Assessment of Faults in the Performance of Hydropower Plants within Power Systems

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***Abstract* — Energy is crucial for a country's development, with renewable and non-renewable sources being the most environmentally friendly. One advantage of a hydropower plant is that it produces clean, renewable energy, while a disadvantage is that it can have negative impacts on local ecosystems and wildlife. This study focusses on monitoring and assessing faults such as changes in reference power and three-phase short circuits in hydropower plant. The analysis involves examining these faults in various parameters, including voltage and current of the generator, power and reactive power, generator output power, deviation in generator speed from its rated speed, generator rotational speed, torque, and d and q axis voltage of the generator. The simulations were conducted using MATLAB/Simulink. The results of the simulations demonstrate the effects of these faults on the parameters, providing valuable insights for monitoring the hydropower plant under such conditions. Overall, the generator's performance in both scenarios demonstrates its reliability and effectiveness in maintaining power supply during unexpected events. The successful outcomes in both cases highlight the importance of having a robust and well-functioning generator system in place for ensuring continuous power supply.**

***Index Terms* — faults, hydropower plant, power output, 3-phase short-circuit, renewable energy source, MATLAB simulation.**

I. INTRODUCTION

Paper [1] presents a simulation of the Shiroro hydropower plant (SHPP) using MATLAB/Simulink software to analyze its stability and performance, with potential applications to other generating stations in Nigeria or developing nations. The operational aspects of hydropower plants, emphasizing energy generation with minimal operational costs and environmental impact are reveiwed in [2]. The author discusses components, parameters, mathematical models, and techniques for cost reduction and energy generation optimization. In [3], the invstigation focuses on various models and correlations used to evaluate the costs of small hydropower projects. The advantages, including internal rate of return and clean development processes, along with optimization strategies to lower installation costs, are also highlighted.

A review of analytical models for hydropower generation, highlighting their limitations in capturing dynamic aspects such as water flow and gate control is presented in [4]. Furthermore, when a three-phase-to-ground fault occurred at 0.2 s, the system's output voltage stabilized rapidly upon fault removal at $t = 0.4$ s, attributed to the high excitation voltage maintained by the PID control systems. In [5], the authors introduce a condition monitoring and fault diagnostics (CMFD) system for hydropower plants (HPP) based on industrial product-service systems (IPS2).

The hydro power plant model developed can be utilized independently, as demonstrated in the direct-online starting example, or integrated into an advanced drive system. A simulation of a three-phase fault scenario is applied to the

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model using the Simulink section in MATLAB [6]. Hydraulic turbine and governor models are expored in MATLAB/Simulink and Simscape Power Systems in [7]. The main focus is on analyzing plant models and determining controller suitability for fault incidence through Simulink simulation and Ziegler-Nichols tuning methodology. A review of hydropower models and their applications is made providing valuable insights into state-of-the-art hydropower modeling techniques in [8]. An emphasis is also made on the progress in dynamic models for both classical and variable speed plants, emphasizing the critical need for increased accuracy in these models. A diagnostic method for frequent system problems after integrating the hydraulic system with the turbine and power generation is proposed in [9].

The ETAP software is employed [10] to examine minimal fault protection and coordination between embedded generating systems and local utility networks. The paper determines the appropriate time and current gradients for small-scale hydropower facilities through load flow studies and short circuit analysis.

Acknowledging the diverse range of plant designs and configurations, the paper conducts a literature review on hydropower plant model development and control. It also highlights the variations in control strategies and the presence of contributions related to first-order simple linearized models [11]. Hydroelectric plants use a hydraulic turbine to transform the potential energy of the water head into mechanical energy [12]. Water is the most affordable and reliable renewable energy source (RES) curently available [13]. Over the past few decades, there has been a global growth in the production of electricity, particularly in poorer countries where hydropower continues to be the primary source [14]. While some models are purely analytical, others are built using reliable system models that display the dynamic features. The IEEE working group/committee [15, 16] demonstrates a variety of hydropower plant models and power generating control methods. Reference [17] presented a variety of renewable and conventional energy systems, highlighting energy conversion, variable-speed drives, power electronics, and magnetic devices such as transformers and rotating machines, while also including applications of PSpice, MATLAB.

The primary contributions of this study to be outlined are:

a. Evaluating two specific faults: 3-phase short circuit and reference power variation.

b. Examining the hydropower plant's performance under challenging conditions.

c. Expanding the range of parameters analyzed and assessed compared to [4].

d. Describing the parameters assessed, including voltage and current, d-q axis voltage, power and reactive power, generator speed and torque, as well as generator output power and deviation from rated speed during two scenarios.

The remaining sections of the paper are as follows Section II discusses hydropower plant architecture. Section III presents simulation and its results for two scenarios. Section VI contains the discussion and conclusion.

