Generation Reliability Enhancement based on Reliability Indices

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Abstract. Reliability of generation system is an important aspect of planning, designing and operating for forecasting the plant capacity growth to make assurance that the totality generation is adequate to secure demand. The probability distributions correlating with the reliability indices may be utilized as complementary measures for accurate description and worthy information for system planners and operators. In the current research, the yearly load demand and its impact on the reliability of generating units was highlighted by some reliability indices that standardize against the international usefulness custom which are, Loss of Load Probability LOLP, Loss of Load Expectation LOLE, Loss of Energy Expectation LOEE, Loss of Energy Probability LOEP and Expected Energy Not Served EENS. This article is also dealing with the issue of generation capacity reserve assessment and the relation between the system reliability level and the expansion of the load. The notion of capacity extending analysis is clarify using a system of 4 stations. The effect on system reliability of adding a generation unit to the overall system can be observe in terms of decreasing the reliability indices and increasing the system Effective Load Carrying Capability (ELCC). This article has been used the Loss of Load Expectation LOLE in terms of day/year as a critical limit for reliable and unreliable system.

1. Introduction
The modern electrical power system includes three integrated zones in its function, generation, transmission and distribution. Fortunately, the reliability of each one can be analyzed separately to reduce the complexity of the analysis [1]. The reliability evaluation of the electric power generation systems is defined as its ability to provide the sufficient capacity to meet the variable load demand. The lack of balance between the generating capacity and the constantly changing demand poses a serious risk to the reliability of the generating systems [2]. Reliability analysis of the generation systems has two different directions, adequacy and security. The first one (adequacy) is to analyzed the reliability of the generating units under normal operating conditions where the generation system has the ability to equip the profile load demand without the system being exposed to the disturbance. In others words the adequacy of the reliability deals with the static behavior of the system while the security of the reliability deals with the dynamic behavior of the system [3, 4]. The analytical technique has been used to evaluate the reliability indices. This technique depends on probability theory and simulate the system by analytical models. It calculates the generation reliability indices by mathematical solution. Monte Carlo technique predict the generation reliability indices by simulate the actual random behavior of the system. These reliability indices show the ability of the generation system to overcome the load demand [4, 5, 6, 7]. This article concerned with the most important generation reliability indices using the analytical solution for the case of the static condition i.e.
generation system adequacy. These generation reliability indices are: Loss of Load Expectation LOLE (hr/year); Loss of Load Expectation LOLE (day/year); Loss of Load Expectation LOLE (MW); Loss of Energy Expectation LOEE (MWh); Loss of Energy Probability LOEP (without unit); Loss of Load Probability LOLP (without unit); Expected Energy Not Served EENS (MWh); Effective Load Carrying Capacitance ELCC.

2. Generation System Adequacy

A model of the generation system adequacy must be regard the installation capacity of all unit’s during the two states of their operation (i.e. the failure and the restoration states). A failure in a generating unit cause the unit being outage from service until to be repaired or replaced, this event is known as an outage. Such outages can threaten the ability of the system to secure the load demand. The basic steps in the generation reliability system adequacy can be summarized as follows:

- Since the generating system contains many units, then the probability of failure and operation many be need to arranged in a Table. The Capacity Outage Probability based on recursive technique and operating characteristics of the generating units has been formulated as a Table.
- Construct load model through the descending order of loads (load duration curve).
- Derive risk model (Generation < Load) through combined Capacity Outage Probability and load model.
- Determine the reliability indices which indicate the ability of the generating units to meet the system demand [8, 9, 10, 11, 12].

3. Load model

Load model represent the relation between the time and the peak load. The time may be hour, day, week, month, year, …. etc. The peak load will be in kW or MW, …. etc. There are different models to represent the load curve. In this article, the load duration curve is used to represent the load model. It is one of the most important form to create the load and its changes with respect to the time. In the load duration model the peak load is arranged in descending order to form the load model where the highest value of the load will be at time zero and lowest value of the load will be at the end period of the time. If the peak load and the period of the time is according to the time day, the load model is called daily load duration curve and. If the peak load and the period of the time is according to the time week, the load model is called weekly load duration curve and so on for the other period of time month and year. Figure (1) represent the load duration curve for period time T [4].

