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A Novel Approach for the Assessment of the Reliability of Distributed Generation Systems

By

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Abstract:

This paper presents a novel algorithm for adequacy assessment of electrical distribution system including distributed generation. A comparison between the proposed technique and the state duration sampling technique is performed. The proposed technique is integrated with Monte Carlo simulation method to carry out reliability analysis of typical distribution system. The results obtained are presented and discussed.

Keywords:

Distributed generation, Monte Carlo simulation, and Reliability

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I. INTRODUCTION

At present the electric power industry is undergoing considerable charge with respect to structure, operation, and regulation [1-2]. The various electric utility acts introduced in different countries have initiated the restructuring process and the traditional vertically integrated utility structure consisting of generation, transmission, and distribution functions has been dismantled [3]. Due to the wide spread use of distributed generation (DG) which is defined as small scale power generation located at or near to the load being served, several system operating issues have come into sight. These concerns involve both the benefits of using DG_s and the problem associated with the wide implementation of DG units in a well established system for several decades. The concept of implementing small generation in the distribution system has been in practice for several years as backup, standby and standalone generation. However, as a result of the new modern technology achieved in the generation industry and the benefits expected from this technology implementation, a wide spread use of these DG units operated in the system has become a fact [4]. The main reasons behind the expected widespread of DG are:[5,6]

- The deregulation in the power market, which encourage public investment to sustain the
- Development in the power demand. This development has led to the breaking up of investments
- The emergence of new generation techniques with small rating ,ecological benefits, increased profitability ,and which can be combined with heat generation.
- The saturation of the existing networks and the continuous growth of the demand.

The difficulties in the operation and distribution systems are still the main challenges associated with parallel operation of DG with these systems [7]. In the real life systems , the operation of these DG units   undergoes different scenarios according to the strategies of the electricity producers , the needs of the consumers and the zonal load time variation characteristics. Therefore , some uncertainties are introduced in the operation of such units and thus , stochastic modeling of systems involving DG units becomes of a great interest[8] .

The sources of uncertainty in the operation of DG connected systems at a certain hour of the day include the number of the running DG units at this hour , the locations of these units and the power exported to the system by these units . These uncertainties affect the modeling and evaluation of the system capacity , generation scheduling , and reliability adequacy assessment .

In this paper the proposed technique incorporated Monte Carlo simulation and give a comparison with the State Sampling technique . The adequacy assessment of the system and the calculation of reliability indices are performed using the proposed

technique ,also this study examine the impact of DG units with different capacity and location on the excepted reliability indices.

Billinton and Wang in [9] calculate the reliability indices: average load failure rate , average load outage rate, and average load outage time,also determine SAIFI, CAIDI, ASAI, and SAIDI of distribution system of the RBTS using sequential Monte Carlo simulation .They performed analysis with both analytical and simulation technique where the simulation approach can provide information on the load point and system indices that the analytical techniques can not provide.

Chowdhury and el. in [3] determine the size of distributed generator or combination of smaller distributed units by adding to the existing system and compare its effect on the reliability of the system with a adding extra feeder from substation to the existing system. They verify the presence of DG is enhancing the system reliability , where the duration of interruptions per customer per year and the duration of system interruptions per year are reduced.

Hegazy and Salama in [4] General procedure to assess the ability of the system power capacity to meet the total demand is presented and implemented in atypical case study where several distributed generation units are running in parallel within a system and the system margins and the average amount of unsupplied loads are estimated using Monte Carlo simulation . The results obtained showed that DG can enhance the overall capacity of the distribution system and be used an alternative to substation expansion in case expected demand growth.

