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Impact of Location of Distributed Generation On Reliability of Distribution System

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Abstract:- Generally distributed generation (DG) is connected at distribution level voltage and it provides support to the distribution network. The connection of DG with distribution system improves the system reliability. The reliability improvement depends on the capacity and availability of DG and on the location of the DG connected to the distribution system. The aim of the paper is to study the impact of different locations of DG on reliability of distribution system.

Keywords:- Distributed generation, radial distribution system, improper and proper disconnects, reliability indices, renewable energy resources, optimal location.

I. INTRODUCTION

All developmental works including industrialization depend on availability of energy. Energy security is the greatest concern all over the world. Electrical energy takes higher place than other form of energy in the energy hierarchy. World energy consumption is increasing by 2% per year. The demand of electrical energy is rising more rapidly in developing countries. Fossil fuels have been the main sources of electrical energy so far. If alternative arrangement is not made in case of fuel, the world will have to face severe problems in the near future. The country like India depends mainly on fossil fuel. The International Energy Agency projects India's oil consumption going up from 2.5 million barrel a day in 2002 to 5.6 million barrel a day in 2030.

The present energy crisis raises the demand for renewable sources of energy such as wind, solar, biomass, wave, geothermal, small hydel, tidal etc. Renewable energy sources provide different types of benefits. There is a limitation in the availability of renewable energy sources and their behavior is not uniform. But the use of renewable sources is increasing gradually all over the world. More than 50% of world's electrical energy is expected from renewable sources by the year 2060.

DG helps in solving energy problem. Both renewable and non renewable technologies can be used for DG [1]. Renewable technologies include solar, photovoltaic, wind, geothermal, tidal, micro-hydel, energy from municipal waste and biomass generation etc. whereas non-renewable technologies include internal combustion engine, combined engine, combustion turbine, fuel cell. DG plays an important role in improving the reliability of the system.

The increasing penetration of DG in the power system is raising the technical problems such as voltage regulation, network protection etc. The technical problems to be addressed when connecting a DG with distribution network are: power flow, steady state voltage variation, network loss, power quality, fault level contribution, transient stability etc [2]. Penetration of DG changes the characteristics of the distribution network since it converts the passive network into active distribution network [3].

A new analytical method for calculation of load point indices of distribution system including DG is proposed in [4]. In [5], the authors show that type and location of switches play an important role on reliability improvement of distribution system. In [6], the authors have discussed the impact of DG on reliability of a radial distribution system. The authors have also examined the improvement of reliability by connecting DG at different locations. In [7], the authors investigate the impact of conventional and renewable DG on the reliability of future distribution system. A new reliability evaluation method using Monte Carlo time sequential simulation for the distribution system with distributed generations is discussed in [8]. A distribution network reliability calculation model considering the act of weather and DG is presented in [9]. In [10], the optimal location and output power of distributed generators along with the type of cross-connection are determined as the transformer and feeders are optimally upgraded.

II. AIM AND OBJECTIVE

In this paper, customer related reliability indices of a radial distribution system with DG connected at different locations of the system are evaluated by using the load point indices. The DG units are used as stand by operation. The load point indices and customer related indices are evaluated with proper and improper disconnects at sections forming a junction. The impact of location of DG on reliability of distribution system is studied using those indices.

III. DISTRIBUTION SYSTEM RELIABILITY

In conventional power system reliability evaluation methods the three functional zones: generation, transmission and distribution, develop three hierarchical levels: HL-I, HL-II and HL-III. HL-I includes only the generation facilities. HL-II includes both generation and transmission facilities. HL-III includes all three functional zones.

Reliability analysis of HL-III is most complex because it includes all three functional zones of power system. The aim of the HL-III study is to obtain suitable reliability indices at consumer load point.

The three basic customer related indices for reliability analysis of distribution system are: rate (or frequency) of failure λ_s, average outage time (or average duration of failure) r_s and annual outage time U_s, which can be expressed as

$$\lambda_s = \sum \lambda_I \quad \text{(i)}$$

$$U_s = \sum \lambda_i r_i \quad \text{(ii)}$$

$$r_s = U_s/\lambda_s \quad \text{(iii)}$$

These indices are used to get the customer related additional indices: SAIFI(System Average Interruption Duration Index), SAIDI (System Average Interruption Duration Index), CAIDI(Customer Average Interruption Duration Index), ASAI (Average System Availability Index), ENS (Energy Not Supplied) etc.

