# Reliability Enhancement of Power System using Risk Index Estimation Technique

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**Abstract- The paper presents a simplified approach to evaluate the risk index whose minimization results in the enhancement of power system reliability. The risk indices evaluated in the paper includes mainly LOLP (loss of load probability) and LOLE (loss of load expectation) with more emphasis on LOLE as it indicates the expected number of days in the specified periods in which the daily peak load will exceed the available capacity. There are too many other reliability considerations to bridge the gap between the total generation and total load in any practical power system operation. The addition of generating units in electrical power systems is often viewed as a complex situation and the effects of unit addition on reliability are being investigated in the paper. The reliability indices for load points and the overall system performance have also been studied and a computer program has been developed to examine the effectiveness of the system under investigation by using C-language. The results of simulation runs provide justification for use of the program so developed for the purpose.**

**Key words- LOLP (loss of load probability), LOLE (loss of load expectation), LOL (loss of load), Reliability indices.**

## I. INTRODUCTION

The main function of an electric power system operation is to satisfy the system load demand with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term of reliability. The economic and social effects of loss of electrical energy supply have significant impacts on the utility supplying electric energy as well as the end users / customers. The cost of a major power outage confined to one state can be on the order of crores of rupees. If a major power outage affects multiple states, then the cost can be much higher. The power system is vulnerable to system abnormalities such as control failures, protection or communication system failures, and disturbances, such as lightning, and human operational errors. Therefore, maintaining a reliable power supply is a very important issue for power systems planning and operation. The concept of power-system reliability is extremely a broad area of study and covers all aspects of the ability of the system to satisfy the customer needs [4]. The system adequacy relates to the existence of sufficient facilities within the system to satisfy the consumers' load demand and the system security corresponds to the ability of the system to respond to disturbances arising within that system [8, 9].

After the installation of a specific generation capacity, it is assumed that the amount of electrical power required will always be available to cater the load demand. However, it is not so happened in practical systems as the load goes on increasing every year. For instance, in the developed countries, the load becomes double in every ten years and in developing countries the load becomes double in every seven years. India, being a fast developing country, there is an incremental load change at the rate of about 10% approximately in every year.

In the paper, with the help of risk index analysis, an attempt has been made to determine how many generating units should be added to a particular power generation system to meet the changing load demand. This approach will help the power system planners / designers in a big way at decision making process from the point of view of generation system expansion planning. A program algorithm has been developed using C-language to study the reliability improvements with the addition of more number of generating units. This algorithm is also expected to find its suitability to explore the placement of generating units at right time and its effects on the power system reliability with the variation of load demands. Two cases have been analyzed and reliability indices for the said cases were examined through simulation runs of the program developed for the purpose. The entire system provides concrete figures to assess reliability improvements. The program algorithm is also expected to find its suitability to explore the placement of generators and its effects on the power system reliability with the variation of load demands.

## II. RELIABILITY OF A POWER GENERATION SYSTEM

The power system under consideration is a single node system in which all the generating units and system loads are connected to a single bus bar. The influence upon reliability by the transmission system and distribution system is not considered while evaluating the reliability of a power generation system. At present there are two methods of evaluating reliability for a power generation system as discuss below:

*(a). Probability Array Method-* This treats the generating unit model and the load model as two independent events. Then the probability and frequency of system failures (i.e. deficiency in power supply) is calculated. This is a very tedious method, especially for the calculation of frequency.

*(b). Recurrent Convolution Method-* The surplus state table is directly convolved by applying the parallel calculation formula to the generating unit outage table and the load outage table. The reliability index evaluation using convolution method requires two tables namely Generating unit outage table and Load outage table.

In general, the results on the reliability of power generation systems are more established and therefore have wide applications because the system failure mode, reliability indices, etc., are all very clear[4,6,7].

### *2.1 Power Generation System Reliability Indices-*

The power generation system reliability indices are usually a measure of power supply reduction to customers (load point) as a result of faults developed in the power-generating unit. There are many kinds of indices put forward in the literature from different angles. Four indices are adopted in this book based on practical situations in countries including the United Kingdom, the United States and China [6, 7, 8].

