Reliability Indices Evaluation of LV Distribution System and Inclusion of Protective Devices for Reliability Improvement

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Abstract: This paper analyzes the reliability of low voltage (LV) distribution system of the Sri Lankan power system. Performance of LV distribution systems where mainly domestic consumers depend on the individual components of the system. Failure rates of elements of the system are calculated based on the historical data of the LV distribution system in a semi-urban area. Load point reliability indices are calculated using the analytical method. Consumer-oriented reliability parameters and energy not served, and its cost are determined. As a method of improvement of reliability, inclusion of fuses to the lateral feeders of the main feeder is proposed. Load point reliability indices, consumer-oriented reliability indices, and energy not served are calculated for the distribution system with fuses in lateral feeders. The results are compared with the reliability indices of the present system and analyzed.

Keywords: LV Distribution System, Reliability Indices, Failure Rate, Energy Not Served

1 Introduction

Human activities in modern society are highly dependent on the availability of electrical energy and therefore consumers expect a high level of a reliable supply of electricity from utility companies. Under these circumstances, utility companies are entrusted to supply an uninterrupted supply of electricity to consumers. LV distribution systems to which most consumers are connected, consist of radial distributors. Except in cities where the lying of overhead conductors is not practical, many of the LV systems consists of overhead lines because of financial constraints. The reliability of electricity supply to consumers depends on the reliability of the electrical equipment that contributes to delivering electricity to the doorstep of the energy users. The reliability of individual network components (lines, poles, insulator, etc.) in many of the distribution systems are high, but hundred percent fault-free systems are not possible. This is because consumers' reliability depends on several other factors such as faults due to environmental effects, human activities, maintenance practices, etc. The LV systems are vulnerable to the aforementioned factors. But, still, the number of consumers affected by such faults can be minimized by sectionalizing distributors using protective devices. Utility companies always look for methods of reliability improvement since they are benefited due to minimizing the drop of energy sales and avoiding payment for energy not supplied. The Topology of the LV distributor is similar to a structure of a tree that has the main branch and subbranches divided from the main branch. LV distributor runs along the road supply electricity to the consumers at both sides of it and lateral distributors supply electricity to the consumers in streets, avenues, etc. Generally, the distributor is protected only by a HRC fuse/Moulded Case Circuit Breaker(MCCB)installed at the point where it is connected to the distribution transformer. Hence, any fault in the distributor causes interruption of electricity consumption of hundreds of consumers of that distributor. Inclusion of fuses to the lateral distributors can reduce the number of consumers affected and hence improve the reliability of electricity supply to the consumers. This paper analyzes the level of reliability improvement of the present LV distribution system with the inclusion of protective devices to lateral distributors and the amount of energy that can be sold with this improvement. Data used in this work has been collected from a LV distribution system of a semi-urban area and results reflect the level of reliability of electricity supply of energy users of the country. In distribution system reliability analysis, much of attention has been paid to the reliability of primary distribution systems [1-2]. At the meantime, studies related to LV systems reliability are not many [3]. The structure of LV systems and the protective devices used are vary from country to country and less attention has been paid to the reliability analysis of local low voltage distribution systems. The present study is an attempt to assess the reliability of electricity supply to consumers. Reliability analyses can be carried out using an analytical method or probabilistic method. In this study, the analytical method has been used [4].

2 Methodology

2.1 Calculation of Distribution System Elements' Reliability Indices

LV distribution system consists of a distribution transformer, overhead lines, poles, insulators, and fuse. Historical data on number of failures and time duration for restoration (repair time) of the above electrical equipment were collected and these data were used to calculate failure rate (λ), average repair time (r), and annual outage time (u) of the equipment [4].

$$\lambda = \frac{number\ of\ failures}{total\ operating\ time\ of\ units} \quad (1)$$

$$u = \lambda r \quad (2)$$

2.2 Calculation of Consumer Reliability Indices

Consumers of the LV distribution system are fed from the grid via a distribution transformer. Generally, the LV distribution system consists of three to five distributors and the consumers are connected to the distributors at the poles. The distributors are protected by either HRC fuse or MCCB that is installed at the connecting point of the distributor to the distribution transformer. Therefore, fault at any point in the distributor causes disconnection of the entire distributor from the supply. This results interruption of electrical supply to all the consumers connected to the affected feeder. Because of this arrangement, all the consumers of a feeder do have the same reliability indices. Failure rate of any consumer of the distributor was calculated using formula (3).

$$\lambda_{consumer} = \lambda_T + \lambda_{line}\, l_{line} + \lambda_{pole} N_{pole} + \lambda_{inulator} N_{insultor} \quad (3)$$

Where

$\lambda_{T,}\lambda_{line}, \lambda_{pole}, \lambda_{inulator}$ – failure rate of the distribution transformer, line (distributor), pole, and insulator respectively.