One potential research gap in modeling and assessing hydropower plants in MATLAB is the lack of comprehensive and accurate models to take into account the complex interactions between various components of the plant, such as turbines, generators, and control systems. The second gap could be assessment of faults in the model used for hydropower plant. Due to this gap, this study introduces a robust model simulated in MATLAB. Furthermore, variations in reference power and occurrences of short circuits within a hydropower plant represent critical conditions that can significantly influence the plant's performance, efficiency, and safety. Implementing effective monitoring and control systems is essential to promptly detect and address these conditions. While the assessment of shortcomings in hydropower facilities is not well explored, the significance of this assessment cannot be overstated. Improving the efficiency and reliability of hydropower facilities requires the analysis of flaws, such as short circuit and reference power variations. These evaluations aid in spotting any difficulties, solving issues, and guaranteeing the facility runs smoothly and continuously. Comprehensive fault analysis also helps to enhance performance overall, minimize downtime, and improve safety precautions. As a result, making an investment in fault assessment is essential to maximize hydropower plant output and longevity.

To bridge the specific gap in the state-of-the-art hydropower plant modeling, numerous studies were conducted [1, 2, 4, 6, 7, 11, 12, 19] to propose different modeling approaches. In this work, the model presented in

[4] is used for simulation. This work differs from [4] in trying to expand and analyze a greater number of significant parameters during faults, while [4] analyzes only short circuit, voltage, and speed characteristics. This work focuses on two faults, and power and reactive power, voltage and current, voltage of d-q axis of generator, speed and torque of generator, voltage and current of generator, power and speed deviations of generator, which demonstrates the significant expansion of [4].

II. HYDROPOWER PLANT ARCHITECTURE

The foundational model for hydropower plants typically begins with the calculation of hydraulic power. Hydraulic power is generated when a volume of water descends from a higher level to a lower level [4]. The descriptions of the components and the simulation are derived from [4]. Xu et al. [18], highlighted some practical challenges associated with modeling actual machines. The findings presented are highly beneficial for modeling real hydroturbine systems.

In general, linear models are typically applied for analyzing the small signal behavior of turbines, while non-linear models are more suited for simulating signals over a broader range. Conversely, certain models were developed analytically. They were implemented as simulated systems using various software tools. For example, a model introduced in [20] was constructed in Simulink, comprising dynamic sub-models such as the controller, hydraulic and mechanical systems, and turbine regulator. Additionally, Simulink was employed to establish a Model Predictive Control system for a hydropower plant [21]. Through this research, comparisons were drawn between contemporary methods, revealing enhancements in control efficiency. Moreover, in [21], a robust model for a hydropower plant is developed, wherein two established control techniques were pitted against each other. These methods comprised the conventional Integral controller (PI) and the Model Predictive Control. The study demonstrated the superior robustness of the Model Predictive Control, maintaining consistent performance across both Single-Input Single-Output (SISO) and Multiple-Input Multiple-Output (MIMO) scenarios.

This stage encompasses a comprehensive investigation into the modeling of hydropower plants utilizing a hydraulic turbine model developed by the IEEE working group in 1992 [22], which is compatible with MATLAB simulation software and accessible on the MathWorks website [23].

There are some studies on faults in hydropower plant [4, 5, 7, 9, 10], with [4] focused on 3-phase short-circuit faults. An algorithm for fault detection in hydropower plant is presented in [24], although there are few works concentrated on faults, especially on their impact on important parameters of hydropower plants. The examined characteristics of the auxiliary systems of hydroelectric power plants included fault detection techniques, critical conditions, and neutral grounded types.

Short-circuit tests and auxiliary winding response during a short circuit on a high-voltage cable-wound hydropower generator in Porjus, Sweden, with a 45 kV and 11 MVA rating, are presented after 13 700 hours of operation [25]. In [26], a computational model of a micro-power system with a mini-HPP assesses network parameters during autonomous and parallel operation. Simulation results obtained in [27] validate the control performances of the proposed fault tolerant control system for a small hydropower plant. The strategy prevents interruption by allowing operation in the fault state up until the fault reaches a limit value.

After the initial description, the model undergoes further modifications and simulation. Illustrated in Fig. 2, the Hydraulic Turbine and Governor block incorporates a PID governor system, a servomotor, and a non-linear hydraulic turbine model. Figure 1 presents an overview of the significance of evaluating faults in hydropower plants, and Figure 2 illustrates the model of the plant used.

The density of water is represented by ρ (1000 kg/m^3), the mechanical power generated at the turbine shaft is measured in Watts, and the water flow rate through the turbine is Q (m^3/s), the effective pressure head of the water across the turbine is H (m), and g is the acceleration due to gravity (9.81 m/s^2). The turbine then converts the hydraulic power into mechanical power. There were numerous attempts in the past to develop an analytical model for a hydraulic turbine. Equations (1) - (2) refer to p_h and P_m:

$$p_h = \rho\, gQH\ , \tag{1}$$

$$P_m = \mu * p_h\ , \tag{2}$$

where μ represents the turbine's efficiency.

