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Reliability Comparison of Rural & Urban LVDS Networks with Corresponding HVDS Networks Including Substation Reliability

G Vasantha, E. Vidya Sagar

Abstract: This paper mainly determines the comparison of reliability of an existing rural area & urban area LVDS (low voltage distribution system) with their respective proposed high voltage distribution system (HVDS) and also including their 33/11 kV Substation. Ring main substation and single bus bar substation configuration are considered for urban and rural distribution systems respectively. The reliability of ring bus substation used in urban area is more as compared to single bus substation used in rural area. The load point reliability indices are calculated considering both substation reliability indices and radial feeder indices. The substation failure rate is calculated by considering overlapping outages approach and whereas the radial feeder indices are calculated by using cut set approach. Further, the LVDS Network is converted into the HVDS Network by replacing a high rating distribution transformer (DTR) supplying to a group of customers with Large in number with multiple small rating distribution transformers near to consumer terminals with less number of customers in each group. This conversion leads to Minimum length of LT Lines in HVDS Which results in improving voltage profile, reliability and efficiency. In this paper the disconnecting switches and alternative supply are also considered on both LVDS and HVDS Networks in the calculation of the reliability of to assess the reliability of the radial distribution system (FMEA)Failure mode effect analysis is used. This study uses a LVDS and HVDS system, and uses an alternative power source and disconnectors, to determine reliability indices of the rural area network and urban area network distribution system. In this paper the important distribution reliability indices to reduce system average interruption durations (SAIDI), Energy Not Supplied (ENS) and ASAI for LVDS and corresponding HVDS are calculated. The research idea is proposed on a Indian practical networks

Keywords: LVDS, HVDS, Reliability Evaluation, System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Energy Not Supplied (ENS) , Average Service Availability Index (ASAI).

I. INTRODUCTION

A power system is made up of numerous types of producing stations connected by a network of distribution grid, transmission lines and feeders to supply various kinds of loads to multiple consumers.

The distribution grid is the component of an ‘electrical power system’ that is in charge of distributing electricity to consumers. The distribution grid employs the secondary substation, main feeder, load transformer, and distribution feeder to distribute electricity to the loads. Because distribution grid has 90% of all load reliability issues, enhancing distribution reliability is the key to improvise load reliability. To develop effective modifications, a basic understanding of distribution grid parameters, sub-modules, topologies and working principle is mandatory. The distribution grid is the component of an electrical power system that is responsible for distributing electricity to the consumer. To supply electric power to consumers, the distribution system employs the distribution substation, primary feeder, distribution transformer (DTR), and distribution feeder. The secondary substation converts electrical power to lower voltage levels and usually enhance facilities for voltage regulation of the distribution voltage. It directly supplies power to large consumers, and has a working voltage of 220 kV, 132 kV, 66 kV, 33 kV, 22 kV, 11 kV, 6.6 kV, 3.3 kV. 22 kV and 11 kV are the main secondary distribution voltages utilized in India. The higher voltage is used for larger rating loads [1-3].

The DTR is fed from the distribution substation to the primary feeder. DTR is usually integrated on the poles or close to load sites which transform high voltage levels to low voltage levels. Its working voltage ranges are 400/230 V and 440/240 V, for 3-phase 4-wire; 415/220 V singe phase to neutral, 440/260 V for high tension (HT) service. The distribution feeder which may be over head or underground cable supplies electric power to consumers for utilization at 400/230 V with a specified tolerance of ±6% [4].

Distribution exists between secondary transmission and consumer service point. It contains

1. Substations
2. Primary feeders
3. Distribution transformers
4. Secondary circuits
5. Service

Among these given modules, different types of substations ring and single bus substation configuration used for urban and rural distribution system.

A. Low Voltage Distribution System (HVDS)

At present most of the Indian electrical distribution networks are operating in radial in nature, with short feeders (11kV), and high rated distributed transformers(11kV/440V) long distributors (440V).

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This type of network is known as Low Voltage Distribution network (LVDS). The primary drawbacks of LVDS in agricultural feeders are: i) The entire unit must be replaced or repaired if a three-phase big capacity distribution transformer fails, which will affect more users. ii) DTR replacement and repair take additional time. iii) due to over loading frequent faults occur in lines& distribution transformer. iv) improper 433 V line hook up, which affects the voltage profile of the lines and increases power losses. v) the low voltage feeder monitoring is difficult [9].

Primarily in rural areas, three phase HVDS is used to give power to users in agriculture [12] [25]. With voltage drop above 5%, the majority of low voltage feeders are challenging to maintain in the field, which results in higher current losses than are allowed by loading restrictions. In rural locations, the loads are dispersed widely, and low tension 433volt lines must travel great distances just to serve a modest load. Large defects in the low voltage distribution network cause frequent supply interruptions.

Low tension fault currents cause distribution transformer failure. A minimum voltage of 370 V or less is recorded at the customer's meter, and there are 15,000 low tension faults every 100circuit km on lines that power agricultural pumps [1]. To confirm the technical and financial viability of the HVDS, it is crucial to assess reliability indices.

The LT network at 433 V is converted to 11 kV in order to address these drawbacks in the LT distribution system. The 11 kV power delivery to consumer premises is referred to as HVDS.