l_{line} - length of the distributor (km)

N_{pole},- total number of poles of a distributor

$N_{insultor}$ - total number of insulators of a distributor

Annual outage time ($U_{consumer}$) was calculated using formula (4)

$$U_{consumer=} \sum \lambda_i r_i \quad (4)$$

Where λ_i and r_i are failure rate and average repair time of each electrical equipment (transformer, line, pole, and insulator) of the distribution system respectively Average outage time ($r_{consumer}$) of the consumers was calculated using formula (5).

$$r_{consumer} = \frac{U_{consumer}}{\lambda_{consumer}} \quad (5)$$

2.3 Calculation of consumer-oriented reliability indices

Standard set of reliability indices was determined to assess the network reliability. These reliability indices are System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI). Load and energy reliability indices (Energy Not Served – ENS, Average energy Not Supplied - AENS) also were calculated to assess the energy that has not been served to the consumers due the failures [5].

$$SAFI = \frac{\sum \lambda_i N_i}{\sum N_i} \tag{6}$$

$$SAIDI = \frac{\sum U_{consumer,i} N_i}{\sum N_i} \tag{7}$$

$$CAIDI = \frac{SAIDI}{SAIFI} \tag{8}$$

$$ENS = \sum L_i U_{conusmer,i} \tag{9}$$

$$AENS = \frac{\sum L_i U_{conusmer,i}}{\sum N_i} \tag{10}$$

Where

L_i- average load of the consumer

N_i-number of consumers of a distributor.

Determination of the average load of the consumers in the LV distribution system is a difficult task. This is because of the non-availability of load variation data of the consumers. But, if smart energy meters are installed at the consumers' location, the daily load profile of each consumer can be obtained easily. Considering the load profile of the consumers, the average load of each consumer and average load of the distributor were calculated. If the consumers in the distribution system do not have smart energy meters, sample load measurement of selected consumers needs to be carried out, and based on the measurements the load profiles of the rest of the consumers are estimated.

2.4 Inclusion of HRC Fuses to the Lateral Branches of the Feeders.

After determination of reliability indices of consumers of the existing system, consumers reliability improvement was analyzed with the inclusion of fusses to the lateral distributors. This enables to keep the part of the feeder without interruption when there is a failure in the sections of the feeder. Consumers’ reliability indices, system reliability indices, and ENS of the system after inclusion of additional fuses to the lateral distributors were calculated. Reliability parameters and ENS of the system after modification were compared with the same parameters in the present system.

3 Results and Discussion

The reliability improvement of the system after the inclusion of additional fuses to the lateral feeders was evaluated using a LV distribution system of a semi-urban area consisting of five feeders. A single line diagram of the system is shown in Fig. 1(a). The LV distribution system after inclusion of fuses at the lateral distributors is shown in Fig.1(b).

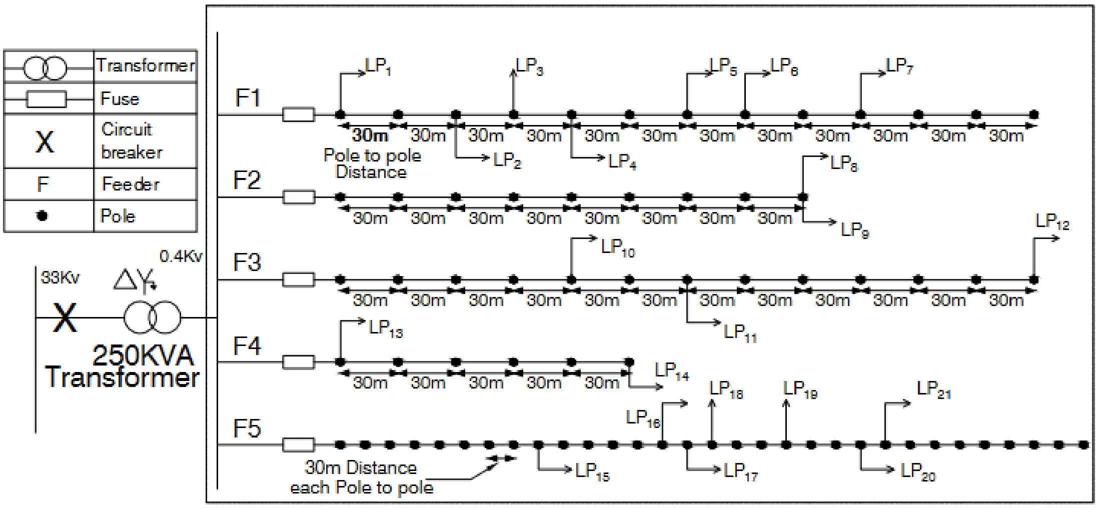
Failure rates and average repair time of the components of the distribution system were calculated based on the collected data on interruptions for three years (2017, 2018 and 2019) and are given in Table 1.

