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Evaluation of wind-solar hybrid power generation system based on Monte Carlo method

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ABSTRACT

The application of wind-photovoltaic complementary power generation systems is becoming more and more widespread, but its intermittent and fluctuating characteristics may have a certain impact on the system's reliability. To better evaluate the reliability of stand-alone power generation systems with wind and photovoltaic generators, a reliability assessment model for stand-alone power generation systems with wind and photovoltaic generators was developed based on the analysis of the impact of wind and photovoltaic generator outages and derating on reliability. A sequential Monte Carlo method was used to evaluate the impact of the wind turbine, photovoltaic (PV) turbine, wind/photovoltaic complementary system, the randomness of wind turbine/photovoltaic outage status and penetration rate on the reliability of Independent photovoltaic power generation system (IPPS) under the reliability test system (RBTS). The results show that this reliability assessment method can provide some reference for planning the actual IPP system with wind and complementary solar systems.

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1. INTRODUCTION

With the increasing environmental problems and new energy generation technology development, wind and complementary solar systems are more widely used in power generation systems [1]. However, the intermittent and variable nature of wind and photo voltaic strength era may affect the system's dependability [2], [3]. Therefore, conducting an in-depth study on the reliability assessment of stand-alone power generation systems containing wind and solar power is important. In the literature [4], a Monte Carlo approach based totally on a welfare mannequin used to be employed to consider the dependability of wind electricity vegetation below three wonderful running situations. In phrases of storage capability and top load, these two factors affect the dependability of small remoted wind strength structures used to be explored. Feixiang *et al.* [5], the reliability of the power generation system containing wind farms was evaluated by using the sequential Monte Carlo method based on the two-dimensional fuzzy c-mean clustering method to divide the wind farms into multiple states and calculate the transfer probabilities between the states of the wind farms based on the measured data. Jichao *et al.* [6], the photovoltaic (PV) output was segmented based on Fisher's optimal segmentation and elbow point methods. Each period's PV output was simulated using the fuzzy c-mean clustering method. The reliability of the PV farm power generation system was evaluated by the Monte Carlo method. Kai *et al.* [7], the irradiance fluctuation index and clear sky index are solved by the actual data of the PV plant in each state, and the irradiance in the corresponding state is simulated in time. Finally, the sequential Monte Carlo approach evaluated the PV electricity producing system's dependability.

In the literature [8], the reliability test system (RTS) check device was once used to calculate the reliability indices of strength manufacturing structures incorporating wind farms and PV systems. Then, they examined the dependability of the complementing wind and photo voltaic energy producing system. In the literature [9], the Copula principle was once used to consider the dependability of the wind and PV complementary energy technology system, taking into account the unpredictability and correlation of the output energy of the wind and photo voltaic complementary electricity technology system. In the previous literature [4]–[7], solely the reliability of wind electricity or photovoltaic structures used to be evaluated, now not the reliability of complementary wind energy systems; in the literature as mentioned above [8], [9], the effect of wind turbine and photovoltaic generator shutdown on gadget reliability was once now not evaluated. To consider the reliability of the complementary wind and wind impartial electricity technology system, we first regarded the electricity output of wind turbine and the usage of the wind farm energy mannequin underneath the impact of estimated wind pace and wind turbine three-state model; then, we viewed the impact of PV electricity bistatic model, and PV strength era used to be bought the use of the sequence of illuminance generated by way of Homer software program and PV model. On the foundation of the reliability test system (RBTS), take a look at the system. The sequential Monte Carlo method was once used to look at the effects of wind power, PV power, wind/PV power, shutdown country unpredictability, and permeability on the reliability of wind/PV generators.

2. METHOD

2.1. Wind farm output model

2.1.1. Wind speed model

There are many methods for forecasting wind pace models, including the Weibull distribution approach, the time sequence method, and the synthetic neural community technique. The autoregressive shifting common (ARMA) is used in this work to forecast the wind pace because the time sequence method can more precisely depict the time sequence of wind velocity modifications and estimate the future wind velocity from a small volume of wind velocity facts [10]. Firstly, the historical wind speed is normalized, and its autocorrelation coefficient and bias correlation coefficient are found; secondly, the ARMA model's autoregressive order p and sliding average order q are determined from the obtained values the unknown parameters are estimated. The final step is to forecast the future wind speed using the fitted model [11], [12] and the projected wind speed at time t. SW_t is the term for the anticipated wind speed at time t, is as (1) and (2).

