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RELIABILITY CONSTRAINED PLANNING OF DISTRIBUTION SYSTEM UNDER HIGH PENETRATION OF STOCHASTIC DG UNITS

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ABSTRACT

Reliability worth is very important in power system planning and operation. Due to continuous growth of demand, power system restructuring, and deregulation, small scattered generators referred as Dispersed Generation (DG) units are gaining momentum due to their network support capabilities and modular designs. Integration of the DG units into distribution systems is one of the effective and viable planning option for improving the supply quality and reliability of the system with ever increasing demand. It is predicted that non-conventional DG units may play key role in future power distribution systems for sustainable and emission free energy supply. However the stochastic nature and the uncertainties associated with the renewable sources introduce special technical and economical challenges that have to be comprehensively investigated in order to facilitate the deployment of these stochastic DG units in the distribution system. With this intent, this paper aims to analyze the effectiveness of various stochastic DG units available in literature based on the calculations of various reliability indices. The focus of this paper is on generating a probabilistic generation-load model that combines all possible operating conditions of the stochastic renewable DG units with their probabilities, hence accommodating this model in a deterministic planning problem for enhancement of system reliability.

KEYWORDS: Stochastic DG units, Reliability Indices, Active distribution system planning, Probabilistic model, High penetration.

I. INTRODUCTION

Dispersed Generation (DG) inform of conventional and non-conventional sources concentrated near to the load centre, can play a major role in planning and design of reliable distribution systems due to their potential positive impacts such as voltage level maximization, power loss minimization, emission reduction, reliability enhancement and minimization of cost investments on transmission and distribution infrastruction. The technological advancement, economic savings and environmental concerns promote DG integration as one of the one of the attractive alternative option for distribution system planning. However, challenges still exist for successful deployment of DGs in distribution systems due to the inherent changes in the operational practice of traditional distribution system planning. This emphasizes the need for devising strategies of optimal allocation of DG units in distribution systems based on comprehensive economical and technical considerations, which this paper aims to fulfill.

The grid integration of dispatchable DG units including renewable and non-renewable energy sources which exhibit network support capabilities can be one of the attractive choice to meet the ever increasing load demands while minimizing overall investment cost and improving the system reliability. In recent years, the integration of non-dispatchable renewable active DG units into passive distribution systems may pose difficulties to the distribution system planners due to the requirements of possible alternations in the existing infrastructure and system operating strategies. The direction of power flow over the distribution feeder may significantly change at different nodes due to the injection of active and reactive powers supplied by interconnected DG units, thereby affecting system voltage profiles and energy losses. Moreover, integration of stochastic renewable DG units such as wind and photovoltaic (PV) systems demands special considerations to deal with the uncertainty in power availability during both islanded and grid connected operation modes. Although different aspects related to integration of stochastic DG units have been investigated to some extent in literature, gaps and difficulties still exist in distribution system planning and reliability assessment with incorporation of schedulable and non schedulable DG sources.

It has been realized that most of the literature considers DG as a pure active power resource in case of distribution system planning study. Moreover, limited outcomes have been reported with uncertainties associated with intermittent renewable DG units, time varying load demand and considering the different operating power factors of DG units, especially at distribution system planning stage. The non-consideration of reactive power capability and generation patterns exhibited by stochastic DG units may lead to potential increase in the investment cost and improper allocation of DG units because the uncertainties associated in the power output of DG can significantly influence the system voltage profile and energy losses. The optimal allocation of stochastic DG units inclusive of reactive power capability limits of generators, uncertainties associated with load demand and generating patterns of DG units is essential for distribution system planning considering high penetration of DG units.

In general, Distribution system reliability described by annual average interruption duration and frequency is commonly assessed by enumerating all possible events leading to failure of load points and simulating the restoration process by assuming the static load and available supply capacity over the restoration period. However, this may not be applicable for distribution systems considering high penetration of stochastic DG units having intermittent generation patterns such as wind and PV. The increasing penetration of stochastic DG units into distribution networks demands a new analytical and simulation tool for reliability assessment typically to deal with stochastic nature of renewable DG source and time varying load demand.

DG technologies such as doubly fed induction generator based wind systems, synchronous machine based biomass generators and voltage source inverter based PV systems are considered as candidate DG systems in this planning frame work developed to effectively allocate the stochastic DG units in the distribution networks, especially with technical and economical considerations.

