Power Supply Reliability Analysis on Floating Photovoltaic Systems through Exceedance Probability Approach

Ching-Feng CHEN†

(Received October 25, 2021)

With the growing impact caused by the greenhouse gasses (GHG) emissions from traditional thermal power generation, solar energy has drawn much attention from governments in recent years. Constrained by the land factor, the Taiwan Energy Bureau released the “Photovoltaic Two-Year Promotion Plan” on September 8, 2016 to promote the Floating Photovoltaic (FPV) industry. After that, the Agongdian Reservoir FPV became the first successful commercial project. In this paper, the authors proposed a synthesis approach based on the exceedance probability approach to conduct the FPV reliability analysis. The case analysis results show that this paper’s proposal is feasible. The plan’s implementation will obtain the effect of CO₂ emission reduction of approximately 1,920 kt (kilo tons) in 20 years. The presented methodology may help evaluate the power supply reliability, reduce failures of FPV systems that have been installed or will install, and assist in extending the FPV system to areas with insufficient power but water bodies.

Key Words
Greenhouse gasses (GHG), Floating photovoltaic (FPV), Exceedance Probability, Agongdian Reservoir, CO₂ emission

1. Introduction

1.1 Research Background

For improving the impact on GHG, many countries have accelerated the transition from traditional carbon-based energy to clean energy ¹. Solar energy is a relatively stable and safe energy solution among all the clean energy sources. Installing the solar modules requires a large amount of land. Land factors restrict the development of the solar energy industry in countries or regions with fewer territories.

Due to Taiwan’s limited land area, it has challenged the development of the solar energy industry. To encourage people to participate in renewable energy investment, the Bureau of Energy of Taiwan issued the “Photovoltaic Two-year Promotion Plan” on September 8, 2016 ². Taiwan initially developed floating photovoltaic (FPV) systems benefiting from this project. Agongdian Reservoir FPV is the first successful system among the installed projects and has contributed to Taiwan’s FPV development.

Because of various residential and other applications worldwide, research topics related to the efficiency, reliability, and safety of PV systems, either stand-alone or integrated into the grid, arise ³ ⁴. System reliability refers to the operational stability without incidents within a specified time, under previously established conditions. Establishing an acceptable maintenance plan for the reliability analysis of the power supply can also minimize the occurrence of power outages. Grid-connected systems are usually connected to the public electricity grid and feed power directly into the grid ⁵ ⁶. Compared to off-grid systems, on-grid ones have fewer components because the grid can provide plenty of stable power ⁷ ⁸. In addition, as they dispatched under load following (LF) strategy, it is more optimal than off-grid systems with a net present value (NPV) and cost of energy (COE) for the technique ⁹. The system studied in this paper adopted the grid-connected method to integrate the electricity generated into the power grid and cooperated with the local power plant ⁹. When using grid-connected PV systems, if a system failure occurs, it will affect the operation of other interconnected systems, and the result will affect the power supply of users. Therefore, it
is necessary to conduct a thorough reliability analysis of the power system paralleled to the grid [10-12].

In previous research, Aihara et al. proposed a genetic algorithm and tabu search-based method to improve generation benefits and system reliability. They evaluated the impact and enhanced the power supply reliability by arranging the effective operating pattern and integrating the PV system into a pumped-storage hydropower plant [13]. Some researchers used PV syst software to simulate the total energy generated and put the simulation results into the field grid-connected [14]. Other researchers used stochastic dynamic programming to obtain operation decisions based on initial storage, streamflow, and PV output functions to improve a large-scale hydro-PV hybrid power plant [15].

A few studies adopted a dynamic programming technique to solve the optimization problem, system sizing, and control optimization. The authors combined a genetic algorithm and designed objective functions, such as investment cost and loss of power supply probability, as design variables. In addition, they developed a long-term stochastic optimization method that simultaneously considers the uncertainty of the streamflow and PV power output to obtain operational decisions [16].

Although the above technologies have good simulation and use effects for hybrid systems, they are mainly for off-grid applications. Even if the researchers simulate the grid impact by dedicated software, nor is it intended to be a reliability indicator of the power supply. Moreover, the failure of PV members from the ground shows that some manufacturers' reliability analysis of the PV module is insufficient. Due to the more severe use conditions of the later developed FPV than those of ground systems, it is more likely that the structure will fail before the end of its life cycle and affect the power supply stability [17]. Consequently, developing an elaborated approach to analyze and estimate the system's near-term and long-term power supply reliability and create a balance indicator for planning and assessing the grid's potential power supply and demand risks.