$$\mathrm{S\,W_t} = \mu_t + \sigma_t\, y_t \tag{1}$$

$$y_t = \alpha_t + \sum_{i=1}^{p} \varphi_i y_{t-i} - \sum_{j=1}^{q} \theta_j \alpha_{t-j} \tag{2}$$

where μ_t is the mean value of wind speed at time t, σ_t is the variance, y_t is the time series value, and the expression of y_t is shown in (2). The autoregressive coefficient is denoted by φ_i ($i=0,1,2,3,...,p$), the sliding average coefficient is denoted by θ_j ($j=0,1,2,3, ...,q$), $\{\alpha_t\}$ is the white with a mean of 0 and a variance of σ_α^2 .

2.1.2. Fan outage model

In order to simplify the calculation, the conventional shutdown model usually only considers two states: normal and shutdown, but in practice, due to wind speed fluctuations, external environment and other factors, when the load is too large to cause the unit gearbox oil temperature to reach the critical condition and alarm, the fan does not appear to be shut down and will not run according to the original state, but to protect the fan by reducing the wind energy absorbed by the fan with the propeller, and then after the alarm state is lifted Therefore, the derating state of the wind turbine should also be considered [13]. The three-state space model of the wind turbine is shown in Figure 1.

In Figure 1 λ_1 is the transfer rate of turbine outage, λ_2 is the transfer rate of turbine derating, and μ_1 and μ_2 are the repair rates. The three states of the wind turbine are random variables, which can be solved probabilistically by Markov's method [14], and the solution process is shown as follows:

Construct the transfer matrix based on the state model diagram:

$$T=\begin{bmatrix}1-(\lambda_2+\lambda_1) & \lambda_2 & \lambda_1\\ \mu_2 & 1-\mu_2 & 0\\ \mu_1 & 0 & 1-\mu_1\end{bmatrix} \tag{3}$$

Apply Markov process approximation principle:

$$PT=P \tag{4}$$

where P is the probability vector for the limit state and T is the transfer matrix. Rewrite (4) as the expression shown in (5):

$$P(T-I)=0 \tag{5}$$

where I is the unit matrix. Applying (5) to the transfer matrix of (3) gives the expression shown in (6).

$$[P_1 \quad P_2 \quad P_3]\begin{bmatrix}-(\lambda_2+\lambda_1) & \lambda_2 & \lambda_1\\ \mu_2 & -\mu_2 & 0\\ \mu_1 & 0 & -\mu_1\end{bmatrix}=[0 \quad 0 \quad 0] \tag{6}$$

The result of transposing (6) is shown in (7).

$$\begin{bmatrix}-(\lambda_2+\lambda_1) & \mu_2 & \mu_1\\ \lambda_2 & -\mu_2 & 0\\ \lambda_1 & 0 & -\mu_1\end{bmatrix}\begin{bmatrix}P_1\\P_2\\P_3\end{bmatrix}=\begin{bmatrix}0\\0\\0\end{bmatrix} \tag{7}$$

Add the complete probability condition and replace any equation of the matrix in the above equation with the complete probability condition; here, the first equation is replaced with the total probability condition. The first equation is replaced by the complete probability condition to obtain the expression shown in (8).

$$\begin{bmatrix}1 & 1 & 1\\ \lambda_2 & -\mu_2 & 0\\ \lambda_1 & 0 & -\mu_1\end{bmatrix}\begin{bmatrix}P_1\\P_2\\P_3\end{bmatrix}=\begin{bmatrix}1\\0\\0\end{bmatrix} \tag{8}$$

where P_1, P_2, P_3 are the probability of the turbine being in operation, derating and shutdown respectively, the result is shown in (9).

$$\begin{cases}P_1=\frac{\mu_1\mu_2}{\mu_1\lambda_2+\lambda_1\mu_2+\mu_1\mu_2}\\ P_2=\frac{\mu_1\lambda_2}{\mu_1\lambda_2+\lambda_1\mu_2+\mu_1\mu_2}\\ P_3=\frac{\lambda_1\mu_2}{\mu_1\lambda_2+\lambda_1\mu_2+\mu_1\mu_2}\end{cases} \tag{9}$$