B. High Voltage Distribution System (HVDS)

The purpose of the HVDS project is to convert the current Low Voltage (LT) network into a High Voltage Distribution System. In order to provide a higher quality power supply, the 11kV line is placed as close to the loads as possible, and the LT power supply is fed by supplying an appropriate capacity transformer and a minimal length of LT line, reduction of losses and better consumer service. The existing system provides a single point where large capacity transformers are available, and long LT lines are used to connect each load. This long length of LT lines is causing low voltage condition to the majority of the consumers and high technical losses [10,11] [27]. Long LT mains are transformed into 11 kV mains as part of the HVDS project, building the proper capacity distribution transformer as close to the end as possible, and supplying the consumer at the right voltage level. These lines can be converted to HVDS, which will dramatically minimise the technical losses in the LT line and allow the current flowing through the lines to be reduced by 28 times. This can be demonstrated by the fact that a 100 KVA load draws 5 amps at 11 kV, but 140 amps at LT voltage of 415 volts [13,14].

C. Conversion of an Existing LVDS Network to Corresponding HVDS network

The LT network must be rebuilt with new 11 kV pin insulators and 11 kV cross arms in order to provide the necessary clearances between the phases of an existing network and the ground. The existing conductor and poles were left alone. But if there is more sag, the conductor is straightened, and a few poles are put up in the middle to give enough space to the ground. The LT lines would carry 133 A of current for LVDS (using a Weasel or Rabbit conductor), and once the line was converted to HT, the current would be around 5% of the LVDS current that was flown in the original line. Therefore, a conductor change is not required. A plinth or double pole (DP) construction is not required because the poles are used for the low capacity three phase transformers. To connect 2 to 5 customers, service wires are run from the secondary distribution box. A aerial bunched cable (ABC) rather than a bare conductor is used as the LT conductor where necessary [5,7].

II. RELIABILITY EVALUATION FOR THE COMBINATION OF SUBSTATION & FEEDER

For distribution systems, there are two set types of indices: the fundamental load point indices and the system performance indices. The load point indices are mostly used as substation reliability indices. The performance indices are used for feeder system [15].

These load point indices are calculated utilizing the parallel system approach i.e., by using overlapping forced outage method. In rural locations, the loads are dispersed widely, and low tension 433volt lines must travel great distances just to serve a modest load. Large defects in the low voltage distribution network cause frequent supply interruptions [17-18]. Low tension fault currents cause distribution transformer failure. A minimum voltage of 370 V or less is recorded at the customer's metre, and there are 15,000 low tension faults every 100circuit km on lines that power agricultural pumps [6]. To confirm the technical and financial viability of the HVDS, it is crucial to assess reliability indices.

The primary drawbacks of LVDS in agricultural feeders are: i) The entire unit must be replaced or repaired if a three-phase big capacity distribution transformer fails, which will affect more users. ii) DTR replacement and repair take additional time. iii) due to over loading frequent faults occur in lines& distribution transformer. iv) improper 433 V line hook up, which affects the voltage profile of the lines and increases power losses. v) the low voltage feeder monitoring is difficult [19] [26].

The LT network at 433 V is converted to 11 kV in order to address these drawbacks in the LT distribution system. The 11 KV power delivery to consumer premises is referred to as HVDS.

HVDS is the most efficient way for lowering technical losses and enhancing supply quality in the power distribution system. High voltage lines are brought as close to the loads as possible in this system, and small size transformers are built [20-24].

For the substation load point indices are calculated using the parallel system approach. The basic load point indices of load point ‘i’ are: average failure rate λi (f/yr), average outage time r_i (hr) and average annual outage time Ui (hr/yr) [5].

$$\lambda_T = \lambda_1 \lambda_2 (r_1 + r_2) \qquad (1)$$

$$r_{T=}\ r_1 * r_2 \quad (2)$$

$$U_T = \lambda_T * r_T \quad (3)$$

$$Total\ Availability\ = 1 - U_T \quad (4)$$

The series system is used to calculate the feeder fundamental(basic) load point indices. $Average\ failure$ rate λ_i is for load point 'i' is given in equation (5)

$$\lambda_i = \sum \lambda_c \quad {}^{f}/_{yr} \quad (5)$$

$Average\ Outage\ Time\ r_i$ is for load 'i' is given in equation (6)

$$r_i = \frac{U_i}{\lambda_i}\ hr \quad (6)$$

$Average\ Annual\ outage\ time\ \ U_i$ is for load i' is given in equation (7)

$$U_i = \sum \lambda_c\, r_c \quad {}^{hr}/_{yr} \quad (7)$$

where, λ_c is annual failure rate on average (f/yr) fundamental cut set ('c' is system component suffers from persistent errors) used in equation (5) and rc the average restoration time (in hours) as a result of component 'c' failing used in equation (7). The switching procedure or the repair/replacement process could both be the cause of the typical restoration time. Fundamentally, there are three main load point indices. The system behaviour and response, however, are not always fully represented by them. System performance indices are additional reliability indices that are used to reflect the degree or importance of a system outage caused by persistent problems [3-6]. [28] [29]

Performance or reliability Indices of System

(i) System Average Interruption Frequency Index, SAIFI

$$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{total\ number\ of\ customer\ sserved} = \frac{\frac{\sum \lambda_i N_i}{\sum N_i} f}{customer.yr} \quad (8)$$

(ii) System Average Interruption Duration Index, SAIDI

$$\text{SAIDI} = \frac{sum\ of\ customer\ interruption\ durations}{total\ number\ of\ customers\ served}\ \ \frac{\sum U_i N_i}{\sum N_i}\ hr \quad (9)$$

