Governor Upgrades for Grand Coulee's Third Powerhouse

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Abstract

The US Bureau of Reclamation (USBR) Grand Coulee Third Powerhouse has the largest hydro units in North America at approximately 750MW each. Together they total approximately 4.5GW, making it one of the largest power plants in the world. Facing increasing difficulty obtaining spare parts for the 30+ year old analog governors used on these units, USBR decided to contract for turnkey digital governor conversions on all six units in this powerhouse over a period of three years. The governor project is scheduled in tandem with the installation of new voltage regulator/excitation systems.

Introduction

Due to a growing demand for electricity after WWII, construction of a third power plant at the Grand Coulee Dam was begun in 1967. A 1,170-foot-long, 201-foot-high forebay dam was built along the right abutment at a 64 degree angle to the rest of the dam. This addition made the original 4,300-foot-long dam nearly a mile long. Three 600 MW units were manufactured by Westinghouse and three 700 MW units were manufactured by General Electric which were later upgraded to 805 MW by Siemens. The first new generator was commissioned in 1975 and the final one in 1980 [2].

Figure 1: Grand Coulee Dam, Washington, USA

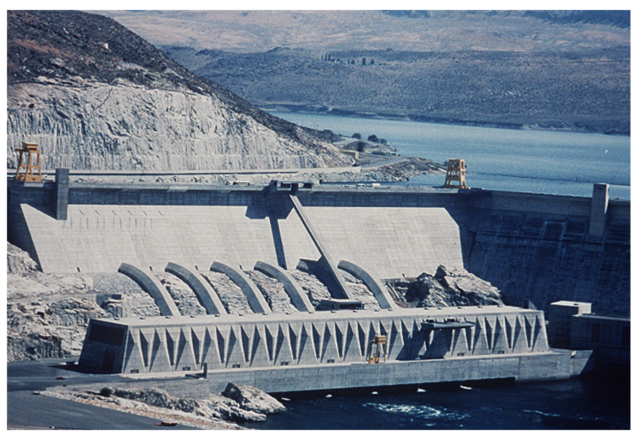

Figure 2: Grand Coulee Third Powerhouse

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Lack of support from the governor manufacturers of the 30+ year old units had begun to cause real concern that a failure in a primary component could result in a very lengthy outage. Spare parts had been salvaged from other powerhouses but the supply was dwindling.

USBR is currently in the middle of a major overhaul project that was started in March 2008 [1]. When completed, the project will ensure continued operation of the Third Powerhouse and will allow the USBR to continue to provide a reliable source of hydroelectric power to the region. Major aspects of the overhaul project include the construction of a new materials storage building, replacement of the excitation system, transformers, and governor controls, rehabilitation of two elevators, as well as draft tube repairs.

American Governor Company was awarded a turnkey contract to upgrade the six analog governors to digital governors. This paper provides an overview of the governor controls system upgrade and a review of the technical aspects and special requirements at this powerhouse. The units that are part of this project are Units G-19, G-20 & G-21, which have Cheston Pelton analog electric cabinet actuator governors originally installed in 1970, and Units G-22, G-23 & G-24, which have Voest-Alpine analog electric cabinet actuator governors originally installed in 1973. Figures 3 and 4 show the front panel of the Third Powerhouse's current Cheston Pelton and Voest-Alpine cabinet actuators, respectively.

American Governor strives for excellence in engineering and project management. As a result, American Governor uses a variety of project management tools ranging from Primavera, MS Project, to ACE Project. Given the extent of the installation and engineering work and the complexity of the other overhaul activities at the Grand Coulee Third Powerhouse, Primavera was used for project scheduling.

