Attachment B

Unit Retrofit Feasibility Study – Burton PUBLIC DISCLOSURE

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PUBLIC DISCLOSURE

Turbine Sluicing Study

Burton Hydroelectric Project

Southern Company

Clarkesville, Georgia

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1.0 Introduction

The purpose of these studies is to evaluate concepts for modifying the Francis turbines at Burton Hydroelectric Project, to install a means to pass water flow through the turbine spiral case without power generation.

It has been assumed that the turbine will be modified to the minimum extent possible, to make the conversion economically attractive, yet assuring the maximum flow rate possible in a controlled manner.

2.0 Basic Concepts

Energy dissipation of the water pressure within the turbine conveyance passageway is associated with negative effects, with cavitation being the dominating one. The presence of cavitation will result in pressure pulsation, noise and erosion of the conveyance structure.

For a hydropower unit the components of the water conveyance are designed to minimize dissipation of energy through losses to maximize efficiency to the turbine. This study explores the reverse situation, where the energy losses have to be maximized to reduce the energy which would have normally been removed by the turbine runner/generator to be converted into electrical energy. Two energy reducing modification scenarios are considered here:

1. Installation of a custom-made dissipating device in place of the existing runner
2. Install an energy dissipating valve in place of the existing Turbine Isolation Valve (TIV)

In both cases, it will be necessary to fully disassemble the unit to remove the turbine runner.

2.1 Install a Dissipating Device in Place of the Runner

The principle of operation of a reaction-type hydraulic turbine consists of the creation of a vortex in the spiral (or semi-spiral) case and extracting the energy contained in the rotating water by straightening the flow in the runner. The hydropower unit's fixed stay vanes are a structural element of the conveyance system, aligned to create the least obstruction to water flow, while the adjustable wicket gates control the flow rate, and flow angle into the runner at the same time.

Removal of the turbine runner allows the flow to continue its rotation, without losing its initial energy. The dissipation of that energy along with the strongly rotating nature of the flow must be considered when designing a dissipating device.

Although the presence of cavitation cannot be avoided, the process of energy dissipation should be accomplished in ways that do not cause cavitation erosion or excessive vibration of the remaining turbine components. The time-proven methods of doing this in non-powered hydraulic systems in general, include:

- Dividing the main flow into a large number of small jets

- Directing the jets away from solid walls, so the collapsing cavitation voids do not cause erosion of the conveyance structure
- Allowing sufficient aeration, so the air can penetrate cavitation voids and reduce their collapsing energy

These tasks can be accomplished by directing the water flow through a structure filled with a large number of holes. Figure 1 shown below is an example of an insert, splitting water flow into a large number of small jets. It is essential to direct the water jets away from flow boundaries, to avoid cavitation erosion of solid walls.

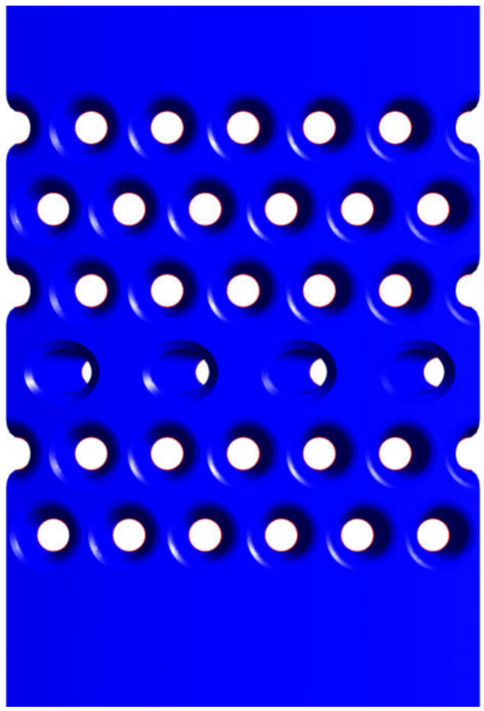

Figure 1. Example of a Section of an Energy Dissipating Structure

The difficulty in using this kind of energy dissipating device in place of the removed turbine runner is the rotating flow into the runner space may be subject to high cavitation and reduced flow through the dissipator. The radial holes, oriented towards the center of the dissipating device, are exposed to an inclined inflow. This will result in a complex flow pattern in the dissipating holes. The consequence of that is a reduction of discharge through the holes, as well as an increased possibility of cavitation erosion. An example of a numerical simulation of such flow is shown in Figure 2. Some improvement of this situation can be accomplished by making the holes inclined, as shown in Figure 1, but this may result in an increase in cavitation erosion of the dissipating device, since the cavitation voids will be formed on the side of the jet closer to the sold wall.

