Journal of Engineering Research and Education
Volume 17, 2025 [140-153]

Determined the Worst Served Customer using Regulatory-based Monte Carlo Simulation

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ABSTRACT

Electric utilities typically present their network performance regarding System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), and Customer Average Interruption Duration Index (CAIDI) indices. These indices are mean values for the fictitious types of customers. The report presents No values for the best, average, and worst types of customers. Normally, the best customer should have a high-performance value, while the worst customer should have a low-performance value. However, with the performance standards introduced by the energy regulator, the classification of best- and worst-served customers (WSC) should differ. Energy regulators in most countries regulate the electricity customers' minimum standard performance in terms of the number of interruptions and duration of the interruptions. These requirements are to protect customers from experiencing excessive interruption and duration. The method used to assess customer performance is Monte Carlo simulation, which incorporates performance standard limits. The network used in this simulation is an IEEE 30 bus, and the output of the simulation is the number of interruptions and duration of interruption for each customer in the network. The WSC is the customer that able to refined both it lowed its own interruption and duration of interruption specifically and improved SAIFI/CAIDI of network performance generally. Plus, the electric utility company may pay fewer penalties if WSC is served better.

Keywords: Best-served customer, Duration of interruption, Monte Carlo simulation, Performance standard limits, Penalty, Worst-served customer.

1. INTRODUCTION

Electric power systems are fundamental to the fabric of modern society, providing the energy that fuels nearly all aspects of daily life. However, the reliability of these systems is often tested by interruptions ranging from transient outages to prolonged blackouts. Regulatory bodies globally have established stringent standards for the number and duration of power interruptions to manage and minimise these disruptions. Metrics such as the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI) are crucial in these regulatory frameworks [1]. They are benchmarks for assessing utility performance and enforcing compliance with reliability standards.

Energy regulators have certain requirements for electrical energy utilities to follow to protect customers. These requirements are mainly the excessive number of interruptions and duration of interruptions. Any excessive interruption and interruption duration experienced by customers will result in penalties to the electric utility. Conversely, penalties are imposed when utilities fail to meet established standards.

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These penalties can take various forms, such as financial fines, reduced allowed revenue for future periods, or compulsory investment in infrastructure upgrades. Such penalties are crucial for maintaining a service quality baseline and holding utilities accountable [2], [3].

A utility can earn additional revenues if it achieves or surpasses these targets. This motivates continuous improvement in network reliability and fosters innovation in grid management and maintenance practices [4]. For instance, during the Revenue Incentives Innovation Outputs Electricity Distribution 1 (RIIO-ED1) period, substantial investments were made in advanced technological solutions like automated switchgear and predictive analytics tools to minimise outage times and frequency, leading to better-than-expected reliability performances and subsequent financial rewards for the utilities involved [5], [6].

The dual approach of rewards and penalties has proven effective in driving improvements in power system reliability [7]. Utilities are prompted to avoid penalties and strive for rewards, leading to proactive investments in grid resilience [8], [9]. This is particularly important in an era where power systems are increasingly stressed by growing demands, renewable integration, and extreme weather conditions due to climate change [10]. However, previous literature has primarily focused on the operational or maintenance costs associated with implementing rewards-penalty rather than the identifying words-served customers either in terms of the number of interruptions or/and duration of the interruption [6]. Therefore, this study presents a methodology for calculating the probability for the entire distribution system and specific customer types, such as the worst-served customers.

This paper provides a comprehensive database of fault rates, mean repair times of network components, and types of faults that are used in MCS procedures [10], [11], [12]. A straightforward methodology for assessing the reliability performance that responds to the regulation requirement limit imposed by the Regulator to protect domestic (residential) and non-domestic customers from excessive long restoration times.

The organization of this paper is as follows: the regulator requirements is described in section 2. It defined the requirements set by Energy Regulator which include maximum restoration times and value of penalty. Section 2 also presents the reliability assessment of power system. The section 3 present the type of network used in this research. The section 4 presents the worst-served customer (WSC) assessment. In section 5, the result of network performance in system and customer perspective while discussion of result in section 6. Finally, the conclusions are drawn in Section 7.

2. REGULATORY REQUIREMENTS

Regulatory requirements typically define the maximum number of interruptions and maximum duration of interruptions to electric utility customers. These requirements are applicable (depending on factors set by the Energy Regulator) to all types of electric utility customers: domestic, commercial and industry. If the utility does not restore supply within the specific times as in the requirements, the electric utility must compensate the customer or provide a rebate in the next electrical bill.

