REACTOR CORE ISOLATION COOLING TRACG MODEL

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ABSTRACT

Increased emphasis has been placed on the ability to mitigate station blackouts (SBO) in the wake of the events at Fukushima Daiichi. In the majority of operating Boiling Water Reactors (BWR), types 4-6, the Reactor Core Isolation Cooling (RCIC) system is the primary system available for SBO mitigation. The RCIC system consists of a steam turbine driven pump that nominally provides a constant flow rate to the vessel over a large range of reactor pressure. It is vital to understand how the RCIC system behaves under extended SBO conditions in which the containment conditions may progressively become degraded.

A detailed, physics-based RCIC model has been developed using a GE Hitachi proprietary version of the Transient Reactor Analysis Code (TRACG). The RCIC system piping is directly modeled with TRACG components. The performance of the RCIC system is captured in the TRACG control system by deriving an efficiency correlation from the Terry turbine specifications and calculating the amount of energy to extract in the turbine and the torque to supply to the pump based on the usable work. The built-in TRACG pump homologous curves were also modified to better align with RCIC pump specifications.

The paper presents the RCIC model development as well as its performance against RCIC specifications a cross the nominal range of reactor pressure. The model is also tested outside of its expected operating range by imposing conditions such as high backpressure at the turbine exhaust or varying steam quality at the turbine inlet.

KEYWORDS
RCIC, SBO, BWR, TRACG

1. INTRODUCTION

A number of investigations have been done in the wake of the Fukushima events to understand the behavior of BWRs in the event of a Station Blackout (SBO). These analyses are generally performed with codes such as MELCOR or TRACG (among others). In these events the Reactor Core Isolation Cooling (RCIC) system is often the only system available for core cooling (for BWR/4-BWR/6 designs). Generally the RCIC system in SBO analyses is modeled in a limited way, i.e. a prescribed constant flow rate from some high pressure (7.5-8.3 MPa) to some low pressure (1.0-1.35 MPa) while the vessel level is between low (level 2) and high (level 8) setpoints based on RCIC design documents. It is well documented that the RCIC system at Fukushima Daiichi Unit 2 (1F2) operated for roughly 70 hours after the reactor scram. The conditions for RCIC operation became increasingly degraded over this time (increasing turbine back pressure and pump suction from the wetwell which eventually became essentially saturated through continual SRV actuation). Simple RCIC modeling will not predict system degradation such as what likely occurred at 1F2. Some SBO analyses conducted since the Fukushima events simply decrease RCIC liquid flow to the vessel to better match the available plant data, which potentially just masks other modeling deficiencies rather than giving a reasonable picture of RCIC performance.

The objective of developing a detailed Reactor Core Isolation Cooling (RCIC) system model is to be able to not only match the expected performance over the normal range of operation but also to model scenarios, such as SBOs, in which the system may operate outside its normal range of operation. Developing a model based on the actual physics and response of the real system and showing that it functions as expected in the normal operating range allows for increased confidence in predicting how it will operate outside the expected conditions. This design will physically model the RCIC system piping on both the steam and liquid sides and the turbine and pump performance will be specified using the actual system performance curves. In this way a prediction of functionality outside of expected operating conditions can be made and potential system failure modes can be analyzed.

2. RCIC GENERAL DESCRIPTION

The objective of the RCIC system is to provide makeup water to the reactor vessel so that core cooling is maintained in the event that the reactor pressure vessel is isolated. The makeup capacity, generally between 0.0252 and 0.0505 m^3/s (400-800 gpm), is equal to the boil-off rate due to decay heat 15 minutes after reactor shutdown. The system is designed such that it can operate in the event of a complete loss of AC power. Most system valves are open when the system is in standby and the remaining valves only require DC power to actuate. The RCIC system is a safety related system, however it is not considered part of the Emergency Core Cooling Systems (ECCS).

A detailed schematic of a typical RCIC system is provided in Fig. 1. The RCIC system primarily consists of a steam turbine connected on the same shaft to a pump. During operation steam is taken from the main steam line, upstream of the safety relief valves (SRVs) and main steam isolation valves (MSIVs), to drive the turbine. The RCIC turbine is generally a single stage non-condensing Terry turbine designed to operate with steam supply pressure between roughly 1.1 and 8.1 MPa (165 and 1175 psia). The turbine exhaust is routed to the suppression pool below the nominal water level. The turbine turns the pump, which provides makeup water to the reactor vessel, generally through the feedwater line. The pump takes suction from the Condensate Storage Tank (CST) when available with the suppression pool acting as a secondary source when the CST level is low. A small percentage of the pump discharge is routed through a lube oil cooler, which provides lubrication to the turbine and associated bearings and a barometric condenser, which captures and condenses any steam leakage in the turbine.

When operating in automatic mode the RCIC system initiates at water level 2 (approximately 1.83 m below normal level) and isolates at level 8 (about 0.46 m above normal level). The system is designed to attempt to deliver the rated flow at all times. This is accomplished with a flow controller and the turbine governor valve. The turbine governor valve position is determined based on feedback from the flow controller, which is comparing the actual system flow with the desired flow.