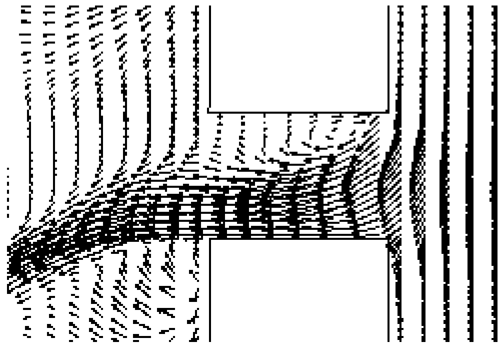

Figure 2. Example of computational simulation of inclined flow through an orifice

The dissipating device will be exposed to vibration and must be sufficiently rigid, to assure its durability. Also, the dissipating device will require trash racks with the spacing between the bars small enough, to reduce the possibility of clogging.

The design of the dissipating ring/cylinder within the device will be an iterative process of optimization using Computational Fluid Dynamics (similar in scope and cost to the design of a modern replacement runner). The optimized parameters are the shape of the holes, their number, distribution and the angle of inclination. It should be followed by a Finite Element Analysis (FEA) of the dissipating ring and supporting structure, to assure its adequate rigidity.

For all reasons described above, this kind of dissipating device, per HDR's knowledge, has not been implemented as a replacement of a Francis turbine runner.

2.1.1 Air Admission

Operation of the energy dissipating device installed in place of the runner will require sufficient air admission into the turbine. The air is needed for:

- Reducing the intensity of pressure pulsations and erosion, caused by cavitation
- Providing a break of the water column at the entrance to the draft tube, thereby reducing the effective head to be dissipated in the turbine chamber

The air should be supplied in two ways: central aeration, through the center of the head cover, and peripheral aeration, close to the walls of the dissipating ring.

It is expected that large quantities of air will be needed, perhaps as much as 10% of the flow rate of water. The airflow conduits should be equipped with regulating valves.

Such a large quantity of air will affect the quality of water leaving the plant with the dissipator in operation. On the positive side, it can provide a substantial improvement of Dissolved Oxygen. The possible negative effect is in an increase of Total Dissolved Gases in water (excess nitrogen in the water induces symptoms in fish that are comparable to decompression sickness, commonly known as the bends in people). Proper monitoring of water quality will be therefore necessary.

The design study of the dissipating device should include the assessment of the quantity of air, ways to channel the air as well as its environmental effects. Operation of the dissipating device will therefore require an arrangement where dissolved gases downstream of the powerhouse are monitored, providing real-time feedback to the PLC, controlling the flow rate of water and air admission.

2.1.2 Case Study

A cross section of the Burton turbine is shown in Figure 3.

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Figure 3. Cross section of the Burton Francis turbine

The flow rate through the dissipating device is proportional to the flow velocity of the jets and to the number of holes creating those jets. As discussed earlier, it is also affected by the rotation of water exiting the wicket gates and the resulting flow into the dissipation device chamber.

The flow rate estimates presented in this report are calculated using the following process:

- The head at the turbine centerline (elevation difference between Head Water and Centerline of the turbine) was used
- Rotation of the flow coming from the spiral case was assumed to be preserved in the fully open wicket gate position
- An iterative process of calculation of the flow angle at the dissipating structure, using the principle of conservation of angular momentum was applied

- Calculation of hydraulic losses for the inclined flow used guidelines from literature[1]

Another important factor is structural stability of the dissipating device. It should be firmly anchored in the turbine structure (minus the runner), since dissipation of large amounts of energy may result in vibration of the dissipating structure. However, it is anticipated that the large number of relatively small holes will reduce the risk of vibration, since none of the resulting jets will have enough energy to excite the structure of the dissipating device.

Figure 4 and Figure 5 show two examples of the dissipating rings installed that could be installed in the Burton turbine. Red lines on the sketches show the structural part of the dissipating ring, green line – the part with energy dissipating holes. Table 1 shows estimated design and operating parameters of those two alternatives.

In Alternative A, the dissipating ring fits within the space of the original (and now removed) runner and is additionally anchored at the discharge ring and in the space left from removal of the turbine shaft and bearing. This is a rigid structure, suitable to withstand dynamic loads resulting from the dissipated energy of water. Also, it is easily accessible to remove debris. Its drawback is a limited space devoted to the dissipating device. Consequently, the estimated maximum flow rate is rather low, as shown in Table 1.