II. ACTIVE DISTRIBUTION SYSTEM PLANNING

The conventional distribution systems are seen to be passive network units because of uni-directional power flow from substations to end consumers. Traditionally, the expansion of distribution system is carried out with the aid of additional new components such as transformers, transmission lines and others for satisfying the load growth over a planning horizon. In recent times, the factors like incentives and environmental considerations are forcing the penetration of DG units into traditional distribution networks as an attractive option for distribution system planning. Active distribution system planning demands dedicated operating strategies since the DG units installed near the load centers can possibly change the direction of power flows and consequently alters the system operating conditions. The effective upgradation of overall performance of distribution system and reliability enhancement can be possible only with optimal allocation of DG units taking technical and economical considerations.

A. Perspectives on planning with DG units

The Active distribution system (distribution system deploying DG units) planning has received specific attention especially with considerations of technical aspects such as voltage regulation, power loss minimization, economic system operation and system reliability maximization.

- Effective voltage regulation with DG units can be made possible with consideration of two main aspects in terms of minimum DG capacity for maximum voltage support and maximum DG penetration without voltage violation.
- Another important aspect to be considered at the stage of distribution system planning is impact of DG integration on system power losses, which can be calculated based on load flow studies. It is a complex optimization problem due to the consideration of power generation pattern associated with stochastic DG technologies, demand variations, uncertainty aspects and other network constraints.
- For the deployment of DG units into electrical grids, the economic considerations are equally important along with the technical considerations from long term planning perspective. The associated costs to be incurred while deploying DG units in distribution system includes capital cost of DG units, fuel cost especially for fuel based DG units, cost of emissions, cost of electricity purchased from grid, cost of conventional network reinforcement and expansion, operation and maintenance cost of DG units, and cost of reliability towards compensation for interrupted customers.

B. Distributed Generation (DG) Technologies

DG technologies can be classified into Conventional and Renewable DG technologies. The conventional technologies like fossil fuel based generations have been widely deployed in distribution systems as cogeneration or backup generation without having significant interaction with distribution networks. In recent days, DG has become one of the attractive option for distribution system reinforcement due to technical advancement and distribution system automation. On the flip side, the DGs based on renewable technologies such as wind generation, PV generation and micro turbines and clean fuel based generations are also seen to be increasingly employed in distribution networks due to their environmental concerns and associated incentives.

Table 1 DG technologies and their advantages and disadvantages

DG Technology	Type of technology	Description
Conventional DG Units	Fossil fuel based generators (Diesel / Coal / Gas / Combined heat & Power)	**Advantages:** Readily available with continuous production Controllable and dispatchable Relatively low capital investment **Disadvantages:** High operation and maintenance cost High emissions and noise pollution
Renewable DG Units	Wind turbine (WT) based DG units	**Advantages:** No emissions and No fuel cost Low operation and maintenance cost Possible to export reactive power to grid for network support **Disadvantages:** Intermittent and low capacity power generation Difficult to predict power generation and not suitable for all locations
	Solar (PV) based DG units	**Advantages:** No emissions ; No fuel cost ; No noise impact Capacity augmentation is easy Possible to export reactive power to grid for network support **Disadvantages:** Non firm power generation ; low efficiency ; requires large area High capital investment on PV modules and ancillary equipments
	Clean Fuel based DG units (Biomass / Fuel Cells / Micro turbines)	**Advantages:** Readily available with continuous production ; less emissions Controllable and dispatchable Possible to export reactive power to grid for network support **Disadvantages:** High capital investment ; High fuel cost Risk associated with fuel availability

III. RELIABILITY ASSESSMENT FOR ACTIVE DISTRIBUTION SYSTEM

A. Techniques for reliability assessment of distribution system

The basic techniques developed for distribution system reliability assessment are Contingency based approach and reliability equivalent network approach. The main difficulty associated with contingency based approach of reliability evaluation of distribution system is that the contingencies relevant to all components of the distribution system are to be exhaustively enumerated, which may pose heavy computational burden to the reliability evaluation of large sized distribution systems.