Figure 3: Third Powerhouse Unit G-19
Cheston Pelton Cabinet Actuator

Figure 4: Third Powerhouse Unit G-22
Voest-Alpine Cabinet Actuator

Digital Governor Software Features

Rough Zone Detection

When reaction style turbines are operated at heads and flows other than what they are designed for, they experience rough operation. This rough zone typically occurs when the unit is operated in a region of 25%-75% of the rated machine power output capacity. Operating in the turbine rough zones over a period of months or years can cause extensive damage to the turbine runners. The Third Powerhouse's new governor control system will be able to detect when the system is operating in a rough zone. When the governor is in any On-line mode, the *Rough Zone Indication* is active. Draft tube pressure and nine bearing runout (vibration) probes provide 4-20mA signals that are received by the governor as analog inputs. The signals are fed through a specially designed bandpass filter and compared to a threshold value to determine if the unit is in a rough zone. If a rough zone is detected, the governor annunciates the unit is in a rough zone and the operating range needs to be changed. A block diagram of the bandpass filter is shown in Figure 5 below.

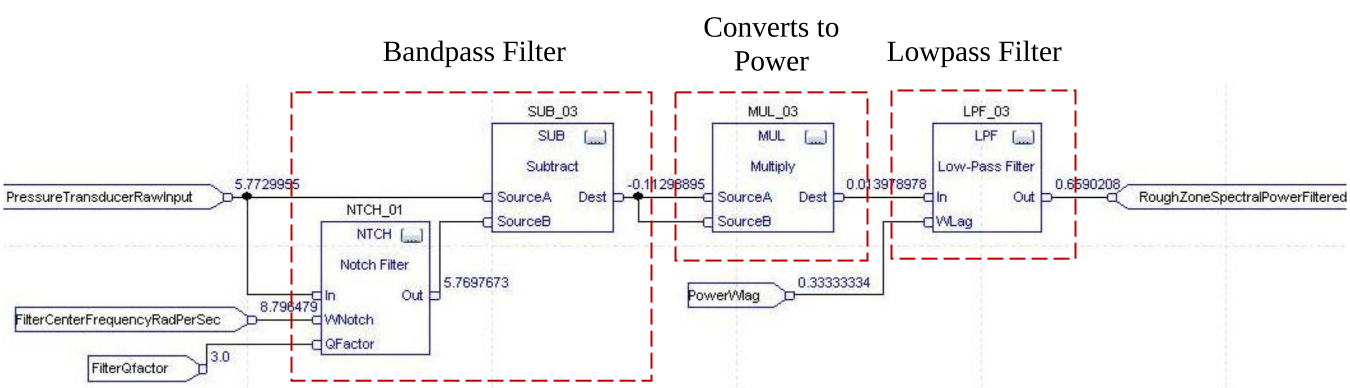

Figure 5: Block diagram of Rough Zone Detection Filter

Extensive testing of the rough zone detection software was performed to ensure it would perform as needed once installed. Simulated pressure transducer signals of varying frequencies were fed into the bandpass filter and the output signals were analyzed. For this simulation, the system was tested for rough zone operation that occurs between 1 to 2 Hz. The table on the next page shows the results of the test.

Table1: Results of Bandpass Filter Testing

Signal Properties	Graph Color	Pressure Transducer Raw - Frequency				
		0.5	**1.0**	**1.5**	**2.0**	**2.5**
Pressure Transducer - Bias (mA)	Purple	5.469	5.469	5.469	5.469	5.469
Pressure Transducer - Amplitude (mA)	Purple	0.219	0.219	0.219	0.219	0.219
Filtered Bandpower (normalized mW)	Blue	0.001	0.0074	0.012	0.071	0.003
Threshold /Trigger (normalized mW)	Red	0.007	0.007	0.007	0.007	0.007
Rough Zone Detected	Green	No	Yes	Yes	Yes	No

As you can see from table 1, the bandpass filter performed as expected and detected that the simulated unit was in a rough zone when the pressure transducer raw input signal had a substantial component between 1 and 2 Hz. Similarly, for frequencies less than 1Hz and greater than 2Hz, the filter determined that there was no rough zone present. Figures 6 and 7 below show the graphical data for the pressure transducer–frequency trials of 0.5Hz and 1.0Hz respectively.

