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System Reliability Evaluation of Dadin Kowa Hydro Power Plant

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ABSTRACT

Dadin Kowa hydro power plant (DKHPP) is connected to national grid via 132 bus and fed to Gombe and Biu. Like many generating station, they are faced with interruption and consistent outages. In DKHPP there is the problem of dropping of generated power between the design minimum and fault in cooling shaft seal of the turbine. Furthermore people in the neighboring local government are not enjoying continuous electricity supply it's very important for DKHPP utilities to properly manage and utilizes their existing facilities to maintain or enhance the system reliability. To address this, two methods was adopted and compared; Markov model and Energy index of reliability in the reliability evaluation of DKHPP which has generating capacity of 40 MW. For this research work the operational data regarding failure and maintenance, time taken for repairs and analysis of all parts of generating unit of the power plant for period of 2021-2022 is considered. The results revealed that using Markov model the reliability is 0.9919 for unit one and 0.9909 for unit two. So also the availability is 0.9894 for unit one and 09893 for unit two. The reliability using Energy index of reliability method is 0.9393 with LOLE of 16.899h/year which is far ahead of 4.8h/y of international utility practice. The plant has a unit derate factor of 1.164% which shows that if the plant is not properly maintained it could lead to degradation. Finally though the plant is reliable but daily seasonal and annual energy management system is recommended to enhance availability.

Key words: HEP plant, MTBF, MTTF, MTTR, Markov Model, Dadin-kowa.

1. INTRODUCTION

Reliability is the probability of a system or device operating as planned under specific conditions. It is not suitable for continuously operating systems that can withstand failures. In hydroelectric power plants, availability is used to measure repairable systems like turbines, transformers, and generators. It also includes the likelihood of discovering the component in operational state during failure.

Dependability evaluation methods include analytical and simulation techniques, which use mathematical models to define systems and assess reliability indices, and Monte Carlo simulation approaches to model actual system behavior (Depak et al., 2014).

In this work, data from 2021 to 2022 were used to evaluate the reliability and availability of the Dadin Kowa hydro power project units. The study uses data and failure types to define stages and assess reliability indices like time between failures, time to failure, time to repair, failure rate, and repair rate. Comparative states' failure and repair rates are used to compute state probabilities. The decrease in plant reliability index is calculated using expected energy not supplied, expected demand not supplied, and energy index of dependability. The main focus is on safe and reliable electricity transfer to customers covered by the generation.

The block diagram of a typical hydro power plant is shown in figure 1.

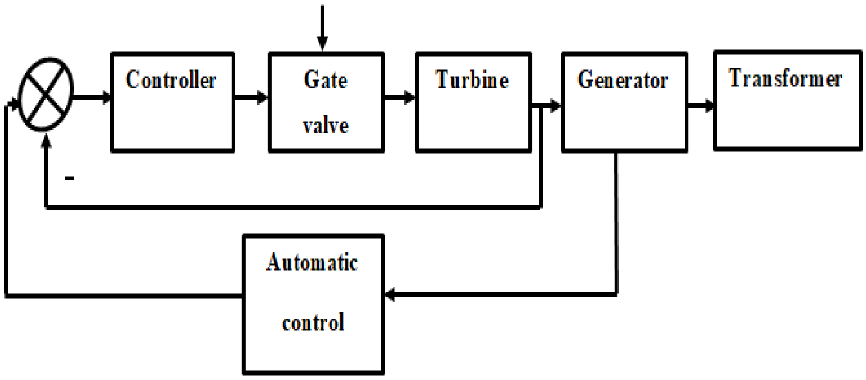

Figure 1: *Block diagram of the hydro power plant*

When water is flowing and falling due to gravity, it can be used to operate turbines and generators that produce electricity. This source of sustainable energy is known as hydroelectric power.

The Dadin Kowa hydro power plant faces various challenges, leading to power outages and power drops below design minimums. This affects neighboring local governments and hinders reliability evaluation using Markov models and energy index methods, affecting continuous electricity supply.

2. LITERATURE REVIEW

2.1 Fundamental Concept.

The Institute of Electrical and Electronics Engineering (IEEE) defines reliability as an item's ability to perform a required function under specific conditions and time frame (ISO8402) (Elerath, 2010). Reliability was described as a strategy or approach and resolution for power management by operators and managers of the system, respectively, by Borges and Cantarino, (2011). The term "continuity of service" is frequently used, but reliability is not universally defined. It refers to the likelihood that a system or equipment will maintain service continuity for extended periods.

Three key indices are used to assess power system reliability for expansion planning and energy output: loss of load expectation (LOLE), expected demand not supplied (εDNS), and expected energy not supplied (ENS). LOLE indicates the average number of days a system experiences outages, εDNS measures load loss due to frequent outages (Alshalan, 2018). In various fields of engineering, such as the determination of material strength and the subsea compression system Okaro, (2019) reliability analysis has attracted attention.

Switchgear protection, and control are crucial for reliability. Affluent nations often achieve high reliability levels, which are achievable when systems are available, have sufficient reserve capacity, are properly designed, and have a successful operation and maintenance plan.

Al-Shalan, (2019), dependability assessment is crucial for the development, planning, and management of electric power systems. It aims to generate metrics and indices of reliable performance based on component outage data and configuration, focusing on generating units and system configuration.

A power system for electric energy comprises three subsystems: generation, transmission, and distribution. Electricity is produced, sent to distribution substations via high voltage transmission lines, and includes the 11kV to 0.415kV transformation (Theraja and Theraja, 2005).

Generating stations are highly regarded for their dependability evaluation due to their high capital requirements. Generational inadequacy can have devastating impacts on society and the environment, affecting the entire system.

Generation reliability evaluations are primarily deterministic, but are being developed using probabilistic models. Loss of load expectancy (LOLE) is a useful tool for predicting generation reliability using probabilistic methodology. LOLE represents the likelihood of a generation system not meeting predicted load demand, typically in terms of days per year.

Load shedding events occur when a generation system fails to meet demand, resulting in "demand not served" and "expected un-served energy." Two main reasons for load shedding events are a small capacity margin and transmission inadequacy. LOLE assessments assume the system's ability to balance generation and load is not constrained by transmission capacity. Understanding component reliability indices helps determine expected failure rate, typical outage length, and unavailability. Increased power supply is essential for meeting electricity demand and providing a competitive advantage (Airoboman et. al., 2022).

