Best Practice Catalog

Governor

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Prepared by

MESA ASSOCIATES, INC.
Chattanooga, TN 37402

and

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
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Contents

1.0 Scope and Purpose

This best practice for a hydraulic turbine governor addresses the technology, condition assessment, operations, and maintenance best practices with the objective to maximize performance and reliability of the generating units. The primary purpose of the governor is to control the turbine servomotors which adjust the flow of water through the turbine regulating unit speed and power. How the governor is designed, operated, and maintained will directly impact the reliability of a hydro unit.

1.1 Hydropower Taxonomy Position

Hydropower Facility → Powerhouse → Power Train Equipment → Governor

1.1.1 Governor Components

A governor is a combination of devices that monitor speed deviations in a hydraulic turbine and converts that speed variation into a change of wicket gate servomotor position which changes the wicket gate opening. This assembly of devices would be known as a "governing system". In a hydro plant this system is simply called the "governor" or "governor equipment". For a single regulating turbine (Francis and Propeller), a governor is used to start a hydro unit, synchronize the unit to the grid, and load and shut down the unit. For a double regulating turbine (Kaplan), a governor would also add control to the runner blade servomotor which changes the pitch of the runner blades to maintain optimal efficiency of the turbine for a given wicket gate opening. This is usually done through a mechanical cam or digitally through an electronic controller. Double regulating is also used for dual control of a Pelton's nozzle opening and deflector position. This double regulation establishes an exact relationship between the position of the needle valve and the deflector to allow the deflector to intercept the jet of water flow before closure of the needle valve thereby reducing the water hammer effect in the penstock.

A governor is usually not considered as an efficiency component of a hydro unit, except for a Kaplan unit's double regulation of blade angle versus wicket gate position or Pelton needle versus deflector position, which is an important driver for performance and efficiency. For a Kaplan turbine governor, a 2D or 3D cam (or electronic equal) for blade positioning and the Kaplan feedback/restoring mechanism, together supply the double regulating function. The details are described as follows:

Double Regulating Device: The function of the double regulating device for a Kaplan turbine is to provide a predetermined relationship between the blade tilt angle and the wicket gate opening. This is done by a 2 dimensional (2D) or a 3 dimensional (3D) cam. A 2D mechanical cam provides a relationship between blade tilt angle and wicket gate opening. A 3D cam adds the third dimension of head usually by means of an electronic or digital controller. A 2D cam has to be manually adjusted for different head ranges whereas a 3D cam automatically adjusts for head changes.

Kaplan Blade Position Feedback: The restoring mechanism is a "feedback" device that feeds back the current blade tilt angle and the post movement command position to the control system. In a mechanical governor, this is typically a pulley cable system, and with digital governors it may be a linear potentiometer or linear magnetostrictive (non-contact) electrical positioning system.

The non-performance but reliability related components of a governor include the oil pressure system, flow distributing valves, control system, Permanent Magnet Generator (PMG) or speed sensor, control system, wicket gate restoring mechanism, and creep detector. As a note, many references consider the wicket gate servomotors as part of the governor system. However for HAP, the servomotors are considered part of the turbines and are addressed in the turbine best practices.

Oil Pressure System: The oil pressure system consists of oil pump/s, oil accumulator tank/s, oil sump, and the necessary valves, piping, and filtering required. Pressure tanks/accumulators and Kidney Loop filtration systems are not addressed in this best practice document.

Flow Distributing Valves: The distributing valve system varies in design depending on the type of governor. For a common mechanical governor, the system consists of a regulating valve (that moves the servomotors) that is controlled by the valve actuator, which is in turn controlled by the pilot valve. These valves coupled with the oil pressure system provide power amplification in which small low force movements are amplified into movements of the servomotors.

Control System: The control system can be mechanical, analog, or digital depending on the type of governor. In the truest sense, the control system is the "governor". The purpose of all other components in a governor system is to carry out the instructions of the control system (governor). For mechanical governors, the control system consists of the fly-ball/motor assembly (ball-head or governing head) driven by the PMG, linkages, compensating dashpot, and speed droop device.

