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POWER SYSTEM RELIABILITY ANALYSIS FOR DIFFERENT LINE OUTAGE CONDITIONS

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ABSTRACT: Power System Reliability Assessment is a crucial and significant feature of power system design, planning, and operation. A power system comprises many components that are interconnected in meaningful and rational ways. In the present paper, a simulation is carried out for line outage conditions. In a power system, some of the lines are extremely important. If such a line outage is happening then a cascading failure may occur. This failure leads to grid collapse. So, a power engineer needs to know which line will be more important. In the present work, reliability was done for different line outage conditions to check the importance of the line. This report defines a transmission network, generation system, and load model that can be used to compare the power system of reliability assessment methods. The objective is to estimate the reliability index for improvement of power system reliability analysis for different line outage conditions. The improvement in reliability assessment was evaluated with a reliability index that includes ACCI (Average Customer Curtailment Index), AENS (Average Energy Not Supplied), ASAI (Average Service Availability Index), ASUI (Average Service Unavailability Index), CAIDI (Customer Average Interruption Duration Index), CTAIDI (Customer Total Average Interruption Duration Index), EENS (Expected Energy Not Supplied), SAIDI (System Average Interruption Duration Index), and SAIFI (System Average Interruption Frequency Index) for different line-outage conditions using Electrical Transient Analyzer Program (ETAP) software. The transmission system comprises 24 load/generation buses that are connected by 38 switches or transformers with two voltages that is, 138 KV and 230 KV. Transmission system data consists of line, transformer, impedance, and reliability data.

Keywords: ETAP Software, Reliability Indices, Line Outages, IEEE 24 bus system.

1. Introduction

Power system reliability is an abstract term that means consistency and good presentation. However, in the case of technical systems, it's not just an abstract concept; it can be measured, calculated, designed, and connected to a device or system.

The Reliability Analysis is one of the most important criteria to be considered in all phases of power system planning, design, and operation. Power systems are prone to system anomalies like, control errors, communication system failures or protection, and faults like, human operation errors and lightning. Reliable power is very important when designing and operating [1]. In this study, reliability is evaluated using the "Electrical Transient Analyzer Program, ETAP" software and implemented in the IEEE 24 bus test system [2]. In the reliability calculation process, the ETAP software generates results based on both the base case and seven enhanced cases [3]. Reliability improvement in different cases was evaluated based on different reliability indexes, including; load point index and system index using ETAP Software [4].

In [5, 6] provided a general method for solving a reliability problem using the ETAP software and provided instructions on how to operate the ETAP reliability function. In [7] a typical distribution system and to demonstrate the improvement of system reliability, various components (fuses, switches, DGs) are examined step by step and added to the system in five cases. In [8], to realize the methodology related to reliability analysis, a comparative study between various components was carried out and the optimal techniques for maintaining the reliability of the system were proposed. In [9] ETAP software can be used more effectively by more companies to evaluate the impact of distribution system component failures and assess distribution system reliability. Using data collected from substations and supply centers, we used analytical and simulation techniques to evaluate existing distribution system reliability indices and redesign distribution systems to improve system reliability [10]. A practical application example for assessing power system reliability based on (n-1) contingencies and based on a combination of reliability index evaluation and contingency analysis [11]. To improve system reliability by placing DG in different buses, simplified mathematical formulas are introduced, and analyzing the graphs, a comparative conclusion is made [12]. The purpose of this study was to obtain the reliability value of the IEEE 24-bus power distribution network system has failure frequency, average production time, average annual unavailability, SAIFI, SAIDI, CAIDI, ENS, and then AENS [13].

In [14], the reliability assessment must be carried out appropriately with reliable and trustworthy performance measurements, criteria, and indices based on component failure data and configuration. In [15], to improve the reliability indices, an analysis of the effects of distributed generation (DG) on the operation of the residential network is carried out using MATLAB software. In [16] based on resource availability, cost factors, and application area, the microturbine/fuel cell hybrid system is selected from among other distributed generation resources and studying the improvement of power reliability using DG as a backup. In [17], define a sufficiently comprehensive system to provide a basis for reporting combined generation/transmission reliability analysis methods.

