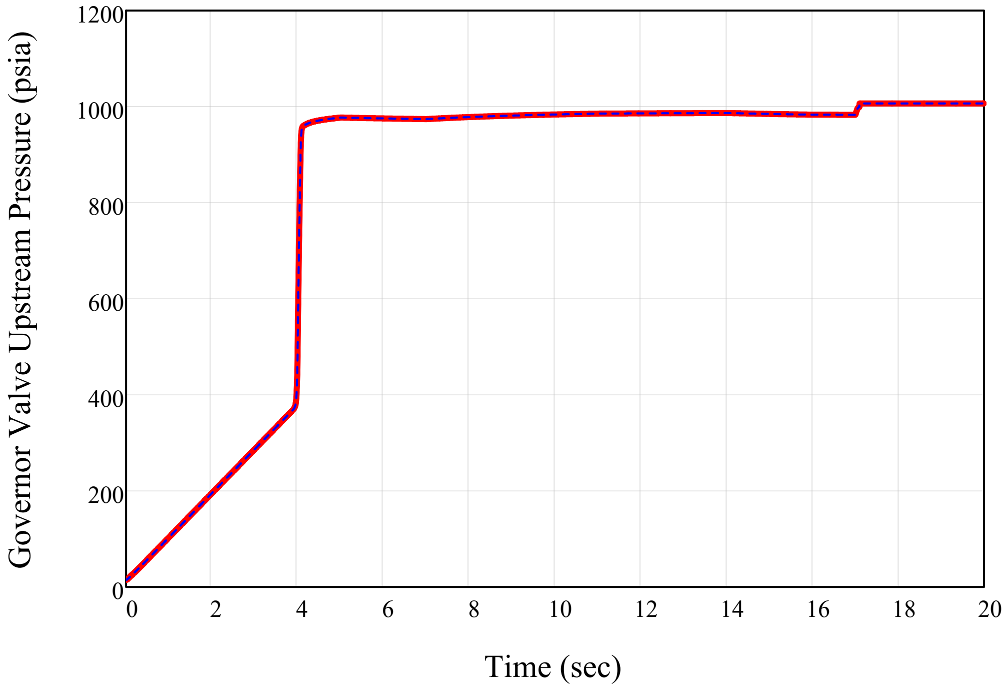
$$B \leftarrow \text{augment}\left(\frac{Q_{sg}}{\text{gpm}}, \frac{Q_{cst}}{\text{gpm}}, \frac{Torq_{tb}}{\text{lbf}\cdot\text{ft}}, \frac{Torq_{pmp}}{\text{lbf}\cdot\text{ft}}, \frac{Lift_{gv}}{\text{in}}\right)$$

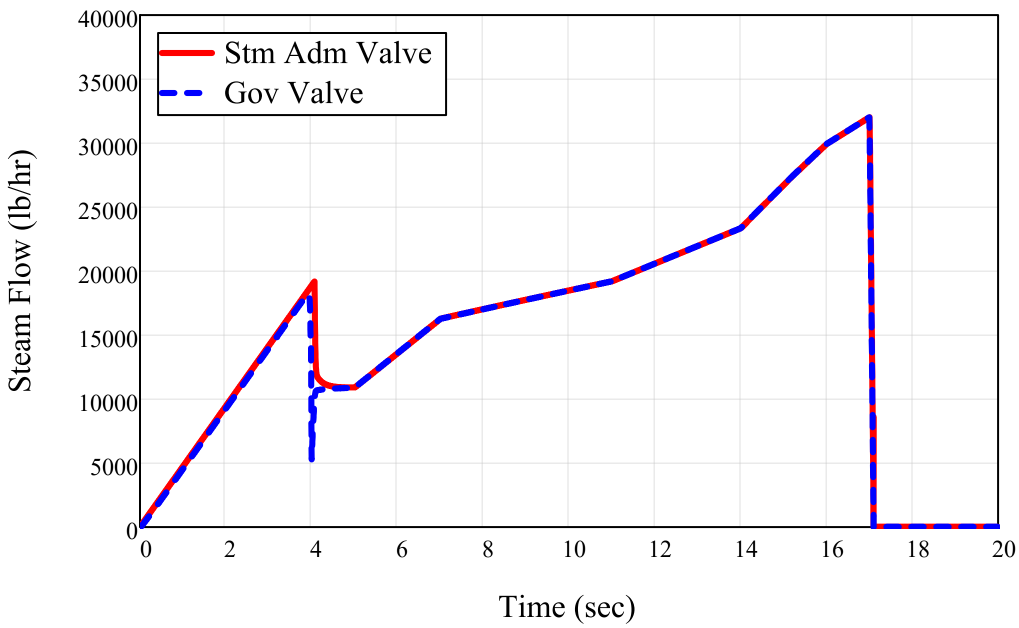
augment(A, B)

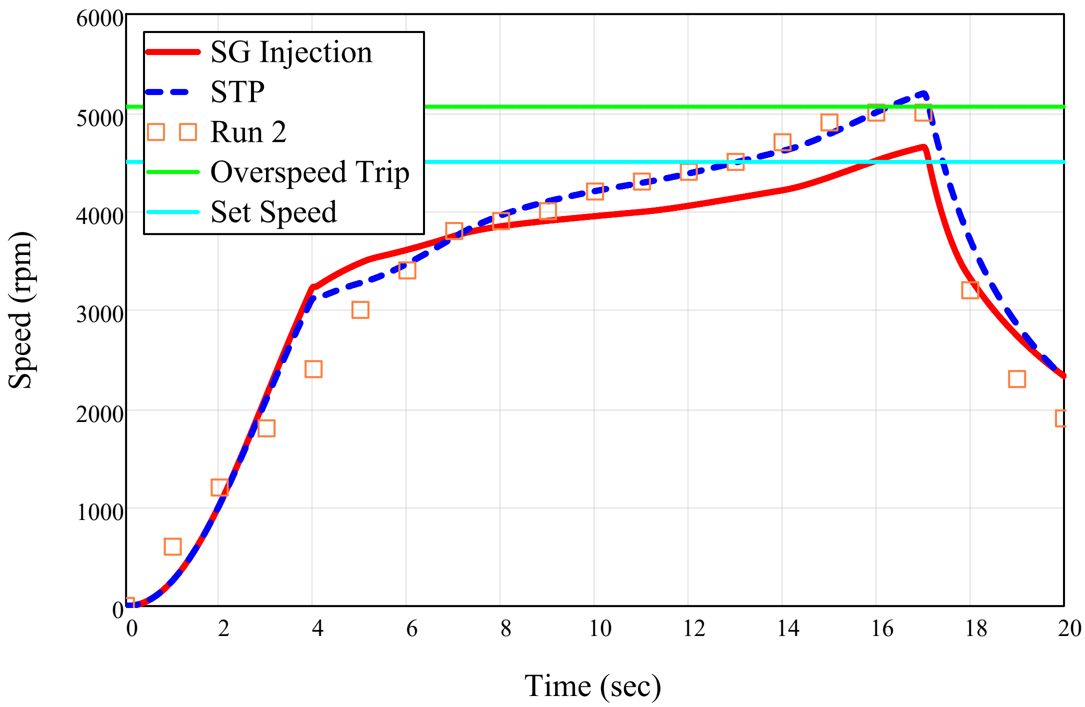
$Y := X(\text{"Inj"})$ Matrix of results for SG injection

$Z := X(\text{"STP"})$ Matrix of results for STP




Governor Valve Upstream Pressure (psia)
0
200
400
600
800
1000
1200
0
2
4
6
8
10
12
14
16
18
20
Time (sec)


Stm Adm Valve
Gov Valve
Steam Flow (lb/hr)
0
5000
10000
15000
20000
25000
30000
35000
40000
0
2
4
6
8
10
12
14
16
18
20
Time (sec)


SG Injection
STP
Run 2
Overspeed Trip
Set Speed
Speed (rpm)
Time (sec)
0
1000
2000
3000
4000
5000
6000
0
2
4
6
8
10
12
14
16
18
20

B Case B Analysis

$N_{step} := 8000$	Number of time steps
$\Delta t := 0.0025 \cdot sec$	Time step size
$\rho := 62.3 \cdot \frac{lb}{ft^3}$	Water density
$L_{iner.sg} := 1326 \cdot ft^{-1}$	Inertial length of SG path
$L_{iner.cst} := 5011 \cdot ft^{-1}$	Inertial length of the mini flow path back to the CST
$L_{iner.stp} := 4673 \cdot ft^{-1}$	Inertial length of the test and mini flow path back to the CST
$P_{suction} := 23.8 \cdot psi$	Pump suction pressure
$H_{inj} := 3900 \cdot ft$	Pump head when injecting to SGs at steady state
$P_{disch} := P_{suction} + H_{inj} \cdot \rho \cdot g = 1.711 \times 10^3 \cdot psi$	Discharge pressure of the pump when injection to the SGs
$P_{sg} := (985 + 14.7) \cdot psi = 999.7 \cdot psi$	Steam generator pressure
$\Delta H_{sg} := (419.2 - 477.26) \cdot ft = -58.06\ ft$	Elevation head between the pump and the SGs
$Q_{sg} := 530 \cdot gpm$	Steady state flow to the SGs
$R_{sg} := \frac{2 \cdot \left(P_{disch} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g\right)}{\rho \cdot Q_{sg}^2} = 7.32 \times 10^4 \frac{1}{ft^4}$	Resistance of the flow path to the SGs
$P_{cst} := 14.7 \cdot psi$	Pressure of the return location in the CST
$\Delta H_{cst} := (414 - 450.3) \cdot ft$	Elevation head between the pump and the return point to the CST
$Q_{cst.mini} := 100 \cdot gpm$	Flow through the mini flow line during injection to the SGs
$Q_{cst.stp} := 300 \cdot gpm$	Flow during the STP

$H_{stp} := 4030 \cdot ft$ Pump TDH during STP at 300 gpm flow

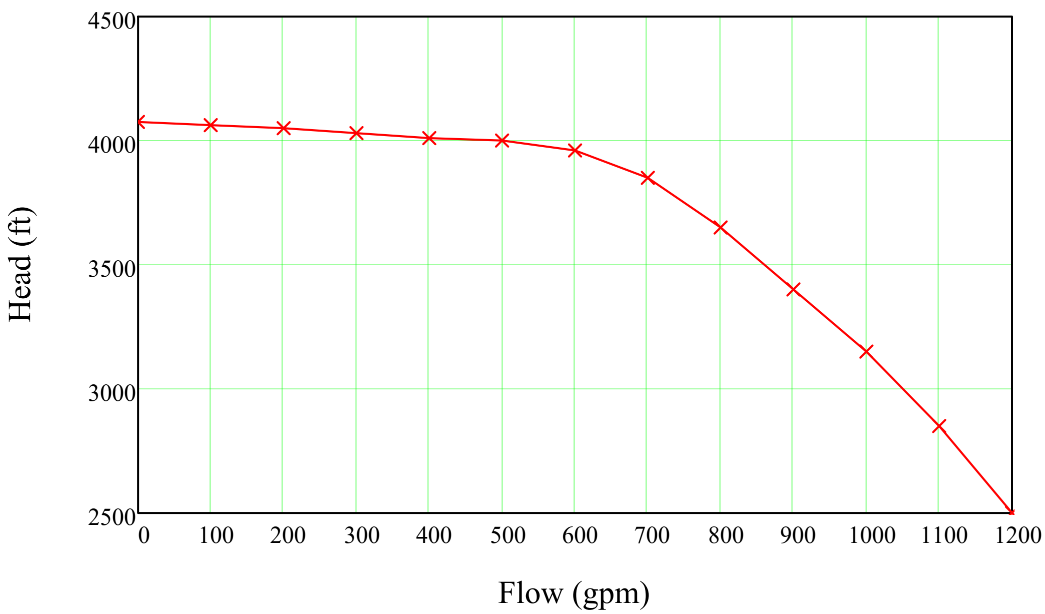
$N_{rate} := 4600$ Rated speed

Speed ramp data (This is the speed ramp from Run 2)

$$t := \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \\ 15 \\ 16 \\ 17 \\ 18 \\ 19 \\ 20 \end{pmatrix} \cdot sec \qquad Spd := \begin{pmatrix} 0 \\ 600 \\ 1200 \\ 1800 \\ 2400 \\ 3000 \\ 3400 \\ 3800 \\ 3900 \\ 4000 \\ 4200 \\ 4300 \\ 4400 \\ 4500 \\ 4700 \\ 4900 \\ 5000 \\ 5000 \\ 3200 \\ 2300 \\ 1900 \end{pmatrix} \div N_{rate}$$

