Low voltage reliability equivalent using monte-carlo simulation technique

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Abstract. Reliability is the ability of a system to supply continuous electricity to customer which ends with zero fault that occurs under a specific period of time. Most of the literature focus more on medium voltage (MV) and high voltage (HV) compared to the low voltage (LV) due to the general absence of exact data in LV network and sizing of LV network. In addition, an increment in size of the LV network makes the network more complex and difficult to assess. Therefore, in this paper, the performance of reliability in LV network will be evaluated in detailed network model. To reduce simulation time, methodology of reducing detailed network into an equivalent network is introduced. This equivalent network is obtained by simplifying the complex network using Monte-Carlo Simulation technique. The results in this research are quantified and compared between these detailed and equivalent networks in reliability indices; SAIFI, SAIDI and CAIDI. The values of SAIFI, SAIDI and CAIDI in detailed network are slightly higher than in equivalent network.

1. Introduction
Power systems are perhaps the most complex large-scale engineered systems today, and it is predicted to have the highest level of reliability. The interruption always occurs in the system, yet their customers expect more reliability and affordability [1]. Over decades, the reliability of power system evaluation was focused more on the generation and transmission compared to the distribution system especially on the low-voltage distribution although this low voltage will also affect the performance of power system. The goal of the present planned in distribution system is to ensure that the performance of power system, especially in LV and MV will give better effect to the customers. Thus, it is important to ensure that the customer will get the continuity of supply with minimum interruption occurring. In most of the power system, both MV and LV are represented in a lumped model due to the complexity of calculation and the volumes of LV and MV [2]. Hence, the simulation will take time to compute the result for the reliability analysis in such a complex and large network. Thus, the representation of an equivalent network will simplify the complex network, consequently reducing simulation time.

Since distribution network is currently supplying the most customers, it is tied up by the target or minimum customer satisfaction level imposed by Energy Regular, which in Malaysia is Energy Commission (EC). These targets mostly involve the frequency and duration of interruption. To attain that target, distribution network operators (DNOs) must correctly assess their reliability performance. Therefore, it is critical to have accurate distribution network configurations and parameters. However, due to the size of distribution network, low voltage (LV) network is often represented by aggregate model [3-8].
In this research, the main intention is to represent the whole LV network with a single equivalent component. This simplified equivalent component is implemented in MV system specifically at the downstream of the aggregation of MV point. The performance of reliability in a detailed network should be assessed first before an assessment in an equivalent network can be done. The detailed network will give more details and specific information of the system such as the interruption on the specific location and occurrence of fault while the equivalent network consists of simplified information of the network.

2. Monte-Carlo simulation technique

In reliability assessment, there are two types of methods that can be used to evaluate the reliability performance of the network, which are analytical and probability assessment. The analytical method uses a mathematical based approach which evaluates the performance of reliability in power system using mathematical solution while the probability method uses random nature process. In terms of contingency, basically the analytical approach will choose the states in increasing order of which each state is evaluated in just one time. The reliability indices are then calculated using mathematic solution based on the statistical data related to each state [9]. As power system consists of a large and complex network, Monte-Carlo Simulation (MCS) will be used to evaluate and assess the performance of networks [10, 12]. Figure 1 shows the flowchart of how the performance of reliability in the system is assessed. The sequential MCS technique is used which simulates the system chronological behaviour by sampling the system state sequences for several period of time. For this method, two basic inputs which are fault rate and repair time, need to be identified first before it can be randomly generated [13, 14].

![Flowchart of Monte-Carlo simulation.](image)

In this research, two models of bus system, which are Network 14 and Network 4gs (networks from Matpower) are used to represent the distribution network. Network 14 represents LV distribution.
network for Case 1 as shown in figure 2. Meanwhile Network 4gs represents MV distribution network for Case 2 as shown in figure 3. Both of the networks are being modified by only one generator to analyse the reliability performance of the systems. Before an equivalent network can be assessed, a few analysis needs to be done in both LV and MV networks. In distribution system, the LV network is always located to the downstream of MV network. Even though the objective of this research is to evaluate the performance of LV network, the assessment of MV network is also included to quantify and justify the importance of detailing the distribution network. Hence, there are about 4 different networks that need to be analysed differently tabulated in table 1.

