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Failure-Based Maintenance Planning Using Bayesian Networks: A Case Study Hydraulic Turbine

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Abstract

The assessment of existing infrastructures in the energy sector is of great economic importance for the world. The extension of the power generation life of hydroelectric power plants depends on decisions regarding the maintenance and renewal of the equipment. For this purpose, a Bayesian network (BN) has been applied to evaluate the failures in the hydraulic turbine to calculate the failure of the turbine. Forty-six nodes have been identified that will affect the operation of the system. Preventive measures have been established for failures with the highest posterior probability. By creating four different cases, failure probabilities and the change of the main fault have been calculated. How much savings could be made in each case is determined. This proposed framework will be guided in determining the maintenance strategies for hydroelectric power plant operators.

1. Introduction

An increase in production facilities is necessary for the development of the economy. The increase in production brings many problems, especially environmental ones. Environmental impacts of non-renewable energy, countries need to use renewable energy sources to plan a low carbon future and ensure environmental quality [1]. 24.5% of the energy produced worldwide is produced from renewable energy sources, and 16.6% is composed of hydraulic energy. The rest comprises wind, bio-gas, solar, and other energy sources [2]. The fact that hydraulic energy has such great importance among renewable energy sources increases the importance of scientific studies to increase the efficiency of hydroelectric power plants, eliminate failures and increase the residence time quickly.

Unexpected failures, wasting time, loss of production, and higher maintenance costs are essential problems in any process plant [3]. All equipment of the hydroelectric power plant units may fail. It can be graded according to the damages caused by the failures caused by the hydroelectric power plant units and the cost they create.

Failures in hydroelectric power plants are usually related to cavitation, erosion, operational errors, and material defects. Due to high water pressures, pressure changes, and high-water speeds, serious problems can occur in hydroelectric power plants. Furthermore, if adequate preventive maintenance and clearly defined revision procedures are implemented in hydroelectric power plants, the occurrence of failures is significantly reduced [4-5]. Due to the combination of hydraulic, mechanical and electrical systems and complex interactions, it is challenging for decision-makers to estimate the number and quality of different factors that may cause equipment failure [6-7].

Regular and predictive maintenance can be performed where significant faults occur. With the complexity of bureaucratic procedures, high costs,

and the need for a lot of repair time, the maintenance activities of hydroelectric power plants are pretty tiring and costly for enterprises [8-10].

Maintenance in businesses is essential. Production equipment in most enterprises makes up the majority of the investment.

The malfunctions in the facilities increase the costs and cause significant losses to the investor [11].

Reduces costs, and extends the system's life cycle [12]. A well-organized maintenance strategy increases system security. The performance of quantitative assessment is more detailed than the qualitative assessment process. The expert system and process information are prerequisites for starting the evaluation process. This expert knowledge is acquired through system information, event, process information, knowledge of normal and abnormal conditions, accident operation procedures, and specific failure information research. Various methods have been proposed in the literature to assess the risk and safety of processes [13]. These drawbacks are mainly due to these classical techniques' static structure and ineffectiveness in dealing with uncertainties. More complex techniques such as BN have been proposed [14].

BN presents a graphic illustration of any complex system that uses basic and conditional probabilities for system inputs. For subsystems and interactions, one of the main advantages of BNs is that they can combine all types of data (social, environmental, technical, etc.) into a single unified representation. The main challenge is to find information to improve BN and predict system failures due to multiple factors [15]. This method is an effective tool for risk analysis, developing accident prevention strategies, and taking preventive measures [16]. BN is probabilistic technique for reasoning under uncertainty. The main improvement of BN is its ability to update probability [17].

In the hydroelectric field, BN has been used quite frequently. Studies in this area have generally focused on weather forecasting [18-21]. A diagnostic model based on Bayesian networks has been proposed in the study to assess the risks in energy generation in hydroelectric power plants [22].

This study aims to determine the most important failures in hydroelectric power generation units considering the usability and human safety criteria and to create a framework for the practitioners and decision-makers. In addition, BN has been updated for different cases, and it has been predicted how much money can be saved for new cases.

The organization of the study is as follows. In section 2 of the study, BN is defined. In Section 3, the failures in the hydroelectric power plant are identified, and a BN network is established. In Section 4, the most probable failures are explained in detail and discussed how to prevent these failures. In addition, maintenance recommendations are given based on the calculations from BN. The conclusion part summarizes the study and evaluates its contributions to the literature.