### *2.2 Relationship between Loss of Load Probability (LOLP) and Loss of Load Expectation (LOLE)-*

The LOLP is defined as the probability of the effective system capacity not meeting the load demand, which can be written as:

$$\mathrm{LOLP} = P(X > R)$$

where X = system outage capacity; R = C-L = system reserve capacity;
C = maximum generation capacity and L = maximum load [5].

Usually it is not the probability indices but expectations that are used in engineering applications. The latter means the expected number of days or number of hours in the period investigated when the maximum load exceeds the system effective capacity.

Therefore, $\mathrm{LOLE} = \mathrm{LOLP} \times T$

Or

$$\mathrm{LOLE} = \sum_{i=1}^{n} P_i\,(C_i - L_i)\ \text{days / period}$$

Where $C_i$ = available capacity on day i; $L_i$ = forecast peak load on day i;
$P_i\,(C_i - L_i)$ = probability of loss of load on day i;[1,2,3].

In much of the literature, strict distinctions are not made and the LOLP index referred to is actually the LOLE index. Here if the load model is an annual continuous load curve (day maximum load), then T is 365 days and the unit of LOLE is days per year.

## III. DEVELOPMENT OF PROGRAM FLOW CHART

The flow chart used to compute the risk index; LOLE is shown in figure 2. This analysis relies on two general classes of information to estimate the reliability i.e. component reliability parameters and system structure. Using system structure and component performance data can evaluate the reliability of specific load points. However, the predictive reliability techniques suffer from data collection difficulties.