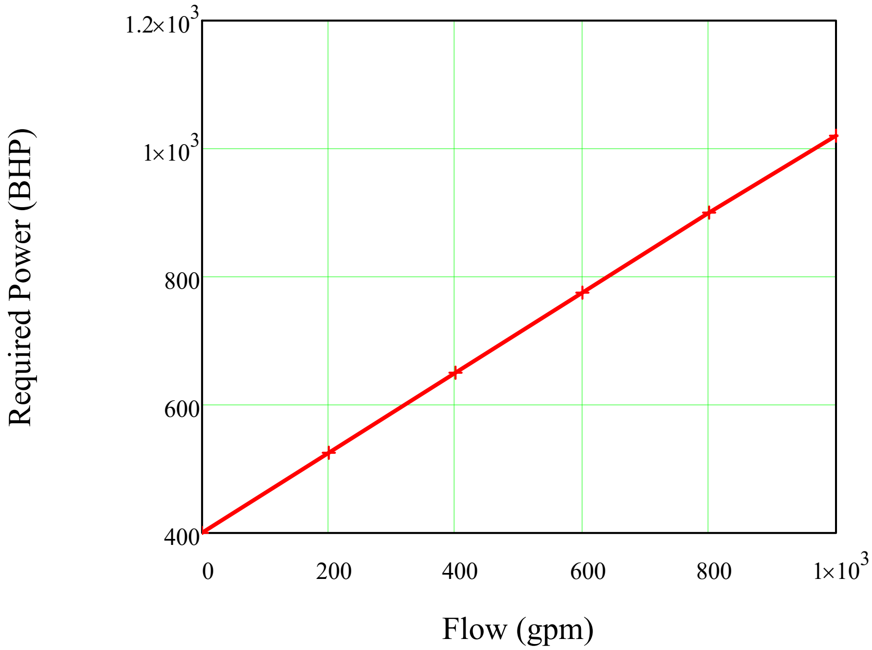
Head flow curve

$$Q_p := \begin{pmatrix} 0 \\ 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \\ 700 \\ 800 \\ 900 \\ 1000 \\ 1100 \\ 1200 \end{pmatrix} \cdot gpm \qquad Hd := \begin{pmatrix} 4075 \\ 4062 \\ 4050 \\ 4030 \\ 4010 \\ 4000 \\ 3960 \\ 3850 \\ 3650 \\ 3400 \\ 3150 \\ 2850 \\ 2500 \end{pmatrix} \cdot ft$$



BHP Curve

$$Qb := \begin{pmatrix} 0 \\ 200 \\ 400 \\ 600 \\ 800 \\ 1000 \end{pmatrix} \cdot gpm \qquad BHP := \begin{pmatrix} 400 \\ 525 \\ 650 \\ 775 \\ 900 \\ 1020 \end{pmatrix} \cdot hp$$



$d_{pipe} := 3.826 \cdot in$ — Steam supply piping ID

$L_{pipe} := 3.508 \cdot ft$ — Steam supply piping length

$P_{down} := 14.7 \cdot psi$ — Pressure downstream of the nozzles

$Cv_{sa} := \dfrac{155 \cdot gpm}{\sqrt{psi}}$ — Steam admission valve flow coefficient

$A_{sa} := 3 \cdot in^2$ — Steam admission valve flow area

$t_{stroke.sa} := 32$ — Steam admission valve stroke time

$Pow := 990 \cdot hp$ Rated power of the turbine

$w_{pow} := 37 \cdot \frac{lb}{hr \cdot hp}$ Steam flow per unit power

$w_{rated} := Pow \cdot w_{pow} = 3.663 \times 10^4 \cdot \frac{lb}{hr}$ Rated flow

Turbine performance curve

$$N_{speed} := \begin{pmatrix} 1000 \\ 1600 \\ 2200 \\ 2800 \\ 3400 \\ 4000 \\ 4600 \end{pmatrix} \cdot rpm \qquad Power := \begin{pmatrix} 310 \\ 480 \\ 620 \\ 740 \\ 840 \\ 920 \\ 990 \end{pmatrix} \cdot hp \qquad Torque := \frac{Power}{N_{speed}} = \begin{pmatrix} 1628.2 \\ 1575.6 \\ 1480.1 \\ 1388.1 \\ 1297.6 \\ 1208 \\ 1130.3 \end{pmatrix} \cdot ft \cdot lbf$$

$$Torq_{rate} := \frac{Torque}{w_{rated}} = \begin{pmatrix} 0.044 \\ 0.043 \\ 0.04 \\ 0.038 \\ 0.035 \\ 0.033 \\ 0.031 \end{pmatrix} \cdot \frac{lbf \cdot ft}{lb \div hr}$$

$N_{ost} := 5060 \cdot rpm$ Overspeed trip setpoint

$N_{set} := 4500 \cdot rpm$ Speed setpoint

$Lift_{open} := \frac{5}{8} \cdot in$ Initial (full open) lift of the valve

$Lift_{close.inj} := 0.105 \cdot in$

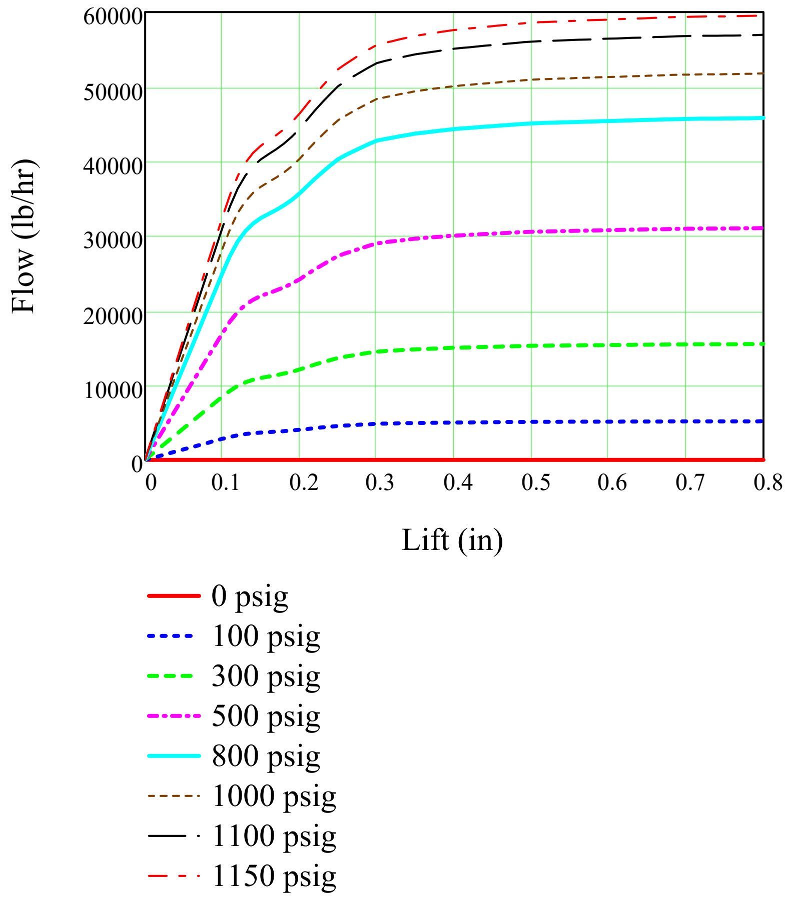
$Lift_{close.stp} := 0.077 \cdot in$

$$t2 := \begin{pmatrix} 0 \\ 2 \\ 5 \\ 13 \\ 14 \\ 16 \\ 17 \\ 17.1 \\ 20 \end{pmatrix} \cdot sec \qquad Lift_{govern.STP} := \begin{pmatrix} Lift_{open} \\ Lift_{open} \\ Lift_{close.stp} \\ Lift_{close.stp} \\ Lift_{close.stp} \\ Lift_{close.stp} \\ Lift_{close.stp} \\ Lift_{close.stp} \\ Lift_{close.stp} \end{pmatrix} \qquad Lift_{govern.Inj} := \begin{pmatrix} Lift_{open} \\ Lift_{open} \\ Lift_{close.inj} \\ Lift_{close.inj} \\ Lift_{close.inj} \\ Lift_{close.inj} \\ Lift_{close.inj} \\ Lift_{close.inj} \\ Lift_{close.inj} \end{pmatrix}$$

$Gov_{val.lift} := READEXCEL("LiftCurveR1.xlsx")$ — Read lift curves from excel file

$P_{vec} := (0 \;\; 100 \;\; 300 \;\; 600 \;\; 885 \;\; 1000 \;\; 1100 \;\; 1150)$ — $Title := "Lift/P"$

$B := stack(augment(Title, P_{vec}), Gov_{val.lift})$ — Create a table of lift curves with pressure


60000
50000
40000
30000
20000
10000
0
Flow (lb/hr)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Lift (in)
0 psig
100 psig
300 psig
500 psig
800 psig
1000 psig
1100 psig
1150 psig

$Pos := \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ $Cv := \begin{pmatrix} 0 \\ Cv_{sa} \end{pmatrix}$ Cv vs position for steam admission valve

$tx := \begin{pmatrix} 0 \\ t_{stroke.sa} \\ 100 \\ 1000 \end{pmatrix} \cdot sec$ $Pos_{sa} := \begin{pmatrix} 0 \\ 1 \\ 1 \\ 1 \end{pmatrix}$ Time vs position for steam admission valve

$I_{rot} := 120 \cdot lb \cdot ft^2$ Pump and turbine rotary inertia (assumed)

Linear interpolation function for speed

$Speed(x) := linterp(t, Spd, x)$

Function for determination of pump head as a function of volumetric flow (q) and speed ratio (nr)

$$
\begin{aligned}
Hx(n_r, q) := \; & \text{for } i \in 1 .. rows(Q_p) \\
& \quad Qx_i \leftarrow n_r \cdot Q_{p_i} \\
& \quad Hx_i \leftarrow n_r^{\,2} \cdot Hd_i \\
& H \leftarrow 0 \;\; \text{if } n_r = 0 \\
& H \leftarrow 0 \;\; \text{if } H < 0 \\
& H \leftarrow linterp(Qx, Hx, q) \;\; \text{otherwise}
\end{aligned}
$$

Function for determination of pump required BHP as a function of volumetric flow (q) and speed ratio (nr)

$$
\begin{aligned}
BHP_{req}(n_r, q) := \; & \text{for } i \in 1 .. rows(Qb) \\
& \quad Qx_i \leftarrow n_r \cdot Qb_i \\
& \quad PowerX_i \leftarrow n_r^{\,3} \cdot BHP_i \\
& Pow \leftarrow 0 \;\; \text{if } n_r = 0 \\
& Pow \leftarrow 0 \;\; \text{if } Pow < 0 \\
& Pow \leftarrow linterp(Qx, PowerX, q) \;\; \text{otherwise}
\end{aligned}
$$

Calculate the resistance of the line to the CST based on flow and the pump head

$$Res_{cst}(Hd, Q) := \left| \begin{array}{l} P \leftarrow P_{suction} + Hd \cdot \rho \cdot g \\ R \leftarrow \dfrac{2 \cdot \left(P - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g\right)}{\rho \cdot Q^2} \\ R \end{array} \right.$$

$$Res_{cst}(4030 \cdot ft, 300 \cdot gpm) = 5.783 \times 10^5 \frac{1}{ft^4}$$

Determine the SG pressure, CST path inertial length and the CST path resistance depending on if it is injection or STP.

$$Setup(x) := \left| \begin{array}{l} \text{if } x = \text{"Inj"} \\ \quad \left| \begin{array}{l} P \leftarrow P_{sg} \\ L_{in} \leftarrow L_{iner.cst} \\ R \leftarrow Res_{cst}\left(H_{inj}, Q_{cst.mini}\right) \end{array} \right. \\ \text{if } x = \text{"STP"} \\ \quad \left| \begin{array}{l} P \leftarrow 10000 \cdot psi \\ L_{in} \leftarrow L_{iner.stp} \\ R \leftarrow Res_{cst}\left(H_{stp}, Q_{cst.stp}\right) \end{array} \right. \\ augment\left(\dfrac{P}{psi}, \dfrac{L_{in}}{ft^{-1}}, \dfrac{R}{ft^{-4}}\right) \end{array} \right.$$

The SG pressure is made 10000 psi for the STP case to prevent any flow.

