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RELIABILITY ANALYSIS OF A HYBRID PV/WIND/BATTERY SYSTEM USING EVENT TREE APPROACH

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ABSTRACT
Renewable energy sources are very attractive energy sources due to their abundant available nature, highly clean energy source because of their environmental friendly nature and cheap continuous nature. However, because of their intermittent available property, hybrid renewable energy sources are used to counter this drawback. In this study, the reliability of a hybrid renewable energy complex system with five components subsystem is evaluated. The reliability of the components is assumed to follow the Weibull failure laws. The reliability of the system is determined using the Event Tree approach. The effect of operating time (t), failure parameter (λ) and repair parameters (β) are shown both graphically and numerically for arbitrarily value of different parameters. The sensitivity analysis was carried out to investigate the overall system reliability with the value of t ranges between $0\ to\ 150$, λbetween $0.01\ to\ 0.05$ and β between $0.1\ to\ 0.5$. The practical realization of this study is envisioned in a hybrid renewable power system network.

Keywords: Reliability, failure rate, repair rate, time, renewable energy

INTRODUCTION

Renewable energy system is a very attractive energy system due to its abundant available nature, highly clean energy source because of their environmental friendly nature and cheap continuous nature. However, because of their intermittent available property, hybrid renewable energy sources are used to counter this drawback (Alayande *et al.*, 2025). The way components are structured plays a vital role in improving reliability performance of the system (Adaramola *et al.*, 2019). Recent innovations in reliability engineering showed that a lot of efforts have been put in place to improve customer's satisfaction (Mehrbakhsh *et al.*, 2019). Today, so many system structures of component, either series, parallel, series-parallel, parallel-series or complex system exist (Ajiboye *et al.*, 2018). From the literature, it has been shown that parallel systems are better than series system so long as reliability is concerned (Armaroli *et al.*, 2016). In Biello (2014), the reliability of a series-parallel system is evaluated with random failure propagation. In Chanchangi *et al*. (2022), the reliability of parallel-series and series-parallel components were compared with Weibull failure laws. There results revealed that a system having series-parallel composition is more reliable than a system with parallel-series composition. On the other hand, system components are not always exactly series or parallel. A complex system may be simplified to produce a non series-parallel structure. Most of the electronics and electrical circuit components are non series-parallel in nature. In this work, a non series-parallel system (Hybrid Renewable Energy System (HRES)) is adopted and the reliability of the system is determined using Weibull failure laws with arbitrary values of the parameters.

Renewable energy sources, such as solar photovoltaic (PV), wind, hydroelectric, geothermal, and biomass, are growing in popularity due to their minimal carbon footprint, endless supply, stable price points in the energy market, and financial advantages (Dong *et al*., 2022). Nigeria is endowed with conventional energy resources (Non-Renewable) and renewable energy resources (biomass, hydro, solar, and wind) that are sufficient to satisfy the demand of its populace and export the excess to neighboring countries as a tradable commodity to generate funds (El Boujdaini *et al*., 2022). Thus far, the in-house supply is still inadequate and unable to meet the country's demand, and this is continuously increasing due to a continuous increase in population, requiring an immediate response before it reaches an unrecoverable situation.

This energy supply shortage poses challenges to both the rural and urban populations. However, the problem is most severe in the rural areas, where most of the population lives without access to the national grid, and besides, even most urban dwellers suffer from an unstable and insufficient power supply (Energy Information Administration, 2023). The frequent power outages have compelled many Nigerians to adopt self-energy generation using various fossil fuel-powered generators to generate electricity for domestic, commercial, and industrial consumption. The by-products of this have adverse effects on humans and the environment.

HRES systems have so far been the focus of research that has been published in a few journals. However, most of the articles' analyses focused on the operating states of HRES systems with simple topology. In this study, reliability analysis of the series-parallel network for a hybrid system of photovoltaic, wind energy and battery system is analyzed using Event tree analysis with Weibull failure laws.

MATERIALS AND METHODS

Block Diagram of System

The reliability of a system is a function of the reliabilities of its components and building blocks. Block diagram is a way of representing systems by means of component configuration. The reliability of the system is obtained by means of relevant rules of probability according to system configuration of components. Figure 1 shows the hybrid renewable system configuration under review.