Speed Sensor: Mechanical governors use a permanent magnet generator (PMG) as rotating speed sensor which is driven directly by the hydro unit. It is basically a multi-phase PMG that is electrically connected to a matching multi-phase motor (ball head motor) inside the governor cabinet that drives the fly-ball assembly (or governing head) which is part of the control system. Analog and Digital governors use a Speed Signal Generator (SSG) driven directly by the unit which provides a frequency signal proportional to the unit speed usually through a zero velocity magnetic pickup monitoring rotating gear teeth or through generator bus frequency measured directly by a Potential Transformer (PT).

Double Regulating Device for Pelton Turbine: Double regulation for a Pelton turbine provides for an exact relationship between the position of the needle valve and the deflector to allow the deflector to intercept the jet of water before closure of the needle valve thereby reducing any water hammer in the penstock. This is done by a mechanical connection between the needle valve and deflector.

Wicket Gate Position Feedback: The restoring mechanism is a "feedback" device that feeds back the current wicket gate position and the post movement command position to the control system. In a mechanical governor this is typically a pulley cable system, and with digital governors, it may be a linear potentiometer or linear magnetostrictive (non-contact) electrical positioning system.

Creep Detector: The creep detector is a device, usually mounted on the PMG or part of speed sensor, which is capable of measuring very slow shaft revolutions. Its purpose is to detect the beginning of shaft rotation that might occur from leakage of the wicket gates while the unit is shut down. The system detects movement and turns on auxiliary equipment, such as bearing oil pumps, to prevent damage.

In addition to the above devices, some auxiliary equipment associated closely with the governing system and often found in, on, or near the governor cabinet which is not addressed in this Best Practice includes: synchronizer, shutdown solenoid, tachometer, over speed switch, generator brake applicator, governor air compressor, and various gages and instruments. These can vary greatly in design depending on the type of governor or turbine.

1.2 Summary of Best Practices

1.2.1 Performance/Efficiency & Capability - Oriented Best Practices

Performance levels for governors can be stated at three levels as follows:

The Installed Performance Level (IPL) is described by the governor performance characteristics at the time of commissioning. These may be determined from manufacturer shop reports and records from field commissioning tests.

The Current Performance Level (CPL) is described by an accurate set of governor performance characteristics determined by field testing.

Determination of the Potential Performance Level (PPL) typically requires reference to governor design information from the manufacturer.

- The governor performance refers to the ability of off-line and on-line responses, sensitivity to hunting, accuracy of frequency, synchronization time, and the ability to start remotely. These performances can affect the unit generation performance directly or indirectly. One best practice is periodic testing to establish accurate current governor performance characteristics and limits.

- Periodic analysis of governor performance at CPL to detect and mitigate deviations of expected performance from the IPL due to degradation or wear.

- Periodic comparison of the CPL to the PPL to trigger feasibility studies of major upgrades.

- Maintain documentation of the IPL and update when modifications to equipment are made.

- Index testing of Kaplan turbines following ASME PTC 18-2011 [19] must be done periodically (10 year cycle minimum) or after major maintenance activities on the turbine, to establish the best blade angle to the gate opening relationship and update the 2D or 3D cam.

