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Hydropower Evaluation Framework for Wildfire Resilient Microgrids

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***Abstract*—The increasing occurrence and severity of wildfires in recent years is severely impacting critical infrastructures, including the power grid, compromising the quality of life and provision of essential services, including electricity. The western parts of the United States, more specifically Washington, Oregon, and California, which are prone to large wildfires, are also rich in hydropower resources. Hydropower resources located close to communities vulnerable to wildfire can be utilized to develop wildfire-resilient microgrids to support critical needs of those communities. Therefore, this paper develops a framework to characterize hydropower plants and evaluate their feasibility to operate in microgrids during wildfire-related outages. In the proposed framework, hydropower plants are characterized using various plant and site attributes and evaluated in terms of capability and performance indicative metrics. A case study is carried out evaluating the Hills Creek hydropower plant located in a wildfire-prone region of Oregon for wildfire-resilient microgrid. The results of steady-state and dynamic simulations show that the hydropower plant is capable of providing the essential microgrid services and powering nearby communities during extended wildfire-related outages.**

***Index Terms*—Wildfire, hydropower, resilience, microgrids.**

I. Introduction

The rising temperature and drier conditions due to climate change have resulted in increased occurrence and severity of wildfires in recent years [1]. Nearly 90 percent of recent wildfires in the United States are due to human actions [2]. The human-sparked fires mainly come from campfires, electrical power lines, negligently thrown cigarettes, and intentional acts of arson.

While electrical utilities always face significant damages due to wildfires, the growing evidence suggests that the power lines are themselves triggering many wildfires, especially the most destructive ones [3]. In 2018, more than 17 major wildfires in the US were triggered by power lines, including the Camp Fire, the deadliest wildfire in California's history, which resulted in an estimated US$17 billion in damages, 153,336 acres of burned areas, and deaths of 85 people [3]. Similarly, in 2017, the Redwood and Atlas fires, both originated from power transmission lines, combinedly burned over 88,000 acres, destroyed 1326 structures, and killed fifteen civilians. Considering extreme liabilities of destruction due to grid-induced wildfires, power utilities are resorting to extreme measures such as proactive de-energization of transmission lines during hot, dry-wind conditions, also known as public safety power shutoff (PSPS), to prevent transmission lines from igniting wildfires [3]. These PSPS events can leave communities without electricity in extreme weather situations for extended periods. The PSPS is an emergency short-term solution in place of longer-term more cost-intensive solutions like reconductoring, reinforcement, undergrounding, or introducing new energy assets to form microgrids.

Microgrids have long been discussed as a means to ride through and recover from catastrophic impacts of wildfires and other natural events [3]. Microgrids utilize locally available distributed energy resources to meet critical energy needs. Microgrids can island on and off from the grid and operate in an independent or semi-independent manner [4]. With microgrids, a section of the electrical grid in the path of wildfire can be islanded in an orderly fashion without blacking out large territory around them. The formation of microgrids can alleviate transmission congestion from overloaded lines, which can significantly reduce the risk of grid-induced wildfires.

Even though the costs of wind and solar photovoltaic (PV) have fallen, their uncertain and variable generation makes them highly unreliable to form microgrids without dispatchable generation or storage support. Hydropower generation, is less variable, can be dispatched with higher certainty, and reservoir-based hydro's resilience support is well established [5]. Hydropower without reservoir, such as those operating in run-of-river (ROR) mode may lack adequate dispatchability, yet has demonstrated black start and microgrid formation capability during extreme events such as wildfire [6], and winter storms [7]. These capabilities can enable interconnection of grid-following inverter-based wind and PV resources and expedite the grid restoration.