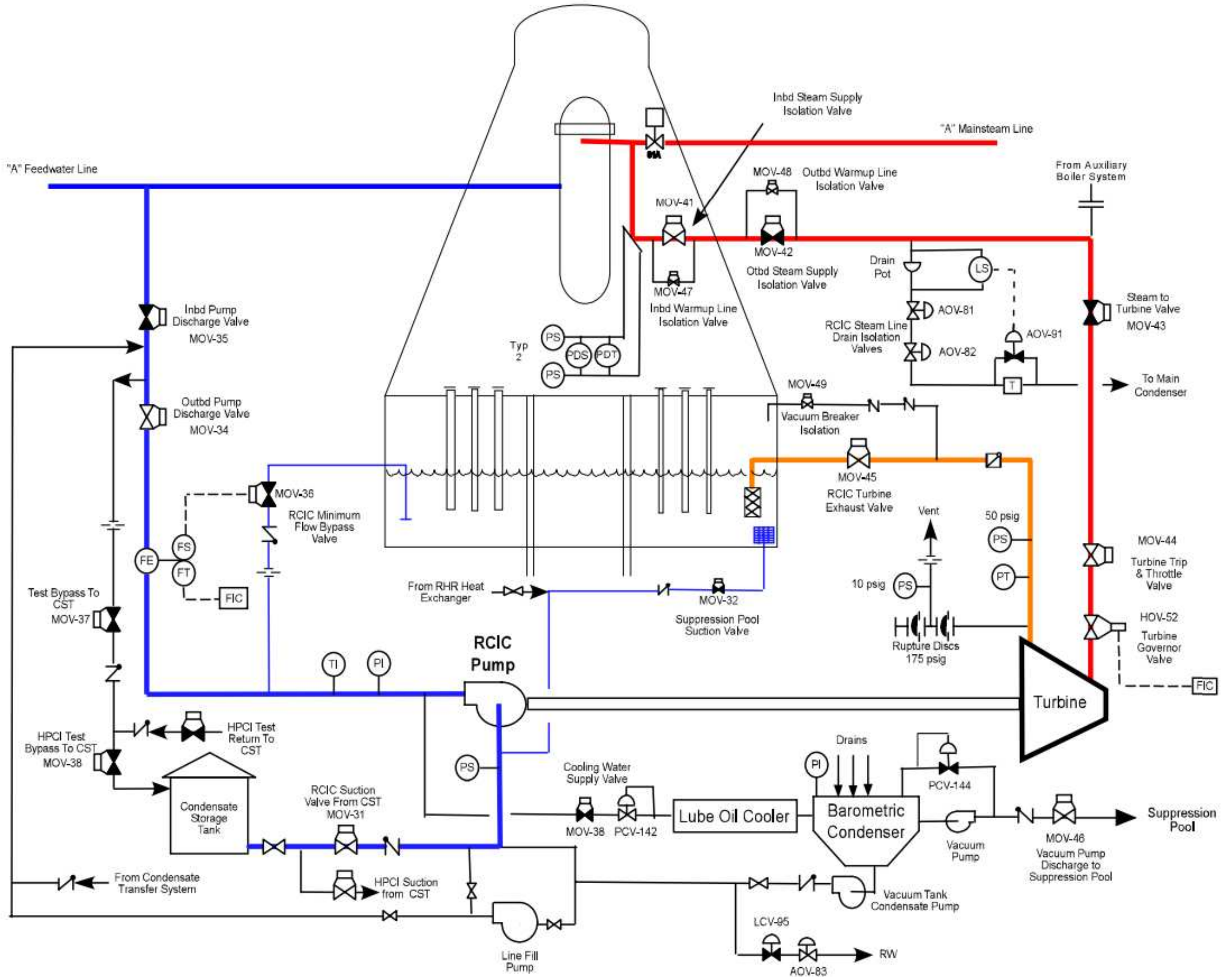

Figure 1. RCIC System Schematic [1]

3. DETAILED MODEL

3.1. RCIC OPERATING PARAMETERS

Table I gives the pump flow rate and normal operating pressure range of the RCIC system for a typical BWR/5. The rated pump discharge flow of 0.0394 m^3/s (625 gpm) includes a relatively small amount of flow that goes to cooling the turbine oil cooler and the turbine barometric condenser such that the amount of flow returning to the reactor vessel is 0.0379 m^3/s (600 gpm) rated. These alternate flow paths are not modeled in the TRACG RCIC system, though the target pump discharge flow remains 0.0394 m^3/s. The RCIC system is generally designed to supply the rated flow rate to the reactor vessel for the entire range of reactor pressure given in Table I.

Under normal operation the fluid entering the RCIC turbine is high quality steam and the turbine is largely non-condensing such that the turbine exhaust has very little condensate. Though this model was developed based on a 0.0394 m^3/s (600 gpm) system, RCIC systems across the BWR fleet are largely very similar in overall design. The primary difference is in the rated system flow, which ranges from 0.0139 m^3/s (220 gpm) in smaller plants up to as much as 0.0505 m^3/s (800 gpm) for the larger BWRs.

Table I. Representative BWR/5 RCIC Operating Parameters

Rated Pump Flow Rate	0.0394 m^3/s (625 gpm)
High Pressure Specification Limit	8.09 MPa (1173 psia)
Low Pressure Specification Limit	1.14 MPa (165 psia)

3.2. Model Geometry

Figure 2 is a schematic of the detailed RCIC model for evaluation with TRACG with identifying model component types. The inlet is an offshoot of the main steam line just upstream of the SRVs. Under normal operation PIPE-852 takes steam from the main steam line to the RCIC turbine. The elevation drop for this pipe reflects the approximate vertical distance from the main steam line to the RCIC turbine.

Just prior to the RCIC turbine inlet is the regulator valve, shown in Fig. 2 as VALVE-853. This is assumed to be horizontally oriented and at the same elevation as the RCIC turbine such that the elevation change from the main steam line to the turbine is accounted for in PIPE-852. VALVE-853 has two cells with the center face being the operating area and the exit face of the valve being the RCIC turbine inlet.

The RCIC turbine is implemented in TRACG as a TEE component (TEE-854). The volume of the turbine is estimated from general Terry Turbine designs, though it is largely unimportant in the performance of the system. The TEE component is chosen to model the turbine in this application because of the TRACG ability to model component-wise energy balance including heat input and work output.

The condensate line is not modeled in the TRACG RCIC model, nor is the barometric condenser. The amount of flow through this path is very low relative to the total flow rate so it assumed that it will not impact the results significantly. The exhaust from the turbine, almost entirely steam during normal operation, travels through TEE-855 to the suppression pool where it is condensed in the pool liquid. The side branches on the turbine and TEE-855 could be used to model the turbine condensate line or a turbine bypass line but they are blocked off in this model.

TEE-856 provides the suction from the suppression pool to the pump inlet. The elevation change for a typical BWR/5 is modeled for this component. In the integrated model the pump has the ability to take suction from either the Condensate Storage Tank (CST) or the suppression pool, which is controlled by components VALVE-861 and VALVE-862 as well as the associated control system logic. Only the path from the pool was used in the stand-alone model because the suction head is lower from the pool than it is from the CST and it was desired to test the impact of degraded pool conditions on the RCIC system performance.