1.2.2 Reliability/Operations & Maintenance - Oriented Best Practices

- Since digital governors are the state of the art technology for hydro turbine governing system, use digital type governor for new installation. They can be either proprietary controllers or controllers based on industrial PLCs.
- Rather than replace the entire governing system it may be more cost effective to retain many of the mechanical components (i.e. pumps, accumulator tank, sump, etc.) and perform a digital upgrade or retrofit.
- As a best practice, use a non-contact linear displacement feedback sensor such as a Magnetostrictive Linear Displacement Transducer (MLDT) rather than a contact sensor such as a linear potentiometer which will wear over time.
- For new governors or retrofits, choose a well known reputable manufacturer that will be around to support the equipment for long term. Use industry acknowledged "up-to-date" choices for governor component materials and maintenance practices.
- Monitor the governor pump cycle time during regulating and shutdown to establish a baseline and trend any increases that may be indicative of internal leakage of the valves or problems with the turbine servomotors. Monitor pump noise and vibration which can be an indication of bearing failures, excessive oil foaming, loose pipe connections, and possible blockage of oil flow. Adjust maintenance and capitalization programs to correct deficiencies.
- Oil tests should show oil cleanliness meeting an ISO particle count of 16/13, viscosity should be within +/-10% of manufacturer's recommended viscosity, metals should be under 100 parts per million (ppm), acid number less than 0.3, and the moisture content should be less than 0.1%. Oil should be tested at a minimum of every 6 months. Compare and contrast the results to establish trends for increases in contamination or decrease in lubricant properties.
- Only lint-free rags should be used to wipe down the vital parts inside a governor since the lint can be a source of oil contamination leading to binding of certain critical control valves.

1.3 Best Practice Cross-references

- I&C - Automation
- Mechanical – Lubrication System
- Mechanical – Francis Turbine
- Mechanical – Propeller/Kaplan Turbine
- Mechanical – Pelton Turbine

2.0 Technology Design Summary

2.1 Material and Design Technology Evolution

The four types of governors that have been used for hydraulic turbines throughout history are: mechanical, mechanical-hydraulic, analog, and digital. The purely mechanical governor is for very small applications requiring little motive force in the actuator and was developed in the late 1800's. Amos Woodward received his first governor patent for controlling water wheels in 1870. A significant improvement occurred in 1911 when Elmer Woodward perfected the mechanical-hydraulic actuator governor adding power amplification through hydraulics [3]. One of the first being a gate shaft type governor as shown in Figure 1. These actuator governors could be applied to very large hydraulic turbines which required large forces to control the wicket gates. They ultimately evolved into the cabinet actuator governor as shown in Figure 2. Analog governors, with electronic Proportional-Integral-Derivative (PID) control functions, which replaced the ball-head, dashpot, and linkages, were developed in the early 1960's. Digital governors (PID through software) were developed in the late 1980's and have advanced with improvements of micro-processor capabilities [1].

Figure 3 shows a block diagram for a single regulating mechanical-hydraulic governor and turbine control system as compared to Figure 4 showing a digital governor. The solid line blocks are part of the governor controls and the dashed line blocks are part of the turbine controls.

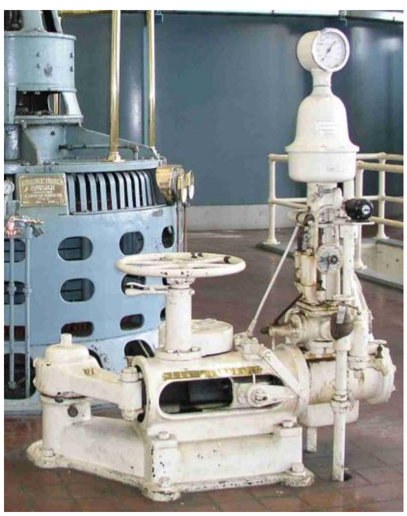

Figure 1: Gate Shaft Governor

Figure 2: Mechanical Cabinet Actuator Governor

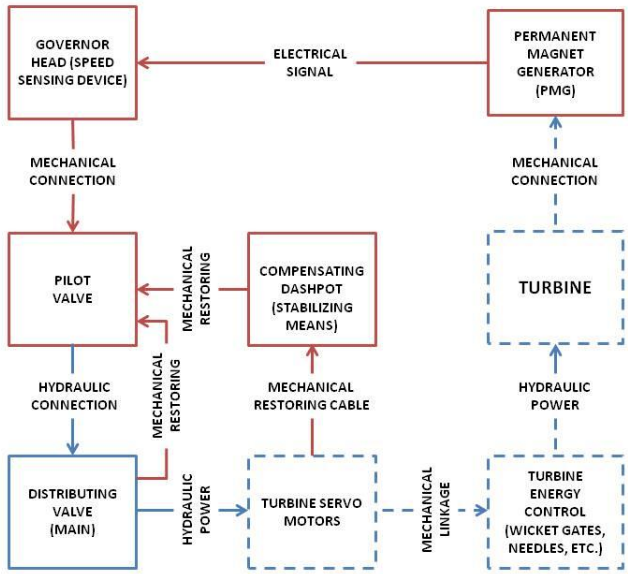

Figure 3: Mechanical-Hydraulic Governor (Solid line) and Turbine Control System (Dashed line) [7]