The exceedance probability refers to a likelihood that a specific value, or level of drought, will occur based on historical data. It has been widely used in climate change research as an assumed risk [18-19] and natural disaster risk assessment [20]. Compared to the above methods, the exceedance probability approach proposed in this paper has the advantages of flexibility and readily use. As a power supply dispatch index, the actual demand can set various thresholds based on long-term meteorological data for local power plants.

In the context of the above background, the essential directions for such a strategy could be as follows:

- Synthesize the Mann-Kendall and auto-correlogram tests to analyze an FPV system for specific applications to pre-examine the correlation between the previous and lagging meteorological data.
- Develop a practical approach to discover whether the system's electricity can meet the near-future electricity demand of users.

Although existing research has established the models to analyze PV systems' efficiency, reliability, and safety, it has not yet presented a more straightforward and model-free method of assessing the reliability of FPV power supplies. This paper proposes a synthesis methodology based on the exceedance probability approach to analyze Aongdagian's FPV system. The study results may extend the FPV development to small land, and water bodies are available, but electricity is still insufficient [5-20].

2. FPV system

2.1 PV system

PV systems can divide into land-based and water-based installations depending on the installation location. The land-based installation method depends on whether it installs on a building or a non-building site. According to this classification method, the scholars can classify photovoltaic systems into four types: ground-mounted, roof-mounted, building integrated photovoltaic (BIPV), and building attached photovoltaic (BAPV) (refer to Fig. 1). Contractors usually realize water-based PV systems using abandoned mines or ponds, reservoirs, and lakes [22].

2.2 FPV system

FPV refers to a PV system installed on a structure floating on a water body. It commonly consists of five units: a floating platform, a supporting structure, an anchoring system, underwater cables, and a PV system (see Fig. 2). It is usually installed on floating boats made of plastic and galvanized steel or entirely plastic units [23].

![Fig. 1 PV System Type](image-url)
3. Research Method and Design

The author designs the following research steps to apply the exceedance probability method to analyze the reliability of the FPV power supply and demand capacity. The measures include data collection, determining the time series trend, and illustrating the auto-correlogram. In addition, the author also calculated the annual and the monthly power generation, plotted the daily and the monthly power generation duration curves, and performed the reliability analysis of the power supply and demand capacity.

Among the above sequential steps, the author uses the second step to determine whether the collected data will continue increasing or decreasing over time. Steps 3 to 5 are adopted to illustrate the auto-correlogram, calculate the annual and the monthly power generation, and plot the daily and the monthly power generation duration curves. The last step is to analyze the power supply and demand reliability of the FPV system in the Agongdian reservoir.

4. Case Study

The contractor completed the installation of the Agongdian Reservoir Phase II FPV in March 2019, with a total installed capacity of 10MWp. The estimated annual power generation is 12.5 GWh (gigawatts-hour), providing annual electricity consumption for 3,100 households and reducing carbon dioxide (CO₂) emissions by 7,500 tons. It is Taiwan’s first large-scale commercial FPV. After being put into use, it has undergone various tests during the reservoir’s dry period, entire water period, and typhoon period. Therefore, this paper selects it as a case study. This case analysis may help understand the reliability of FPV power supply and demand.

4.1 Study Area

The Agongdian Reservoir (see Figs. 3 (a) and 3 (b)) locates at Gangshan, Yanchao, and Tianliao district at the eastern foot of Xiaogang Mountain in Kaohsiung city. Its primary function is flood control and farmland irrigation.
4.2 Main components of FPV system

4.2.1 Solar module

The electrical specifications in Table 1 indicate that the selected solar photovoltaic module is a monocrystalline solar module with a maximum power of 315Wp (efficiency: 19.36%). It is to comply with the PV TAIWAN Plus Technical Specifications promulgated by the Ministry of Economic Affairs of Taiwan on using high-efficiency solar modules when FPV operators apply for FIT (Feed-In Tariff). This regulation requires that from 2019, all solar modules adopted by FIT applicants must meet the technical specifications of CNS (National Standard of the Republic of China) 15114 and CNS 15115. In addition, the module's power output guarantee period is 25 years to ensure the long-term power supply of the photovoltaic system.