2. Material and Method

Bayesian network is the Thomas Bayes theorem, which connects the conditional probabilities of two events that condition each other [23-25]. BN is a commonly used graphical inference probability method. Due to its flexible structure and ability to represent large systems, the use of BN is very common in subjects such as risk analysis. [26].

A BN is a directed acyclic graph, where the nodes represent the variables $U = \{A_i, \cdots A_n\}$ Moreover, the directed links between them indicate the relationship among the nodes. BN specifies a unique joint probability distribution of all nodes $P(U) = P(A_1, \ldots, A_n)$ given by the product of all conditional probability tables specified in BN [27].

$$P(U) = \prod_{i=1}^{n} P(A_i|pa(A_i)) \qquad (1)$$

Where $pa(A_i)$ are parents of node A_i and $P(A_i|pa(A_i))$ specifies a conditional probability distribution. The calculations are based on Bayesian theory, where the probability of event A at the condition of event B is expressed as:

$$P(A|B) = \frac{P(B|A)xP(A)}{P(B)} \qquad (2)$$

In which $P(A)$ is the prior probability of A, $P(B|A)$ is the probability of B under the condition of a known event A [26]. $P(B)$ is prior probability of B. Probabilistic relationship between nodes given in Figure 1.
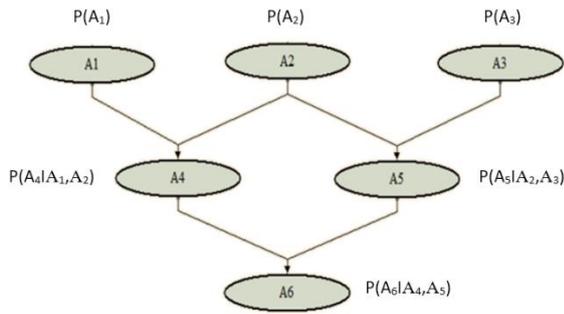
Figure 1. Probabilistic relationship between nodes [26]

3. Methodology

Hydroelectric power plants are composed of dam body, penstock, volute, adjusting blades, turbine part, shaft, bearings, generator part, warning system, switchyard, and auxiliary types of equipment (speed regulator system, oil, air cooling system, pumps, etc.). Failures to occur in any of this equipment will prevent the system's operation and disrupt energy production.

3.1. Defining The System and Collecting Information

Francis turbines. The annual average energy production is 6 billion kilowatt-hours. The dam is predominantly stone filling and concrete. The crest elevation is 848 meters. Storage capacity is 31000 hm³. The turbine speed is 166.7 rpm. The net head

of the turbine is 145 meters. The flow is 135 m³ / h [28].

Information about all processes in the hydroelectric power plant is collected. The dam is located 45 kilometers northwest of Elazığ. The dam capacity is 1330 MW. The potential energy of water is used to generate electricity in a hydropower plant. This potential energy is transmitted to the turbines via forced tubes. In the turbine, the potential energy of water is converted to kinetic energy (mechanical energy) and then to electrical energy by the rotation of the generator motor connected to the turbine wheel. The operating principle scheme of a hydroelectric power plant is shown in Figure 2. Figure 2. Process principle scheme of a hydroelectric power plan
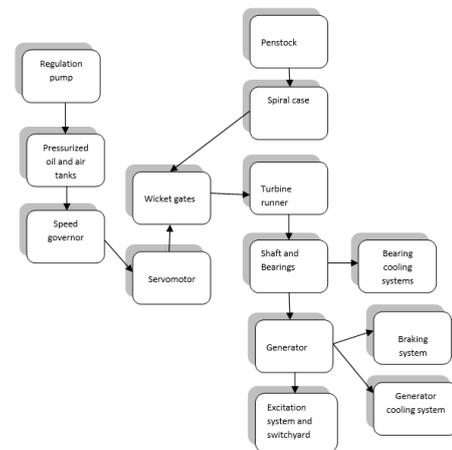