PUMP-857, which is on the same elevation as the turbine, pumps the liquid from the CST or suppression pool through PIPE-858 and back to the vessel via the feedwater line. The elevation change along PIPE-858 was set as the vertical distance between the pump and the feedwater line vessel penetration elevation.

A number of valves present in the actual system were not modeled in the stand-alone model. These are primarily valves that will actuate to isolate the system or valves that will open or close based on where the RCIC pump is taking suction. These valves will be either fully open or fully shut. In addition to the isolation valve at the inlet of the steam side of the system there are also check valves just after the turbine and pump. These serve to prevent flow backwards into the turbine and pump components when the system is isolated.

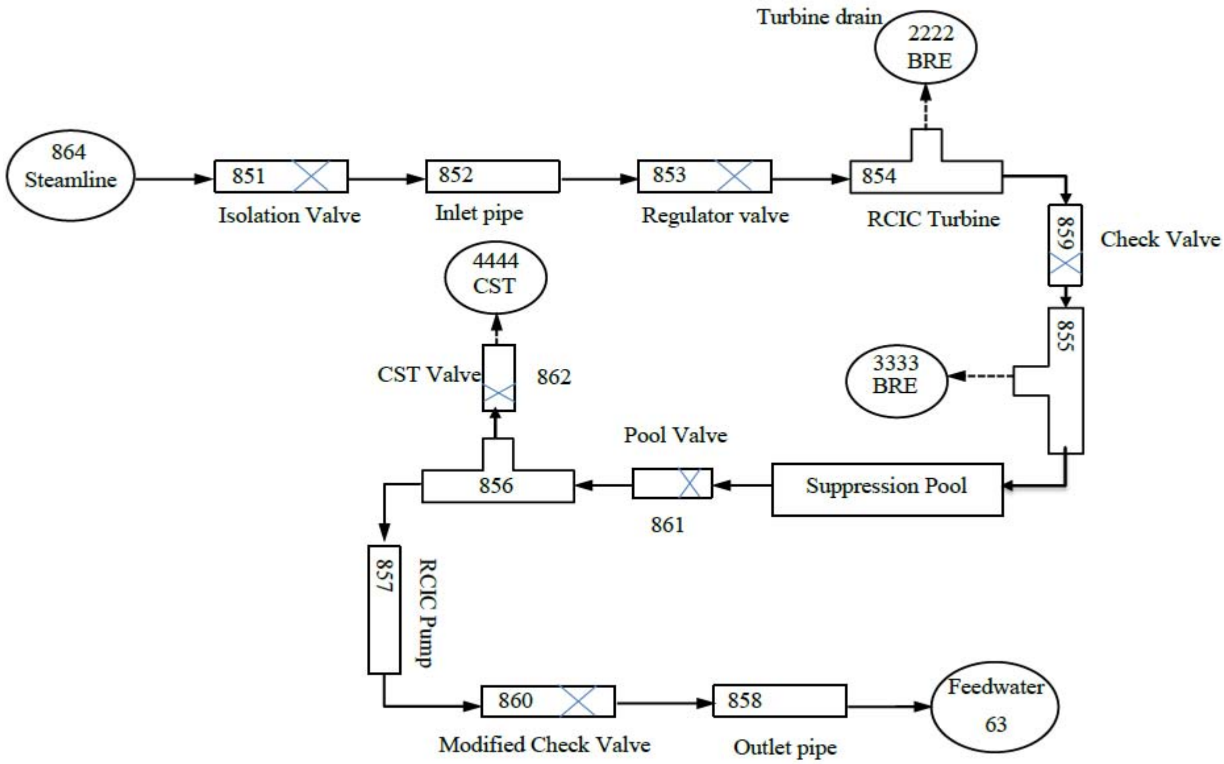

Figure 2. TRACG RCIC Component Model

3.3. TURBINE REGULATOR VALVE OPERATION AND CONTROL

In the TRACG model the turbine regulator valve dynamics are governed by the control system. In the actual RCIC system the automatic mode of operation means that the regulator valve will operate such that the pump will produce the rated volumetric flow rate. The RCIC system can also be operated in a mode in which a target speed is applied and the regulator valve responds to meet that target (manual). The method used to model both of these modes in TRACG is essentially the same. In automatic mode, where the system is trying to maintain a constant (rated) volumetric flow rate at the pump exit, the control system performs the following actions at a particular time step:

- Queries the mass flow rate and density of the fluid exiting the pump
- Divides the mass flow rate by the density to obtain the current volumetric flow rate:

$$V_t = m_t/\rho_t \tag{1}$$

- Obtains the volumetric flow ratio (R_F) by dividing the volumetric flow at that timestep by the rated volumetric flow rate:

$$R_f = V_t/V_{tR} \tag{2}$$

- The valve area at that timestep is multiplied by the inverse of R_f subject to the constraint that the resulting valve area be greater than the minimum valve area of 0.5% full open and less than or equal to the full open area (A_0):

$$A_{t+1} = A_t*(1/R_f),\ 0.005A_0<A_{t+1}<A_0 \tag{3}$$

3.4. TURBINE OPERATION AND CONTROL

3.4.1. Turbine isentropic expansion

One of the primary objectives of the detailed RCIC model is that it be able to handle some level of moisture coming in the turbine, as it is expected that in reality of a SBO event the system may need to operate in this scenario, albeit in a degraded state. In order to accomplish this, enthalpy at the turbine exhaust needs to be calculated in a way that is independent of the system feedback. Simply querying the enthalpy in the control system at the turbine exhaust creates instability because of the feedback loop present in the model. The method used to combat this is calculating the exit enthalpy based on a perfect turbine (isentropic expansion) and then applying an efficiency determined from the RCIC turbine characteristic curves.