(iii) Customer Average Interruption Duration Index, CAIDI

$$\text{CAIDI} = \frac{Sumofcustomer\ interruption\ durations}{totalnumberofcustomer\ interruptions} = \frac{\sum U_i N_i}{\sum \lambda_i N_i}\ \ \frac{hr}{failure} \quad (10)$$

(iv) Average Service Availability Index, ASAI

$$ASAI = \frac{Customerhoursavailableforservice}{customerhoursdemanded} = \frac{\sum N_i \times 8760 - \sum U_i N_i}{\sum N_i \times 8760} \quad (11)$$

$$(v)\ Energy\ Not\ Supplied, ENS = \sum L_{a(i)}\, U_i \frac{kWh}{yr} \quad (12)$$

where La(i) represents the average load connected to load point i and N is the number of customers at load point i. The significant reliability indices that show the level of dependability of an electrical distribution system are SAIDI, ENS, and %ASAI. An electrical distribution grid with low SAIDI and ENS and with high %ASAI is said to be a more reliable system [6]. For the total distribution system i.e., combination of substation and feeder, the failure rate of substation and failure rate of feeder will be added.

III. CASE STUDY

A. Urban Case

An existing distribution system consists of subsystems are substation and feeder, is ring type substation 33 kV/11kV connected to 11kV feeder Whose DTR capacity is 1.32MVA low voltage distribution system (LVDS) supplying commercial and residential loads shown in Fig.1 is considered for the case study. The details of LVDS feeder are: length of 11kV (HT) feeder is 4.2kM, length of 0.433 kV (LT) distributor is 6.12 kM, number of 11/0.433 kV, 63 kVA, 100 kVA & S250kVA DTRs are 4 ,7 & 4 respectively, number of disconnecting switches are 6, no. of fuses (placed before each DTR) is 15. The Table-I shows the average failure rates and average repair times of feeder sections and different capacity distribution transformers and substation components [2,3]. Table.2 shows the load and customer data of an existing radial LVDS feeder [16,17].

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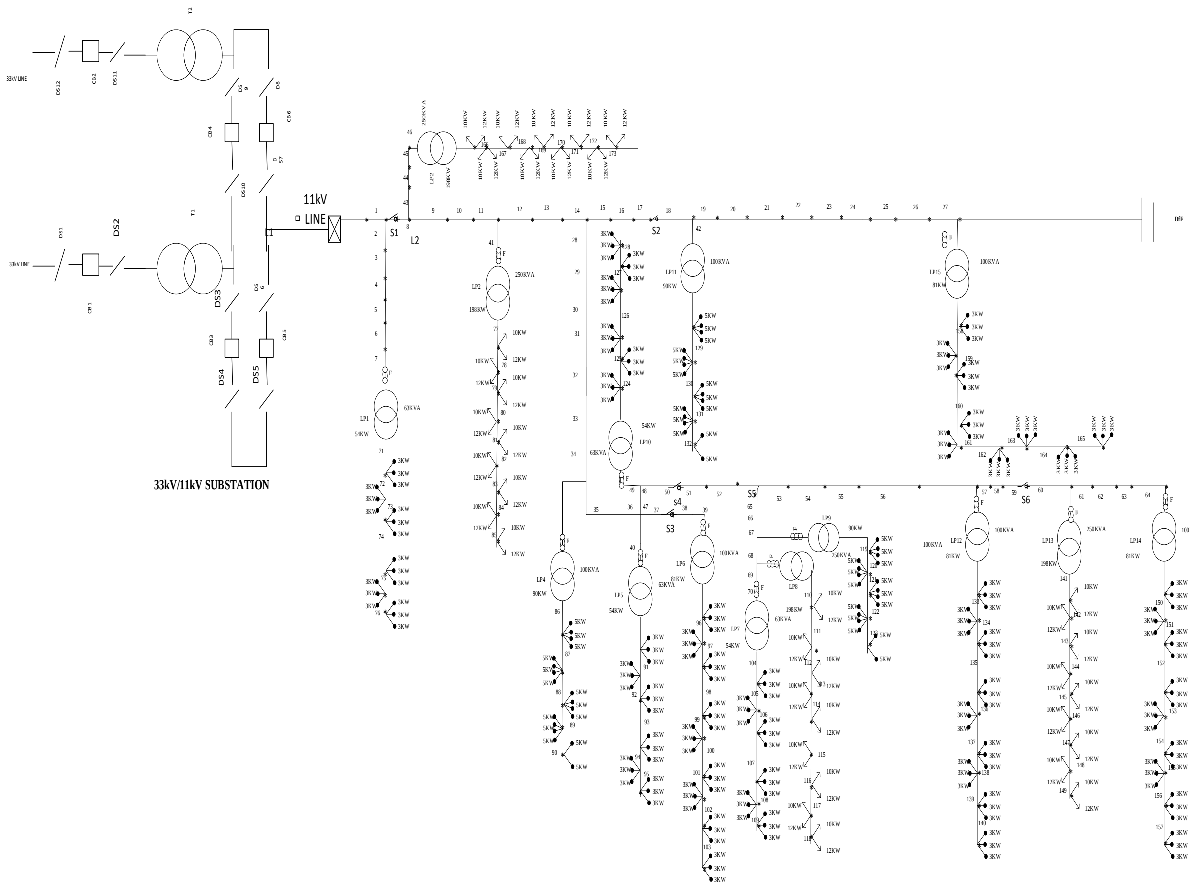