In Alternative B, the ring is anchored on the discharge ring and in the space of the turbine shaft bearing. This arrangement allows for a larger area devoted to the dissipating device, with a larger number of holes. The entire structure is not as rigid as in Alternative A and will likely require additional braces. The downside is that those braces will be exposed to cavitation erosion. The other drawback is difficult removal of debris, as the only access is through open wicket gates.

In both cases, modification of the turbine components will require disassembly of the turbine. All rotating parts, including the runner, the turbine and generator shafts as well as the generator rotor, will be removed. The turbine bearing will also be removed. The dissipating ring should be of a welded construction, bolted in place. The head cover and the operating mechanism of the wicket gates will be reinstalled. The head cover will be exposed to the penstock pressure, and industry experience indicates its replacement should be considered based upon the age and material composition of the components. It is expected that the turbine governor could be used for operation of the wicket gates without major modifications.

[1] I.E. Idelchik *Handbook of Hydraulic Resistance* 4th Ed. Begell House, 2007

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Figure 4. Alternative A of dissipating ring in the Burton turbine

Figure 5. Alternative B of dissipating ring in the Burton turbine

Flow through the modified turbine can be adjusted using the wicket gates requiring the governor oil system to remain functional. Although the wicket gates can also stop the flow, for a longer duration shut-down, the use of the TIV is recommended. Relying on the TIV may require its replacement for long term use.

Table 1. Characteristics of two Alternatives of Dissipating Device

Item	Unit of Measure	Alt. A	Alt. B
Static head at turbine centerline Summer/winter operation	ft	102.5/95.5	
Outside diameter	in	56.5	80
Height of dissipating part	in	24.5	45
Hole diameter	in	4	4
Approx. number of holes		174	350
Ring material		400-series stainless steel	
Ring thickness	in	2	2
Ring weight, including structural part	lbs.	3,400	7,250
Maximum wicket gate opening	in	6.88	
Approx. maximum discharge Summer/winter	cfs	195/188	370/360

2.1.3 Scope of Work

The following steps are foreseen in the process of implementation of the dissipating device:

- Hydraulic design, supported by the CFD, similar to the level of effort for the design of a modern runner

- Hydraulic analysis of the effect of the modified flow pattern on the draft tube of the turbine
- Design of the aeration system, including determining the amount of air admission, system piping and electrically operated control valves, with consideration of its effect on DO and TDG;
- Detailed mechanical design of the dissipating structure, supported by the FEA of the dissipating structure and its interface with remaining turbine components
- Design of modification to turbine components remaining in place
- Manufacturing
- Study of environmental impact related to the introduction of flow aeration as required for the energy dissipation device functionality and also fish entrainment due to the potential change to the trash rack spacing
- Electrical design for power to the control valves
- Civil design for hangers and support of aeration piping within the wheelpit
- Design of intake silencers to reduce sound levels in the wheelpit
- Design and supply of a new headcover
- Complete disassembly of the existing hydropower unit and installation of the energy dissipation device and its related components.
- Commissioning

2.1.4 Maintenance Requirements

The energy dissipating device will require periodic maintenance with the turbine water passages dewatered. Removal of the debris, accumulating between the wicket gates and the dissipating ring can be accomplished through the wicket gates, in their fully open position.

Since the dissipating ring will be exposed to cavitation erosion, periodic cavitation repairs will be necessary similar to those in vintage hydraulic turbines. For smaller repairs, they could be done in place, accessing the dissipating ring from the draft tube. For larger repairs, the head cover would have to be removed, the ring unbolted and raised for easy access to all eroded areas. It should be noted that replacement hydraulic turbines with a modern hydraulic design required significantly less cavitation repairs which leads to less O&M costs and reduced outages.

Operation of the remaining turbine components will also require maintenance. More specifically:

- The governor system will require ongoing maintenance
- The TIV would require ongoing maintenance and inspection
- Wicket gate bushing lubrication
- Typical instrumentation inspection and calibration

2.2 Dissipating Valve

It is possible to install a conventional energy dissipating valve in place of the existing turbine inlet valve (TIV). An example of such valve is MONOVAR, manufactured by Sapag Valves. Burton’s head and maximum flow rate are compatible with characteristics of the largest of the available MONOVAR valves. In HDR’s previous study, the operating pressure of the high head site was exceeding the valve maximum. The turbine inlet dimensions for the low head site were in excess of the size of the largest dissipating valve.