Electric utilities consistently upgrade and modify their equipment by integrating advanced technological devices and components to improve network performance and achieve the goals established by the Energy Regulator. This strategy enhances network performance and ensures alignment with the Energy Regulator's objectives. To maintain the highest standards of quality and reliability, the Energy Regulator periodically implements new benchmarks for maximum restoration times after an appropriate interval. These revisions include not only shortening the duration of restoration times but also raising the penalties for non-compliance.

Table 1 Performance Standard Limits in Malaysia]13[

GSL	Area	Performance level
GSL1: Frequency of Interruption	Kuala Lumpur/Putrajaya - cities	4 per year
	Other areas	5 per year
GSL2: Restoration Times	Minor distribution network fault	3 hours
	Major distribution network (system with feedback)	4 hours
	Major distribution network (system without feedback)	12 hours

Table 2 Performance Standard Limits in UK [14]

Supply Restoration Time		Compensation Paid to:	
No. of customers interrupted	**Maximum supply restoration time**	**Domestic customers**	**Non-domestic customers**
< 5,000	12 h	£75	£150
	After each succeeding 12h	£35	
≥ 5,000	24 h	£75	£150
	After each succeeding 12h	£35	
	Maximum	£300	

Table 3 Performance Standard Limits in Countries of Portugal, Spain, Moldova and Romania [15]

Country	Area	Interruption limit	Duration of interruption limit (hours)
Portugal	Urban	10	6
	Sub-urban	15	10
	Rural	20	17
Spain	Urban	10	5
	Semi-urban	13	9
	Rural concentrated area	16	14
	Rural dispersed area	22	19
Moldova	Urban	9	7
	Rural	12	10
Romania	Urban	12	6
	Rural	24	12

In Malaysia, the Energy Commission (EC), as an Energy Regulator, has published the Electricity Supply Service Performance Standard (ESSPS) [13], [15]. In Table 1, there are typically two guaranteed service levels: frequency of interruption (1) and restoration times (2). For GSL1, the number of maximum interruptions is based on the type of area, while restoration times depend on the number of faults and distribution connections. In another country, such as the UK, Ofgem, an energy regulator, defines a Guaranteed Standard of performance based on the number of interrupted customers. In Table 2, the maximum restoration time for less than 5000 interrupted customers is 12 hours, while for more than 5000 interrupted customers, it is 12 hours [14]. The value and duration of interruption limits vary by country. In certain countries, energy regulators separate the performance standard limit by area: urban, suburban, and rural [8].