Consumers reliability indices for the existing system were calculated using formulas (3), (4) and (5) and the results are given in Table 2.

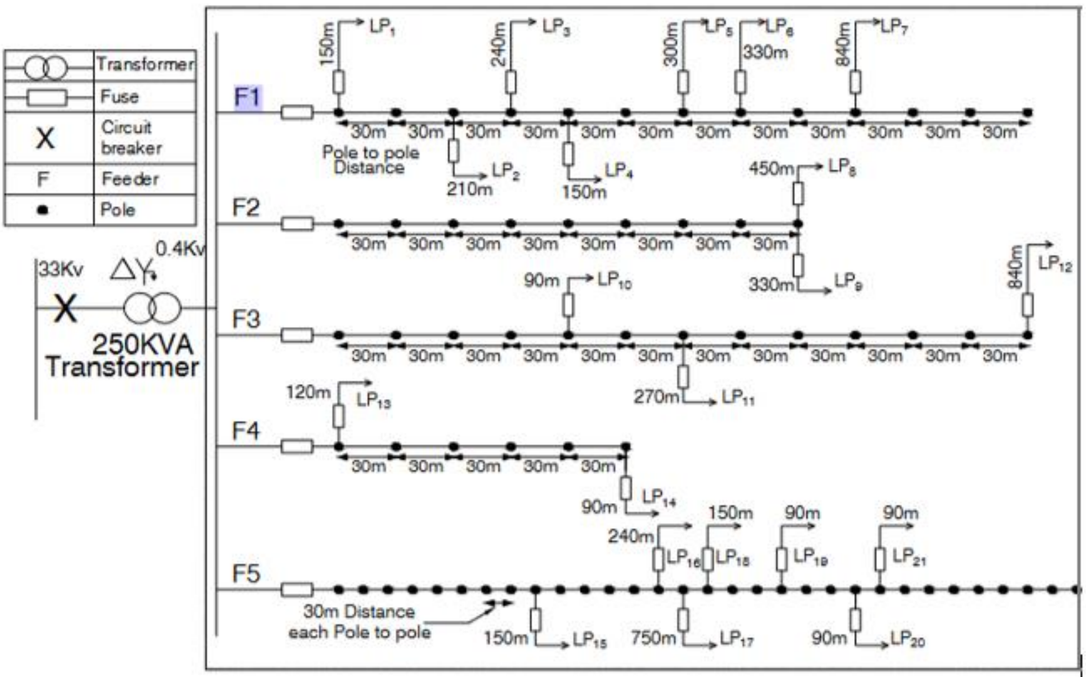
Consumer-oriented reliability indices were calculated using formula (6)-(8) and are shown in Table 3. Reliability indices of the consumers after the inclusion of fuses to the lateral feeders are given in table 5and load data of the feeders are given in table 4.

System reliability indices for the proposed system is given in Table 6.

System reliability indices (SAIFI, SAIDI, CAIDI) of the existing system and the system with the proposed system are shown in fig.2,3 and 4.



(a)



(b)

Fig.1 Distribution Systems (a) Existing Distribution System (b) Distribution System after Inclusion of Fuses

Table 1 Failure Rates and Average Repair Time of the Elements of the System

Component	λ faults/year	Average Repair Time (Min)	Outage Time (Min)
Transformer	0.0419	327	13.704
Pole	0.00070	166	0.11169
Distributor- (Al conductor (per km)	0.0614	181	11.113
Insulator	0.00154	74	0.11396

Table 2 Customers' Reliability Indices (Existing System)

Feeder	Consumers	λ f/Year	r Min	U Min/Year
F-I	221	0.817	146	120
F-II	53	0.309	177	55
F-III	88	0.341	173	59
F-IV	73	0.179	204	37
F-V	203	0.713	155	111

Table 3 Consumer-oriented Reliability Indices

Feeder	SAIFI	SAIDI	CAIDI	ASAI	ENS
F-I	0.817	2	2.44	0.99	242.326
F-II	0.309	0.91	2.96	0.99	30.987
F-III	0.341	0.98	2.88	0.99	50.421
F-IV	0.179	0.61	3.45	0.99	21.376
F-V	0.713	1.85	2.59	0.99	203.929

Table 4 Load Data

Feeder	Average Load kW
F-I	121.63
F-II	33.804
F-III	51.276
F-IV	34.665
F-V	110.232

It is observed that with the inclusion of fusses to the lateral feeders the reliability indices have been improved. System oriented reliability indices such as SAIDI and SAIFI also have been reduced which indicates that the reliability of electricity supply to the consumers has been improved. After the inclusion of fuses to the lateral feeders CAIDI has been increased. Energy not served to the consumers also has reduced and this also is a positive aspect for the utility organizations. This is because utility organizations have to bear the cost for energy not served for the consumers. According to the calculations, energy not served has been dropped by 20%.