\[
\begin{align*}
\text{Load (MW)} & \quad C_d \quad \text{Installed capacity} \\
\text{Peak load} & \quad P^k \\
\text{Load (L)} & \quad R^k \quad \text{Reserve capacity} \\
L_k & \quad t_k \quad \text{specific section of time} \\
T (\text{hour}) & \quad L_k
\end{align*}
\]

where \(L\) is the load duration curve in MW; \(P^k\) is the peak load in MW; \(C_d\) is the total capacity of the generation system; \(T\) is the total number of hours (8760 for the year); \(t_k\) is the specific section of time; \(L_k\) is the required load at time \(t_k\); \(R_k\) is the reserve capacity at load \(L_k\), where

\[
R_k = C_d - L_k
\]
4. Forced Outage Rate FOR
The Forced Outage Rate FOR of the generation station or any parameters in the power system refer to the failure rate for a specific period of time. This station or parameter will be not able to service when its required at this period of the failure. FOR defined as the number of outage hours of the unit over the total number of hours in a period of time as shown in equation (2) [3, 4].

\[
\text{FOR} = \frac{\text{Outage hour}}{\text{Service hour} + \text{Outage hour}} \quad (2)
\]

5. Generation Reliability Indices
Evaluating the reliability of the electrical power system in general and the generating units in particular are the utmost importance of representation by ensuring the continuity of consumer processing. It also gives a future prediction of the work of the system in the case of an increase in the load demand by calculating multiple types of reliability indicators [3, 10, 11]. There are many type of the reliability indices to express the generation system reliability. This article deals with some of the most important generation reliability indices which explain as follow:

5.1 Loss of Load Expectation LOLE (hr/year)
It is the time in which the energy generation is insufficient to cover the required load demand. In other word when the load demand exceeds the generation capacity of the units, there is a shortages occur in the generation system (Outage of the generation units). The time of this shortages is called the Loss of Load Expectation LOLE. This indicator of the generation system reliability is measured by the term of unit (hour/year). Also it can be measured by the unit of (day/year). [10, 13]. Through the load duration curve in figure 2, the mathematical equation can be formulated to calculate the Loss of Load Expectation LOLE in terms of the unit of (hour/year) for an expected load \( L \) and available generation capacity \( C \) as shown in the equation (3) below [14-19]

\[
\text{LOLE} = \sum_{i=1}^{T} \sum_{k=1}^{N} P_i T_k \quad \text{for } O_i > R_k \quad (3)
\]

where \( i=1, 2, \ldots, N \); \( N \) is the total number of generation units; \( O_i \) is the value of the \( i \)-th outage unit from the service; \( T \) is the total number of hours (8760 for the year); \( P_i \) is the probability of the total outage unit \( O_i \). The probability of the outage each unit can be represent by the formula in equation (4)

\[
P_r = \frac{n!}{r!(n-r)!} q^{n-r} \quad (4)
\]

Where \( i \)-th is number of unit that out of the service; \( n \) is the number of units in each generation station; \( r \) is the number of outage units; \( q \) is the Force Outage Rate FOR of the unit.

5.2 Loss of Load Probability LOLP (without unit)
It is the probability in which the generating capacity is insufficient to meet the load demand. It is the same index of Loss of Load Expectation LOLE in (hr/year) but this index in the form of probability. This index of the generation reliability indices has no units as shown in the equations (6, 7 and 8) [10, 16-19].

\[
\text{LOLP (without unit)} = L \text{OLE} \quad (6)
\]
5.3 Loss of Load Expectation LOLE (MW)

The loss of Load Expectation LOLE in terms of MW represent the total expectation outage load of the system in MW or how much power in MW the system of generation failed to supply the load demand for a given period of time [10]. In other words, it is the value of the shortages in the generation system in terms of MW units for the given period of the time. It the same of the reliability index Loss of Load Expectation LOLE in terms of (hr/year) but this indicator in terms of MW units for the given period of time. LOLE (MW) can be represent as in equation (9)

$$LOLE = \frac{\sum_{i=1}^{N} \sum_{t=1}^{T} (O_i - R_k) \times P_i \times \frac{t_k}{T}}{8760} \quad \text{for } O_i > R_k$$

5.4 Loss of Energy Expectation LOEE (MWh)

It the same of the reliability index of Loss of Load Expectation LOLE (MW) but this indicator in terms of the MWh units as shown in the equation (10)

$$LOEE = \sum_{i=1}^{N} \sum_{t=1}^{T} (O_i - R_k) \times P_i \times \frac{t_k}{T} \quad \text{for } O_i > R_k$$

LOEE (MWh) represent how much the generation system cannot be able to supply the load demand in terms of MWh units [10, 20, 21, 22].