The interest in the methods of reliability analysis of power systems continues and grows. When comparing the results obtained by different methods, it is recommended to use a reference or test system as a basis, which contains the basic information necessary for reliability assessment. This report determines to provide such “reliability testing for different line outage conditions.” This report includes loads, generation systems, and transmission systems. The objective is to evaluate the reliability indices for the improvement of power system reliability analysis for different line outage conditions. The reliability index such as ACCI (Average Customer Curtailment Index), AENS (Average Energy Not Supplied), ASAI (Average Service Availability Index), ASUI (Average Service Unavailability Index), CAIDI (Customer Average Interruption Duration Index), CTAIDI (Customer Total Average Interruption Duration Index), EENS (Expected Energy Not Supplied), SAIDI (System Average Interruption Duration Index), and SAIFI (System Average Interruption Frequency Index) presented by the IEEE (Institute of Electrical and Electronics Engineers) Guide is used to estimate system reliability for different line-outage conditions. Reliability indices and related terms and definitions have been provided in the IEEE Guide.

2. Reliability Index

This paper calculates the reliability index of power system reliability analysis for different line outage conditions using ETAP (Electrical Transient Analyzer Program) Software. The formulae for determining the reliability index include:

2.1. Customer Average Interruption Duration Index (CAIDI)

To estimate the CAIDI, divide the sum of the duration of customer interruptions by the total number of interrupted customers.

$$CAIDI = \frac{\sum Duration\ of\ Customer\ Interruptions}{Total\ No.\ of\ Interrupted\ Customers}$$

$$CAIDI = \frac{\sum r_t \times N_i}{\sum N_i} \quad \text{hrs./Customer Interr.} \qquad (1)$$

2.2. System Average Interruption Duration Index (SAIDI)

To evaluate the SAIDI, divide the sum of the duration of customer interruptions by the total number of served customers.

$$SAIDI = \frac{\sum Duration\ of\ Customer\ Interruptions}{Total\ No.\ of\ Served\ Customers}$$

$$SAIDI = \frac{\sum r_t \times N_i}{N_T} \quad \text{hrs./Customer.yr} \qquad (2)$$

2.3. System Average Interruption Frequency Index (SAIFI)

By dividing the sum of the total number of interrupted customers by the total number of served customers, SAIFI is calculated.

$$SAIFI = \frac{\sum Total\ No.\ of\ Interrupted\ Customers}{Total\ No.\ of\ Served\ Customers}$$

$$SAIFI = \frac{\sum N_i}{N_T} \quad \text{f/Customer.yr} \qquad (3)$$

2.4. Average Service Availability Index (ASAI)

The ASAI is the ratio of the total number of customer hours served during a specified period to the total number of customer hours of service demanded.

$$ASAI = \frac{Customer\ Hrs\ Service\ Available}{Customer\ Hrs\ Service\ Demands}$$

$$ASAI = 1 - \left[\frac{\sum r_t \times N_i}{\sum N_T \times T}\right] \quad \text{p.u} \qquad (4)$$

$$ASAI = \left[\frac{8760 - SAIDI}{8760}\right]$$

2.5. Average Service Unavailability Index (ASUI)

The ASUI is defined as the ratio of the duration of interruption in hours to the total number of hours demanded.

$$ASUI = \frac{Duration\ of\ Interruption\ in\ Hours}{Total\ No.\ Hours\ Demand}$$

$$ASUI = 1 - ASAI$$

$$ASUI = \frac{\sum r_t \times N_i}{\sum N_T \times T} \quad \text{p.u} \qquad (5)$$

2.6. System Expected Energy Not Supplied (EENS)

EENS represents energy for which supply is not due to insufficient resources to meet demand in a given zone and period.

$$EENS = \sum EENS_i \quad \text{MW.hour/year} \qquad (6)$$

2.7. Average Energy Not Supplied (AENS)

To evaluate the AENS, by dividing the total unsupplied energy by the total number of customers served.