$Vol_{stm} := \frac{\pi}{4} \cdot d_{pipe}^{2} \cdot L_{pipe} = 0.28 \cdot ft^{3}$

Volume of steam between admission and governor valves

$\rho_{sg} := StmPQV\left(\frac{P_{sg}}{psi}, 1, 0\right)^{-1} \cdot \frac{lb}{ft^{3}} = 2.241 \frac{lb}{ft^{3}}$

Steam density

$h_{sg} := StmPQH\left(\frac{P_{sg}}{psi}, 1, 0\right) \cdot \frac{BTU}{lb}$

Steam enthalpy

$Cv_{fn}(x) := linterp(Pos, Cv, x)$

Admission valve Cv as a function of position

Governor valve lift as a function of time

$$Lift\_Gov(x, str) := \begin{vmatrix} Temp \leftarrow linterp\left(t2, Lift_{govern.STP}, x\right) \;\; \text{if } str = \text{"STP"} \\ Temp \leftarrow linterp\left(t2, Lift_{govern.Inj}, x\right) \;\; \text{if } str = \text{"Inj"} \\ Temp \end{vmatrix}$$

$A_{val}(Pos) := Pos \cdot A_{sa}$

Steam admission valve flow area as a function of position

$Vpos(t) := linterp\left(tx, Pos_{sa}, t\right)$

Valve position as a function of time

$$T_{rate}(x) := \begin{vmatrix} a \leftarrow linterp\left(N_{speed}, Torq_{rate}, x\right) \\ a \leftarrow 0 \;\; \text{if } a < 0 \\ a \end{vmatrix}$$

Torque per unit flow as a function of speed

$Torq(Nx, w) := T_{rate}(Nx) \cdot w$

Torque as a function of flow and turbine speed

$Torq\left(0, 68 \cdot \frac{lb}{hr}\right) = 3.185 \cdot lbf \cdot ft$

Test

Double interpolation function that returns the flow through the governor valve, given the pressure upstream of the valve and the valve lift

```
Fun_Interp(Pr, Lift) :=
  Error ← "Inputs out of range"
  if [Lift < 0 ∨ Lift > (B^⟨1⟩)_rows(B)]
      Error
      break
  if (Pr < 0 ∨ Pr > Pvec_1,cols(Pvec))
      Error
      break
  otherwise
      for i ∈ 2 .. cols(B) − 1
          if Pr ≥ (B^⟨i⟩)_1,1 ∧ Pr ≤ (B^⟨i+1⟩)_1,1
              A ← submatrix(B^⟨i⟩, 2, rows(B^⟨i⟩), 1, cols(B^⟨i⟩))
              C ← submatrix(B^⟨i+1⟩, 2, rows(B^⟨i+1⟩), 1, cols(B^⟨i+1⟩))
              HX1 ← (B^⟨i⟩)_1,1
              HX2 ← (B^⟨i+1⟩)_1,1
          ""
      for j ∈ 1 .. rows(B) − 1
        Column_new_j ← ((Pr − HX1)/(HX2 − HX1))·(C_j − A_j) + A_j
      P_new ← submatrix(B^⟨1⟩, 2, rows(B^⟨1⟩), 1, 1)
      Value(x) ← linterp(P_new, Column_new, x)
      Output ← Value(Lift)·(lb/hr)
  Output
```

Function for critical mass flux as a function of stagnation pressure and enthalpy

$$\text{s\_fun}(po,ho) := \text{StmPHS}\left(\frac{po}{psi},\frac{ho}{BTU \div lbm},0\right)\cdot\frac{BTU}{lbm\cdot R}$$

$$\rho\text{\_fun}(p,po,ho) := \text{StmPSV}\left[\frac{p}{psi},\frac{\text{s\_fun}(po,ho)}{BTU \div (lbm\cdot R)},0\right]^{-1}\frac{lbm}{ft^3}$$

$$\text{h\_fun}(p,po,ho) := \text{StmPSH}\left[\frac{p}{psi},\frac{\text{s\_fun}(po,ho)}{BTU \div (lbm\cdot R)},0\right]\frac{BTU}{lbm}$$

$$\text{g\_fun}(p,po,ho) := \rho\text{\_fun}(p,po,ho)\cdot\sqrt{2\cdot(ho - \text{h\_fun}(p,po,ho))}$$

$$\text{PCRIT}(po,ho,p) := \text{Maximize}(\text{g\_fun},p)$$

$$\text{GCRIT}_{guess}(po,ho,pguess) := \text{g\_fun}(\text{PCRIT}(po,ho,pguess),po,ho)$$

$$\text{GCRIT}(po,ho) := \text{GCRIT}_{guess}\left(po,ho,\frac{po}{2}\right)$$

$$\text{Flux} := \left| \begin{array}{l} h \leftarrow \text{StmPQH}\left(\frac{P_{sg}}{psi},1,0\right)\cdot\frac{BTU}{lb} \\ f_{crit} \leftarrow \text{GCRIT}\left(P_{sg},h\right) \end{array} \right. = 2.011\times10^{3}\,\frac{lb}{s\cdot ft^2}$$

Critical mass flux for the SG steam conditions

Pressure as a function of density and enthalpy

Given

$$\rho = \text{StmPHV}\left(\frac{P_{guess}}{psi},\frac{h}{\frac{BTU}{lb}},0\right)^{-1}\cdot\frac{lb}{ft^3}$$

$$\text{PState}\left(P_{guess},\rho,h\right) := \text{Find}\left(P_{guess}\right)$$

Steam admission valve resistance as a function of position

$$R_{stm.adm}(pos) := \left| \begin{array}{l} Q \leftarrow Cv_{fn}(pos) \\ Rx \leftarrow 100000000 \cdot ft^{-4} \quad \text{if } Q = 0 \\ Rx \leftarrow \dfrac{2}{\rho \cdot Q^2} \quad \text{otherwise} \end{array} \right.$$

Function for steam flow calculation (calculates both choked and non-choked flows and selects the lower of the two)

$$Stm_{Flow}(P_d, t, mass) := \left| \begin{array}{l} vpos \leftarrow Vpos(t) \\ Rx \leftarrow R_{stm.adm}(vpos) \\ \rho_d \leftarrow mass \div Vol_{stm} \\ w_{noncrit} \leftarrow \sqrt{\dfrac{2 \cdot (P_{sg} - P_d) \cdot mean(\rho_{sg}, \rho_d)}{Rx}} \quad \text{if } P_d \le P_{sg} \\ w_{noncrit} \leftarrow 0 \quad \text{otherwise} \\ Area_{val} \leftarrow A_{val}(vpos) \\ w_{crit} \leftarrow Flux \cdot Area_{val} \\ w \leftarrow w_{crit} \quad \text{if } w_{crit} < w_{noncrit} \\ w \leftarrow w_{noncrit} \quad \text{otherwise} \\ w \end{array} \right.$$

Mass and energy calculation for steam volume between the admission valve and governor valve (used to set initial conditions)

$$Stm_{m.U}(P, Vol) := \left| \begin{array}{l} v \leftarrow StmPQV(P \div psi, 1, 0) \cdot \dfrac{ft^3}{lb} \\ h \leftarrow StmPQH(P \div psi, 1, 0) \cdot \dfrac{BTU}{lb} \\ m \leftarrow Vol \div v \\ e \leftarrow h - P \cdot v \\ U \leftarrow e \cdot m \\ augment\left(\dfrac{m}{lb}, \dfrac{U}{BTU}\right) \end{array} \right.$$

Steam pressure calculation function for the volume between the admission valve and governor valve (calculates pressure based on mass, energy and volume of steam)

$$Stm_P(m, U, Vol, P) := \left| \begin{array}{l} \rho \leftarrow m \div Vol \\ e \leftarrow U \div m \\ h \leftarrow e + \dfrac{P}{\rho} \\ Px \leftarrow PState(P, \rho, h) \end{array} \right.$$

Main solver (solves the differentiual equations for STP or SG injection alignments)

The solves need a string, either "STP" or "Inj".

$$X(str) := \left| \begin{array}{l} \text{for } i \in ORIGIN .. N_{step} \\ \quad \left| \begin{array}{l} \text{if } i = ORIGIN \\ \quad \left| \begin{array}{l} t_i \leftarrow 0 \\ Pos_{sa_i} \leftarrow Vpos(t_i) \\ N_{turb_i} \leftarrow 0 \\ Torq_{tb_i} \leftarrow 0 \\ w_{s_i} \leftarrow 0 \\ P_{pipe_i} \leftarrow P_{down} \\ w_{gv_i} \leftarrow 0 \\ Lift_{gv_i} \leftarrow Lift\_Gov(t_i, str) \\ m_{stm_i} \leftarrow Stm_{m.U}(P_{pipe_i}, Vol_{stm})_{1,1} \cdot lb \\ U_{stm_i} \leftarrow Stm_{m.U}(P_{pipe_i}, Vol_{stm})_{1,2} \cdot BTU \\ e_{stm_i} \leftarrow U_{stm_i} \div m_{stm_i} \\ v_{stm_i} \leftarrow Vol_{stm} \div m_{stm_i} \end{array} \right. \end{array} \right. \end{array} \right.$$

$$h_{stm_i} \leftarrow StmPQH\left(\frac{P_{pipe_i}}{psi}, 1, 0\right) \cdot \frac{BTU}{lb}$$

$$w_{sg_i} \leftarrow 0$$

$$Q_{sg_i} \leftarrow 0$$

$$w_{cst_i} \leftarrow 0$$

$$Q_{cst_i} \leftarrow 0$$

$$Hd_i \leftarrow 0$$

$$P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g$$

$$Pow_{pmp_i} \leftarrow 0$$

$$Spd_{r2_i} \leftarrow Speed\left(t_i\right) \cdot N_{rate}$$

$$N_{o_i} \leftarrow N_{ost}$$

$$N_{s_i} \leftarrow N_{set}$$

otherwise

$$t_i \leftarrow t_{i-1} + \Delta t$$

$$Pos_{sa_i} \leftarrow Vpos\left(t_i\right)$$

$$Lift_{gv_i} \leftarrow Lift\_Gov\left(t_i, str\right)$$

$$w_{s_i} \leftarrow Stm_{Flow}\left(P_{pipe_{i-1}}, t_i, m_{stm_{i-1}}\right)$$

$$m_{stm_i} \leftarrow m_{stm_{i-1}} + w_{s_i} \cdot \Delta t - w_{gv_{i-1}} \cdot \Delta t$$

$$U_{stm_i} \leftarrow U_{stm_{i-1}} + w_{s_i} \cdot h_{sg} \cdot \Delta t - h_{stm_{i-1}} \cdot \left(w_{gv_{i-1}} \cdot \Delta t\right)$$

$$e_{stm_i} \leftarrow U_{stm_i} \div m_{stm_i}$$

$$v_{stm_i} \leftarrow Vol_{stm} \div m_{stm_i}$$

$$h_{stm_i} \leftarrow e_{stm_i} + P_{pipe_{i-1}} \cdot v_{stm_i}$$

$$P_{pipe_i} \leftarrow PState\left(P_{pipe_{i-1}}, \frac{1}{v_{stm_i}}, h_{stm_i}\right)$$

$$w_{gv_i} \leftarrow \text{Fun\_Interp}\left(\frac{P_{pipe_i}}{psi} - 14.7, \frac{Lift_{gv_i}}{in}\right)$$

$$Torq_{tb_i} \leftarrow Torq\left(N_{turb_{i-1}}, w_{gv_i}\right)$$

$$Hd_i \leftarrow Hx\left(\frac{N_{turb_{i-1}}}{N_{rate} \cdot rpm}, Q_{sg_{i-1}} + Q_{cst_{i-1}}\right)$$

$$Pow_{pmp_i} \leftarrow BHP_{req}\left(\frac{N_{turb_{i-1}}}{N_{rate} \cdot rpm}, Q_{sg_{i-1}} + Q_{cst_{i-1}}\right)$$

$$P_{disch_i} \leftarrow P_{suction} + Hd_i \cdot \rho \cdot g$$

$$Mx \leftarrow Setup(str)$$

$$P_{sg} \leftarrow Mx_{1,1} \cdot psi$$

$$L_{iner.cst} \leftarrow Mx_{1,2} \cdot ft^{-1}$$

$$R_{cst} \leftarrow Mx_{1,3} \cdot ft^{-4}$$

$$wdot_{sg} \leftarrow \frac{1}{L_{iner.sg}} \cdot \left(P_{disch_i} - P_{sg} + \Delta H_{sg} \cdot \rho \cdot g - \frac{R_{sg} \cdot w_{sg_{i-1}} \cdot \left|w_{sg_{i-1}}\right|}{2 \cdot \rho}\right)$$

$$wdot_{cst} \leftarrow \frac{1}{L_{iner.cst}} \cdot \left(P_{disch_i} - P_{cst} + \Delta H_{cst} \cdot \rho \cdot g - \frac{R_{cst} \cdot w_{cst_{i-1}} \cdot \left|w_{cst_{i-1}}\right|}{2 \cdot \rho}\right)$$