5.5 Expected Energy Not Served EENS (MWh)

This indicator is the same of the Loss of Load Expectation LOLE (MWh) with the same unit of MWh and value, where [10, 18, 20, 21, 22]

$$EENS = \sum_{i=1}^{N} \sum_{t=1}^{T} (O_i - R_k) \times P_i \times \frac{t_k}{T} \quad \text{for } O_i > R_k$$

5.6 Loss of Energy probability LOEP (without unit)

It is defined as the ratio of the Expected Energy Not Served (EENS (MWh) during a period of monitoring to the total demand of the energy for the same period of time E(MWh). From figure 2, the mathematical equations can be formulated as below [10].

$$LOEP = \frac{EENS (MWh)}{E (MWh)} - \frac{LOEE(MWh)}{E (MWh)}$$

$$E = \sum_{k} L_k \times i_k$$

6. Effective Load Carrying Capability ELCC

This article deals with the issue of Generation Capacity Reserve Assessment and the connection between the system reliability level and the expansion of the load. The effect of adding a generation unit to the overall system on the reliability can be observed in terms of increased the system peak load
carrying capability (Effective Load Carrying Capability ELCC). The limitation of such a schedule is depend on an agreeable level of risk by one of the reliability indices, and on the rate of expected load growth in the future. The propose algorithm will be used the Loss of Load Expectation LOLE in terms of (day/year) indicator as a reliability level of the risk for generation capacity reserve assessment. It can be determined how much capacity is required to obtain a specified level of risk. As load grows over the time, generation additions are schedule such that the LOLE does not exceed the design criterion. This schedule design criterion of LOLE = 0.1 day in one year is achieved for a specific peak load. With adding new generation unit and the load remain the same, the LOLE would go down (get better) to about less than 0.1. Assume that the requirement is maintain the same LOLE value 0.1 day in one year. In this case, the algorithm can be increase the load from specific peak load to other higher peak load. This load growth is called the Effective Load Carrying Capability ELCC of the additional generation as shown in figure 2 [11].

7. The result and calculation

One system has been tested in this article to satisfied the propose algorithm of generation reliability improvement based on reliability indices, where a generation system details of this case study system are presented in Table 1 [3, 4]. This system contains 4 stations with 6 units. Table 1 consists the Forced Outage Rate FOR of each station. The installed capacity of this system is 280 MW with peak load of 200 MW. Table 2 represent the load duration data for one year of this system [3, 4].

| Table 1. Generation system data |
|----------------------------------|
| Generation station | No. of units | Capacity of each unit (MW) | FOR  |
| 1                  | 2            | 25                          | 0.03 |
| 2                  | 2            | 40                          | 0.02 |
| 3                  | 1            | 50                          | 0.01 |
| 4                  | 1            | 100                         | 0.01 |

| Table 2. Load duration data for one year |
|-----------------------------------------|
| Number of sector | Period of time (day) | Peak demand (MW) |
|------------------|----------------------|------------------|
| 1                | 0-12                 | 200              |
| 2                | 12-95                | 160              |
| 3                | 95-202               | 130              |
| 4                | 202-318              | 100              |
| 5                | 318-365              | 50               |
According to Table 1, the probability \( P_T \) of the outage units according to equations (4 and 5) are illustrate in Table 3

| Generation Station | Outage of units | 0 unit | 1 unit | 2 units |
|--------------------|----------------|--------|--------|--------|
| 1                  | 0.9409         | 25     | 0.0582 | 50     | 0.0009 |
| 2                  | 0.9604         | 40     | 0.0392 | 80     | 0.0004 |
| 3                  | 0.9900         | 50     | 0.0100 | 0      | 0.0000 |
| 4                  | 0.9900         | 100    | 0.0100 | 0      | 0.0000 |

According to the case study in Table 1, there are 36 cases of possibilities for the outage units. The outage power of each generation unit with the probability of the total capacity outage are illustrated in Table 4.

