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Reliability assessment of power systems considering renewable energy sources

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ABSTRACT

Various types of renewable energy systems can make vulnerable the reliability of the system because of initiating noteworthy degrees of uncertainty and availability despite of their good effects on the system operation cost and global concerns. The difficulty can be removed with using special renewable energy sources with have complimentary in natures. This paper presents the reliability assessment of wind and solar energy based power system at different levels. The optimization problem is to increase the reliability of the system with both solar and wind energy systems. First, the system is developed by taking the effect of uncertain nature of wind and solar energy sources, the probability of the top event and failure rate of different components. The model predictive method is used to take the different future value of the daily data. For this investigation, total 11 cases are taken and reliability indices are considered for every case. Data of each basic event of solar-wind energy system components are taken from the old research. Further, the gamma model is used to obtain the system model and different reliability indices are evaluated. The top event probability for case 1, case 2, case 3, case 4, case 5, case 6, case 7, case 8, case 9, case 10 are 0.0234, 0.0245, 0.0256, 0.0263, 0.0267, 0.0268, 0.273, 0.0278, 0.0286 and 0.0288 respectively. The helpfulness of the proposed technique is provided through different evaluation data.

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1. Introduction

The sophisticated interconnection of different renewable energy sources to the grid has both its merits and demerits. This integration helps to provide power to different types of consumers, overcome the generation loss in a system by other system therefore decrease the cost and enhance the reliability. Recent development in the solar and wind energy system technologies show power industry to see the installation of solar and wind energy system around the different areas. In the literature, many works suggested the effect of the wind and solar energy system generation on the reliability of the system. For utilities, changes in the solar and wind power can create serious issues of reliability reduction [1]. The synthetic data are used to model the grid reliability council and different case study are developed based on different factors. Further sensitivity analysis of wind and solar energy based grid connected system has been investigated to know the effect of these sources to the grid [2]. In [3] fault tree based on fuzzy theory has been presented and it is applied to the wind energy system. Different control techniques for wind-solar energy system has been developed to control the output power of the sources and to get the accurate power [4]. Hidden Markov models can also be used to investigate the power output of the renewable energy sources [5]. Different approaches such as time dependent approach to know the capacity value of the renewable energy based generation have been developed [6]. Forecasting is also important factor to get the maximum output of the particular system. If, good system is used then burden on the utility grid will be reduced [7] and [8]. Risk analysis of different renewable energy sources is very important when these sources are integrated to the grid [9] and [10]. In [11] an overall examination on availability, reliability, and maintainability for every components of solar based energy system in grid connected mode that uses low value of reliability, considering the failure evidences and repairing gap is discussed. Furthermore, a fuzzy fault tree based technique for assessing the wind based energy system reliability is discussed [12] A best sizing organisa-

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tion for WSB-HPS, and sensible optimum sizing model is settled compelling into account that the network is operating in grid connected mode as well as standalone mode [13]. Therefore, in this paper, a method for the solar-wind energy system reliability analysis with adequate information has been proposed to avoid the actual safely analysis issues. Further, Gamma model and model predictive technique have been applied to calculate the failure probability of the top event.

In this paper Solar and wind energy based power system is presented in Section 2. In Section 3, Gamma model based solar and wind energy system reliability analysis is proposed. Reliability analysis outcomes are defined in Section 4. Lastly, final statements are presented in Section 5.

2. Solar and wind energy based power system

Recent development in the solar and wind energy system technologies make different researchers to look at the growth of solar and wind based system around the world. The reliability and power quality of the particular system are influenced by the increased rate of penetration of these powers in the system because of stochastic performance of solar and wind energy systems.

Wind and solar power systems are main and rising sources among the various renewable energy sources available. The photovoltaic system and wind turbines are widely used in the distribution systems. These sources are now connected directly to the power grid at high power scale. The solar and wind energy systems have notable impacts on the advanced power system. Therefore reliability assessment is necessary for good operation of the entire system. Fig. 1 shows the grid connected solar and wind energy system and it consists of a solar energy system, wind energy system, power converters. The solar energy systems and wind energy systems have different components which has different failure rates. Parameter specification for the selected system is provided in Table 1. The main faults of the defined power system are as follows: PV cell faults, AC and DC switch crack faults, gear box faults, generator faults, converter faults and inverter faults.