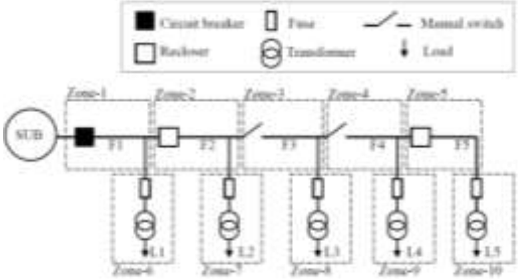
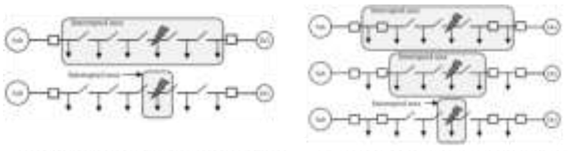


Figure 1 Reliability equivalent network for reliability assessment of distribution system

In order to minimize this computational burden while ensuring accurate reliability assessment, a distribution system can be converted into a reliability equivalent model [10] based on the location of the protection devices like reclosers, isolators, switches and fuses. With this approach of reliability equivalent network, the contingencies can be recited to limited number of zones rather than for all components of the distribution system.

B. System restoration with DG units

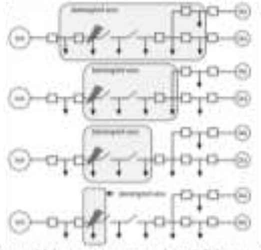
The distribution system reliability can be effectively improved by deployment of DG units into the system if islanded operation of DG units is allowed for system restoration. In case of a fault in the distribution system, the faulty section will be isolated by employing manual or automated switching operations based on the location of the fault. Accordingly, the system restoration can be carried out to reconnect the interrupted customers to the available sources. The customers on the upstream side of the fault can be restored from main supply. The customers on the downstream side of the fault may be restored through the sequence of operations with the available DG units. Sometimes, it may be possible to restore few customers due to the network constraints and DG capacity limits. In such case, the total capacity of customer loads interrupted and capacity of available DG units on the downstream side of the fault should be estimated carefully. The reliability of the system can be maximized if the DG units are properly integrated to the distribution system. The available restoration strategies of the distribution system are Single stage restoration with DG unit, Two stage restoration with DG unit and Multi stage restoration with DG unit.



a) Single stage restoration model with DG unit

b) Two stage restoration model with DG unit

Figure 2 Single and two stage restoration models



c) Multi stage restoration model with DG unit

Figure 3 Multi stage restoration model

C. Reliability assessment indices of distribution system

Reliability modeling and assessment of distribution system encompassing stochastic DG units has intensive research efforts due to rapid and increasing deployment of stochastic DG units in distribution systems. A set of power distribution system reliability indices are established for the assessment of reliability of distribution systems based on the average duration and frequency of momentary and sustained interruptions during predefined interval of time. Reliability indices of a distribution system are functions of component failures, repairs and restoration times which are random by nature. Several publications addressed the technical merits associated with the implementation of distributed generation [4-6]. Barker [4] analyzed the impact of DG on the voltage regulation, losses and short circuit levels of radial distribution systems. Farls et. al [5] highlights the use of DG as a viable solution for managing electric energy costs. Willis [6] discussed the use of DG to shave the peak load and to provide more capacity to the system. The main conclusions drawn from these studies are DG can provide voltage support, reduce the energy loss, and release the system capacity. Girgis et al [7] investigated the effect of DG on protective device coordination in distribution systems and pointed out the need for nonconventional schemes to protect systems with DG. Hadjsaid et al. [8] presented a discussion on the increase of the complexity of controlling and protecting the distribution systems with DG. The islanding phenomenon and the method used to detect it and protect the system against its consequences has been the subject of several publications among these papers is Kim et al. [9] and Usta et al [10].

Reliability Indices are the functions of various factors such as failure rate, repair time, switching time, etc. of various components. As factors are random in nature, reliability indices are also random in nature. The predictive reliability assessment of distribution systems requires the evaluation of two groups of indices namely, load point indices and system performance indices. The load point indices are the average load point failure rate (l failures/year), the average load point outage rate (r hr/failure) and the average annual load point outage time or average annual unavailability (U hr/year). Analytically, these indices are calculated using the following equations [11]:

$$\lambda_S = \sum \lambda_i \qquad (1)$$

$$r_S = \frac{\sum \lambda_i r_i}{\sum \lambda_i} \tag{2}$$

$$U_S = \lambda_S r_S \tag{3}$$

Where i is the number of feeder sections (main or laterals) connecting the load point to the supply and s is the name of this load point. These indices do not always give a complete representation of system behavior and response. The system performance indices are the weighted averages of the load point indices. The descriptions of the power distribution reliability indices are summarized as follows:

Table 2 Power distribution system reliability indices for reliability assessment

Name of the index	Description	Analytical expression to evaluate the index
SAIFI	System Average Interruption Frequency Index (SAIFI): The average number of interruptions per customer served per year	$SAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total number of customers served}} = \frac{\sum \lambda_i N_i}{\sum N_i}$
CAIFI	Customer Average Interruption Frequency Index (CAIFI): The average number of interruptions per customer affected per year	$CAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total number of customers affected}} = \frac{\sum \lambda_i N_i}{\sum N_a}$
SAIDI	System Average Interruption Duration Index (SAIDI): The average interruption duration per customer served per year	$SAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total number of customers}} = \frac{\sum U_i N_i}{\sum N_i}$
CAIDI	Customer Average Interruption Duration Index (CAIDI): The average interruption duration per customer interruption	$CAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total number of customer interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i}$
ASAI & ASUI	Average Service Availability Index (ASAI): The rating of the total number of customer hours that service was available during a year to the total customer hours demanded.	$ASAI = \frac{\text{Customer Hours of Available Service}}{\text{Customer Hours demanded}} = \frac{8760\sum N_i - \sum U_i N_i}{8760\sum N_i}$ $ASUI = 1 - ASAI = \frac{\text{Customer Hours of Unavailable Service}}{\text{Customer Hours demanded}} = \frac{\sum U_i N_i}{8760\sum N_i}$
AENS	Average Energy Not Supplied (AENS): The average energy not supplied per customer served per year	$AENS = \frac{\text{Total Energy not supplied}}{\text{Total number of customers}} = \frac{\sum U_i L_i}{\sum N_i}$
ECOST	Expected Interruption Cost Index at Load Point (ECOST): the cost of not supplying energy at that load point.	$ECOST = \sum_{i=1}^{n} L_i C_i \lambda_i$
EENS	Expected Energy Not Supplied Index (EENS): The amount of energy not supplied to customer	$EENS = P_i - U_i$
IEAR	Interrupted Energy Assessment Rate Index (IEAR): The IEAR at a load point shows how vulnerable is that load point in cost terms.	$IEAR = \frac{ECOST_i}{EENS_i}$
CTAIDI	Customer Total Average Interruption Duration Index (CTAIDI): The average duration of a sustained interruption for customers involved in the interruptions in the reporting period	
CEMI	Customers Experiencing Multiple Interruptions (CEMI): The ratio of individual customers experiencing more than n sustained interruptions to the total number of customers served	
ASIFI	Average System Interruption Frequency Index (ASIFI): The ratio of summation of interrupted load capacity (in kVA) of each sustained interruption to the total connected load served in the distribution system	
ASIDI	Average System Interruption Duration Index (ASIDI): The ratio of summation of interrupted load capacity (in kVAh) of each sustained interruption to the total connected load served in the distribution system	
MAIFI	Momentary Average Interruption Frequency Index (MAIFI): The average frequency of momentary interruptions.	
CEMSMI	Customers Experiencing Multiple Sustained Interruptions and Momentary Interruptions Index (CEMSMI): The ratio of individual customers experiencing more than n sustained interruptions and momentary interruption events to the total number of customers served	

Where λ_i is the failure rate (fails/year) ; N_i is the number of customers of load point i.; U_i is the annual outage time ; 8760 is the number of hours in a calendar year ; L_i is the average load connected to load point i; P_i is the average load of load point i. The above discussed indices are used to evaluate the complete scenario of distribution system reliability.

IV. CASE STUDY ON RELIABILITY ASSESSMENT OF ACTIVE DISTRIBUTION SYSTEM

A. Distribution system without DG units

RBTS Bus 2 system was considered as test system for many distribution network reliability studies reported in the literature. This network offer the information needed to conduct a reliability study. The system of RBTS Bus 2 without having DG units is shown in Figure 4. It is assumed that 100% reliability performance from generators and transmission lines of RBTS. The test system consists a 33kV main bus correspond to bus which is connected to 11kV supply through two transformers in parallel. There are 4 main feeders (M1, M2, M3, M4) at 11kV, which operate as radial feeders. Each distributor is supplies power to load points as shown in figure 4.