The entropy of the fluid at the inlet of the RCIC turbine is obtained from the steam tables as:

$$s_{in} = F(P_{in},h_{in}) \tag{4}$$

When the RCIC turbine is perfect, fluid expands from inlet to exit isentropically. The enthalpy at the exit of the RCIC turbine may then be obtained from the steam tables and applied as:

$$h_{ex} = F(P_{ex},s_{in}) \tag{5}$$

In Eqs. (4-5) h_{in} is the inlet enthalpy, P_{in} the inlet pressure, and h_{ex} is the exhaust enthalpy determined for a given exit pressure, P_{ex}.

3.4.2. RCIC turbine efficiency

The actual turbine power versus inlet mass flow rate at a prescribed inlet and exhaust pressure of 1105 psig and 10 psig is available from turbine vendor data. The form of the efficiency was obtained using a curve fit to the turbine characteristic curves. The functional form of the efficiency is proprietary, but it may be expressed as:

$$\eta_1 = F(W,\Omega) \tag{6}$$

W is the steam flow rate, Ω is the turbine/pump shaft speed, and η_1 is the turbine efficiency in percent.

The efficiency does not include the effect of moisture in the inlet steam flow. There is no data specifically given for Terry turbines when steam quality is less than 1.0. However, a figure of merit is given in Reference [2] to account for the effect of quality as a 1.15% reduction in turbine efficiency for every 1% reduction in quality. In this model an efficiency reduction of 1.5% for every 1% reduction in quality was used to be on the conservative side. This can be expressed as:

$$\eta_2 = \eta_1 * (1.5x - 0.5) \text{ if } x < 1,\ \eta_2 = \eta_1 \text{ if } x=1 \quad (7)$$

In order to prevent the turbine efficiency from going negative the following condition is implemented in the TRACG control system. The minimum turbine efficiency of 2.0% is provided to ensure that the system will spin up from a zero speed initial condition.

The flow quality is calculated from available quantities as follows:

$$x = (\alpha * \rho_g * V_g)/[\ \alpha * \rho_g * V_g + (1-\alpha) * \rho_l * V_l)] \quad (8)$$

In Eq. (8), the subscript ‘g’ refers to the gas phase and ‘l’ to the liquid phase. The void fraction is represented by α, the density by ρ, and the velocity by V.

3.4.3. Turbine torque calculation

For given inlet pressure, inlet enthalpy, exit pressure, pump speed and the turbine mass flow rate, the turbine torque can be obtained as follows. For a perfect turbine, the enthalpy of the steam exiting the turbine, h_{ex}, is obtained from Eq. (5) for the given inlet and exit pressures and the inlet enthalpy. The turbine efficiency is calculated from Eqs. (6-7) for a given turbine mass flow rate, W, and turbine (or pump) speed, Ω.

The power provided by the turbine is obtained from:

$$E_t = \eta * W * (h_{in} - h_{ex}) \quad (9)$$

The turbine power calculated from Eq. (9) is fed back to the turbine via the control system. This informs TRACG how much energy to remove from the fluid passing through the turbine for the next time step.

The torque provided by the turbine at these conditions is calculated as:

$$T = E_t/\Omega \quad (10)$$

The calculated torque is then fed to the pump model which calculates a corresponding speed based on the homologous curves.

3.4.4. Turbine orifice sizing

In order to match the RCIC system specification an orifice was added at the exit of the RCIC turbine. The choked flow model in TRACG was turned on for this orifice. It should be sized such that at the low reactor pressure condition the regulator valve will be just fully open to meet the specification that the system provide the rated flow rate out of the pump over the pressure range given in Table I. Any further decrease in reactor pressure would result in increasingly degraded flow. The orifice diameter is plant dependent but does not impact the dynamics of the system except at very low pressures.

3.5. PUMP OPERATION AND CONTROL

There are two built-in pump homologous curves in TRACG: large and semi-scale. The RCIC pump performance is assumed to take the form of the semi-scale pump homologous curve. The semi-scale homologous curves were adjusted to better match the RCIC pump characteristic. Figure 3 illustrates the modification of the homologous torque curves. The head curves were modified in a similar fashion. 'SS' refers to the built-in TRACG semi-scale curves on the figures. The data for the figures and the labels on the plots have been removed as the pump homologous curves are proprietary information.

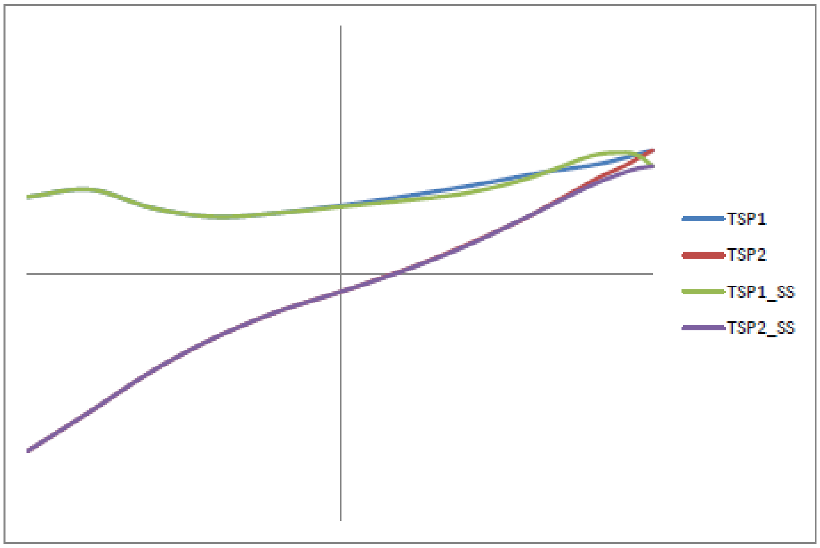

Figure 3. Single-Phase Homologous Torque Curves

Figure 4 illustrates the brake horsepower (BHP) and head behavior at constant volumetric flow and varying speed for the built-in curves ("SS"), modified curves ("New"), and the actual pump characteristic. After the curve changes, the BHP response as a function of speed matches to within roughly 5% from rated down to about half speed. The head response agrees within 5% down to about 70% speed and varies by as much as 12% at half speed. The variation at lower speeds is acceptable as the system most often operates at higher speeds.