Figure 2. Process principle scheme of a hydroelectric power plant

Table 1. Failure Name and Explanation

Code	Name	Explanation
H1	Failures that may occur in the turbine-generator unit during power generation	Many failures can occur when the turbine-generator unit generates energy. These failures can have many causes. These reasons are given below in failure codes H1 to H60.
H2	Not enough water pressure in forced pipe	H3 failure may have arisen
H3	Forced pipe inlet cover closed	Forced pipe seal changes or any maintenance such as sandblasting to the forced pipe is performed. The forced pipe cover is closed. Before the turbine generator unit is commissioned for power generation, it is necessary to fully open the penstock inlet cover by equalizing the water pressure on the reservoir and the turbine side of the penstock.
H4	Generator brakes solenoid valve failure	Generator brakes operate with 7 bar compressed air. The solenoid valve controls compressed air. The brakes do not start if there is a failure in the solenoid valve.
H5	The low bearing oil film pressure	When the carrier-bearing oil pump unit is first started, it must generate sufficient oil film pressure between the bearing socket and the ring. The unit will not operate if the oil pressure is too low.
H6	Adjustment wing locks do not open	H8 and H9 failures may have arisen
H7	Speed governor regulation pumps are not working	H59 and H60 failures may have arisen

H8	Control wing locks solenoid valve failure	The adjustment is controlled by a solenoid valve in the pressure oil speed regulator that controls the wing locks. If the solenoid valve is faulty, the adjustment flaps will not be opened, and as a result, the adjustment flaps will not be opened and the water required for generating the turbine energy will not come.
H9	Relay failure energizing control wing lock solenoid valve	The solenoid valve does not work if the relay that energizes the regulator wing solenoid valve is faulty.
H10	Pressure oil tank isolating valve failure	The speed regulator receives the pressure oil from the pressure oil tank, which it sends to control the servomotor. The solenoid valve located at the bottom of the pressurized oil tank is energized with the start of the unit. It sends the pressurized oil to the speed regulator main distribution valve. If there is a failure in the solenoid valve, the speed regulator cannot send pressurized oil to the servo motors, the wing is not opened, and the unit does not start.
H11	Generator brake failure	H4 and H12 failures may have arisen
H12	Compressed air seal gasket failure of generator brake pads	The generator brakes are activated by compressed air and disengaged with a spring's aid when the compressed air is released. If there is any deformation in the compressed air sealing gaskets, the brakes will not be activated since the sealing cannot be achieved. This fault does not cause problems while the unit is operating, but it cannot be stopped when it is intended to be stopped.
H13	Low amount of pressurized oil driving the adjustment wing lock	The timing lock mechanism must be released when commissioning the unit. If the lock is released with pressurized oil and is not sent, the lock is applied using leaf springs. If enough pressure oil does not come to the lock locks, the lock cannot be opened so that the unit cannot generate energy.
H14	Breakage of leaf springs inside the adjustment wing locks mechanism	If the leaf springs in the timing lock mechanism break, the unit cannot generate energy because the adjustment wing locks do not move.
H15	No energization of the bearing pressure oil pump	If the pump does not operate due to lack of energy to the bearing pressure oil pump, the unit shaft will not rotate and generate energy because there will be no oil film between the bearing and ring.
H16	Winding or bearing failure in bearing pressurized oil pump motor	In the case of winding or bearing failure in the bearing pressure oil pump motor, the bearing pump does not start and consequently, the situation in the H15 failure occurs.
H17	Cooling water pump failure	H18, H19, and H20 failures may have arisen
H18	Cooling water pump shaft bearings failure	The generator windings and bearings cannot be cooled as the coolant pump will not start. Therefore, the unit cannot generate energy.
H19	Winding insulation perforation in the coolant pump motor	The generator windings and bearings cannot be cooled as the coolant pump will not start. Therefore, the unit cannot generate energy.
H20	Cooling water pump valve failure	The generator windings and bearings cannot be cooled as the coolant pump will not start. Therefore, the unit cannot generate energy.
H21	Electrical voltage failure	H22, H26 and H56 failures may have arisen
H22	Insulation resistance weakness in generator stator windings	Generator stator winding isolations may weaken over time due to external factors (such as oil mist and dust). A short circuit of the current passing over the insulation weakness causes a failure.
H23	Thrust and guide bearing heat exchanger cooling water output flowmeter failure	The carrier and guide-bearing heat exchanger have a flowmeter to control the flow at the cooling water outlet. The unit cannot be commissioned if this flow meter does not indicate water flow.
H25	Stator-ground fault	H26 and H56 failures may have arisen
H26	Current flow to the ground as a result of weakening of the stator windings	H22 failure arises
H27	Generator differential failure	H28 failure may have arisen
H28	Phase-to-phase short circuit fault	An electrical short circuit occurs between phases.
H29	Unit differential failure	H30 failure may have arisen
H30	Short circuit between generator output busbar and transformer entrance	Failure occurs due to short circuit between generator output busbar and transformer entrance.

