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Power System Reliability Analysis using Renewable Energy Conversion Systems

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Abstract: ***Renewable energy is collected by natural means like, solar, wind, tides, waves, and geothermal heat etc. This energy is very important in hazardous emissions reduction. Owing to the nature of non-continuous of solar and wind systems power, the reliability evaluation of system is harder. To address such uncertainties, probabilistic methods such as an analytical method are available. By the usage of an analytical method, the large power system reliability can be evaluated using PV and wind renewable generation. One of an analytical method is the LOL (LOL) method. In this, every system generating unit is developed by two-state model. It can be designed on the basis of Markov method. The mathematical model is used to evaluate the reliability indices. There are various reliability indices which gives the analytical solution for system reliability evaluation.***

The Capacity Outage Probability Table (COPT) and the Load Duration Curves (LDC) are used for finding the system indices for estimating the system reliability, considering PV as well as wind Renewable Energy System (RES) each having specific Forced Outage Rate (FOR). The objective of the proposed work is to implement solar and wind energy systems with power system to improve the reliability indices taking data from the load duration curves. MATLAB Program/SIMULINK blocks have been developed and results obtained are analyzed on a sample power system network, and the results are presented.

Keywords : Reliability of Generation System evaluation, LOL method, Wind System, Solar PV Power, Reliability Indices.

I. INTRODUCTION

Electricity is a crucial factor for the world economies and it also supplies the day necessity for all the world population when needed [1]. Based on the nature of systems of electricity, any time the demand will change. The change in demand at every instant need to effectuate by proper supply of electricity and making sure the continuous availability of the resources. In any case, if the supply is not meeting the load demand will give the income loss on the generators and also to the consumers. Due to the nature of non-continuous of solar and wind systems power, the reliability of the system is very harder to evaluate.

In the previous years, the power system reliability can be evaluated by using deterministic methods to analyze the occurrence. A single failure must not develop into a significant failure of the system. This method doesn't say anything about the probability of occurrence of individual events. The impact of uncertainties only considered in the evaluation of the power system network reliability in different modes of operation without giving any concern for the power loss [3]. Here, we are not considered the power loss concept. Due to the non-continuous nature; the reliability doesn't improve by the RES as much as conventional energy sources. The major objective of the proposed work is to enhance the reliability by implementing the solar and wind energy sources of power system collecting the data from LDC curves and also from the COPT table. In this proposed work, the power system reliability will be enhanced by increasing the usage of RES when compared with the existing system.

Here 810 W capacities of 200 PV panels are used instead of 50 panels with the maximum capacity factor of 28% and also the 2 MW capacity of 35 wind turbines are used instead of 20 wind turbines with the maximum capacity factor of 50.6% [4].

The large power system reliability with solar PV and wind renewable energy systems can be calculated with the help of analytical methods. There are several reliability indices for analyzing the system reliability [5-6] given as follows:

(a) LOLE - LOL Expectation
(b) LOLP - LOL Probability
(c) EENS - Expected Energy Not Supplied

For calculating reliability indices of the system, the data from the LDC curves and the COPT table is used in this paper. The reliability indices can be used in evaluating the system reliability by considering solar and wind renewable energy systems each having specific Forced Outage Rate (FOR).

II. GENERATION PROBABILISTIC PLANNING METHODOLOGY

The combination of different types of generation, transmission and distribution systems is refers as the Power system. By the help of an analytical method, the large power system with solar PV and wind RES will be evaluated. The power system reliability means the load demand probability not being able to meet by the generating systems, and it is evaluated by understanding the reliability system indices.

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The system reliability indices for the reliability evaluation are given as follows, LOLE, LOLP, and EENS [7-9]. If in the case of the reserve capacity is more than the outage capacity, the LOL cannot occur. The generation capacity model is entitled by COPT; it provides, occurrence of probability for each possible level of the outage capacity.

Furthermore, the LDC introduces load model; it is arranged by hourly basis load values in chronological order.

To express the characteristics of the load, the LDC is the more effective model [10-12].

The FOR of generating unit, is denoted by U it is the unit probability in the forced outage stage or unavailable stage. The FOR is obtained by the following expression.

$$FOR = U = \frac{\sum T_{down}}{\sum T_{up} + \sum T_{down}} = \frac{\lambda}{\lambda + \mu} \quad (1)$$

$$P_{up} = \frac{\mu}{\lambda+\mu} \quad (2)$$

$$P_{down} = \frac{\lambda}{\lambda+\mu} \quad (3)$$

where, the failure-rate of unit is λ, repair-rate of unit is μ, $P_{\mu p}$ is the unit generating probability in up State, and P_{down} is the unit generating probability in down state. $T_{\mu p}$ and T_{down} are the unit duration in the operating and failure state respectively.

