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Reliability Assessment of Electric Distribution System Based on Weibull Markov Stochastic Model. (A case Study of JEDC Dorowa 33kV Feeder)

Ogaji A. A, Professor U.O. Aliyu, Dr. Sadiq A. A.
Department of Electrical Electronics Engineering, Electrical Power and Machine Engineering,
Abubakar Tafawa Balewa University, Bauchi

Abstract- The research explores the assessment of reliability, encompassing the monitoring of system performance, evaluating reliability deterministically through outages or active failures, and assessing reliability stochastically by employing stochastic failure models. Each of these classifications plays a role in achieving a thorough comprehension of power system reliability, spanning from tracking historical performance to anticipating the system's reactions to different disruptions. The objective is to guarantee the consistent, uninterrupted, and dependable supply of electricity despite various challenges and uncertainties. This was done using the Weibull Markov model to analyse. Dorowa 33kV distribution feeder network. The result showed the feeder network was not reliable and thus required upgrade.

Keywords- failure rate, Mean Time to Failure (MTTF), Mean Time To Repair (MTTR), Mean Time Between Failure (MTBF), Reliability and unreliable

I. INTRODUCTION

The establishment of power distribution network systems was driven by the primary objective of providing affordable and reliable electricity to customers. As these networks have exponentially grown in size and technology, utility companies face the challenge of meeting customer reliability requirements through strategic planning while minimizing costs. Reliability evaluation significantly impacts the design and asset management of power systems, with substations playing a crucial role in the transmission and distribution of electricity.

Automatic systems protect most equipment, triggering switches to isolate equipment if specific limits are breached. System incidents causing an opening with breached limits can lead to cascading failures and, in extreme cases, a complete system collapse known as a "system blackout." Modern society's practices are heavily reliant on a constant electricity supply, and unpredictable power system Break downs hinder the achievement of uninterrupted power.

Investments during the planning, design, and operating phases of power systems can mitigate the impact of failures. The reliability of a power system design is a key consideration, and achieving a perfect power system with constant supply and ideal voltage requires substantial investments. Deviations from ideal power quality, known as power quality disturbances, result in various expenses due to inadequate performance, including customer loss, tariff reductions, and regulatory penalties.

Liberalization of electrical markets has compelled electrical firms to reassess their infrastructure, emphasizing cost reduction and maximizing returns on investments. Reliability engineers play a crucial role in providing performance indicators for decision-making during planning, and reliability worth evaluation creates financial indices based on the definition of harm caused by customer interruptions.

Power quality, which influences the capacity to use electrical equipment, is affected by voltage and current variations. Power quality disturbances include events like voltage fluctuations, unbalance, and harmonic distortion. Reliability analysis classifies disruptions into security analysis and adequacy analysis, examining the frequency and severity of power outages.

The study discusses reliability evaluation, covering system performance monitoring, deterministic reliability assessment based on outages or active failures, and stochastic reliability assessment using stochastic failure models. Each category contributes to a comprehensive understanding of power system reliability, from monitoring historical performance to predicting system responses to various disruptions. The aim is to ensure the continuous, uninterrupted, and reliable delivery of electricity in the face of diverse challenges and uncertainties.

II. LITERATURE REVIEW

This review delves into the critical area of reliability assessment and optimization within power distribution networks, underscoring the pivotal role of a dependable electrical infrastructure in smart grids. It encompasses a breadth of contributions from different studies, each focusing on distinct facets of power system reliability. It also covers failure effect analysis using the Weibull

Yuan et al. (2019) proposed methodologies for reliability assessment and optimization, integrating deterministic and probabilistic techniques to accommodate the stochastic nature of power generation sources. Tabares et al. (2019) centered their research on risk assessment, highlighting weather as a significant factor impacting power distribution system reliability, particularly emphasizing the modelling of weather-related failure events.