While hydropower plants are excellent resources in the face of extreme events, the drier and drought conditions, which result in wildfires, also constrain the ability of hydropower plants to produce power [8]. The capabilities and limitations—based on plant design, hydrology, environmental and institutional factors such as Federal Energy Regulatory Commission licenses and power purchase agreements determine the response characteristics of hydropower plants at any given time [8]–[10]. Therefore, this paper develops a framework to characterize hydropower plants based on these capabilities and limitations to evaluate their suitability to form wildfire-resilient

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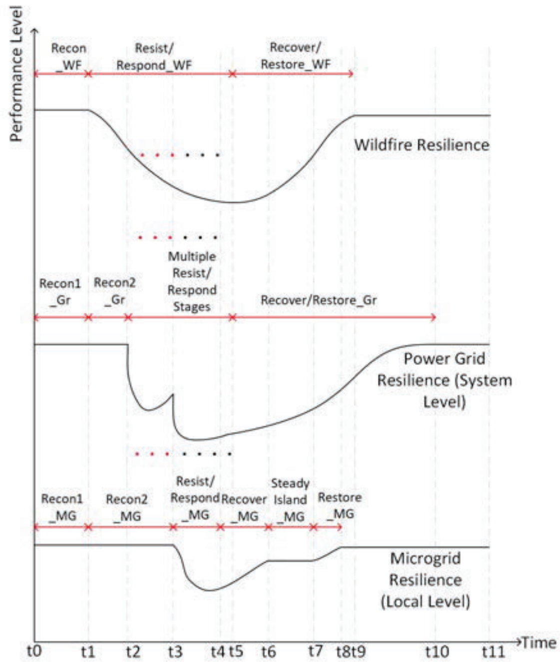

Fig. 1. Wildfire event mapped into DIRE characteristics.

microgrids.

The rest of the paper is organized as follows: Section II summarizes the development of the hydropower plant evaluation framework discussing the characterization of wildfire events, characteristics of hydropower plants, and metrics for wildfire-resilient microgrids. Section III provides a case study for an existing hydropower plant showing steady-state and dynamic simulations to evaluate a subset of metrics. Section IV concludes the paper with potential future work.

II. The Framework

A. Resilience Characterization of Wildfire Events

Resilience is the ability of the system to withstand and recover from severe disturbances. It can be characterized by the disturbance and impact resilience evaluation (DIRE) approach [11]. In this approach, the inherent characteristics and capabilities of a system to slow down the rate of performance degradation are evaluated by looking forward into the future to trace the system performance against potential extreme events, referred to as the DIRE curve. The DIRE curve is generally divided into five different periods of action against extreme events: Recon, Resist, Response, Recover and Restore, commonly known as DIRE epochs. Depending upon the type, severity, and frequency of an extreme event, the capabilities and operational strategies necessary at each DIRE epoch are different.

Fig. 1 plots a generic characteristic of wildfire propagation and maps it into power system resilience at both system and local levels. The time t_1 represents the inception of a wildfire event. Following its inception, wildfire propagates disrupting assets, properties, and livelihoods of the habitations within its territory. Depending upon where it originates and how it propagates, a wildfire may not immediately result in a grid contingency. Therefore, to generalize, we assume the first grid contingency starts at time t_2 impacting the steady state and dynamic performance of the grid. Because wildfire typically impacts large geographical areas, the number of contingencies in the power grid will also rise as wildfire progresses. Hence, multiple contingencies will occur in a discrete manner. Before the grid could fully recover from one contingency, another contingency may occur, as seen at t_3. Looking at the local level, at some point in time, the wildfire will start to impact the performance of the microgrid. Microgrid represents a small segment of the power grid consisting of a load center and local generation which may or may not be located near wildfire incidence. At t_3, microgrid islands either due to unintentional isolation or proactive islanding decision, and its performance starts to degrade. Microgrid utilizes local energy assets to respond to transients during islanding. The grid, on the other hand, faces further contingencies with propagating wildfire. At t_5, the wildfire stops progressing, and therefore no further contingencies occur in the grid. Following this, wildfire starts to extinguish and the grid recovery commences. In parallel, microgrids start to recover, albeit mostly operating in compromised mode due to the absence of grid support. At t_7, the microgrid reconnects with the grid, officially beginning the microgrid restoration process which completes at t_8. Wildfire is extinguished at t_9, and the grid is fully restored at t_{10}.