Because calculating the hydraulic turbine efficiency is so challenging, numerical calculations based on robust mathematical models are employed:

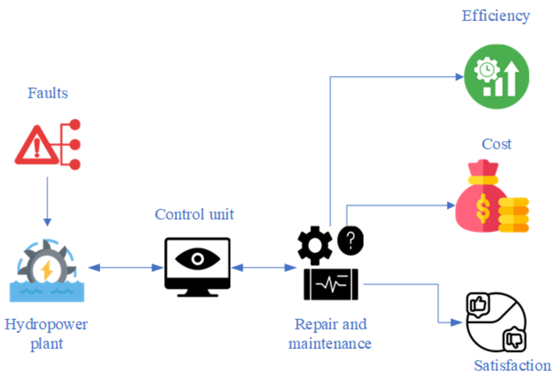

Fig. 1. Overview of the significance of evaluating faults in hydropower plants.

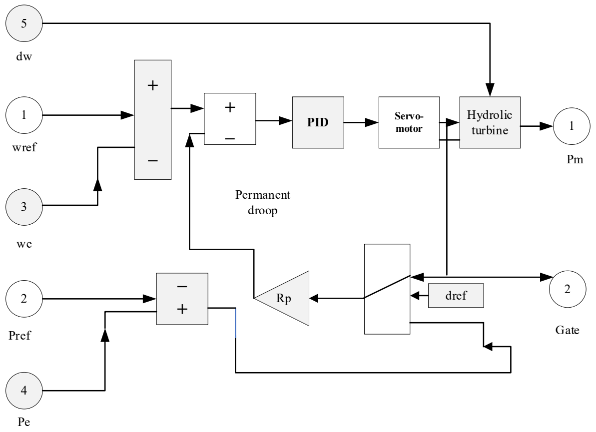

Fig. 2. A typical hydropower plant model.

$$\mu(\lambda, Q) = \left(\frac{1}{2} \left(\frac{90}{\lambda_i} + Q + \frac{78}{100} \right) * \exp\left(\frac{-50}{\lambda_i} \right) \right) (3.33Q), \quad (3)$$

$$\lambda_i = \left(\frac{1}{\lambda + 0.089} - 0.0035 \right)^{-1}, \quad (4)$$

$$\lambda = \frac{RA\omega}{Q}, \quad (5)$$

where Q is water flow rate, ω is turbine rotor angular speed, R is hydraulic turbine blade radius (m), and A is rotor blade sweep area (m^2). This is a fully analytical model that can be used with MATLAB to program and simulate in order to display the power generated from a hydropower plant with different water flow model parameters.

Figure 3 shows the nonlinear model for hydraulic turbine, and Fig. 4 illustrates a second-order system that models the gate servomotor. Figure 5 shows the hydraulic model inputs/outputs. Table 1 includes input and output details in the block for a hydropower plant in MATLAB. Figure 6 shows the system simulated in MATLAB in this study.

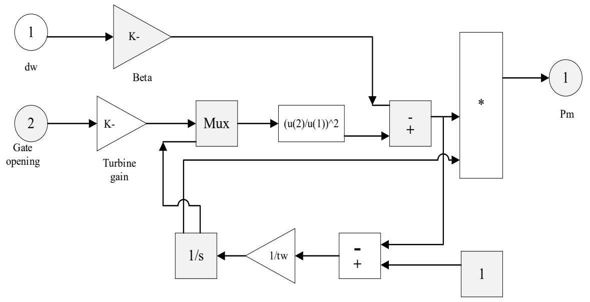

Fig. 3. The nonlinear system that models the hydraulic turbine.

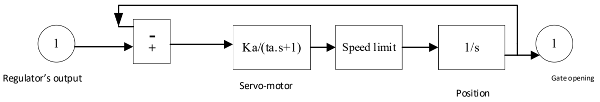

Fig. 4. Gate servomotor model.

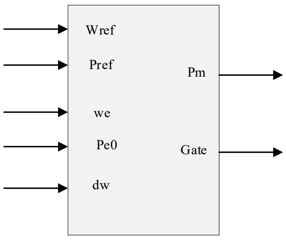

Fig. 5. MATLAB/Simulink block of a hydraulic turbine model.

The final model in Fig. 6 is constructed and simulated using MATLAB/Simulink, considering all the components previously mentioned in the Figures. The model comprises a synchronous machine connected to the Excitation System, Hydraulic Turbine, and Governor (HTG) blocks.

TABLE 1. Details of the Block for a Hydropower Plant in MATLAB, Outlining Input and Output Parameters

Parameters	Description and unit
Wref	Reference speed in per unit (pu)
Pref	Reference mechanical power in (pu)
We	Current Speed of Machine (pu)
Gate	Gate opening (pu)
Pe0	Electrical power of the machine (pu)
Dw	Speed deviation (pu)
Pm	Mechanical power Pm for the Synchronous Machine block (pu)