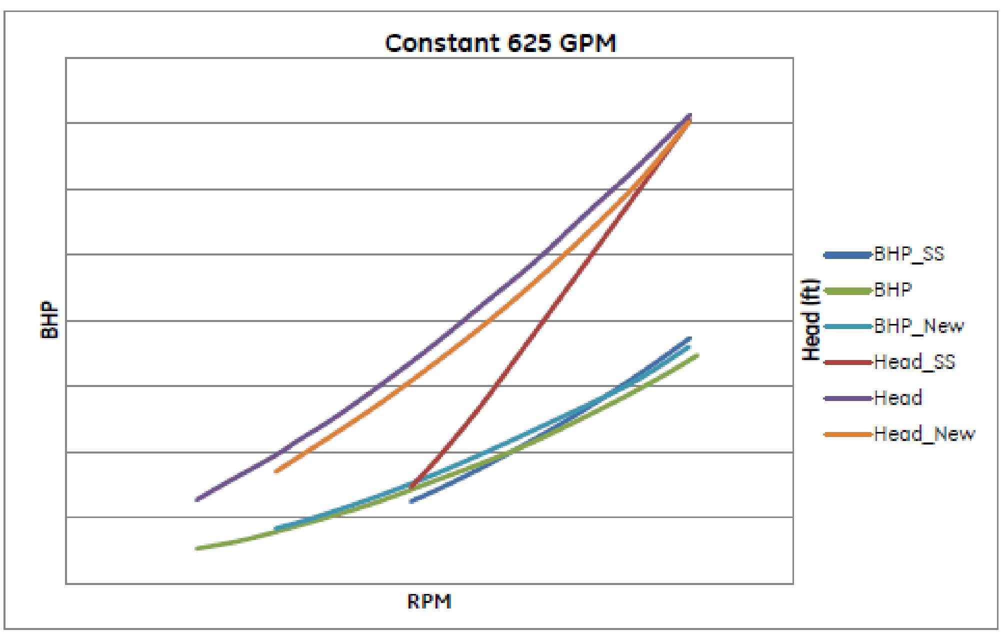

Figure 4. RCIC Pump Behavior at Constant Flow

4. RESULTS

4.1. STAND-ALONE TESTING

This section and associated subsections describe the results of the stand-alone RCIC model. In this setup the boundary conditions are prescribed in order to test system behavior to particular events in a controlled way.

4.1.1. Normal operating envelope

The most basic conditions that the RCIC system model had to sufficiently match were those in the expected operating range described by the reactor pressure range in Table I with the turbine discharge and pump suction both at low pressure. The system specification states that the pump should be able to provide full rated volumetric flow of 0.0394 m^3/s (625 gpm) at any reactor pressure between 1.14 and 8.09 MPa (165-1173 psia).

Figure 5 illustrates the dynamic behavior of the system as the simulated reactor pressure is decreased from 8.09 MPa to 1.14 MPa from 400 to 2000 seconds. Shown in the figure are the speed, flow rate, and torque as a ratio to the rated quantities as well as the regulator valve area fraction. At 8.09 MPa the speed and flow are both at rated and the torque is approximately 1.08 times the rated torque. This 8% additional torque is required to overcome the friction and bearing torque, which was an input assumption to the pump model. The regulator valve is almost completely closed as the amount of steam flow necessary to produce rated flow at high reactor pressure is very small. As the reactor depressurizes the torque and speed begin to decrease and the valve opens further so that the system maintains rated flow. At 1.14 MPa the regulator valve is completely open and the flow is at approximately 97% of rated. The turbine speed is at 48.5% of rated compared to the specification of 49% at the low pressure condition. After 2200 seconds the pressure is further reduced to 0.48 MPa (70 psia) at 2400 seconds. This illustrates the system behavior at pressures below the specification. Once the regulator valve is fully open further decreases in pressure result in insufficient enthalpy drop across the turbine. This reduction in available work manifests itself in decreasing pump flow rate.