B. Hydropower Plant Characteristics

The characterization of a hydropower plant requires a comprehensive understanding of both technical and non-technical aspects. The hydropower characteristics relevant to microgrid operation are summarized below from [5], [8]–[10], [12].

1) *Physical and Design Characteristics* include (a) plant size and location, (b) electrical characteristics such as generator's power & energy ratings, capability curve, and excitation system to determine real and reactive power limits, (c) mechanical characteristics such as rotating mass inertia and hydrogovernor control to maintain frequency stability and adjust turbine discharge, (d) servomotor response time to determine control and actuation delay in ramping, (e) reservoir size to determine the storage capacity of the hydropower plant, and (f) turbine type.
2) *Operational Characteristics* include (a) hydrological characteristics (water head level, water inflow and outflow, and drought characteristics) to identify the resource availability for power production, (b) mode of operation (e.g., run-of-the-river, baseload, peaking, or cascaded hydro operation unit), and (c) non-power applications to identify the use of the water resource for non-power services (e.g., flood control, irrigation, drinking water, and recreational activities).
3) *Development Stage* (planned, under construction, operating, or under maintenance) helps to determine the status and age of the hydropower plant.

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4) *Market Characteristics* identify if plant is being used for grid support for energy, ancillary, or resiliency services.
5) *Environmental Characteristics* identify flora and fauna in the water body to ensure the operational changes for microgrid do not disrupt their habitat.
6) *Regulatory Characteristics* identify the regulating entity for the water body, dam, reservoir, and electricity to ensure that the plant operation in microgrid is permitted.
7) *Stakeholders* are a group of people and organizations impacted or benefited by proposed operational changes. This includes plant owners, utility companies, and wildfire-affected communities.

C. Evaluation Metrics for Wildfire Resilient Microgrids

The characteristics discussed in Section II.A directly or indirectly influence hydropower plant operation in microgrids during wildfire. To standardize the hydropower plant evaluation, nine representative metrics are proposed, as listed in the middle column in Fig. 2. The proposed nine metrics are evaluated from hydropower plant characteristics to predict the performance of hydropower plants in wildfire-resilient microgrids. Among these, the first metric (i.e., microgrid formation) serves as an initial technical and regulatory screening to identify if a hydropower plant is suitable and permitted to form a microgrid. The next four metrics–reactive power, inertial response, ramping capability, and storage capacity– are plant capabilities necessary for microgrid operation, typically identified through physical design characteristics and operational constraints. The last four metrics–seamless islanding, black start, sustained generation and seamless reconnection– are performance metrics that are evaluated through steady-state and dynamic operations. In the proposed framework, the candidate hydropower plant is first screened using microgrid formation metric followed by the identification of capability metrics to quantify its operational capabilities. Finally, simulations and testing are carried out to analyze performance metrics to evaluate performance during resilience events. The relevance of these metrics to DIRE microgrid epochs of Fig. 1 is shown in Fig. 2 [5], [11].

The relationship between the hydropower plant characteristics and the evaluation metrics can be both qualitative and quantitative in nature and should be analyzed on a case by case basis. To show an example, a preliminary case study is presented in the next section evaluating a subset of these metrics using a subset of the hydropower plant characteristics considering two of the DIRE epochs (all highlighted in Fig. 2).

III. The Case Study

A preliminary case study is carried out in this section showing the evaluation of a subset of metrics discussed in Section II.C. The metrics analyzed are sustained generation, black start and seamless islanding of hydropower plant during wildfire-related grid outage. Hills Creek hydropower plant located near the city of Oakridge in Oregon, USA is used as a use case for this analysis.