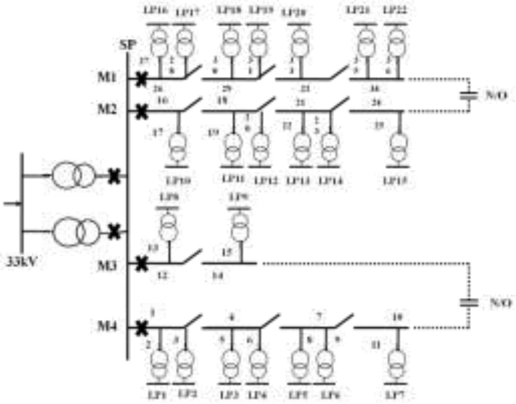


Figure 4 RBTS Bus 2 distribution test system for reliability assessment

Table 3 Feeder data of RBTS Bus 2 distribution test system

Type	Length (km)	Feeder section numbers
1	0.60	2, 6, 10, 14, 17, 21, 25, 28, 30, 34
2	0.75	1, 4, 7, 9, 12, 16, 19, 22, 24, 27, 29, 32, 35
3	0.80	3, 5, 8, 11, 13, 15, 18, 20, 23, 26, 31, 33, 36

Table 4 Types of customers, number and load point data

Load point	Type of customer	Average load per load point (MW)	No of customers per load point
1, 2, 3, 10, 11	Residential	0.535	210
12, 17, 18, 19	Residential	0.450	200
8	Industrial	1	1
9	Industrial	1.15	1
4, 5, 13, 14, 20, 21	Govt & Institution	0.566	1
6, 7, 15, 16, 22	Commercial	0.454	10
Total		12.291	1908

Table 5 reliability data of components of test system

Type of component	Failure rate (f/yr)	Repair time (h)	Switching time (h)
Transformers			
HT (33/11kV)	0.015	15	1
LT (11kV/415V)	0.015	10	1
Breakers			
33kV	0.002	4	1
11kV	0.006	4	1
Busbars			
33kV	0.001	2	1
11kV	0.001	2	1
Feeders			
11kV	0.65	5	1

The failure rates and repair duration of different components of the distribution system such as feeders, transformers, breakers, busbars are tabulated below. 33/11kV transformers are considered as 16MVA rating and LT transformers are considered as 2MVA rating.

The interruption cost at a single customer depends on the characteristic of the customer. The combination results in formation of Composite Customer Damage Function (CCDF).

The calculated individual load point indices are tabulated in table 6 given below. As the considered distribution test system is radial system with no mesh connections, the average failure rate (λ) increases as the load points (LP) are far from the supply point (SP). However, the average outage duration time (r) tends to be smaller. The annual unavailability (U) increases as far away from supply point.

Table 6 Load point indices of distributed test system

Load point	**Main feeder no**	**Distance from SP (Km)**	**Average failure rate λ (f/yr)**	**Average outage duration r (h)**	**Annual unavailability U (h/yr)**
1	M1	1.35	0.1658	5.01	0.8307
2	M1	1.55	0.1788	5.01	0.8957
3	M1	2.3	0.2465	4.92	1.2135
4	M1	2.1	0.2335	4.92	1.1485
5	M1	3.05	0.3143	4.87	1.5313
6	M1	3.05	0.3110	4.87	1.5150
7	M1	3.65	.3473	4.86	1.6873
8	M2	1.55	0.1568	4.59	0.7197
9	M2	2.15	0.2028	4.64	0.9407
10	M3	1.35	0.1598	5.05	0.8067
11	M3	2.3	0.2405	4.95	1.1895
12	M3	2.35	0.2438	4.95	1.2058
13	M3	2.9	0.2985	4.89	1.4585
14	M3	2.95	0.3018	4.89	1.4748
15	M3	3.5	0.3445	4.88	1.6795
16	M4	1.55	0.1788	5.01	0.8957
17	M4	1.4	0.1690	5.01	0.8470
18	M4	2.15	0.2368	4.92	1.1648
19	M4	2.35	0.2498	4.92	1.2298
20	M4	3.1	0.3115	4.89	1.5235
21	M4	3.65	0.3603	4.86	1.7523
22	M4	3.7	0.3635	4.87	1.7685

Table 7 Interruption cost for various customers in $/MW [15]

	Type of customer						
Duration (min.)	**Agriculture**	**Commercial**	**Govt & Institutions**	**Industrial**	**Large users**	**Office & buildings**	**Residential**
1	0.060	0.381	0.044	1.625	1.001	4.778	0.001
20	0.343	2.969	0.369	3.868	1.508	9.878	0.093
60	0.649	8.552	1.492	9.085	2.225	21.060	0.482
240	2.064	31.32	6.558	25.160	3.968	68.83	4.914
480	4.120	88.01	26.04	55.810	8.24	119.20	15.690

Load point indices are mostly calculated related to the unsupplied energy and costs, which are determined by EENS, ECOST and IEAR values. The values of these indices are tabulated below. A priority based ranking is allotted to load points based on the value of IEAR calculated at that point.