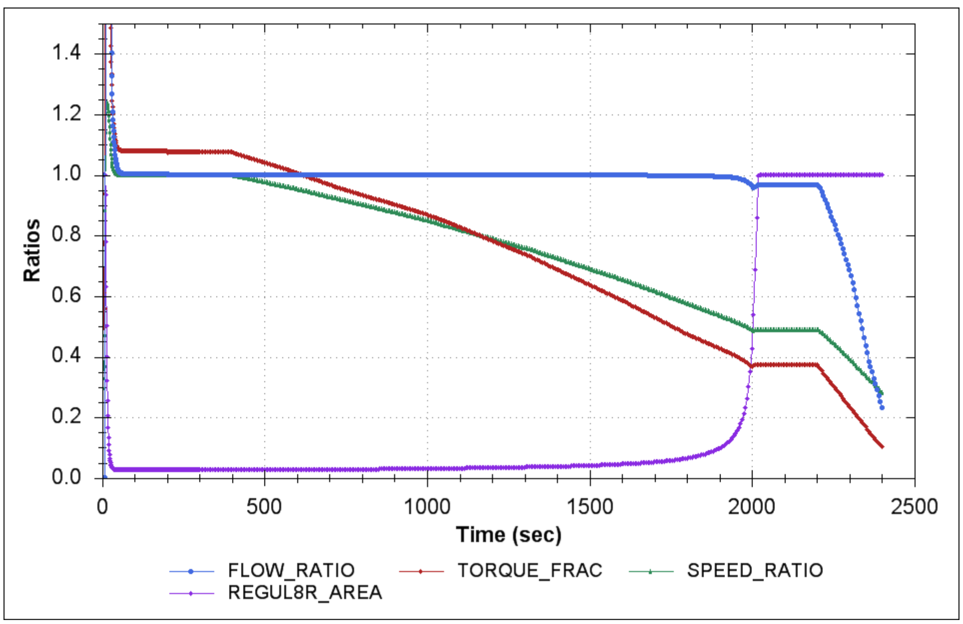

Figure 5. RCIC Parameters vs. Pressure

4.1.2. High backpressure

Figure 6 shows a similar depressurization scenario as Fig. 5 (8.09 to 1.14 MPa from 400 to 2000 seconds) but the simulated suppression pool is at 0.48 MPa (70 psia) instead of atmospheric. This reflects a scenario where the turbine sees increased backpressure and the pump sees a higher pressure water source (source is assumed to be the suppression pool in this case rather than the CST). For the first 200 seconds the system is operating in a speed control mode (manual) in which 100% rated speed is targeted. At 200 seconds the switch is made to flow control mode (automatic) to show any mismatch. In the nominal conditions in Fig. 5 the mismatch is almost non-existent. In this case the pump suction pressure is higher and the result is larger than rated flow/torque when the turbine is at rated speed due to the pump suction being at a higher pressure. Once the depressurization starts the dynamics look similar to the nominal case. The difference appears later in the scenario when the regulator valve reaches the fully open position sooner than in the nominal case. Further decreasing the pressure results in significant flow degradation at 1.14 MPa simulated reactor pressure. The system is no longer able to provide rated flow to as low of a pressure because the available work is less for the same turbine inlet conditions when the exhaust is at higher back pressure.

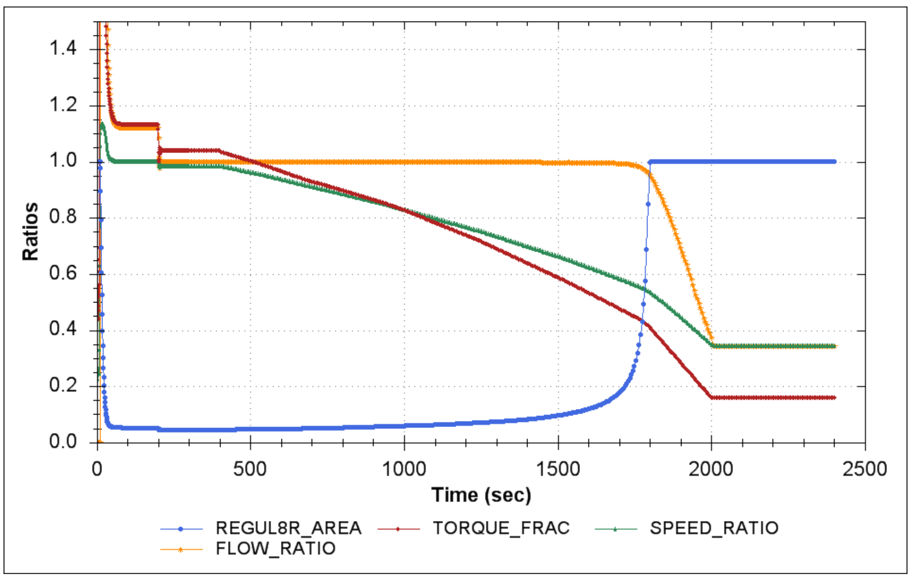

Figure 6. Suppression Pool at 70 psia

4.1.3. Turbine inlet moisture

The same depressurization scenario was performed with the boundary condition on the steam side of the system set to 99% void fraction to simulate the impact of moisture on the system performance. Shown in Fig. 7 are the simulated RPV pressure (Y2 axis), the regulator valve area, flow ratio to rated, and the quality of the steam at the turbine inlet. At high reactor pressure 99% void fraction corresponds to over 85% steam quality. As the reactor pressure decreases the steam quality also decreases for a given void fraction due to the changing phasic density ratio. At around 70% steam quality the regulator valve reaches fully open. Further decreases in pressure (quality) result in degraded pump flow. There exists a minimum steam quality, dependent to some extent on the RPV pressure, at which the turbine is no longer able to apply enough torque on the shaft for the pump to produce the required head. At this point the pump flow rate goes to zero. This scenario uses the turbine efficiency degradation with steam quality assumption laid out in Section 3.4.2.

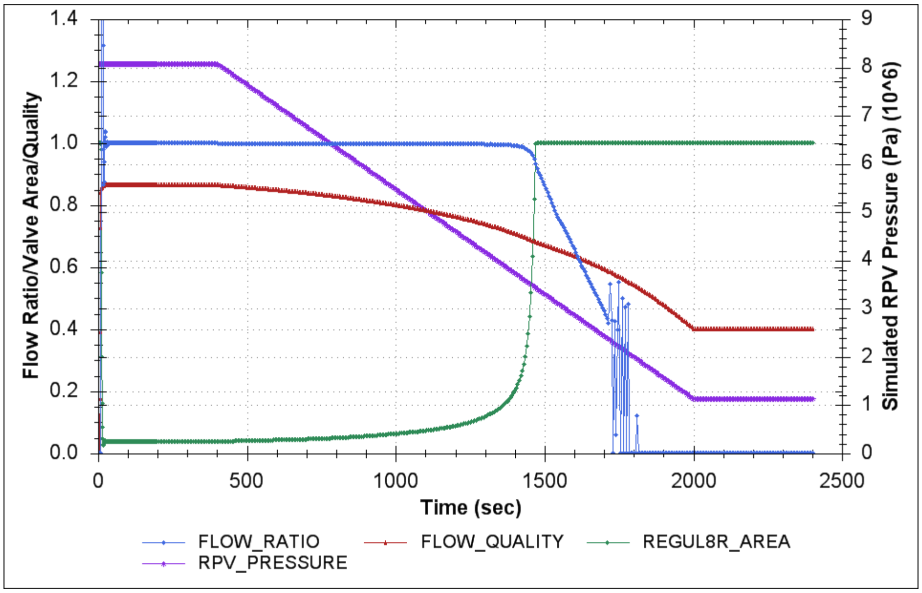

Figure 7. Turbine Inlet Void Fraction 99%

4.2. Integrated Containment Testing

This section will discuss testing of the RCIC system integrated into a coupled reactor pressure vessel and Mark II containment TRACG model. The performance of the detailed RCIC system will be base-lined against a simplified RCIC model. The base RCIC modeling is essentially a flow boundary condition that removes water from the CST or wetwell depending on the RCIC suction and another flow boundary on the feedwater line that injects a constant mass flow rate into the vessel. The simplified model injects water between level 2 and 8 and if the RPV pressure is between 1.14 and 8.09 MPa (165 and 1173 psia). Outside this range no injection would occur. This model does not account for degraded operation in any way due to low RPV pressure, high turbine back pressure, etc. It also does not account for the steam flow path from the main steam line through the RCIC turbine to the suppression pool, though this is largely unimportant as the steam will still make its way to the pool via the SRVs. Also, the actual RCIC system injects based on volumetric flow rate, while the flow boundary condition used in the simplified modeling specifies a constant mass flow rate. This will result in relatively minor differences as the density of the fluid being pumped changes.