H33	Rotor-ground fault	H34 failure may have arisen
H34	Current flow to the ground due to weakening of the insulation of the windings of the rotor poles	Insulation of the rotor poles may be weakened, or conductive material (such as welding slag) may enter between the rotor poles.
H35	Warning current fault	H36 failure may have arisen
H36	Short circuit between rotor poles	A short circuit between the rotor poles may fail.
H41	No breaker open information	H42 failure may arise
H42	Sending information Relay Failure	The sending information relay may fail over time. Relays must be tested periodically.
H44	No Separator open information	H42 failure may arise
H50	Warning system and switchyard failures	It depends on H35, H41, H44, and H55failures.
H51	Generator failures	It depends on H11, H21, H25, H27, H29, and H33failures.
H52	Turbine failures	It depends on H5 and H58failures.
H53	Speed regulator failure	It depends on H6, H7, H8, H10 failures.
H54	Failures caused by forced pipe section	It depends on H2 and H3failures.
H56	Overheating of generator windings	It depends on H57 failure.
H57	Flowmeter failure in generator radiators	The generator heat exchanger has a flow meter to control the flow at the cooling water outlet. If this flow meter does not indicate water flow, the unit cannot be started.
H58	Thrust and guide bearing failures	It depends on H17 and H23 failures.
H59	Regulation pump motor winding insulation puncture	Since the regulating pump will not start and cannot send oil to the pressurized oil tank, the unit will not start.
H60	Regulation pump bearing failure	Since the regulating pump will not operate, the unit cannot send oil to the pressurized oil tank, and the unit does not start.

Table 2. Probability of Independent Nodes

Failure modes	Yes	No	Failure modes	Yes	No
H59	0.0017	0.9983	H18	0.009	0.991
H60	0.002	0.998	H19	0.008	0.992
H3	0.9995	0.0005	H20	0.01	0.99
H9	0.03	0.97	H4	0.03	0.97
H10	0.03	0.97	H12	0.01	0.99
H8	0.03	0.97	H36	0.007	0.993
H13	0.07	0.93	H42	0.012	0.988
H14	0.008	0.992	H34	0.003	0.997
H15	0.005	0.995	H30	0.004	0.996
H16	0.003	0.997	H28	0,004	0,996

Hydroelectric power plants are composed of dam body, penstock, volute, adjusting blades, turbine part, shaft, bearings, generator part, warning system, switchyard, and auxiliary types of equipment (speed regulator system, oil, air cooling system, pumps, etc.). Failures to occur in any of this equipment will prevent the system's operation and disrupt energy production.

3.2. Failure Identification

The failures that occurred in the turbine-generator unit were examined. A BN network scenario was realized to prevent the operation of the system. The failure codes and explanations are given to them are given in Table 1.

3.3. Model development

The objective at this stage is to develop a quantitative computational model. In general, when the probability of input events is uncertain due to data expertise or limited information for a system, evidence theory is used to gather the information of multiple experts into probabilities. The probability values in the study were evaluated based on the knowledge and translations of the experts. In Table 2, the probabilities of independent events are given. "Yes" and "No" are used for failure modes.

3.4. Failure Analysis

The failure assessment begins with identifying the major potential hazards (most important events) that each failure scenario can cause. The error data for the basic events of the subsystem is used to estimate the probability of a subsystem failure.