IV. METHODOLOGY AND PROBLEM DEFINITION

A radial distributor is considered with sections and lateral distributors. There are two ways of connection of disconnects considered in this paper. In one type, disconnects are installed 'properly' in every section including the sections forming a junction. In the other type, disconnects are connected 'improperly' in sections forming a junction. Failure at all sections and lateral distributor connected to a load point has the contribution to the failure rate of that particular load point. The load point failure λ_i can be expressed in the form given in equation (iv) [11].

$$\lambda_i = r\,L_T + r_i^{/} \quad \text{(iv)}$$

r = failure rate /m of the section

L_T = total length of all sections in meter

$r_i^{/}$ = failure of lateral connected to load point i

λ_i = failure rate at load point i

The annual outage time for the load point i can be calculated by adding the affect of outage of all sections on that point plus the outage time of lateral connected to that point as shown in equation (v).

$$U_i = r\,L_e\,R + r\,(L_T - L_e)\,R^{/} + r_i^{/}\,r^{//} \quad \text{(v)}$$

r = Failure rate /m of the section

L_T = Total length of all sections in meter

L_e = Length of affected section (sections) due to failure

R = Repairing time of the section

$R^{/}$ = Switching time of the section

$r_i^{/}$ = Failure of lateral connected to load point i

$r^{//}$ = Repairing time of lateral

Average outage time (or average duration of failure) r_i of load point I by using λ_I and U_i as shown in equation (vi).

$$r_i = U_i/\lambda_i \quad \text{(vi)}$$

The customer related additional indices are calculated through conventional method by using three basic indices, number of customers and load connected to each load points in the system. The customer related additional indices are:

System Average interruption Frequency Index (SAIFI), $SAIFI = \sum\lambda_i N_i/\sum N_i$ (vii)

System Average Interruption Duration Index (SAIDI), $SAIDI = \sum U_i N_i/\sum N_i$ (viii)

Customer Average Interruption Duration Index, $CAIDI = \sum U_i N_i/\sum \lambda_i N_i$ (ix)

Customer Average Interruption Frequency Index (CAIFI),

CAIFI= Total no of customer interruption /Total no of customer affected (x)

Average Service Availability Index (ASAI), $ASAI = (\sum N_i * 8760 - \sum U_i N_i)/\sum N_i * 8760$ (xi)

Average Service Unavailability Index (ASUI), ASUI = 1- ASAI (xi)

Energy Not Supplied (ENS), $ENS = \sum L_{a(i)} U_i$ (xiii)

Average Energy Not Supplied (AENS), $AENS = (\sum L_{a(i)} U_i)/\sum N_i$ (xiv)

Here, λ_i is the failure rate at load point i, N_i is the no of customer at load point i, U_i is the annual outage time at load point i.
All those indices are calculated for a residential distribution network of a particular locality as explained in the next section.

V. CASE STUDY

A residential distribution network of Chandmari – Milonpur area in Guwahati, Assam is considered for reliability analysis. The network is having three junction points. The first junction is among the sections 2, 3 and 17. The second junction is among the sections 17,18 and 19 and the third junction is among the sections 9,10 and 12. The network is shown in Fig. 1. The reliability analysis is performed with DG under the following conditions:

i. With improper disconnects (ID) installed at sections forming a junction
ii. With proper disconnects (PD) installed at sections forming a junction

Following assumptions are made for reliability analysis:

- repairing time for section is 4 hr and for lateral is 2 hr.
- switching time for section and lateral is 0.5 hr
- failure rate for section is 0.0056 f/m yr.

The reliability data considered for analysis are presented in Table 1, 2 and 3. The study has been conducted for two different cases and results are presented in the following sections:

Case I:

DG of capacity 3500 KW is connected to the load points X, Y and Z separately with improper and proper disconnects at sections forming the junction (Fig. 1). When DG of capacity of 3500 KW is connected to X or Y, then it can supply power up to the junction J_1. When DG of capacity of 3500 KW is connected to Z, then it can supply power up to the junction J_2.

From Table 4 it is seen that SAIFI is same for proper and improper disconnect installed at sections forming a junction. The improvement of SAIDI between X & Y, X & Z and Y & Z for improper disconnects are 5.2%, 31.25% and 27.45% respectively and for proper disconnects 6.1% , 23.3% and 18.3% respectively. SAIDI improvement between proper and improper disconnects at junction for location of DG at X, Y and Z are 5.9%, 5.1% and 15.7% respectively.