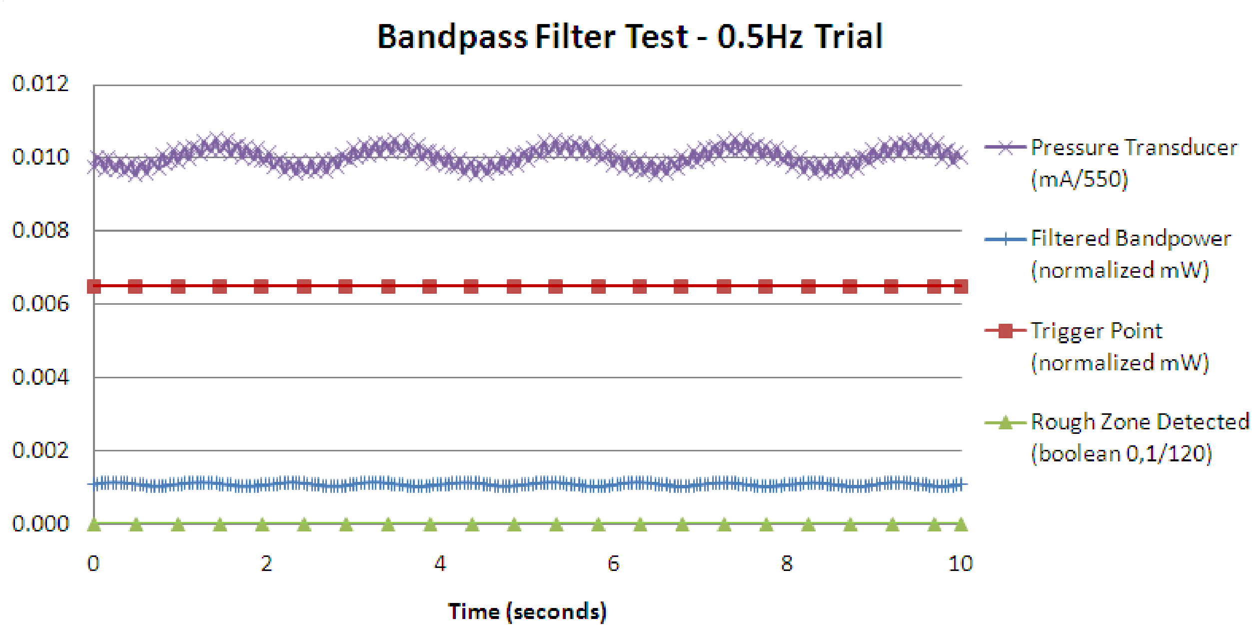

Figure 6: Plot of Bandpass Filter Test – 0.5 Hz Trial

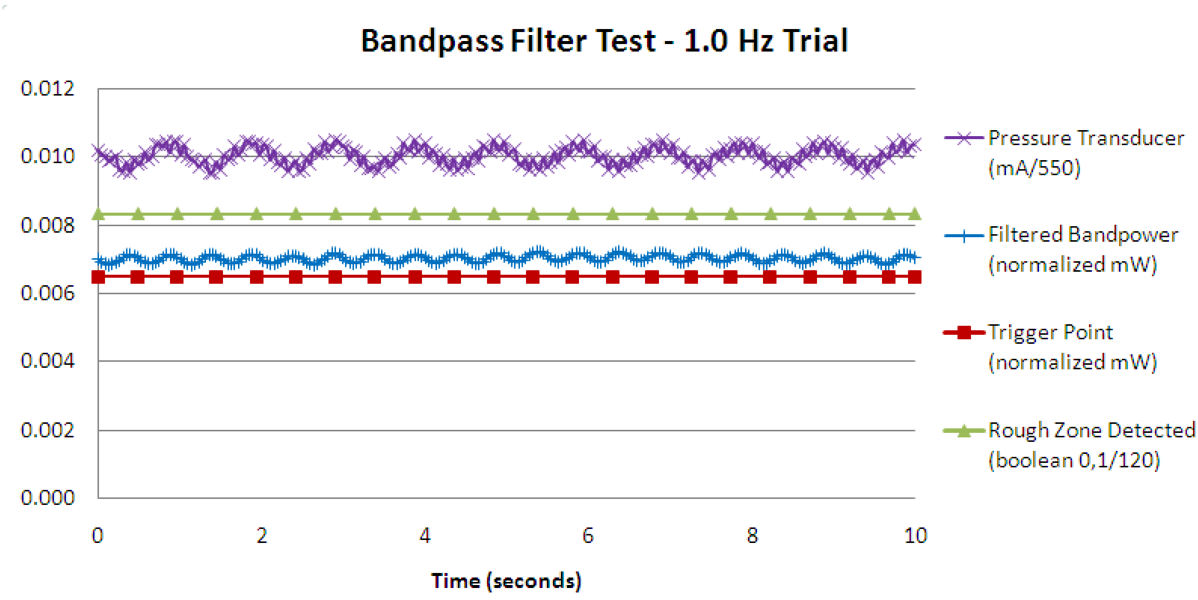

Figure 7: Plot of Bandpass Filter Test – 1.0 Hz Trial

Lead-Lag Algorithm

The USBR has determined that for this particular application a lead-lag controller provides superior feedback control over a PID type controller. For recent powerplant governor upgrades, the USBR has used three lead-lag blocks. However, for Grand Coulee, they chose to expand this algorithm to four lead-lag blocks. The four-stage lead-lag controller allows fine adjustment of the phase characteristics of the controller, which allow better preservation of the phase and gain stability margins across a variety of linearized models given the time varying and non-linear nature of the real world plant. The latest algorithm has passed an extensive factory testing protocol operating a simulated turbine/generator system. Parameters and gains will be fine-tuned during the on-site commissioning. The block diagram in Figure 8 represents their lead-lag algorithm with four lead-lag blocks.