$$AENS = \frac{Total\ No.\ of\ Average\ Unsupplied\ Energy}{Total\ No.\ Served\ Customer}$$

$$AENS = \frac{\sum EENS_i}{\sum N_T} \quad \text{MW.hour/Customer.yr}$$

2.8. Average Customer Curtailment Index (ACCI)

The ACCI shows the total unsupplied energy to the total number of interrupted customers.

$$ACCI = \frac{Total\ No.\ of\ Unsupplied\ Energy}{Total\ No.\ of\ Interrupted\ Customers}$$

$$ACCI = \frac{\sum ENS_i}{\sum N_i} \quad \text{kVA/Customer} \qquad (8)$$

2.9 Customer Total Average Interruption Duration Index (CTAIDI)

The *CTAIDI* is the average total duration of interruption *for customers who had at least one interruption during the period of analysis*, and is calculated as:

$$CTAIDI = \frac{Sum\ of\ Durations\ Cust.\ Interruptions}{No.\ of\ Distinct\ Custs.\ Interrupted}$$

$$CTAIDI = \frac{\sum U_i N_i}{\sum N_{io}} \quad \text{kVA/Customer}$$

CTAIDI is measured in units of time, such as minutes or hours. It is similar to *CAIDI*, but *CAIDI* divides the total duration of interruptions by the number of interruptions whereas *CTAIDI* divides by the number of interrupted customers. When *CTAIDI* is much greater than *CAIDI*, the service outages are more concentrated among certain customers.

2.10. Interruption Energy Assessment Rate (IEAR)

The IEAR is calculated as the quotient of ECOST to EENS.

$$IEAR = \frac{ECOST}{EENS} \quad \text{Rs./kW.hour} \qquad (9)$$

where,

r_t = Restoration Time
N_i = Total no. of customers interrupted
N_T = Total no. of customers served.
T = Time period under steady state

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N_{io} = is the number of customers at a location that were interrupted.

3. Bus Model

The simulation model is completed on IEEE-24 Bus system using Electrical Transient Analyzer Program (ETAP) Software shown in Figure 1 (Appendix). The transmission system comprises 24 load/generation buses connected to 38 switches and transformers, as in Figure 1. There are two voltages on the transmission line, 138 KV, and 230 KV. 230 KV system is in Figure 1 upper part, 230 KV/138 KV connecting stations in buses 11, 12 and 24 and 138 KV system is in Figure 1 bottom part, 138 KV/230 KV connecting stations in buses 3, 9 and 10.