The transfer rates of the wind turbine from the operating state to the shutdown state and the derating state are λ_1 and λ_2, and the duration of state 1 operation τ_{12} before state 1 enters state 2 is shown in (10):

$$\tau_{12}=-\frac{1}{\lambda_2}\ln\gamma_{12}=-MTTF\ln\gamma_{12} \tag{10}$$

The duration τ_{13} of state one operation before state one enters state three is shown in (11):

$$\tau_{13}=-\frac{1}{\lambda_1}\ln\gamma_{13}=-MTTF\ln\gamma_{13} \tag{11}$$

where MTTF is the mean operating time before failure, γ_{12} and γ_{13} are uniformly distributed random numbers within [0,1]. The transfer rates of wind turbines from the outage and derating states to the operating state are μ_1 and μ_2, and the derating and outage fault repair times τ_{21} and τ_{31} are shown in (12) and (13), respectively:

$$\tau_{21}=-\frac{1}{\mu_2}ln\,\gamma_{21}=-MTTR\;ln\,\gamma_{21} \tag{12}$$

$$\tau_{31} = -\frac{1}{\mu_1}\ln\gamma_{31} = -MTTR\ln\gamma_{31} \tag{13}$$

where MTTR is the mean time to repair, γ_{21} and γ_{31} are uniformly distributed random numbers within [0,1].

2.1.3. Fan outage model

Under the impact of wind speed, the fan output is nonlinearly proportional to wind speed, as considered in Figure 2's strength output attribute curve [15]. In Figure 2, v_{ci}, v_r, v_{co} replicate the cut-in wind speed, rated wind speed, and cut-out wind velocity of the turbine, whereas p_r represents the turbine's rated power. The wind turbine output strength mannequin curve may additionally be written as a segmental feature of (14).

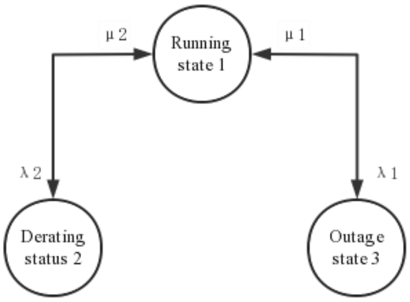

Figure 1. Wind turbine three-state model

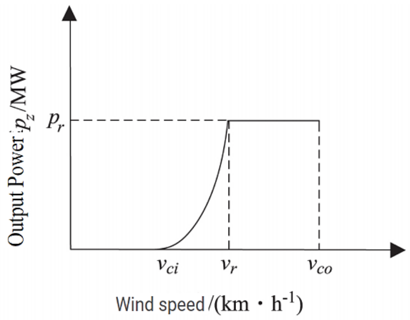

Figure 2. Typical output power curve for wind turbines

$$p_z = \begin{cases} 0 \quad (0 \le v_t \le v_{ci}) \\ (\alpha + \beta v_t + \gamma v_t^2)p_r \quad (v_{ci} \le v_t \le v_r) \\ p_r \quad (v_r \le v_t \le v_{co}) \\ 0 \quad (v_t \ge v_{co}) \end{cases} \tag{14}$$

where v_t is the predicted wind speed, α, β, γ are the coefficient of the power characteristic curve for wind turbines, and the solution formula is shown in (15).

$$\begin{cases} \alpha = \frac{1}{(v_{ci}-v_r)^2}\left[v_{ci}^2 + v_{ci}v_r - 4v_{ci}v_r\left[\frac{v_{ci}+v_r}{2v_r}\right]^3\right] \\ \beta = \frac{1}{(v_{ci}-v_r)^2}\left[4(v_{ci}+v_r)\left[\frac{v_{ci}+v_r}{2v_r}\right]^3 - (3v_{ci}+v_r)\right] \\ \gamma = \frac{1}{(v_{ci}-v_r)^2}\left[2 - 4\left[\frac{v_{ci}+v_r}{2v_r}\right]^3\right] \end{cases} \tag{15}$$

2.2. Photovoltaic power generation output model

2.2.1. Photovoltaic generator outage model

The PV power generation system mainly consists of transmission lines, transformers, inverters, PV arrays and other components, and the failure of any component will have a particular impact on the PV output, so the PV generator outage model adopts the conventional two-state model [16], and its two-state space model diagram is shown in Figure 3. In Figure 3, λ_3 is the transfer rate of the PV generator from the operating state to the decommissioning state, and μ_3 is the repair rate. Markov's method is used to solve the probability, P_4 and P_5 are the probability that the PV generator is in operation and out of operation respectively, and the result is shown in (16).