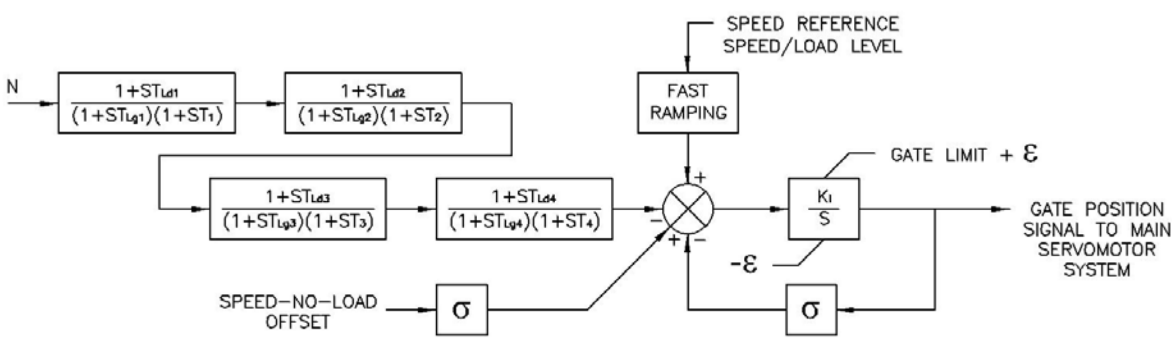

Figure 8: USBR Four-Stage Lead-Lag Algorithm

Redundant Creep Detection Software

To detect and respond to unit creep, the governor control system will utilize redundant creep detection software and hardware. The Governor PLC determines whether the requirements are met to allow Brake operation. These requirements include confirmation that the gates are closed, the unit is shutdown, that the brake permissives are met, all of which are communicated to the Creep PLC via Ethernet. The Creep PLC independently determines unit speed and confirms slow rotation (creep) of the unit. Operation of the Brake Auxiliary Relays and the Creep Auxiliary Relay requires that both the Governor PLC and the Creep PLC agree that the unit is creeping and the brakes should be applied. Should either of the PLC processors fail, the brakes cannot be automatically applied. If either the Governor PLC or the Creep PLC detects creep, the Creep Auxiliary Relay will be activated.