3. IEEE 33 BUS NETWORK

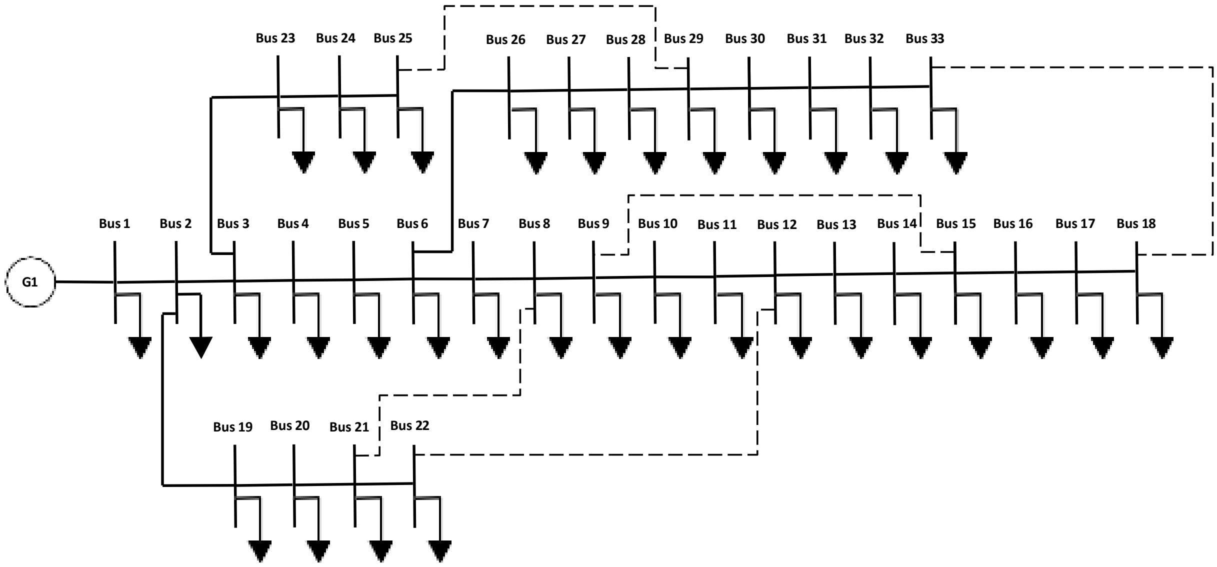

Figure 1. IEEE 33 Bus Network

The IEEE 33-bus system is a standardized test feeder devised to support academic and industry research in power distribution networks. It represents a single-line diagram consisting of 33 buses and 32 lines, thereby structuring a radial topology which is common in electrical distribution systems due to its operational and economic efficiency. The design of this network is based on a typical urban distribution scenario, making it a pertinent model for practical and theoretical studies.

Regarding electrical load, the IEEE 33-bus system illustrates a diverse range of static and dynamic loads typical to urban environments, summing up to a total load demand of approximately 3.715 MW with a reactive power draw of about 2.3 MVAr. This setup allows researchers to conduct comprehensive load flow analyses and evaluate the distribution system's performance under various load conditions. Each bus in the network has a specified voltage level, typically set to 12.66 kV, representing medium voltage distribution systems in urban areas.

4. WORST-SERVED CUSTOMER (WSC) ASSESSMENT

This study chooses the Monte Carlo Simulation (MCS) methodology for its robust capability to produce outputs as probability distribution functions, capturing a broad spectrum of potential outcomes. This method is particularly effective as it incorporates any chosen distribution function. Specifically, this research employs the exponential distribution to characterise the system conditions of components based on their failure rates, while the Weibull distribution is utilised to define the mean times to repair (MTTR).

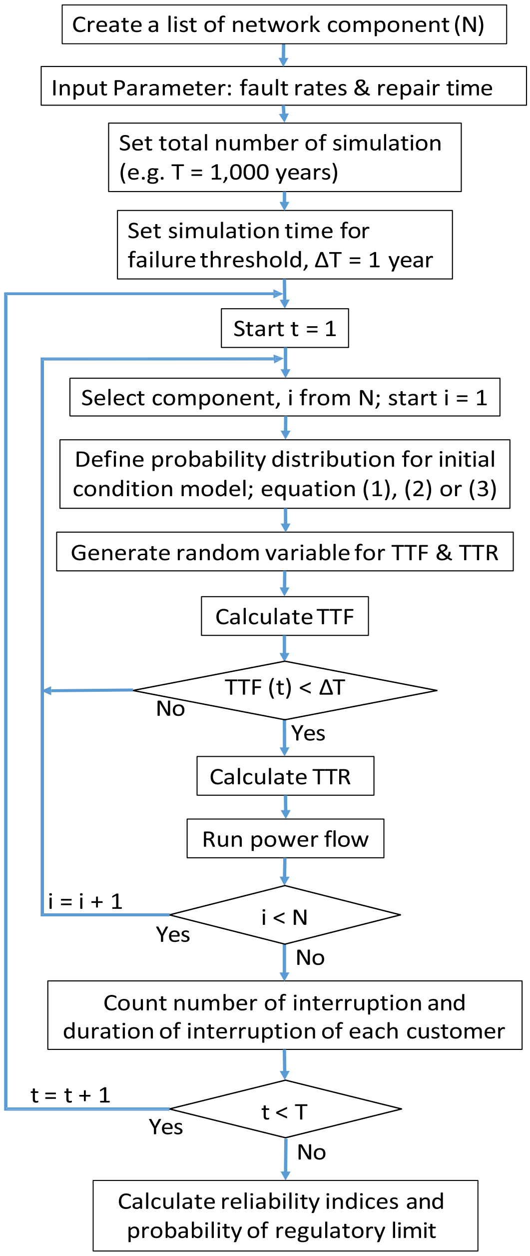

Figure 2. Regulatory-based Monte Carlo Simulation (MCS)

Figure 2 illustrates the general process of the Regulatory-based MCS assessment, which provides a systematic framework for evaluating system reliability. This process involves integrating a random variable into an inverse cumulative function, which is used to transform fault rates into times to failure (TTF) and mean times to repair into actual times to repair (TTR). The application of various distribution functions, including Exponential (1), Weibull (2), and Raleigh (3), allows for effective modelling of network component states, facilitating a detailed reliability analysis [16], [17].