III. LOL METHOD ALGORITHM – AN ANALYTICAL METHOD

The reliability is defined as the non-failure system probability within the time period (t). The power system reliability is expressed as:

$$R(t) = P\,(T > t) \quad (4)$$

where, T is the system time to failure. The total unreliability probability is estimated by:

$$F(t) = 1 - R(t) = P(T < t) \quad (5)$$

One of an analytical method is the LOL method which is adopted and implemented. In this method, the system generation capacity is entitled by the COPT table. By the usage of an analytical method, the large power system reliability can be evaluated using PV and wind renewable generation. In this, every system generating unit is developed by two-state model. It can be designed on the basis of Markov method. With the help of mathematical model, the reliability indices are evaluated. The various reliability system indices like LOLP, LOLE and EENS, can be evaluated from this state model.

The "LOL" index gives the how many days (or hours) information which is expected in the given time period; where the daily/hourly maximum load is beyond the capacity available. The LOLE can be expressed as:

$$LOLE = \sum_{i=1}^{n} (p_i * t_i)\ (L_{max} > C)\ (h/yr) \quad (6)$$

where, p_i is the probability of i_{th} outage calculated straightly from the COPT table, t_i is the no. of time units the LOL is caused by this outage and n is how many days or hours of period scope. We already knew that the reserve capacity is more than the outage capacity, so the LOL cannot occur.

Nowadays, the LOLP index was not uses continuously why means, it specifies the failure system probability only. The LOLP index can be given by the below equation

$$LOLP = \sum_{i=1}^{n} (p_i)\ \ (L_{max} > C) \quad (7)$$

The Fig. 1 shows the step-by-step flowchart algorithm used for calculating the LOLE index that calculates, the level of reliability in the power system planning process in the order for determining the arrogate reserve capacity margin for every year of the planning range of vision. $LOLE_p$ indicates the desired level of LOLE.

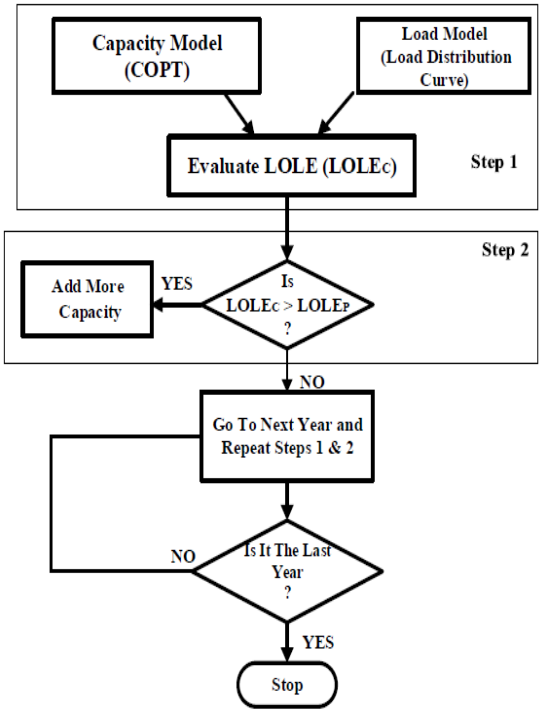

Fig. 1. LOL method step-by-step flow chart for evaluation

Nowadays, the LOLP index was not uses continuously why means, it specifies the failure system probability only. The LOLP index can be given by the below equation

$$LOLP = \sum_{i=1}^{n} (p_i)\ \ (L_{max} > C) \quad (7)$$

A first and foremost objective of the utility company is the energy sale and the second extremely important and necessarily wanted reliability index is the EENS i.e., expected energy not supplied, this one is also taken in this method. The EENS will be given as below

$$EENS = \sum_{i=1}^{n} (ENS_i * p_i)(L_{max} > C)\ (MWh/yr) \quad (8)$$

IV. RESULTS OF PROPOSED SYSTEM USING SOLAR AND WIND

Roy Billinton Test System (RBTS) is taken as reference in this paper [7]. The schematic diagram of RBTS is shown in Fig. 2. This system having a total of 6 buses. Here, 240 MW is the total capacity connected. Similarly, 185 MW is the peak load of the system. The Table-1 gives the reliability data of RBTS for various ratings of generator.