Figure 6 shows overall view of the valve. The valve is capable of adjusting the flow rate by a vertical movement of a sliding plate 3, shown in Figure 7. The flow approaching the valve has no rotating component due to its location being upstream of the turbine water passages, unlike the dissipating device discussed in Scenario 1 above. This allows for a comparatively higher flow rate.

The maximum flow rate of the valve is limited by cavitation and requires certain back pressure. With the MONOVAR in place, the turbine runner, shaft and bearing at Burton would have to be removed. The wicket gates would stay in place, to be able to create the required back pressure. Table 2 summarizes principal characteristics of the MONOVAR, suitable for the Burton application.

Figure 6. MONOVAR energy dissipating valve

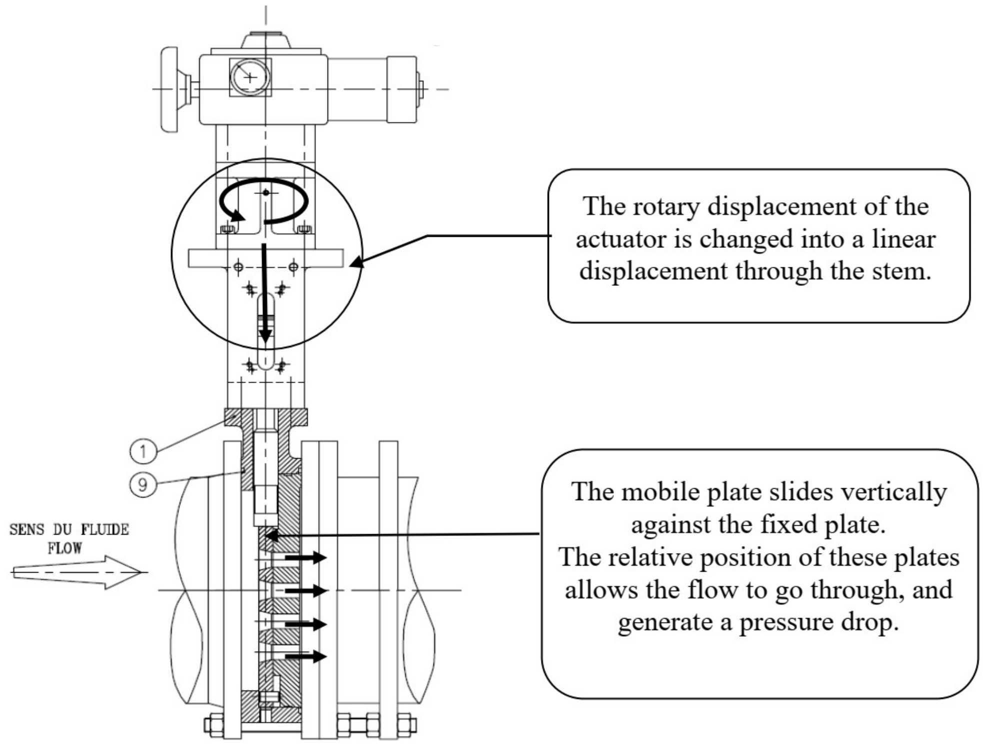

Figure 7. Principle of operation of MONOVAR

Table 2. Characteristics of the MONOVAR Valve for Burton Energy Dissipation

Item	Unit of Measure	Value
Static head at turbine centerline Summer/winter operation	ft	102.5/95.5
Nominal diameter	mm (in)	2100 (82.67)
Outside diameter	mm (in)	2564 (100.95)
Valve thickness	mm (in)	450 (17.71)
Hole diameter	mm (in)	152 (6)
Maximum valve pressure	psi	43.5
Maximum flow rate Summer/winter operation	cfs	700/675
Required back pressure	ft w.c.	11.0
Valve weight	Lbs.	19,000

To assure proper maintenance of the MONOVAR valve, it is recommended to isolate it from the inlet header by a butterfly valve. Two optional solutions are shown in Figure 8 and Figure 9. In the arrangement shown in Figure 8, the penstock is modified to increase the spacing between flanges to allow the insertion of an upstream block valve along with a space and manhole and then the MONOVAR valve.

The arrangement shown in Figure 9 assumes keeping the existing TIV and installing the MONOVAR valve downstream of the TIV downstream of the mandoor. This would require modification of the floor above.

It is also conceivable to install the MONOVAR valve in place of the existing TIV. In this arrangement, the MONOVAR capability to shut-off the flow would be used. The space available after removal of the TIV would allow installation of the MONOVAR and an upstream spool piece with a mandoor. However, it would require the use of head gates to allow accessing the new valve for inspection.