Three cases were run with the RCIC model integrated into a Mark II containment basedeck. Case 1 is a 4-hour coping duration SBO simulation where the reactor pressure remains high for the entire event. Case 2 has the same coping duration; however, the RPV is depressurized from about 7.58 to 3.17 MPa (1100-460 psia) in 600 seconds, 3600 seconds into the event. The RPV is then held at this pressure for the rest of the simulation. Figure 8 illustrates the RPV pressure behavior for cases 1 and 2 using the integrated model.

Figure 9 illustrates the RCIC flow rate and the RPV water level for the integrated (“New”) model as well as the simplified model (“Base”) that simulates RCIC operation with a flow control function based on level. The dynamics of the integrated model are evident as the system attempts to maintain rated flow while the RPV pressure is constantly fluctuating between the SRV setpoints. The detailed model produces a higher flow rate than the baseline because the rated flow of the actual pump is 0.0394 m^3/s (625 gpm), of which 0.0379 m^3/s (600 gpm) is returned to the vessel in reality. It can be seen from the RPV water level response, however, that this does not make a significant impact.

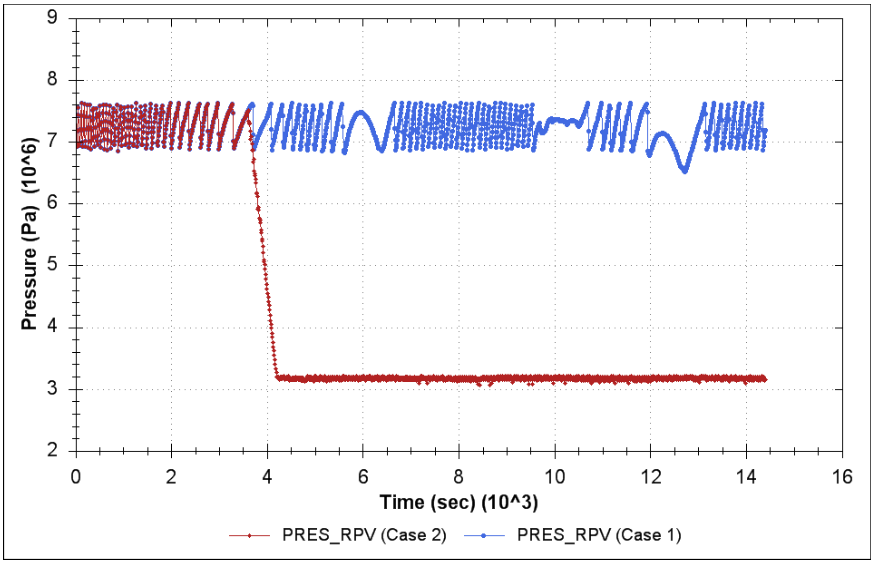

Figure 8. RPV Pressure

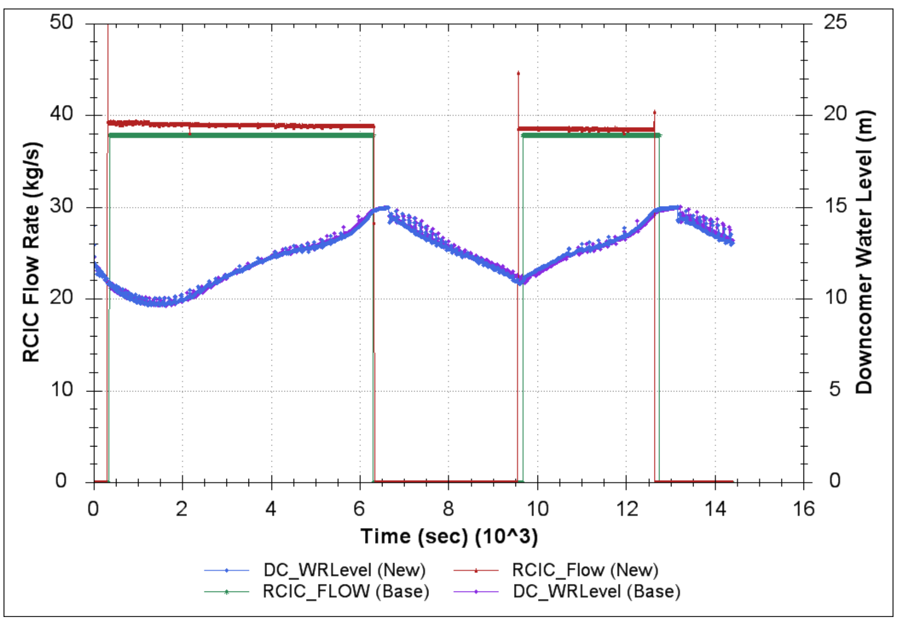

Figure 9. Case 1 RCIC Flow and RPV Level

Figure 10 shows the same parameters as Fig. 9 but for Case 2. At 3600 seconds the reactor is depressurized from over 7.58 to 3.17 MPa over the course of 10 minutes. The RPV level drops almost 3 meters as the saturation temperature comes down with the pressure and more steam is generated and transported to the wetwell through the SRVs. Again the detailed RCIC model performance tracks well with the baseline model especially when considering that the recirculation flow path is not currently modeled.