4.2.2 Inverter

To meet the FPV system performance requirements, contractors must select an inverter with built-in maximum power point tracking (MPPT) algorithmic technique. Moreover, it must pass the salt spray test (IEC 60068-2-52 severity 5) to test the reliability of the inverter in a salt mist environment. MPPT helps track the best linear relationship between voltage and current and generates the maximum power of the solar module. In addition, this technique also helps solar modules to improve their photoelectric effect sensitivity performance under the minimum irradiation conditions to produce the maximum photovoltaic current. As the performance of MPPT will affect the fill factor by approximately 4% when the temperature rises, the power generation of the solar system will vary due to changes in climatic conditions and regional characteristics.

4.3 Results and discussion

4.3.1 Data collection

Five thousand four hundred seventy-nine data on insolation, sunshine hours, radiation amount, and the specifications of main components were collected and compiled. The author also compared and contained the Installation setting ratios of the Agongdian Reservoir and the Yamakura Reservoir and the "Technical Specifications for High-Efficiency Solar Modules" issued by the Bureau of Standards, Metrology, and Inspection in 2019 for the system reliability analysis.

4.3.2 Time-series trend and auto-correlogram

The 180 monthly power generation data obtained through the Mann-Kendall trend test were transformed and fitted, and the results are shown in Fig. 4.

Fig. 5 illustrates the auto-correlogram for the 180-sample data. By shifting the data value and then calculating the correlation between the original and the lag values, we can draw an auto-correlogram graph to determine whether the data will converge. We can find

| Pmax | >315 W |
| Vmax | >34 V  |
| Imax | >9.5 A |
| Voc | >40 V  |
| Isc | >9.56 A |
| Efficiency (%) | >19.36% |
| VSYS | DC 1000 V |
| Max Series Current | >15 A |

Unit: KWh

Fig. 4 Monthly Time Series Trend Graph
from the figure that as the autocorrelation function between the original and the lag values in the time series slowly decreases. In addition, the autocorrelation gradually converges and approaches zero after 130 lags. It indicates a correlation between the two kinds of data. The results based on the Mann-Kendall test and the auto-correlogram test are consistent, demonstrating a correlation between the original and lagging data.

As $T_{\alpha/2} > 1.96$ ($T_{\alpha/2}=2$ under the condition of significance level $\alpha=5\%$; $T$ indicates the trend sign value), it means that the trend meets the null hypothesis. Therefore, we may determine that the time-series tested steadily increased.

**4.3.3 Annual and monthly power generation curves**

Figs. 6 and 7 show the histograms of annual and monthly power generation from 2004 to 2018, respectively. Figs. 6 and 7 illustrate the consistent annual power generation results vary with climate conditions. The average power generation in summer is prominently higher than in winter. It is the highest from May to July, while significantly lower than in summer from November to February.

**4.3.4 Power generation duration curves**

To understand the power generation will exceed or fall below the specific power consumption value in a period, we can obtain it by calculating and sorting all the daily power generation data through equations (1) and (2) from January 1, 2004, to December 31, 2018. The Weibull method (Equation (3)) can help sort and descend the monthly power generation data (see Table 2) in order. Then, the total number of samples $Nts$, the number of rankings $mr$, and the value of excess probability $Pex\%$ can be acquired.

Consequently, we can draw the monthly duration curve according to the calculation results.

$$\text{MJ/s} ÷ 3.6 = (1000 \text{ W/m}^2)$$

$$Y_{\text{die}} = \frac{G_{\text{die}} \times 1000 \text{ W/m}^2 ÷ 1000 \text{ W/kW} \times C_{\text{eff}} \times S_{\text{eff}} \times (1-D_a) \times (1-M_d)}{(1-D_a) \times (1-M_d) \text{(kW/m}^2)}$$

where $Y_{\text{die}}$ represents the daily incident energy, $G_{\text{die}}$ means effective daily electricity generation hours (4 hours in southern Taiwan). $C_{\text{eff}}$ denotes solar module photoelectric...
conversion efficiency. \( S_n \) is system efficiency. \( D_n \) represents the annual decay rate (1% based on annual average). \( M_m \) means the proportion of downtime for system shutdown and maintenance (5% based on sound management).

\[
P_m = \frac{m}{N_n + 1}
\]  

(3)

**Fig. 8** shows the difference in the daily power generation to illustrate the duration curve. In contrast, **Fig. 9** provides a variety of potential monthly power ratios, explains the potential power generation of the PV system under different climatic conditions, and illustrates the exceedance probability distribution curve based on the possible power generation data.