$$w_{sg_i} \leftarrow w_{sg_{i-1}} + wdot_{sg} \cdot \Delta t$$

$$w_{sg_i} \leftarrow 0 \quad \text{if } w_{sg_i} < 0$$

$$w_{cst_i} \leftarrow w_{cst_{i-1}} + wdot_{cst} \cdot \Delta t$$

$$w_{cst_i} \leftarrow 0 \quad \text{if } w_{cst_i} < 0$$

$$Q_{sg_i} \leftarrow w_{sg_i} \div \rho$$

$$Q_{cst_i} \leftarrow w_{cst_i} \div \rho$$

$$Torq_{pmp_i} \leftarrow 0 \quad \text{if } N_{turb_{i-1}} = 0$$

$$Torq_{pmp_i} \leftarrow Pow_{pmp_i} \div N_{turb_{i-1}} \quad \text{otherwise}$$

$$N_{turb_i} \leftarrow N_{turb_{i-1}} + \frac{\left(Torq_{tb_i} - Torq_{pmp_i}\right) \cdot \Delta t}{I_{rot}}$$

$$Spd_{r2_i} \leftarrow Speed(t_i) \cdot N_{rate}$$

$$N_{o_i} \leftarrow N_{ost}$$

$$N_{s_i} \leftarrow N_{set}$$

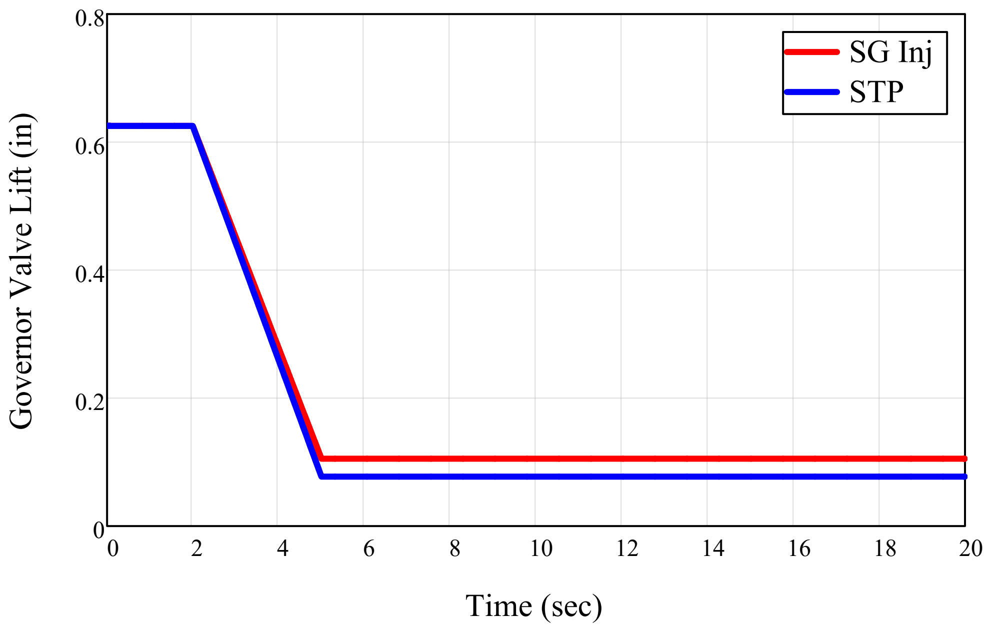
$$A \leftarrow augment\left(\frac{t}{sec}, Pos_{sa}, \frac{P_{pipe}}{psi}, \frac{w_s}{\frac{lb}{hr}}, \frac{w_{gv}}{\frac{lb}{hr}}, \frac{Torq_{tb}}{lbf \cdot ft}, \frac{N_{turb}}{rpm}, \frac{Torq_{pmp}}{lbf \cdot ft}, Spd_{r2}, \frac{N_o}{rpm}, \frac{N_s}{rpm}\right)$$

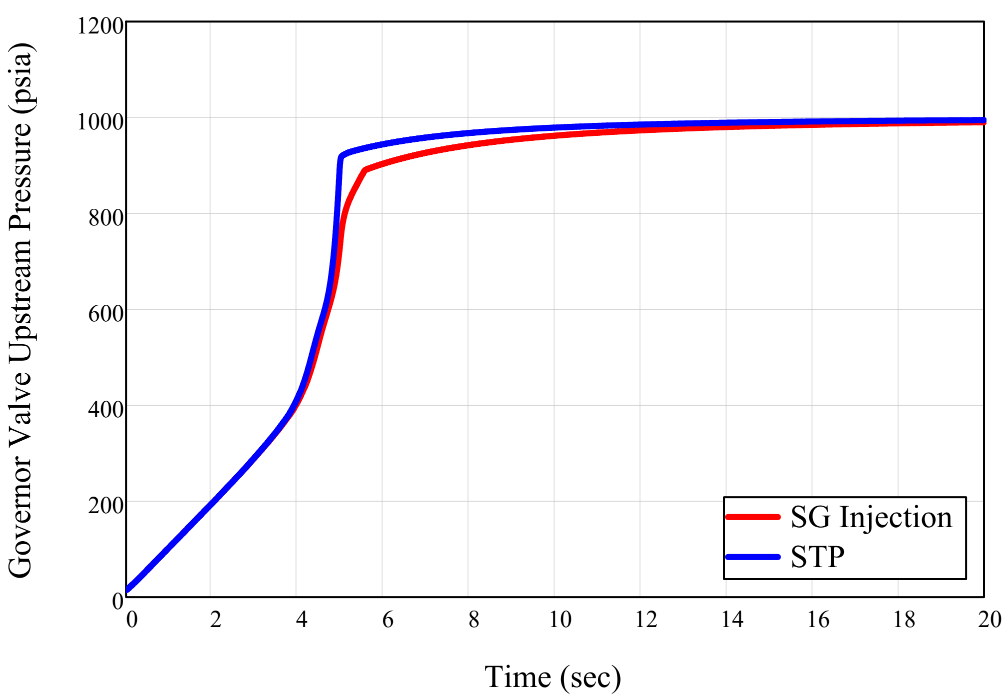
$$B \leftarrow augment\left(\frac{Q_{sg}}{gpm}, \frac{Q_{cst}}{gpm}, \frac{Torq_{tb}}{lbf \cdot ft}, \frac{Torq_{pmp}}{lbf \cdot ft}, \frac{Lift_{gv}}{in}, \frac{Pow_{pmp}}{hp}\right)$$

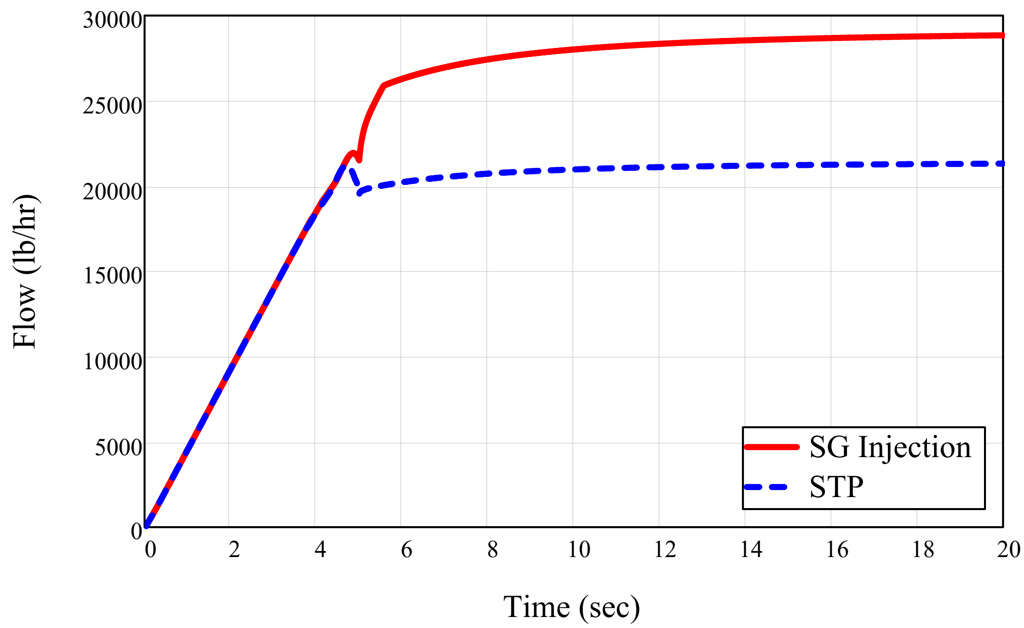
$$augment(A, B)$$

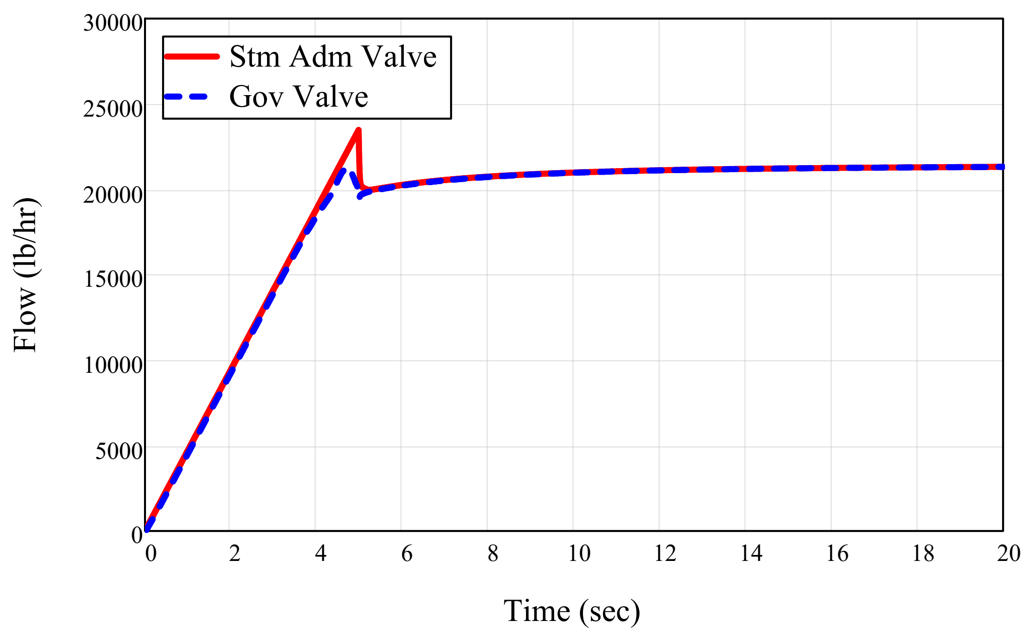
Y := X("Inj") Matrix of results for SG injection