Kaigui and el in[10] they presents algorithm, which can be used to evaluate the reliability of complex medium voltage, an approach to searching for the shortest paths from a node to source and between any two nodes is presented ,based on graph theory and structural features. The approach can be used to consider the effect of breakers ,fuses ,disconnect switches ,alternative supplies and replacing transformers in addition to other system

II. THE PROPOSED APPROACH

 The distribution system under study is comprised of two centralized substation the ratings are 6*100 and 4*150 MW ,so that the total generated power is 1200 MVA. The data required to construct the load model are presented as a part of IEEE reliability test system in[11,12] with the peak system load is 1000 MW. Let P_T is the total power received from substation transformers, and P_{tr} is the output power of each transformer ,where

$$P_T = \sum P_{tr} \qquad\qquad (1)$$

P_{tr} is vary randomly in the range from 90 to 100% of its nominal capacity (100 or 150 MW) .Adding DG (distributed generator) units to operate in parallel with the substation transformers will increase P_S (distribution system power capacity) where

$$P_S = P_T + P_{DG} \qquad (2)$$

P_{DG} is the total power received from DG units.

$$P_{DG} = \sum P_{Gi} \qquad (3)$$

The system capacity curve is superimposed on the chronological load curve in [9,10] to obtain the system available margin model ,then the reliability indices can be calculated using Monte Carlo method .In each sample year(i), the loss of load duration (LLD_i) in hr , the loss of load occurrence (LLO_i) , and the energy not supplied (ENS_i) in MWh. The reliability indices in N sampling years can be estimated using the following equations:

(1) Loss of Load Expectation (LOLE) , hr/yr

$$LOLE = \sum_{i=1}^{N} \frac{LLDi}{N} \qquad (4)$$

(2) Loss of Energy Expectation (LOEE) , MWh/yr

$$LOEE = \sum_{i=1}^{N} \frac{ENSi}{N} \qquad (5)$$

(3) Loss of load Frequency (LOLF) occ./yr

$$LOLF = \sum_{i=1}^{N} \frac{LLOi}{N} \qquad (6)$$

In this paper, a random-number generator is employed to generate an integer (k_1), where $k_1 \in [1,\ldots,10]$ to represent the expected number of transformers in their "on state." and Transformers' rating are then identified, by generating a random sequence of integers(k_1), where this sequence represents the transformer number and P_T is calculated ,the sequence above is repeated each hour in year.

Also another random-number generator is employed to generate an integer (k_2), where $k_2 \in [1,\ldots,M]$ to represent the expected number of DGs in their" on state." where M is the total no of DGs ,and DGs ' rating are then identified, by generating a random sequence of integers(k_2), where this sequence represents the DG number and P_{DG} is calculated .