In the 1980s, Nigeria's Nigerian Power Sector (NPS) was robust and effective, providing electrical power to meet population expectations. However, rapid technological advancements, small population growth, and public perception of power led to its unreliability due to changes in population and technology.

Around 1.6 billion people worldwide lack access to electricity, according to Airoboman *et al.* (2020) and the sector's unreliability is evident as customers and consumers have recently rioted due to dissatisfaction, posing a threat to system operators and potentially leading to power equipment vandalism.

2.2 Review of Relevant Literatures

2.2.1 Analytical Method

Analytical procedures use a mathematical model to represent the system and use mathematical solutions to assess reliability indices. Analytical technique research includes the following studies. Work by Nillai, (2011) on the likelihood of a power system load loss. He attempted to assess the Kerela power system's dependability by applying the loss of load LOLP approach in his work.

According to Adamu, (2012), multiple methods have been used for reliability assessment of power system generation, including frequency and duration techniques, considering various plant methodologies and models.

According to Omar *et al*. (2016), the Saudi Electricity Company (SEC) assessed generating adequacy in 2013 using experience and worldwide utility practices. To maintain environmental standards and lower fuel costs, SEC plans to integrate renewable energy sources like solar and wind. The capacity value of these sources was calculated using ELCC and VER techniques.

Alshammari, (2019) the methodology, combining contingency analysis and dependability index evaluation, was successfully used to evaluate composite system performance reliability indices on a real-world power system representing the Saudi electrical grid, involving hundreds of buses and complex stations.

According to ALshammari, (2020), the (N-2) outage contingency scenario was used to evaluate power system reliability and quality levels. The methodology combines quality indices, dependability measurements, and contingency analysis. Large-scale reliability and quality assessment require highly developed algorithms for systems with hundreds of buses and intricate stations. System adequacy analysis focuses on providing loads within performance criteria.

According to Mahdieh *et al*. (2020), a new method for evaluating the reliability of complex power networks, which integrate power generating units and transmission lines, is being developed. This method decomposes the entire network into smaller islands, allowing for a more precise calculation of network reliability, using the network reliability theory..

Fault Tree Analysis (FTA) was used by Idoniboyeobu *et al*. (2020) aims to assess the reliability of a power distribution system using the 33/11kv injection substation at Rivers State University. A reliability analysis was conducted using a fault tree diagram and qualitative analysis using logic symbols AND-GATE and OR-GATE. Reliability metrics like Mean Time Between Failures, Mean Time to Repair, and Unavailability were quantified. The study identified substation feeders, such as the 11kv UST Feeder, 11kv Federal Feeder, and 11kv Wokoma Feeder, as significant contributors.

According to Ravindra *et al*. (2021), customers expect constant electricity supply, and a reliable generation system analysis can be achieved using a neural network technique. Radial basis function neural network (RBFNN) is used to build a learning model for assessing reliability indices in generation planning. Validity of the proposed technique is tested using the Roy Billinton Test System and IEEE-Reliability Test System.

Adel, (2021), the modified grey wolf optimizer (M-GWO) is a novel metaheuristic method for optimizing a hybrid renewable energy system, reducing the total cost of supply (TCS) while considering component power balance. It compares findings with Grey Wolf Optimizer (GWO) and particle swarm optimization (PSO) methods to find the global optimum and robustness.

In order to increase accuracy and speed up analysis, Kai *et al*. (2021) proposes a more accurate reliability evaluation approach using the impact increment method and the shadow price method. This method reduces higher-order contingency states and simplifies the optimal power flow problem. Case studies on IEEE 118-bus and RTS-79 systems show this method outperforms conventional techniques in terms of calculation time and accuracy.

Fabio, (2021), the framework focuses on power distribution systems and introduces interruption flows (iflows) to convert analytical reliability evaluation into linear equations. It provides data for linear reliability optimization issues and illustrates the evaluation procedure in distributed generation networks. A case study and computational studies show the approach's effectiveness in providing high-quality data and optimal trade-offs for energy network reliability decisions.

Getaye *et al*. (2021) reported tha the Bahir Dar power distribution system's reliability is improved using smart grid technology applications. Genetic Algorithm and Prims Algorithm optimize device locations and network reconfiguration. The study tests Bata's 34 bus feeder, assessing dependability indices using ETAP 12.6.0 software.

In order to assess the current status of the network and how it has performed over time, Airoboman, (2022) reviewed the state of the reliability of the Nigerian power system network and contrasted it with what is feasible elsewhere.

2.2.2 Deterministic Method (Simulation)

Simulation on the other hand, like Monte Carlo simulation methods, estimates the reliability indices by simulating the actual process and random behavior of the system.

A reliability assessment of the electricity system, including failures of the protective systems, was reported by Ronita, in 2020. A modified protection reliability model system identifies two main types of protection failures: breakdown of protective mechanisms and design. The model assesses component and protection system failures, using non-sequential simulation and the IEEE-9 bus system to determine system susceptibility to cascading outages.

According to Ashoke, (2021), uses fault tree analysis (FTA) to analyze the reliability of three gearbox systems. It compares performance features like minimal cut sets, important measures, and time-based metrics. The study identifies the large switch as the most important piece of equipment in HVAC systems, AC/DC converters in HVDC systems, and DC/AC converters and Cycloconverters in LFAC gearbox systems. The research also presents essential offshore wind power forecasting methods.

The largest project of its sort in Australia, the projected Kalbarri micro grid project, was reported by Shaksi, (2021) to optimize sizing and conduct a feasibility study. The development of algorithms, modeling, and simulation of the micro grid model in MATLAB will be the main topics.

The model focuses on a resilient rural micro grid system, analyzing economic and reliability metrics. It challenges obtaining information from renewable energy resources due to intermittent nature. Historical hourly data from a network service provider is consolidated for future network restrictions.

For both existing and potential medium voltage (MV) electric distribution system topologies, Mirolaw*et al*. (2022) published a reliability analysis. The study examines the impact of location and distributed generation (DG) technology on power supply reliability. It proposes dependability models for various energy sources and ICT components. The study calculates system structures using data on DG types, locations, power capacities, and automation. Reliability tests are conducted on the distribution network and associated communications network.