**Table 1. Description of cases.**

| Case | Description |
|------|-------------|
| 1    | LV network consists of 14 buses and 20 branches (figure 2) |
| 2    | MV network consists of 4 buses & 4 branches (figure 3) |
| 3    | Detailed (a combination of MV and LV) network consists of 56 buses & 84 branches (figure 4) |
| 4    | Equivalent network (a combination of MV and LV equivalent) network (figure 5) |

**Figure 2.** LV Network for case 1.
**Figure 3.** MV Network for case 2.

**Figure 4.** MV and detailed LV Networks for case 3.
2.1. Input data, fault rate and repair time
As stated above, two basic inputs in the reliability assessment are fault rate and repair time. It is very important to select the accurate value for both of these inputs since it will indirectly affect reliability performance. For each of failure rate and repair time, it will consider the reliability performance of every component in the network such as transformer, circuit breaker, etc as tabulated in table 2. In this research, two components of power systems are included, but the main focus is overhead line since it is the most dominant component in the network.

Table 2. Parameter for reliability analysis in LV and MV network [15,16].

| Component       | Voltage (kV) | Fault rates (failure/year) | Repair times (hours/fault) |
|-----------------|--------------|---------------------------|---------------------------|
| Overhead lines  | 11           | 0.123                     | 5                         |
|                 | 0.4          | 0.168                     | 6.44                      |
| Transformer     | 11/0.4       | 0.015                     | 5                         |

2.2. Reliability Indices
In distribution system, the assessment of the reliability can be divided into two different groups which are load indices and system indices [17]. There are a few reliability indices used as a parameter to evaluate the performance of reliability in the system which are SAIDI, SAIFI, MAIFI, CAIDI, ENS and AENS [18]. In this analysis, only three common indices are considered, which are SAIDI, SAIFI and CAIDI as defined by equation (1) to equation (3). These indices are very important especially to the service provider to record the performance of reliability in power system in order to ensure better quality of services received by the customers [19].

\[SAIFI = \frac{\text{Total number of customers interrupted (LI)}}{\text{Total number of customers served}}\] (1)
\[ SAIDI = \frac{\text{Total number of interruption durations (LI)}}{\text{Total number of customers served}} \]  
\[ CAIDI = \frac{SAIDI}{SAIFI} \]

3. Results and discussion

Figure 6 below illustrates the average indices of 4 different cases. Based on figure 6, the average of \( SAIFI \) in Case 1 network is slightly lower than in Case 2. This is because the total interruption in LV is lower than in MV, which is directly related to failure rates from table 2. Another contributing factor is the number of component in Case 1 is higher than Case 2. Since the formula of \( SAIFI \) is related the total interruption, hence an increase in the occurrence of interruptions in the system will also increase the value of \( SAIFI \). Since LV network is located to the downstream of MV; thus the interruptions in LV will affect the total interruptions in MV for Case 3 and 4. Hence, the interruptions in MV will be higher than in LV. This is one of the reasons why the average of \( SAIFI \) is lower than in MV.

The repair time used in Case 1 and Case 2 are 5 hours/fault and 6.44 hours/fault, respectively. Since the average of interruption hours (\( CAIDI \)) is inversely proportional to the average failure rate (\( SAIFI \)), hence the higher the value of \( SAIFI \), the lower the value of \( CAIDI \). Figure 6 illustrates Case 2, which has higher \( SAIFI \) and the lowest \( CAIDI \). While for Case 3 and Case 4, the average values of \( SAIFI \), \( SAIDI \) and \( CAIDI \) are close each other. The result of the average reliability indices obtained in both Case 3 and Case 4 are acceptable since these network models need to be the same or almost the same for all the indices. This is because the representation of the equivalent network (Case 4) is to simplify the large/complex network (Case 3) without changing any parameters of the network.

