International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 14 (2015) pp 34132-34136

Reliability Evaluation of Power System Using Equivalent Energy Function Method with Integration of Solar Power Plant

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Abstract

Generation system reliability is a main feature in the planning for future system capacity expansion to confirm that the total installed capacity is enough to deliver adequate electricity when needed. The planning method uses reliability indices as a criteria to decide on new investments in new generation capacities. With the development of renewable energy as the promising future generating options, system planners now focus on integrating large amount of renewable resources, namely wind, solar, wave and tidal energy which are intermittent in nature. The intermittency of these resources contributes little to the electricity system reliability. This paperfocused on evaluating how intermittent solar generation contributes to the generation system adequacy and affects system reliability. The reliability evaluation is carried out using Equivalent Energy Function method on IEEE- One Area RTS-96 test system with two cases as with and without solar power plant.

Keywords: Equivalent Energy Function Method, IEEE- One Area RTS-96, Reliability Evaluation, Solar Power Plant.

Introduction

Electricity has been the driving force for economies of the world and offers day-to-day need for the people in the world. The generation, transmission and selling of electricity have occurred hundreds of years in providing the much required electricity. Because of the nature of electricity systems, the inconstant demand at every moment wants to be met by constant electricity supply in assure the uninterrupted availability of the resources. Not meeting the demand in any case will lead to a massive loss of income to the generators along with to the consumers. The reliability of the generation, transmission and distribution of electricity in this sense is critical for the continuous supply of electricity to meet the demand.

A modern power system is composite, highly integrated and very large. Opportunely, the system can be separated into proper subsystems or practical areas that can beinvestigated separately [1]. These practical areas are generation, transmission and distribution. The role of the generation system is to make sure sufficient capacity is available to meet the load/demand at any time. Transmission and distribution systems need to be consistent in making sure the electricity generator can be distributed to the consumers. System planners have been assigned the role of planning for forecasting the load into the future and plant capacity addition to satisfy the load and offer a level of reliability in case some of the plants are out on maintenance or breakdown. Probabilistic method is often used to determine the system reliability and the system reliability can be summed up into a single value, the reliability indices. Reliability studies are done for two purposes. Long-term evaluations are done to support in system planning and short-term evaluations to support in day to day operating decisions.

Nowadays, renewable technologies have been in the attention and became highly favorable generation resources owing to the increasing of oil prices, uncertainty of fossil fuel or security of supplies in the future and worries on the environmental impact because of the over intake of fossil resources. With that, renewables look hopeful as the fuel that are almost available at the local level, green to the environment and progressively cost competitive with technology maturity and rising fossil fuel prices. Though, one of the main obstacles of integrating large amount of renewable resources, namely wind, solar, wave and tidal energy are the variability of the natural resources. This variability of the renewable resources is also known as intermittency of the resources. Power system reliability evaluation is essential for learning the current system to recognize weak points in the system, determining what implementation is needed to meet future demand and planning for new reliable power system, i.e., network expansion. Reliability studies is vital to avoid economic and social losses causing from power outages [2].

In this paper the reliability evaluation is carried out using Equivalent Energy Function method on IEEE- One Area RTS-96 test system with two cases as with and without solar power plant.

Description of Test System

The 24 bus system [3] is shown in Figure 1.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 14 (2015) pp 34132-34136