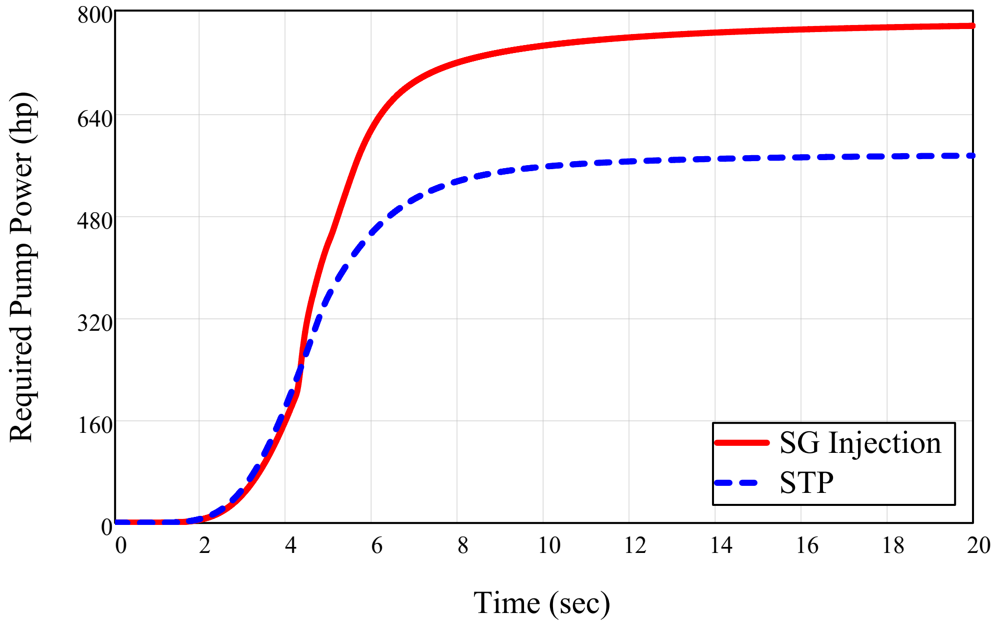
Z := X("STP") Matrix of results for STP

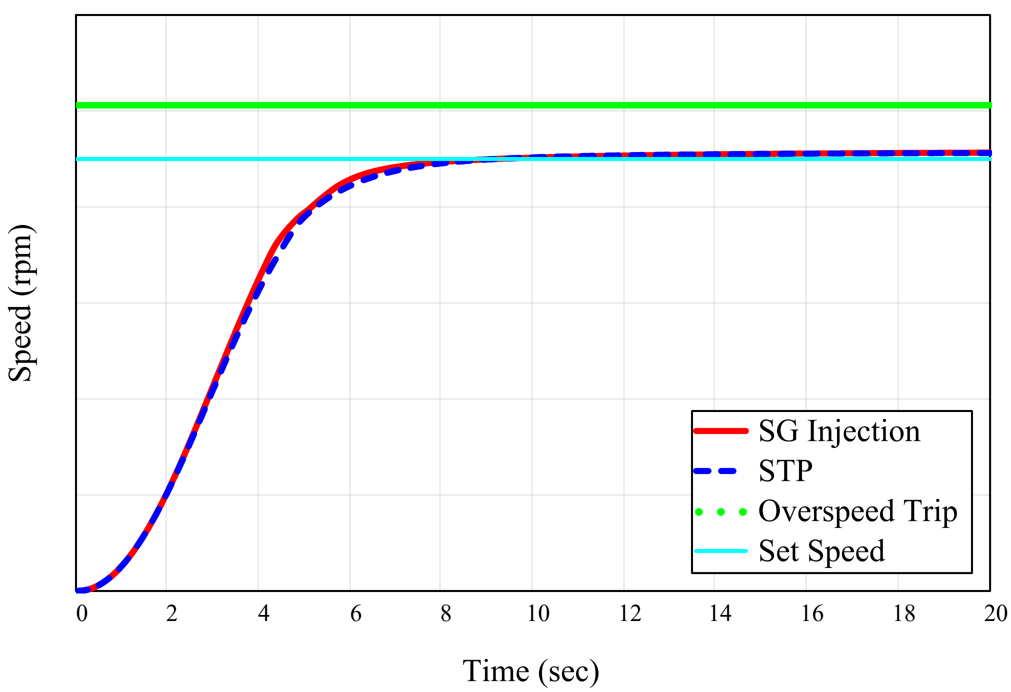





Flow (lb/hr)
Time (sec)
SG Injection
STP
0
5000
10000
15000
20000
25000
30000
0
2
4
6
8
10
12
14
16
18
20


Flow (lb/hr)
Time (sec)
Stm Adm Valve
Gov Valve
0
5000
10000
15000
20000
25000
30000
0
2
4
6
8
10
12
14
16
18
20


Required Pump Power (hp)
800
640
480
320
160
0
0 2 4 6 8 10 12 14 16 18 20
Time (sec)
SG Injection
STP


Speed (rpm)
0 2 4 6 8 10 12 14 16 18 20
Time (sec)
SG Injection
STP
Overspeed Trip
Set Speed

C V.C. Summer Timeline of Events (Reference 2)

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
N/A	10/14/2025 15:52	Reactor and Turbine Trip due Fire in Main Generator Field Control Breaker Crew entered EOP-1.0 Plant Trip and AOP-900 series for Fire response.	Plant Computer Data lost concurrent with plant trip. No useful trend data available [Oct. 14th Trip].
N/A	10/14/2025 17:11	Secured Turbine Driven Emergency Feedwater Pump	
N/A	10/14/2025 17:25	Turbine Driven Emergency Feedwater Pump Reset	
N/A	10/24/2025 05:29	The reactor is critical	None
N/A	10/27/2025 04:39	Commence STP0121.002C-MS TURBINE DRIVEN EMERGENCY FEEDWATER PUMP MAIN STEAM SUPPLY VALVE OPERABILITY TEST. WO#88201764260	None
N/A	10/27/2025 06:13	Completed STP0121.002C-MS TURBINE DRIVEN EMERGENCY FEEDWATER PUMP MAIN STEAM SUPPLY VALVE OPERABILITY TEST. WO#88201764260	None
1	11/12/2025 01:43	Commenced STP-220.002, TDEFW PUMP AND VALVE OPERABILITY TEST. WO# 88201770671 & 88201766054.	None
N/A	11/12/2025 02:23	At 0223 on 11/12/25, the Turbine Driven EFW Pump Tripped on Overspeed after start during performance of STP-220.002. PVG-2030-EF STEAM SUPPLY TO TD EFW PUMP TRAIN B switch on the Main Control Board was held in OPEN position. There was indication on the Main Control Board for pump startup and run. Valve position for PVG-2030 for both Train A and Train B switches went to intermediate then full open position. Turbine Speed on EF Turbine Speed indicator on MCB went from 0 to 4000 rpm. After approximately 10 seconds, annunciator XCP-622 3-4 TD EFP STP VLV	Computer Data Provided from 11/12/2025 02:00 to 11/12/2025 03:00 [11-12-25 Initiating Event Trip]. Interviewed Control Board Operators. When alarm came in, they looked up at the Main Control Board (MCB) and

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		NOT OPEN OIL PRESS LO was received and speed began to lower to 0 rpm indicating a trip of the TDEWFP. Local report from the field was that the TDEFW Pump tripped on overspeed. Turbine Driven Emergency Feedwater Pump is inoperable. T.S. 3.7.1.2 action A.	saw 4000 RPM. The actual peak speed was not completely observed or captured. Subsequent troubleshooting identified an actual overspeed condition. It is likely that the turbine got higher than 4000 RPM on the initial event but just wasn't observed by the Operators.
N/A	11/12/2025 04:00	Completed Quarantining TDEFW Pump Room per OP-AA-1300 with Trip Throttle Valve not RESET and Field Standards still installed.	None
N/A	11/12/202514:14	Reset the TDEFW Pump per SOP-211 section IV D.	None
N/A	11/12/2025 17:40 Eng. Log	CR1306541 - Test Failure: TDEFW Pump Tripped on Overspeed after start during performance of STP-220.002 Work Completed: As-Found visual inspection - complete / nothing abnormal noted Fleet Jump Call Completed at 1030 - recommendations evaluated and included in FMA/Troubleshooting Plan Industry SME Call completed at 1400 - recommendations evaluated and included in FMA/Troubleshooting Plan Site Engineering observed Reset and noted no abnormalities. Developed Focused Troubleshooting plan and briefed with OPS Shift. Priorities: 1. Develop MA-AA-103 Troubleshooting Plan and Support Maintenance Run - Plan Developed and Approved. i. Support Implementation of the plan. 2. Continue to refine FMA Support/Refute Matrix 3. CR1306622, TPP0008 Emergency Head Lever Unevaluated Changes, - Site Eng to review for change in Form, Fit, and Function for Emergency Head Lever, then generate Log Entry and contact SCM to remove from block stock.	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
N/A	11/12/2025 18:01 Eng. Log	Engineering supported the development of a troubleshooting plan and a Support/Refute Matrix per MA-AA-103 Attachments 2 and 4 respectively. The troubleshooting plan was approved at approximately 17:30 with an Operations, Engineering, and Maintenance brief immediately following. It is expected that the TDEFW pump run will be before shift turnover at 19:00 tonight. FMA Team members are on station to support the run with cameras and observation. Information from this run will be used as input to the Support/Refute Matrix to determine the cause. A field service representative from ESI will be arriving on site at approximately 19:30 for troubleshooting support.	None
2	~11/12/2025 18:28	TDEFW Pump started based on P2032A Steam Pressure	Computer Data Provided from 11/12/25 18:25 to 11/12/25 18:40. [1st Troubleshooting Run (11-12)] Videos Provided [11-12-25 1830 1st Troubleshooting Run] Confirmed true overspeed trip was occurring.
	11/12/2025 19:49	Completed STP0220.002 STP0220.002-XPP0008 TURBINE DRIVEN EMER FW PUMP TEST. UNSAT. WO#88201770671. CR1306541 R&R 25-ACT-00261	
3	11/12/2025 23:22	Started Turbine Driven Emergency Feedwater Pump per STP-220.002. Governor was set to lowest setting per troubleshooting plan before starting. Turbine came up to approximately 3800 RPM (MCB) before settling in at 2350 RPM per MCB. (Local RPM 2371)	Computer Data Provided from 11/12/2025 23:15 to 11/12/2025 23:55. [2nd Troubleshooting Run (11-12)] Videos Provided [11-12-25 2322 2nd Troubleshooting Run]
	11/12/2025 23:42	Tripped the Turbine Driven EFW Pump locally per MMP0300.015	
N/A	11/13/2025 02:42	Tagout #25-EF -0659, TPP0008 REMOVED FROM SERVICE TO MAKE REPAIRS has been hung.	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
N/A	11/13/2025 05:03 Eng. Log	Summary of Terry Turbine Night Shift Troubleshooting Activities First Troubleshooting Run (~18:30): • TDEFP started, accelerated to ~5,000 rpm, then tripped on overspeed. Overspeed trip device functioned as designed. • Video review indicated Governor Control Valve (XVM11025-EF) appeared to bind before reaching normal running position, allowing valve to stall in open/near open position and providing more steam to the turbine. • Following troubleshooting run, multiple resets/trips of the overspeed trip device showed no abnormalities. Second Troubleshooting Run (~2300): • Adjusted governor speed control to minimum (~2,200 rpm) and restarted: o TDEFP stabilized at ~2,350 rpm after peaking at ~3,800 rpm. o Bump tests Governor Control Valve linkage at 2,350, 3,500, and 4,500 rpm showed greater speed change at lower rpm. o Overspeed test confirmed trip at 5,060 rpm. Findings Mechanical Inspection Following Troubleshooting Runs: • Manual actuation of governor linkage confirmed binding between Cam Follower/Valve Stem Connector and Cam Plate. • Valve stem connector angled, causing it to “dig in” to Cam Plate—worse at full-open or high force positions. • The Governor valve internals were free of binding and the governor controlled as required Recommended Actions: • Determine the optimal dimensions of the Cam Follower/Valve Stem Connector pin. Use feeler gauges or another acceptable method to ensure that the mating surfaces of the Valve Stem Connector and Cam Plate remain parallel. • Clean grease from affected parts and re-take measurements to ensure accuracy.	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		• Disassemble XVM11025-EF linkage to remove pin to determine dimensions. • Determined if a new pin is available. If not, determine material and fabricate new pin. • Dress the sliding/mating surfaces of the valve linkage as needed to ensure smooth operation. • Consider installing a bronze/copper fender washer between the valve stem connector and cam plate to reduce drag, provide more surface area. (potential long term). • Reassemble and test.	
N/A	11/13/2025 17:48 Eng. Log	CR1306541 - Turbine Driven EFW Pump Tripped on Overspeed FMA Update 1000 - Presented FMA and Troubleshooting to Site Management - Actions taken to address recommendations. 1500 - NOED briefing call held to gain station alignment on path forward and current troubleshooting/repair status. 1600 - Fleet Challenge Meeting held to present current status of FMA Support/Refute Matrix. Actions taken and documented in Outage Log Entry. Issued PO for Curtiss-Wright field technician support. Field Technician supported technical phone call and provided recommendations to perform alignment and clearance checks. Technician expected to arrive onsite by 2200. Completed field inspections of governor valve linkage to assess cause of binding. Decision made to disassemble the governor valve by removing bonnet to further assess cause of binding and potential solution. Engineering Priorities:	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		1. MA-AA-103 Troubleshooting Plan and Repair i. Support Implementation of the plan. ii. Support Implementation of Engineering Recommendations in William Wood log entry 1) Determined required materials and dimensions 2) Evaluate availability of spare parts 3) Work with mech maint to develop repair plan 4) Provide re-test guidance to OPS 2. Continue to refine FMA Support/Refute Matrix i. 1000 internal management challenge - complete 1600 Fleet SME Challenge - complete	
N/A	11/13/2025 18:06 Eng. Log	FMA Team continued supporting efforts to identify the cause of the TDEFW Pump overspeed trip. Field team members supported Maintenance in obtaining measurements of the Control Valve Linkage for the EF Pump Turbine Speed Control Governor Valve (XVM11025-EF). The field team along with Maintenance identified that the valve stem exhibited binding when linkages were disconnected. Maintenance will focus on the valve binding, the FMA Team will support this effort along with continuing to look at the control mechanism potential binding locations. A representative from Curtiss-Wright (Anthony Valeri 757-536-6975) will be on site during night shift tonight. A representative from ESI (John Battigelli 919-357-4232) is also on stand-by to be called in to support the next run to observe governor operation.	None
N/A	11/14/2025 06:13 Eng. Log	Nightshift 11/14/25 turnover: Engineering and Mechanical Maintenance disassembled the TDEFP governor valve (XVM11025-EF) and associated linkages, checking for freedom of movement as the parts were disassembled. Reference drawing 1MS-17-199 for part names. Personnel noted some binding between the Valve Stem Connector and Cam Crank, due to rough edges and a damaged/rough area on the face of the Cam Crank. The Valve Stem Connector pin and the associated slot on the Cam Crank Support also showed some wear, contributing to jerky movement/binding by allowing the Valve Stem Connector to rotate slightly when loaded. Some slop was also noted on the Cam Crank Pivot Pin. Lastly, damage was noted on the Valve Stem where it traversed through the outer	Pictures of Governor Valve Provided [2025-11-13 1000 Gov Contr Mechanism Pictures], [2025-11-13 Nightshift Governor Valve Inspection]