3. Gamma model based solar and wind energy system reliability analysis

Gamma model involves the two parameter model which is used for reliability analysis. The associated functions are defined as:

$$Y(t) = \frac{\delta}{(b-1)!}(\delta_t)^{b-1}\frac{e^{-\delta t}}{G(t)}$$

$$G(t) = \sum_{i=0}^{b-1}\frac{(\delta_t)^i}{i!}e^{-\delta t}$$

$$F(t) = \frac{\delta}{(b-1)!}(\delta_t)^{b-1}e^{-\delta t}$$

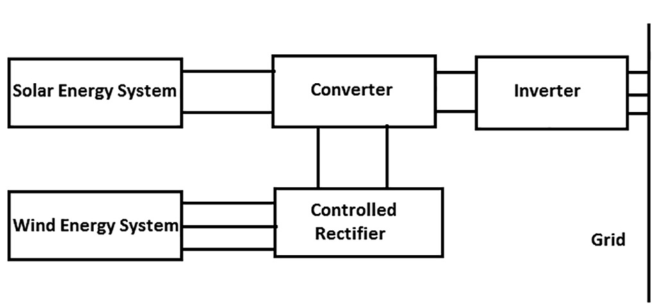

Fig. 1. Solar and wind energy based power system.

Table 1
Solar-wind energy system components failure rates.

Top Event	Basic Event	Failure Rate (occ/year)
Solar-wind energy system fault (no/less energy output)	BE1: PV cells failure	0.015
	BE2. AC button crack	0.042
	BE3. DC button crack	0.244
	BE4. Connector failure	0.526
	BE5. Pitch error	0.031
	BE6. Oxidation	0.045
	BE7. Unbalanced rotor	0.064
	BE8: Inappropriate maintenance	0.032
	BE9: Semiconductor fault	0.037
	BE10: Inverter fault	0.021
	BE11: Overstress	0.021
	BE12: Lubrication issue	0.027
	BE13: Temperature issue	0.032
	BE14: Construction fault	0.012
	BE15: Poor quality	0.029

where b and δ are positive integer and positive constant respectively.

$$MTTF = \frac{b}{\delta}$$

For b > 1, $Y(t)$ increases and for b = 1, it shows a constant-hazard rate system.

LOLP - Loss of Load Probability

LOLE - Loss of Load Expectation

For the implementation of the Gamma model based reliability evaluation of the solar-wind energy based power system, a technique is presented in Fig. 2. Initially, data identification step is conducted by taking the earlier data, observing the system operation and using the model predictive technique to know the daily upcoming data. Identify the top event is the main step in Gamma model based solar-wind energy system reliability analysis then Gamma model is developed and failure rate assessment is done. A risk management has been done to get the impact of the basic event which is responsible to the system damage. It is used to know the design and appropriate changes in the system.

4. Reliability analysis outcomes

The Solar-wind energy system components failure rates data are calculated from the 15 years survey data and data obtained from the model predictive based technique as mentioned in Table 1. Solar-wind energy system fault (no/less energy output) is the top event.

The reliability analysis of the selected model having solar and wind energy system is done. Predictive risk index for basic events of the proposed system is presented in Table 2. The test system has 10 generating units. The generating capacity of system is 300 MW and a total connected load s 275 MW.