Two separate sets of high resolution creep detectors are installed on each unit; one for the Governor PLC and one for the Creep PLC. The high-resolution creep detectors are designed to be immune from normal powerhouse vibrations. Each detector consists of two proximity sensors looking at a 360 tooth steel gear connected to the generator shaft. The probes are out of phase with each other so that when one probe sees a tooth, the other sees a valley. Figure 9 below illustrates a high resolution creep detector and how it is mounted to the unit. Each sensor produces a voltage signal when the gear tooth is within the threshold level of the pickup and zero volts when the gear tooth is outside the threshold level. Should the unit rotate sufficiently so the Governor PLC or Creep PLC witness a rise and fall of DC voltage in their discrete input channels then one degree of rotation of the unit has occurred. Three degrees of rotation will activate the “Creep” function.

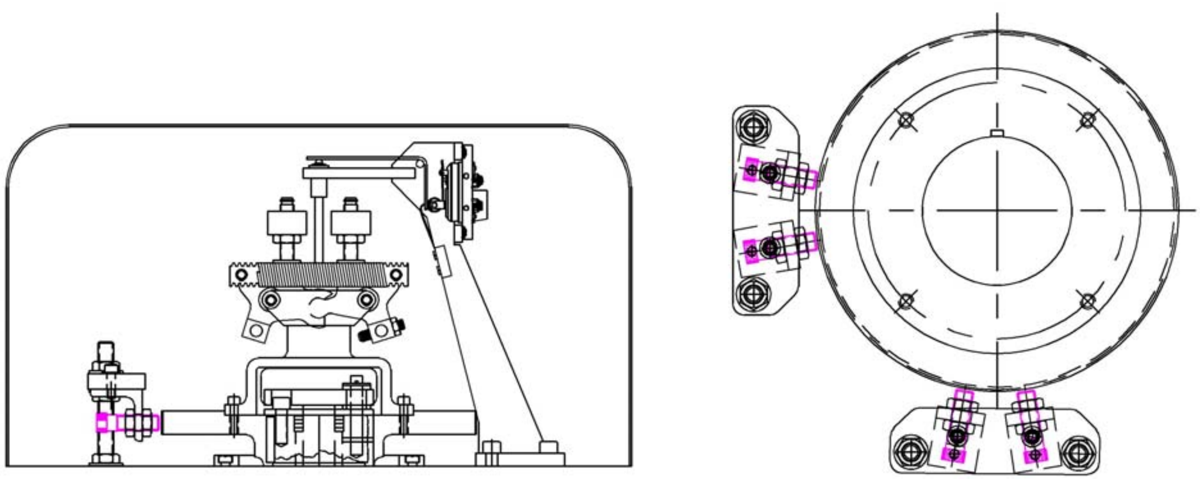

Figure 9: Proximity Sensors Used for Governor Speed and Creep Detection

Hardware

Proprietary vs. Non-Proprietary

The new governor control systems for Grand Coulee's Third Powerhouse were made with non-proprietary components and hardware. This will allow USBR to easily purchase replacement components in the future when repairs are needed or when further upgrades become available. This will extend the life of the system and will prolong the need for a complete replacement by years or even decades. With the programming tools and software licenses provided, the USBR can also make program changes on their own if they desire.

Governor Fabrication

Each unit in the Third Powerhouse will receive all new governor controller equipment. This includes the PLCs, HMI, relays, electro-hydraulic interface (EHI), Linear Variable Differential Transducer (LVDT), and Magneto-strictive Linear Displacement Transducer (MLDT). The Governor PLC, Creep PLC, HMI, breakers, and main power supplies are all housed in an enclosure cabinet that will be installed in the actuator cabinet. Figures 10 and 11 on the next page illustrate the layout of the components in the enclosure cabinet. Each Unit's 39 relays and relay components are mounted to a 46x22 inch panel that will be housed in the existing relay cabinet inside the actuator cabinet. Figure 12 on the next page illustrates the layout of the components on the relay panel. The power generation signal equipment is separated into two panels. The first one houses the voltage phase angle transducer components and the second houses the watt transducer components. Figures 13 and 14 on the next page illustrate the arrangement of the components on the voltage phase angle transducer and watt transducer panel respectively.