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		"Guide Valve Stem Upper." The combination of the wear on the Valve Stem at the outer guide and damage on the Cam Crank are believed to be the main contributors to the binding. When the outer Guide was removed, the valve stroked smoothly and no binding was noted. Maintenance disassembled and inspected the governor valve, took critical measurements, replaced the carbon bushings, and reassembled it per MMP-300.015. After discussing with Engineering and Curtiss Wright, they then hand dressed the various linkages and subcomponents to remove rough edges and spots and ensure smooth operation and reassembled the linkages. After reassembly, personnel ensured smooth operation through the range of motion of the governor valve linkage.	
N/A	11/14/2025 07:43	TDEFW pump has been reset IAW SOP-211.	None
N/A	11/14/2025 08:09	Tagout #25-EF -0659, TPP0008 REMOVED FROM SERVICE TO MAKE REPAIRS has been Cleared.	None
4	11/14/2025 08:48	Started TDEFW per MMP-300.015.	Video Provided [2025-11-14 Maintenance Run Videos] Trend Data 11/14/25 08:35 to 09:15 [11-14 Maint. Run Slow]
	11/14/2025 09:08	TDEFW Pump is secured per MMP-300.015.	
	11/14/2025 09:24	TDEFW pump has been reset IAW SOP-211.	
5	11/14/2025 09:42	Started Turbine Driven EFW pump per SOP-211	Video Provided [2025-11-14 Maintenance Run Videos] Trend Data 11/14/2025 09:40 to 09:55. [11-14 Maint. Run Fast]
	11/14/2025 09:43	TPP0008 EMERGENCY FEEDWATER PUMP TURBINE is FUNCTIONAL. PHEONIX is GREEN, FEP is GREEN, FLEX remains RED.	
	11/14/2025 09:50	TDEFW Pump is secured per SOP-211.	

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
6	11/14/2025 11:30	Commenced STP-220.002, TURBINE DRIVEN EMERGENCY FEEDWATER PUMP AND VALVE TEST. WO88201772182 and WO88201766054.	Video Provided [2025-11-14 STP Run Videos] Trend Data 11/14/2025 11:55 to 14:10 [11-14 STP Run]
	11/14/2025 12:04	Turbine Driven Emergency Feedwater pump started. Pump reached approximately 5000rpm and tripped. OCC and OMOC informed. CR1306770	
N/A	11/14/2025 16:48	TDEFW pump has been reset IAW STP-220.002.	None
7	11/14/2025 17:12	Started the TDEFW Pump IAW STP-220.002.	Trend Data 11/14/25 17:05 to 17:55 [11-14 1712 Run]
N/A	11/14/2025 17:22	Closed WO88201772182, DEMAND-STP0220.002-XPP0008 TURBINE DRIVEN EMER FW PUMP TEST (GROUP B) % TURBINE DRIVEN EMER FW P. Turbine Driven Emergency Feedwater pump started. Pump reached approximately 5000rpm and tripped. CR1306770 No data capture. UNSAT STP. CLOSING WO.	
N/A	11/14/2025 17:46	TDEFW pump is secured. This was done per STP-220.002.	
N/A	11/14/2025 17:54	TDEFW pump has been reset IAW STP-220.002.	None
N/A	11/14/2025 19:30	On 11/14/2025 at 1800, VCS held a phone call with the NRC HOO and Region II to request Enforcement Discretion for TS 3.7.1.2, Action a, per NRC Enforcement Manual, Appendix F. At approximately 1930, the NRC provided verbal approval of the Notice of Enforcement Discretion (NOED) for 79 hours beyond the Completion Time expiration at 0208 ET on 11/15/2025. This NOED allows continued operation during repair of the TDEFP until 0908 on 11/18/2025. VCS will provide a submittal documenting the request within 2 business days.	None
N/A	11/14/2025 21:10	Dayshift 11/14/25 activities related to restoring the TDEFP governor and governor valve included adjusting the TDEFP governor compensating needle	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
	Eng. Log	valve to make the governor more responsive. This was partially retested by restarting the TDEFP after adjustment and noting that the TDEFP speed did not overspeed. MMP-300.015 Section 7.11.14 provides additional steps to perform to ensure proper operation. Engineering recommends performing the following steps to perform as a retest following the adjustment of the needle valve on Dayshift 11/14/25. 1) HAVE Operations start-up XPP0008 (Turbine Driven EF Pump or TDEFP) per STP-220.002 (EF Quarterly Inservice Test) 2) Allow TDEFP to run for 30 minutes to allow temperatures to stabilize. 3) Perform bump testing as follows: a. CHECK turbine is operating at lowest possible speed. b. CHECK turbine stability by manually disturbing governor valve linkage, IF turbine returns speed with only a slight overshoot or undershoot, compensation needle valve setting is correct. c. Operations to adjust the Governor Speed Control adjustment knob and TDEFP speed as requested by Engineering and Vendor, then repeat stability check. d. If necessary, adjust Needle Valve per MMP-300.015 and repeat as necessary. 4) When the Governor is responding satisfactorily, ENSURE Governor Speed Control Knob is rotated fully clockwise (max speed). 5) Secure XPP0008, TDEFP, per STP-220.002.	
8	11/14/2025 22:57	Started Turbine Driven Emergency Feedwater Pump per STP 220.002. RPM stabilized at 4533 by field standard tachometer locally.	Video provided [2025-11-14 Run Following Needle Adjustment] – Uncertain on which 11/14 run this goes with. Trend Data provided 11/14/25 22:50 to 11/15/25 00:05 [11-14 2257 Run]
N/A	11/14/2025 23:55	11/14/2025 23:55:00 11/14/2025 23:01:58 Secured Turbine Driven EFW Pump per STP 220.002.	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
9	11/15/2025 03:13	Started Turbine Driven Emergency Feedwater Pump per STP 220.002 RPM stabilized at 4519 RPM per field standard.	Trend Data provided 11/15/25 03:11 to 03:48
N/A	11/15/2025 03:43	Secured Turbine Driven EFW per STP 220.002	None
N/A	11/15/2025 05:42 Eng. Log	Nightshift 11/14/25 Engineering Turnover: Performed bump testing of the TDEFP during two separate maintenance runs: First Run: 11/14/25 @ 23:30 1) With the TDEFP governor compensating needle valve in the as-left position from dayshift (Approximately ¼ turn open), Operations started the TDEFP. Noted that the TDEFP started, and speed increased to approximately 4500 rpm with very little overshoot. Allowed the TDEFP to run for 30 minutes to allow oil in the governor to reach stable running temperature. 2) After the hold time, Operations began manually lowering the TDEFP speed using the Governor speed control knob. The TDEFP speed immediately began hunting. When the speed control knob reached the fully counterclockwise position (minimum speed), personnel noted that the speed did not stabilize. 3) Mechanical maintenance adjusted the governor compensating needle valve per MMP-300.015, closing the needle valve until the oscillations were minimized. Speed appeared to mostly stabilize, with some small variations. The needle valve was in a similar position to what it was prior to being adjusted on 11/14/25 (approximately 1/16-1/8 turn open). 4) Personnel performed bump testing at 2300, 3500, and 4500rpm, noting that speed was more stable with less oscillations at higher speeds, but response time was slow. 5) Operations secured the TDEFP. Second Run: 11/15/25 @ 03:00. 1) With the TDEFP governor compensating needle valve in the as-left position, Operations started the TDEFP. Noted that the TDEFP started, and speed increased to 4960 rpm, then stabilized at 4500rpm. Allowed the TDEFP to run for while Operations performed post-start checks, closed drain lines, etc. 2) Performed bump testing again at 2300, 3500, and 4500 rpm while videoing from several angles. Noted similar behavior. 3) Opened the need valve to midway to ¼ turn open and performed bump testing again at 2300, 3500, and 4500 rpm while videoing from several angles. Response time was quicker, but noted a higher number of oscillations	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		prior to stabilizing. 4) Operations lowered speed to 2300 rpm again in preparation for a final adjustment on the governor needle valve to ¼ turn open. After allowing speed to stabilize, noted a sudden 500 rpm change and associated oscillations prior to stabilizing. This occurred twice while observing. 5) Opened the need valve to ¼ turn open. TDEFP speed began hunting and would not stabilize. MMP-300.015 Step 7.11.14 requires the needle valve to be adjusted so that hunting is just eliminated at the minimum speed, therefore this is not in accordance with the procedure. No further bump testing was performed at this needle valve position. 6) The governor needle valve was adjusted back to the as-found position of approximately 1/8 turn open, ensured minimal hunting, and Operations secured the TDEFP.	
N/A	11/15/2025 06:33	Tagout #25-EF -0659A, Contingency for TPP0008 maintenance run failure/degradation. has been Hung.	None
N/A	11/15/2025 12:16	Tagout #25-EF -0659A, Contingency for TPP0008 maintenance run failure/degradation. has been Cleared.	None
10	11/15/2025 13:55	Started XPP0008, TDEFW Pump per SOP-211 and MMP-300.015, Step 7.11 in support of Governor replacement.	Videos Provided [2025-11-15 Run 1 following Governor Replacement] Trend Data Provided 11/15/25 13:50 to 15:15.
N/A	11/15/2025 15:13 Eng. Log	Day Shift Update: CR1306541 - Turbine Driven EFW Pump Tripped on Overspeed 1. FMA Team • Cross-Functional FMA Team met to update FMA Support/Refute matrix with information from TDEFW pump runs performed on night shift and field inspections of the Governor Lever arms performed early on day shfit. • FMA Team Lead presented updated support/refute matrix to Site Management and received recommendations to incorporate.	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		2. Engineering • Supported maintenance with inspection of the governor and valve level arms for presence of inadequate amount of play. • Supported terry turbine maintenance run including bump test (MMP-300.015 Section 7.11) and full speed start using STP-220.002 lineup. ESI/PSE on-station to support Governor Needle Compensating valve tuning • Design Engineering supported VCS Procurement Engineering with ES-425 reviews for Governor Valve Cam Crank IEE • Engineering supported SCM and Maintenance with questions on parts related to the governor valve maintenance.	
N/A	11/15/2025 15:25	Secured XPP0008, TDEFW Pump per SOP-211 and MMP-300.015, in support of Governor replacement.	None
11	11/15/2025 16:55	Started XPP0008, TDEFW Pump per STP-220.002 in support of Governor replacement. Low Oil pressure trip linkage did not engage with the trip latch lever as required in Step 6.6.e. Reference CR1306839.	Videos Provided [2025-11-15 Run 2 following Governor Replacement] Trend data provided 11/15/25 16:50 to 17:16
N/A	11/15/2025 17:07	Secured XPP0008, TDEFW Pump per STP-220.002 in support of Governor replacement.	None
N/A	11/15/2025 17:13 Eng. Log	XVM11025-EF EF PUMP TURBINE SPEED CONT GOVERNOR VLV plug wear was not identified by the FMA process as a potential contributor to the overspeed trip condition. The valve plug is nominally open approximately 1/16 inch (total stroke length is 5/8 inch) during operation at rated speed. The plug was hand dressed and polished, and the previous steady control of the turbine showed that the plug condition does not contribute to governor stability. The valve was disassembled on 11/14/2025 to investigate potential damaged carbon rings in the stuffing box that had been identified as a potential to cause the stem binding that was observed. There is no failure mode that requires replacement of the valve stem or valve plug. The maintenance inspection performed 11/14/2025 found a burred/burnished area on the stem indicating binding at the outer stem positioning bushings. This condition was resolved by polishing and	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		dressing the stem area and an acceptable stem surface was re-established. The acceptability of this maintenance was confirmed by post-maintenance hand-stroking of the valve stem and governor linkage assemblies. Replacement of the valve plug was identified as a recommended maintenance item based on previous inspection during a routine maintenance activity. This activity was only recommended as an opportunistic task because the existing maintenance will result in disassembly of the governor valve which exposes the valve internals for contingent replacement.	
N/A	11/15/2025 17:53 Eng. Log	Day Shift Update #2: CR1306541 - Turbine Driven EFW Pump Tripped on Overspeed Engineering, Maintenance, and ESI witnessed the successful terry turbine full speed start in the STP-220.002 lineup. ESI and Engineering agreed the governor and governor valve operated as expected to bring the turbine to running speed without overshoot, and then controlled without any hunting observed. Engineering generated log entry to document assessment of the governor valve plug and stem and identified that there are no current FMA failure modes that require replacement of the plug or stem. PRIORITIES FOR ENGINEERING: 1. Engineering documenting testing results from day shift runs in a log entry. 2. Support tear down and rebuild of the governor valve and control assembly. PSE and Curtiss-Wright to be in field during the maintenance duration to assess part condition and make recommendations. Engineering to continue finalization of the FMA Support/Refute Matrix.	None
N/A	11/15/2025 18:24 Eng. Log	Engineering supported Governor replacement and post testing. The replaced governor Compensating Needle Valve was left at 1/8" (heavy), and the full speed run was SAT. Engineering updated the FMA Support/Refute Matrix to include up-to-date documentation of "Supported" failure modes (Control Valve Linkage binding with Governor Compensating Needle Valve set too low for valve linkage binding, resulting in overspeed).	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
N/A	11/15/2025 19:35	Tagout #25-EF -0663, TPP0008 REASSEMBLE LINKAGE (STEAM SIDE ISOLATION). has been Hung.	None
N/A	11/16/2025 01:00 Eng. Log	Night Shift Update #1: Engineering and Curtiss-Wright representatives observed the maintenance team disassemble the TDEP governor valve (XVM11025-EF) and its associated linkage. Measurement activities are currently underway. Engineering Priority: PSE and Curtiss-Wright will continue supporting field maintenance to evaluate component condition and support linkage refurbishment.	None
N/A	11/16/2025 09:32	Tagout #25-EF -0663, TPP0008 REASSEMBLE LINKAGE (STEAM SIDE ISOLATION). has been Cleared.	None
N/A	11/16/2025 04:39 Eng. Log	Emergency FW Turbine Driven Pump 11/15/2025Nightshift Update #2 Engineering and Curtis Wright representative witnessed Maintenance tear down and inspected new components for the Turbine Drive Emergency Feedwater (FW) Pump's governor valve (XVM11025-EF) and linkage assembly. The most susceptible wear components were replaced, and multiple new parts were installed that were procured from other stations however, some old components had to be utilized when new parts did not fit properly. Currently, Maintenance is making minor machining adjustments/polishing to the new Cam Plate's Valve Stem Connector Groove to resolve fit up concerns so that installation can be completed. Engineering Priority: Continue support field maintenance to evaluation component condition and support linkage refurbishment.	None
N/A	11/16/2025 07:35 Eng. Log	Terry Turbine Linkage Refurbishment Site Engineering and Curtiss-Wright supported Mechanical Maintenance refurbishment of Terry Turbine linkages over the night shift.	See Drawings T98701E and T98702A