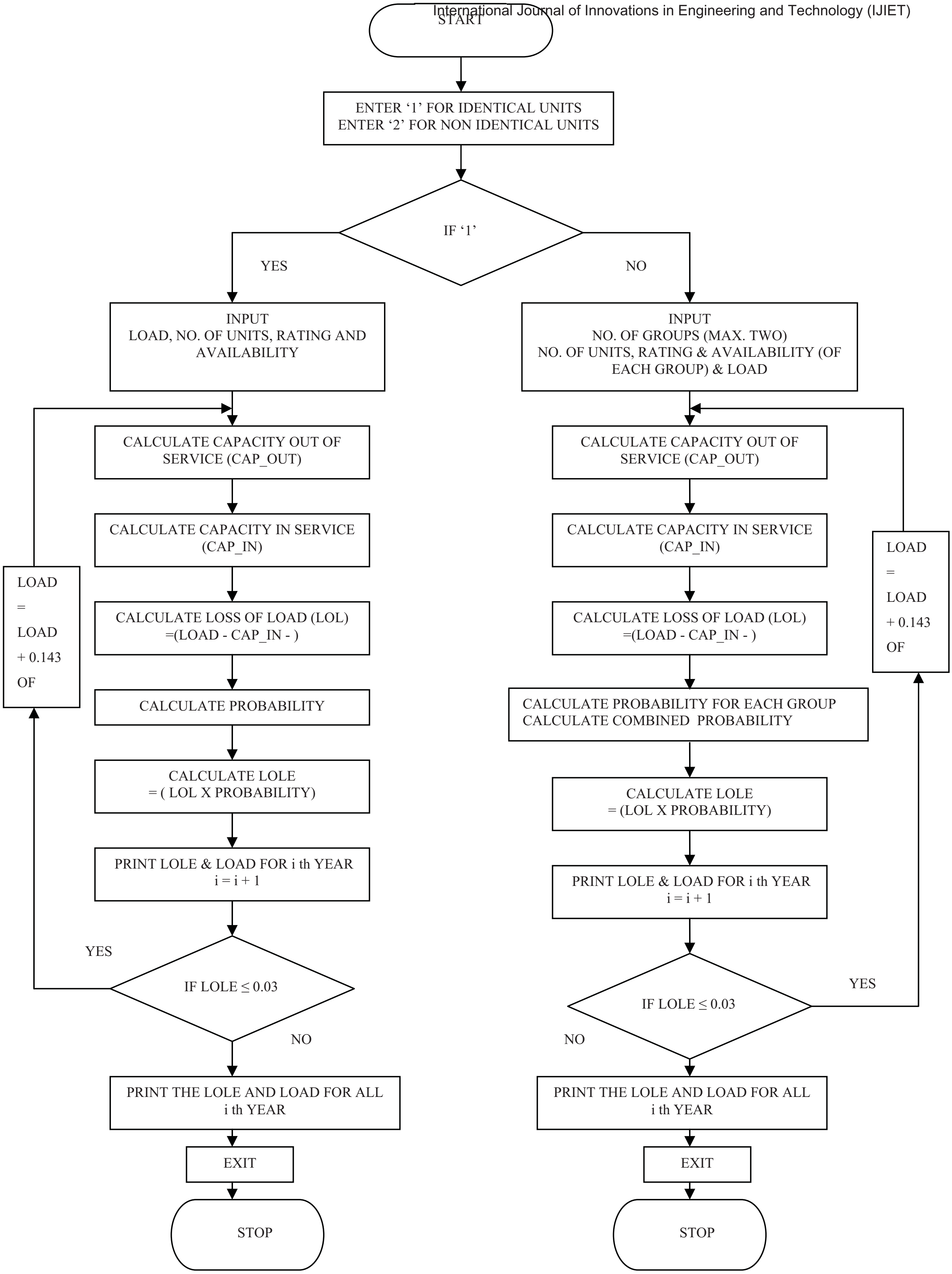

Figure 2: Program Flow Chart to evaluate LOLE & Load year wise

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*3.1 Program Algorithm-* The various steps involved while developing the required program algorithm is enlisted below:

*STEP 1-* Whether the system has IDENTICAL units or NON-IDENTICAL units ; If IDENTICAL units GOTO STEP 2; else GOTO STEP-3

*STEP 2- a)* Enter no. of generating units (U), load (L), Availability (Av), Rating (R) as input; b) Calculate capacities out of service; c) Calculate capacities in service; d) Calculate loss of load (LOL); e) Calculate probability; f) Calculate Loss of Load Expected (LOLE); g) Print LOLE & load for the $i^{th}$ year; $i = i+1$; h) If LOLE $\le 0.03$ GOTO STEP (b); i) Print LOLE & load for all $i^{th}$ year; j) Exit; and k) Stop.

*STEP 3-*

(i) Enter number of groups (Max 2);
(ii) Enter number of generating units, ratings and availability (of each group) and load;
(iii) Calculate Capacity out of service;
(iv) Calculate capacity in service;
(v) Calculate Loss of Load (LOL);
(vi) Calculate probability of each group and then combined probability;
(vii) Calculate Loss of Load Expected (LOLE);
(viii) Print LOLE and load for $i^{th}$ year;
(ix) If LOLE $\le 0.03$, GOTO STEP (iii);
(x) Print LOLE and load for all $i^{th}$ ;
(xi) Exit;
(xii) Stop.

## IV. RESULTS

*Case Study -I:* Simulation was carried out with the following assumptions:

Nature of generating units: Identical generating units
Total load on the system = 50 MW;
Total number of generating Units = 6 units (with a capacity of 10 MW each);
Total installed capacity = 6×10 MW= 60 MW;
Availability of each machine (considered) = 0.99;
Maximum LOLE = 0.03;
Spinning Reserve = 20-25% of the peak load;
Load increment = 14.3% per year

*Program Input for Case-I in the First Year:*

No.of Generating Units : 6
Total Load of System : 50
Availability of Each Unit : 0.99
Rating of Each Machine :10