### Table 2 Statistics on the Exceedance Probability of Monthly Power Generation

| Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.1  | 29,523 | 25,627 | 34,995 | 39,575 | 48,973 | 53,278 | 48,383 | 36,530 | 34,605 | 37,056 | 22,045 | 20,381 |
| 0.2  | 24,333 | 23,460 | 29,925 | 33,575 | 42,441 | 38,598 | 44,052 | 33,409 | 32,213 | 32,765 | 19,603 | 19,990 |
| 0.3  | 21,108 | 21,182 | 29,065 | 33,265 | 41,087 | 38,224 | 40,946 | 33,073 | 31,313 | 29,336 | 18,391 | 18,719 |
| 0.4  | 16,924 | 20,153 | 28,682 | 30,236 | 37,913 | 37,129 | 38,960 | 32,255 | 28,379 | 27,176 | 17,136 | 18,319 |
| 0.5  | 16,184 | 19,527 | 27,239 | 28,313 | 35,751 | 30,201 | 36,431 | 30,413 | 25,588 | 24,359 | 16,490 | 17,664 |
| 0.6  | 15,603 | 18,498 | 23,911 | 25,670 | 33,430 | 29,766 | 35,794 | 25,214 | 23,869 | 23,932 | 16,377 | 13,445 |
| 0.7  | 14,644 | 17,520 | 21,504 | 23,834 | 30,120 | 26,710 | 32,350 | 21,729 | 21,823 | 23,321 | 15,358 | 12,609 |
| 0.8  | 12,100 | 14,588 | 18,271 | 22,717 | 26,898 | 25,878 | 31,691 | 16,128 | 20,215 | 20,539 | 14,682 | 10,198 |
| 0.9  | 10,734 | 13,700 | 16,867 | 18,823 | 14,784 | 18,050 | 28,428 | 14,059 | 19,992 | 18,864 | 11,728 | 8,056 |

---

**Unit: KWh**

**Fig. 7** Average Monthly Electricity Generation Amount from '04 to '18

**Table 2** Statistics on the Exceedance Probability of Monthly Power Generation

**Fig. 8** Daily Electricity Generation Duration Curve (\( E \geq E_p \))

**Fig. 9** Monthly Power Generation Duration Curve
As can be seen from those mentioned above, researchers can use the exceedance probability as a risk indicator. When the daily power generation is lower than the specific value, the local power plant must dispatch insufficient electricity to meet users’ demands. Therefore, this indicator can help power companies consider adopting curtailment measures or increasing the power generation to provide the power consumption required by the users. Both Figs. 8 and 9 will allow power companies to view more macroscopically how to dispatch power supply between FPV and self-owned power plants to meet the power needs of users. Indeed, as the daily climatic conditions change, a shorter-term duration curve will be more helpful to power scheduling.

4.3.5 Power supply reliability analysis

We can achieve electricity consumption by utilizing the total number of households in the Gangshan District. If the daily electricity consumption per household is 12 kWh, the total daily electricity consumption will be 421.74 MWh, and the installed capacity of solar modules, according to equation (4), will be 185 MWp.

\[ C_{\text{ins}} = D_{\text{wp}} + P_{\text{e}} + S_{\text{ml}} + (1-D_{\text{wp}}) + (1-M_{\text{wp}}) \] (4)

where \( C_{\text{ins}} \) represents solar module installation capacity, \( D_{\text{wp}} \) means daily power demand, \( P_{\text{e}} \) denotes that effective power generation hours per day is 4 hours, \( S_{\text{ml}} \) represents the efficiency of the FPV system, usually calculated as 75% \( M_{\text{wp}} \) means decay rate of solar modules: conservatively estimated at an attenuation rate of 20%. \( M_{\text{wp}} \) is System shutdown and maintenance time: depends on management and other climatic factors, such as typhoons and cloudy days calculated as 5%.

As shown in Fig. 9, \( E \) indicates the power source, and \( e \) denotes the electricity demand. To meet the user’s power consumption, \( E \) must be greater than or equal to \( e \). Therefore, the probability of occurrence is \( P(E > e) \) or \( 1-P(E < e) \). As a result, we can replace the demand with the probability distribution of a specific day to obtain a predetermined exceedance probability value. We can also use this value as a power supply and demand balance index to help local power companies transmit electricity.