2.3 Method of Analysis

To model a hydro unit, the states can be classified into up-state and down-state as shown in figure 2.

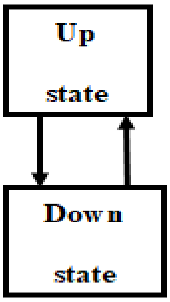

Figure 2: *Two-state model (Majeed & Sadiq, 2006)*

A unit is in up-state when in use, but moves between upstate and downstate due to interruptions. Forced outages occur when generators shut down urgently or due to breakdowns. Scheduled outages involve unit closures for inspection or repair (Sahu & Barve, 2013). Forced outages do not affect scheduled downtime, and the device will return to up-state after repair. A three-state Markov model was created to analyze this situation (Majeed & Sadiq, 2006), as depicted in figure 3.

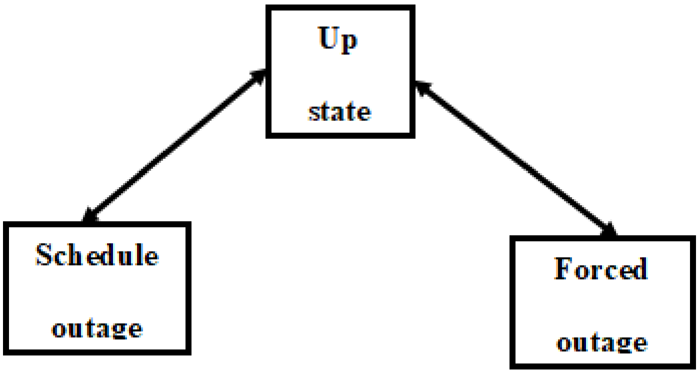

Figure 3: *Two state* Markov *model (Majeed & Sadiq, 2006)*

For the ease of study, events of hydro-unit and its down states are classified into:

1. **Schedule outage:** Preventive maintenance involves overhauling, cleaning, and inspecting spiral casings, penstocks, and other equipment to prevent system failure, T/L upkeep, and water shortages.
2. **Turbine:** The process involves replacing the guiding vane link rod, shear pin, head cover repair, changing turbine oil, and maintaining the intake gate.

3. **Generator:** This pertains to the generator's current transformer (CT), potential transformer (PT), energy meter change, etc
4. **Power transformer:** This includes power transformer maintenance, gas relay maintenance, Clamp change etc.
5. **Excitation:** This involves changing the carbon brush on the generator, the card, the relay, etc.

More developed hydro unit model is shown in Figure 4.

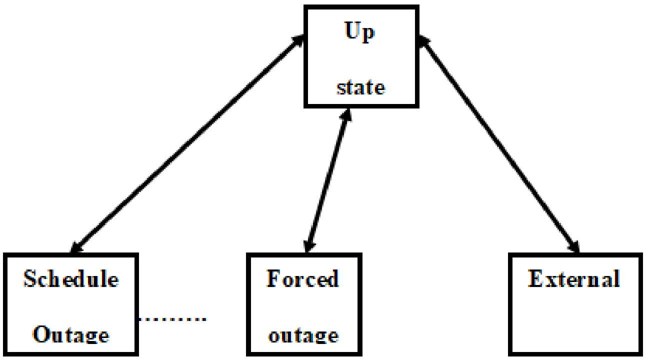

Figure 4: *Three State Markov Model (Majeed & Sadiq, 2006)*

State probability of each state is calculated with the repair rate (μ) and failure rate (λ) method as shown in Table 1.

Table 1*: State Probability Value*

State Number	State Probability	
0	μ1μ2μ3μ4μ5μ6μ7μ8/D	d0/D
1	λ1μ2μ3μ4μ5μ6μ7μ8/D	d1/D
2	μ1λ2μ3μ4μ5μ6μ7μ8/D	d2/D
3	μ1μ2λ3μ4μ5μ6μ7μ8/D	d3/D
4	μ1μ2μ3λ4μ5μ6μ7μ8/D	d4/D
5	μ1μ2μ3μ4λ5μ6μ7μ8/D	d5/D
6	μ1μ2μ3μ4μ5λ6μ7μ8/D	d6/D
7	μ1μ2μ3μ4μ5μ6λ7μ8/D	d7/D
8	μ1μ2μ3μ4μ5μ6μ7λ8/D	D8/D
Where D= d0+d1+d2+d3+d4+d5+d6+d7+d8		

Source: (Dinesh *et al*.2021).

2.4 Energy Index of Reliability and Indices of Reliability

The following are adopted for Energy index of reliability method and are briefly detailed as follows (Zungeru and Araoye, 2012; Abdullah, 2019).

(i) Availability Factor

$$AF=\frac{PH-SOH-FOH}{PH} \qquad \ldots(1)$$

Where PH = period hours, SOH = schedule outage hour and FOH = force outage hour.

(ii) Mean Time To Repair (Mean Down Time MTTR)

$$MTTR=\frac{FOH}{NO} \qquad \ldots(2)$$

where NO = number of failure occurrence.

(iii) Mean Time To Failure (Mean Up Time MTTF)

$$MTTF=MTBF-MTTR \qquad \ldots(3)$$

(iv) Mean Time Between Failures (MTBF)

$$MTBF = \frac{Total\ observed\ time}{N} \qquad \dots (4)$$

(v) Frequency

$$F = \frac{1}{MTBF} \qquad \dots (5)$$

(vi) Repair Rate (Μ)

$$\mu = \frac{1}{MTTR} \qquad \dots (6)$$

(vii) Failure Rate (Λ)

$$\lambda = \frac{1}{MTTF} \qquad \dots (7)$$

Where, N (Number of failures) = number of times a unit experiences outage. FOH (forced outage hours) – time in hours during which a unit or major equipment is unavailable due to outage.

(viii) Binomial Distribution Models: Being a discrete distribution, the binomial distribution is independent of time and may be applied to units for which time is not a determining factor. The model is represented as

$$\mathrm{p(g, n, FORn} = \{\binom{n}{g}(FORav)^{\wedge}g(1 - FORg)^{\wedge(n-g)}\} \qquad \dots (8)$$

(ix) Capacity Model: The "Capacity Outage Probability Table (COPT)" is a capacity model that ranks available and unavoidable capacity states descending in severity, with a binomial distribution used for identical units.