Fig 1. Single Line Diagram of Combination of Substation and Feeder of Urban Area Network

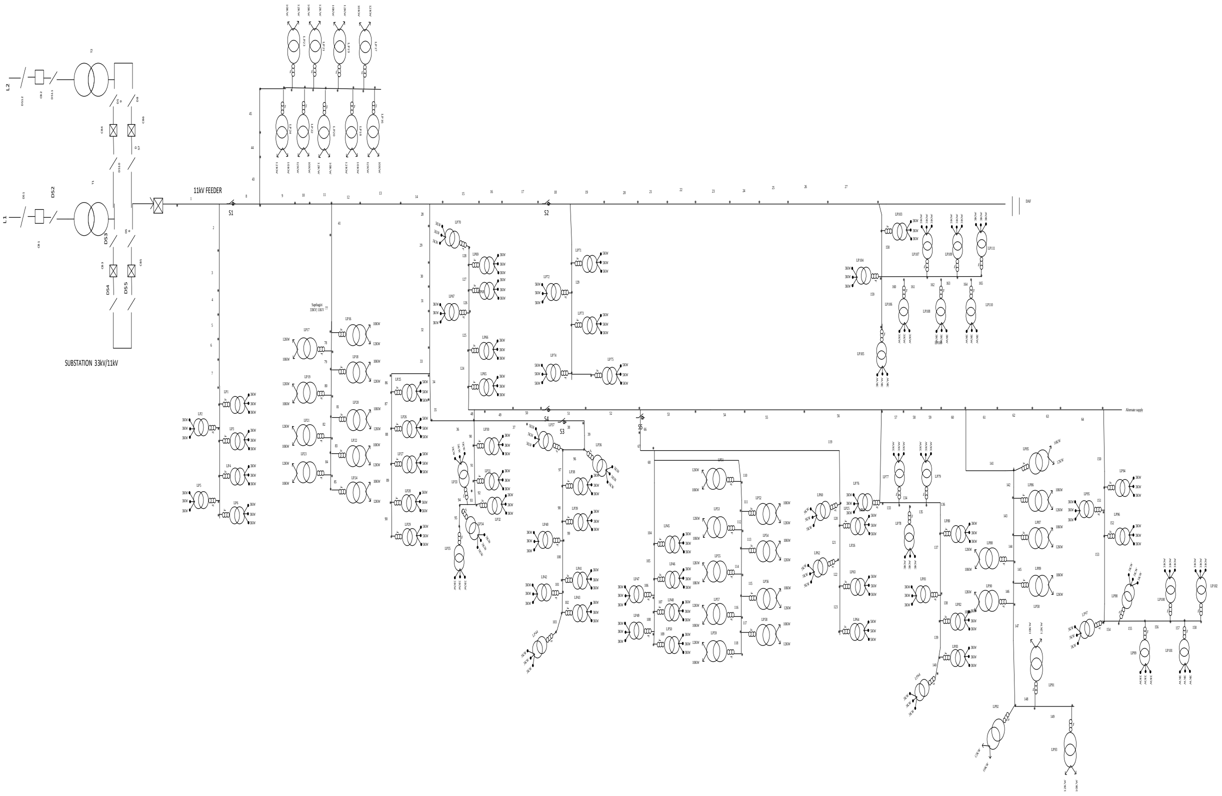

Fig 2. Single Line Diagram of Combination of Substation and HVDS Feeder of Urban Area Network

Table -I: Shows the Average Failure Rates and Average Repair Times of Feeder and Substation

Description	λ(f/yr)	r(hr)
SUBSTATION Component name		
33kV HV Lines	0.092	8
33kV CB	0.0035	4
33/11kV T/F	0.030	15
11kV CB	0.010	4
33kVBusbar	0.002	2
11kVBusbar	0.002	2
Disconnectors	0.010	4
FEEDER Component name		
HT Line (11kV)	0.0124(f/yr/km)	2
Secondary (LT) line &service drop lines	0.0124(f/yr/km	1.5
High capacity DTR (63 kVA & Above	0.0150(f/yr)	20
Low – capacity pole mounted DTR(25kVA&below)	0.0100(f/yr)	36

Table II: Load and Customer Data of an Existing LVDS Radial Feeder

Load point	DTR (kVA)	Number of customers	Connected load(kW)	Total average load(kW)
1	63	18	18x3	54
2	250	18	9x12+9x 10	198
3	250	18	9x12+9x 10	198
4	100	18	16 x 5+2x 5	90
5	63	18	18 x 3	54
6	100	27	27 x 3	81
7	63	18	18 x 3	54
8	250	18	9x12+9x 10	198
9	100	18	16 x5+2 x 5	90
10	63	18	18 x 3	54
11	100	18	16x+2 x 5	90
12	100	27	27x 3	81
13	250	18	9x12+9x 10	198
14	100	27	27 x 3	81
15	100	27	27 x 3	81

By using above Table-I &Table-II, with Failure mode and effects analysis (FMEA) techniques is applied and CYME software is used to confirm the reliability indices [8,16]. The basic load point indices of all 15 load points of an existing LVDS feeder are calculated. The results of basic load point indices (Table -III) and the customer & load data are used to obtain the system performance indices and tabulated in Table-IV.