Result analysis is used to measure the impact of the emergence of each failure scenario. The probability of failure of the top event and the final state results is calculated with the BN model.
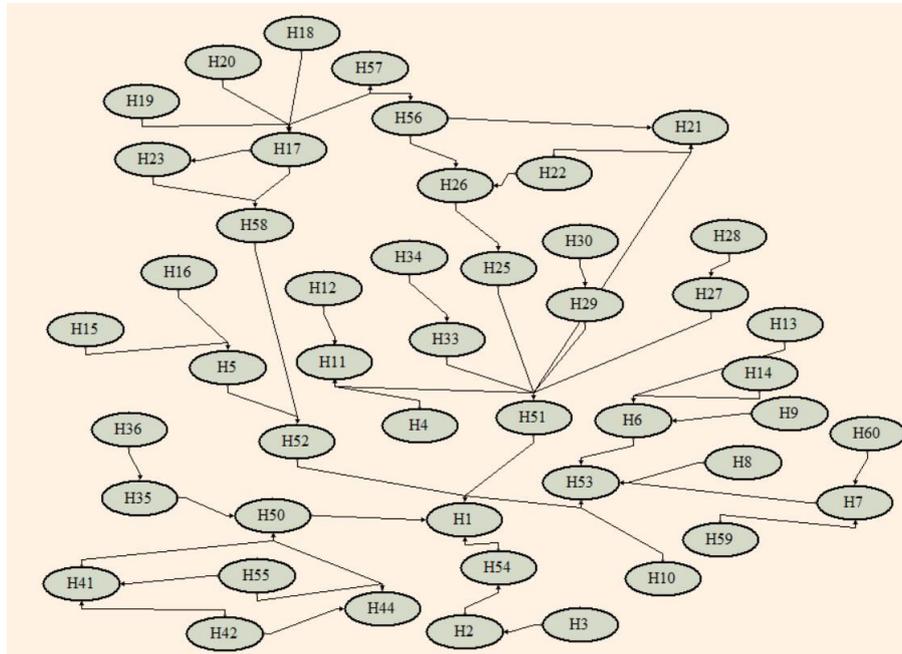
Figure 3. The Bayesian network of the fault diagnosis of the Hydroelectric power plant

The calculation was carried out and the probability values in Table 3 were obtained. The four most frequent failure modes are H51, H21, H25 and H26, respectively.

Table 3. Probability of Failures

Failure modes	Yes	No
H51	0.7129	0.2871
H21	0.7002	0.2998
H25	0.6231	0.3769
H26	0.6231	0.3769

Failures related to error types and the failures affecting these failures are plotted in Microsoft Research's Bayesian network authoring and evaluation tool (MSBNx) [29], as shown in Figure 3. Independent events were identified in the program, and their probabilities were entered. Afterward, Conditional probability tables (CPT) were determined by the brainstorming of experts. Due to space constraints, CPTs are not included here.

3.5. Comparative Study

In the previous section, the Bayesian network was created by considering the relationships of the failure modes with each other, and the final probabilities of the failure modes were calculated with the help of the probabilities of the independent and dependent events. In this section, MCDM, which is widely used in risk analysis, is used [30,31]. While determining the failure modes weights, the Best worst method recommended by Rezaei [32], which is a popular method especially in recent years, has been used. BWM requires less comparison matrices than other methods such as AHP. In this respect, it saves time for decision-makers [33-34]. First of all, a new hierarchy was created for failure modes and presented in Figure 4. Later on, Best and Worst criteria are determined. Using expert opinions, the best-to-other vector is determined by comparing the best criterion with other criteria. Then, the Others-to-worst criterion is determined by comparing the worst criterion with

the other criteria. A mathematical model is created with the determined vectors [32].

Due to the hierarchical structure; Firstly, the weights of Governor (w1), Bearing (w2), Generator (w3), Auxiliary equipment (w4), Turbine (w5), and Electrical fault (w6) will be calculated via experts' opinion. The weights are calculated using the following mathematical model.