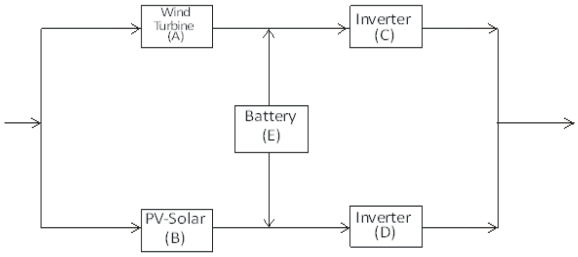

Figure 1: System block diagram

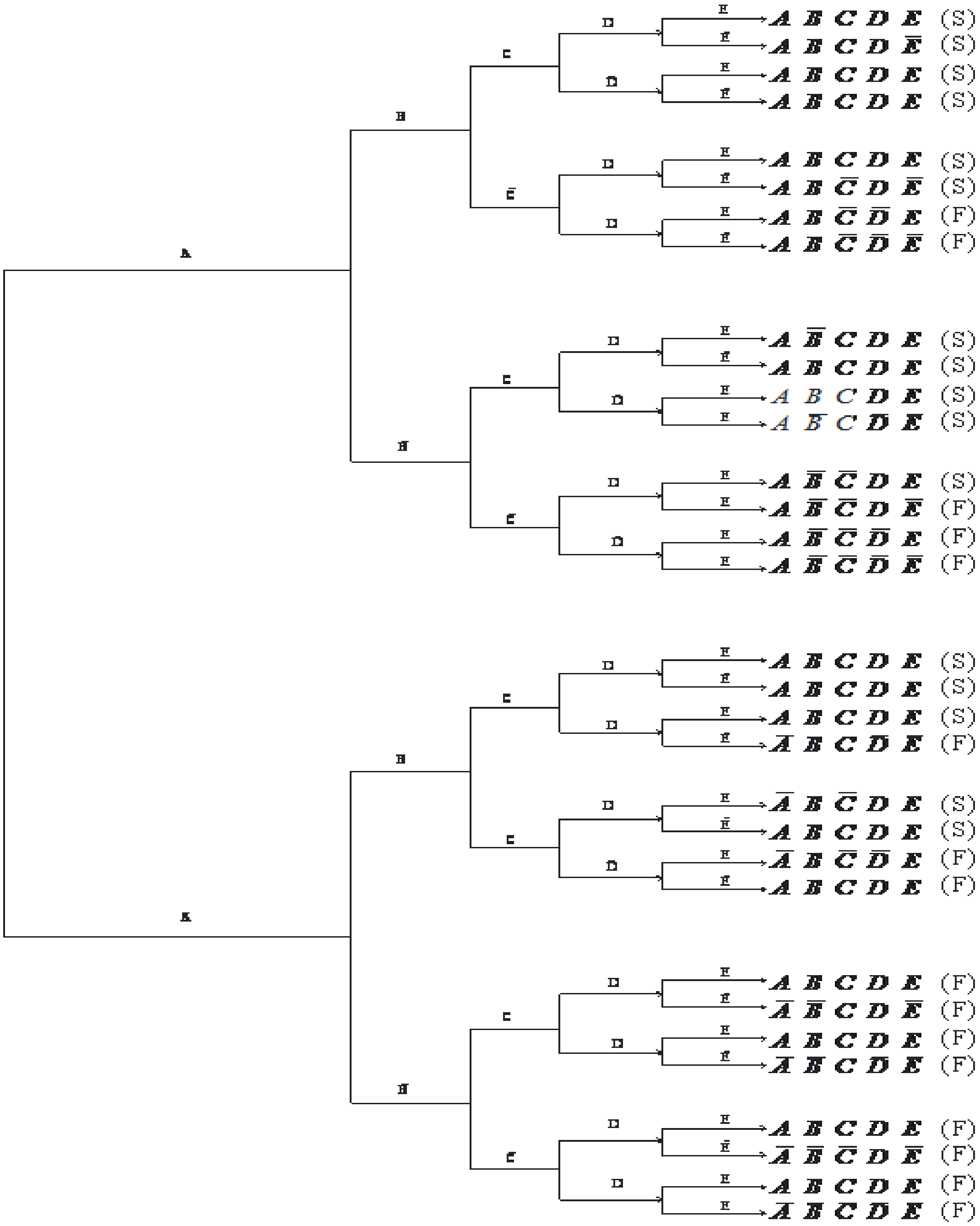

Figure 2: Event tree diagram of system

Event Tree Diagram

Event tree is a pictorial expression of all possible events that can occur in a system. It is called a tree because the pictorial expression looks like the branches that emanates from a tree. Event tree analysis identifies all possible combinations of success (S) or failure (F) of each unit and the resulting success or failure of the entire system. For a system with 'n' components, there are 2^n possible states (success or failure) in the system. The event tree diagram for the system under study (Figure 1) is shown in Figure 2.

The reliability of the components is assumed to follow Weibull failure law (Ahlawat *et al.*, 2019). Hence, the reliability of the component is given by Ahlawat *et al.* (2019):

$$R_i = e^{-\lambda\frac{t^{\beta_i+1}}{\beta_i+1}} \quad 1$$

Where: $\lambda = failure\ rate, \beta = repair\ rate$ and $t = time$

From Figure 1, $A = Wind\ turbine, B = PV - Solar, C = Inverter\ 1, D = Inverter\ 2$ and $E = Battery\ system.$

Using the event tree approach, the reliability of the system is given as:

$$R_s(t) = (Sum\ of\ the\ probabilities\ of\ all\ the\ events\ for\ which\ the\ system\ is\ in\ working\ state) \quad 1$$

From the event tree diagram, the reliability of the system is given by:

$$R_s = ABCDE + ABCD\bar{E} + ABC\bar{D}E + ABC\bar{D}\bar{E} + AB\bar{C}DE + AB\bar{C}D\bar{E} + A\bar{B}CDE + A\bar{B}CD\bar{E} + A\bar{B}C\bar{D}E + A\bar{B}C\bar{D}\bar{E} + A\bar{B}\bar{C}DE + \bar{A}BCDE + \bar{A}BCD\bar{E} + \bar{A}BC\bar{D}E + \bar{A}B\bar{C}DE + \bar{A}B\bar{C}D\bar{E} \quad 2$$