Table-III: Results of Basic Load Point Indices of COMBINATION OF SUBSTATION &LVDS FEEDER

λ(f/yr)	r(hr)	U(hr)
2.14	4.3	9.24

Table-IV: System Performance Indices of COMBINATION of SUBSTATION & LVDS FEEDER

Reliability indices	COMBINATION OF SUBSTATION & LVDS FEEDERS
SAIDI	0.616552867
CAIDI	0.287373338
ENS	987.9154226
%ASAI	0.999929617

After conversion LVDS Feeder into HVDS feeder, the same network of small rated DTRs and even customers are grouped in large no. of groups as shown in Fig 2. For example, the load point 1 of an existing LVDS consists of one DTR (1*63kVA) and six residential loads(18*3kW) whereas the corresponding HVDS network consists of six small rated DTRS (6*10kVA) DTRs, six load points (3*3kw, 3*3kw, 3*3kw, 3*3k, 3*3kw, 3*3kw as shown in Table-V. Similarly, all high rated DTRs are being replaced by small rated DTRs. Since the number of small rated DTRs are high, only some of the load points, customer and load data of corresponding HVDS network are shown in Table-V.

Table-V: Load and Customer Data of Some Load Points of HVDS radial feeder

Load point	DTR (kVA)	Number of customers	Connected load(kW)	Total average load(kW)	Length of LT line (kM)
1	10	3	3x3	9	0
2	10	3	3 x 3	9	0
3	10	3	3 x 3	9	0
4	10	3	3 x 3	9	0
5	10	3	3 x 3	9	0
6	10	3	3 x 3	9	0
20	25	3	1x12+ 1x10	22	0
38	10	3	3 x 3	9	0
56	10	2	3 x 3	9	0
83	25	4	4 x 5	20	0
100	25	3	1x12+ 1x10	22	0
111	25	3	3 x 3	9	0

The basic load point indices of all 111 load points of the corresponding HVDS radial feeder are calculated. By using Table-V & Table-I. The results of basic load point indices are shown in Table-VI and the customer & load data are employed to obtain the system performance indices and tabulated in Table VII.

Table-VI: Results of Basic Load Point Indices of SUBSTATION & HVDS FEEDER

λ(f/yr)	r(hr)	U(hr)
15.3215293	19.00587	291.198

Table-VII System Performance Indices of an Existing SUBSTATION & HVDS FEEDER

Reliability indices	SUBSTATION & HVDS FEEDER
SAIDI	0.362643508
CAIDI	0.023668885
ENS	581.1384494
%ASAI	0.999958192

The improvement in reliability is shown by comparing the values of reliability indices such as SAIDI, CAIDI and ENS as shown in Table-VII. When it is converted from LVDS to HVDS the percentage reduction in value of SAIDI, CAIDI and ENS are considerable and they are 41.182, 91.7and 41.175 respectively and shown in Fig 3.

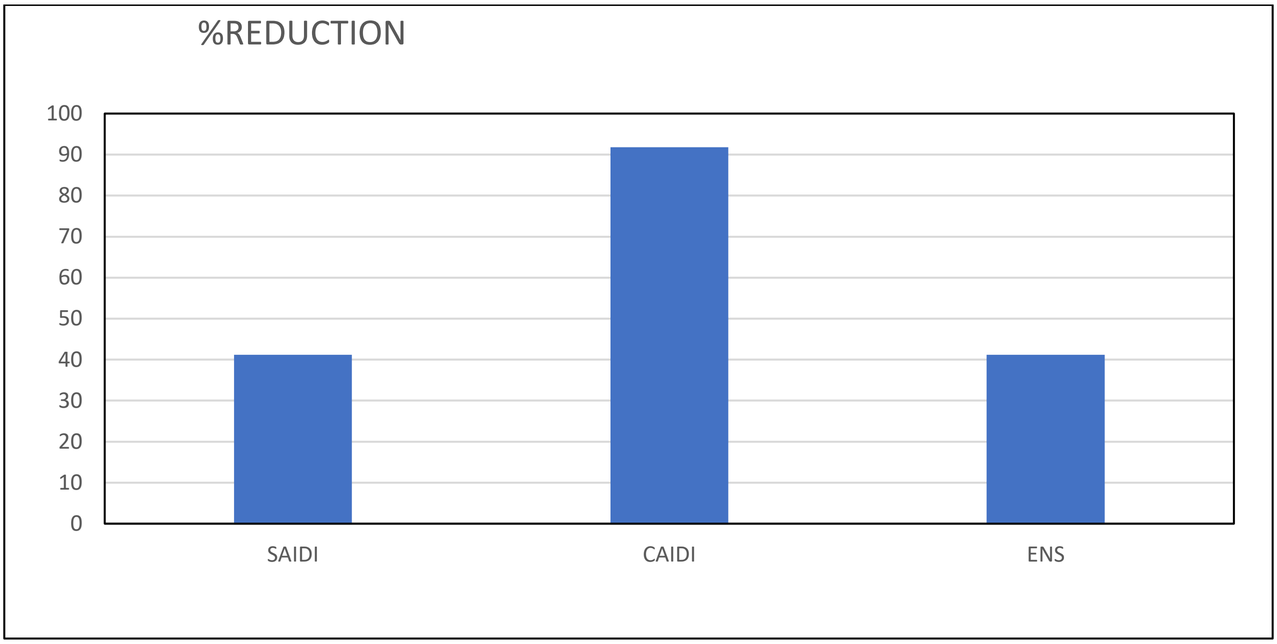

Fig 3. Percentage Reduction in System Performance Indices (ENS, CAIDI, SAIDI) of Combination of SUBSTATION & HVDS FEEDER Network Corresponding Substation & Lvds Feeder Network