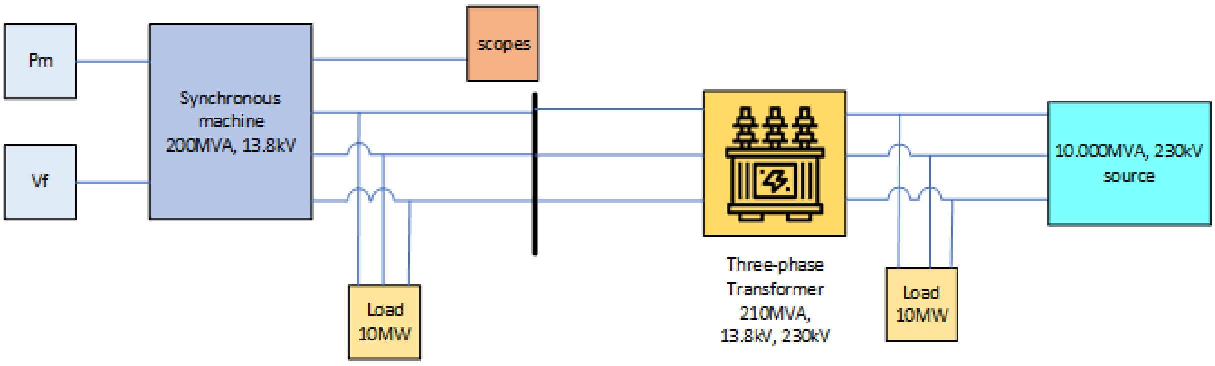

Fig. 6. Hydropower plant simulated in MATLAB.

III. SIMULATION AND RESULTS

The simulation includes a 200 MW hydro generator turbine connected to both the load and the grid. This study addresses two challenges for the model to analyze the performance of the plant.

1. Change in the Reference Power

An output of the hydropower plant and its ability to supply power to the grid both can be affected by changing the reference power. When there is a short circuit in a three-phase electrical system, current flows. This is known as the three-phase short-circuit current (Isc). The stability and security of the electrical network connected to the hydropower plant are evaluated using this parameter, which is critical.

In this scenario, the reference power of the hydro turbine is set at 0.75 pu. Given that the generator's rated power is 200 MW, the generator effectively generates 150 MW. Adjusting the reference power of the turbine can lead to variations in the generator's power output. Out of the total 150 MW generated by the generator, 10 MW are utilized by load, with the remaining power being fed into the grid. The simulation results are presented below. The simulation time is 10 seconds for the first scenario. To better illustrate the changes in voltage and current of the generator, it is recommended to decrease the time scale (x-axis) to enhance the clarity of Fig. 8.

Figures 7 to 11 illustrate the active and reactive power, voltage and current, voltage of the d-q axis of the generator, as well as speed and torque. Additionally, they depict the deviations of the generator's output power and speed from their rated values, all in the context of being the challenge to the plant.

The simulation results clearly indicate that the generator in the hydropower plant functions efficiently by adapting its power output to align with the changing reference power requirements outlined in the scenario. The generator shows its ability to accurately respond to fluctuations in load demand or grid conditions, ensuring the delivery of the required power to the network as specified in the scenario details. This dynamic response not only highlights the plant's capacity to optimize performance but also underscores its capability to uphold system stability and effectively meet the evolving power demands.

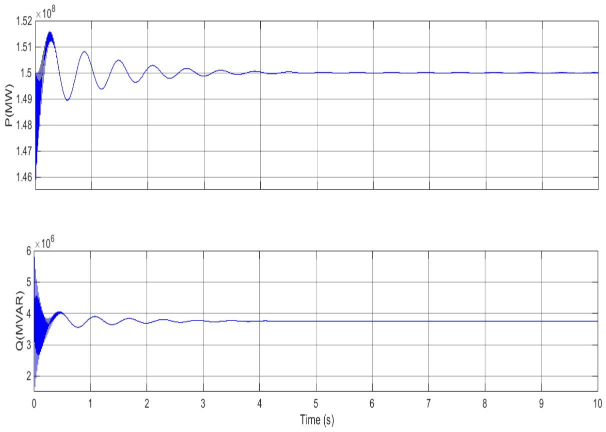

Fig. 7. Active and reactive power of generator.

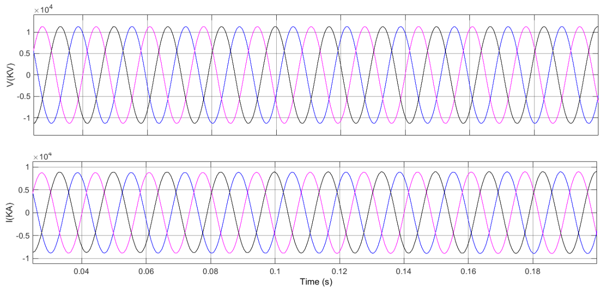

Fig. 8. Voltage and current of generator.

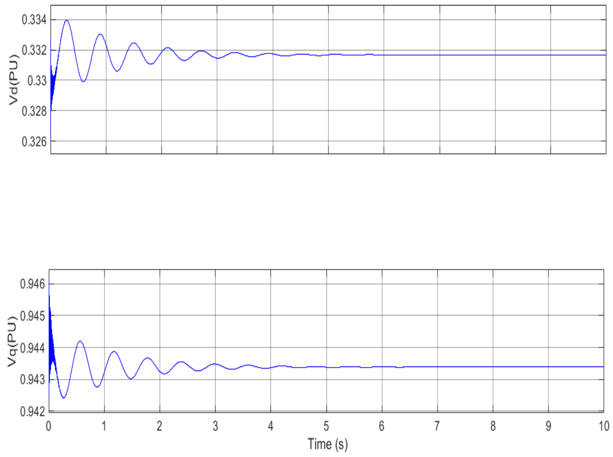

Fig. 9. Voltage of d-q axis of generator.