(xi) Load Model

The most advantageous load model to utilize instead of the typical load fluctuation curve is called the "load duration curve (LDC)". There are some LDC facts that should be understood that are best summed up as follows:

a. All load levels are arranged in the LDC in descending order of magnitude.

b. The system's (consumed) energy demand is represented by the area beneath the LDC.

c. Planning and running of power systems, reliability assessment, and economic dispatching are all applications of LDC.

d. LDC is easier to manage than the typical timely load fluctuation curve. Figure 5 illustrates the load duration curve discussed previously and includes all relevant details.

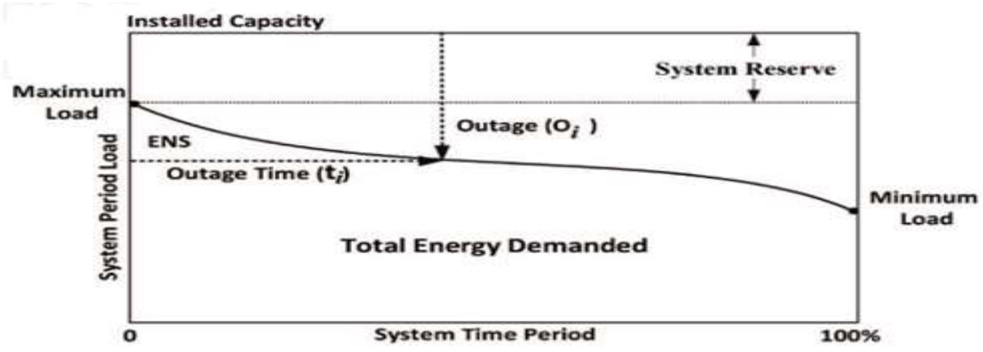

Figure 5*: Load duration curve,*

where Oi = ith outage(s) in the COPT, $t_{i=}$ *number of times unit(s) is unavailable, P= probability of the ith unavailable, and ENS = energy not supplied due to severe outage(s) occurrence. (Abdullah, 2019)*

(x) Loss of Load Expectation (LOLE): The LOLE risk index is a widely used probabilistic measure for assessing power generation dependability for system expansion and interconnection, measuring in days per year or hours per day. The following mathematical formula represents the LOLE evaluation method:

$$\mathrm{LOLE} = \sum_{i=1}^{n} \mathrm{TiPiOi}\frac{\mathrm{days}}{\mathrm{year}}\ [\mathrm{Lmax} > Reserve] \qquad \dots.(9)$$

Using the aforementioned equation as a guide, the LOLE would only be effective if the maximum load (Lmax) exceeded the system reserve.

(x) Expected Demand not Supplied (εDNS): To calculate the load loss due to severe outages, a dependability index, εDNS, may be added to the LOLE in power system planning.

$$\text{EDNS} = \sum_{i=1}^{n} (\text{DNS})\text{Pi}\ (\text{MW/year})\ [\text{Lmax} > Reserve] \qquad \text{...(10)}$$

(xi) Expected Energy Not Supplied (εENS)

Power systems are actually energy systems, hence it is possible to determine the expected energy not supplied index as shown in Figure 5. The energy sale calculation, which represents the actual revenue for each electric firm, is done using the εENS index.

$$\text{ƐENS} = \sum_{i=i}^{n} \text{Pi}\frac{\text{MWh}}{\text{year}}[\text{Lmax} > Resrve] \qquad \text{....(11)}$$

(xii) Energy Index of Reliability (EIR)

The ratio of expected energy not supplied (εENS) to the system's total energy demanded (TED) can be found as

$$\text{ƐENS}= \frac{\text{ƐENS}}{\text{TED}} \qquad \text{... (12)}$$

The small size of εENS and TED has resulted in a low ratio, allowing for the inference of the EIR, a significant reliability index.

$$\boldsymbol{EIR = 1 - \text{Ɛ}ENSpu} \qquad \text{... (13)}$$

(xiii) Unit Derated Factor

The unit derated factor measures the ratio of reaction equipment to reduction force operating level, indicating abnormal unit running time and potential deterioration in reliability.

$$\text{Unit derated factor} = \frac{\text{unit derated hour}}{\text{planned hour}} \qquad \text{... (14)}$$

2.5 Reliability Evaluation Processes

The six-step procedure for a power system dependability study involves identifying component capabilities, outages, and potential failure modes. The system performance is assessed through actual or simulated performance, and the system model is determined using power Sow analysis. The results are then analyzed to determine system reliability.

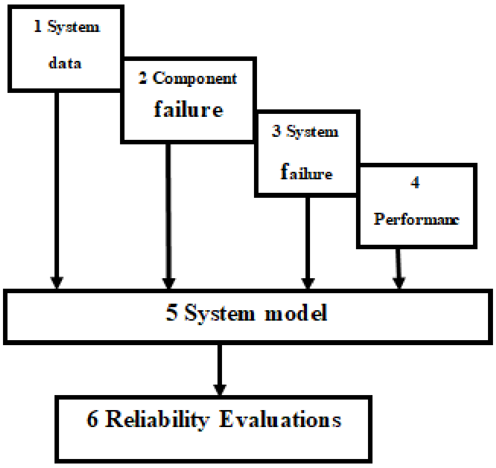

Figure 6: *Reliability evaluation processes (Vancasteren et al, 2000)*

The Dadin Kowa hydro power station, with a 40 MW capacity, is located on the Gongola River in Nigeria. It has been considered a viable location for hydropower generation since 1957, with two identical units with 20 MW capacities.

The reservoir has a 300 km2 surface area, a total storage capacity of 2.88 X 109 m3, live storage of 1.77 X 109 m3, and a maximum flood elevation of 249m3. It features a gate dog crest overflow spillway.

The power house intake structure is located on the right side of the spillway, with two sluice gates set below the minimum supply level. The invert level discharges into steel pen stocks. The power plant consists of two 20 MW Francis turbines connected by vertical shaft umbrellas and generators.