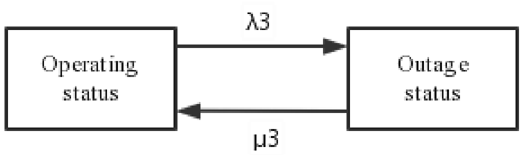

Figure 3. Photovoltaic generator set dual state model

$$\begin{cases} P_4 = \frac{\mu_3}{\lambda_3+\mu_3} \\ P_5 = \frac{\lambda_3}{\lambda_3+\mu_3} \end{cases} \tag{16}$$

The duration of the operating condition τ_3 and the repair time of the outage τ_4 are shown in (17) and (18), respectively:

$$\tau_3 = -\frac{1}{\lambda_3}\ln\gamma_3 = -MTTF\ln\gamma_3 \tag{17}$$

$$\tau_4 = -\frac{1}{\mu_3}\ln\gamma_4 = -MTTR\ln\gamma_4 \tag{18}$$

where MTTF is the mean duration of operation before failure, MTTR is the mean repair time, and γ_3 and γ_4 are uniformly distributed random numbers within [0,1].

2.2.2. Photovoltaic generator set power output model

Similar to wind power system, the power output of PV system is influenced by external factors and has certain fluctuation and randomness. After sunset and before sunrise, the PV output is 0. After sunrise, the PV output gradually increases with the increasing irradiance of sunlight and reaches the maximum value at a certain time, and then decreases with the decreasing intensity of light during the period from that time to sunset. In this paper, the power output characteristic curve is shown in Figure 4, using the method of Wenyi *et al.* [17].

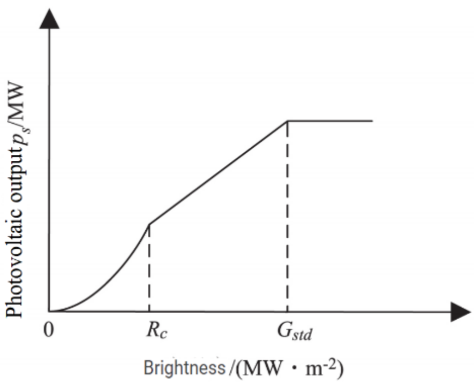

Figure 4. Photovoltaic generator set power output characteristic curve

In Figure 4, G_{std}, R_c and p_s represent the rated light intensity, specific light intensity and PV output during the transition from nonlinear to linear PV output, respectively. The PV output power model curve can be expressed as a segmented function as in (19):

$$P_s = \begin{cases} P_{sn}\left(G_{bt}^2/(G_{std}R_c)\right) & (0 \leq G_{bt} \leq R_c) \\ P_{sn}(G_{bt}/G_{std}) & (R_c \leq G_{bt} \leq G_{std}) \\ P_{sn} & (G_{std} \leq G_{bt}) \end{cases} \tag{19}$$

where p_{sn} is the photovoltaic rated power, G_{bt} is the real-time light intensity sequence, where G_{bt} is generated by Homer software.

3. RESULTS AND DISCUSSION

3.1. Principles of reliability evaluation for independent power generation systems

The examination of the dependability of electricity manufacturing structures is categorized into two categories: impartial structures and linked systems. It is assumed that the on-hand producing capability of any electricity supply in the stand-alone gadget can also be linked to any load factor. The line is completely reliable as if all generators and all loads are connected to the same busbar. The model is shown in Figure 5 [18].

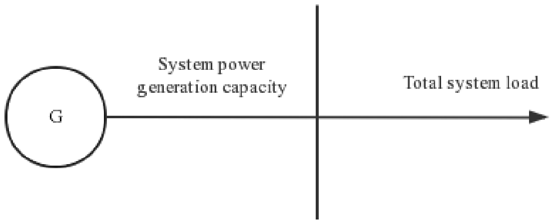

Figure 5. Model diagram of independent power generation system

3.2. Evaluation criteria, algorithms and indicators

For machines with unbiased power technology for scenery complementarity, the machine is unreliable due to a lack of power when the equipment capacity is much less than the load. Moreover, when the machine potential is higher than the load, the machine is in a reliable state. Figure 6 shows the time-series superposition of the independent power producer (IPP) system capacity state concerning the load, where T(R1) and T(R2) denote the time interval when the system is in an unreliable state, respectively [12].