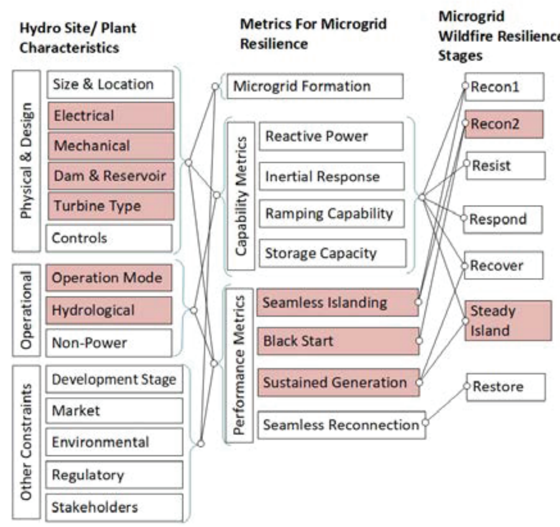

Fig. 2. Hydropower plant characteristics driving the proposed nine metrics. The cases study focuses on the highlighted characteristics, metrics and stages.

A. System Description

Hills Creek reservoir serves the primary authorized purpose of flood control and secondary uses of power generation, navigation, and irrigation. The usable storage is between the reservoir pool elevation of 1414 to 1541 ft, which is equivalent to 234,300 acre-feet (AF). This roughly translates to 7 days of full power operation of Hills Creek hydro. The pool elevation is maintained at 1448 ft in normal conditions to temporarily store snow-melt for flood control [13]. The powerhouse consists of two Francis units with a total 34.5 MW capacity. Each of these units operates with a rated net head of 256 ft and a design flow rate of 891 cubic feet per second (cfs) [14].

B. Steady-State Results

To evaluate the sustained generation metric of Hills Creek hydro for wildfire resilient microgrid, a steady state analysis is carried out considering a year-long hourly dispatch optimization. The hydropower plant and Oakridge load are modeled in XENDEE–a microgrid optimization tool for operational planning [15], [16]. The reservoir is modeled as a rectangular prism assuming a linear relationship between the elevation and water volume. Two different scenarios are considered for comparison: Base case and Microgrid case.

1) Base case (BC): In the base case, the hydropower plant is operated without any operational adaptation for microgrid. The hydropower plant operates independent of Oakridge demand utilizing the full available inflow for power production. The reservoir capacity is not utilized. No grid outage is considered.
2) Microgrid case (MC): In the microgrid case, the operation of hills creek hydro is adapted to prioritize meeting the Oakridge load demand. The plant is optimized considering a month-long wildfire-related grid outage.

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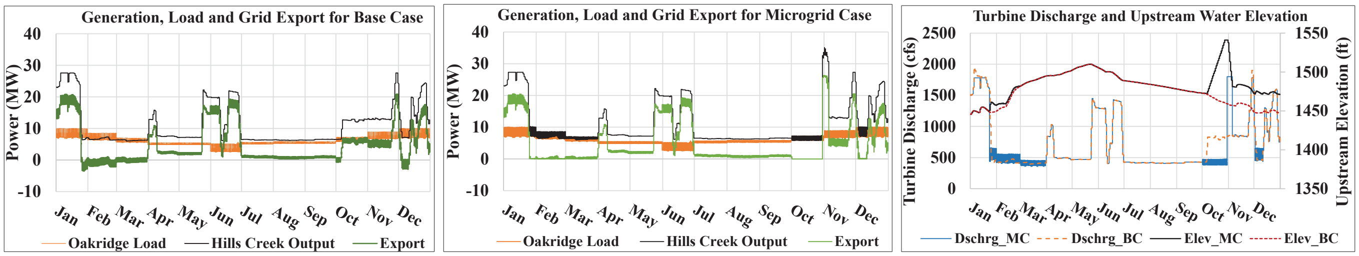

(a) (b) (c)

Fig. 3. (a) Dispatch for base case, (b) Dispatch for microgrid case, (c) Turbine discharge and water elevation for base case (BC) and microgrid case (MC).