*Program output for the above case:*

| CAP OUT (MW) | CAP IN (MW) | PROBABILITY | LOL (lol*prob) | LOLE (days / year) |
|---|---|---|---|---|
| 0.000000 | 60.000000 | 0.941480203817 | 0.000000000000 | |
| 10.000000 | 50.000000 | 0.057059351326 | 0.000000 | 0.000000000000 |
| 20.000000 | 40.000000 | 0.001440891322 | 10.000000 | 0.014408913222 |
| 30.000000 | 30.000000 | 0.000019405925 | 20.000000 | 0.000388118501 |
| 40.000000 | 20.000000 | 0.000000147014 | 30.000000 | 0.000004410433 |
| 50.000000 | 10.000000 | 0.000000000594 | 40.000000 | 0.000000023760 |
| 60.000000 | 0.000000 | 0.000000000001 | 50.000000 | 0.000000000050 |

Total LOLE = 0.014801465966 and Total load = 50.000000 MW.

*Program output for total load of 57.150002 MW without adding any generating unit:*

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CAP OUT     CAP IN       PROBABILITY          LOL             LOLE
(MW)        (MW)                              (lol*prob)      (days / year)

0.000000    60.000000    0.941480203817       0.0000000
10.000000   50.000000    0.057059351326       7.150002        0.407974449048
20.000000   40.000000    0.001440891322       17.150002       0.024711288375
30.000000   30.000000    0.000019405925       27.150002       0.000526870894
40.000000   20.000000    0.000000147014       37.150002       0.000005461587
50.000000   10.000000    0.000000000594       47.150002       0.000000028007
60.000000   0.000000     0.000000000001       57.150002       0.000000000057
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Total LOLE = 0.433218097968

Since LOLE for the second year without addition of new generating unit is obtained as 43.32 %, so a new generating unit is necessary to add in the second year to cater the consumers' load demand to enhance the reliability of power supply.

Similarly, for five consecutive years, simulation runs were performed using the program so developed and a table has been formulated to examine the effect of increase in load on the system risk indices with initial load of 50 MW on the system for an installed generating capacity of 60 MW as depicted in table 1. From this table, it is observed that in all the consecutive years, the value of LOLE was more than the desired value (i.e. 0.03). So, to ensure the reliable, uninterrupted and good quality power supply to the consumer, new generating units are required to be added in the 2nd, 3rd, 4th and 5th years. A graphical representation of the result so obtained is shown in figure 3.

Table 1: Effect of increase in load on the system risk indices with identical generating units.

| Year | LOLE (days / year) | Increase in Load (MW) | Units Added (MW) | Total Capacity (MW) |
|---|---|---|---|---|
| 1 | 0.014801 | 50 | | 6X10MW = 60MW |
| 2 | 0.43321 | 57.15 | WITHOUT ADDING | 60MW |
| 2 | 0.0148649 | 57.15 | 1x10MW (ADDED) | 70 MW |
| 3 | 0.38223 | 65.32 | WITHOUT ADDING | 70 MW |
| 3 | 0.0148639 | 65.32 | 1x10MW (ADDED) | 80 MW |
| 4 | 0.387731 | 74.76 | WITHOUT ADDING | 80 MW |
| 4 | 0.0168378 | 74.66 | 1x10MW (ADDED) | 90 MW |
| 5 | 0.497028 | 85.34 | WITHOUT ADDING | 90 MW |
| 5 | 0.023942 | 85.34 | 1x10MW (ADDED) | 100 MW |