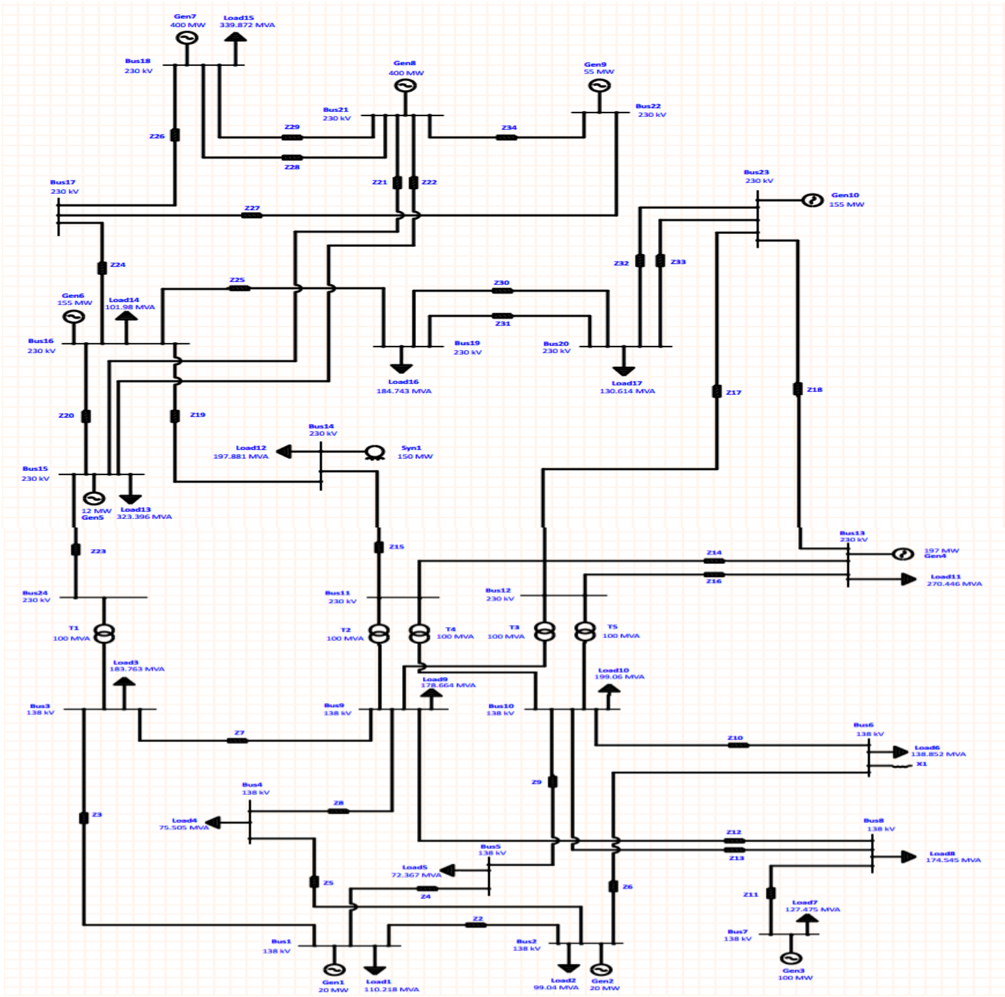

Figure 1. Reliability Test of IEEE 24 Bus

4. Results and Discussion

A Power System Reliability Analysis for different line outage conditions for an IEEE 24 bus system is shown in Figure 1. The load flow analysis of this system should be implemented first. Then use the transmission line forced outage data needed for the reliability analysis and perform a reliability assessment using ETAP Software. This paper evaluates the Reliability Indices for different line outage conditions of IEEE 24 Bus System for improvement of Power System Reliability Analysis by using ETAP (Electrical Transient and Analysis Program) software. The power loss and reliability indices for different line outages are shown in Table 1 (Appendix). IEEE 24-bus system contains 38 switches, in case I consider no line outage and evaluate power loss and reliability index by using ETAP software.

TABLE 1. Power Loss And Reliability Indices

case	Line outage conditions	Power loss		Realibility indices								
		Active power (MW)	Reactive power (MVAR)	ACCI	AENS	ASAI	ASUI	CAIDI	CTAIDI	EENS	SAIDI	SAIFI
1	No line outages	51.246	454.77	2325.99	50933.47	0.965	0.0348	22.388	305.12	916802.50	305.02	13.624
2	1,2,6	51.969	463.24	2142.26	48905.08	0.967	0.0334	23.344	292.83	880291.40	292.83	12.544
3	2,6,9	52.141	463.80	2130.01	49025.88	0.966	0.0336	23.495	293.94	882465.90	2939.35	125.107
4	2,4,6,12	54.602	476.60	2046.56	48209.66	0.967	0.0330	24.045	289.04	867773.90	2890.35	120.207
5	1,2,6,18,30	56.047	498.60	2019.33	47582.56	0.968	0.0325	24.096	284.91	856486.10	284.91	11.824
6	1,3,4,6,21,28	85.53	711.25	1924.17	46636.74	0.968	0.0319	24.792	279.21	839461.40	2792.04	112.618
7	1,2,5,6,19,22	100.661	862.49	1958.44	46954.03	0.968	0.0322	21.416	281.94	845172.60	2819.41	115.473
8	1,2,5,7,19,31,37	116.175	919.71	1879.32	41620.90	0.972	0.0279	22.621	244.64	749176.30	2446.44	108.150
9	3,4,5,6,20,24,29,30	133.241	1075.61	1828.12	45838.57	0.969	0.0314	25.517	275.26	825094.30	2752.61	107.873
10	3,4,5,6,20,21,24,29,30	168,341	1480.56	1740.01	44883.41	0.969	0.0308	26.252	269.54	807901.40	1695.41	102.673