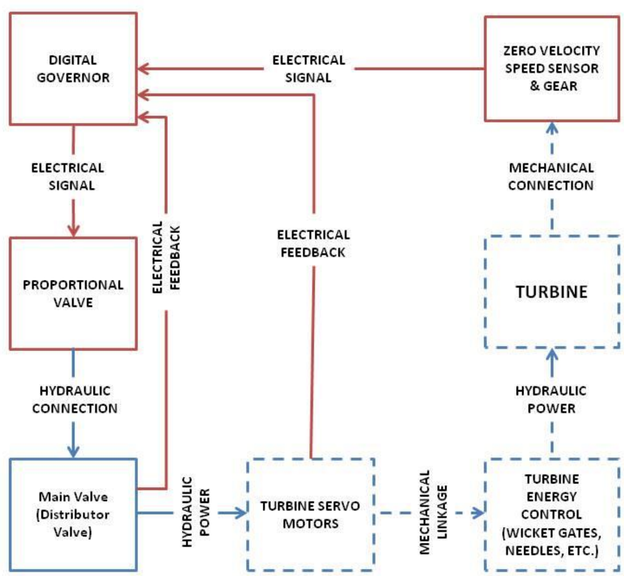

Figure 4: Digital Governor (Solid line) and Turbine Control System (Dashed line)

As a best practice, governors being purchased should be specified according to IEEE 125 [15] and/or IEC 61362 [17].

2.2 State of the Art Technology

Mechanical cabinet actuator governors (Figures 2 and 5) are the dominate type of governors in service today for hydro turbines but are no longer manufactured due to their high cost. Analog governors have more functionality over mechanical governors but still have more hardware components than a modern digital governor [1]. As a result, digital governors, with their lower cost and versatility through software programmability, are the governors of default today for new installations or replacements and are the state of the art technology for hydro turbine governors. Custom proprietary controllers such as that shown in Figure 8 are available, as well as systems based on industrial Programmable Logic Controllers (PLCs).

Figure 5: Mechanical-Hydraulic Governor

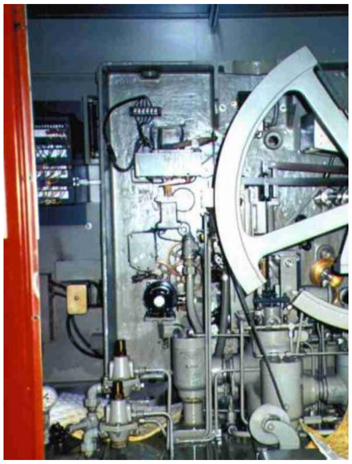

Figure 6: Analog Governor

Figure 7: Proportional Valve - Main Valve Assembly for Digital Governor

Figure 8: Digital Governor

As a best practice, rather than replace the entire mechanical or analog governing system, often a cost effective solution is to retain many of the mechanical components (i.e. pumps, accumulator tank, sump, etc) and perform a digital upgrade or retrofit. This allows the hydro plant to retain the reliability of some of the existing equipment and also retain the familiarity with that equipment while reducing the installed cost as compared to a new governor. The upgrades usually include installing a digital controller (PLC) and electronic speed sensor to replace the mechanical components (PMG, ball-head, linkages, dashpot, etc.) and an analog controller.

In addition, a proportional valve usually replaces the pilot valve and an electronic feedback position sensor replaces mechanical restoring cable. It is possible to add remote communication features, fast on-line ramp rates, out-of-calibration alarms, a touch screen human machine interface (HMI), and many other features not possible with legacy governors [11]. Figure 6 shows an original analog governor and Figures 7 and 8 show the same governor upgraded to digital controls. Figure 9 shows a PMG and associated mechanical speed switches with a speed indicator probe and creep detector on top. Figure 10 shows an electronic speed sensor assembly with zero velocity sensors monitoring a gear.