Where: $A, B, C, D\ and\ E$ are the reliability of the components, while $\bar{A}, \bar{B}, \bar{C}, \bar{D}\ and\ \bar{E}$ are the unreliability of the components

RESULTS AND DISCUSSION

The reliability of the system is determined for arbitrary values of λ and β parameters with operating time of the system. The results are presented numerically in Tables 1 – 2 and graphically in Figures 3 – 4, respectively.

Table 1: System reliability with varying time and failure rate

Time (h)	System Reliability (R_s)				
	β = 0.1 and λ = 0.01	β = 0.1 and λ = 0.02	β = 0.1 and λ = 0.03	β = 0.1 and λ = 0.04	β = 0.1 and λ = 0.05
0	1	1	1	1	1
10	0.97473574	0.90720346	0.813527979	0.708679639	0.603629816
20	0.89497752	0.678167576	0.465966619	0.302412853	0.189828886
30	0.77761855	0.442721679	0.220267325	0.103445417	0.04749534
40	0.64569591	0.265272501	0.094528859	0.03236457	0.011023818
50	0.51722658	0.150696063	0.038674656	0.009764827	0.002485617
60	0.40282742	0.082841439	0.015451292	0.002894513	0.000550021
70	0.30693573	0.044633674	0.006093937	0.000847248	0.000119569
80	0.22992884	0.023752204	0.002382825	0.000245084	2.5535E-05
90	0.16998989	0.012540784	0.000924992	7.00588E-05	5.35957E-06
100	0.12440505	0.006585621	0.000356571	1.97919E-05	1.10659E-06
110	0.09033407	0.003443999	0.000136491	5.52754E-06	2.24986E-07
120	0.0652001	0.001794602	5.18805E-05	1.5269E-06	4.50917E-08
130	0.04684146	0.000931971	1.9583E-05	4.17416E-07	8.91734E-09
140	0.03353172	0.000482376	7.34181E-06	1.12996E-07	1.74162E-09
150	0.02393688	0.000248836	2.73445E-06	3.0306E-08	3.36196E-10