Table 3 below shows the percentage error between detailed (Case 3) and equivalent network (Case 4). The average of \( SAIFI \) between Case 3 and Case 4 are close to each other. Hence, the percentage error between these two is the lowest. Since Case 3 is the combination of LV and MV networks, therefore, the repair time of the components is different according to the types of networks. Thus, the percentage error in the average of \( CAIDI \) between Case 3 and Case 4 is about 0.72% which is higher than percentage error in \( SAIFI \). Lastly, the percentage of error in \( SAIDI \) is the highest compared to the others. The \( SAIDI \) index is the total duration of interruption over the total number of customers. The total duration of interruptions is related to the repair time and interruptions of components. Since the interruptions in detailed network varies and there are a few customers who are not interrupted at all, hence it will affect the overall average of \( SAIDI \) in detailed network. Thus, the percentage error of \( SAIDI \) between these two

| Case 1 | Case 2 | Case 3 | Case 4 |
|--------|--------|--------|--------|
| 0.0601 | 0.07125| 0.06531| 0.0625 |
| 0.086525| 0.086525| 0.086525| 0.086525|
| 0.356786| 0.35625| 0.36018| 0.35625|
| 0.4170 | 0.4170 | 0.4170 | 0.4170 |
| 5.56   | 5.56   | 5.56   | 5.56   |

Figure 6. Reliability results for four cases.
networks are the highest. This percentage error of SAIDI can be reduced by increasing the simulation time.

Table 3. The percentage error between detailed (Case 3) and equivalent network (Case 4).

| Average Index | Case 3 | Case 4 | Percentage Error (%) |
|---------------|--------|--------|----------------------|
| SAIFI         | 0.06531| 0.06525| 0.09                 |
| SAIDI         | 0.4170 | 0.36018| 13.63                |
| CAIDI         | 5.56   | 5.52   | 0.72                 |

3.1. Detailed network
The detailed network (Case 3) represents the combination of both MV with LV detailed networks. All the parameters of components in the network must be configured and analysed. These parameters such as resistance, R and reactance, X of components in the network must be represented by equivalent values, which are Req and Xeq. All the information of parameters used in this analysis are obtained from MatPower. In Case 3, detailing the network model required more time to model the network and higher simulation time compared to Case 4. The positive side of Case 4 is it can provide more detailed information, especially on the specific location/component of interruption and duration of interruption in the system.

Since the failure rate of the lines depends on the length of lines, hence increasing the length of the line will increase the failure rate. The data of interruptions of a specific customer will facilitate the service provider to detect the location of failure in a short time, hence reducing the duration of interruptions experienced by the customers. Figure 7 shows the reliability indices for each of the customers. This graph displays that the reliability indices for every customer varied among them. This means that each of the customer will experience a different total number of interruptions. Based on the graph, for customers 1, 31, 32, 33, 44, 46 and 47, there is no reliability indices recorded. It means that these customers did not experience interruptions at all. This is due to many combinations of electrical path from source to load, which increase the security level for these customers.

![Figure 7. Detail reliability indices for case 3.](image)

3.2. Equivalent network
This equivalent representation (Case 4) will not change the parameter of the components in the network because the total number of the same parameter is represented with one equivalent value. There are about 56 customers in the detailed network (Case 3); thus, the parameters of LV network (Case 1) at
every 14 customers will be represented with one equivalent customer. In this case, the reliability indices (SAIFI, SAIDI, CAIDI) are used to justify the representation of detailed network (Case 3) with an equivalent network (Case 4).

The equivalent network (Case 4) has benefits, especially in reducing the simulation time, but it is really difficult to detect the interruption and location of interruption occurring in the network. This is because one equivalent value represents a numerous values of components and configurations in the LV network. If the type of fault component and location of fault is detected, the service provider will be able to provide mitigation plan to overcome this interruption by re-routing the electrical path from source to customers. Hence, it is crucial, especially to the service provider to decide, either to detect the specific location of the failure in the network or save detailed network modelling time and simulation time.

Figure 8 shows the reliability indices obtained for each customer in Case 4. Based on the graph, the value of CAIDI obtained is constant for each of the customers. The result is acceptable since the values for Case 3, and Case 4 are almost the same. The value differences between Case 3 and Case 4 are able to be reduced by increasing the simulation value.

![Figure 8. Detail reliability indices for case 4.](image)

4. Conclusion
This paper has introduced the methodology of reducing large/complex network into a single equivalent network. The complexity of the network is represented by one equivalent network in which the parameter of reliability indices of these networks will have the same value or close to each other depending on the number of simulations. The percentage error of reliability indices can be reduced by increasing the number of simulations (years). Although the equivalent of a network can simplify the network and reduce simulation time, the disadvantage of this network is the difficulty to determine the location of fault and faulty component.