Hills Creek hydro can utilize the flood control pool and reservoir capacity for water management and storage to support the electrical demand during the outage.

The inflow and head information for 2021 are used for this analysis. The input data already considers the flood control operation carried out in 2021 [13]. Besides evaluating Hills Creek hydro in microgrid, this analysis also compare hydropower plant's operation with and without microgrid.

As per 2021 data, the power generated by Hills Creek hydro for base case is not sufficient for Oakridge load during some of the hours in January, February, March, October, and December (total 896 h), as shown by the dispatch results in Fig. 3 (a). During these hours, the deficient power is imported from the grid as shown by negative exports in Fig. 3 (a). Note that in the base case, the hydropower plant is operated independent of Oakridge demand, only utilizing the available inflow and without utilizing the reservoir. In the microgrid case, the Hills Creek hydro prioritizes meeting the Oakridge demand utilizing the reservoir whenever required. An extended outage is considered in October between Oct 1st, 14:00 to Oct 30th, 22:00. Fig. 3 (b) shows generation, load, and power export for the microgrid case. The dispatch result show that Hills Creek hydro can meet Oakridge demand throughout the year without ever importing from the grid. Any excess power produced is exported to the grid.

Fig. 3 (c) plots the turbine discharge and upstream water elevation for microgrid case and compares them with the base case. Note that turbine discharge for base case ($Dschrg\_BC$) in Fig. 3 (c) is equal to the available inflow. In microgrid case, when the available inflow is not sufficient, the water stored in the reservoir is utilized. This phenomenon is clear from turbine discharge for microgrid case ($Dschrg\_MC$) rising above $Dschrg\_BC$ in some of the hours in Fig. 3 (c).

Because meeting Oakridge demand is a priority in microgrid case, it stores additional water in the reservoir in late January to utilize it in February and March when the available inflow is not sufficient to meet Oakridge load. Due to this, the upstream water elevation for microgrid case ($Elev\_MC$) rises above that for base case ($Elev\_BC$), starting late January and falls back by late March.

In October, when the hydropower plant is islanded from the grid, the reservoir is utilized to its full capacity to store excess inflow or provide supplemental water to turbines as required. The discharge to the turbine is driven by the Oakridge demand. After October 6th, the available inflow is higher than what is required for the Oakridge load. Therefore, the optimization problem essentially turns into reducing water spillage for the rest of the October. The excess water is stored in the reservoir, and therefore the upstream elevation for microgrid case rises above that for base case as seen in Fig. 3 (c). After the reservoir is full ($Elev\_MC$ = 1541 ft), the excess flow is bypassed as water spillage. When the microgrid reconnects to the grid, the hydropower plant starts to operate at maximum capacity, supplying excess electricity back to the grid. The head starts to decrease. The additional water stored during the wildfire event is also useful in some of the hours in December, when the available inflow is not sufficient.

C. Dynamic Results

Based on the findings from the steady-state analysis, we pick three dispatch instances from Fig. 3 (b) as listed in Table I to investigate transient stability in the event of islanding and black start. Because two units of Hills Creek hydro are identical, we only simulated one unit for dynamic analysis considering its share of Oakridge load shown in Table I.

TABLE I
SELECTED SCENARIOS OF HILLS CREEK UNIT DISPATCH

Scenario	Date and Time	Oakridge Load (MW) (single unit)	Unit Dispatch (MW) (single unit)
1	19th June 2021, 15:00 h	1.3	11
2	27th Nov 2021, 19:00 h	4.5	11.5
3	1st Oct 2021, 14:00 h	3	3