The draught tubes' invert level at exit is 204.1 m, rising to 212 m and entering the river channel 160 m downstream. Tailrace water level downstream is 213.9 m.

Two transformers and a 13.8KVA distribution system transport generator output, enabling access to local resources for irrigation, domestic water, and residential buildings after connecting to the national grid.

The study focuses on the failure of various components in the Dadin Kowa hydroelectric power plant, highlighting the impact on the plant's availability and dependability.

Assessing availability and dependability is crucial for understanding unit performance, capabilities, and weaknesses, and planning periodic maintenance, replacement, or repair programs is beneficial in case of breakdowns.

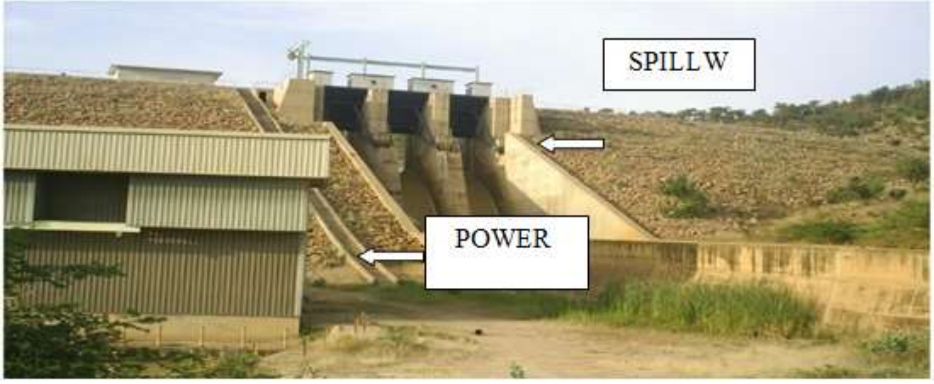

Plate I: *Dadin kowa hydro power plant dam yemelto deba gombe(Abubakar, 2014)*

Plate II displays a single-line diagram of the plant's SCADA, showing a 20MW generator fed by a 132kVA transformer, connected to the national grid and neighboring community.

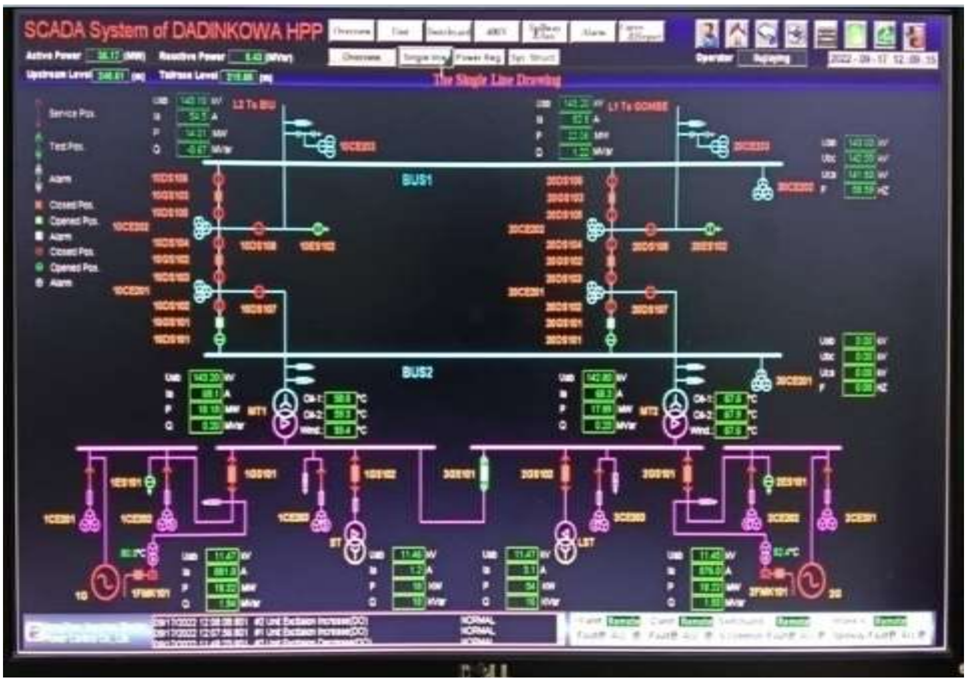

Plate 2: *Single line diagram of Dadin kowa hydro power plant (* SCADA system of DKHPP)

3. MATERIALS AND METHOD

3.1 Materials

This study utilized personal computers, MATLAB R2018a software, internet resources, and data from Dadin Kowa hydro power plant.

3.2 Methodology

The following was adopted to achieve the aim and objective this research:

Step 1: Collection of data on outages in various subsystems of the DKHPP power plant, including scheduled, scheduled, and external effects.

Step 2: Development of Markov model with the state probability table and reliability indices like force outage rate, availability, failure rate, repair rate ,MTBF, MTTF, MTTR and the reliability (p0+p1) were determined.

Step 3: Determination of Probabilistic energy index of reliability using reliability indices such as LOLP, LOLE, eENS and eDNS,

Step 4: The reliability indices of various generating units were evaluated using Markov models and Probabilistic energy index methods in MATLAB software environment.

Step 5: Comparison of the result with available standard values.

Step 6: Conclusion and recommendations were made.

Beow is the flow chart of the reliability evaluation of DKHPP.

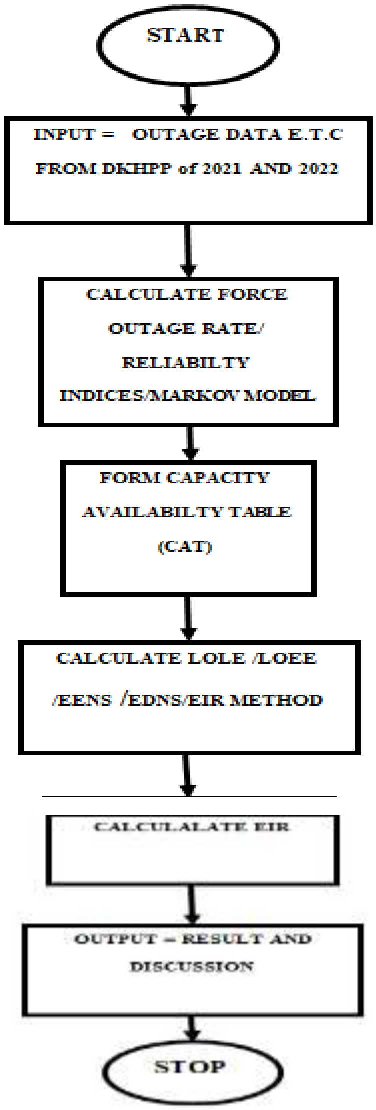

Figure 7: *Dadin kowa Hydro Power Plant Algorithm*

4. RESULTS AND DISCUSSION

4.1 Availability Factor

Table 2 shows the computation of availability factor (AF) for the plant. The AF expression used to obtain the results is given in Eqn. (1). Turbine Gen 1 has higher availability.