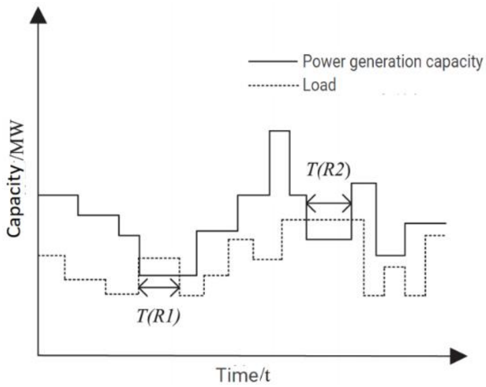

Figure 6. Independent power generation system capacity status and load time series overlay

Currently, the reliability assessment methods include network, state space, state enumeration, and Monte Carlo simulation methods. However, in the reliability assessment of the IPP system with scenic complementarity, the assessment process has more influencing factors and larger computation than the traditional power system reliability assessment [18]. In the reliability assessment of the stand-alone power generation system with wind and solar complementarity, the common reliability assessment indexes are loss of load probability (LOLP), power shortage expectation expected energy not serviced (EENS), power shortage expectation loss of load expectation (LOLE), and expectation) [16]. Since LOLP is closely related to the reliability of the power generation and transmission system, it can reflect the supply and demand situation of the power market more realistically and directly. It can also quantify the risk caused by the lack of system capacity more intuitively, so it is chosen as the reliability evaluation index in this paper. Its calculation formula is shown in (20):

$$LOLP = \frac{X}{N} \tag{20}$$

where X is the number of times the system load (maximum load in a day) exceeds the effective generating capacity in the system during the simulation time, and N is the simulation time.

3.3. Evaluation flowchart

Figure 7 depicts the assessment flowchart for the wind-complementary impartial energy producing device reliability evaluation process: First, the uncooked statistics are loaded, then the wind pace of 8,760 h for one year is forecasted primarily based on the uncooked statistics the use of the ARMA algorithm, and the three-state reliability mannequin of the wind turbine is built taking shutdown, operation, and derating into account. The wind turbine output feature calculates an annual wind strength manufacturing of 8,760 h primarily based on the mannequin and previous records. The model generates the simulated load of 8,760 h a year, and the LOLP value is calculated. The impact of the wind turbine/photovoltaic generator set and its state randomness on the reliability, the impact of the wind/photovoltaic and scenic complementary generator set on the reliability, and the impact of the penetration rate on the reliability are also analyzed.