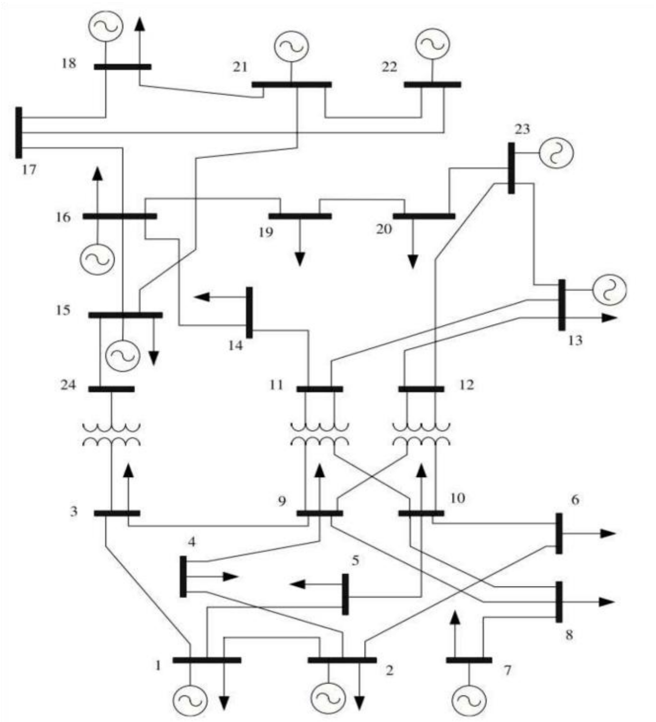

Fig 1. 24-bus power system – IEEE One Area RTS-96

Table 1 categorizes the units in different types which are used in different location of the IEEE One Area RTS test system and it's Forced Outage Rate (FOR) values.

TABLE 1: Unit Type and FOR values

Unit Type	Unit(s)	FOR
Nuclear	18 21	0.070
Coal/Stream	1 2 15 16 23a	0.020
Coal/3 Stream	23 b	0.025
Oil/Stream	7 13 15	0.070
Hydro	22	0.015

The capacity values of different types of plants are shown in Figure 2.

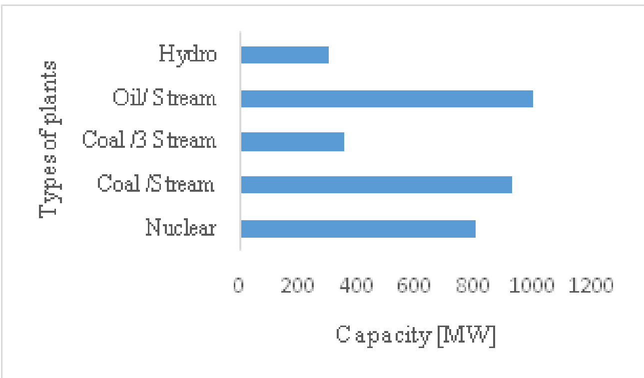

Fig 2. Capacity values of different types of plants

In Figure 3, the load profile is illustrated. Table 2 provides the total system demand per hour.

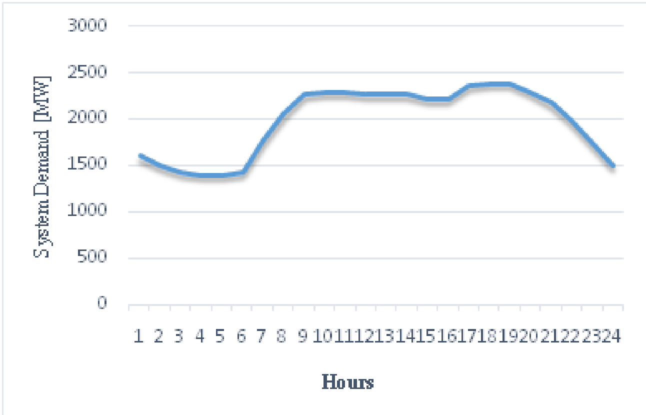

Fig 3. System Demand Profile

TABLE 2. Load Profile

Hour	System Demand MW	Hour	System Demand MW
1	1598.252	**13**	2266.178
2	1502.834	**14**	2266.178
3	1431.270	**15**	2218.469
4	1407.416	**16**	2218.469
5	1407.416	**17**	2361.596
6	1431.270	**18**	2385.450
7	1765.233	**19**	2385.450
8	2051.487	**20**	2290.032
9	2266.178	**21**	2170.760
10	2290.032	**22**	1979.924
11	2290.032	**23**	1741.379
12	2266.178	**24**	1502.834

Calculation of EENS

The LOLE represents the expected number of hours per year during which the system load exceeds the available generating capacity [4].