Table 4 Fault Rates and Repair Time

Component	**Fault rates (fault/year per meter)**	**Repair Times (hours/fault)**
Lines	0.034	18.8

The application of the MCS methodology, combined with appropriate distribution functions, offers a comprehensive approach to analysing the reliability characteristics of the power system. This approach accounts for various input variables and their respective distributions, leading to a more realistic and precise evaluation of the system's reliability [18]. Such an approach enhances the accuracy of reliability assessments and aids in foreseeing potential system failures and scheduling maintenance, thereby increasing the system's overall resilience and operational efficiency [16], [19].

Exponential: $\text{TTF or TTR} = inverse\{1 - e^{(-\lambda t)}\}$ (1)

Weibull: $\text{TTF or TTR} = inverse\{1 - e^{(-\frac{t}{\delta})^{\beta}}\}$ (2)

Rayleigh: $\text{TTF or TTR} = inverse\{1 - e^{(-0.5(\frac{t}{\sigma})^{2})}\}$ (3)

5. RESULTS

Table 5 System Indices (Overall)

Indices	Value
SAIFI	0.6185
SAIDI	11.7800
CAIDI	17.6034

Table 6 Bus Customer Performance

Customer bus	Average number of interruption	Average duration of interruption	% Regulatory limit (≥4 interruptions)	% Regulatory limit (≥12 hours)
1	0	0	0	0
2	0	0	0	0
3	0.038	20.73684211	0	2.3
4	0.072	16.92957746	0	3.9
5	0.107	21.29326923	0	6.2
6	0.23	19.30049261	0	11.9
7	0.239	19.5414673	0	12.5
8	0.329	17.64336918	0	15.3
9	0.556	17.46474057	0.5	23.6
10	0.77	18.50044614	0.7	30.6
11	0.776	18.43826336	0.8	30.7
12	0.812	18.4953567	1	32.1
13	1.261	18.33048722	3.8	42.4
14	1.321	18.30185446	4.2	44.2
15	1.384	18.69828767	4.8	45.8
16	1.502	18.69313596	6.3	47.7

17	1.815	18.63854931	10.8	54.8

18	1.934	18.69670483	12.7	57.3
19	0.005	8	0	0.2
20	0.454	18.72015611	0.3	21.9
21	0.493	18.5452381	0.3	22.8
22	0.6	18.47203579	0.4	26.9
23	0.087	20.47590361	0	5.2
24	0.248	19.28453453	0	13.1
25	0.393	19.42623364	0.1	19.5
26	0.242	19.09952607	0	12.5
27	0.26	20.05259259	0	13.7
28	0.493	20.9353042	0.2	25.4
29	0.634	19.42774262	0.4	30.5
30	0.685	19.64349112	0.6	32.8
31	0.87	19.75561167	1.3	39.5
32	0.891	19.589701	1.3	39.8
33	0.908	19.78097588	1.3	40.4

In this section, the network performance is assessed using standard reliability indices: SAIFI, SAIDI and CAIDI. The network components presented in Table 3 are modelled using an exponential distribution function established by prior studies. To guarantee precision, the simulations are conducted over a 1,000-year period with a convergence level set at 5% [20]. This duration has been confirmed in previous research to be adequate for preserving the accuracy of Monte Carlo simulations. Furthermore, the penalty condition or threshold set by the regulatory authority is adopted as the benchmark for assessing the penalty risk encountered by electric utilities[11].

Table 7 Top 5 Best and Worst served customers based on number of interruptions and duration of interruptions

Level	Type	Customer bus	Value
Minimum (Best customer)	Average number of interruption	2	0
		19	0.005
		3	0.038
		4	0.072
		23	0.087
	Average duration of interruption	2	0
		19	8
		4	16.92957746
		9	17.46474057
		8	17.64336918
Maximum (Worst Customer) –	Average number of interruption	14	1.321
		15	1.384

WSC1		16	1.502
		17	1.815
		18	1.934
	Average duration of interruption	27	20.05259259
		23	20.47590361
		3	20.73684211
		28	20.9353042
		5	21.29326923