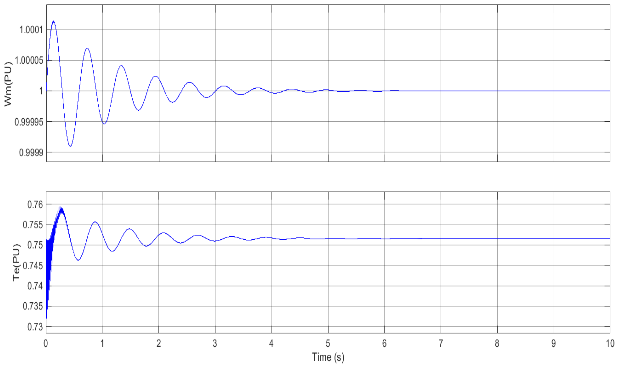

Fig. 10. Speed and torque of generator.

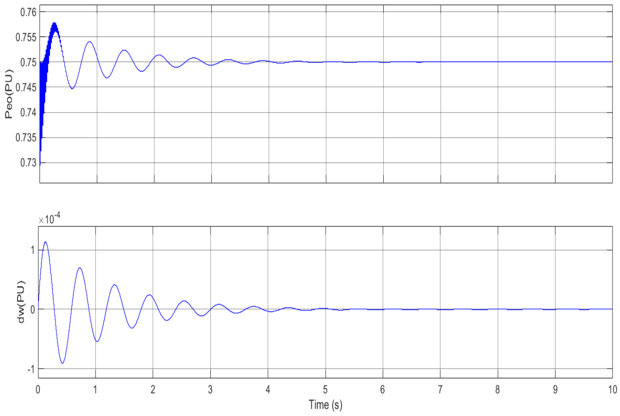

Fig. 11. Deviation of generator output power and speed from their rated values.

2. Three-phase short-circuit current

Assessing a three-phase short circuit in a hydropower plant is essential for ensuring safety, preventing equipment damage, and maintaining system reliability. By conducting a thorough assessment, operators can implement necessary precautions to prevent accidents and safeguard the well-being of workers.

Simulating a short circuit in the plant is equally important for gaining a comprehensive understanding of the fault, testing the effectiveness of protection systems, and training operators on proper response procedures. Through simulation, operators can visualize and analyze the behavior of the system during a fault, identify potential vulnerabilities, and verify that protection systems are functioning as intended. This proactive approach helps enhance the plant's overall safety, reliability, and operational efficiency. In this scenario, a three-phase short circuit occurs at the 10-th second and lasts for 0.1 second. The simulation outputs are presented in the following Figures for a simulation time of 20 seconds.

Following an in-depth analysis of the simulation results, it becomes apparent that the hydropower plant's generator adeptly managed the three-phase short circuit fault that occurred. The generator's protective systems swiftly detected the fault and initiated the necessary actions to mitigate its impact, ensuring the safety of the equipment and preventing any further damage. During the fault event, the generator responded promptly and effectively, safeguarding its components and minimizing the risk of prolonged downtime. Once the fault was successfully resolved and the system restored to normal operating conditions, the generator seamlessly transitioned back to a stable state, ready to resume its crucial role in generating electricity. Figures 12 to 16 illustrate the power and reactive power, voltage and current, voltage of the d-q axis of the generator, as well as speed and torque. Additionally, they depict the deviations of the generator's output power and speed from their rated values, all in the context of a three-phase short circuit at the plant.

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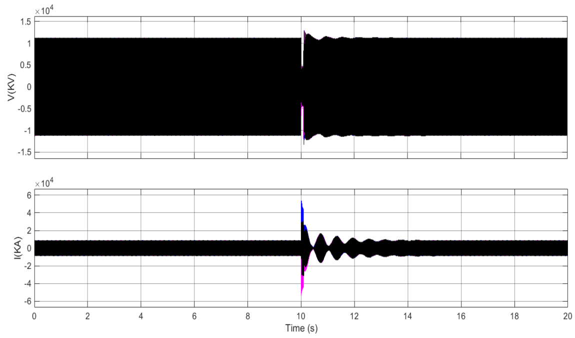

Fig. 12. Voltage and current of generator.

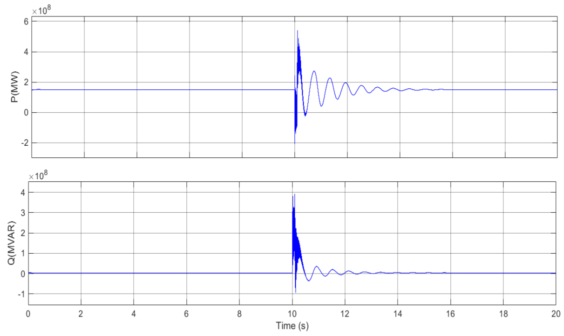

Fig. 13. Active and reactive power.