| Case no. \((i)\) | Out of unit 1 (MW) | Out of unit 2 (MW) | Out of unit 3 (MW) | Total outage of units \(Q_i\) (MW) | Probability \(P_i\) |
|-----------------|-------------------|-------------------|-------------------|------------------------------------|-------------------|
| 1               | 0                 | 0                 | 0                 | 0                                 | 0.885657916836    |
| 2               | 25                | 0                 | 0                 | 25                                 | 0.054782963928    |
| 3               | 0                 | 40                | 0                 | 40                                 | 0.036149302728    |
| 4               | 0                 | 0                 | 50                | 50                                 | 0.008946039564    |
| 5               | 0                 | 0                 | 0                 | 50                                 | 0.000847159236    |
| 6               | 25                | 40                | 0                 | 65                                 | 0.002236039344    |
| 7               | 25                | 0                 | 50                | 75                                 | 0.000553363272    |
| 8               | 0                 | 80                | 0                 | 80                                 | 0.000368870436    |
| 9               | 0                 | 40                | 50                | 90                                 | 0.000365144472    |
| 10              | 50                | 40                | 0                 | 90                                 | 0.000034577928    |
| 11              | 0                 | 0                 | 100               | 100                                | 0.008946039564    |
| 12              | 50                | 0                 | 50                | 100                                | 0.000008557164    |
| 13              | 25                | 80                | 0                 | 105                                | 0.00022816728     |
| 14              | 25                | 40                | 50                | 115                                | 0.00022586256     |
| 15              | 25                | 0                 | 100               | 125                                | 0.000553363272    |
| 16              | 0                 | 80                | 50                | 130                                | 0.00000375964     |
| 17              | 50                | 80                | 0                 | 130                                | 0.00000352836     |
| 18              | 0                 | 40                | 0                 | 140                                | 0.000365144472    |
| 19              | 50                | 40                | 50                | 140                                | 0.00000349272     |
| 20              | 0                 | 0                 | 50                | 150                                | 0.0000090364036   |
| 21              | 50                | 0                 | 100               | 150                                | 0.000008557164    |
| 22              | 25                | 80                | 50                | 155                                | 0.00000230472     |
| 23              | 25                | 40                | 0                 | 165                                | 0.000022586256    |
| 24              | 25                | 0                 | 50                | 175                                | 0.000005589528    |
| 25              | 0                 | 80                | 0                 | 180                                | 0.00000375964     |
| 26              | 50                | 80                | 50                | 180                                | 0.00000003564     |
| 27              | 0                 | 40                | 50                | 190                                | 0.000003688328    |
| 28              | 50                | 40                | 0                 | 190                                | 0.00000349272     |
| 29              | 50                | 0                 | 50                | 200                                | 0.00000008636     |
| 30              | 25                | 80                | 0                 | 205                                | 0.000000230472    |
| 31              | 25                | 40                | 50                | 215                                | 0.000000228144    |
| 32              | 0                 | 80                | 50                | 230                                | 0.00000037636     |
| 33              | 50                | 80                | 0                 | 230                                | 0.00000003564     |
| 34              | 50                | 40                | 50                | 240                                | 0.00000003528     |
| 35              | 25                | 80                | 50                | 255                                | 0.00000002328     |
| 36              | 50                | 80                | 50                | 280                                | 0.00000000036     |
The propose algorithm in this article prepare Table 4 with all the possibilities cases of the total outage capacity of units. As example for the first case of the posibilities of the total outage unit capactiy at \( i = 1 \) where the probability of the zero total outage unit according to Table 3 is

\[
P_{i=1} = P_{G1} \times P_{G2} \times P_{G3} \times P_{G4} = 0.9409 \times 0.9604 \times 0.9900 = 0.885657916836
\]

and so on for the other possibilities until the end of this possibilities cases at number at \( i = 36 \), where all generation unit will be outage at 280 MW and this will be according to outage the following units: two unit of the first station \( (2 \times 25 = 50 \text{ MW}) \) with outage unit probability of 0.0009; two unit of the second station \( (2 \times 40 = 80 \text{ MW}) \) with outage unit probability of 0.0004; one unit of the third station \( (50 \text{ MW}) \) with outage unit probability of 0.0009; one unit of the fourth station \( (100 \text{ MW}) \) with outage unit probability of 0.0009, therefore the total probability of this total outage unit 280 MW is

\[
P_{i=36} = P_{G1} \times P_{G2} \times P_{G3} \times P_{G4} = 0.0009 \times 0.0004 \times 0.01 \times 0.01 = 0.000000000036
\]