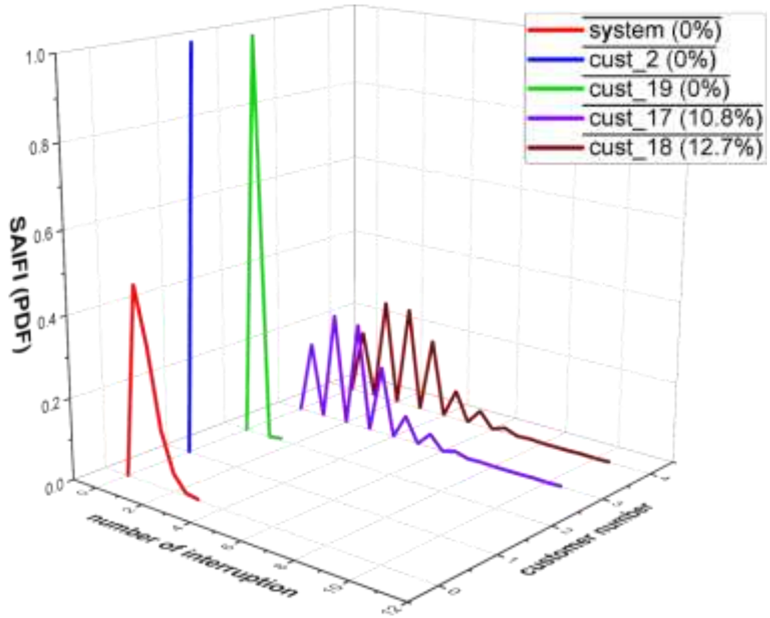

Figure 3. System Average, best-served and worst-served customer in interruption

Table 8 Percentage of interruption and duration of interruption exceed Regulatory limit for system indices (overall)

Regulatory limit	Indices	Percentage exceed limit
4 interruptions	SAIFI	0
12 hours	CAIDI	66.8

Table 9 Percentage of interruption and duration of interruption exceeds Regulatory limit for best and worst served customer

Level	Regulatory limit	Customer bus	Percentage exceed limit
Minimum (Best customer)	≥4 interruptions	2	0
		19	0
		3	0
		4	0
		23	0
	≥12 hours	2	0

		19	0.2
		3	2.3
		4	3.9
		23	5.2
	≥4 interruptions	14	4.2
		15	4.8
		16	6.3
		17	10.8
Maximum (Worst Customer) – WSC2		18	12.7
	≥12 hours	14	44.2
		15	45.8
		16	47.7
		17	54.8
		18	57.3

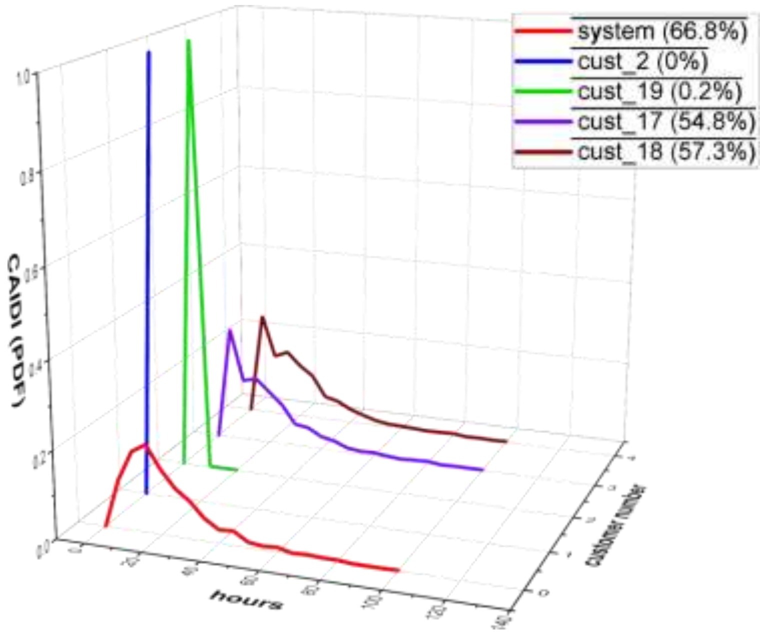

Figure 4. System average, best-served and worst-served customer in duration of interruption

6. DISCUSSION

Electrical energy utilities usually report network performance to energy regulators regarding SAIFI and CAIDI. SAIFI represents the average number of interruptions per customer, while CAIDI represents the average duration of interruptions per customer. These two indices do not illustrate the best-served customer and worst-served customer. Thus, only energy utilities know the location and type of customer for best-served and worst-served customers. Typical determinations of best-served customers and worst-served customers are based on the minimum and maximum number of interruptions or duration of interruptions, respectively.

In the 7th CEER-ERCB Benchmarking report [8], only 4 countries provide a definition of Worst-Served Customers (WSC). In Great Britain, the customers identified as the worst-served are those who experience 12 or more unplanned interruptions at higher voltage levels over a three-year period, with a minimum of three such interruptions annually. Hungary has a monitoring indicator for the number and percentage of interruptions, but no specific requirements are tied to it. The worst-served customers in Hungary are those who encounter one or more unplanned interruptions lasting longer than three hours, more than six unplanned long interruptions, or more than 30 short interruptions within a year. Ireland categorises its worst-served customers as those who have faced at least 15 outages over three years, with at least five outages occurring in the most recent year. It also highlights that climate change significantly impacts these customers, with 65% outages occurring on storm days. In Portugal, the worst-served customers are defined as the worst 5% of customers based on the SAIDI value for medium voltage.