Figure 9: Top of PMG

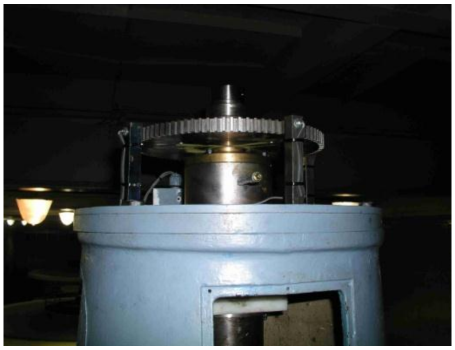

Figure 10: Digital Speed Sensor/s

Figures 11 and 12 show the contrast between a typical wicket gate servomotor mechanical restoring cable for a mechanical governor feedback versus an electronic MLDT for feedback to a digital governor. As a best practice, use a non-contact linear displacement feedback sensor such as a MLDT rather than a contact sensor such as a linear potentiometer which will wear over time.

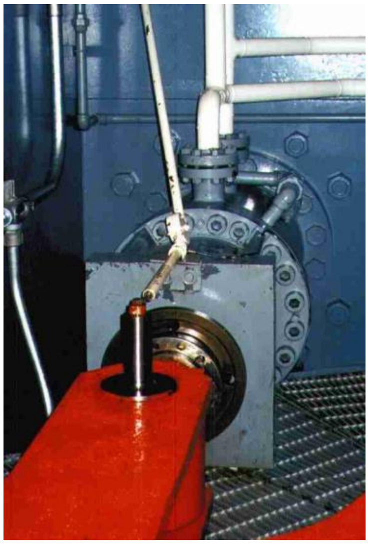

Figure 11: Restoring Cable – Mechanical Feedback

Figure 12: MLDT Electronic Feedback

As a general cautionary note, one should be aware that the product life cycle of digital governors is relatively short, as with most computerized technology of today. Therefore, over time, spare parts can become difficult to procure. The software and the hardware used can be obsolete in as little as 10 years [11]. A best practice would be to choose a well-known reputable manufacturer that will be around to support the equipment for long term. Use industry acknowledged "up-to-date" choices for governor components materials and maintenance practices.

3.0 Operation and Maintenance Practices

3.1 Condition Assessment

After commercial operation begins, how the governor is operated and maintained will have a major impact on loss prevention of the IPL and CPL and maintaining the unit reliability. An unforeseen failure of the governor can have a substantial impact on revenues due to the extended forced outage. Therefore, it is important to maintain a current assessment of the condition of the governor and plan accordingly. A condition assessment of a governor system would include the evaluation of the age of the equipment, operating and maintenance history, availability of spare parts, and performance [10].

Using the age of any equipment to assess the condition is very subjective, since how the equipment is operated and maintained over its life will directly affect the wear of its components. However, age is still an important measure of wear of mechanical parts. Just as with electronic parts, as the components age, they may deteriorate from exposure to heat, vibration, and contamination of dirt and oil [10].

Mechanical-hydraulic governors (Figures 1, 2, and 5) are usually very reliable, with the most common problems being oil leakage (external and internal), sticking valves, looseness in pins and linkages due to wear, and maladjustments. Some leakage is acceptable and provisions are usually made by the manufacturer for normal leakage. A condition assessment would include observation of the leakage and discussion with the hydro plant maintenance technicians as to the amount of daily or weekly maintenance required and any major past repairs. A sign of excessive external oil leakage is usually evident from the observation of extreme use of oil absorbent materials, rags, and catch containers in the governor cabinet. This external oil leakage drains back to the sump bringing with it any dust and dirt that enters the cabinet resulting in contamination of the oil.