The EENS is defined as the expected energy that will not be supplied due to those occurrences when the load exceeds the available generation. The area under the load duration curve signifies the energy consumed during the specified period and can be used to calculate the expected energy not supplied due to lackingin installed capacity [5].

The probabilities of having varying amounts of capacity unavailable are combined with the system load as shown in figure 4. Any outage of generating capacity exceeding the reserve will result in a curtailment of system load energy.

Let:

O_k = magnitude of the capacity outage

P_k = probability of a capacity outage equal to O_k

E_k = energy curtailed by a capacity outage equal to O_k

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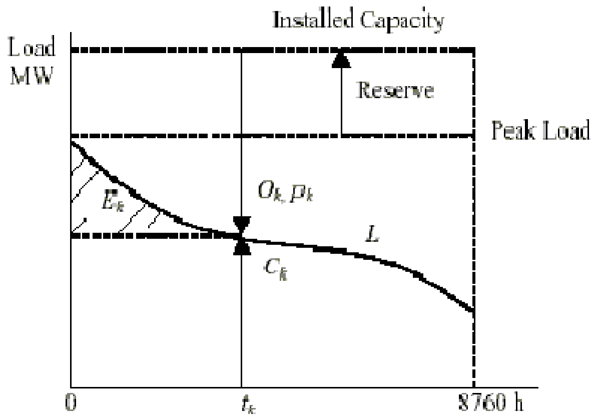

Fig 4. Energy curtailment due to a given capacity outage conditions

The shaded area in figure 4 $E_k$provides this energy curtailment. The probable energy curtailed is E_k*P_k. The sum of these products is the total expected energy curtailment or LOEE

where

$$\text{LOEE} = \sum_{K=1}^{N} E_k P_k \quad (1)$$

A. Equivalent energy function method

In this method [6], the operations are done on electrical energy rather than load. Since, it uses an energy index for calculations; it excels in both computation and accuracy. If we know energy consumed in different load level segments and directly modifying it, when unit failure effects are taken into consideration, then we can easily carry out an indices calculation. In addition to LOEE calculation, without any extra computational effort, we can easily calculate LOLP also. The equivalent energy function is an energy function that takes into account the influence of the generating unit's outage. Suppose the system load duration curve in the investigated period T is known, then the load duration curve's probability distribution is,

$$P = f(x) = \frac{F(x)}{T} \quad (2)$$

A discrete energy function can be defined as

$$E(J) = \int_{x}^{x+\Delta x} F(x)d(x) = T\int_{x}^{x+\Delta x} F(x)d(x) \quad (3)$$

where,
Δx = greatest common factor of allgenerating unit capacities.
J = < x / Δ x > +1; <> means an integer not greater than x / Δ x

E(J) correspond to the area under a section of the load curve from x to Δx, or the energy that corresponds to this section of load.

If X_{max} is maximum load, thenN_E = < X_{max} / Δ x > +1
Let the generating unit i is having a capacity of C_i and forced outage rate (FOR) of qi. The Equivalent Load Duration Curve (ELDC) f(x) can be represented as,

$$F^{i}(x) = p_i f^{(i-1)}(x) + q_i f^{(i-1)}(x - C_i) \quad (4)$$

From equation 3

$$E^{(i)}(J) = T\int f^{(i)}(x)dx \quad (5)$$

From eqn. (4) &(5)

$$E^{(i)}(J) = p_i E^{(i-1)}(J) + q_i E^{(i-1)}(J - K_i) \quad (6)$$

where

Ki = Ci / Δ x

The load in the interval (1,Ji) has been shared by proceeding unit i generating units when generating unit i has been committed. The load energy not served by the systems is,

$$E_{Di} = \sum_{J>J_i} E^{(i)}(J) \quad (7)$$

If we consider n generating units, then

$$E_{Dn} = \sum_{J>J_n} E^{(n)}(J) \quad (8)$$

$$EENS = \sum_{J>J_n} E^{(n)}(J) \quad (9)$$

B. Steps to calculate EENS

- Separate the load model with fixed segment size.
- Calculate the area of the each segment size, which is nothing but the energy of the segment.
- From that calculate the equivalent energy function as per the Eq. (6)
- Calculate the expected energy output of the each unit.
- Calculate EENS as per the Eq. (9)

It is to be noted that the procedure followed here has considerable computational advantages, i.e. the amount of computation has been reduced to the greatest extent possible.