The summation of all probabilities of the total outage unit should be equal to 1 as shown in Table 4. According to the load duration curve in Table 2, the number of sectors, peak load, reserve capacity and the period of the time based on day and hour are illustrated in Table 5.

| No. of sector \((k)\) | Peak demand \(L_d\) (MW) | Reserve capacity \(R_q\) (MW) | Period of time \(t_q\) (day) | Period of time \(t_q\) (hour) |
|----------------------|--------------------------|------------------------------|----------------------------|----------------------------|
| 1                    | 200                      | 80                           | 0-12=12                   | 12\times24=288             |
| 2                    | 160                      | 120                          | 12-95=83                  | 83\times24=1992            |
| 3                    | 130                      | 150                          | 95-202=107                | 107\times24=2568           |
| 4                    | 100                      | 180                          | 202-318=116               | 116\times24=2784           |
| 5                    | 50                       | 230                          | 318-365=47                | 47\times24=1128            |

In order to find the generation reliability indices for specific load duration curve, the propose algorithm must be calculates the factor \((O_i - R_q) \times P_i \times t_q\) for all the sectors \(k\) as follow:

1- At first sector \((k=1)\). Reserve capacity is 80 MW; The period of time is 288 hours. The propose algorithm must be takes all the total outage generation capacity \(O_i\) (36 cases) in Table (4) as follow:

a- At the first case \((i=1)\) and sector \(k=1\). The total outage generation capacity \(O_1 = 0\) MW. The outage generation capacity is less than the reserve capacity \(R_q = 80\) MW of the first sector \((O_1 < R_q)\), therefore the generation system has the ability to overcome the load demand and no shortage in the generation system until the case of \(i=9\).

b- At the ninth case \((i=9)\) and sector \(k=1\). The total outage generation capacity \(O_9 = 90\) MW. This total outage power is according to outage one units of the second station 40 MW and one unit of the third station 50 MW. The outage generation capacity is more than the reserve capacity \(R_q = 80\) MW of the first sector \((O_q > R_q)\), therefore the generation has not able to overcome the load demand. In other words there is a shortage in the generation system by a value of \(O_9 - R_q = 90 - 80 = 10\) MW. According to Table 4. The probability of this outage of generation units 90 MW is \(P_1 - P_9 = 0.000365144472\).

According to Table 5, the period time of the first sector is 288 hour, therefore the factor \((O_9 - R_q) \times P_9 \times t_q = 10 \times 0.000365144472 \times 288 = 1.05161607936\).

This factor will be summation at each case of outage the generation units \(O_i > R_q\) until \(i=36\). All the pervious process at sector \(k=1\) will be repeated for the remaining sectors \((k=2, 3, 4 \text{ and 5})\) in Table 5. Then the propose algorithm calculates the reliability induces where The Loss of Load Expectation \(\text{LOLE}\) in terms of \((\text{hr/year})\) according to equation (3) is \(\text{LOLE}=5.22\ \text{hr/year}\); The Loss of
Load Expectation LOLE in terms of (day/year) is equal to 0.2178 day/year; The Loss of Load expectation LOLE (MW) based on equation (9) is $LOLE = 0.021233$ MW; The Loss of Energy Expectation LOEE (MWh) is evaluating according to equation (10), where $LOEE=101.65$ MWh; The Expected Energy not Served EENS (MWh) that consumed by the load is calculated according to equation (13) is 1044960 MWh; The Loss of Energy Probability LOEP without unit is calculated according to equation (12) is $9.727 \times 10^{-5}$; The Loss of Load Probability LOLP without unit is calculated according to equation (8) is $5.958904109589041 \times 10^{-4}$.

From the above calculation, it is clear that’s the generation system has not be able to supply the required load demand by 0.021233 MW or 101.65 MWh or 0.2178 da in one year (that’s mean, there is a shortage in the generation system by 0.021233 MW or 101.65 MWh or 0.2178 da in one year).

To knew the system reliability, the propose algorithm has been used the Loss of Load Expectation LOLE in terms of (day/year) as a critical limit for reliable and unreliable system where in the case study of this article LOLE (day/year) is equal to 0.2178 (day/year) which is more than 0.1 (the critical limit of the reliability system, therefore the system is unreliable).