Since there are various versions of classification to determine the worst-served customer (WSC), for this paper, only two types are considered: WSC1, which is a customer with the highest value of interruption or duration of interruption, and WSC2, which is for customers exceeding the regulatory limit in terms of interruption or duration of interruption. Table 7 presents the top 5 best and worst-served customers of WSC1. Meanwhile, Table 4 presents the top 5 best-served and worst-served customers for WSC2.

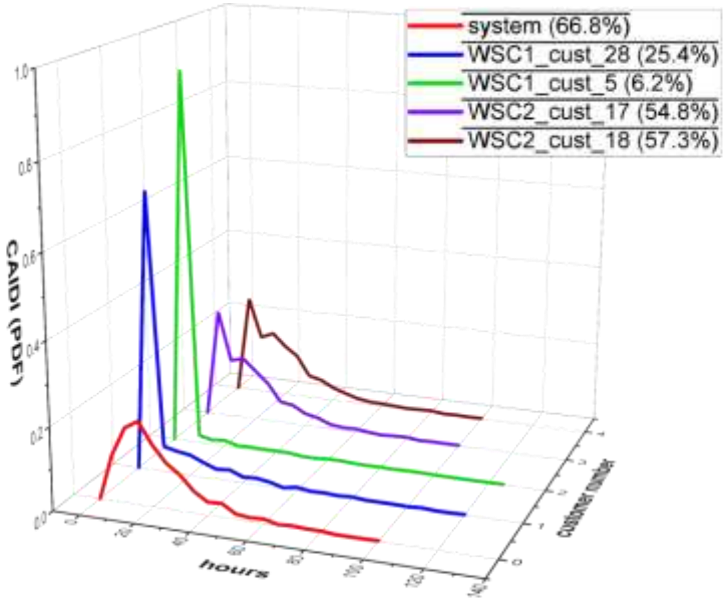

Figure 5. System average, WSC1 customers and WSC2 customers

Figures 3 and 4 show the system average, best-served, and worst-served customers based on the regulatory limits for SAIFI and CAIDI, respectively. In both figures, the graph for the best-served customers is thin due to less interruption or interruption concentrated with a certain minimum area only. For customers who are worst served, the interruption varies, and various values of the interruption duration cause the graph to elongate along the x-axis. A certain duration of interruption exceeds the prescribed limit by the energy regulator.

For best and worst-served customers focused on the number of interruptions, both customers in WSC1 and WSC2 are identical. Meanwhile, best and worst-served customers focused on the duration of interruption show otherwise. The yellow highlighted value is classified as customers not in both WSC1 and WSC2. This happened due to the high frequency of
≥12 hours duration of interruption for customer numbers 14, 15, 16, 17 and 18 compared to customers 27, 23, 3, 28 and 5.

Figure 4 compares the top 2 of WSC1 and WSC2. For WSC1 of customers 28 and 5, the area under the curve that exceeds the regulatory limit of 12 hours is minor, but the 'tail' of the graph is quite long, exceeding 120 hours. This means customers 28 and 5 will experience 1 or 2 interruptions for over 5 days. For WSC2, the 'tail' of the graph is shorted, but the area under the graph exceeding 12 hours is high. This means that for customers 17 and 18, more than half of its interruptions are more than 12 hours.

Table 10 Description of Scenarios

Scenario	Description
1	Both the average duration of the interruption and the percentage limit of that customer are high
2	The average duration of interruption of WSC1 and average duration of interruption of WSC2 is the same in value
3	The average duration of interruption of WSC1 is higher than average duration of interruption of WSC2
4	The average duration of interruption of WSC2 is higher than average duration of interruption of WSC1

Table 11 Before the implementation any network improvement

Scenario	Worst type	1st	2nd	3rd	4th	5th	Average
1	WSC3	10.5	12	10.5	12	10.5	11.1
2	WSC1	11	10.5	11	10.5	11	10.8
	WSC2	10	12	10	12	10	10.8
3	WSC1	11	11	11	11	11	11
	WSC2	10	12	10	12	10	10.8
4	WSC1	11	10.5	11	10.5	11	10.8
	WSC2	10	12.5	10	12.5	10	11