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Figure 8. Example of Installation of MONOVAR with an Addition of a Block Valve

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Figure 9. Example of Installation of MONOVAR Downstream of the Existing TIV

It is worth noting that as the MONOVAR valve will dissipate the majority of energy of the water, the spiral case and the head cover will not be pressurized. This means that a reuse of the head cover is conceivable but will require modifications once the runner and turbine shaft are removed.

With proper back pressure, adjusted using the turbine wicket gates, flow aeration will not be necessary, mitigating possible environmental impact of an increase in Total Dissolved Gases (TDG.)

2.2.1 Scope of Work

The following steps are necessary to install the MONOVAR valve:

- Design of modification of plant conduit flanges and penstock, to be compatible with the valve dimensional requirements
- Design and integration of control system into the existing plant control system for the valve operation, including operation logic
- Manufacturing
- Electrical design for power to the control valve motor operator
- Complete disassembly of the existing hydropower unit, removal of the runner, turbine shaft and bearing, removal of the existing turbine inlet valve and installation of the energy dissipation MONOVAR valve and its related components.
- Commissioning

2.2.2 Maintenance Requirements

MONOVAR Maintenance

Apart from its actuator, the MONOVAR valve does not require any maintenance, although it is necessary to check the valve operation once a month:

- Perform a complete "Close-Open" sequence to prevent deposits from forming on the fixed and mobile plates
- Check the operating stem seal

If high silt content in water is experienced, it can be cleaned periodically by opening a plug located at the bottom of the valve. In addition, the penstock extension (see Figure 8) can be equipped with a manhole, allowing accessing the upstream side of the valve for inspection. The existing spiral case manhole downstream of the valve can also be used to access the downstream face of the valve.

The remaining turbine components will require maintenance as well. This includes

- Governor oil system for wicket gate control
- Wicket gate bushing lubrication
- Typical maintenance of a motor driven gear operator
- Typical maintenance on position feed back device for wicket gate and valve position indication

3.0 Cost Study

HDR reviewed the items noted in the sections above for all 3 alternatives and produced cost estimates for each alternative per AACE Class 5 requirements as noted in Table 3 below. For the cost opinion of replacing the power turbine with the non-powered dissipating device, much of the scope of work for either solution is very similar. The turbine components must be completely disassembled and reassembled, and the runner replaced with a newly purchased non-powered device.

HDR has previously completed a few studies for the modifications within the turbine water passage ways to support the energy dissipating valve in place of the rotating turbine runner. There is limited industry experience with actually retrofitting an existing hydropower unit with a non-powered energy dissipating device due to the total costs of converting a powered unit to a non-powered option being very close. Therefore, hydropower Owners do not implement the non-powered option.

Much of the scope for the field work is identical for both options, so the costs to disassemble, rehabilitate the flow control components and reassemble a hydropower unit are very well understood. HDR was able to utilize our in-house proprietary database for those costs for similar units and then were prorated to the dimensional parameters of these units and escalated to 2024 dollars.

For the cost of the dissipating device, HDR worked with an energy dissipating valve manufacturer who provided a rough-order-of- magnitude cost information based upon a budget per pound of material approach as the valve required for the Burton application is much larger than what they typically offer. Additionally, HDR utilized dimensional information to develop the prorated costs to disassemble, rehabilitate and reassemble the units at Burton, and to incorporate the non-powered device option. The costs for the unit disassembly/water passage rehab and reassembly is based upon the diameter of the runner.

Table 3. AACE Cost Classification

Estimate Class	Class 5	
LEVEL OF PROJECT DEFINITION Expressed as a % of complete definition	0% to 2%	
END USAGE Typical purpose of estimate	Concept Screening	
METHODOLOGY Typical estimating method	Capacity Factored, Parametric Models, Judgment, or Analogy	
EXPECTED ACCURACY RANGE Typical variation in low and high ranges (a)	L: -20% to -50%	H: +30% to +100%
PREPARATION EFFORT Typical degree of effort relative to least cost index of 1 (b)	1	

The following assumptions were also made:

- Engineering and analysis are required to design the dissipating device.
- Fabrication and shipment of procured materials is assumed.
- Reprogramming the governors will be needed for each unit to run with the dissipating device installed instead of normal turbine governing operation.
- No rehabilitation or replacement was assumed for the existing governor systems or unit wicket gates and linkages.
- Future year escalation has not been factored into estimate.