Karngala et al. (2021) made significant contributions to power system reliability analysis, emphasizing protective relaying in the context of integrating renewable energy. Khan et al. (2019) shed light on the relevance of Flexible AC Transmission System (FACTS) devices in enhancing distribution system reliability through quick and accurate fault detection. Oti (2018) employed SWOT analysis to strengthen reliability-centered maintenance in power distribution networks, providing a strategic framework for implementation. Razavi et al. (2019) contributed to reliability analysis and optimization, exploring advanced numerical methods and their application with FACTS devices.

Jaleel (2021) suggested a comprehensive study on power system dependability and asset management, utilizing analytical and simulation techniques to enhance computational capabilities for reliability evaluation. Jibril et al. (2018) addressed the challenges posed by aging infrastructure through the application of sequential Monte Carlo analysis in the assessment and optimization of distribution system reliability.

Briad et al. (2018) proposed strategies for controlling and optimizing distribution system dependability, emphasizing the role of marginal pricing in ensuring investment cost recovery. Zhang et al. (2020) added insights into power system reliability research, categorizing feeders' dependability and suggesting measures to reduce system failures.

The study by TCN (2022) introduced a dependability assessment technique, encompassing system state analysis, fault modeling, and the determination of reliability performance indicators. Additionally, the literature review provides an in-depth exploration of failure models, failure effect analysis (FEA), stochastic modeling, interruption analysis, and the Weibull-Markov system, offering a comprehensive foundation for understanding and evaluating power system reliability.

This not only consolidates diverse contributions to the field but also introduces key concepts such as FEA, failure models, and stochastic modeling, contributing to the broader understanding of power distribution network reliability assessment and optimization.

The Failure Effect Analysis (FEA) aims to assess whether a power system can sustain all loads with sufficient power after a failure without violating design restrictions. If some loads cannot receive power, the FEA identifies which loads experience interruptions and their duration. Umar (2019) emphasizes that FEA is a nearly steady-state analysis, focusing on the system's ability to handle faults and maintain power during and after disruptions.

FEA involves simulating the system's response to faults and emergencies, incorporating short-circuit investigations, load flow computations, topological analyses, and system simulations. These simulations actively modify the power system, including switching operations to clear faults, restore power, and implement load-shedding for overload relief. The complexity and calculation speed of FEA depend on the detail in these sub-analyses and simulations (Sultana, 2016).

Nordel (2018) states that FEA generates a list of interrupted busbars and terminals, detailing the duration of each interruption during the examined operating state. The assumption is made that switch placements do not affect the system topology, and the fundamental topology remains unchanged, regardless of switch positions (Jiang, 2014). The operational system state includes anticipated peak load profiles, forecasted transport flows, switch locations, generator information, planned outages, and ongoing repairs.

The effects of failures are categorized into Primary Failure Effect Analysis whose objective is to eliminate active failures by locating the fault in the smallest possible area, Secondary Failure Effect Analysis which accounts for the reaction of the power system and its operators to the state that is achieved after original reaction, and Tertiary Failure Effect Analysis whose goal is to maximize the operational state that has been reached.

To assess power system reliability, it is crucial to consider both electric system and component failures, generating contingencies for states with failures. A stochastic model, like the Weibull Markov model, is employed to account for fluctuating random quantities, allowing the evaluation of interruptions caused by severe harmonic distortion. The model calculates a ratio (α_i) based on a component's active failure frequency to its total failure frequency. The survival function, denoting the likelihood of a component operating without failure for a specific period (MTTF), is expressed as $1/\lambda$. Additionally, repair processes are vital, and the mean time to repair (MTTR) is represented as $1/\mu$, emphasizing the stochastic characteristics of the repair duration in power system reliability assessments (Fei et al., 2019; Montoya et al., 2019).
Before maintenance is carried out, repairable and non-repairable components are distinguished. Non-repairable parts are usually easily replaceable or of negligible consequence in electric power systems. A repair can be “as-bad-as old” leaving it in roughly the same state as it was just below failure or “as-good-as-new” returning it to its original state which is the best repair (Haghifam et al., 2017)

Similar to the homogeneous Markov system, the Weibull-Markov system is defined as a stochastic model of a power system for which all of the stochastic components are Weibull-Markov components. The state probability is equal to the predicted state duration for the stationary system, often known as the "state expectancy" in terms of time units. The system state expectancy is then divided by the system state frequency to determine the predicted system state duration (Willis, 2016).
A model for the synchronous generator serves as the foundation of other uses (Francesco et al., 2016) and provides a foundation for potential implementation of Weibull-Markov model for the for the representation of stochastic power system elements.