In order to change the system from the unreliability to the reliability case, one generation unit is adding for this purpose. Table 6 show that’s, increasing the power of the new adding generation unit lead to decrease the reliability indices for the same required load. Also this Table show that’s, an adding a generation unit of 20 MW with Forced Outage Rate of 0.01 make the Loss of the Load Expectation in terms of (day/year) LOLE is less than 0.1(equal to 0.0279) for reliable system. Figure 3 shows the response of LOLE (day/year) with respect the increasing of the adding generation units.

| Add one unit (MW) | LOLE h/yr | LOLE day/yr | LOLE MW | LOEE MWh | LOEP $\times 10^{-5}$ | LOLP $\times 10^{-4}$ |
|-------------------|------------|-------------|--------|-----------|----------------------|----------------------|
| 0                 | 5.228      | 0.2178      | 0.0123 | 101.65    | 9.720                | 5.968                |
| 2                 | 5.228      | 0.2178      | 0.0110 | 91.300    | 8.730                | 5.968                |
| 3                 | 5.228      | 0.2178      | 0.0104 | 86.124    | 8.240                | 5.968                |
| 5                 | 4.136      | 0.1723      | 0.0091 | 75.770    | 7.251                | 4.721                |
| 7                 | 4.136      | 0.1723      | 0.0081 | 67.605    | 6.469                | 4.721                |
| 10                | 4.003      | 0.1667      | 0.0066 | 55.350    | 5.297                | 4.569                |
| 12                | 4.003      | 0.1667      | 0.0057 | 47.450    | 4.540                | 4.569                |
| 15                | 3.945      | 0.1644      | 0.0042 | 35.600    | 3.406                | 4.504                |
| 18                | 3.945      | 0.1644      | 0.0028 | 23.919    | 2.289                | 4.504                |
| 19                | 3.945      | 0.1644      | 0.0024 | 20.025    | 1.910                | 4.504                |
| 20                | 0.671      | 0.0279      | 0.0019 | 16.132    | 1.540                | 0.766                |

Figure 3. The response of LOLE (day/year) with increasing the power MW of the adding generation unit.
In order to find the Effective Load Carrying Capability ELCC of the case study, the propose algorithm in this article increase the peak load from 200 MW to the value of 251 MW in which the LOLE(day/year) of the new system with adding the new unit of 20 MW is equal or near to the LOLE(day/year) of the old system without adding any unit (the new LOLE (day/year)=0.298864 near to the old or original LOLE(day/year)= 0.2178), therefore the Effective Load Carrying Capability ELCC is equal to 251-200=51 MW. That's mean the propose algorithm after adding the new unit of 20 MW can be increase the peak load from 200 MW to 251 MW for the same value of LOLE (day/year) of the system LOLE(day/year) = 0.027979 which less than 0.1 for reliable system as shown in Table 7.

Table 7. Capacity outage with its probability for the original system (4 generation stations)

| Peak load (MW) | LOLE (day/year) after adding the new unit of 20 MW |
|---------------|-----------------------------------------------|
| 200           | 0.027979                                      |
| 210           | 0.134470                                      |
| 220           | 0.139487                                      |
| 230           | 0.150443                                      |
| 240           | 0.178183                                      |
| 250           | 0.182521                                      |
| 251           | 0.298864                                      |

8. Conclusion
In this article different reliability indices are tested for generation reliability analysis. These indices are the Loss of Load Expectation LOLE in terms of the units (hour/year), (day/year) and in terms of (MW), Loss of Energy Expectation LOEE in terms of MWh, Loss of Energy probability LOEP (without unit) and Loss of Load probability LOLP (without unit). The 0.1 (day/year) of the LOLE are used as a critical limit for reliability generation system. The system is considered to be reliable if the value of LOLE (day/year) less than 0.1, otherwise the system is unreliable. One case study system has been tested in this article. This case study has 4 stations of 6 units. The propose algorithm add a new generation station of 20 MW to change the system from the unreliability case of LOLE=0.2178 (day/year) to reliable case of LOLE=0.0279 (da/year) (less than 0.1). Increasing the power of the adding new generation unit leads to decrease the reliability indices. The Effective Load Carrying Capability ELCC of the system can be evaluated by increasing the peak load until LOLE (day/year) of the new system after adding the unit is equal or near the LOLE(day/year) of the old system. The ELCC of the case study is equal to 51 MW. The structure of the propose algorithm are programming by the authors using matlab software without using any simulator.