In the proposed algorithm, the power exported from each DG unit to the distribution system is assumed to be varying randomly. To simulate this feature, the magnitude of the generator power is calculated each time the simulation is recalled. The DG nominal rating is multiplied by a random number , where
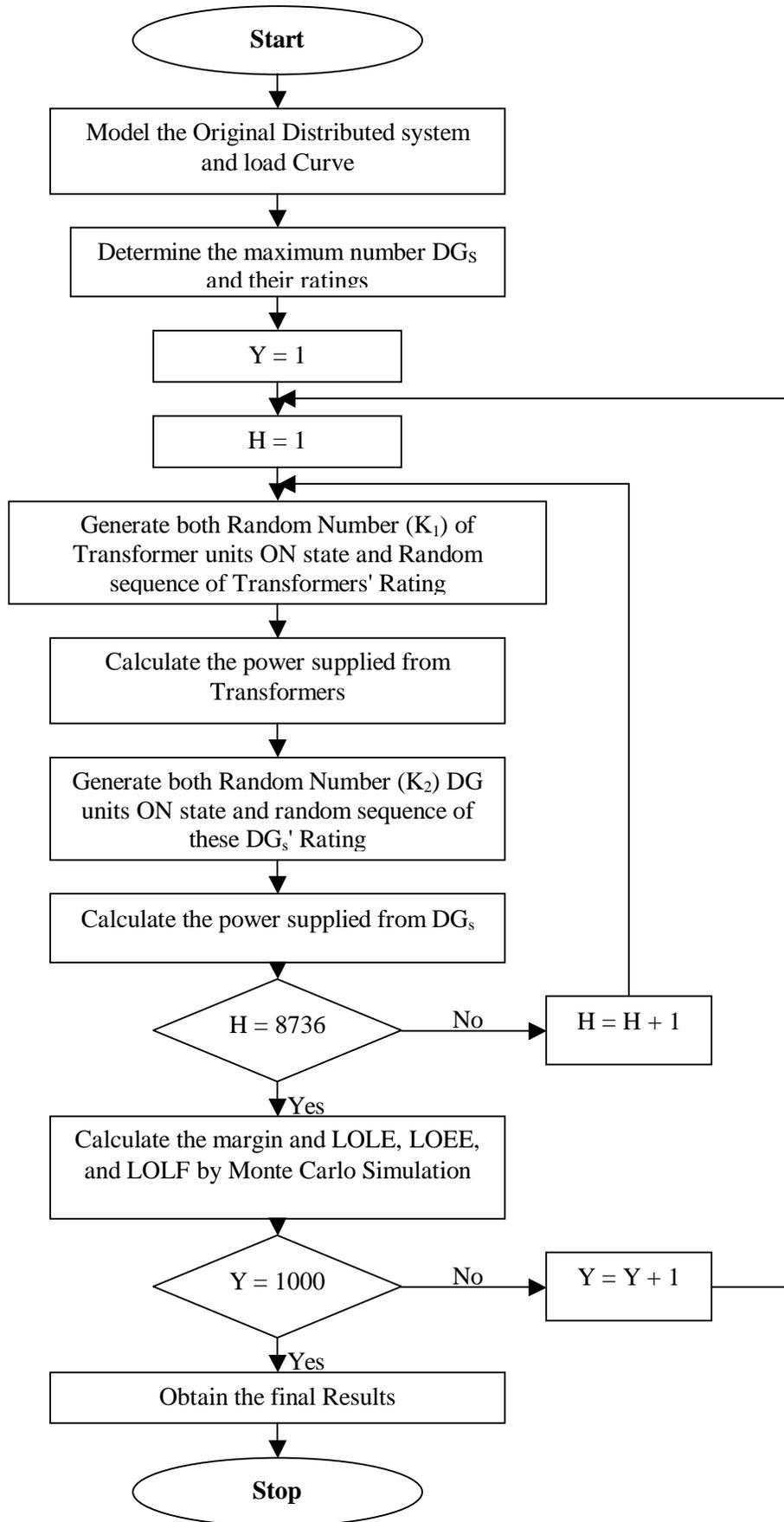
is a uniformly distributed random number U, where U is uniformly random number sequence generally between [0, 1]. However, the minimum value of U can be adjusted according to the historical primary distribution system where

$$P_{Gi} = P_{Ri}*U \qquad\qquad (7)$$

P_{Ri} is rated power of each DG, and P_{Gi} is generated power of DG at each hour in the year. MATLAB programs is used and m-files are performed by author for this study.

The flow chart of the Monte Carlo base algorithm is showing in fig.1 and step by step procedure as follows:

1) Model the load curve , rating of substation transformer, and the max. no. of DGs (M).
2) Estimate the hourly operating transformer number, sequence, and power and run the model:
3) Generate random integer k1 each hour in the year ,to represent the expected no. of transformer operating .
4) Generate random sequence of the selected integer k1 each hour in the year to represent any transformer ON .
5) Generate random power multiplier Utr to calculate each transformer export power, the min value of Utr is 0.9.
6) Calculate PT
   a) Estimate the hourly operating DG number, sequence, and power and run the model:
   b) Generate random integer k2 each hour in the year ,to represent the expected no. of DG operating .
7) Generate random sequence of the selected integer k2 each hour in the year to represent any transformer ON .
8) Generate random power multiplier U_{DG} to calculate each DG export power, the min value of U_{DG} is adjusted.
9) Calculate P_{DG}
   a) Calculate PS , the margin, and the reliability indices(LOLE,LOEE,LOLF).
   b) Perform the Monte Carlo convergence till all indices reach saturation.
   c) Repeat step-2 for all hours of the year.