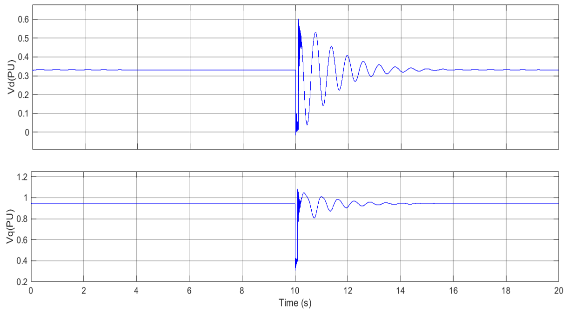

Fig. 14. Voltage of d-q axis generator.

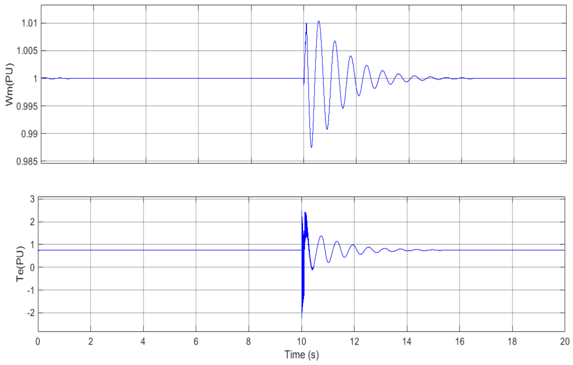

Fig. 15. Speed and torque of generator.

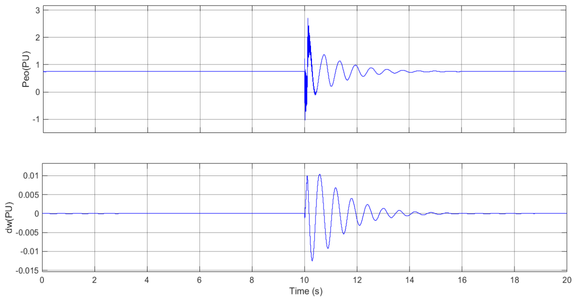

Fig. 16. Generator output power and generator speed deviation from rated values.

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IV. DISCUSSION

To address a specific gap in the state-of-the-art hydropower plant modeling, various studies were conducted, including [1, 2, 4, 6, 7, 11, 12, 19]. These studies delved into the modeling of hydropower plants. The simulation in this study is based on the model proposed in [4]. This research sets itself apart from [4] by exploring and analyzing a broader array of critical parameters during fault scenarios. Unlike [4], which primarily focuses on analyzing short-circuit events, voltage, and speed characteristics, the study presented dives deeper into the analysis.

This study involved examining two specific faults, along with parameters such as active power; reactive power; voltage; current; voltage of the generator's d-q axis; speed, torque, voltage, and current of the generator; as well as power and speed deviations of the generator. This analysis highlights the scope of expansion beyond the scope of [4]. Figure 17 illustrates the disparities between the findings of this study and study discussed in [4].

It is imperative to address the parameters such as active power; reactive power; voltage; current; voltage along the generator's d-q axis; speed, torque, voltage, and current of the generator; power and speed deviations during short-circuit faults and fluctuations in reference power when assessing the performance of a hydropower plant. This analysis serves several key purposes:

- Fault Detection and Diagnosis: Monitoring these parameters aids in the identification and rectification of system faults. Variations in power, voltage, and current profiles can uncover crucial insights into the nature and existence of ongoing issues within the system;
- Performance Assessment: Evaluating the hydropower plant's performance across diverse conditions becomes feasible through the examination of these parameters. Understanding the repercussions of short-circuit faults and reference power fluctuations for these parameters is pivotal for gauging the plant's overall efficiency and effectiveness;
- System Stability Evaluation: The scrutiny of variables such as torque, speed, and voltage variations facilitates the assessment of system stability. Sudden changes in these parameters during faults or power variations may indicate potential stability hurdles that need to be addressed to ensure the plant's reliable operation;
- Optimization Possibilities: A comprehensive analysis of these variables provides a holistic perspective on the plant's behavior. Leveraging these data can aid in overall performance enhancement, operational efficiency improvements across various operational scenarios, and the optimization of plant operations for higher efficiency of the plant.

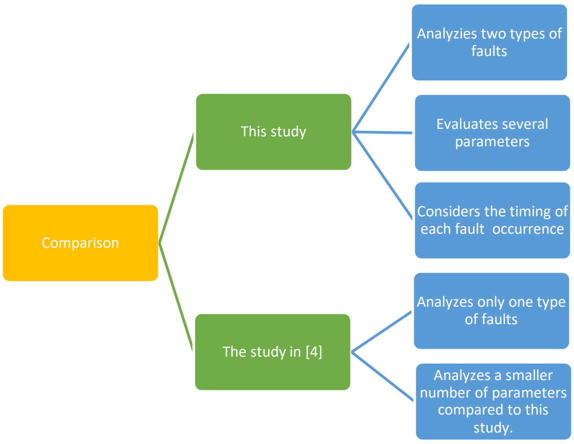

Fig. 17. Comparison between this study and study presented in [4].