The dynamic parameters for Hills Creek plant are obtained from the system stability planning database of the Western electricity coordinating council (WECC) [17]. Among these, the per-unit head ($hdam$), and water starting time (T_w) are updated according to the available head and flow rate information for each scenario from Table I and applying respective formulas [13], [18]. The proportional, integral, and derivative coefficients of the governor control are set according to the optimal criteria from [18]. These parameters are used on a "H6E" hydrogovernor model to capture the transient characteristics of a Francis unit from Hills Creek plant [19]. Scenarios 1 and 2 represent the case of minimum and maximum dispatch to the city of Oakridge, respectively. Scenario 3 represents the islanding instance of the Hills Creek plant and Oakridge load

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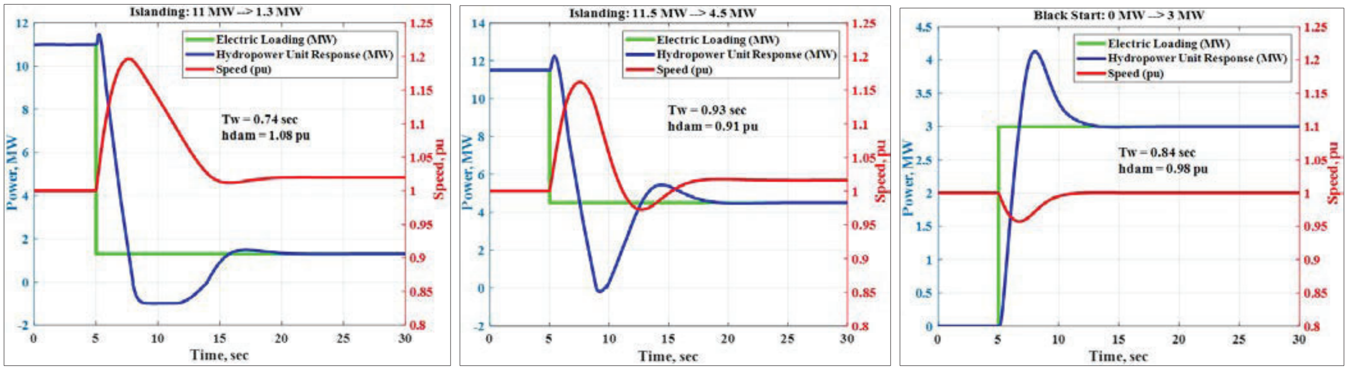

(a) (b) (c)

Fig. 4. Transients of a Hills Creek hydro unit simulated for seamless islanding and black start: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3

(i.e., 1st Oct 2021, 14:00 h). Transients from grid islanding are shown for scenarios 1 and 2 in Fig. 4 (a) and (b), respectively. It should be noted that the simulation captures extreme transients with no restriction from the generator protection settings. Standard protection settings would avoid over speed driven pumping action (reflected through the negative mechanical power) through trip-off and cause blackout to the city of Oakridge instead of seamless islanding. In scenario 3, Hills Creek hydro units were producing power just to meet the Oakridge load, and the exchange with the grid was zero. Therefore, the transient simulation is carried out to simulate scenario 3 for the black start instead of seamless islanding. The simulation results for the black start scenario captured in Fig. 4 (c) shows that the hydropower plant will be able to pick up the entire Oakridge load while maintaining transient stability during the black start.

IV. Conclusion and Future Work

This paper discussed a three-fold framework to characterize hydropower plants for wildfire-resilient microgrids. The framework includes technical and regulatory screening of hydropower plant for microgrid formation, capability metrics to quantify hydropower plant's ability to provide real and reactive power flexibility, and performance metrics to evaluate the performance of hydropower plant in steady-state and dynamic operations. A preliminary case study is shown evaluating a subset of these metrics for Hills Creek hydropower plant. Based on our analysis, Hills Creek hydropower plant was capable of providing sustained generation during an extended wildfire-related outage and maintaining adequate dynamic performance during microgrid transition through black start. Future study will incorporate rest of the characteristics, metrics, and epochs. Furthermore, some failure cases caused by either transmission unavailability, inadequate hydropower capacity, insufficient water flow and headroom during the wildfire season or a combination of these [20] will be analyzed to comprehend the proposed framework.