$$min\ \xi$$
$$s.t.$$
$$\left|\frac{w_3}{w_1}-4\right|\le\xi, \left|\frac{w_3}{w_2}-5\right|\le\xi, \left|\frac{w_3}{w_4}-2\right|\le\xi, \left|\frac{w_3}{w_5}-7\right|\le\xi,$$
$$\left|\frac{w_3}{w_6}-3\right|\le\xi, \left|\frac{w_1}{w_5}-3\right|\le\xi, \left|\frac{w_2}{w_5}-2\right|\le\xi, \left|\frac{w_4}{w_5}-5\right|\le\xi,$$
$$\left|\frac{w_6}{w_5}-4\right|\le\xi,$$
$$\sum_{i=1}^{6} w_i = 1\ (i = 1,\dots,6)$$
$$w_i \ge 0 \text{ for all } i$$
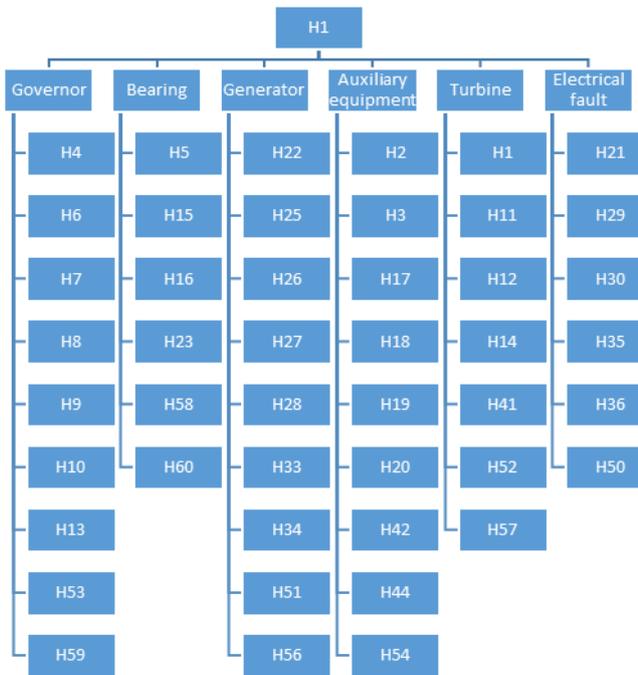
Figure 4. Hierarchy of failure Modes

Due to space constraints, other mathematical models could not be included. All the results obtained are presented in Table 4.

When the probabilities of occurrence of the faults are examined in Table 4, the four highest probabilities were H33, H17, H34 and H56 faults. In this new method for benchmarking with the other calculation method, the interaction of the faults with each other is neglected. When the independent methods are compared, the probability of H51, H21, H25, H26 faults in the first method and H33, H17, H34, H56 faults in the second

method is high. In fact, all of these failures are explained as generator failures. For example, while the weakening of the stator windings (H26) stands out in the first method, the weakening of the rotor windings (H33) stands out in the second method. This shows that both methods give correct results. The calculated results show how important the generator part is in hydroelectric power plants.

4. BN-Based Maıntenance Advice

The highest frequency H51, H21, H25, H26 failures ,calculated with BN, have been examined in detail. Preventive measures have been proposed to minimize the probability of occurrence of failures and the effect of elimination of these failures on the main failure has been examined.

4.1 Generator failures (H51)

Hydroelectric power plant units consist of two main parts: turbine and generator. The generator part can fail more frequently than the turbine part. The generator part has a more complex structure than the turbine part. The effects of temperature increases and tensile forces caused by the passage of electric current in the generator part are effective. In hydroelectric power plant units, the generator part is where mechanical energy is converted into electrical energy. According to Faraday law, a current is generated by moving a magnet in a closed circuit. This effect is called electromagnetic induction. Electromagnetic induction forms the basis of converting mechanical energy into electrical energy in hydroelectric power plants. Figure 5 shows the arrangement of the generator stator windings in a hydroelectric power plant.

Figure 5. Generator stator windings

The failures that may occur in the generator section are listed below.

- **Short-circuits in the rotor poles** These failures occur by short-circuiting substances such as welding slag at the rotor poles. To reduce the frequency of this failure, the unit must be unplugged and cleaned. Electrical tests are performed every 20.000 hours.
- **Failures due to magnetic imbalance;** If the air gaps between the stator and rotor poles of the generator are disproportionate, excessive shaft oscillations are generated in the rotating mass caused by magnetic short circuits. To reduce the frequency of this failure, the stator windings must be reassembled after the stator sheets have been redesigned. If preventive measures are applied, this fault will almost disappear.