B. Rural Case:

An existing 33kV/11 kV distribution system consists of subsystems are substation and feeder, is single bus type substation 33/11 kV connected to 11 kV feeder shown in Fig 4 Whose DTR capacity is 2.086 MVA is considered for the case study, is considered for the case study. The information on LVDS feeder are: length of 11kV (HT) feeder is 12.9 kM, length of 0.433 kV (LT) distributor is 6.36 kM, number of 11/0.433 kV, 63 kVA & 100 kVA DTRs are 23 & 9 respectively, number of disconnecting switches are 6, no. of fuses (placed before each DTR) is 30. The Table-VIII shows an average failure rates and average repair times of feeder sections and different capacity distribution transformers and substation components. Table-IX shows the load and customer data of an existing radial LVDS feeder.

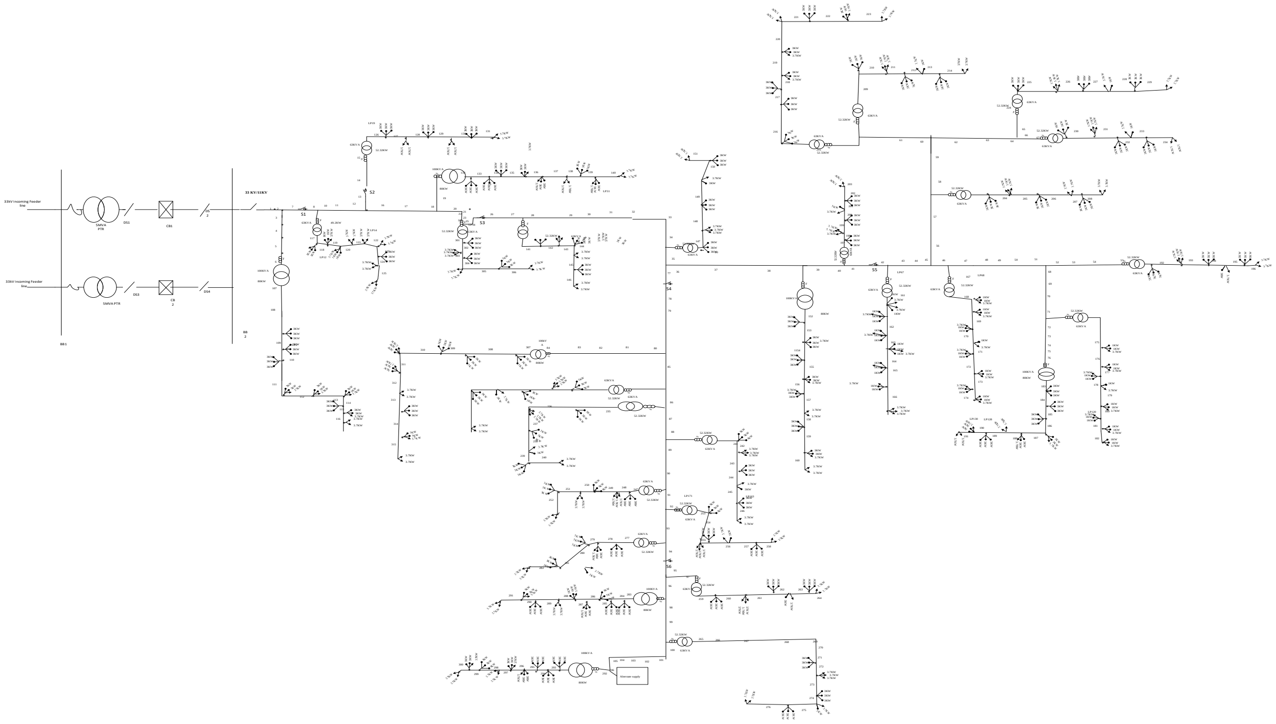

Fig 4. Single Line Diagram of Combination of Substation and LVDS Feeder of Rural Network