Evaluation of Reliability Using Equivalent Energy Function Method

The reliability evaluation is carried out using Equivalent Energy Function method on IEEE- One Area RTS-96 test system with two cases as with and without solar power plant.

A. Case 1: Without Solar Power plant

The reliability values are evaluated for the test system and tabulated below. The Table 3 shows the values of Expected Energy Not Served (EENS) in MWh and Loss of Load Probability (LOLP) for 24 hours of time period.

B. Case 2: With Solar Power plant

The Six (Five 60 MW and One 50 MW) no. of solar power plants having the capacity of 350 MW are integrated at different locations throughout the grid. It is proposed to locate the solar plants at 3, 5, 7, 16, 21 and 23 nodes. The FOR value of solar power plant is taken as 0.7. The capacity values are shown in Figure 4. The reliability values are evaluated for the test system and tabulated below. The Table 4 shows the values of Expected Energy Not Served (EENS) in MWh and Loss of Load Probability (LOLP) for 24 hours of time period with solar power plant.

TABLE 3. Evaluated reliability values without Solar Power plant

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
EENS (MWh)	0.0159	0.0066	0.0036	0.0029	0.0029	0.0036	0.1262	1.172	6.1332	7.3167	7.3167	6.1332
LOLP	1.16×10^{-06}	5.285×10^{-06}	2.96×10^{-06}	2.52×10^{-06}	2.52×10^{-06}	2.96×10^{-06}	9.40×10^{-05}	1.30×10^{-03}	3.00×10^{-03}	3.70×10^{-03}	3.70×10^{-03}	3.00×10^{-03}
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
EENS (MWh)	6.1332	6.1332	4.806	4.806	10.870	12.037	12.037	7.316	3.5933	0.5566	0.0928	0.0066
LOLP	3.00×10^{-03}	3.00×10^{-03}	2.10×10^{-03}	2.10×10^{-03}	4.70×10^{-03}	5.20×10^{-03}	5.20×10^{-03}	3.70×10^{-03}	2.00×10^{-03}	3.27×10^{-04}	9.26×10^{-05}	5.285×10^{-06}

TABLE 4. Evaluated reliability values with Solar Power plant

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
EENS (MWh)	0.1578	0.0694	0.0332	0.026	0.026	0.0332	0.777	6.5075	31.460	37.999	37.999	31.460
LOLP	1.04×10^{-04}	5.46×10^{-05}	3.11×10^{-05}	2.96×10^{-05}	2.96×10^{-05}	3.11×10^{-05}	6.89×10^{-04}	3.80×10^{-03}	1.66×10^{-02}	2.02×10^{-02}	2.02×10^{-02}	1.66×10^{-02}
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
EENS (MWh)	31.460	31.460	23.183	23.183	56.997	63.453	63.453	37.999	16.356	4.2061	0.5518	0.0694
LOLP	1.66×10^{-02}	1.66×10^{-02}	1.48×10^{-02}	1.48×10^{-02}	2.64×10^{-02}	2.70×10^{-02}	2.70×10^{-02}	2.02×10^{-02}	1.13×10^{-02}	2.10×10^{-03}	4.47×10^{-04}	5.46×10^{-05}

Results and Discussion

The evaluated values of EENS are compared for Case 1 and Case 2 is shown in Figure5. And the evaluated values of LOLP are compared for Case 1 and Case 2 is shown in Figure 6. The Figures show that the values of EENS and LOLP are increased when integrating the solar power plant and satisfy the standards of the reliability.