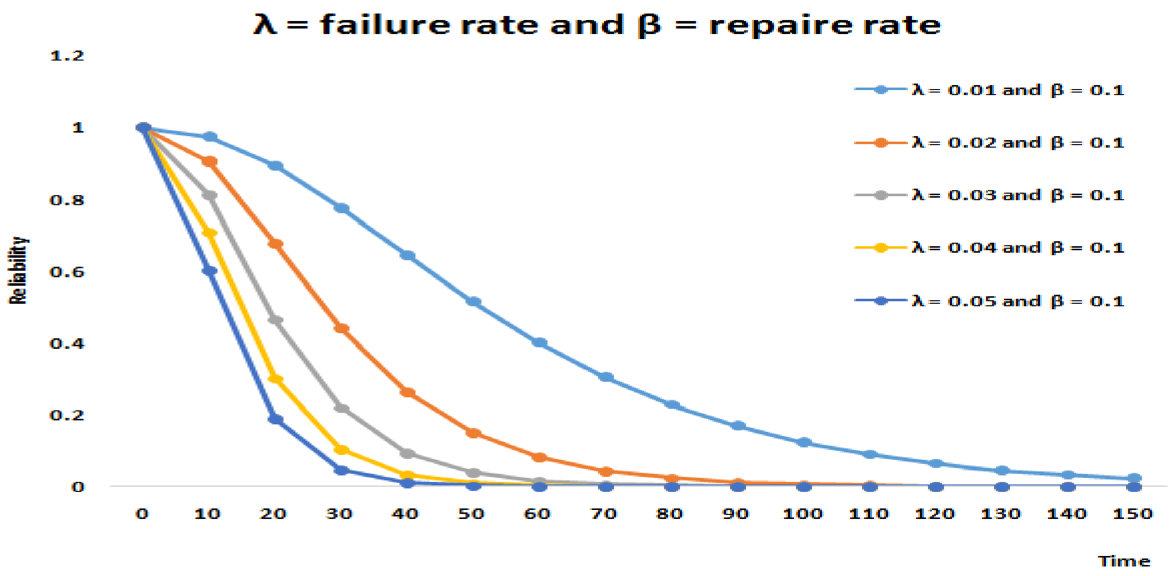

Figure 3: System reliability with varying failure rate Vs time

Table 2: System reliability with varying time and repair rate

	System Reliability (R_s)				
Time (h)	**β = 0.1 and λ = 0.01**	**β = 0.2 and λ = 0.01**	**β = 0.3 and λ = 0.01**	**β = 0.4 and λ = 0.01**	**β = 0.5 and λ = 0.01**
0	1	1	1	1	1
10	0.97473574	0.966710409	0.955682423	0.940584837	0.920035512
20	0.89497752	0.848158569	0.782445855	0.694084258	0.582244488
30	0.77761855	0.675445316	0.544120331	0.393205553	0.244262006
40	0.64569591	0.496800333	0.331816548	0.181533665	0.075820803
50	0.51722658	0.343659561	0.183617431	0.072622497	0.019248572
60	0.40282742	0.226980513	0.094765519	0.026318595	0.004235362
70	0.30693573	0.144831689	0.046528856	0.008876735	0.00082782
80	0.22992884	0.090073755	0.022025462	0.002825699	0.000144947
90	0.16998989	0.054956754	0.010136447	0.000854381	2.28236E-05
100	0.12440505	0.033049139	0.004557397	0.000246079	3.2433E-06
110	0.09033407	0.01965296	0.002007124	6.76273E-05	4.17523E-07
120	0.0652001	0.011581824	0.000867111	1.7759E-05	4.88839E-08
130	0.04684146	0.00677373	0.000367761	4.46285E-06	5.22484E-09
140	0.03353172	0.003935249	0.000153209	1.07492E-06	5.11571E-10
150	0.02393688	0.002272218	6.27237E-05	2.48532E-07	4.60292E-11