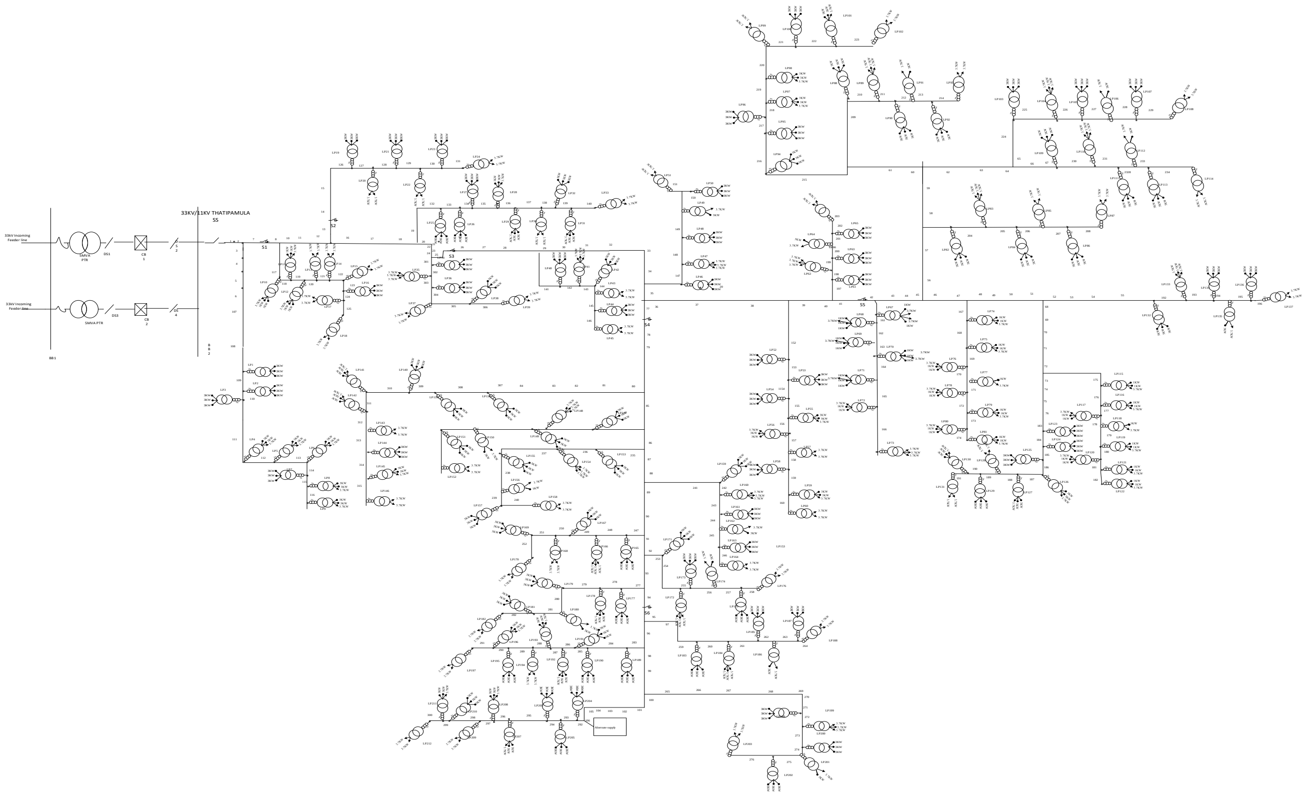

Fig 5. Single line Diagram of Combination of Substation and HVDS Feeder of Rural Network

Table-VIII: Shows the Average Failure Rates and Average Repair Times of an Existing Feeder and Substation

Description	λ(f/yr)	r(hr)
SUBSTATION Component name		
Lines	0.046	8
T/F	0.015	15
CB	0.006	4
Busbar	0.002	2
Disconnectors	0.010	4
FEEDER Component name		
HT Line (11kV)	0.0124(f/yr/km)	2
Secondary (LT) line &service drop lines	0.0124(f/yr/km	1.5
High capacity DTR (63 kVA &Above	0.0150(f/yr)	20
Low – capacity pole mounted DTR(25kVA&below)	0.0100(f/yr)	36

Table-IX: Load and Customer Data of an Existing LVDS Radial Feeder

Load point	DTR (kVA)	No. of Customers with			Total average load(kW)
		3 kW	3.72 kW	1kw	
1	100	18	7	-	80.04
2	63	-	10	-	49.2
3	63	10	6	-	52.32
4	100	18	7	-	80.04
5	63	10	6	-	52.32
6	63	10	6	-	52.32
7	63	10	6	-	52.32
8	100	18	7	-	80.04
9	63	10	6	-	52.32
10	63	-	8	20	49.76
11	63	-	8	15	44.76
12	63	10	6	-	52.32
13	63	10	6	-	52.32
14	100	18	7	-	80.04
15	63	10	6	-	52.32
16	63	10	6	-	52.32
17	63	15	8	15	44.76
18	100	18	7	-	80.04
19	63	10	6	-	52.32
20	100	18	7	-	80.04
21	63	10	6	-	52.32
22	63	10	6	-	52.32
23	63	10	6	-	52.32
24	63	10	6	-	52.32
25	63	10	6	-	52.32
26	63	10	6	-	52.32
27	63	10	6	-	52.32
28	100	18	7	-	80.04
29	63	10	6	-	52.32
30	100	18	7	-	80.04

By using above Tables-VIII & Table-IX, with Failure mode and effects analysis (FMEA) techniques is applied and CYME software is used to confirm the reliability indices [8,16]. The Fundamental load point indices of all 30 load points of an existing combination of substation and LVDS feeder are calculated.

The results of basic load point indices shown in Table X of an existing LVDS Feeder & Substation and the customer & load data are used to obtain the system performance indices and tabulated in Table- XI

Table-X: Results of Basic Load Point Indices of Combination of Substation and LVDS Feeder

λ(f/yr)	r(hr)	U(hr)
7.74	12.2	94.76

Table-XI: System Performance Indices of Combination of SUBSTATION & LVDS FEEDER

Reliability indices	COMBINATION OF SUBSTATION AND LVDS FEEDER
SAIDI	3.160917
CAIDI	0.407922
ENS	5592.376
%ASAI	0.999639

The same network of low-rated DTRs and even consumers are grouped together in a significant number of groups after conversion to HVDS. For example, the load point 1 of an existing LVDS consists of one DTR (1*100kVA) and seven agricultural pump sets(7*5HP) and four residential loads(4*9kw), whereas the corresponding HVDS network consists of nine small rated DTRS (3*15KVA & 6*10KVA) DTRs, nine load points as shown in Table 12. Similarly, all high rated DTRs are being replaced by small rated DTRs. Since the number of small rated DTRs are high, only some of the load points, customer and load data of corresponding HVDS network are shown in Table-XII