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                    ( Start )
                        │
                        ▼
         ┌──────────────────────────────┐
         │  Model the Original Distributed system
         │         and load Curve         │
         └──────────────────────────────┘
                        │
                        ▼
         ┌──────────────────────────────┐
         │  Determine the maximum number DGS
         │         and their ratings      │
         └──────────────────────────────┘
                        │
                        ▼
              ┌──────────────────┐
              │      Y = 1        │
              └──────────────────┘
                        │
                        ▼
              ┌──────────────────┐
              │      H = 1        │
              └──────────────────┘
                        │
                        ▼
         ┌──────────────────────────────┐
         │  Generate both Random Number (K₁) of
         │  Transformer units ON state and Random
         │  sequence of Transformers' Rating │
         └──────────────────────────────┘
                        │
                        ▼
         ┌──────────────────────────────┐
         │  Calculate the power supplied from
         │           Transformers         │
         └──────────────────────────────┘
                        │
                        ▼
         ┌──────────────────────────────┐
         │  Generate both Random Number (K₂) DG
         │  units ON state and random sequence of
         │         these DGs' Rating      │
         └──────────────────────────────┘
                        │
                        ▼
         ┌──────────────────────────────┐
         │  Calculate the power supplied from DGs │
         └──────────────────────────────┘
                        │
                        ▼
                  < H = 8736 >──No──► [ H = H + 1 ]
                        │ Yes
                        ▼
         ┌──────────────────────────────┐
         │  Calculate the margin and LOLE, LOEE,
         │  and LOLF by Monte Carlo Simulation │
         └──────────────────────────────┘