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		The following parts as listed on 1MS-17-199 Sheet 2 were refurbished/replaced on night shift 11/13 – 11/14: - Part 9, Bonnet Spacer - Part 19, R-1 15 P Flex. Gasket - Part 48, Guide Bushing (cleaned & reinstalled) The following parts as listed on 1MS-17-199 Sheet 2 were refurbished/replaced on night shift 11/15 – 11/16: - Part 2, Cam Crank - Part 8, N-5000-112 Truarc Snap Ring - Part 10, Flat Washer (cleaned & reinstalled) - Part 19, R-1 15 P Flex. Gasket - Part 21, Tapered Pins (refurbished) - Part 22, 1/4 x 1 1/2 Lg Key (new, made on site) - Part 33, Garlock Thrust Washer DU20 (cleaned & reinstalled) - Part 34, Garlock Bushing 20-DU-12 - Part 37, Cam Crank Pivot Pin - Part 38, Garlock Thrust Washer DU10 - Part 39, Garlock Bushing 12-DU-12 - Part 40, Garlock Thrust Washer DU12 - Part 44, Valve Stem Connector - Part 45, Valve Stem Conn. Bushing - Part 47, Washer (cleaned & reinstalled)	
12	11/16/2025 11:48	Started XPP0008, TDEFW Pump per SOP-211 and MMP-300.015, Step 7.11 in support of Governor replacement.	Videos Provided [2025-11-16 Maintenance Run] – slow start Trend Data provided 11/16/25 11:45 to 12:30.
N/A	11/16/2025 12:36	Post Maintenance run for XPP-008 per MMP-300.015 is complete. XPP-0008 is being aligned to perform fast start to verify governor control.	None
13	11/16/2025 12:55	Started XPP0008, TDEFW Pump per STP-220.002 in support of Governor replacement testing.	Videos Provided

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
			[2025-11-16 Maintenance Run] – fast start Trend Data provided 11/16/25 12:50 to 13:15
N/A	11/16/2025 13:05	Secured XPP0008, TDEFW Pump per STP-220.002 in support of Governor replacement testing.	None
N/A	11/16/2025 15:08	Commenced STP-220.002, TURBINE DRIVEN EMERGENCY FEEDWATER PUMP AND VALVE TEST. WO# 88201777288.	None
14	11/16/2025 15:23	Started XPP0008, EMERG FEEDWATER TURBINE DRIVEN PUMP. Pump start was SAT and speed stabilized at 4520 rpms.	Videos Provided [2025-11-16 STP-220.002 Retest Trend Data provided 11/16/25 15:20 to 16:40
N/A	11/16/2025 16:20	Secured XPP0008, EMERG FEEDWATER TURBINE DRIVEN PUMP.	None
N/A	11/16/2025 16:59 Eng. Log	Terry Turbine Run Observations (FMA Update) Site Engineering observed/recorded the maintenance run per MMP-300.015 section 7.11, the subsequent fast start of the terry turbine per the STP-220.002 lineup, and the STP-220.002 retest following the 2 hour cool down time. During the initial maintenance run, two bump tests were performed and the governor was observed to be responding appropriately, controlling within band with minimal hunting. The linkages that were refurbished/replaced were observed to be operating satisfactorily with no binding. All items related to identification of the cause as detailed on the FMA chart have been addressed as required at this point. Items remaining open include sending the governor that was removed off to ESI for inspection/refurbishment and testing the oil in the governor that was removed for contaminants. These items are only to assist in confirmation of cause for the FMA chart as the underlying causes have been addressed via corrective maintenance.	None

Timeline of Events			
Reference Run	**Time**	**Event Description**	**Notes**
		At this point the FMA team has confidence in the ability of the terry turbine to perform its design basis safety function and should be considered for operability.	
N/A	11/16/2025 17:00	Completed STP-220.002, TURBINE DRIVEN EMERGENCY FEEDWATER PUMP AND VALVE TEST. WO# 88201777288.	None
N/A	11/16/2025 17:23	CR1306899. Turbine Driven Emergency Feedwater Pump Low Lube Oil Pressure Trip Linkage did not engage with the Trip Latch Lever per step 6.6.e of STP-220.002.	None
N/A	11/16/2025 17:47	CLEARED R&R 25-ACT-00261, "TPP0008, EMERG FEEDWATER TURBINE DRIVEN PUMP declared inoperable during STP-220.002 due to turbine tripping after startup".	None
N/A	11/16/2025 17:47	Exited Action Statement Unit: 1, Type: Technical Specifications, Section Number: 3.7.1.2 a. (1) on R&R 25-ACT-00261, "TPP0008, EMERG FEEDWATER TURBINE DRIVEN PUMP declared inoperable during STP-220.002 due to turbine tripping after startup"; on 11/16/2025 17:47	None
N/A	11/16/2025 17:48	NRC Senior Resident notified that TPP0008, Turbine Driven EFW Pump, is OPERABLE.	None

D Governor Valve Linkage Friction Impact Evaluation

Excessive friction was identified between governor valve linkages (Reference 2). The following appendix provides additional data to show governor valve linkage behavior was repeatable. This data demonstrates that any variability in the friction does not introduce significant uncertainty when predicting pump start transient behavior.

EFW suction pressure data from Run 1 (the initial STP run) is reviewed and compared with Run 2 (the first troubleshooting run) to evaluate the repeatability of the pump start transient in the as-found condition, including the potential impact of the variability of friction or bind/slip behavior.

Figure D-1 compares normalized suction pressure data from Run 1 and Run 2. Data is aligned with time equal to zero when pump start signal turns on. The magnitude of the pressure decrease at each instant in time and the time to trip are very similar between the runs. The similarity in the suction pressure trends for these runs indicates the condition/friction experienced by the pump was repeatable between runs.

Note that the EFW suction pressure is used for comparison because speed data is not available for Run 1. The suction pressure was normalized by subtracting the suction pressure at the time of the start signal from each data set to better compare the transient data. The difference in suction pressure is expected to be due to differing levels in the condensate storage tank (CST), which supplies the EFW pumps and is not expected to impact the pump start transient.

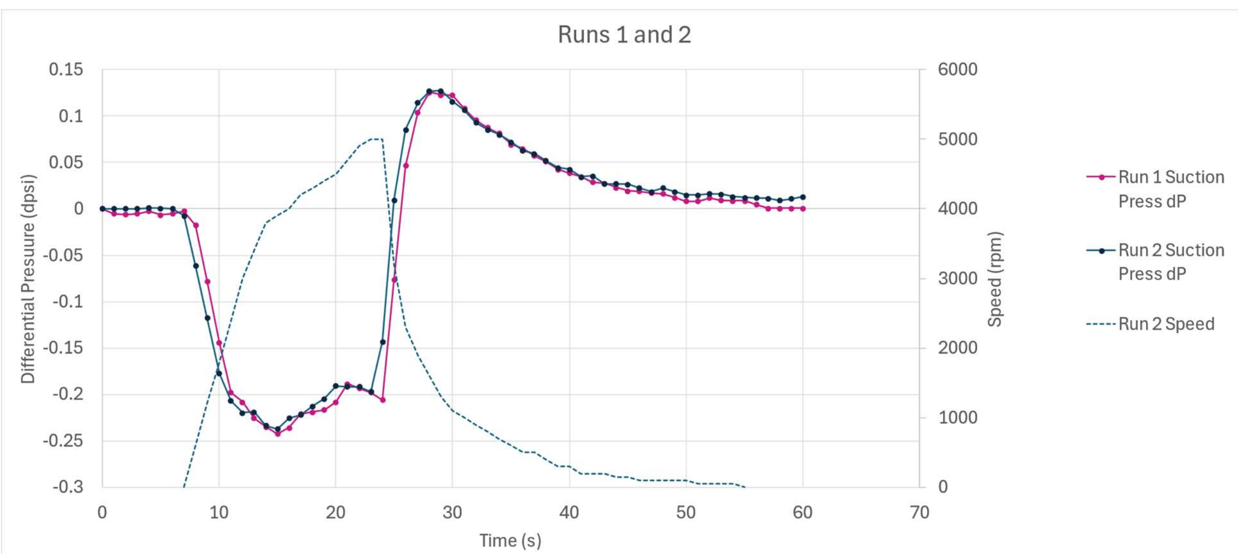


Figure D-1. Run 1 and 2 Suction Pressure Data (References 5.A and 5.B)

E Time to Open Steam Admission Valve

Table E-1 provides the time to open the steam admission valve during each November 2025 troubleshooting run.

Table E-1. Time to Open Steam Admission Valve

Date and Time	Run Number	Time to Open Steam Admission Valve (s) (Ref 5.B)	Train (Ref 13)
11/12/2025 01:43:00	1	34	B
11/12/2025 18:28:00	2	33	B
11/12/2025 23:22:00	3	33	B
11/13-14/2025 Night	Linkages between governor and governor valve dressed		
11/14/2025 08:48:00	4	35	B
11/14/2025 09:42:00	5	32	B
11/14/2025 12:04:00	6	34	B
11/14/2025 17:22:00	7	31	B
11/14/2025 Day	Governor needle valve adjusted from between 1/16 and 1/8 turn to 1/4 turn open		
11/14/2025 22:57:00	8	30	B
11/15/2025 03:13:00	9	31	B
11/15/2025 Day	Replaced governor with spare (and set needle valve to 1/8 turn open)		
11/15/2025 13:55:00	10	25	A
11/15/2025 16:55:00	11	23	A
11/15-16/2025 Night	Disassembled and rebuilt governor linkages with new parts		
11/16/2025 11:48:00	12	26	A
11/16/2025 12:55:00	13	23	A
11/16/2025 15:23:00	14	23	A

The replacement of the governor coincided with the swap to the Train A solenoid on the steam admission valve which was found to have a significantly faster opening time than Train B (Figure E-1). Therefore, the swap from Train B to Train A is expected to be the reason for the notable step change in the steam admission valve opening times.