In Case II to Case X consider nine different line outage conditions and estimate the power loss and reliability index shown in Table 1. With the ETAP Software, the result of reliability indices for no line outage case (Case I) and nine different line outage cases (Case II to Case X) is generated. From the simulation results, reliability indices for nine different line outage conditions are clearly shown in Table 1. In Table 1, Case I (i.e., no line outage condition) is the base case, and as such, it is treated as the benchmark against which the performance of the succeeding cases is evaluated. It can also be observed from Table 1 that Case X (with nine different line outage conditions) performs poorly.

By comparison, the simulation results of Case I and Case X, show an Active Power loss increased from 51.246 MW to 168.341 MW as shown in Figure 2, while the Reactive Power loss improved from 454.77 MVAR to 1480.56 MVAR as indicated in Figure 3.

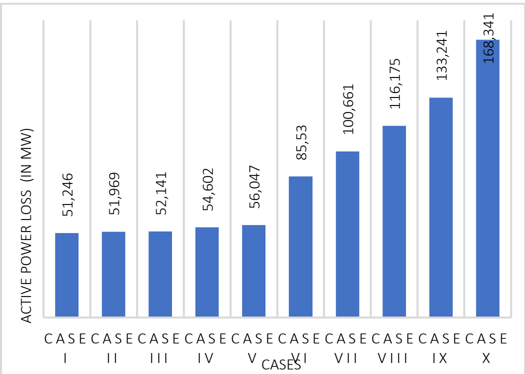

Figure 2 Comparison of active power loss for different line outage conditions.

The Average Customer Curtailment Index (ACCI) decreased from 2325.991 MVA per customer to 1740.011 MVA per customer as shown in Figure 4, while the Average Energy Not Supplied (AENS) decreased from 50933.47 MW hr. per customer. yr. to 44884.31 MW hr. per customer. yr., as shown in Figure 5, while ASAI is increased from 0.9652 p.u to 0.9692 p.u as shown in Figure 6.

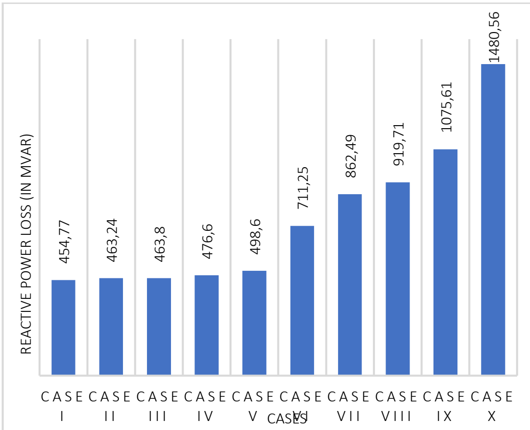

Figure 3. Comparison of reactive power loss for different line outage conditions.

The Average Service Unavailability Index (ASUI) is reduced from 0.03482 p.u to 0.03077 p.u as shown in Figure 7, while CAIDI is increased from 22.388 hr. per customer interrupted to 26.252 hr. per customer interrupted as shown in Figure 8. CTAIDI has decreased from 305.018 hr. per customer.yr. to 269.541 hr. per customer. yr. as indicated in Figure 9, while EENS is reduced from 916802.5 MW hr. per yr. to 807,901.40 MW hr. per yr. as shown in Figure 10. SAIDI is reduced from 305.018 hr. per customer. yr. to 269.5414 hr. per customer. yr. as

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shown in Figure 11 and SAIFI is reduced from 13.624 f per customer. yr. to 10.2673 f per customer. yr. as shown in Figure 12.