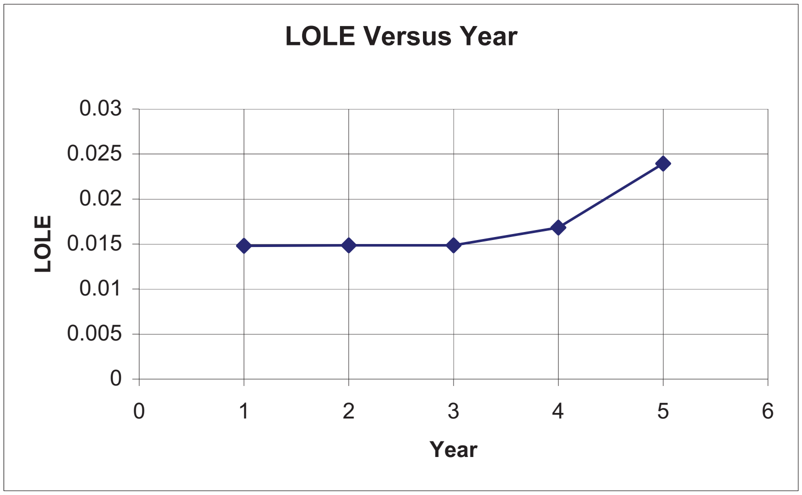

Figure 3. Graphical representation of Table-1.

Case Study -II: In this case, simulation was carried out with the following assumptions:

Nature of generating units: Non-identical generating units
Total load on the system = 100 MW;
Total number of generating units = 5 units (with a capacity of 25 MW each);
Total installed capacity = 5×25 MW= 125 MW;
Availability of each machine (considered) = 0.99;
Maximum LOLE = 0.03;
Spinning Reserve = 20-25% of the peak load;
Load increment = 14.3% per year

*Program Input for Case-II in the First Year:*

No. of Generating Units : 5
Total Load of System : 100
Availability of Each Unit : 0.99
Rating of Each Machine : 25

*Program output for the above case:*

| **CAP OUT (MW)** | **CAP IN (MW)** | **PROBABILITY** | **LOL (lol*prob)** | **LOLE (days / year)** |
|---|---|---|---|---|
| 0.000000 | 145.000000 | 0.941480203817 | 0.000000000000 | |
| 20.000000 | 125.000000 | 0.009509891888 | 0.000000000000 | |
| 25.000000 | 120.000000 | 0.047549459438 | 0.000000000000 | |
| 45.000000 | 100.000000 | 0.000480297107 | 0.000000 | 0.000000000000 |
| 50.000000 | 95.000000 | 0.000960594215 | 5.000000 | 0.004802971074 |
| 70.000000 | 75.000000 | 0.000009702963 | 25.000000 | 0.000242574063 |
| 75.000000 | 70.000000 | 0.000009702963 | 30.000000 | 0.000291088876 |
| 95.000000 | 50.000000 | 0.000000098010 | 50.000000 | 0.000004900481 |
| 100.000000 | 45.000000 | 0.000000049005 | 55.000000 | 0.000002695265 |
| 120.000000 | 25.000000 | 0.000000000495 | 75.000000 | 0.000000037125 |
| 125.000000 | 20.000000 | 0.000000000099 | 80.000000 | 0.000000007920 |

Total LOLE = 0.005344274804
Total load = 100.000000 MW

*Program output for total load of 114.300003 MW without adding any generating unit:*

| **CAP OUT (MW)** | **CAP IN (MW)** | **PROBABILITY** | **LOL (lol*prob)** | **LOLE (days / year)** |
|---|---|---|---|---|
| 0.000000 | 145.000000 | 0.941480203817 | 0.000000000000 | |
| 20.000000 | 125.000000 | 0.009509891888 | 0.000000000000 | |
| 25.000000 | 120.000000 | 0.047549459438 | 0.000000000000 | |
| 45.000000 | 100.000000 | 0.000480297107 | 14.300003 | 0.006868250102 |
| 50.000000 | 95.000000 | 0.000960594215 | 19.300003 | 0.018539471278 |
| 70.000000 | 75.000000 | 0.000009702963 | 39.300003 | 0.000381326457 |
| 75.000000 | 70.000000 | 0.000009702963 | 44.300003 | 0.000429841269 |
| 95.000000 | 50.000000 | 0.000000098010 | 64.300003 | 0.000006302019 |
| 100.000000 | 45.000000 | 0.000000049005 | 69.300003 | 0.000003396034 |
| 120.000000 | 25.000000 | 0.000000000495 | 89.300003 | 0.000000044203 |
| 125.000000 | 20.000000 | 0.000000000099 | 4.300003 | 0.000000009336 |
| 145.000000 | 0.000000 | 0.000000000001 | 114.300003 | 0.000000000114 |

Total LOLE = 0.026228640812 and Total load = 114.300003. In this case, when the load is increased by 14.3% also the value of LOLE was obtained within the desired range thereby allowing the system to work properly. However, in the next consecutive year, the load increases further to another 14.3% compelling to increase the value of LOLE beyond 0.03 (the maximum limit). The simulation runs were carried out for a period of 8th consecutive years and the computed values of reliability parameters are shown in Table 2.