Table 2: *Dadin Kowa Hydro Power Plant Summary of Generation Capabilities (2021 &2022)*

Unit	Installed Capacity (MW)	Average Generation Capacity (MW)	Availability Factor (%)
GEN 1	20	18	98.1
GEN 2	20	18	97.9

4.2 Markov Model

Table 3 through 9 shows the computation of reliability parameters using Markov method. The expression used to obtain the results using the Markov method is in Table 1. In table 3 state probability for up (Available, service operation) state is 0.9815 and for down (Unavailable, Planned, External) state is 0.0103 and 0.0082.

Table 3: *Reliability Parameters of Unit 1 And 2 Using Markov Model for Year (2021)*

State No	Basic event	No of Occurrence	Repair Rate(H)	Failure Rate(H)	MTTR(H)	MTTF(H)	MTBF(H)	State Probability
0	Up State	Nil	Nil	Nil	Nil	Nil	Nil	0.9815
1	Planed Outage	1	0.0114	0.0012	88	8584	8672	0.0103
8	External Effect	26	0.3611	0.0032	2.77	331.88	334.15	0.0082

Table 4 shows the computation of reliability and availability for the plant for the period 2021 both units have similar value because they have identical force outage rate. The result obtained mean that both unit one and two are 99.18% reliable with availability of 98.0%.

Table 4*: Yearly Unit Reliability and Availability Using Markov Model for Year (2021)*

No of unit	Reliability	Availability
1	0.9918	0.98
2	0.9918	0.98

Table 5 also shows the reliability performance of DKHPP unit one for the period 2022 using Markov model with an upstate of 0.9815 and down state of 0.00867 and 0.00258.

Table 5*: Reliability Parameters of Unit 1 Using Markov Model for Year (2022)*

State No	Basic Event	No of Occurrence	Repair Rate (H)	Failure Rate (H)	MTTR (H)	MTTF (H)	MTBF (H)	State Probability
0	Up State	Nil	Nil	Nil	Nil	Nil	Nil	0.9815
1	Planed Outage	1	0.0114	0.0012	88	8584	8672	0.00867
8	External Effect	29	0.333	0.0034	3	296.07	299.07	0.00258

Table 6 shows the reliability performance of DKHPP of unit two with an upstate of 0.97841 and downstate of 0.058 and 0.013.

Table 6*: Reliability Parameters of Unit 2 Using Markov Model for Year (2022)*

State No	**Basic Event**	**No Of Occurrence**	**Repair Rate(H)**	**Failure Rate(H)**	**MTTR(H)**	**MTTF(H)**	**MTBF(H)**	**State Probability**
0	Up State	Nil	Nil	Nil	Nil	Nil	Nil	0.97841
1	Planed Outage	1	0.0114	0.0012	88	8584	8672	0.00858
8	External Effect	35	0.307	0.0040	3.257	243.772	247.024	0.013

Table 7 shows the reliability and availability of DKHPP for the period 2022 with unit one having highest reliability of 99.74% than 98.87% of unit two and availability of 98.88% of unit one than 98.78% of unit two.

Table 7*: Yearly Unit Reliability and Availability Markov Model for Year (2022)*

No of unit	Reliability	Availability
1	0.9974	0.9888
2	0.987	0.9878

Table 8 shows the reliability performance for unit one for the period 2021 and 2022 using Markov model. The expression which shows the result is in table 1. Upstate is 0.9816 and down state is 0.0103 and 0.0091.

Table 8*: Reliability Parameters of Unit 1 Using Markov Model for Year (2021&2022)*

State No	**Basic Event**	**No Of Occurrence**	**Repair Rate(H)**	**Failure Rate(H)**	**MTTR (H)**	**MTTF (H)**	**MTBF (H)**	**State Probability**
0	Up State	NIL	NIL	NIL	NIL	NIL	NIL	0.9816
1	Planed Outage	2	0.0114	0.0012	88	8584	8672	0.0103
8	External Effect	55	0.346	0.0032	2.891	312.76	315.65	0.0091

Table 9 gives the reliability performance of DKHHP unit two for the period 2021 and 2022 using Markov model. The result obtained which was shown in the expression in table 1. gives 0.9791 in upstate and 0.01031, 0.016 in the down state

Table 9*: Reliability Parameters of Unit 2 Using Markov Model for Year (2021&2022)*

State No	**Basic Event**	**No Of Occurrence**	**Repair Rate(H)**	**Failure Rate(H)**	**MTTR (H)**	**MTTF (H)**	**MTBF (H)**	**State Probability**
0	Up State	NIL	NIL	NIL	NIL	NIL	NIL	0.9791
1	Planed Outage	2	0.0114	0.0012	88	8584	8672	0.01031
8	External Effect	61	0.333	0.0034	3	296.07	299.07	0.0106

Table 10 shows the reliability and availability for unit one and two for the period 2021 and 2022 using Markov model with unit one having highest reliability 99.19%than unit two with reliability of 98.94%.So also the availability of unit one within the period is 99.09% higher than 98.93% of unit two.

Table10*: Yearly Unit Reliability and Availability Markov Model for Year (2021 And 2022)*

No Of Unit	**Reliability**	**Availability**
1	0.9919	0.9909
2	0.9894	0.9893

4.3 Energy Index of Reliability Method

Table 11 shows the reliability performance of DKHPP for the period 2021using EIR method. The result obtained was expressed in Eqn. (8) to (13). The reliability of the units is 92.7% and LOLE of 0.5369h/y.