A sign of excessive internal oil leakage is a frequent cycle time of the governor oil pump. IEEE 125 [15] and Goncharov [9] recommend that the oil pressure system (pump/s and accumulator/s) should be designed such that the minimum pump cycle is 10 minutes while the governor is controlling steady state. This value factors in internal leakage and the regulating use of the oil. However, even with minimal internal leakage, the pump cycle time will vary greatly depending on whether the unit is shutdown, starting up, regulating (isolated mode will require more than when connected to a stable grid), or shutting down since the amounts of oil use are different at all these different circumstances. For example, the pump may not cycle for 30 minutes, an hour, or longer while the unit is shut down, but may operate continuously while the unit is starting up or shutting down. In any case, the pump/s should be rated for the service that they actually see in service. Some very large governors use a small "jockey pump" which is designed to operate continuously while the unit is operating steady state. So this pump would be rated for continuous service. As a best practice, one should monitor the pump cycle time of the plant governors during regulating and shutdown to establish a baseline and trend increases that may be indicative of internal leakage of the valves or problems with the turbine servomotors. This also allows such trending of pump cycles to be used to compare the governor condition of similar units. Also, one should monitor pump noise and vibration which can be an indication of bearing failures, excessive oil foaming, loose pipe connections, and possible blockage of oil flow [12].

Since the importance of clean oil cannot be understated, any condition assessment should analyze oil test reports to ensure the oil suspended particulate is low and moisture content is low. Excessive metal particulate is a sign of major wear of valve internals (pilot, valve actuator, proportional, or distributor) and should be addressed as soon as possible. As a best practice, results from oil tests should show oil cleanliness meeting an ISO 4406 particle count of 16/13, viscosity should be within +/-10% of manufacturer's recommended viscosity, metals should be under 100 parts per million (ppm), acid number less than 0.3, and the moisture content should be less than 0.1%. Oil should be tested as a minimum every 6 months.

Analog and digital governors (Figures 6, 7, and 8) have mechanical components so they share many of the same maintenance requirements as a mechanical-hydraulic governor. A condition assessment would include the same approach, as stated above, with the mechanical inspection generally limited to the hydraulic governor head assembly which consists of the proportional valve and associated control components [10]. Electronic components should be inspected for any signs of looseness in connections, overheating, and any contamination of dirt or oil on the components. Overheating of the oil in the sump, from an extended unit operation or excessive internal leakage in the system, can cause the release of oil vapors into the governor cabinet which will condense on the cooler surfaces. Also, oil leakage will increase with oil temperature. This oil vapor condensation can cause major problems with electronic components if they happen to be located within the cabinet.

Any condition assessment should also include an inventory of spare parts. All necessary mechanical and electronic parts required to keep the governor operational should be available in plant inventory or on short notice depending on the criticality of the unit to the system.

The measured performance of a governor is a major indicator for the condition assessment. Performance measures should include off-line and on-line response, sensitivity to hunting, accuracy of frequency, synchronization time, and the ability to start remotely. ASME Performance Test Code, PTC 29 [14] provides the rules and procedures for executing governor performance tests.

3.2 Operations

A mechanical-hydraulic governor for a hydraulic turbine is a simple and reliable device for controlling speed and power output. Stabilization of the unit is provided by a compensating dashpot while the same function is provided electronically or digitally in an analog or digital governor. Governor dead time is defined as the elapsed time from the initial speed change to the first movement of the wicket gates for a rapid change of more than 10 percent of load. The dead time for a mechanical-hydraulic governor is

0.25 seconds whereas the dead time for an analog or digital governor is less than 0.2 seconds which enables to governor to provide accurate stable speed control [2]. Through the operation of a governor, a unit is started up, synchronized to the grid, loaded, and then shut down. Also, its function is coordinated with the operation of various other types of auxiliary equipment in the unit such as lubrication pumps, cooling water pumps, excitation control, brakes, protective relays, and the main generator breaker.