CAIDI improvement between X &Y, X & Z and Y & Z for improper disconnects are 5.5%, 27.3% and 31.3% respectively and for proper disconnects are 5.9%, 18.1% and 22.9% respectively. CAIDI improvement for proper and improper disconnects at junction for location of DG at X,Y and Z are 5.8%, 5.2% and 16.2% respectively.

For improper disconnect at sections forming the junction, improvement of EENS at X than Y is 5.2%, at Y than Z is 27.2%, at X than Z is 30.9%. Similarly, for proper disconnect at sections forming the junction, improvement of EENS at X than Y is 6.1%, at Y than Z is 18.1%, at X than Z is 23%. Between proper and improper disconnects improvement of EENS for X is 5.9%, for Y is 7.1%, for Z is 15.6%.
For both proper and improper disconnects at sections forming the junction, SAIDI, CAIDI, ASAI, EENS (when DG is connected) are better at X than other two location of DG at Y & Z. Because DG located at load point X can supply power to the highest nos. of load points than DG located at Y & Z. Again reliability improvement depends on the proper installation of disconnects at sections forming the junctions.

Case II

In this case two DGs of capacity 3500 are connected simultaneously. If one DG at X then other one at Z, if one DG at Y then other one at Z. Reliability analysis is performed for both proper and improper disconnects. DG at Z can supply power up to the junction J_2 and DG at X or Y can supply power up to junction J_1.

It is seen from the Table5 that SAIDI improvement between XZ & YZ for improper disconnect is 6.3% and for proper disconnects is 7.46%. SAIDI improvement between proper and improper disconnects at junction for location of DG at XZ is 8.1%, YZ is 6.9%.
The improvement of CAIDI between XZ & YZ for improper disconnect is 6.7% and for proper disconnects is 8.9%. CAIDI improvement between proper and improper disconnects at junction for location of DG at XZ is 8.9%, YZ is 6.7%.

EENS improvement between XZ & YZ for improper disconnect is 6.2% for proper disconnects is 7.4%. EENS improvement between proper and improper disconnects at junction for location of DG at XZ is 7.9%, YZ is 6.8%.

It is seen from the analysis that for both proper and improper disconnects at sections, the locations of DG with capacity 3500 KW is best at X & Z. But SAIDI, CAIDI and EENS are the lowest and ASAI is the maximum for the location of DG at X & Z with proper disconnects at sections forming the junction.

The pictorial representations of SAIFI, CAIDI and EENS at different conditions are given in Fig. 2, 3 and 4. The percentage improvements of the indices under various conditions are presented in Fig. 5, 6, 7 and 8.

VI. CONCLUSION

Reliability of distribution system can be improved by connecting DG to the system. The reliability improvement depends on the nature of connection of disconnects. If disconnects are installed properly then improvement will be more. But it will be maximum if the DG units are optimally located in the system. In our study, the reliability improvement is maximum when two DG units operate simultaneously from the location X and Z with proper disconnects installed at sections forming a junction. DG units operated simultaneously from these two points can meet the maximum load demand of the consumer.

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Fig. 1: Distribution Network