***Table 11**: Reliability Indices Using Energy Index of Reliability For 2021*

Reliability indices for year 2021	
LOLP	0.00134
LOLE hours/year	0.5369
eDNS (MW)	39.68
eENS (MWH)	33000.234
EIR	0.9275

Table 12 shows reliability performance of DKHPP of unit one for the period of 2022 using EIR method with reliability index of 93.62% and LOLE of 1.127912h/y.

***Table 12**: Reliability Indices Using Energy Index of Reliability for 2022 Unit One*

Reliability indices for the year 2022	
LOLP	0.002874
LOLE hours/year	1.127912
eDNS(MW)	39.54
eENS(MWH)	67945.6748
EIR	0.9362

Table 13 shows the reliability performance of Dadin Kowa hydro power plant for the period of 2021 and 2022 using EIR method with the result expressed from Eqn. (8) to (13). The result obtained indicated that DKHPP is93.93% reliable with LOLE of 16.899h/y.

***Table 13**: Reliability Indices Using Energy Index of Reliability for 2021 And 2022*

Reliability Indices for the year 2021 and 2022	
LOLP	0.019292
LOLE hours/year	16.899
eDNS(MW)	39.44
eENS(MWH)	127482.8504
EIR	0.9393

Table 14 shows the unit derated factor where the units are operated under abnormal condition for the period 2022.The result obtained is expressed in Eqn. (14) and indicated that the unit derated factor is 1.1164%.

***Table 14**: Unit derated factor for unit one and two for the year 2022*

No of unit	Unit derated factor in %
1	1.164
2	1.164

4.4 Validation of results

***Table 16**: Validation of results*

Units	Markov Method Reliability (%)	EIR (%)	Availability (%)	Validated result (%)
1	99.19	93.93	99.09	98.08
2	98.94	93.93	98.93	97.93

Table 15 validates results from DKHPP, showing a 98.08% operation state for unit one and 97.93% operation state for unit two. The data shows total outage hours for unit one and unit two, with total installed capacity of 40MW and average delivered capacity of 36MW.

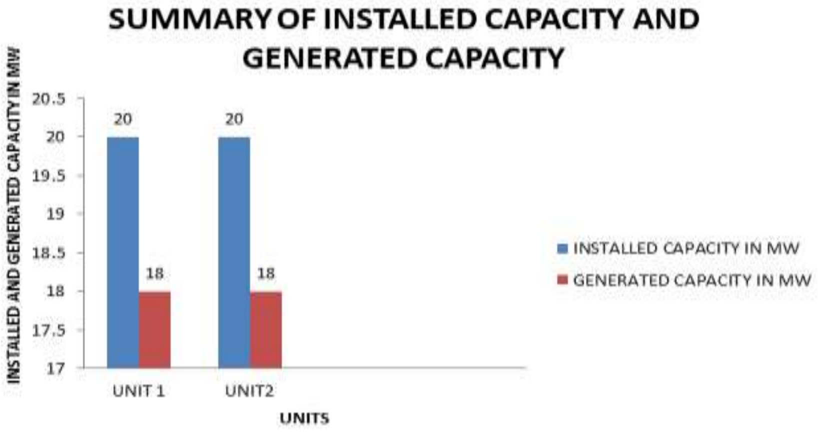

***Figure7**: Summary of Generation Capability of DKHPP*

Figure 8 displays the reliability of unit one at 0.9918 and unit two at 0.9918, with availability at 0.98 due to identical operation in the first year, resulting in the same force outage rate.

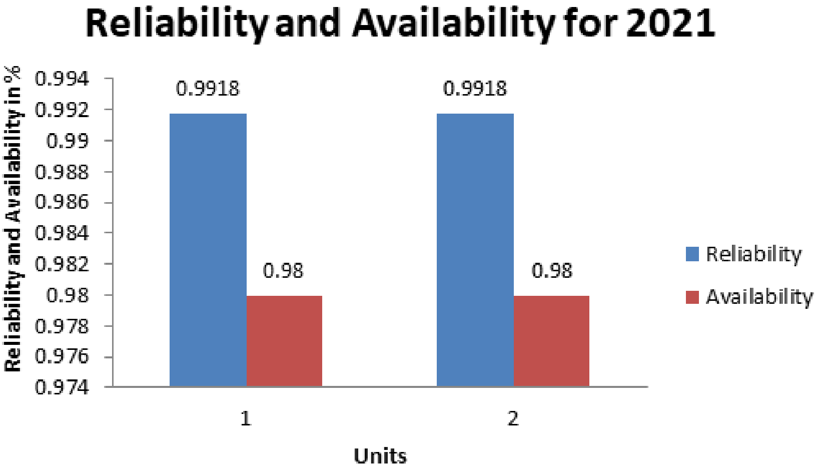

***Figure 8**: Reliability and Availability of DKHPP using Markov Model for the year2021*

Figure 9 shows the reliability of unit one to be 0.9974 and that of unit two is, 0.9888. The availability of DKHPP using Markov model for unit one is 0.987 and that of two is 0.9878.

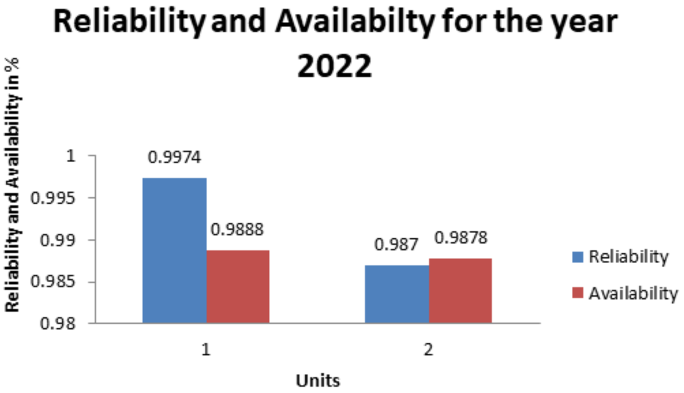

Figure 9*: Reliability and Availability of DKHPP using Markov Model for the year2022*

Figure 10 shows the reliability of DKHPP using Markov for the period 2021 and 2022 for unit one as 0.9919 and unit two as 0.9909.The availability for unit one is 0.9814 and for unit two is 0.9893.