                        │
                        ▼
                  < Y = 1000 >──No──► [ Y = Y + 1 ]
                        │ Yes
                        ▼
         ┌──────────────────────────────┐
         │      Obtain the final Results  │
         └──────────────────────────────┘
                        │
                        ▼
                     ( Stop )
```

Start

Model the Original Distributed system and load Curve

Determine the maximum number DG_S and their ratings

Y = 1

H = 1

Generate both Random Number (K_1) of Transformer units ON state and Random sequence of Transformers' Rating

Calculate the power supplied from Transformers

Generate both Random Number (K_2) DG units ON state and random sequence of these DG_s' Rating

Calculate the power supplied from DG_s

H = 8736   No   H = H + 1

Yes

Calculate the margin and LOLE, LOEE, and LOLF by Monte Carlo Simulation

Y = 1000   No   Y = Y + 1

Yes

Obtain the final Results

Stop

III. VALIDATION OF THE PROPOSED METHOD

The IEEE RTS has 32 generating units ranging from 12 MW to 400 MW as in table 1.the annual load curve of 8736 hourly load points with system peak load 2850 MW, the results of the three reliability indices (LOLE,LOEE,LOLF) are calculated in [12]using State Duration Sampling Method and the results shown in fig.2

In the proposed method divide the generators into two groups :

The first is the largest units from 155 to 400 MW and the number of their 10 units. These units operates as base units like substation transformer, where the minimum number of units ON is 9 units.

The second group is units from 12 to 100 MW and the number of their 22 units. These units operates as a peak units like DGs, where the minimum number of units ON is 15 units (68%).The proposed algorithm is applied and the reliability indices shown in fig.3 , the comparison between the results of the two methods in table 2.

Table 1 Generating unit data

No.	Unit Size MW	Number of units
1	12	5
2	20	4
3	50	6
4	76	4
5	100	3
6	155	4
7	197	3
8	350	1
9	400	2
Total	3405	32
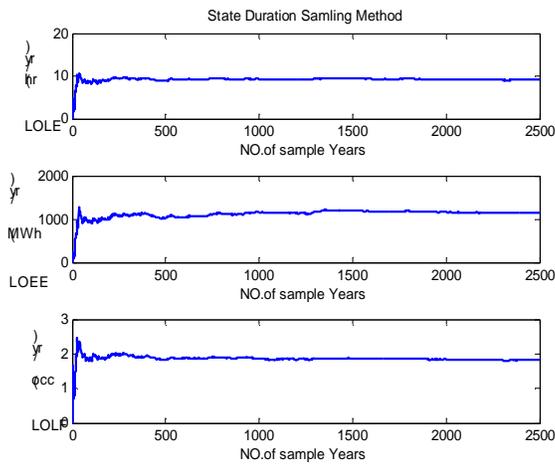
Fig.2 LOLE,LOEE,LOLF vs. the number of sample years