In this study 11 cases are taken to know the effect of solar-wind energy system on the system reliability. In case 1, original system is considered to know the reliability of the system. In case 2 and case 3, addition 15 MW wind turbines and 15 MW solar photovoltaic cells are added to the main system are considered. In case 4 and case 5, 20 MW wind turbines and 20 MW solar photovoltaic cells are used with original system. Similarly for case 6, 7, 8, 9, 10

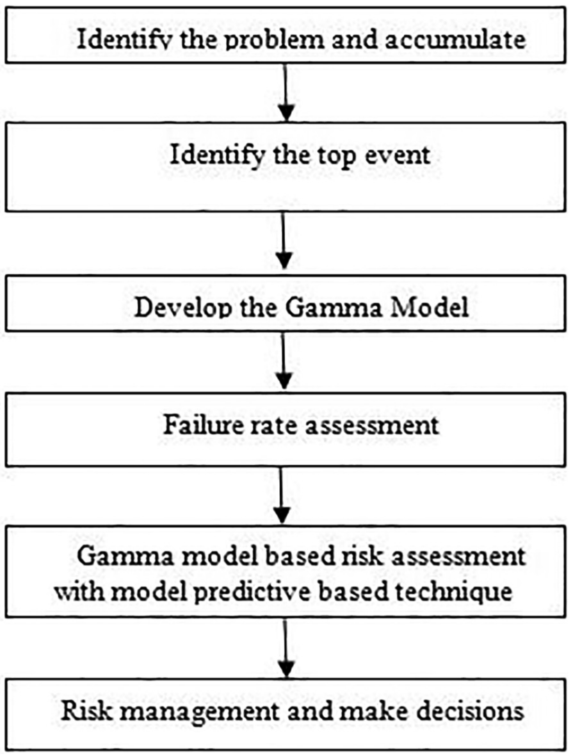

Fig. 2. Flow chart for Gamma model based solar-wind energy system reliability analysis.

Table 2
Predictive risk index for basic events of the proposed system.

Basic Event	Predictive risk index
BE1	4.34E-03
BE2	5.67E-05
BE3	4.89E-07
BE4	5.98E-03
BE5	4.34E-06
BE6	7.85E-05
BE7	2.78E-03
BE8	8.34E-05
BE9	4.67E-03
BE10	3.67E-05
BE11	5.89E-03
BE12	2.46E-05
BE13	4.78E-03
BE14	9.34E-05
BE15	8.26E-04

and 11, 25 MW wind turbines, 25 MW solar photovoltaic cells, 30 MW wind turbines, 30 MW solar photovoltaic cells, 35 MW wind turbines, 35 MW solar photovoltaic cells respectively are added with original system to know the exact risk of the entire system.

Case 1: The original system

Case 2: Increment of 15 MW wind turbines to the original system

Case 3: Increment of 15 MW solar photovoltaic cells to the original system

Case 4: Increment of 20 MW wind turbines to the original system

Case 5: Increment of 20 MW solar photovoltaic to the original system

Case 6: Increment of 25 MW wind turbines to the original system

Table 3
Reliability Indices calculation.

	LOLP	LOLE	Top Event Probability
1	0.0245	3.986	0.0234
2	0.0198	2.086	0.0245
3	0.0196	2.014	0.0256
4	0.0186	1.978	0.0258
5	0.0182	1.864	0.0263
6	0.0180	1.467	0.0267
7	0.0165	1.278	0.0268
8	0.0154	1.245	0.0273
9	0.0145	1.087	0.0278
10	0.0135	1.065	0.0286
11	0.0125	1.038	0.0288

Case 7: Increment of 25 MW solar photovoltaic to the original system

Case 8: Increment of 30 MW wind turbines to the original system

Case 9: Increment of 30 MW solar photovoltaic to the original system

Case 10: Increment of 35 MW wind turbines to the original system

Case 11: Increment of 35 MW solar photovoltaic to the original system

By using model predictive technique and gamma model, different values for 11 cases are obtained. For the 11 cases, the LOLP, LOLE and top event probability are obtained and shown in Table 3.

5. Conclusions

A technique for the solar-wind energy system reliability analysis with good information has been proposed to avoid the actual safely analysis issues. Gamma model and model predictive technique has been applied to compute the failure probability of the top event. For this analysis, total 11 cases are considered and reliability indices are calculated for each case. Data of each basic event of solar-wind energy system components are taken from the old data, interaction with working group and research papers. The proposed technique is wide-ranging and has less computational burden. The obtained outcomes show the advantage of connecting the solar and wind energy systems to any power system to increase the reliability of the system. The manufacture can take these data to review and take care of weak components of the solar-wind energy systems in concern.