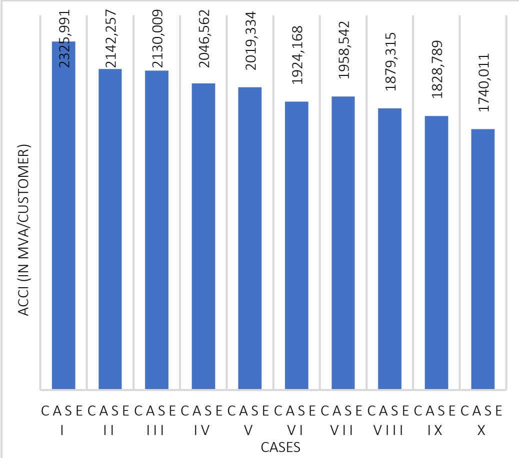

Figure 4 Comparison of ACCI for different line outage conditions.

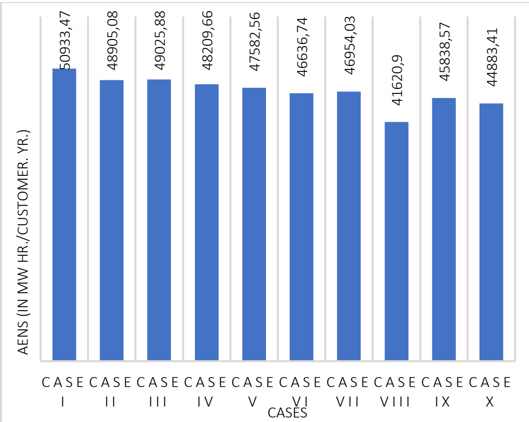

Figure 5 Comparison of AENS for different line outage conditions.

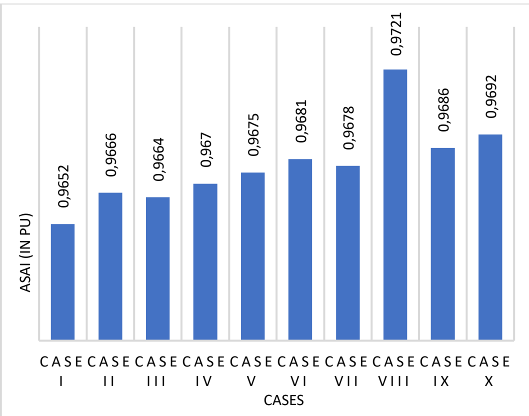

Figure 6 Comparison of ASAI for different line outage conditions.

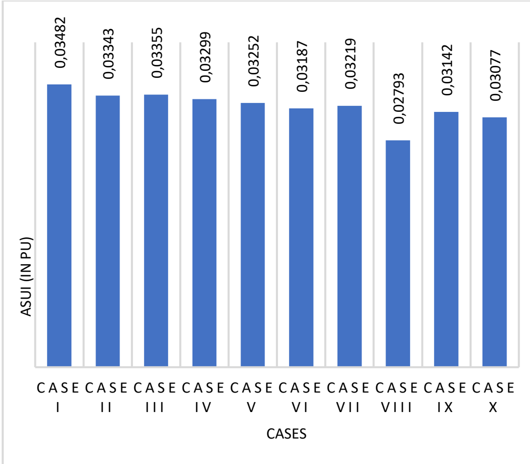

Figure 7 Comparison of ASUI for different line outage conditions.

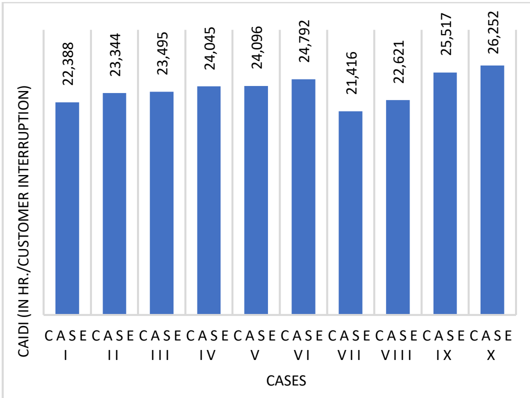

Figure 8 Comparison of CAIDI for different line outage conditions.