Table 4. Criterion Weights

Parameter	Local Weight	Global Weight	Parameter	Local Weight	Global Weight
Governor (w1)	0.1064		Auxiliary equipment (w4)	0.2609	
H4	0.2283	0.0243	H2	0.0589	0.0154
H6	0.1791	0.0191	H3	0.0589	0.0154
H7	0.0242	0.0026	H17	0.1930	0.0504
H8	0.1004	0.0107	H18	0.1750	0.0457
H9	0.0697	0.0074	H19	0.0848	0.0221
H10	0.0697	0.0074	H20	0.1514	0.0395
H13	0.1004	0.0107	H42	0.0180	0.0047
H53	0.2070	0.0220	H44	0.1750	0.0457
H59	0.0213	0.0023	H54	0.0848	0.0221
Bearing (w2)	0.0817		Turbine (w5)	0.0459	
H5	0.2008	0.0164	H1	0.3312	0.0152
H15	0.0372	0.0030	H11	0.0678	0.0031
H16	0.1637	0.0134	H12	0.0298	0.0014
H23	0.1637	0.0134	H14	0.0678	0.0031
H58	0.3936	0.0322	H41	0.2716	0.0125
H60	0.0410	0.0034	H52	0.0563	0.0026
Generator (w3)	0.3528		H57	0.1755	0.0081
H22	0.0406	0.0143	Electrical fault (w6)	0.1523	
H25	0.1118	0.0395	H21	0.4835	0.0736
H26	0.2192	0.0773	H29	0.0641	0.0098
H27	0.0911	0.0322	H30	0.2466	0.0376
H28	0.0207	0.0073	H35	0.1098	0.0167
H33	0.1560	0.0550	H36	0.0504	0.0077
H34	0.1347	0.0475	H50	0.0456	0.0069
H51	0.0911	0.0322			
H56	0.1347	0.0475			

4.2. Electrical voltage failures caused by voltage regulator (H21)

Such failures can often be caused by failure of the voltage regulator electronic boards. In order to reduce the frequency of this failure, voltage regulator electronic boards must be removed, cleaned and tested monthly.

4.3. Heating problem in stator windings (H25)

The problem of heating in the stator windings occurs when the cooling radiators become dirty, the heat transfer surface areas of the radiators are insufficient, or the cooling water flow is insufficient. To reduce the frequency of this failure,

it can be improved by cleaning the radiators during monthly maintenance and maintaining the cooling water system. If the problem is not solved in this way, it should be redesigned by increasing the heat transfer surface area of the radiators.

4.4. Insulation Weakening Problem In Stator Windings (H26)

The problem of insulation of the stator windings can lead to major problems and disrupt the power generation of the unit for long periods. Figure 6 shows the failure of the stator windings due to the insulation weakness problem.

Figure 6. Fault in generator stator windings due to insulation weakening

The fault in the figure is caused by current flowing from the stator windings to the ground due to insulation weakness. Important faults occur if the stator-ground faults are not detected by the protective relay, as shown in Figure 5. The regeneration of the stator windings may take between 5 to 200 days according to the number of damaged faults. To reduce the frequency of occurrence of this fault, stator winding insulation tests should be performed periodically. Stator windings where insulation weakness is detected should be replaced. While the unit generates energy, stator winding temperatures should be recorded hourly and any temperature rise should be monitored.

4.5. Failure Analysis in Cases Where Preventive Measures Are Considered

It is aimed to determine how the main fault will be affected if we can prevent the most frequent faults. Four cases have been determined for this purpose. Case 0 is the case where no preventive measures are applied. In Case 1, H51 failure was prevented.

In Case 2, H21 failure was prevented. In Case 3, H25 failure was prevented. Since faults H25 and H26 are linked, it is assumed that both faults are avoided. In Case 4, it is assumed that all these failures were prevented. The Bayesian network for each case was updated, and the new values are presented in Table 5 and Figure 7. According to the calculations, the preventive studies on the nodes will significantly reduce the main fault.