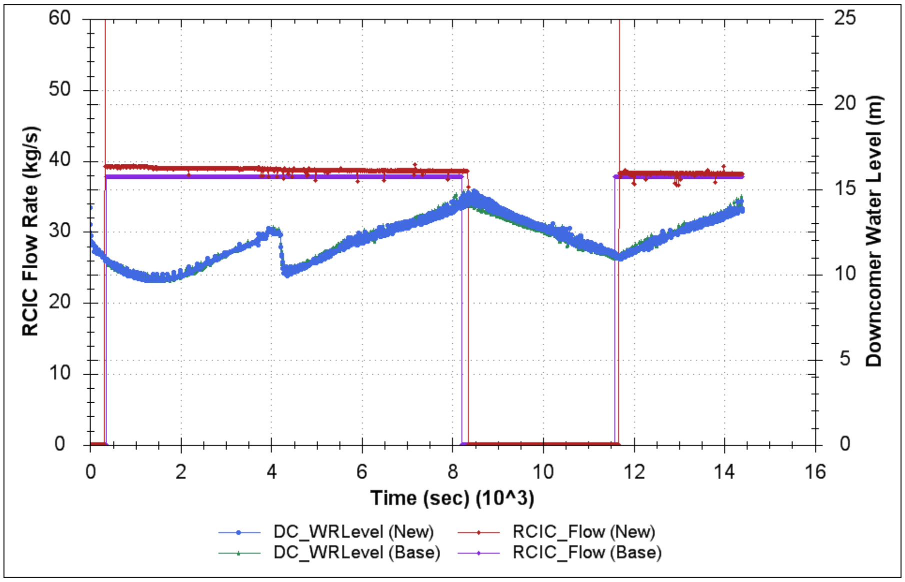

Figure 10. Case 2 RCIC Flow and RPV Level

Another scenario, Case 3, investigates RCIC system performance outside of its normal operating range. The RPV is depressurized and the water level decreases to the point where the ADS system actuates and brings the RPV pressure down below 0.69 MPa (100 psia). Figure 11 demonstrates the RCIC flow behavior as the RPV is depressurized. At 1000 seconds the RPV pressure is decreased to 2.76 MPa (400 psia) over 600 seconds using SRVs. At about 1800 seconds the ADS initiates and the RPV depressurizes down to about 0.41 MPa (60 psia) at the end of the simulation. The RCIC flow ratio is plotted on the secondary axis. The system continues to provide rated flow down to approximately 1.28 MPa (185 psia). The RCIC system specification states that it should provide rated flow down to 1.14 MPa (165 psia). The discrepancy is due to some differences in the stand-alone and integrated models. For example, in the stand alone system the turbine exhaust was maintained at a constant pressure of 0.1013 MPa. In the integrated model the turbine discharges under the nominal water level of the suppression pool. At the point that the regulator valve reaches fully open the turbine exhaust pressure is roughly 0.150 MPa, which gives a higher enthalpy than the stand-alone model. This leads to a smaller enthalpy drop across the turbine for the same inlet steam conditions and the flow begins to degrade at a higher inlet pressure as a result. The turbine exhaust orifice can be modified on a plant specific basis such that the low pressure specification is met. From a vessel pressure of around 1.28 MPa to approximately 0.55 MPa (80 psia) the system is able to provide a decreasing amount of flow to the vessel. The flow goes to zero when the vessel pressure drops below about 0.55 MPa. At this point there is no longer enough available energy across the turbine to operate the pump.

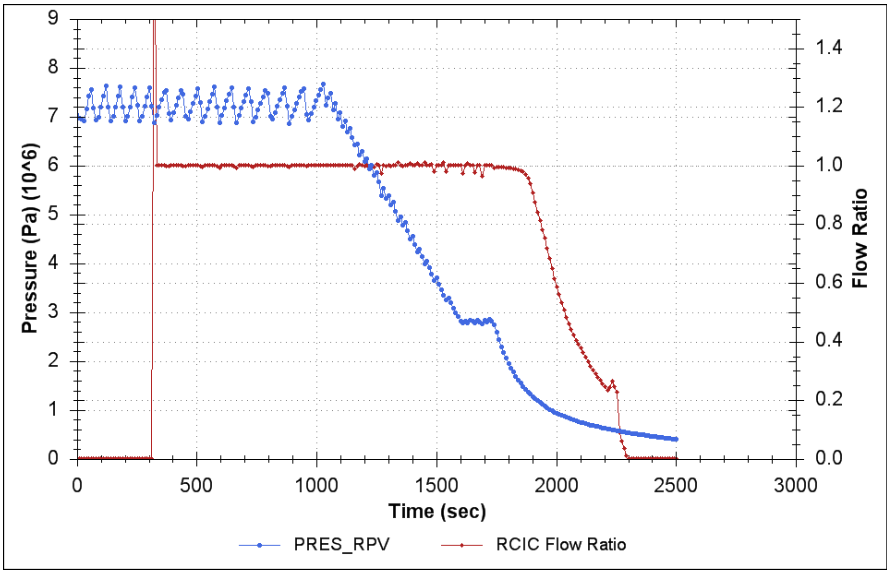

Figure 11. Case 3 RPV Pressure and RCIC Flow

5. CONCLUSIONS

The detailed RCIC system uses the turbine and pump characteristics of the actual RCIC system to provide a more accurate picture of the operation and dynamics of the real system. It is capable of meeting the system specifications over the entire reactor pressure range and provides some insight into how the system might behave under degraded conditions (high turbine back pressure, moisture in the turbine inlet steam, and low RPV pressure).

The system currently delivers about 4% more flow back to the RPV than the actual system does because the small recirculation flow path in the RCIC system is not currently modeled. The pump target flow can be set at any desired value in the current model or an additional flow path accounting for the recirculated water can be added if getting the exact return flow back to vessel is desired. However, little impact is seen in the RPV water level from this small amount of excess flow.

The detailed model was created based on a 0.0379 m^3/s (600 gpm) system and the integration was performed on Mark II containment. Plants that have RCIC systems with different rated capacities and/or different containment types will require additional modifications, though this model can be scaled to fit other RCIC systems because the turbine performance curve is independent of the system capacity.

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Note: Many of the references used to develop the model are GEH proprietary and have been removed from the above list.