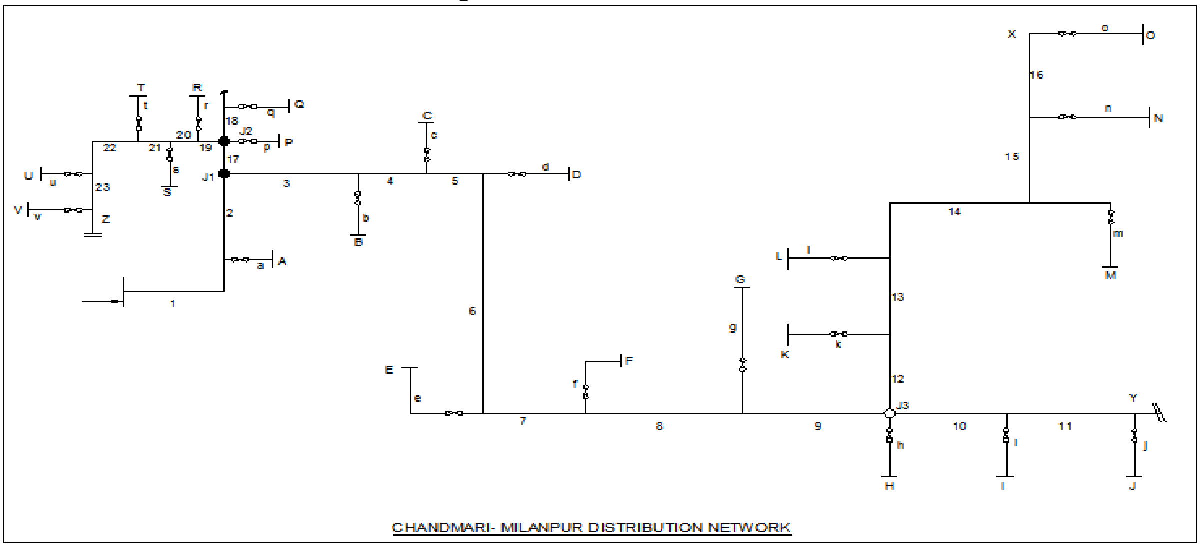

TABLE 1: Failure Rate of lateral

Lateral	Failure rate
a	4
b	2
c	3
d	4
e	3
f	2
g	1
h	4
i	3
j	4
k	3
l	2
m	3
n	4
o	3
p	2
q	3
r	4
s	3
t	1
u	4
v	3

TABLE 2: Loading data

LOAD POINTS	LOAD IN KW	NO OF CUSTOMER
A	190	95
B	238	110
C	238	110
D	238	110
E	238	110
F	60	30
G	238	110
H	24	01
I	238	110
J	238	110
K	476	220
L	300	135
M	238	110
N	238	110
O	95	45
P	238	110
Q	60	30
R	95	45
S	238	110
T	455	190
U	95	45
V	238	110

TABLE 3: Length of section

Section	Length	Section	Length	Section	Length
1	180m	9	300m	17	400m
2	150m	10	50m	18	30m
3	50m	11	30m	19	50m
4	40m	12	50m	20	30m

5	50m	13	40m	21	1000m
6	300m	14	300m	22	25m
7	40m	15	150m	23	500m
8	350m	16	50m	----------	

Table 4: Calculated reliability indices

Reliability Indices	Improper Disconnects at Junction		Proper Disconnects at junction	
	Location XZ	Location YZ	Location XZ	Location YZ
SAIFI	25.93 intr/cus.yr	25.93 intr/cus.yr	25.93 intr/cus.yr	25.93 intr/cus.yr
SAIDI	1450.1 min/cust. yr	1547.6 min/cust. yr	1333.0 min/cust. yr	1440.5 min/cust. yr
CAIDI	56 min/cust. int	60 min/cust. int	51 min/cust. int	56 min/cust. int
ASAI	0.997278	0.9971	0.9975	0.9973
ASUI	0.002722	0.00291	0.002487	0.002692
EENS	114158.9 Kwh/yr	121761.5 Kwh/yr	105065.8 Kwh/yr	113439.19 Kwh/yr
AENS	52.9 Kwh/cust.yr	56.47 Kwh/cust.yr	48.732 Kwh/cust.yr	52.62 Kwh/cust.yr

Table 5: Calculated reliability indices

Reliability Indices	Improper Disconnects at Junction			Proper Disconnects at Junction		
	Location X	Location Y	Location Z	Location X	Location Y	Location Z
SAIFI	25.93 intr/cus.yr	25.93 intr/cus.yr	25.93 intr/cus.yr	25.93 intr/cus.yr	25.93 intr/cus.yr	25.93 intr/cus.yr
SAIDI	1763.6 min/cust. yr	1861.1 min/cust. yr	2565.2 min/cust. yr	1658.8 min/cust. yr	1766.3 min/cust. yr	2162.7 min/ cust. yr
CAIDI	68 min/cust. int	72 min/cust. int	99 min/cust. int	64 min/cust. int	68 min/cust. int	83 min/cust. int
ASAI	0.996645	0.996459	0.995157	0.996848	0.996644	0.995934
ASUI	0.003355	0.003541	0.004843	0.003152	0.003356	0.004066
EENS	139154.6 Kwh/yr	146757.2 Kwh/yr	201619.69 Kwh/yr	130935.8 Kwh/yr	139309.2 Kwh/yr	170130.4 Kwh/yr
AENS	64.543 Kwh/cust.yr	68.07 Kwh/cust.yr	93.516 Kwh/cust.yr	60.73 Kwh/cust.yr	64.61 Kwh/cust.yr	78.91 Kwh/cust.yr