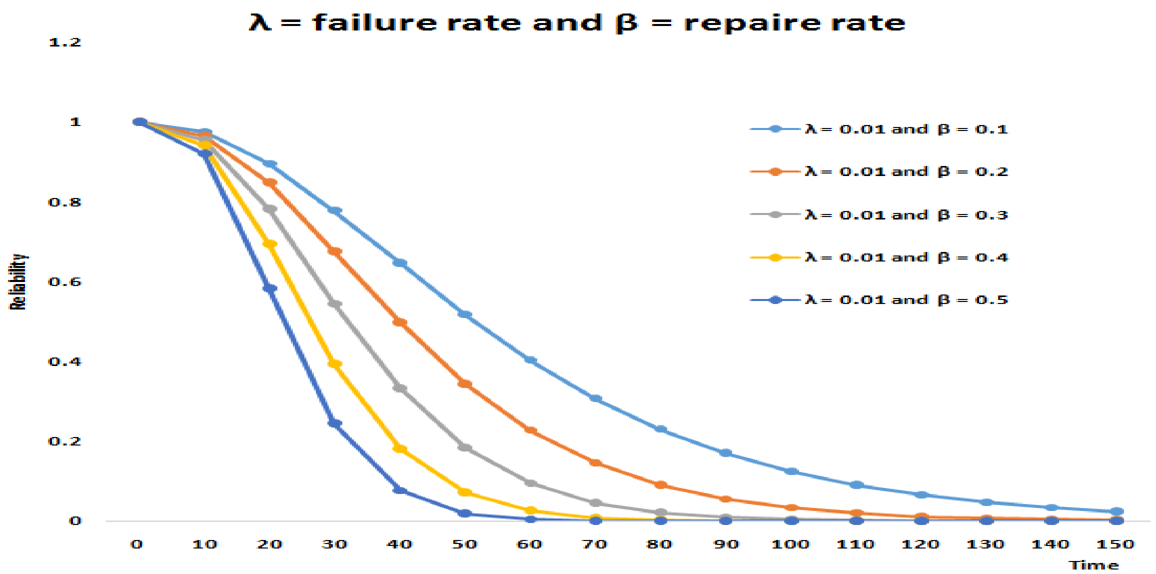

Figure 4: System reliability with varying repair rate Vs time

In this study, the reliability of a non series-paralle component consisting of Wind turbine, PV-Solar, Battery and inverter sub-system is studied. The reliability of the system is evaluated using the Event tree approach. The trend of reliability with respect to arbitrary values of operating time, failure rate (λ) and repair rate (β) are presented. The effect of failure rate, repair rate and operating time of the components on reliability was also examined by Weibull failure laws. From the results, it is observed that reliability of the system keeps decreasing with increase in λ, β and operating time of the components. The results (Figures 3-4) show that the reliability of a non series parallel system is largely dependent on time of operation of the component, hence, reliability decreases as time of operation increases. As the time increases, the rate of wear and tear of components increases, which will ultimately lead to a decrease in reliability. Furthermore, Figures 3-4 show the effect of failure rate (λ) on the reliability of a system. These figures depicts that reliability decreases as failure rate (λ) increases. These results can be validated by comparing with the results in Kaur *et al.* (2025).

CONCLUSION

This study is a reflection of a non-series parallel system in the research area. In this work, the reliability of a non series-paralle component consisting of Wind turbine, PV-Solar, Battery and inverter sub-system is studied. The reliability of the system is evaluated using the Event tree approach. The trend of reliability with respect to arbitrary values of operating time, failure rate (λ) and repair rate (β) is also presented. The effect of failure rate, repair rate and operating time of the components on reliability was also examined by Weibull failure laws. From the results, it is observed that reliability of the system keeps decreasing with increase in λ, β and operating time of the components. The results (Figures 3-4) show that the reliability of a non series parallel system is largely dependent on time of operation of the component, hence, reliability decreases as time of operation increases. As the time increases, the rate of wear and tear of components increases, which will ultimately lead to a decrease in reliability. Also, Figures 3-4 show the effect of failure rate (λ) on the reliability of a system. These figures depicts that reliability decreases as failure rate (λ) increases. This study will suggest the use of other reliability methods for complex simple like Fault Tree Approach (FTA). Furthermore, this study will also suggest the use of a more complex system by incorporating a grid network system with the current study.

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