Kaplan turbines are double regulated such that as the wicket gates move the blades tilt to follow a pre-established relationship with wicket gate position and head. This is usually done in a mechanical governor via a 2D cam as shown in Figure 13. More advanced governors with 3D cams (electronic equal), as shown in Figures 14, 15, and 16, monitor head and continually update that relationship via software. As the turbine condition degrades, the efficiency reduces and subsequently the mechanical 2D cam surface may wear [8]. Therefore, as a best practice, index testing following ASME PTC 18-2011 [19] must be done periodically (10 year cycle minimum) or after major maintenance activities on the turbine to establish the best blade angle to the gate opening relationship and update the 2D or 3D cam. An example of the changing of that relationship and setting of a new curve is shown in Figure 1 of the Propeller/Kaplan Best Practice document.

Figure 13: 2D Mechanical Cam

Figure 14: Kaplan Blade Position – Electronic - MLDT

Figure 15: 3D Digital Cam for Blade

Figure 16: 3D Digital Cam Blade Oil Head

3.3 Maintenance

This best practice document does not replace the manufacturer's maintenance manual for servicing the governor. Governor maintenance and adjustments should be performed following the manufacturer's guidelines. A good third party reference for mechanical-hydraulic governor maintenance is the USBR's Mechanical Governors for Hydroelectric Units [5].

Many hydro plants still prefer a mechanical-hydraulic governor over a modern digital governor. Even though mechanical-hydraulic governors are no longer manufactured, parts can be reversed engineered or procured from third party manufacturers. The part technology is static, reliability is proven, and maintenance cost is generally low and established. Also, the maintenance personnel are familiar with the equipment and are trained to maintain and repair the equipment [1]. However, time and associated wear takes a toll on almost all devices including governing equipment. Electrical and mechanical parts will wear to a point that they have to be replaced. At times, repair parts may be too expensive, obsolete, or not available so the governor has to be replaced or upgraded with new one which is usually digital [6].

Clean oil is the lifeblood of a hydraulic actuated governor. Sticking valves, whether they are pilot valves or distributor valves of a mechanical governor or proportioning valves in a digital governor, is a common symptom of dirty oil. Reconditioning of the oil by routine centrifuging and filtering during routine outages is recommended. As a best practice, many plants connect a kidney loop filtration system to the governor sump to continuously filter the oil, as shown in Figure 17. Such filtration systems are capable of removing particulate and also can remove moisture if designed accordingly.

Figure 17: Kidney Loop Filtration on Sump

Mechanical-hydraulic governors contain sets of delicate and intricate linkages and valves in which if any single component fails it may cause the entire system to malfunction. As a best practice, it is very important to keep the components free from accumulation of dirt and dust and keep the linkages and bearing adequately lubricated with oil [7]. Binding in the linkages and bearings due to lack of lubrication or dirt buildup is a frequent cause of governor trouble. As a best practice, only lint-free rags should be used to wipe down the vital parts since the lint can be a source of oil contamination leading to binding of certain critical control valves. [4].

Analog and digital governor systems have mechanical components that have to be maintained just like mechanical-hydraulic governors. In addition, they have common maintenance problems such as loose wire and card connections that may vibrate free over time. Any maintenance program as a best practice must include checking and tightening these components periodically to avoid unit trips and forced outages. Since electronic components do fail from time to time, it is imperative to have adequate spare parts on site and the maintenance personnel properly trained to troubleshoot and repair the governor.

If the decision is to retain a satisfactorily operating mechanical-hydraulic governor which is in good condition, there are other maintenance related upgrades and retrofits that can be made to the equipment to provide even higher reliability, such as: electronic 3D cams (for Kaplan blade actuation, see section 3.2), pump un-loader pilot valve kit and oil strainer (Figure 18), electronic speed switch kits, and improved pilot valve strainers (Figure 19).

Figure 18: Pump Un-Loader Pilot Valve & Strainer

Figure 19: Pilot Valve Duplex Strainer

4.0 Metrics, Monitoring and Analysis

4.1 Measures of Performance, Condition, and Reliability

The fundamental performance for a governor is described by the quality of its speed regulation of a hydraulic turbine. This quality can be determined by its performance measures.