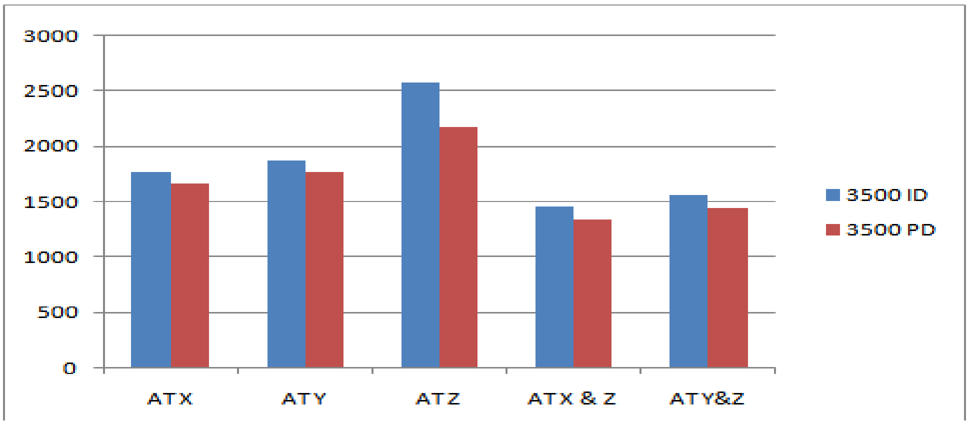

Fig-2. SAIDI at different locations

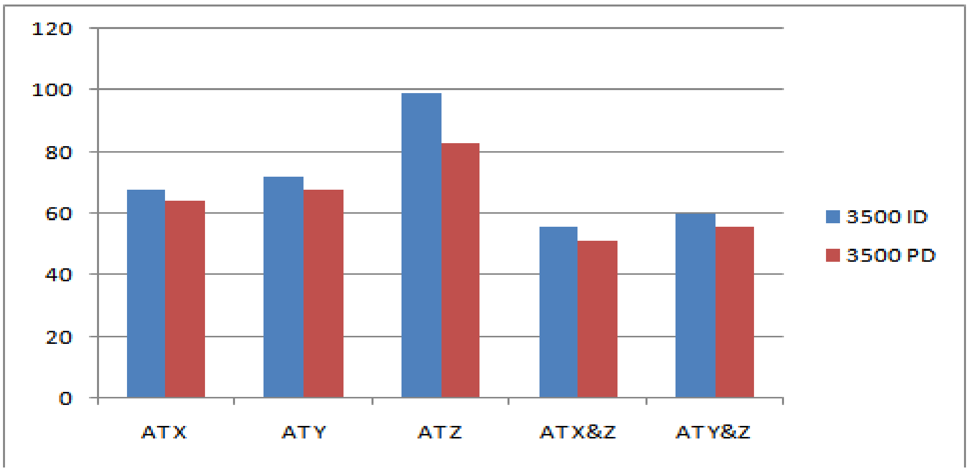

Fig. 3: CAIDI at different locations

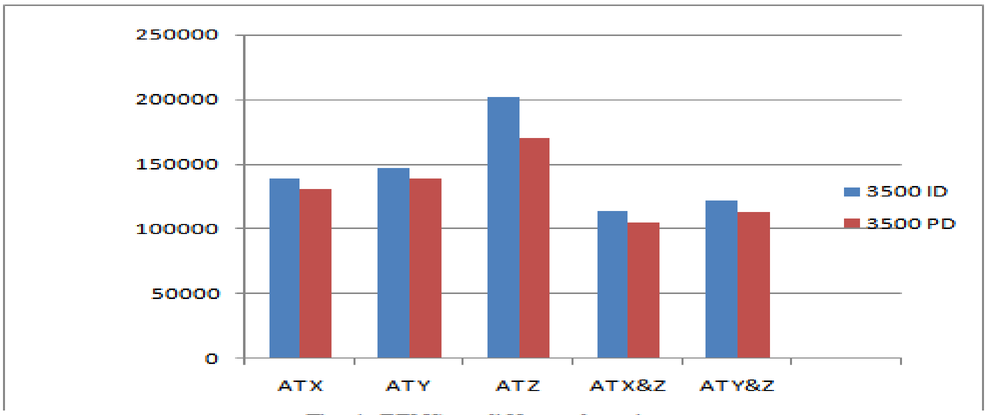

Fig. 4: EENS at different locations

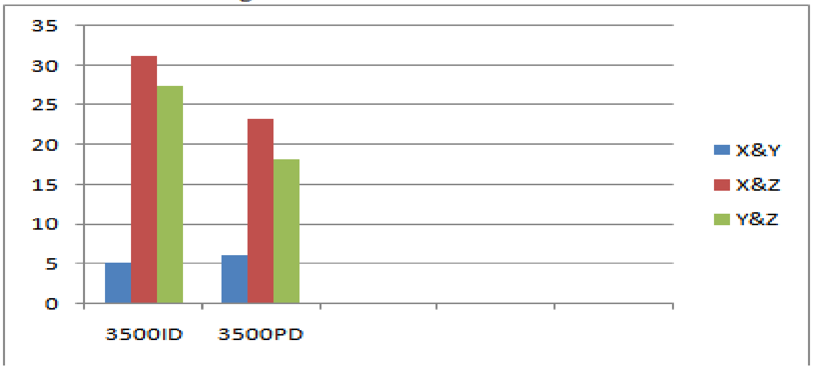

Fig. 5: Percentage improvement of SAIDI