(i) Among 6, 5 buses are load buses,

(ii) 9 - Transmission lines, and
(iii) In buses 1 and 2 total 11 generators are connected, these are having ratings as 5 MW to 40 MW.

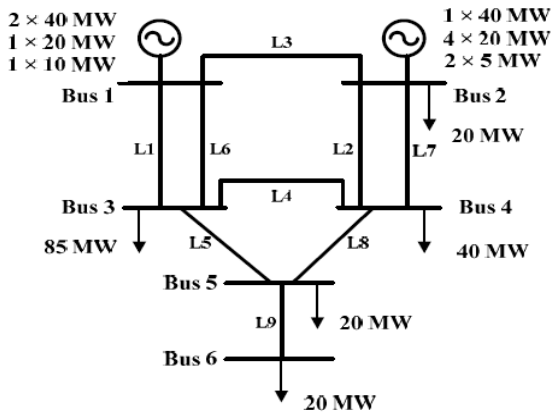

Fig. 2. RBTS Single line diagram

For case (I): Added a combined solar and wind power having the overall capacity of 80.5 MW to the RBTS system. The FOR is 4%.

Wind Power → 20 * 2 MW = 40 MW
Solar PV → 50 * 810 W = 40.5 MW

For case (II): Added thermal units having capacity of 80.5 MW to the RBTS system. The FOR was 4%.

Thermal → 2 * 40.25 MW = 80.5 MW

Table -1: RBTS Reliability Data for Conventional Generation Unit

Type of Unit	Size (MW)	No of Units	FOR	MTTF/h	MTTR/h
Hydro	5	2	0.0100	4380.00	45
Thermal	10	1	0.0200	2190.00	45
Hydro	20	4	0.0150	3650.00	55
Thermal	20	1	0.0250	1752.00	45
Hydro	40	1	0.0200	2920.00	60
Thermal	40	2	0.0300	1460.00	45

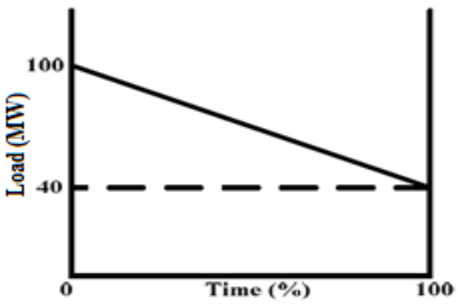

Fig. 3. Load model of the system

The hourly based distribution of load of the system is found by load Duration Curve (LDC). Fig. 3. shows the load model of the system. Here, assuming the linear load model and it is varied from 100-40% of the peak load. It is observed that, the 100% of load model indicates the number of annual hours (8760). Moreover, the LDC is fully designed load model based on the hours.

According to National Renewable Energy Laboratory (NREL), in any region the Transparent Cost Database (TCD) of solar radiation and wind speed variations is 50.6%. Subsequently, PV system and wind turbine maximum capacity factor is 28%. Therefore, the capacity value of one unit of PV array and wind turbine considering the capacity factor are 0.2268 MW 1.012 MW respectively.

Wind Power → 35 * (0.506 * 2 MW) = 35 * 1.012 MW
= 35.22 MW
Solar PV → 200 * (0.28 * 0.810) = 200 * 0.2268 MW
= 45.28 MW
Total → 35.22 + 45.28 = 80.5 MW

Table - 2: Comparing EENS and LOLE for Different Cases with proposed system

Reliability indices	RBTS Base case	Case I	Case II	Proposed System
LOLE (h/yr)	11.4879	0.6201	0.4341	0.3944
EENS (MWh/yr)	116.817	5.6201	4.6657	4.2416

This analysis confirms that the power system reliability is improved crucially by the usage of RES and also it helps the planners of power system while high transfixing of grid-connected RES is considered.

V. CONCLUSION

In this proposed work, the large power system reliability using PV and wind renewable generation can be evaluated and analyzed by the usage of LOL method. The power system reliability will be evaluated by analyzing reliability system indices and the LOLE and EENS are reliability indices which helps in enhancing the reliability of power system.

These values are evaluated by writing MATLAB program for different cases considering the COPT table and LDC curve data. Even if the load is increased beyond the test case load, it can supply as much as needed because of maximum capacity factor for RES. This analysis confirms that the system reliability can be improved significantly by the usage of RES.

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