Table 8 Unsupplied energy and interruption cost indices of load points

Load point	**Type of load**	**EENS (MWh/yr)**	**ECOST (K$/yr)**	**IEAR ($/KWh)**
16	Commercial	0.4067	3.564	8.763
6	Commercial	0.6878	5.925	8.614
15	Residential	0.7625	6.565	8.609
7	Commercial	0.7660	6.587	8.599
22	Commercial	0.8029	6.903	8.597
9	Industrial	1.0819	6.991	6.462

8	Industrial	0.7197	4.645	6.453
4	Govt & Institution	0.6501	1.386	2.133
13	Govt & Institution	0.8255	1.733	2.100
14	Commercial	0.8347	1.752	2.099
20	Govt & Institution	0.8623	1.809	2.098
5	Govt & Institution	0.8667	1.812	2.091
21	Govt & Institution	0.9918	2.062	2.079
10	Residential	0.4316	0.645	1.495
1	Residential	0.4445	0.661	1.487
17	Residential	0.3812	0.566	1.486
2	Residential	0.4792	0.711	1.483
11	Residential	0.6364	0.929	1.460
12	Govt & Institution	0.5426	0.792	1.460
18	Residential	0.5241	0.764	1.457
3	Residential	0.6492	0.945	1.456
19	Residential	0.5534	0.805	1.455
Total		14.9007	58.552	

From the above table, it can be concluded that, the value of IEAR is highly correlated to the type of the customer and tendency of load sector. Most of the commercial load points have the high IEAR value followed by industrial load points, while the govt & institution load points and residential load points have a smaller IEAR. The higher value of IEAR reliability index at load point indicates the poor reliability at that individual load point.

Table 9 System reliability indices of the test system

SAIFI : System Average Interruption Frequency Index:	0.2126 f/customer/yr
SAIDI: System Average Interruption Duration Index :	1.0545 h/customer/yr
CAIDI :Customer Average Interruption Duration Index :	4.960 h/customer interruption
ASAI: Average Service Availability Index :	0.9999 pu
ASUI : Average Service Unavailability Index:	0.00012 pu
AENS: Average Energy Not Supplied :	0.0078 MWh/customer/yr
ECOST: Expected Interruption Cost Index :	58551.64 $/yr
EENS: Expected Energy Not Supplied Index:	14.901 MWh/yr
IEAR: Interrupted Energy Assessment Rate Index:	3.929 $/KWh

B. Distribution system with DG units

The focus of this case study is on integration of DG units to the considered distribution test system at different points of one main feeder. The attention has been given to study the distribution test system main feeder with worth reliability in terms of cost indices.

Table 10 Reliability indices of each feeder of distribution test system

Feeder no	**EENS (MWh/yr)**	**ECOST (K$/yr)**	**IEAR ($/KWh)**
M1	4.5223205	16.4726	3.643
M2	4.0332946	12.4169	3.079
M3	1.8016129	11.6356	6.458
M4	4.5434614	18.0265	3.968

From the above table, the main feeder M4 has high ECOST value in addition with EENS value, which was a burden to the distribution company. Adding a DG unit to this feeder M4 will enhance the system reliability.

Case study:1 This study evaluates the impact of placing DG unit at main feeder M4 of the considered distribution test system.

Table 11 System reliability indices of the main feeder M4 (for LP1 to LP7) of the test system

SAIFI : System Average Interruption Frequency Index:	0.2013 f/customer/yr
SAIDI: System Average Interruption Duration Index :	1.0002 h/customer/yr
CAIDI :Customer Average Interruption Duration Index :	4.9688 h/customer interruption
ASAI: Average Service Availability Index :	0.9999 pu
ASUI : Average Service Unavailability Index:	0.0001 pu
AENS: Average Energy Not Supplied :	0.0070 MWh/customer/yr
ECOST: Expected Interruption Cost Index :	18027 $/yr
EENS: Expected Energy Not Supplied Index:	4.543 MWh/yr
IEAR: Interrupted Energy Assessment Rate Index:	3.968 $/KWh

Among the available DG technologies, a diesel generator based DG unit has been considered in this case study in order to enhance the reliability of the test system by acting like a backup emergency power supply in times of failure of main grid.