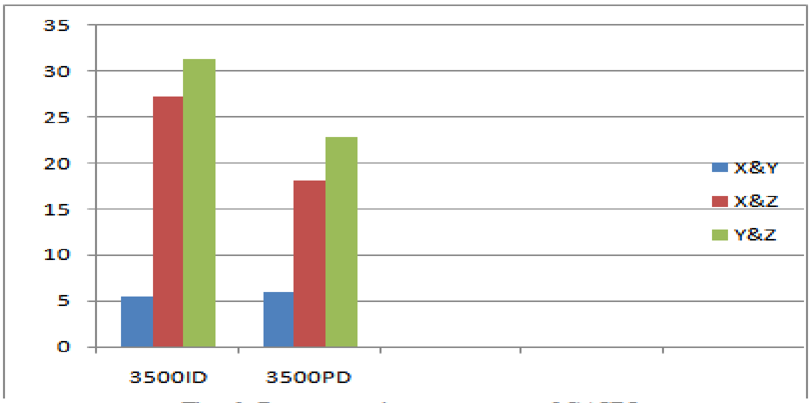

Fig. 6: Percentage improvement of CAIDI

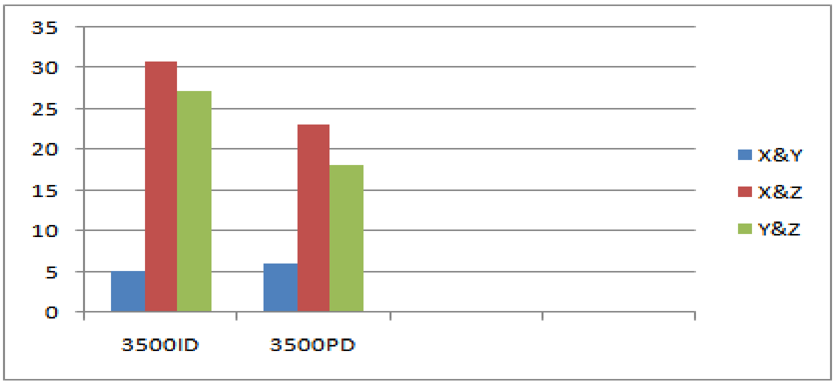

Fig. 7: Percentage improvement of EENS

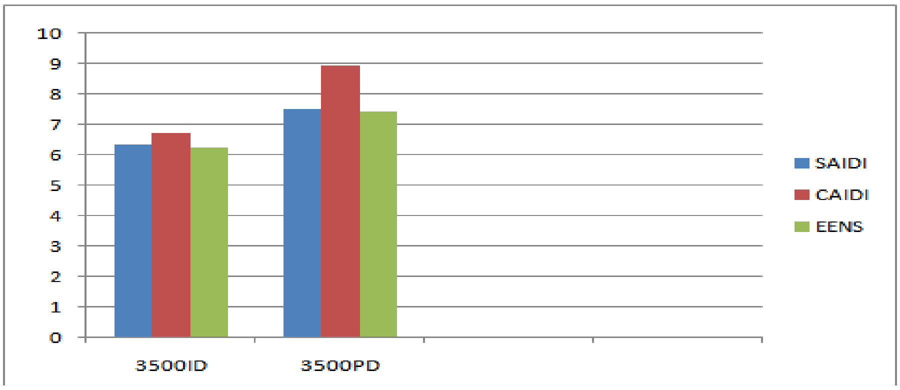

Fig. 8: Percentage improvement for ID between XZ & YZ
And for PD between XZ & YZ