There are some limitations of this study, which can be addressed and improved in future research by:

- Optimizing some important parameters assessed;
- Applying economic analysis of the model used;
- Implementing energy management into the model and study;
- Exploring and implementing advanced control strategies to enable significant enhancement of the operational capabilities of hydropower plants.

Because of computing constraints, simulating problems such as short circuits and variations in reference power in MATLAB may not be appropriate for real-time operation within the hydropower plant itself, but it can be useful for real-time analysis and testing. Hardware-in-the-loop (HIL) systems or specialized real-time simulation platforms are usually utilized for real-time applications.

In a hydropower plant, the following suggestions can help manage faults and enhance reactions during short circuits and variations in reference power:

- Use digital twin technology that creates a virtual replica of the industrial equipment or system, enabling real-time monitoring and simulation of potential faults, including short circuits;
- Develop robust control strategies that can adapt to changes in reference power and respond effectively during short circuits. Implementing predictive control algorithms can help optimize system performance under varying conditions;
- Incorporate redundancy and backup systems to ensure continuity of operations during faults. These include backup power sources, redundant components, and fail-safe mechanisms to prevent system downtime.

The capacity of hydropower plants to handle short-circuit faults, variations in reference power, and other deviations in real-time operations can be improved by putting these suggestions and techniques into practice. This will ultimately increase system efficiency, safety, and reliability.

V. CONCLUSION

Hydropower is an essential renewable energy source that helps reduce dependency on fossil fuel power plants, provides consistent electricity, stabilizes the grid, and meets the world's energy demands without releasing greenhouse gases into the atmosphere. For a hydroelectric plant to operate safely and effectively, fault investigation is essential. For instance, reference power fluctuations, triggered by shifts in load demand or grid conditions, can enhance the plant's adaptability to new power requirements, optimizing output and upholding system stability. Understanding the plant's response to such faults can lead to enhanced performance and reliability.

The power output of the generator will decrease from 200 MW to 150 MW to match the new reference power. The reactive power output may also decrease accordingly.

With the decline in power demand, the generator will operate at a lower speed and torque compared to those when the reference power was 200 MW. The decrease in power output will require less effort from the generator, resulting in reduced speed and torque.

The voltage profile of the d-q axis of the generator may be affected by the decrease in power demand. The decrease in power output may lead to a change in the voltage profile of the generator.

The decrease in reference power will cause a deviation in the output and speed of the generator as it adjusts to meet the new demand. The generator will have to operate at a lower output and speed, leading to deviations from its previous levels.

On the other hand, a three-phase short circuit, a severe fault, can inflict substantial equipment damage and disrupt plant operations. Investigating the root cause and enacting contingency plans can curtail downtime and ensure swift recovery.

A short circuit causes a sudden drop in voltage at the terminals of the generator. The current flowing through the generator increases significantly due to the short circuit condition.

The power output of the generator may be affected by the short circuit. In some cases, the generator may continue to supply power to the system to support the fault condition, but the power output may be limited due to the increased current flow and reduced voltage. The reactive power output may also be affected depending on the system's response to the short circuit.

The speed and torque of the generator may experience fluctuations or disturbances due to the sudden changes in the electrical conditions caused by the short circuit. The generator may need to adjust its output to compensate for the changes in the system.

The voltage profile of the d-q axis of the generator may be impacted by the short circuit. The sudden changes in voltage and current can affect the stability and performance of the generator.

The short circuit can lead to deviations in the output and speed of the generator as it responds to the fault condition. The generator may need to adjust its output and speed to maintain stability and support the system during the short circuit event.

REFERENCES

[1] S. Gbadamosi and O. A. Ojo, “Dynamic modeling and simulation of Shiroro hydropower plant in Nigeria using Matlab/Simulink,” *International Journal of Scientific & Engineering Research*, vol. 6, no. 8, pp. 1–8, 2015.

[2] V. K. Singh and S. K. Singal, “Operation of hydro power plants-a review,” *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 610–619, 2017.

[3] S. Mishra, S. K. Singal, and D. K. Khatod, “Optimal installation of small hydropower plant – a review,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 8, pp. 3862–3869, 2011.

[4] A. Acakpovi, E. B. Hagan, and F. X. Fifatin, “Review of hydropower plant models,” *International Journal of Computer Applications*, vol. 108, no. 18, p. 33–38, 2014.

[5] L. Selak, P. Butala, and A. Sluga, “Condition monitoring and fault diagnostics for hydropower plants,” *Computers in Industry*, vol. 65, no. 6, pp. 924–936, 2014.

[6] M. Sattouf, “Simulation model of hydro power plant using Matlab/Simulink,” *International Journal of Engineering Research and Applications*, vol. 4, no. 1, pp. 295–301, 2014.