Table 12 After the Implementation of any network improvement

Scenario	Worst type	1st	2nd	3rd	4th	5th	Average
1	WSC3	10.5	10	10.5	10	10.5	10.3
2	WSC1	11	10	11	10	11	10.6
	WSC2	10	10	10	10	10	10
3	WSC1	11	10	11	10	11	10.6
	WSC2	10	10	10	10	10	10
4	WSC1	11	10	11	10	11	10.6
	WSC2	10	10	10	10	10	10

Based on Tables 7 and 9, the worst served customers are divided into 3: 1st is high-value duration of interruption's customer only (WSC1), 2nd is high probability of regulatory limit's customer only (WSC2), and 3rd is high in value of duration of the interruption and high probability of regulatory limit's customer. The question is, which one is the priority for network improvement among these three types of worst customers? First, need to define the possible scenarios. There are 4 possible scenarios in Table 10. Tables 11 and 12 are examples of results before and after implementing any network improvement, respectively. These two tables are for understanding the priority of network improvement for the worst type of customer.

In Table 11, each type of customer has 5 different hours of interruption. Any implementation of network improvement is set to 10 hours. These 10-hour improvements are set only at the 2nd and 4th duration of the interruption. Scenario 1 is the easiest. If there is a customer of WSC3 in both Table 7 and 9, that customer is the highest priority in the network. Improvements from that customer will refine the duration of the interruption and percentage of regulatory limit specifically for that customer and in the overall network generally, as in Table XII.

In Table 12 also, the customer priority of network improvement for scenarios 2-4 is customer WSC2. This is due to the value of the interruption duration after improvement for WSC2 (10 hours) compared to WSC1 (10.6 hours). Furthermore, refining WSC2 also reduces the percentage that exceeds the regulatory limit. The WSC1 has a high duration of interruption (average 10.8 hours) without any of it exceeding the regulatory limit. The WSC2 have the same average duration of interruption (10.8 hours) but contain two duration of interruption that exceed the regulatory limit (WSC2 at 2nd and 4th duration of interruption)

7. CONCLUSION

There are various methods of determining the best-served and worst-served customers. For the best-served customer, maybe upgrading or no modification is needed as that customer is experiencing the best service, but for the worst-served customer, it does need some upgrading. Refining the worst-served customer not only improves the number of interruptions and interruption duration for that customer but also refines the SAIFI and CAIDI of the overall network. The electric utility company may also pay fewer penalties if WSC is served better.

The worst served customers are divided into 3: 1st is high-value duration of interruption's customer only (WSC1), 2nd is high probability of regulatory limit's customer only (WSC2), and 3rd is high in value of duration of the interruption and high probability of regulatory limit's customer. The 1st priority is for WSC3, 2nd priority is WSC2, and the less priority is WSC1. By selecting the customers with the highest priority, the advantages are greater; the customers reduce interruption/duration. Generally, network performance also improved, and fewer penalties were paid.

ACKNOWLEDGEMENT

This research is supported by the Ministry of Higher Education Malaysia (FRGS/1/2022/TK07/UMP/02/4) and Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) under grant number RDU220103. The authors would also like to thank the Faculty of Electrical & Electronics Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah for providing facilities to conduct this research.

REFERENCES

[1] J. C. das Neves Neto, A. Abubakar, C. F. Meschini Almeida, and E. Delbone, "Stochastic Analysis (MCS) for Mitigation of Reliability Indicators of the Power Distribution System," in *2022 IEEE PES Generation, Transmission and Distribution Conference and Exposition – Latin America (IEEE PES GTD Latin America)*, IEEE, Oct. 2022, pp. 1–5. doi: 10.1109/IEEEPESGTDLatinAmeri53482.2022.10038302.

[2] J. H. Wang, H. W. Ngan, W. Engriwan, and K. L. Lo, "Performance based regulation of the electricity supply industry in Hong Kong: An empirical efficiency analysis approach," *Energy Policy*, vol. 35, no. 1, pp. 609–615, Jan. 2007, doi: 10.1016/J.ENPOL.2006.01.011.

[3] T. Jamasb and M. Pollitt, "International benchmarking and regulation: an application to European electricity distribution utilities," *Energy Policy*, vol. 31, no. 15, pp. 1609–1622, Dec. 2003, doi: 10.1016/S0301-4215(02)00226-4.

[4] M. H. Enjavimadar and M. Rastegar, "Optimal reliability-centered maintenance strategy based on the failure modes and effect analysis in power distribution systems," *Electric Power Systems Research*, vol. 203, Feb. 2022, doi: 10.1016/j.epsr.2021.107647.