During operation of the unit, the position of the main actuator will be adjusted by the governor through the use of an electro-hydraulic interface (EHI). The EHI consists of a Bosch proportional valve, shutdown solenoid, an adapter block, and a linear Variable Differential Transducer (LVDT). The LVDT is connected directly to the relay valve plunger and provides intermediate feedback to the proportional valve. Two Magneto-strictive Linear Displacement Transducers (MLDTs), one primary and one back-up, determine the position of the turbine servomotor and provide feedback to the controller for accurate control of the wicket gates.

Figure 10: PLC Enclosure Cabinet Exterior

Figure 11: PLC Enclosure Cabinet - Interior

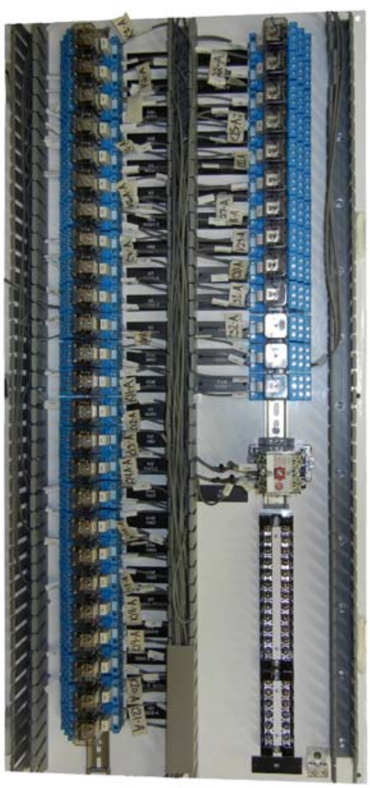

Figure 12: Relay Panel

Figure 13: Voltage Phase Angle Transducer Panel

Figure 14: Watt Transducer Panel

Installation

Installation of the upgraded governors will occur during each unit's scheduled outage period, which will last approximately three months. During this time, the existing governor components will be disassembled and the new equipment will be installed in their place. The new equipment will be integrated into the unit's current control and wiring arrangement. The original relay logic governor controls will be consolidated, while maintaining a familiar sequence of operation for plant personnel. The PLC enclosure cabinet, relay panel, and both power generation signal boards will be installed into the actuator cabinet as illustrated in figure 15.

The MLDT will be installed directly onto the wicket-gate servomotor as illustrated in figure 16 below. The EHI including the LVDT will be installed directly to the main actuator relay valve as illustrated in Figure 17 below.