4 Conclusions

Low voltage distribution systems are mainly radial feeders and, in many cases, change of network topology or interconnection with other systems during the faults are practically not possible. Under these circumstances' inclusions of fuses to the lateral feeders is one of the few methods to improve the reliability of the network. Practical implementation of this proposal is not difficult and the cost for installation is not high. In this work, failure rate and repair time of electrical equipment have been calculated based on the data obtained during three years. For more accurate values of the indices, data relevant to the failures of the equipment for a longer period is required. However, the determined values of this work are closer to the standard values of the equipment [6].

Table 5 Customers' Reliability Indices (inclusion of Fuses to the Lateral Feeders)

Feeder No	Lateral Feeder	Consumers	λ f/Year	Average Repair Time	Outage Time (Min)
I	A0	34	0.243	174	42
	A1	17	0.365	363	65
	A2	11	0.389	355	68
	A3	17	0.381	358	67
	A4	93	0.551	333	91
	A5	15	0.381	358	67
	A6	8	0.365	363	65
	A7	26	0.413	349	72
II	B1	5	0.154	179	28
	B2	31	0.357	348	62
	B3	17	0.236	356	57
III	C1	47	0.187	172	32
	C2	6	0.293	363	53
	C3	22	0.357	355	62
	C5	14	0.333	333	58
IV	D1	27	0.137	186	26
	D2	25	0.208	300	47
	D3	8	0.195	340	46
	D4	13	0.195	340	46
V	E1	58	0.324	158	51
	E2	13	0.422	360	71
	E3	78	0.608	319	96
	E4	18	0.43	355	72
	E5	13	0.454	344	75
	E6	12	0.446	347	74
	E7	11	0.43	355	72
	E8	10	0.43	355	72

Table 6 System Reliability Indices (proposed system)

Feeder	Customers	SAIFI	SAIDI	CAIDI	ASAI	ENS
F - I	221	1.22	0.4336	2.83	0.99	3702.62
F- II	53	0.95	0.2990	3.17	0.99	738.75
F-III	88	0.75	0.2620	2.86	0.99	940.42
F- IV	73	0.64	0.1777	3.61	0.99	512.98
F- V	203	1.31	0.4912	2.67	0.99	3250.81

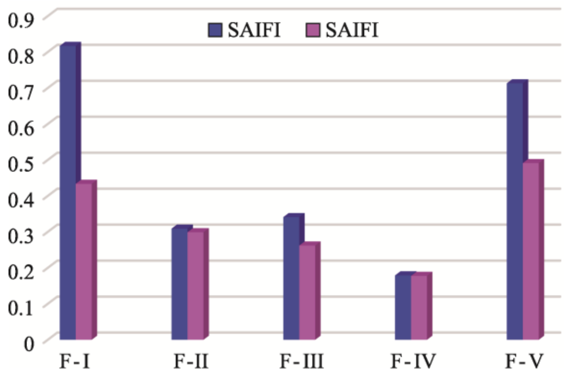


Fig.2 SAIFI

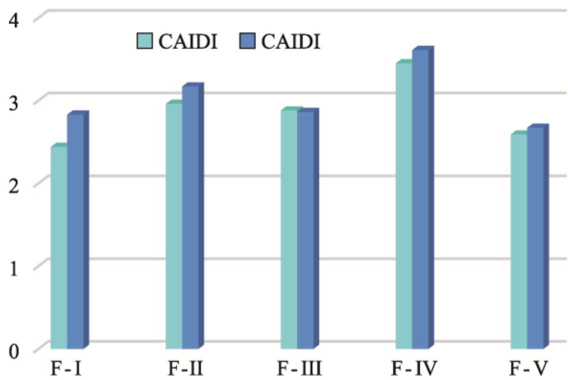


Fig.3 SAIDI

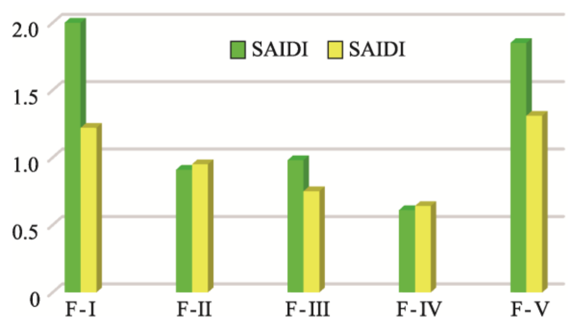


Fig.4 CAIDI

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