[5] Ofgem, "RIIO-ED1 Network Performance Summary 2020-21," 2023. Accessed: May 28, 2024. [Online]. Available: https://www.ofgem.gov.uk/publications/riio-1-electricity-distribution-annual-report-2021-22-and-regulatory-financial-performance-annex-riio-1-annual-reports

[6] M. Esmaeeli, A. Kazemi, H. Shayanfar, M.-R. Haghifam, and P. Siano, "Risk-based planning of distribution substation considering technical and economic uncertainties," *Electric Power Systems Research*, vol. 135, pp. 18–26, Jun. 2016, doi: 10.1016/J.EPSR.2016.03.013.

[7] A. Moradkhani, M. R. Haghifam, and S. M. Abedi, "Risk-based maintenance scheduling in the presence of reward penalty scheme," *Electric Power Systems Research*, vol. 121, pp. 126–133, Apr. 2015, doi: 10.1016/J.EPSR.2014.12.006.

[8] A. M. Spence, "Monopoly, Quality, and Regulation," *The Bell Journal of Economics*, vol. 6, no. 2, p. 417, Autumn 1975, doi: 10.2307/3003237.

[9] H. Mohammadnezhad-Shourkaei, A. Abiri-Jahromi, and M. Fotuhi-Firuzabad, "Incorporating Service Quality Regulation in Distribution System Maintenance Strategy," *IEEE Transactions on Power Delivery*, vol. 26, no. 4, pp. 2495–2504, Oct. 2011, doi: 10.1109/TPWRD.2011.2142200.

[10] E. Tomasson and L. Soder, "Improved Importance Sampling for Reliability Evaluation of Composite Power Systems," *IEEE Transactions on Power Systems*, vol. 32, no. 3, 2017, doi: 10.1109/TPWRS.2016.2614831.

[11] M. I. Muhammad Ridzuan and S. Z. Djokic, "Energy Regulator Supply Restoration Time," *Energies (Basel)*, vol. 12, no. 6, p. 1051, Mar. 2019, doi: 10.3390/en12061051.

[12] M. Firouzi, A. Samimi, and A. Salami, "Reliability evaluation of a composite power system in the presence of renewable generations," *Reliab Eng Syst Saf*, vol. 222, 2022, doi: 10.1016/j.ress.2022.108396.

[13] Energy Commission Malaysia, "Performance Standard Of Electricity Supply Services Of TNB," 2014.

[14] "The Electricity (Standards of Performance) Regulations 2015," *Standard No.699, Office of Gas and Electricity Markets (OFGEM), 2015*.

[15] Energy Commission, "Performance Standard of Electricity Supply Services of TNB," pp. 1–8, 2016, [Online]. Available: https://www.st.gov.my/index.php/en/download-

page/category/94-guidelines-electricity?download=617:performance-standard-of-electricity-supply-services-of-tnb

[16] N. F. Mohd Fauzi, N. N. R. Roslan, and M. I. Muhammad Ridzuan, "Reliability performance of distribution network by various probability distribution functions," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 2, pp. 2316–2325, Apr. 2023, doi: 10.11591/ijece.v13i2.pp2316-2325.

[17] E. O. Amuta, S. T. Wara, A. F. Agbetuyi, and B. A. Sawyerr, "Weibull distribution-based analysis for reliability assessment of an isolated power micro-grid system," *Mater Today Proc*, vol. 65, pp. 2215–2220, Jan. 2022, doi: 10.1016/J.MATPR.2022.06.244.

[18] R. Shiomi, H. Shimasaki, H. Takano, and H. Taoka, "A study on operating lifetime estimation for electrical components in power grids on the basis of analysis of maintenance records," *Journal of International Council on Electrical Engineering*, vol. 9, no. 1, pp. 45–52, Jan. 2019, doi: 10.1080/22348972.2019.1612975.

[19] M. Edimu, C. T. Gaunt, and R. Herman, "Using probability distribution functions in reliability analyses," *Electric Power Systems Research*, vol. 81, no. 4, pp. 915–921, Apr. 2011, doi: 10.1016/J.EPSR.2010.11.022.

[20] N. N. R. Roslan, N. F. M. Fauzi, and M. I. M. Ridzuan, "Variance reduction technique in reliability evaluation for distribution system by using sequential Monte Carlo simulation," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3061– 3068, Dec. 2022, doi: 10.11591/eei.v11i6.3950.