Table 12 Reliability data of the DG unit (500KW diesel generator)

Type of DG	Failure rate (f/yr)	Repair time (h)	Switching time (h)
500KW diesel generator	0.87	3.9	1

Each DG unit is connected to the distribution network with a circuit breaker in order to isolate the DG unit during faults from rest of the system. It is also assumed that all other protections are same as that of load points and feeders.

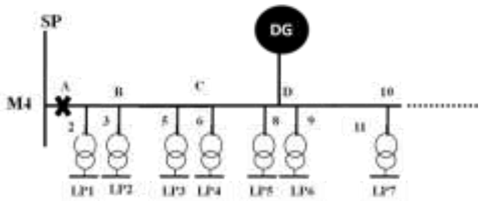


Figure 5 DG unit connected at D of main feeder M4 of the test system

The system reliability indices for different group of feeders and reliability of the overall system are compared in both case studies i.e. before connecting DG unit and after connecting DG unit at D of M4.

Table 13 impact of DG unit on reliability indices of the test system

Reliability index	M1+M2+M3+M4		M1+M2+M3		M4	
	WITH OUT DG	WITH DG	WITH OUT DG	WITH DG	WITH OUT DG	WITH DG
SAIFI	0.2126	0.1828	0.2185	0.2055	0.2013	0.1392
SAIDI	1.0545	0.9319	1.0828	1.0328	1.0002	0.7377
CAIDI	4.9602	5.0973	4.9651	5.0264	4.9688	5.2990
EENS	14.901	12.707	10.357	9.925	4.543	2.782
ECOST	58552	19508	40525	38950	18027	10557

From the above table, it can be concluded that, installing DG unit in distribution network has its impact on the reliability of the system. The installation of DG at D of M4 has improved the EENS index of the system by 80% and ECOST by 83% while other indices by 20% and 17%.

Table 14 impact of DG unit on reliability indices of the test system

Reliability index	M1+M2+M3+M4		M1+M2+M3		M4	
	Before DG- After DG	%	Before DG- After DG	%	Before DG- After DG	%
EENS	2.193	100%	0.432	20%	1.761	80%
ECOST	9044	100%	1575	17%	7469	83%

From the above table, it can be concluded that maximum worth of reliability has been observed at the main feeder connected with DG unit.

Case Study:2 This study focuses on quantifying the value of installing DG at different locations on main feeder of the test distribution system.

Table 15 reliability indices of the test system with DG unit at different locations on M4

Reliability index	**DG locations on M4**					
	WITH OUT DG	**@ A (NEAR SP)**	**@ B (0.75KM FROM SP)**	**@ C (1.5KM FROM SP)**	**@ D (2.25KM FROM SP)**	**@ E (2.85KM FROM SP)**
SAIFI	0.2013	0.1943	0.1713	0.1433	0.1392	0.1381
SAIDI	1.002	0.9742	0.8842	0.7557	0.7377	0.7324
CAIDI	4.9688	5.0140	5.1618	5.2721	5.2990	5.3045
EENS	4.543	4.449	4.121	3.277	2.782	2.614
ECOST	18027	17743	16760	13369	10557	9238

From the above table, it can be concluded that, DG unit installed at beginning of the feeder (@A) barely improves the reliability indices, because of the DG would be used when main grid fails to feed the load point.

Case study:3 This study focus on evaluating the impact of installing more number of DG units on main feeder of the test distribution system. For the analysis purpose, 5 locations (A,B,C,D,E) and 3 DG units are considered on the M4 of the test distribution system.

Table 16 reliability indices of the test system with 3 DG units at different locations on M4

Reliability index	**DG locations on M4**														
	A			**B**			**C**			**D**			**E**		
	DG1	**DG2**	**DG3**	**DG1**	**DG2**	**DG3**	**DG1**	**DG2**	**DG3**	**DG1**	**DG2**	**DG3**	**DG1**	**DG2**	**DG3**
SAIFI	0.1943	0.2008	0.2063	0.1713	0.1773	0.1833	0.1433	0.1455	0.1475	0.1392	0.1394	0.1396	0.1381	01381	0.1382
SAIDI	0.9742	0.9982	1.022	0.8842	0.9082	0.9322	0.7557	0.7642	0.7727	0.7377	0.7384	0.7392	0.7324	0.7327	0.7331
CAIDI	5.014	4.9836	4.955	5.161	5.1225	5.0857	5.272	5.253	5.2357	5.299	5.297	5.295	5.304	5.304	5.3032
EENS	4.449	4.536	4.624	4.121	4.208	4.296	3.277	3.389	3.400	2.782	2.817	2.853	2.614	2.624	2.635
ECOST	17743	18006	18268	16760	17022	17285	13369	13599	13830	10557	10748	10941	9238	9321	9407