III. MATERIALS AND METHODS

1. Materials

The materials or tools used to realize the work are;

- Laptop Computer
- MATLAB/SIMULINK software environment
- Dorowa 33kV distribution feeder network.

(TCN, 2002).

Dorawa Feeder Line Diagram

The network of TCN for Jos metropolis and neighboring states

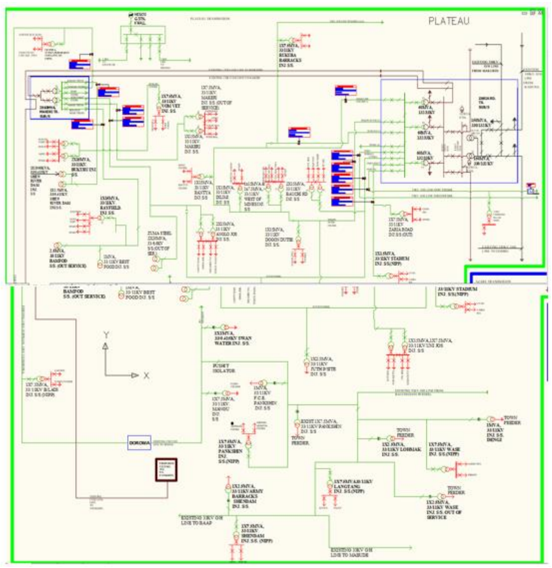

Figure 1: Single Line Diagram of the Case Study Network (TCN, 2022)

Dorawa Layout for the Grid Section

This are the equipment containing in the dorawa feeder, they are circuit breaker, power transformer, current transformer and earthing

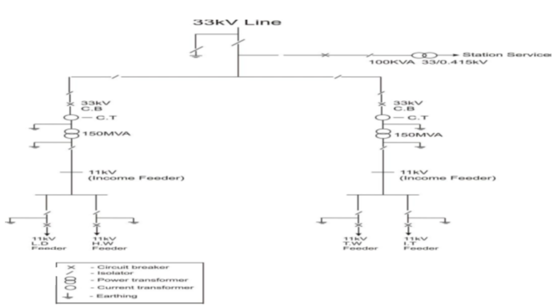

Figure 2: Dorowa layout of the grid section (TCN, 2022)

2. Problem Formulation

The mathematical model for the reliability is formulated as follows ( )

$$\text{Availability} = \frac{\text{Actual operation time}}{\text{Scheduled operation time}} \times 100$$

$$\text{MTBF} = \frac{\text{Actual operation time}}{\text{Number of failure}}$$

$$\text{Failure Rate} = \frac{\text{Number of failures}}{\text{Scheduled operation time}}$$

$$\text{MTTR} = \frac{\text{Down time}}{\text{Number of failure}}$$

3. Methodology

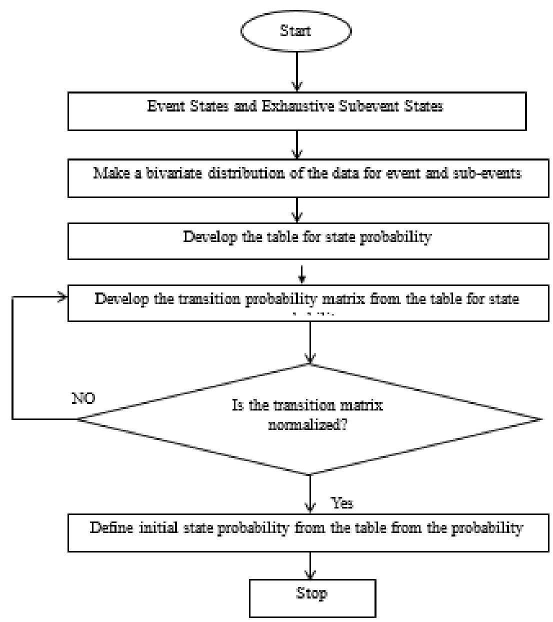

Figure 3. Flow chat for Weibull Markov Stochastic Model

Step 1. At the initial states, collection of data based from TCN Makeri Substation for Dorowa 33kV feeder for quantitative and qualitative analysis, and relevant data such as down time, up time and outage of the feeder.