Table 2. Effect of increase in load on the system risk indices with non-identical generating units.

| **Year** | **LOLE (days / year)** | **Increase in system load (MW)** | **Unit Added (MW)** | **Total Capacity (MW)** |
|---|---|---|---|---|
| 1 | 0.024751 | 100 | | (5x25MW = 125MW) |
| 2 | 0.72559 | 114.3 | WITHOUT ADDING | 125 MW |
| 2 | 0.02622 | 114.3 | 1X20 MW=20MW (ADDED) | 145MW |
| 3 | 0.60994 | 130.65 | WITHOUT ADDING | 145MW |
| 3 | 0.026781 | 130.64 | 1X20MW =20MW (ADDED) | 165MW |
| 4 | 0.58526 | 149.33 | WITHOUT ADDING | 165MW |
| 4 | 0.019725 | 149.33 | 1X25MW=25MW (ADDED) | 190MW |
| 5 | 0.407496 | 170.68 | WITHOUT ADDING | 190MW |
| 5 | 0.027146 | 170.68 | 1X20MW=20MW (ADDED) | 210 MW |
| 6 | 0.81036 | 195.10 | WITHOUT ADDING | 210 MW |
| 6 | 0.002134 | 195.10 | 2X20MW=40MW (ADDED) | 250 MW |
| 7 | 0.099119 | 223 | WITHOUT ADDING | 250 MW |
| 7 | .008368 | 223 | 1X20MW=20MW (ADDED) | 270 MW |
| 8 | .981325 | 254.87 | WITHOUT ADDING | 270 MW |
| 8 | 0.002687 | 254.66 | 1X25+1X20=45MW (ADDED) | 315 MW |

So, in order to provide the reliable supply of power to the consumer load, new generating units were added in the 2nd, 3rd, 4th, 5th, 6th, 7th and 8th years. A graphical representation of the above table is depicted in figure 4.

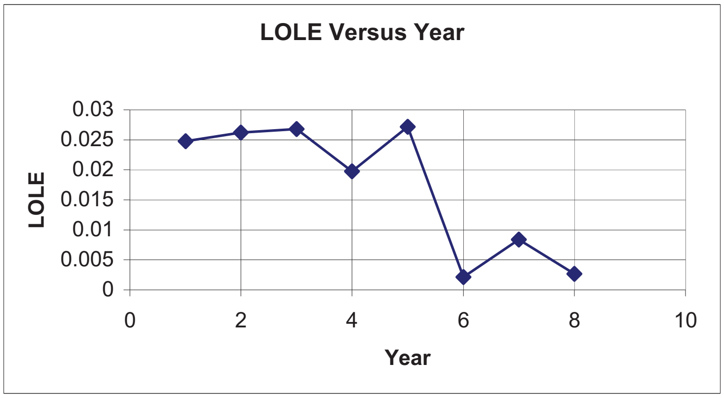

Figure 4. Graphical representation of Table-2.

## V. CONCLUSION

In the paper, the addition of generating units in the power system and its effects on reliability has been studied, from the view of generation system expansion planning. An evaluation of reliability over time varying load curves has also been discussed. Two cases have been analyzed and the reliability indices for the said cases were examined through simulation runs of the program developed for the purpose. The entire system provides concrete figures to assess reliability improvements as depicted in tables1 and 2 along with their corresponding figures 3 and 4. The paper will find its suitability in the process of planning and operation of power system with enhanced reliability.

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