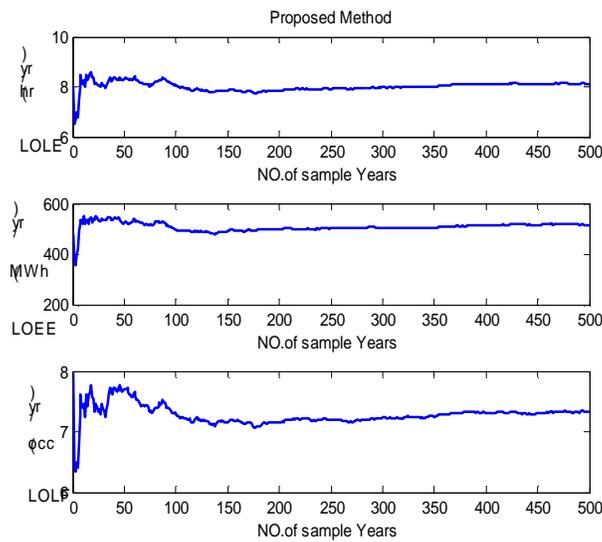
Fig.3: LOLE, LOEE and LOLF vs. the number of sample years

Table2 comparison between the two methods

Index	State Duration Method	Novel Method
LOLE (hr/yr)	9.2341	8.1260
LOEE (MWh/yr)	1134	515
LOLF (occ./yr)	1.92	7.3320

IV. CASE STUDY AND RESULTS

The distribution system consists of two substation 10 transformers with ratings (6x100, and 4x150 MW) ,the maximum capacity is 1200 MW, where the minimum number of transformer (on state)is (8 from 10) .The maximum load is 1000 MW

The results of calculation of LOLE,LOEE ,LOLF without adding DGs shown in fig.4 ,the value of LOLE equal 21.18 (hr/yr), LOEE equal 498.73 (MWh/yr), and LOLF equal 15.8 (occ./yr).

Adding one DG with different ratings 2% of the maximum load capacity (20 MW),4%(40 MW), 7%(70 MW), and 10% (MW) to the generated power from transformer substation will enhance the reliability indices.

Fig.5 show LOLE with adding one DG 2%,4%,7%, and 10% where the generated power from DG is full capacity (UDG =1.0),from this figure it can be observed that the value of LOLE decreased from 21.18(hr/yr)in case of without DG to 10.7 (hr/yr), with adding DG 10%.The same tendency of decrease of LOLE is observed in fig.6 ,where UDG = 0.7 (PGi = PRi*UDG), the comparison of with and without Adding one DG on the value of LOLE is shown in table 3.
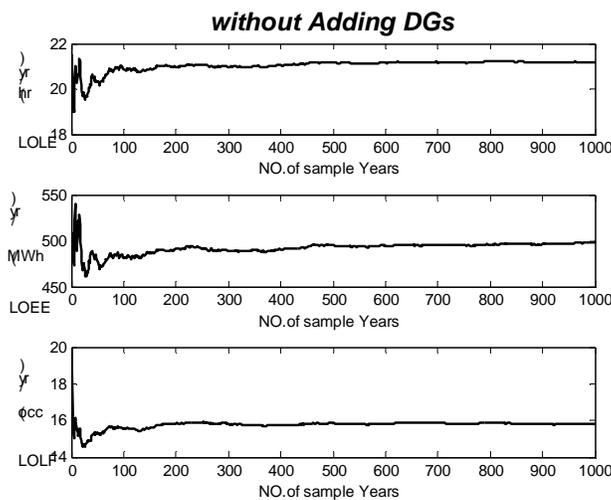
Fig.4 LOLE,LOEE,LOLF vs. the number of sample years, with min 8 transformer ON

Table 3 the value of LOLE (hr/yr)

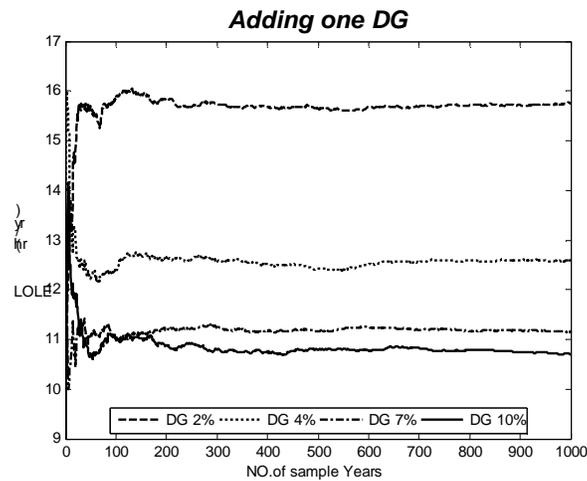| Without DG	Adding one DG				
	U_{DG}	DG 2%	DG 4%	DG 7%	DG 10%
21.18	1.0	15.76	12.61	11.14	10.70
	0.7	16.09	14.17	12.13	10.96

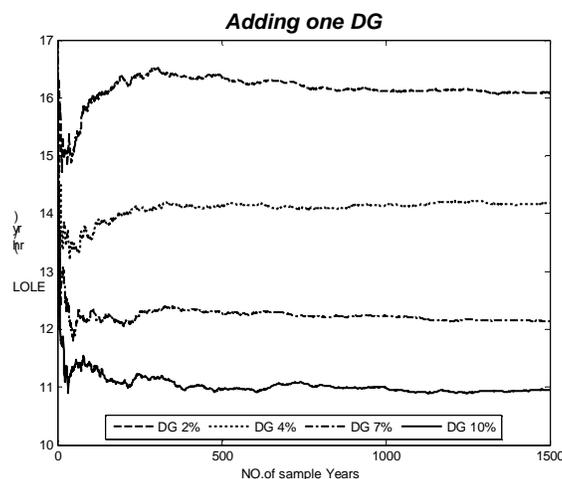Fig.5 The DG power (100%) of its capacity

Fig.6 The DG power (70 to100%) of its capacity

Adding two DGs with ratings capacity (2%,2%), (2%,4%), and(4%,4%) to the capacity of substation transformer have more improvements on the reliability indices than one DG ,these verified in figures 7,8,9,10.

Fig.7 shows the values of LOLE with different probabilities of the two DGs capacity ,where $U_{DG} = 1.0$,and minimum no DG is ON state at any hour .In other words at each hour the number of DGs in ON state are (zero or one or two).