Step 2. Carry out the Bivariate distribution which are statistical method to show the probability of two random variables such as down time, up time and outage of the feeder.

Step 3. The results are to provide the model distribution of monthly feeder availability, unavailability, failure rate, MTTR, MTBF and contribution of outage factors of the feeder.

Step 4. Represent the free response of the system if the state transition matrix completely defines the transition of the states from the initial time t = 0 to any time t when the inputs are zero.

Step 5. Yes, the transition matrix is said to be regular if some of the power T has all positive entries in the feeder. If is No, it will response to the system if the state transition matrix is complete.

Step 6. An initial state probability distribution is a mathematical function that describes the probability of different possible values of a variable. Initial probability is often depicted using graphs or probability tables.

IV. RESULTS AND DISCUSSION

1. Results

Based on the data collected from Jos Electricity Distribution Company (JEDC) for the Dorowa 33kV feeder network was model and applied to compute the reliability indices (Failure Rate, MTBF, MTTR, MTTF, Availability and Unavailability) and finally, the performance was compared with the standard benchmark

Table 1: Total Down Time

Year	Month	Total Down Time Hours/month	In Percentage/ Month
2022	September	151.51	1.61
2022	October	109.11	1.16
2022	November	123.06	1.31
2022	December	101.45	1.08
2023	January	330.28	3.51
2023	February	112.43	1.20

Table 2: Average Down Time

Year	Month	Average Down Time in Hours/month	In Percentage /Month
2022	September	5.05	0.054
2022	October	3.52	0.037
2022	November	4.10	0.044
2022	December	3.38	0.036
2023	January	10.65	0.113
2023	February	4.02	0.043

Table 3: Total Uptime

Year	Month	Total uptime in Hours/Month Percentage/Month	In
2022	September	576	6.122
2022	October	635	6.750
2022	November	597	6.346
2022	December	643	6.835
2023	January	414	4.401
2023	February	560	5.952

Table 4: Average Uptime

Year	Month	Average uptime in Hours/Month	In Percentage /Month
2022	September	19.2	0.204
2022	October	20.4	0.217
2022	November	19.9	0.212
2022	December	20.7	0.220
2023	January	13.4	0.142
2023	February	20.0	0.213