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Reference
[1] I. Hernando-Gil, B. Hayes, A. Collin, and S. Djokic, “Distribution network equivalents for reliability analysis. Part 2: Storage and demand-side resources,” *IEEE PES ISGT Europe*, IEEE, pp. 1–5, Oct-2013.
[2] I. S. Ilie, I. Hernando-Gil, and S. Z. Djokic, “Reliability Equivalents of LV and MV Distribution
Networks,” *IEEE International Energy Conference and Exhibition, ENERGYCON 2012*, pp. 343–348, 2012.

[3] S. Kazemi, “Reliability evaluation of smart distribution grids,” PhD thesis, Aalto University, Espoo, Finland, 2011.

[4] O. Siirto, M. Loukkalahti, M. Hyvarinen, P. Heine, and M. Lehtonen, “Neutral point treatment and earth fault suppression,” in *Electric Power Quality and Supply Reliability Conference (PQ)*, 2012, pp. 1–6.

[5] M. Katsanevakis, R. A. Stewart, and L. Junwei, “A novel voltage stability and quality index demonstrated on a low voltage distribution network with multifunctional energy storage systems,” *Electr. Power Syst. Res.*, vol. 171, pp. 264–282, Jun. 2019.

[6] M.-G. Jeong *et al.*, “Optimal Voltage Control Using an Equivalent Model of a Low-Voltage Network Accommodating Inverter-Interfaced Distributed Generators,” *Energies*, vol. 10, no. 8, p. 1180, Aug. 2017.

[7] I. Afandi, P. Ciufo, A. Agalgaonkar, and S. Perera, “A holistic approach for integrated volt/var control in MV and LV networks,” *Electr. Power Syst. Res.*, vol. 165, pp. 9–17, Dec. 2018.

[8] A. Di Fazio, M. Russo, M. De Santis, A. R. Di Fazio, M. Russo, and M. De Santis, “Zoning Evaluation for Voltage Optimization in Distribution Networks with Distributed Energy Resources,” *Energies*, vol. 12, no. 3, p. 390, Jan. 2019.

[9] O. G. I. Okwe Gerald Ibe, “Adequacy Analysis and Security Reliability Evaluation of Bulk Power System,” *IOSR J. Comput. Eng.*, vol. 11, no. 2, pp. 26–35, 2013.

[10] R. Billinton and R. Allan, *Reliability Evaluation of Power Systems*, 2nd ed. New York, 1996.

[11] D. Urgun and C. Singh, “A Hybrid Monte Carlo Simulation and Multi Label Classification Method for Composite System Reliability Evaluation,” *IEEE Trans. Power Syst.*, vol. 34, no. 2, pp. 908–917, Mar. 2019.

[12] L. Peng, B. Hu, K. Xie, H.-M. Tai, and K. Ashenayi, “Analytical model for fast reliability evaluation of composite generation and transmission system based on sequential Monte Carlo simulation,” *Int. J. Electr. Power Energy Syst.*, vol. 109, pp. 548–557, Jul. 2019.

[13] M. Muhammad Ridzuan, S. Djokic, M. I. Muhammad Ridzuan, and S. Z. Djokic, “Energy Regulator Supply Restoration Time,” *Energies*, vol. 12, no. 6, p. 1051, Mar. 2019.

[14] M. I. Muhammad Ridzuan, I. Hernando-gil, and S. Djokic, “Reliability Analysis on Protection Devices Inclusion in LV Residential Distribution Network,” *J. Telecommun. Electron. Comput. Eng.*, vol. 10, no. 1, pp. 137–141, 2018.

[15] M. I. Muhammad Ridzuan, “Reliability Assessment of Distribution Networks Incorporating Regulator Requirements, Generic Network Equivalents and Smart Grid Functionalities,” The University of Edinburgh, 2017.

[16] I. Hernando Gil, “Integrated assessment of quality of supply in future electricity networks,” *PhD’s thesis, University of Edinburgh*, 2014.

[17] M. Anumaka, “Fundamentals of Reliability of Electric Power System and Equipment,” *Int. J. Eng. Sci. Technol.*, vol. 3, 2011.

[18] “IEEE guide for electric power distribution reliability indices,” *IEEE 1366*, 2004.

[19] Energy Commission Malaysia, “Performance and Statistical Information in Malaysia 2016,” *Suruhanjaya Tenaga*, p. 103, 2016.