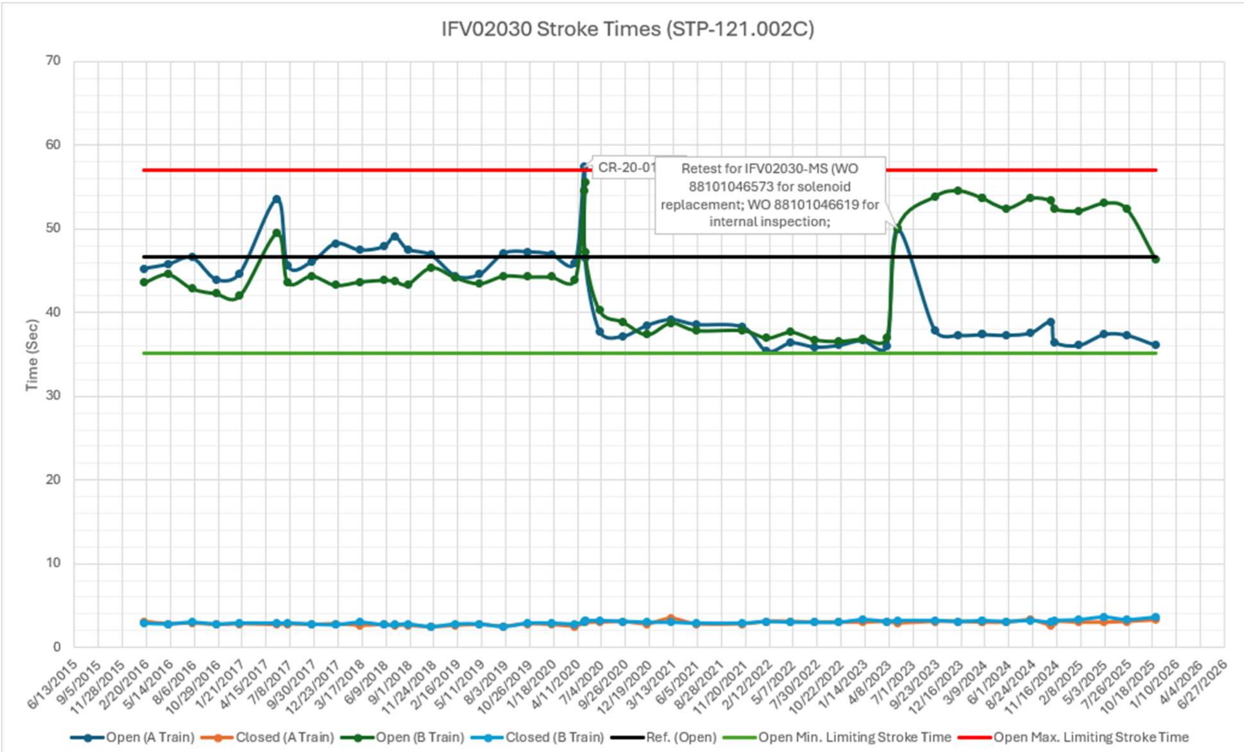


Figure E-1. TDEFW Pump Steam Admission Valve Surveillance Test Data on Trains A and B (Reference 14)

F Governor Valve Position Measurements During Surveillance Testing

Measurements of the governor valve position were taken by hand using a ruler during the surveillance test in February 2026 to assess the difference in valve position for different TDEFW pump flow rates. A cross section of the valve is shown in Figure F-1. Table F-1 shows the measured valve position (Table F-2) relative to the approximate pump flow rate and brake horsepower for each condition.

The governor valve total stroke is 5/8 inch (References 2 and 17). However, the operating range to change the steam flow occurs across a much smaller portion of the stroke[4]. The valve lift curve is very steep across the relevant portion of the stroke, such that small changes in valve position result in significant changes in steam flow.

Due to the uncertainty of the measurement method and the steep valve curve, the changes in valve position are difficult to detect. However, position measurements support that the valve is expected to be open slightly more when the pump flow rate and brake horsepower are higher (e.g., while injecting into the steam generator).

The measured valve positions are compared with the analysis performed in Section 7.3. While the specific valve positions predicted by the analysis differ somewhat from the measured valve positions, the difference in valve position between the STP and SG injection configurations are the same for both the analysis (0.11 inches – 0.08 inches = 0.03 inches) and the measured data (5/32 inches - 1/8 inches). This provides additional confidence in the result of the analysis presented in Section 7.3.

[4] As discussed in Reference 17, Section 7.1.2, the valve is a 3-inch venturi seat governor valve and precise movement of the governor valve stem is needed at low flow conditions because small changes in the valve position have large impacts on the steam flow rate. Specifically, this design requires the use of a cam-augmented linkage design to provide fine movement of the governor valve travel when in its near closed position.

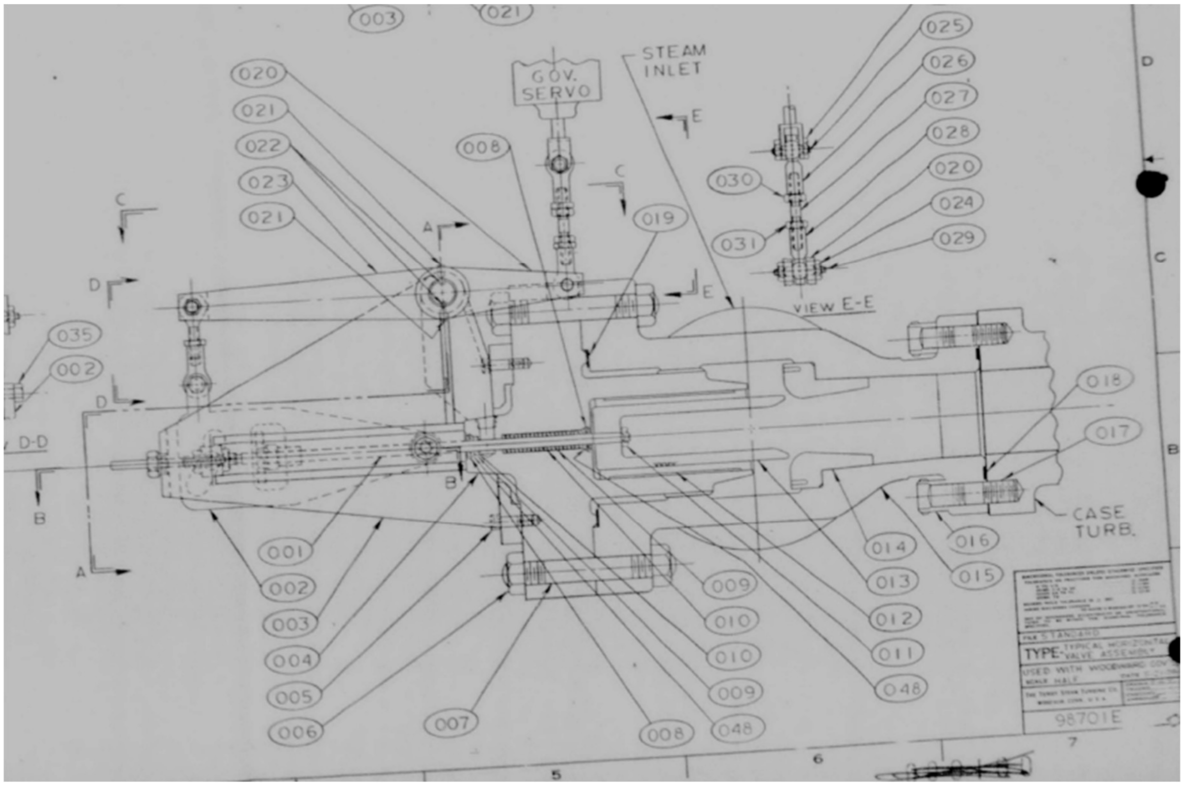


Figure F-1. TDEFW Governor Valve Cross Section (Reference 18)

Table F-1. Valve Position, Flow Rate, and Brake Horsepower (BHP) (References 9, 5.D, 6.A, and 8.A)

Test Date/Time	**Configuration**	**Ruler Measurement, Distance from Full Open**	**TDEFW Governor Valve Position (calculated based on measured position)**	**TDEFW Pump Flow Rate (Ref 6.A, unless otherwise noted)**	**Pump BHP (Ref 8.A)**
2/272026 09:29	Full Open – Prior to Start	~2-3/8" full open	5/8" open 100% open	n/a	n/a
2/27/2026 09:37	STP Steady State Flow	~2-7/8" 1/2" from full open	~1/8" open 20% open	~300 gpm	~600 hp
2/27/2026 11:42	Mini flow	~2-7/8" 1/2" from full open	~1/8" open 20% open	~100 gpm	~450 hp
2/27/2026 12:14	Comprehensive Full Flow Test Injection into all SG	~2-27/32" 15/32" from full open	~5/32" open 25% open	~670 gpm (~570 gpm to SGs[1], ~100 gpm through mini flow line)	~780 hp

Notes

1. Reference 5.D

Table F-2. Governor Valve Measurements (Reference 9)

2/27/2026 9:10:00 AM - Commenced STP-220.002 ESF TIME RESPONSE "B" TRAIN for the TDEFP. WO 88201690801

2/27/2026 9:36:00 AM - TDEFP XPP0008 is running

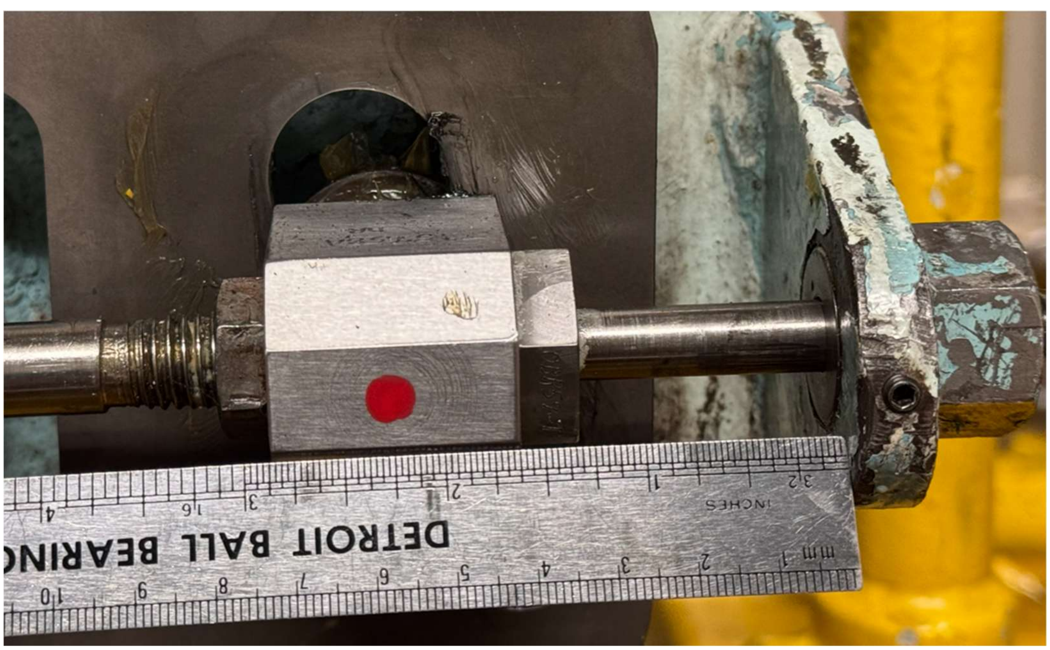
Governor Valve Full Open – Prior to Start

IMG_4634.HEIC [2/27/2026 09:29]

~2 3/8"

After Pump Start

IMG_4650 [2/27/2026 09:37]



~2 7/8"

2/27/2026 11:07:00 AM - Commenced STP-220.008A EFP FULL FLOW TEST EMERGENCY FEEDWATER TURBINE DRIVEN PUMP WO 88201746553

2/27/2026 11:41:00 AM - Started XPP0008 TDEFP per STP-220.008A

Prior to Pump Start

IMG_4683[2/27/2026 11:30]

~2 3/8"

After Startup

IMG_4694 [2/27/2026 11:42]

~2 7/8"

All FCVs Open 2/27/2026 12:02

IMG_4741 [2/27/2026 12:14]

~2 27/32"