9. References
[1] Tarazani K and Katal Y 2012, Effect of Load Profile on Reliability of Power System, Int. J. Acad. Res. Appl. Sci vol. 1, no. 3, pp. 84–93.
[2] Kumar T, Sekhar O, Ramamoorthy M, and Lalitha S 2016, Evaluation of power capacity availability at load bus in a composite power system, IEEE J. Emerg. Sel. Top. Power Electron., vol. 4, no. 4, pp. 1324–1331.
[3] Boroujeni H F, Eghtedari M, Abdollahi M, and Behzadipour E 2012, Calculation of generation system reliability index: Loss of Load Probability, Life Sci. J., vol. 9, no. 4, pp. 4903–4908.
[4] Shirvani M, Memaripour A, Abdollahi M, and Salimi A 2012, Calculation of generation system reliability index: Expected Energy Not Served, Life Sci. J., vol. 9, no. 4, pp. 3443–3448.
[5] Anders G J 1989, Probability concepts in electric power systems.
[6] Wang X and McDonald J 1994, Modern power system planning, McGraw-Hill Companies.
[7] Yip H T, Weller G C, and Allan R N 1984, Reliability evaluation of protection devices in electrical power systems, Reliab. Eng., vol. 9, no. 4, pp. 191–219.
[8] Endrenyi J 1978, Reliability modeling in electric power systems, Wiley New York.
[9] Billinton R and Khan E 1992, *A security based approach to composite power system reliability evaluation*, IEEE Trans. Power Syst., vol. 7, no. 1, pp. 65–72.

[10] Prada J F 1999, *The value of reliability in power systems-pricing operating reserves*.

[11] Çağlar R 2015, *The Effect of Generation Capacity Expansion on the Reliability Indices*.

[12] Preet Lata S V 2019, *State of Art on Reliability Evaluation of Systems Involving Non-Renewable and Renewable Energy Resources*, Int. J. Control Autom., vol. 12, no. 6, pp. 532–553.

[13] Jain A, Balasubramanian R, and Tripathy S C 2011, *Reliability analysis of wind embedded power generation system for Indian Scenario*, Int. J. Eng. Sci. Technol., vol. 3, no. 5.

[14] Esan A, Agbetuyi A, Oghorada O, Ogbeide K, Awelewa A, and Afolabi A 2019, *Reliability assessments of an islanded hybrid PV-diesel-battery system for a typical rural community in Nigeria*, Heliyon, vol. 5, no. 5, p. e01632.

[15] Shalash N and Ahmad A 2014, *Power system generation reliability assessment based on multi-agents technique*, Int. J. Smart Grid Clean Energy.

[16] Ali Kadhem A, Abdul Wahab N, Aris I, Jasni J, and Abdalla A 2017, *Reliability assessment of power generation systems using intelligent search based on disparity theory*, Energies, vol. 10, no. 3, p. 343.

[17] Athraa A, Noor I and Ishak A 2017, *Computational techniques for assessing the reliability and sustainability of electrical power systems: A review*, Renew. Sustain. Energy Rev., vol. 80, pp. 1175–1186.

[18] Fan C, Shaoxiong H, Jinjin D, Bo G, Yuguang X and Xiaoming W 2018, *Fast Reliability Assessing Method for Distribution Network with Distributed Renewable Energy Generation*, *IOP Conf. Ser. Earth Environ. Sci.*, vol. 111, 012036.

[19] Omar M, Asiri I, Yasir A, Mamdooh S, 2016 Reliability Evaluation of Riyadh System Incorporating Renewable Generation, *Int. J. Eng. Sci.*, vol. 6, no. 10, pp. 8–17.

[20] Bindhu L, Kumudeesh K 2016, *Reliability Evaluation of WTG’s based on Reliability Indices*, IJSRD, vol. 1, no. 9.

[21] Manuel S, Jayaweera D 2018, *Aging reliability model for generation adequacy*, IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), pp. 1–6.

[22] Zece Z, Xiuli W, Zечен W, and Tianshi Shen, 2016, *A simplified equivalent method of wind farm for reliability evaluation*, IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), pp. 1250–1253.

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