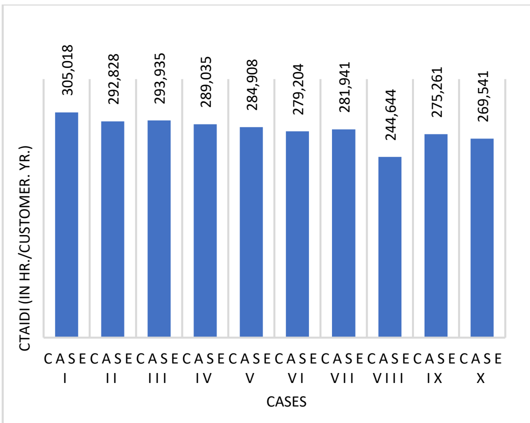

Figure 9 Comparison of CTAIDI for different line outage conditions.

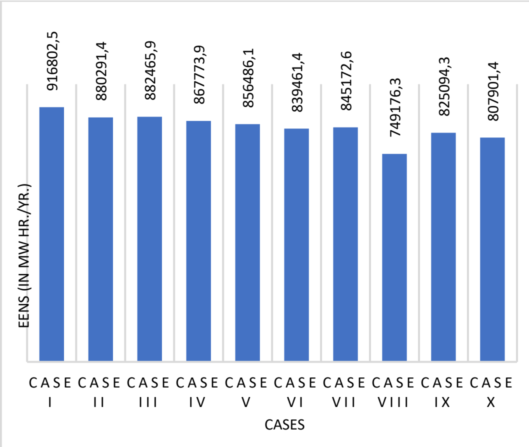

Figure 10 Comparison of EENS for different line outage conditions.

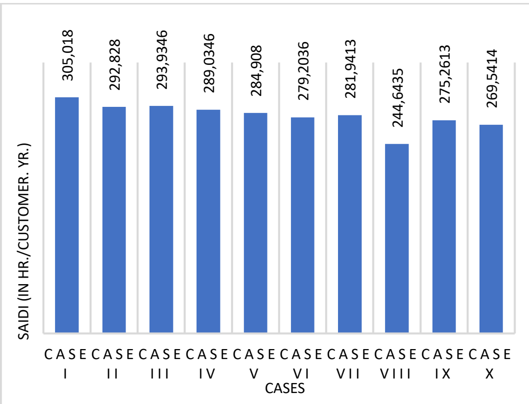

Figure 11 Comparison of SAIDI for different line outage conditions

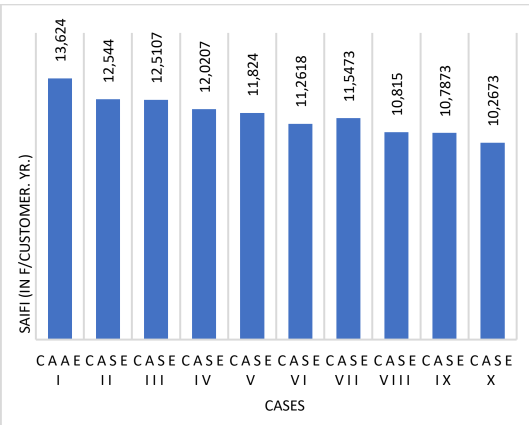

Figure 12 Comparison of SAIFI for different line outage conditions.

5. Conclusion

The reliability evaluation is a valuable tool for power system planning, design, and maintenance. To obtain the best system performance in many utilities, it's crucial to pinpoint the network's weak points and then take steps to make them more reliable. In the present paper, IEEE 24 bus system is considered for the assessment of power system reliability analysis. The reliability indices calculation has been carried out using ETAP software at different line outage conditions. For analysis a total of ten cases were considered out of both no line outage cases i.e., base case (Case I) and nine different line outage cases (Case II to Case X) are shown. The analysis is very much useful for a beginner research scholar of Power system reliability.

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