Table-XII: Load and Customer Data of Some Load Points of HVDS Radial Feeder

Load point	DTR (kVA)	Number of customers	Connected load kW)	Total average load(kW)	Length of LT line(kM)
1	10	3	3*3	9	0
2	10	3	3*3	9	0
3	10	3	3*3	9	0
20	15	3	3*3.72	11.16	0
38	10	3	3*3	9	0
156	10	2	1*3+1*3.72	6.72	0
183	10	3	3*3	9	0
200	10	3	3*3	9	0
212	10	2	2*3.72	7.44	0

The basic load point indices of all 212 load points of Combination of Substation and LVDS Feeder and corresponding Combination of Substation and HVDS radial feeder are calculated. The results of basic load point indices and the customer & load data are used to obtain the system performance indices and tabulated in Table-XIII.

Table-XIII: System Performance Indices of HVDS Feeder

Performance Indices	Combination of Substation and HVDS feeder
SAIDI	1.846634
CAIDI	0.034389
ENS	3258.93
%ASAI	0.999789

The improvement in reliability is shown by comparing the values of reliability indices such as SAIDI, CAIDI and ENS as shown in Table-XIII. When it is converted from combination of LVDS feeder to combination of substation and HVDS feeder, the percentage reduction in value of SAIDI, CAIDI and ENS are considerable and they are 41.57,91.56and 41.72-----respectively and shown in Fig 6.

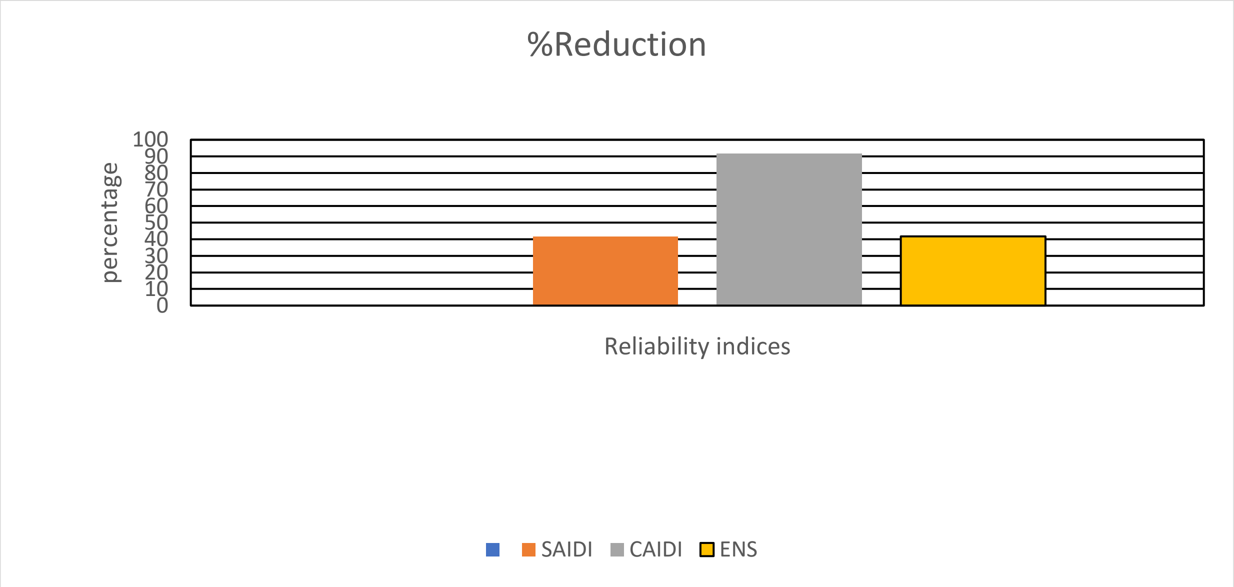

Fig 6. Percentage Reduction in SAIDI, CAIDI, and ENS of HVDS Network with Respect to The Corresponding Lvds Network

The following Table-XIV represents the comparison between rural and urban areas with combination of substation and LVDS feeder and corresponding combination of substation and HVDS feeder. Finally, it shows the ENS more impact on the Rural case compare to Urban area.

Table-XIV: Reliability Comparison of Urban and Rural Distribution System

Reliability indices	URBAN		RURAL	
	SUBSTATION &LVDS FEEDER	SUBSTATION &HVDS FEEDER	SUBSTATION &LVDS FEEDER	SUBSTATION &HVDS FEEDER
SAIDI	0.616	0.3626	3.22	1.846
CAIDI	0.287	0.0236	0.4166	0.034
ENS	987.91	581.13	5714.96	3258.92

IV. CONCLUSION

When combination of Substation and LVDS feeder is transformed into combination of substation and HVDS feeder, the SAIDI value in urban areas is significantly reduced (41.18%), indicating an improvement in reliability. When LVDS is transformed into HVDS, the SAIDI value in rural areas is significantly reduced (41.57%). This enhancement shows that each customer experiences shorter interruption times. After converting from LVDS to HVDS in urban areas, the value of ENS is decreased by 41.17%, while in rural area, it is decreased by 41.72%. This improvement is the result of fewer customers experiencing issues with the HVDS system than the LVDS system. It is observed that from conclusions that the HVDS concept is more impact on Rural area compare to LVDS area and both customer and utility satisfied with implementation of HVDS system from reliability point of view.

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