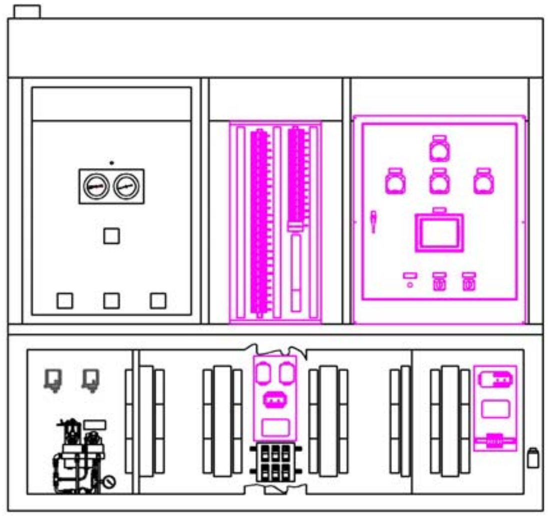

Figure 15: Installation Arrangement of New Governor Panels in Actuator Cabinet

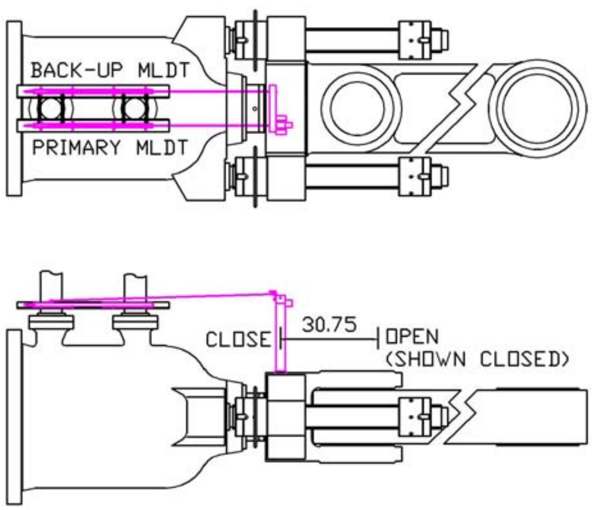

Figure 16: Installation Arrangement of Primary and Back-up MLDTs

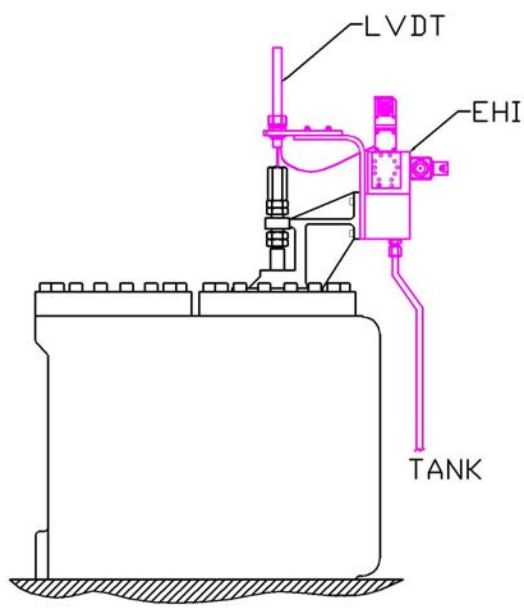

Figure 17: Installation Arrangement of Electro-hydraulic Interface

Conclusion

As part of a larger rehabilitation project, the digital governor upgrades will bring the Grand Coulee Third Powerhouse up-to-date allowing the USBR to continue to provide a reliable source of hydroelectric power to the region long into the future. The Third Powerhouse presented numerous unique challenges. American Governor Company addressed the unique challenges of this project through use of a four-stage lead-lag controller instead of a PID controller, the addition of a rough zone detection system, the independent creep detection PLC, as well as interfacing with the less common governor platforms of Cheston Pelton and Voest-Alpine.

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Authors

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Graduated BSAAE, University of Illinois in 1981. Roger has worked in the hydro governor industry for 24 years. Prior to joining American Governor, Roger worked for two years as a Controls Sales Manager for GE Global Controls Services and four years as a Sales Engineer at Woodward Governor Company. Before that, Roger spent nine years at Digitek, a small manufacturer of integrated generation controllers. He also worked in the wind energy industry for six years as a Research Engineer for Flowind and a Loads & Dynamics Engineer for Boeing. He has been with American Governor for nine years and currently serves as Western Region Manager.

Bill Eberman

Graduate: RCA Technical Institute and NCR Technical Academy. Bill has over 40 years of experience in the hydro industry. He served Voith Hydro for 10 years as a Turbine Field Service Representative, Regional Sales Manager and Controls Commissioning / Application Engineer. Before that, Bill served Woodward for 18 years, as a Production Supervisor, Field Service Supervisor, Business Unit Manager and Project Manager. Notably, he also worked for 8 years at the Cheston Company as a Field Service Engineer specializing in BLH/Pelton governor systems. Bill’s expertise spans the entire range of governor systems: mechanical, analog and digital. He has been with American Governor for six years and currently serves as the Wisconsin Engineering Manager.