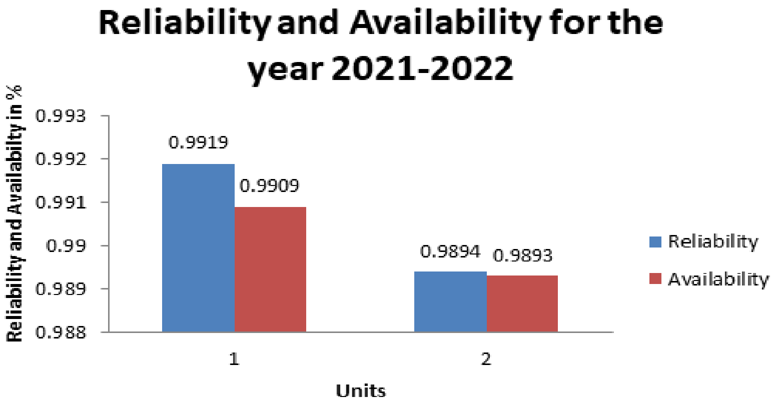

Figure 10*: Reliability and Availability of DKHPP using Markov Model for 2021 and 2022*

Figure 11 shows unit derated factor of DKHPP for the period 2022 where the plant is operated at derated or partial output.

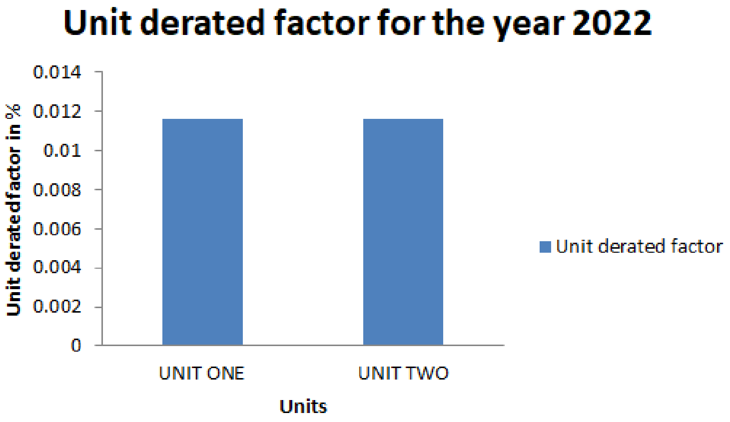

Figure 11*: Unit Derated Factor DKHPP for Unit 1 and 2 for Year 2022.*

Figure 12 also shows unit derated factor of DKHPP for the period 2022 where the plant is operated at derated or partial output. It's shown from the pie chart that from the UDF obtained as a whole unit one operated partially at a 50% of the value so also unit 2.

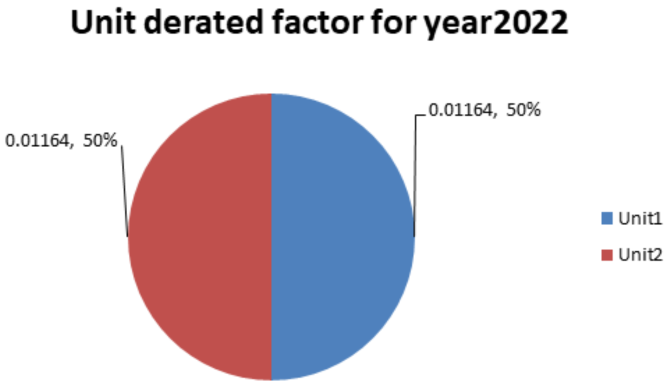

Figure 12*: The unit derated factor of DKHPP for unit 1 and 2 for the year2022*

Figure 13 shows that the validted result and the results obtained from the two methods.

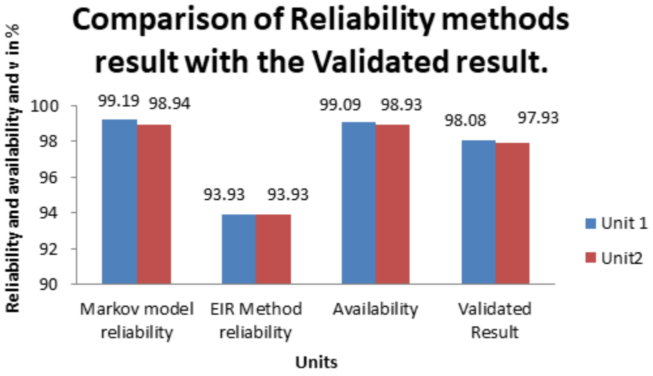

***Figure 13**: Validation of result*

5. DISCUSSIONS

The availability factor AF for unit one and two is 98.1% and 97.9%, indicating good performance of the power plant. Tables 3, 5, 6, and 8 calculate reliability indices like MTTR, MTTF, MTBF, repair rate, and failure rate from operational data for 2021-2022. These indices help determine plant reliability and availability using Markov models. Tables 8 and 9 show reliability and availability for 2021 and 2022, respectively, with 99.18% and 98.0% respectively.

The probabilistic energy index of reliability method is used to calculate reliability indices for 2021-2022. Results show a good performance with an index of 92.75% and LOLE of 0.5369h/y, which is less than the international utility practice of 4.8h/y. Tables 13 and 14 show good performance with reliability indexes of 93.62% and 1.122h/y, respectively, and 93.3% and LOLE of 16.899h/y, respectively.

Understanding the unit derated factor (UDF) in Table 15 shows a 1.164% UDF for unit one and two in 2022, which could lead to plant degradation if maintenance is not carried out.

6. CONCLUSION

This research evaluates the reliability of DKHPP using a Markov model and Energy index of reliability. The Markov model yielded reliability indexes of 99.19% and 98.94% for unit one and two for 2021-2022. The Energy index of reliability method showed a reliable index of 0.9393% and a LOLE of 16.895 Hours/year for 2021-2022. However, the plant's LOLE of 16.895 does not meet the international utility practice of 4.8 hours/year. The study also found that unit one had higher availability than unit two, and the reliability of unit one was higher than unit two. Further studies will focus on cost and reliability analysis, as well as introducing daily, seasonal, and annual energy management systems for DKHPP to enhance availability.

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