Existing components will be reused after removal.

Table 4. Burton Alternative A

Cost Item	% Allocation	Price (2024 $)
Front End Planning	1.37%	79,920
Engineering	11.00%	639,360
Procurement	26.08%	1,516,090
Construction	45.06%	2,619,600
Start Up	0.46%	26,640
Project Management	5.50%	319,680
Other Owner Costs	4.12%	239,760
Removal	0.92%	53,280
AFUDC	5.50%	319,680

Cost Item	% Allocation	Price (2024 $)
SUBTOTAL PROJECT CLASS 5 ESTIMATE (before Contingency)	**100.00%**	**5,814,010**
Contingency	15.00%	799,200
TOTAL PROJECT CLASS 5 ESTIMATE		**6,613,210**
	Min Range (-20%)	**5,290,600**
	Max Range (+50%)	**9,919,800**

Table 5. Burton Alternative B

Cost Item	% Allocation	Price (2024 $)
Front End Planning	1.43%	83,640
Engineering	11.41%	669,120
Procurement	25.93%	1,520,000
Construction	44.12%	2,586,540
Start Up	0.48%	27,880
Project Management	5.71%	334,560
Other Owner Costs	4.28%	250,920
Removal	0.95%	55,760
AFUDC	5.71%	334,560
SUBTOTAL PROJECT CLASS 5 ESTIMATE (before Contingency)	**100.00%**	**5,862,980**
Contingency	15.00%	836,400
TOTAL PROJECT CLASS 5 ESTIMATE		**6,699,380**
	Min Range (-20%)	**5,359,500**
	Max Range (+50%)	**10,049,100**

Table 6. Alternative C Dissipating Valve

Cost Item	% Allocation	Price (2024 $)
Front End Planning	1.41%	89,640
Engineering	11.26%	717,120
Procurement	26.39%	1,680,000
Construction	44.51%	2,833,880
Start Up	0.47%	29,880
Project Management	5.63%	358,560
Other Owner Costs	3.75%	239,040
Removal	0.94%	59,760
AFUDC	5.63%	358,560
SUBTOTAL PROJECT CLASS 5 ESTIMATE (before Contingency)	**100.00%**	**6,366,440**
Contingency	15.00%	896,400
TOTAL PROJECT CLASS 5 ESTIMATE		**7,262,840**
	Min Range (-20%)	**5,810,300**
	Max Range (+50%)	**10,894,300**

4.0 Conclusions

The process to redesign and repurpose an existing turbine hydraulic infrastructure for use as a reservoir flow outlet release is not without challenges. The energy normally used to drive a generator to produce electricity will now have to be dissipated using a new energy dissipating device in place of the turbine runner or a device located upstream of the turbine entrance. Dissipation devices consisting of a series of many small jets have been used successfully in pipeline service to reduce line pressure while minimizing the destructive effects of cavitation or erosion of the pipe wall. Applying this approach to a large hydro turbine-generator modified for the rotational flow regime of water entering a turbine may be used to pass flow through a turbine generator.

Modifications to the turbine will require disassembly of the generator and turbine, structural modifications inside the turbine to secure the new dissipation device inside the turbine spiral case, fabrication of the new dissipation device, potential replacement components that form the pressure boundary and reassembly of the turbine.

Due to the large amount of energy to be dissipated, a careful design study using computational fluid dynamics (CFD) will be necessary to mitigate the effects of cavitation damage to the dissipation device and surrounding turbine structural and pressure boundary components. Additionally, an aeration system used to introduce atmospheric air into the flow stream will be necessary to reduce the formation of cavitation.

Control of the flow through the dissipation device will utilize the turbine’s existing hydraulic governor system and wicket gates but would require re-programming modifications to change the governor system from a speed governing system to a gate positioning system. This report has not included costs for wicket gate bushing replacements or wicket gate refurbishments.

An alternative approach, with the use of a commercially available dissipating valve like the MONOVAR presented in this report, is also potentially feasible. Its advantage is the ability to pass the full flow rate of the turbine.

The cost to implement the design and installation of an energy dissipation device or valve with the intent to pass flow through a turbine without generation closely approaches the cost to rehabilitate the turbine. A review of the equipment and labor costs for the design and fabrication of the dissipation device shows many of the activities associated with installation of the dissipating device such as disassembly and reassembly of the unit are the same as what would be included in a turbine overall. The design and fabrication cost of the dissipation device may also approach the cost of a new runner.

Installation of a dissipation device while feasible involves significant capital investment with no renewable generation benefit.

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