The measured performance of a governor is a major indicator for the condition assessment. ASME PTC-29 [14] specifies procedures for conducting tests to determine the following performance characteristics of hydraulic turbine speed governors:

- Droop - permanent and temporary
- Deadband and Deadtime – speed, position, and power
- Stability index - governing speedband and governing powerband
- Step response
- Gain (PID) - proportional gain, integral gain, and derivative gain
- Setpoint adjustment - range of adjustment and ramp rate

A similar international code is IEC 60300 [16].

Index testing of Kaplan turbines following ASME PTC 18-2011 [19], must be done periodically (10 year cycle minimum) or after major maintenance activities on the turbine, to establish the best blade angle to the gate opening relationship.

The condition of the governor can be monitored by the Condition Indicator (CI) as defined according to HAP Condition Assessment Manual [13].

Unit reliability characteristics, as judged by its availability for generation, can be monitored by use of the North American Electric Reliability Corporation's (NERC) performance indicators, such Equivalent Availability Factor (EAF), Equivalent Forced Outage Factor (EFOR), and event reports. Many utilities supply data to the Generating Availability Data System (GADS) maintained by NERC. This database of operating information is used for improving the performance of electric generating equipment. It can be used to support equipment reliability and availability analysis and decision-making by GADS data users.

4.2 Data Analysis

Analysis of test data is defined in ASME PTC-29 [14] and/or IEC 60300 [16]. Basically, determine current performance measurements (CPL). Compare results to previous or original governor test data (IPL) and determine any reduction in performance. Compare results to new governor design data (from governor manufacturer) and determine potential performance (PPL). For the latter, calculate the installation/rehabilitation cost and internal rate of return to determine upgrade justification.

Analyze index test results performed on Kaplan unit to determine if a new 2D or 3D cam (or electronic equal) must be updated.

Monitor the governor pump cycle time during regulating and off-line to establish a baseline and trend any increases that may be indicative of internal leakage of the valves or problems with the turbine servomotors.

Monitor the condition of the oil through periodic testing and compare the results to establish trends for any increase in contamination or decrease in lubrication properties.

The condition assessment of a governor is quantified through the CI as derived according to HAP Condition Assessment Manual [13]. The overall governor CI is a composite of the CI derived from each component of the governor. This methodology can be applied periodically to derive a CI snapshot of the current governor condition such that it can be monitored over time and studied to determine condition trends that can impact performance and reliability.

The reliability of a unit as judged by its availability to generate can be monitored through reliability indexes or performance indicators as derived according to NERC's Appendix F, Performance Indexes and Equations [18]. Event reports can be analyzed for outages or deratings by equipment cause codes to ascertain the impact of governor related events (governor cause codes 7050 and 7053).

4.3 Integrated Improvements

Periodic index test results should be used to update the Kaplan 2D or 3D cams to maximize efficiency of the turbine.

Projects such as digital governor conversions, retrofits, mechanical upgrades that are justified by a poor CI or poor reliability indices should be implemented.

As the condition of the governor changes, the CI and reliability indices are trended and analyzed. Using this data, projects can be ranked and justified in the maintenance and capital programs to bring the governor back to an acceptable condition and performance level.

5.0 Information Sources

Baseline Knowledge:

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Standards:

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15. IEEE 125, 2007, *Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators*
16. IEC 60308, 2005, *International Code for Testing of Speed Governing Systems for Hydraulic Turbines*
17. IEC 61362, 2000, *Guide for Specification of Hydraulic Turbine Control Systems*
18. NERC, Appendix F, *Performance Indexes and Equations*, January, 2011
19. ASME PTC 18-2011, *Hydraulic Turbines and Pump-Turbines,*

It should be noted by the user that this document is intended only as a guide. Statements are of a general nature and therefore do not take into account special situations that can differ significantly from those discussed in this document.

For overall questions
please contact:

Brennan T. Smith, Ph.D., P.E.
Water Power Program Manager
Oak Ridge National Laboratory
865-241-5160
smithbt@ornl.gov

or

Qin Fen (Katherine) Zhang, Ph. D., P.E.
Hydropower Engineer
Oak Ridge National Laboratory
865-576-2921
zhangq1@ornl.gov