References

[1] K. Hoover and L. A. Hanson, "Wildfire Statistics," Tech. Rep. IF10244, Oct 2022.

[2] K. C. Short, *Spatial wildfire occurrence data for the United States, 1992-2018*, 5th ed. Fort Collins, CO: Forest Service Research Data Archive, 2021.

[3] R. Moreno *et al.*, "Microgrids Against Wildfires: Distributed Energy Resources Enhance System Resilience," *IEEE Power and Energy Magazine*, vol. 20, no. 1, pp. 78–89, 2022.

[4] T. R. McJunkin and J. T. Reilly, "Net-Zero Carbon Microgrids," Idaho National Laboratory, Idaho Falls, ID, United States, Tech. Rep. INL/EXT-21-65125, 2021.

[5] A. Somani *et al.*, "Hydropower's Contributions to Grid Resilience," HydroWIRES Initiative, Department of Energy, Tech. Rep. PNNL-30554, Oct 2021.

[6] P. Keller and S. Tanner, "USACE Cougar Dam Islanded Operation during the Holiay Farm Wildfire," in *2022 HydroVision International Conference*, September 2022.

[7] S. Brosig *et al.*, "Planning Ahead for Stable Operation during Blackstart and Islanded Conditions," in *2022 HydroVision International Conference*, September 2022.

[8] Hydro Performance Processes Inc., "Flexible Operation of Hydropower Plants," Electrical Power Research Institute, Tech. Rep., may 2017.

[9] H. Locher and J. C. Costa, *Hydropower Sustainability Guidelines on Good International Industry Practice*. International Hydropower Association (IHA), 2020, vol. 59.

[10] International Hydropower Association, *Hydropower Sector Climate Resilience Guide*, London, United Kingdom, 2019.

[11] T. Phillips *et al.*, "A metric framework for evaluating the resilience contribution of hydropower to the grid," in *2020 Resilience Week (RWS)*, 2020, pp. 78–85.

[12] A. Somani *et al.*, "Hydropower Value Study: Current Status and Future Opportunities," HydroWIRES Initiative, Department of Energy, Tech. Rep. PNNL-29226, jan 2021.

[13] USACE, "Hills Creek Dam and Lake." [Online]. Available: https://www.nwd-wc.usace.army.mil/dd/common/projects/www/hcr.html

[14] BPA, "Hills Creek Dam G1 & G2: Application for Advisory Opinion and Renewable Energy Facility (WREGIS) Certification," September 2020.

[15] B. Mitra *et al.*, "Hydrogenerate: Open source python tool to estimate hydropower generation time-series, version 3.6 or newer," 10 2021. [Online]. Available: https://www.osti.gov//servlets/purl/1829986

[16] M. Stadler and A. Naslé, "Planning and implementation of bankable microgrids," *The Electricity Journal*, vol. 32, no. 5, pp. 24–29, 2019.

[17] WECC, "System Stability Planning Base Cases." [Online]. Available: https://www.wecc.org/SystemStabilityPlanning/Pages/BaseCases.aspx

[18] P.-M. and Energy-Supply Working-Group, "Hydraulic turbine and turbine control models for system dynamic studies," *IEEE Transactions on Power Systems*, vol. 7, no. 1, pp. 167–179, 1992.

[19] A. Banerjee *et al.*, "Modeling a Bulb-Style Kaplan Unit Hydrogovernor and Turbine in Mathworks-Simulink and RTDS-RSCAD," in *2022 IEEE/PES Transmission and Distribution Conference and Exposition (TD)*, 2022, pp. 1–5.

[20] R. Serrano *et al.*, "Fighting against wildfires in power systems: Lessons and resilient practices from the chilean and brazilian experiences," *IEEE Power and Energy Magazine*, vol. 20, no. 1, pp. 38–51, 2022.

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