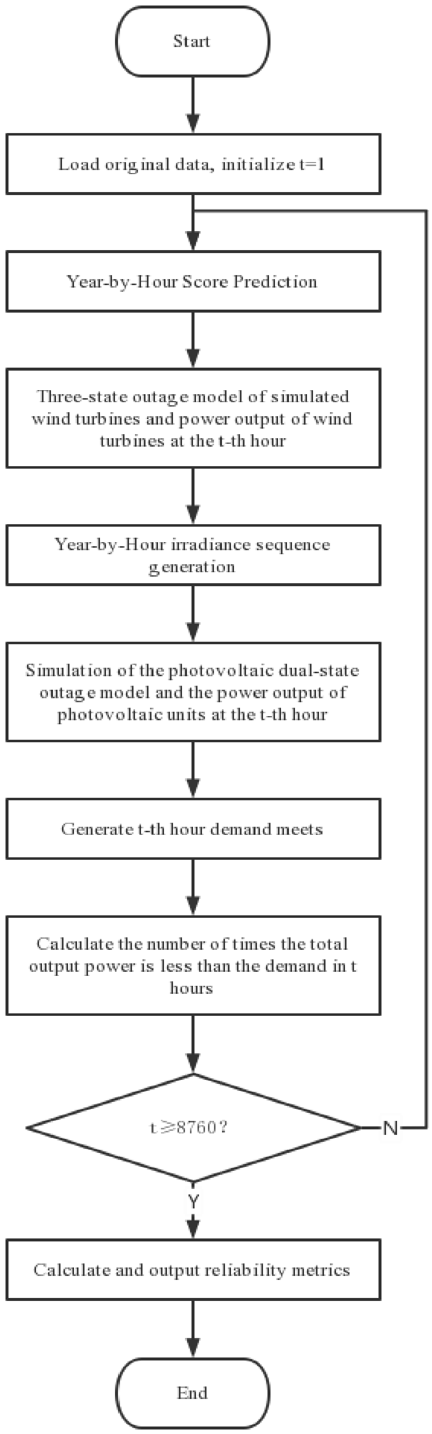

Figure 7. Reliability assessment flow chart

In this study, RBTS looks at machines based on a sequential Monte Carlo approach [19] to check the reliability of independent power generators with wind and PV complementarity. The single-line diagram of the test system is shown in Figure 8, where there are 11 turbines (total build-up potential of 240 MW), 6 buses, and 9 lines. 11 turbines with capacities of 5, 5, 10, 20, 20, 20, 20, 20, 20, 20, 20, 40, 40, 40 (in MW) and 11 generating units with mean repair time MTTR of 2, 2, 4, 2. 4, 2. 4, 2. 4, 2. 4, 2. 4, 5, 3, 6, 6 (in h) and mean of operating time MTTF is 198, 198, 196, 157. 6, 157. 6, 157. 6, 157. 6, 157. 6, 195, 147, 194, 194 (in h), and the forced outage cost FOR is calculated using (21) for a high load of 185 MW and a simulation time of 8,760 h for this system.

$$FOR = \frac{\text{MTTR}}{MTTR+MTTF} \tag{21}$$

The real-time sequence diagram of the 8,760 h load model is shown in Figure 9. For wind farm modelling: In this example, the wind speed prediction model is established by the ARMA algorithm with the historical wind speed data of a regional wind farm; the wind turbine cut-in wind speed is 9 km/h, and the rated wind speed is 43.2 km/h, the cut-out wind speed is 79.99 km/h, the rated power is 2.5 MW, the three-state transfer rate of the wind turbine is obtained from the historical data, λ_1, λ_2, μ_1, μ_2 were taken as 7.96 times/year, 5.84 times/year, 58.4 times/year and 48.3 times/year, respectively, and the derating state output power of the wind turbine was 0.8 times of the normal state. Figure 10 depicts the simulation of the 8,760 h wind speed predicted by the ARMA algorithm. For the PV generator set: In this example, the PV real-time sequence of the PV generator set is generated by Homer software, the p_{sn} of the PV generator set is taken as 1 MW, G_{std} is taken as 1MW/m^2, R_c is taken as 0.15 MW/m2, and the two-state transfer rate of PV generator set is obtained from the historical data, λ_3 and μ_3 are taken as 10.84 times/year and 48.3 times/year, respectively [20]–[26]. In the PV generator set output modelling, Homer software generated an 8,760 h light irradiance real-time sequence diagram, as shown in Figure 11.