[7] W. Innocent and B. A. Amez, “A Matlab/Simulink Based Fault Analysis of Small Hydropower Plant,” *J. Adv. Comp. Engtechnol.*, vol. 5, no. 4, p. 221–232, 2019.

[8] T. Nepal, D. Bista, T. Øyvang, and R. Sharma, “Models for a hydropower plant: a review,” in *64th International Conference of Scandinavian Simulation Society, SIMS 2023*, Västerås, Sweden, Sep. 25–28, 2023, pp. 326–338.

[9] A. Saeed et al., “Power Regulation and Fault Diagnostics of a Three-Pond Run-of-River Hydropower Plant,” *Processes*, vol. 10, no. 2, p. 392, 2022.

[10] M. Noman et al., “Analysis of overcurrent protective relaying as minimum adopted fault protection for small-scale hydropower plants,” *International Journal of Environmental Science and Technology*, vol. 21, no. 4, pp. 4457–4470, 2024.

[11] N. Kishor, R. Saini, and S. Singh, “A review on hydropower plant models and control,” *Renewable and Sustainable Energy Reviews*, vol. 11, no. 5, pp. 776–796, 2007.

[12] A. Acakpovi, E. Ben Hagan, F. X. Fifatin, “Review of Hydropower Plant Models,” *International Journal of Computer Applications*, vol. 108, no. 18, pp. 33–38, 2014.

[13] L. Jasa, A. Priyadi, M. H. Purnomo, “An Alternative Model of Overshot Waterwheel Based on a Tracking Nozzle Angle Technique for Hydropower Converter,” *International Journal of Renewable Energy Research*, vol. 4, no. 4, pp. 1013–1019, 2014.

[14] S. L. Gbadamos, A. O. Ojo, and L. Nnaa, “Evaluation of Operational Efficiency of Shiroro Hydro-Electric Plant in Nigreia,” *International Journal of Science and Engineering Investigations*, vol. 4, no. 42, pp. 33–38, 2015.

[15] IEEE Committee, “Dynamic models for steam and hydro turbines in power system studies,” *IEEE Trans. on Power Appar. Syst.*, vol. 92, pp. 1904–1915, 1973.

[16] IEEE Working Group, “Hydraulic turbine and turbine control models for system dynamic studies,” *IEEE Trans on Power. Syst.*, vol. 7, pp. 167–179, 1992.

[17] E. F. Fuchs, M. A. S. Masoum, *Power Conversion of Renewable Energy Systems*. Springer, 2011. ISBN 978-1-4419-7978-0

[18] F. Xu, Y. Li, C. Qijuan, “Study of the Modelling of Hydroturbine Generating Set,” in *International IEEE/IAS Conference on Industrial Automation and Control: Emerging Technologies,* May 22–27, 1995, pp. 644–647.

[19] G. A. M. Hernandez, S. P. Mansoor, and D. L. Jones, *Modelling and Controlling Hydropower Plants*, Springer, 2012. DOI 10.1007/978-1-4471-2291-312.

[20] I. A. Nassar, H. Weber, “Dynamic Model of Unit 1 of Ataturk Hydro Power Plant in Turkey,” in *13th Middle East Power Systems Conference*, MEPCON’ Assiut University, Egypt, 2009.

[21] G. A. Munoz-Hernandez and D. I. Jones, “Modelling, Simulation and Control of a Hydroelectric Pumped Storage Power Station,” in *Proceedings of the Control 2004*, University of Bath, UK, Sep. 6–9, 2004.

[22] IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies. “Hydraulic Turbine and Turbine Control Models for Dynamic Studies,” *IEEE Transactions on Power Systems*, vol. 7, vo.1, pp. 167–179, 1992.

[23] *Mathworks. 2014. Synchronous Machines*. [Online]. Available: http://www.mathworks.com/examples/simpower/50-synchronous-machine.

[24] V. E. Kozhemyakin, A. A. Achitaev, A. Y. Arestova, and A. G. Rusina, “Single-Phase Short Circuit Determining Algorithm at Hydroelectric Power Plant Auxiliaries Network,” in *2021 XV International Scientific-Technical Conference on Actual Problems of Electronic Instrument Engineering (APEIE)*, IEEE, 2021, pp. 206–211.

[25] S. G. Johansson and B. Larsson, “Short-circuit tests on a high-voltage, cable-wound hydropower generator,” *IEEE Transactions on Energy Conversion*, vol. 19, no. 1, pp. 28–33, 2004.

[26] N. Kholov, M. Solieva, A. Majidov, and S. Khafizov, “Research Stability of Micro-Power Systems with a Mini-Hydroelectric Power Plant at Short-Circuits,” in *2021 4th International Youth Scientific and Technical Conference on Relay Protection and Automation (RPA)*, IEEE, 2021, pp. 1–9.

[27] V. Mureşan et al., “Fault Tolerant Control System for a Mini Hydropower Plant,” *IFAC-PapersOnLine*, vol. 55, no. 9, pp. 537–542, 2022.

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