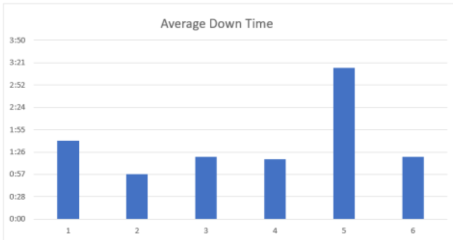

Figure 4: Average Down Time

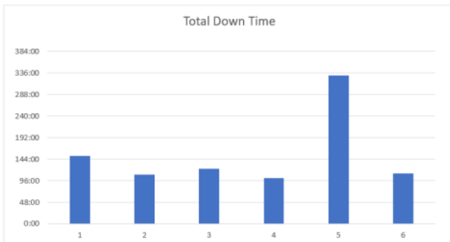

Figure 5: Total Down Time

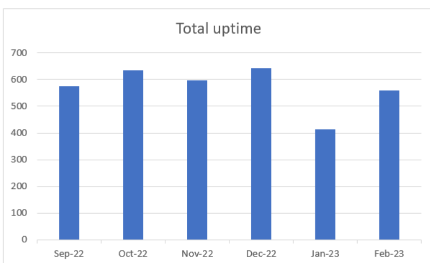

Figure 6: Total Uptime

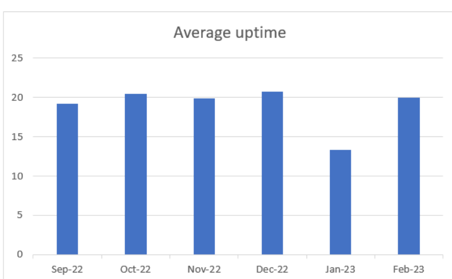

Figure 7: Average Uptime

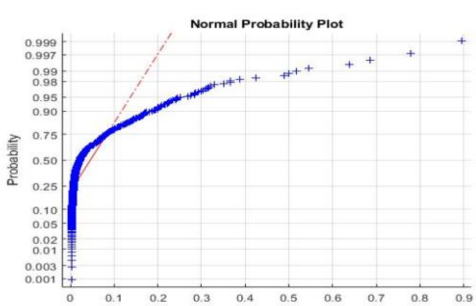

Figure 8: Normal Probability Plot

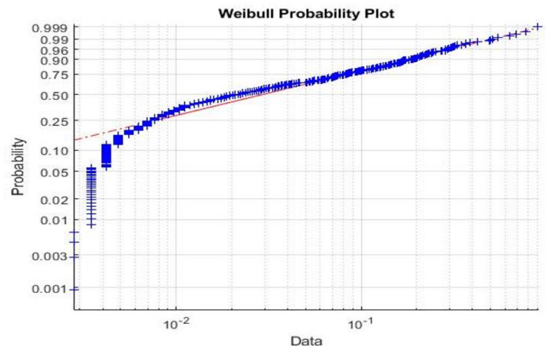

Figure 9: Weibull Markov Plot

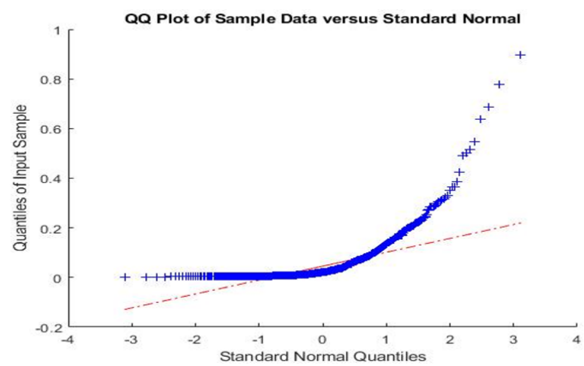

Figure 10: Quantile Quantile Plot

Table 5. Monthly Reliability Indices of the 33kV Feeder

Month Indices	September, 2022	October, 2022	November, 2022	December, 2023	January, 2023	February, 2023
Failure rate	0.0161	0.0578	0.0131	0.0108	0.0351	0.0120
MTTR	2.5	6.6	3.1	3.3	8.8	3.1
MTBF	3.5	3.8	3.7	3.8	2.5	3.7
Availability	0.0612	0.0675	0.0635	0.0683	0.0440	0.0600
Unavailability	0.9388	0.9325	0.9365	0.9317	0.9560	0.9400

V. SUMMARY/CONCLUSION

Summary

The Weibull Markov stochastic method provides a comprehensive and realistic approach to analyzing the reliability of the 33kV distribution feeder. It considers time-dependent failure rates and repair times, offering a more accurate representation of the system's behavior compared to traditional methods. The Weibull distribution accounts for varying failure rates over time, making it suitable for analyzing components with diverse failure patterns.

Conclusion

Sensitivity analysis identified key parameters significantly impacting reliability results, enabling prioritized maintenance and replacement actions for critical components.

The Markov modeling captured state transitions within the system, allowing for a comprehensive evaluation of its reliability performance under various conditions.

The Weibull Markov model proves valuable for assessing the reliability of distribution systems due to its ability to handle uncertainties, non-exponential failure patterns, and state transitions.

Recommendations

Precise data on failures and repairs of the 33kV components, including failure times, repair times, and types of failures encountered should be collected, for accurate model calibration.

Sensitivity analysis should be conducted to identify and prioritize maintenance actions for critical components, ensuring optimal resource allocation.

The system's reliability should be periodically reassessed using the Weibull Markov method to monitor its performance and adjust maintenance strategies as needed.

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