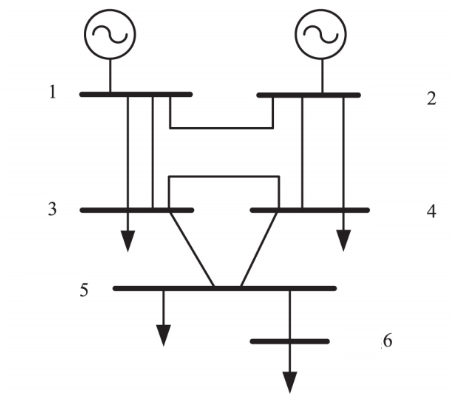

Figure 8. Single line diagram of the RBTS

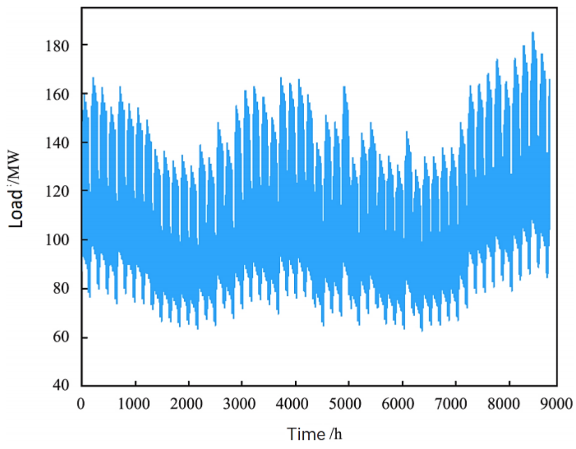

Figure 9. Model diagram of independent power generation system

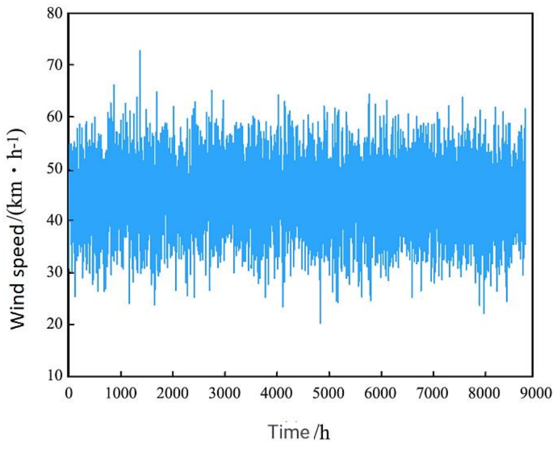

Figure 10. Model diagram of independent power generation system

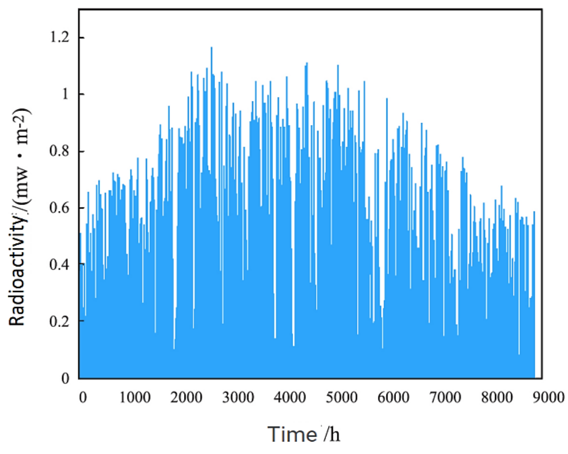

Figure 11. Model diagram of independent power generation system

4. CONCLUSION

In this paper, a sequential Monte Carlo method is used to evaluate the reliability of the wind/light complementary stand-alone power generation system, and the effects of the three-state shutdown model for wind turbines and the two-state shutdown model for PV generating units are considered on the wind farm and PV output. With consistent wind and solar resources, increasing the total installed capacity of new energy generation and the number of turbines can increase the system's reliability. Moreover, for wind power and wind/light complementary power systems, increasing the installed capacity of wind/light complementary power systems has no substantial effect on dependability until the existing capacity exceeds a specific threshold. In the case of wind turbines, for instance, increasing the penetration rate of wind/PV generators decreases the system's reliability, but the effect is subtle; in the case of wind turbines, increasing the penetration rate of wind/PV generators has little effect on the system's reliability; in the case of PV generators, increasing the penetration rate decreases the reliability.

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REFERENCES

[1] G. Cai, C. Chen, and L. Kong, "Modeling and control of wind power/photovoltaic/hydrogen production/supercapacitor grid-connected system," *Power System Technology*, vol. 40, no. 10, pp. 2982–2990, 2016.

[2] Y. Niu and A. Korneev, "Application study of intelligent agricultural photovoltaic power generation tracking system," in *2021 IEEE Bombay Section Signature Conference (IBSSC)*, Nov. 2021, pp. 1–4. doi: 10.1109/IBSSC53889.2021.9673430.

[3] Y. Niu, "Coordinated optimization of parameters of PSS and UPFC-PODCs to improve small-signal stability of a power system with renewable energy generation," in *2021 11th International Conference on Power, Energy and Electrical Engineering (CPEEE)*, Feb. 2021, pp. 249–254. doi: 10.1109/CPEEE51686.2021.9383370.

[4] Y. Feixiang, J. Yanbo, and H. Min, "Progress and prospect of reliability assessment of power system with wind storage system," *Smart Power*, vol. 47, no. 2, pp. 1–8, 2019.

[5] Y. Feixiang, H. Min, and J. Yanbo, "Research progress on reliability assessment of photovoltaic power generation and its power system [J]," *Journal of Yunnan Minzu University (Natural Science Edition)*, vol. 28, no. 5, pp. 523–530, 2019.

[6] Z. Jichao, Y. Yue, and F. Zhixin, "Reliability evaluation of wind-solar hybrid power generation system based on Copula theory," *Electric Power Automation Equipment*, vol. 33, no. 1, pp. 124–129, 2013.

[7] W. Kai, L. Wenyi, and L. Long, "Reliability and economic evaluation of wind/solar hybrid power generation system," *New Technology of Electrical Engineering*, vol. 34, no. 6, pp. 52–56, 2015.

[8] R. Karki, P. Hu, and R. Billinton, "Reliability evaluation considering wind and hydro power coordination," *IEEE Transactions on Power Systems*, vol. 25, no. 2, pp. 685–693, May 2010, doi: 10.1109/TPWRS.2009.2032758.

[9] C. Kongnam, S. Nuchprayoon, S. Premrudeepreechacharn, and S. Uatrongjit, "Decision analysis on generation capacity of a wind park," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 8, pp. 2126–2133, Oct. 2009, doi: 10.1016/j.rser.2009.01.023.

[10] C. Lin and H. Jian, *Reliability principle and application of power system*, 2 editions. Beijing: Tsinghua University Press, 2015.