CRediT authorship contribution statement

Iram Akhtar: Conceptualization, Methodology, Software, Writing - original draft. **Sheeraz Kirmani:** Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] I. Akhtar, S. Kirmani, Error-based wind power prediction technique based on generalized factors analysis with improved power system reliability, IETE J. Res. (2020) 1–12, https://doi.org/10.1080/03772063.2020.1788426.

[2] M.d. Nurunnabi, N.K. Roy, E. Hossain, H.R. Pota, Size optimization and sensitivity analysis of hybrid wind/PV micro-grids- a case study for Bangladesh, IEEE Access 7 (2019) 150120–150140, https://doi.org/10.1109/ACCESS.2019.2945937.

[3] I. Akhtar, S. Kirmani, An application of fuzzy fault tree analysis for reliability evaluation of wind energy system, IETE J. Res. (2020) 1–14, https://doi.org/10.1080/03772063.2020.1791741.
[4] X. Kong, X. Liu, L. Ma, K.Y. Lee, Hierarchical distributed model predictive control of standalone wind/solar/battery power system, IEEE Trans. Syst. Man Cybern. Syst. 49 (8) (2019) 1570–1581, https://doi.org/10.1109/TSMC.622102110.1109/TSMC.2019.2897646.
[5] D. Bhaumik, D. Crommelin, S. Kapodistria, B. Zwart, Hidden markov models for wind farm power output, IEEE Trans. Sustain. Energy. 10 (2) (2019) 533–539, https://doi.org/10.1109/TSTE.2018.2834475.
[6] M. Mosadeghy, R. Yan, T.K. Saha, A time-dependent approach to evaluate capacity value of wind and solar PV generation, IEEE Trans. Sustain. Energy. 7 (1) (2016) 129–138, https://doi.org/10.1109/TSTE.2015.2478518.
[7] K.D. Orwig, M.L. Ahlstrom, V. Banunarayanan, J. Sharp, J.M. Wilczak, J. Freedman, S.E. Haupt, J. Cline, O. Bartholomy, H.F. Hamann, B.-M. Hodge, C. Finley, D. Nakafuji, J. Peterson, D. Maggio, M. Marquis, Recent trends in variable generation forecasting and its value to the power system, IEEE Trans. Sustain. Energy. 6 (3) (2015) 924–933, https://doi.org/10.1109/TSTE.2014.2366118.
[8] A. Safdarian, M. Fotuhi-Firuzabad, F. Aminifar, Compromising wind and solar energies from the power system adequacy viewpoint, IEEE Trans. Power Syst. 27 (4) (2012) 2368–2376, https://doi.org/10.1109/TPWRS.2012.2204409.
[9] Y. Zhang, X. Han, B. Xu, M. Wang, P. Ye, Y. Pei, Risk-based admissibility analysis of wind power integration into power system with energy storage system, IEEE Access 6 (2018) 57400–57413, https://doi.org/10.1109/ACCESS.2018.2870736.
[10] Y.-K. Wu, P.-E. Su, Y. Su, T. Wu, W. Tan, Economics- and reliability-based design for an offshore wind farm, IEEE Trans. Ind. Appl. 53 (2017) 5139–5149, https://doi.org/10.1109/ICPS.2017.7945091.
[11] A. Sayed, M. El-Shimy, M. El-Metwally, M. Elshahed, Reliability, availability and maintainability analysis for grid-connected solar photovoltaic systems, Energies 12 (7) (2019), https://doi.org/10.3390/en12071213.
[12] I. Akhtar, S. Kirmani, An application of fuzzy fault tree analysis for reliability evaluation of wind energy system, IETE J. Res., (2020) 1–14. https://doi.org/10.1080/03772063.2020.1791741.
[13] L. Xu, X. Ruan, C. Mao, B. Zhang, Y. Luo, An improved optimal sizing method for wind-solar-battery hybrid power system, IEEE Trans. Sustain. Energy 4 (3) (2013) 774–785, https://doi.org/10.1109/TSTE.2012.2228509.