Table 5. Failure probability changes for cases

| Cases	H51	H21	H25	H26	Change probability of failure (%)
Case 1	0	0.0134	0.0134	0.0134	0.2717
Case 2	0.0549	0	0.0139	0.0139	0.2509
Case 3	0.2483	0.2157	0	0	0.1772
Case 4	0	0	0	0	0.2718
Case 0	0.7129	0.7002	0.6231	0.6231	
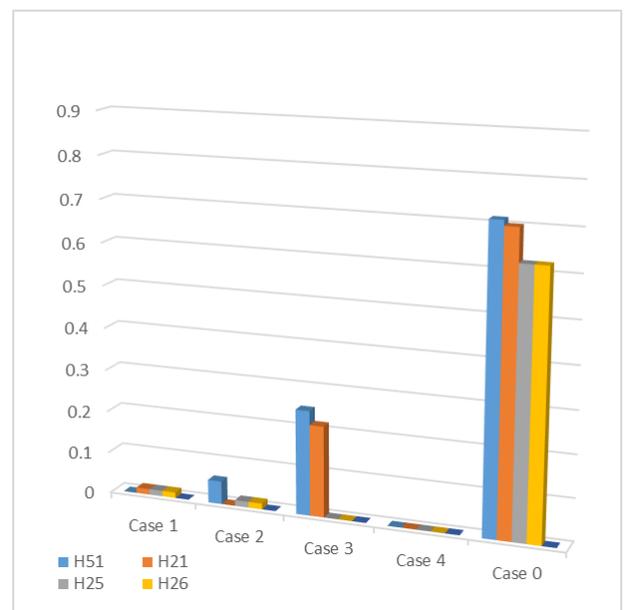
Figure 7. Failure probabilities for each case

According to the data of the last ten years in a hydroelectric power plant, which has 8 Francis turbines with 150 MW of energy production, the current leakage to the ground due to the weakening of the stator windings isolation causes (H26) a mandatory stoppage of 720 hours in an average annual turbine. These are 30 hours generator's top part disassembly and 10 hours test to detect defective winding, 200 hours defective winding removal, 250 hours new winding assembly, 200 hours other windings assembly, 30 hours generator upper part assembly. By taking the price of

electricity 0.029 $/kWh, when the precautions in case 3 are taken for this failure, when we reduced the occurrence period of the fault by 17.72%, the cost graph is shown in Figure 8.

As seen in Figure 7, when the failure rate is reduced by 17.72%, approximately 500000 dollars of energy is produced annually. Considering this saving for all hydroelectric power plants will make significant contributions to the economy.
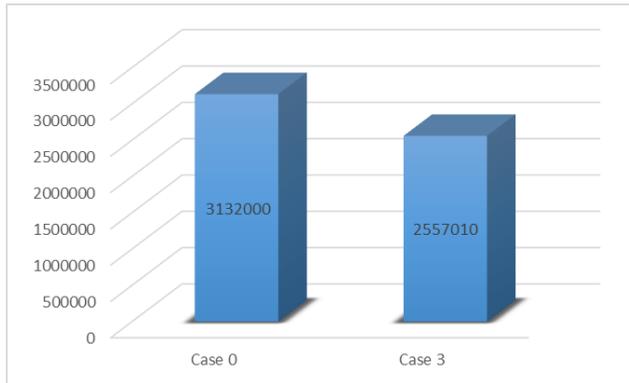
Figure 8. Energy loss cost Case 0 and Case 3

5. Conclusions

The importance of hydraulic energy among renewable energy sources necessitates the rapid elimination of failures by increasing the efficiency of hydroelectric power plants and taking preventive measures before failures occur. In this study, a fault detection methodology is proposed for hydroelectric power plants. Forty-six nodes and the relationship among these nodes were determined, and a Bayesian network was established. Bayesian networks are effective tools for risk and availability analysis of power generation units. They provide basic information in deciding on maintenance, possible repairs, and replacements of turbine components. The main purpose of this study is to provide a framework for determining the operation and maintenance strategy of hydroelectric power plants.

The proposed methodology consists of 4 stages. These stages consist of defining the system and collecting the necessary information, defining faults, model development and fault analysis, respectively. The Bayesian network was established by determining the relationship of 45 nodes and the main fault. The likelihood of independent events and conditional probabilities is based on past recordings and expert experience. In addition, the applied method was compared with a different method. According to the calculations, generator failures are the most important factor stopping electricity production in hydroelectric power plants. Solving this error alone can improve the system approximately 27%. Cases, where four other important faults have been eliminated have been created. For each case, the Bayesian network was recalculated to determine the probability of the main event.

Dam safety and sustainability are critical for dam operators. The different proposed cases will guide decision-makers in defining dam operation scenarios and determining maintenance strategies. Although this study provides a comprehensive framework for identifying failures and preventive measures in hydroelectric power plants, it has some shortcomings. The authors intend to develop a maintenance procedure that includes failures and preventive costs in their following research.

Contribution of the Authors

All authors contributed equally.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study

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