[11] M. Yang, L. Huiyu, and Y. Cui, "Ultra-short-term multi-step forecasting of wind power based on atomic sparse decomposition and chaos theory," *Journal of Kunming University of Science and Technology*, vol. 44, no. 4, pp. 64–71, 2019.

[12] M. Yang and Z. Liang, "Short-term power prediction of photovoltaic power generation based on FA-PCA-LSTM," *Journal of Kunming University of Science and Technology*, vol. 44, no. 1, pp. 61–68, 2019.

[13] W. Min, Z. Xuanjun, and Y. Yue, "Reliability analysis of power generation system with photovoltaic power station," *Chinese Journal of Electrical Engineering*, vol. 33, no. 34, pp. 42–49, 2013.

[14] J. Park, W. Liang, J. Choi, A. A. El-Keib, M. Shahidehpour, and R. Billinton, "A probabilistic reliability evaluation of a power system including Solar/Photovoltaic cell generator," in *2009 IEEE Power & Energy Society General Meeting*, Jul. 2009, pp. 1–6. doi: 10.1109/PES.2009.5275722.

[15] Z. Shixiang and D. Qian, "Reliability analysis of wind-solar hybrid power generation system," *China Electric Power*, vol. 48, no. 6, pp. 8–13, 2015.

[16] Y. Su, H. Junhui, and G. Zhijian, "Research on reliability evaluation method of power generation system including photovoltaic power station," *Power Demand Side Management*, no. 4, pp. 23–28, 2017.

[17] L. Wenyi, W. Yinsha, and G. Xin, "Reliability assessment of wind power generation system based on well-being model," *East China Electric Power*, vol. 39, no. 7, pp. 1062–1065, 2011.

[18] W. Li, *Power system risk assessment model, method and application*. Wiley-IEEE Press, 2006.

[19] J. Cheng, L. Wenxia, Z. Jianhua, Y. Yue, Y. Jiaxi, and L. Dexian, "Risk assessment of power generation and transmission system including wind power access," *Chinese Journal of Electrotechnical Technology*, vol. 29, no. 2, pp. 260–270, 2014.

[20] Y. Niu, S. I. Kadhem, I. A. M. Al Sayed, Z. A. Jaaz, H. M. Gheni, and I. Al Barazanchi, "Energy-saving analysis of wireless body area network based on structural analysis," in *2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, Jun. 2022, pp. 1–6. doi: 10.1109/HORA55278.2022.9799972.

[21] H. S. Mehdy, N. J. Qasim, H. H. Abbas, I. Al_Barazanchi, and H. M. Gheni, "Efficient time-series forecasting of nuclear reactions using swarm intelligence algorithms," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 5, pp. 5093–5103, Oct. 2022, doi: 10.11591/ijece.v12i5.pp5093-5103.

[22] S. A. Shawkat and I. Al-Barazanchi, "A proposed model for text and image encryption using different techniques," *TELKOMNIKA*

(Telecommunication Computing Electronics and Control), vol. 20, no. 4, pp. 858–866, Aug. 2022, doi: 10.12928/telkomnika.v20i4.23367.
[23] Z. A. Jaaz, M. E. Rusli, N. A. Rahmat, I. Y. Khudhair, I. Al Barazanchi, and H. S. Mehdy, "A review on energy-efficient smart home load forecasting techniques," in *2021 8th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, Oct. 2021, pp. 233–240. doi: 10.23919/EECSI53397.2021.9624274.
[24] H. R. Abdulshaheed, Z. T. Yaseen, A. M. Salman, and I. Al_Barazanchi, "A survey on the use of WiMAX and Wi-Fi on vehicular ad-hoc networks (VANETs)," *IOP Conference Series: Materials Science and Engineering*, vol. 870, no. 1, Jun. 2020, doi: 10.1088/1757-899X/870/1/012122.
[25] I. Al-Barazanchi *et al.*, "Remote monitoring of COVID-19 patients using multisensor body area network innovative system," *Computational Intelligence and Neuroscience*, vol. 2022, pp. 1–14, Sep. 2022, doi: 10.1155/2022/9879259.
[26] S. A. Shawkat, B. A. Tuama, and I. Al_Barazanchi, "Proposed system for data security in distributed computing in using triple data encryption standard and Rivest Shamir Adlemen," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 6, pp. 6496–6505, Dec. 2022, doi: 10.11591/ijece.v12i6.pp6496-6505.

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