While fig.8 describe the minimum one from two DGs is ON at each hour(no. of DGs ON are one or two),and $U_{DG}=1.0$
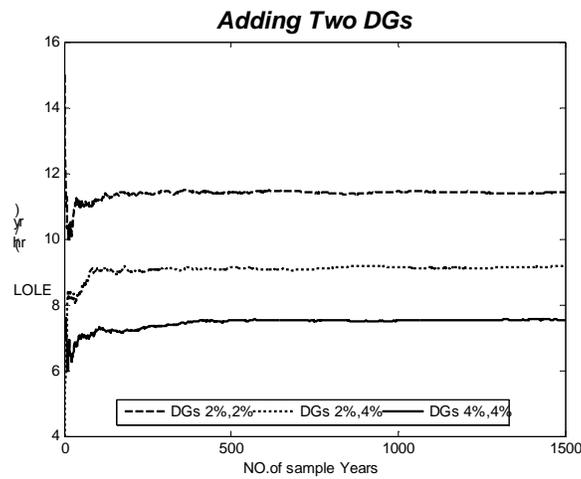
Adding Two DGs

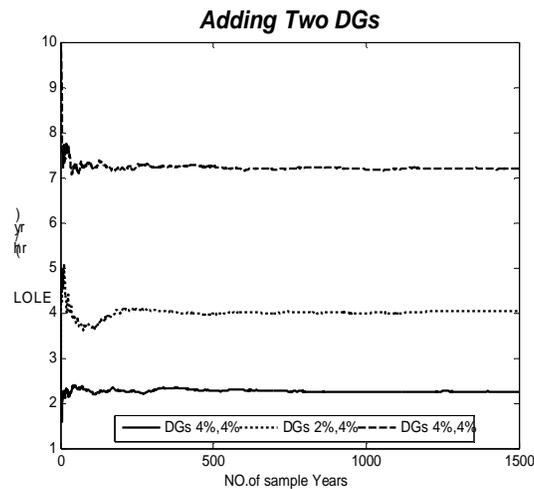Fig.7 The DGs power (100%)of their capacity, and min. no DG is ON

Adding Two DGs

Fig.8 The DGs power (100%) of their capacity, and min. one DG is ON

Fig.9 shows the effect of adding two DGs and UDG = 0.7 , where the minimum number of DGs in ON state is zero, but fig.10 draws with minimum DGs ON is one .
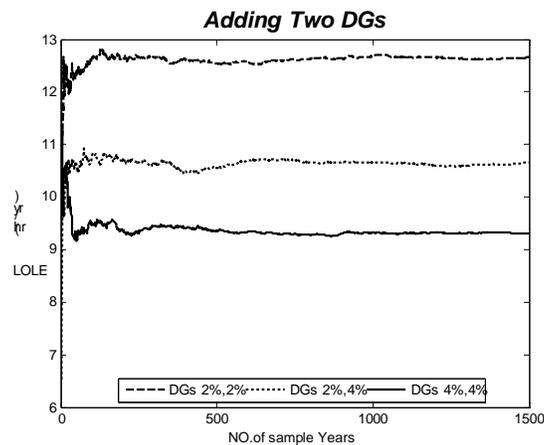The results of the values of LOLE in figures 7,8,9, and 10.

Fig.9 The DGs power (70 to100%) of their capacity, and min. no DG is ON
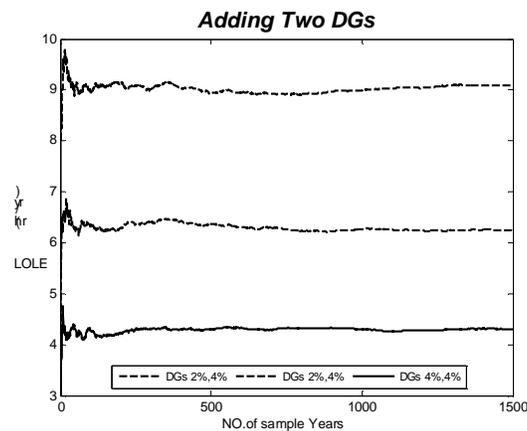

Fig.10 The DGs power (70 to 100%)of their capacity, and min. one DG is ON

V. Conclusions

This paper presents a novel algorithm that incorporates the modeling reliability aspects of distributed generation systems and substation transformer connected to the distribution systems. The algorithm provides the hourly system': centralized power generation from substation, and total DG penetration levels. Monte Carlo simulation technique is employed in the algorithm to cover all possible operation conditions of the systems. A typical case study is analyzed with three penetration levels of DGs.The first adding one DG with different capacity and different percentage of this capacity.
The second adding two DGs with different probabilities of the number of their On state(0 or 1 or 2). The third case adding three DGs and consider all possibilities of the

two previous cases with the minimum number in ON state are (0 or 1 or 2 or 3).According with the results obtained by the algorithm, it can be verified DG can enhance the overall capacity of the distribution system and increase its reliability. Finally in our case study the critical penetration level of DGs to improve the system reliability to approximately one hundred percent is two DGs with capacity four percent of the maximum load capacity on all the time.

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