V.CONCLUSION

The installation of DG units as one the option for improving the reliability of the system by reducing the cost of outage at costumer point has been analyzed in this study. From the test distribution system containing four main feeders, it is observed that feeder 4 (M4) is the less reliable with higher distribution indices. The installation of DG at this feeder has impact for more than a 83% improvement in the value of the index compared to installation at other feeders. The benefits of DG are found close the DG connection point. Installations of DG at supply point will barley improve the indices but not preferred. As far the location is from the substation, there reliability system indices increase. The best location for the placement of the DG is at the end of the feeder M4 (@ point E) in terms of reliability cost due to outage of 9238$/yr for main feeder M4, while it is 18027$/yr for the base case without DG (also for M4). Placing more than one unit at the same location has a inverted effect, the reliability will not improve, this is due to other component failure needed for DG installation as buses and circuit breaker. The DG can be oversized which would make system unreliable when more DGs are installed at same location.

VI. REFERENCES

1. Distributed Generation: Policy Framework and Regulators", Arthur D. Little White Paper, 1999.
2. G. pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, W. GD'haeselle, Distributed generation: definition, benefits ans issues, Energy Policy Vol. 22, p.p. 787-795, 2005.
3. IEEE stands for the Institute of Electrical and Electronics Engineers and the definition is taken from Dondi, Bayoumiet al. (2002), p. 2
4. Billinton, R.N. Allan, L. Salvaderi, Applied reliability assessment in electric power systems, IEEE Press, 1991.
5. R. Billinton and R.N. Allan, Reliability evaluation of power systems Press, New York, 1996
6. Billinton,R, Jonnavithula,S, "A test system for teaching overall power system reliability assessment", Power System, IEEE Transactions.1670-1676, 1996.
7. International Energy in Liberalised Market, 2002 Available at: http://www.iea.org

8. K. Purchala, R. Belmans, L. Exarchakos, A.D. Hawkes, Distributed generation and grid issues, Imperial college London, 2006
9. G. pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, W. GD’haeselle, Distributed generation: definition, benefits and issues, Energy Policy Vol. 22, p.p. 787.
10. I. Waseem, M. Pipattanasomporn, S. Dahman, Reliability Benefits of Distributed Generetation as a Backup Source, Power & Energy Society General Meeting, 200
11. A.M. Leite da Silva, A.M. Cassula, R. Billintion and L.A.F. Manso Integrated reliability evaluation of generation
12. R. Billinton and R.N.Allan, Reliability evaluation of engineering systems Press, New York, 1992.
13. R. N. Allan and M. G. Da Silva, “Evaluation of reliability indices and outage costs in distribution systems,” IEEE Trans. Power Syst., vol. 10, no. 1, pp. 413
14. Wikipedia, http://en.wikipedia.org/wiki/SAIFI
15. R. Billinton et al., “ A Reliability Test System for Educational Purpose”, on Power Systems, Vol. 4, No. 3, August 1989.
16. R. N. Allan, R. Billinton, I. Sjarief, L. educational purposes-basic distribution system data and results,” Systems, vol. 6, no. 2, pp. 813–820, May 1991.
17. L. Goel, R. Billinton, R. Gupta, basic data and evaluation of distribution system reliability worth, IEEE Transactions on Power Systems; 271-277. 1991
18. U.S. census Bureau, Standard Industrial Classification (SIC) System, http://www.census.gov/epcd/www/sic.html
19. R Billinton, S. Kumar. L. Goel, A Reliatlfltty Test System for Educational Purposes Data. IEEE Transactions on Power Apparatus and System, Vol. 4. NO. 3, Aug. 1989. pp. 1238-1244.
20. Chowdhury, A.A.; Agarwal, S.K.; Koval, D.O. conventional distribution systems planning and analysis, 37th IAS Annual Meeting, vol.2, Pag
21. R. Billinton, L. Salvaderi, J. D. McCalley, H. Chao, Th. Seitz, R. N. Allan, J. Odom, C. Fallon, “Reliability Issues in Today’s Electric Power Utility Environment”, IEEE Transactions on Power Systems, Vol. 12, No. 4, November
22. IEEE recommended practice for the design of reliable industrial and commercial power systems. 1998, USA : 1998