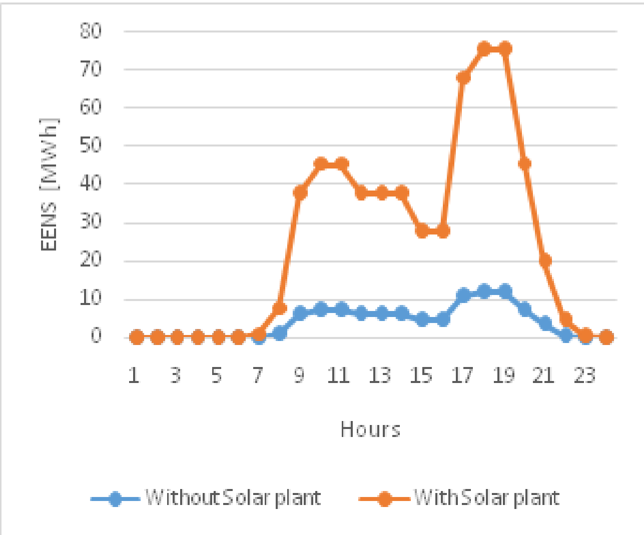

Fig 5. Comparison of EENS for Case 1 and Case 2

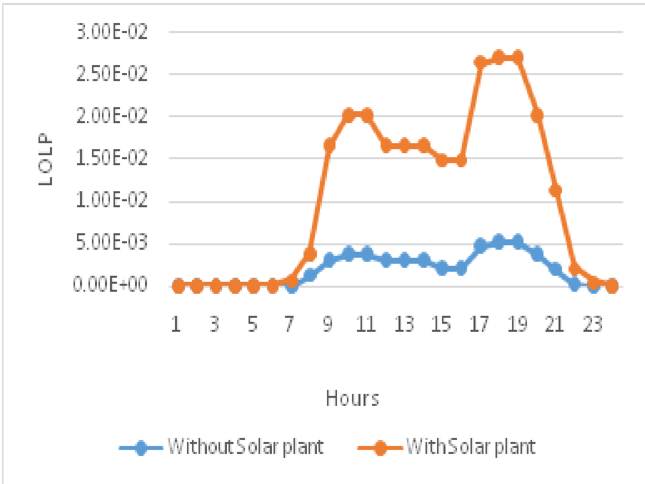

Fig6. Comparison of LOLP for Case 1 and Case 2

Conclusion

This paper gives motivation on calculating how intermittent solar generation contributes to the generation system adequacy and affects system reliability. The reliability evaluation is carried out using Equivalent Energy Function method on IEEE- One Area RTS-96 test system with two cases as with and without solar power plant. The results obtained from reliability studies, give an appropriate standard for measuring the system performance and recognizing the weak point of the system. Authenticating the weak point of the system may make the planners to increase the investment at a certain load point during the planning phase and therefore reduce the extra costs due to supply interruption in operation stage.

REFERENCES

[1]. Billinton, R. and Allan, R.N, "Reliability Evaluation of Power Systems", Plenum Press,New York, NY, 1996.

[2]. Billinton, R., Chen, H. and Ghajar, R, "A Sequential Simulation Technique for Adequacy Evaluation of Generating Systems Including Wind Energy", IEEE/PES Winter Meeting. Baltimore, Maryland, 1996.

[3]. C. Grigg, P. Wong, P. Albrecht, R. Allan, M. Bhavaraju, R. Billinton, Q. Chen, C. Fong, S.Haddad, S. Kuruganty, "The IEEE Reliability Test System 1996". A report prepared by the reliability test system task force of the application of probability methods subcommittee. IEEE Transactions on Power Systems, vol. 14(3): pp.1010-1020, 1999.

[4]. R.Billinton and R.N.Allan, "Probabilistic assessment of power systems", Invited paper, proceedings of the IEEE, Vol. 88, Feb 2000.

[5]. C.Singh, "A concise method for calculating Expected Unserved Energy in generating system reliability analysis "IEEE trans. on power systems, vol. 6 Aug 1991.

[6]. Xifan Wang, Jim Mc Donald, "Modern power system planning", McGraw-Hill International Edition-1994.