4.4 Discussion

The results show that the system performance ratio is 75% using 185 MWp of solar modules spread over an area of 1.59 km² (about 5% of the reservoir catchment area). The total energy infused into the grid is 740 MWh daily. It accounts for approximately 2.11% of the peak power demand of Taiwan’s grid and satisfies the daytime electricity requirement of the Gangshang’s thirty-five thousand one hundred forty-five households.

As of 2010, Taiwan has built 96 reservoirs, including 18 significant ones, the smallest catchment area of 2.88 km², the largest catchment area of 763.4 km², totaling 3749.44 km², of which the Agongdian Reservoir has an area of 31.87 km², accounting for 0.85%. Suppose to build FPV stations for all these 18 pools with the same solar module installation ratio. The installed capacity will reach 2.18 GWp, and the daily power generation will achieve 7.26 GW (considering the different sunshine conditions of each reservoir), accounting for 20.74% of Taiwan’s current daily peak power consumption 35 GW, which is very potential. In addition, it will benefit from reducing about 226 kt of CO₂ emission for a 20-year service life, saving 8.6 kt of water annually, and purifying water quality by inhibiting the growth of algae after installing the FPV systems. Furthermore, after implementing the GHG Emission Reduction Management Act, Kaohsiung and Pingtung cities became the first two cities in Taiwan to enforce total GHG control. The CO₂ emission reduction effect will reach approximately 1,920 kt in 20 years. It can respond to the goals of the Kyoto Protocol and help stabilize the GHG content in the atmosphere at an appropriate level to cope with the impact of climate change.

Moreover, 47 countries have responded to domestic carbon trading platforms. In the future, green energy power generation systems with zero CO₂ emissions may benefit more from carbon rights trading. Although FPV has caused no water pollution incidents in recent years, it still needs to track water quality after installing the system.

4.5 Conclusions

In this paper, the author has proposed a synthesis method to perform the reliability analysis of an FPV system, which facilitates it to function more dependably. The study results have contributed to (1) pre-examine the correlation between the previous and lagging data, (2) see whether the series data has an upward trend and consistency, (3) inspect the reliability of the power supply to obtain the monthly power generation duration curve, and (4) provide local power companies a balance indicator to adopt power curtailment measures or increase the power generation of the system on the day is higher or lower than this indicator value.

The methods proposed in this paper may also assist in extending the FPV system to areas with insufficient power but water bodies. However, since the sample data in this study is only fifteen years, if there are longer time scale samples for analysis, it will help improve the effectiveness of the investigation. A crucial direction for future work might be studying the optimal setting ratio for installing the FPV
system on the water without affecting the water quality and achieving the optimal economic benefits.

References

1) Choi, Y.-J.; Oh, B.-C.; Acquah, M.A.; Kim, D.-M.; Kim, S.Y., *Sustainability*, 13, 5022 (2021)
2) Bureau of Energy, Ministry of Economic Affairs. Available online, https://www.moeaboe.gov.tw (accessed on March 31, 2021) (in Chinese)
3) Huffman, D. L.; Antelme, F. Availability analysis of a solar power system with graceful degradation. In: Proceedings of the Reliability and Maintainability Symposium, Fort Worth, TX 2009
4) De Graaff, D.; Lacerda, R.; Campeau, Z. Degradation mechanisms in Si module technologies observed in the field; their analysis and statistics. In: Presentation at PV Module Reliability Workshop, NREL, Denver, Golden, USA 2011
5) Fu, M.; Lin, L.; Kong, X.; Zhao, W.; Tang, L.; Li, J.; Ouyang, J., *PLoS One*, 8(1), e53580 (2013)
6) Crow, L. H., Evaluating the reliability of repairable systems, *IEEE Proceedings of the Annual Reliability and Maintainability Symposium* 2004, pp. 73-80
7) Crow, L. H., Methods for reducing the cost to maintain a fleet of repairable systems, *IEEE Proceedings of the Annual Reliability and Maintainability Symposium* 2003, pp. 392-399
8) Nesamalar, J. J. D.; Suruthi, S.; Raja S. C.; Tamilarasu, K., *Energy Conversion and Management*, 239, 114188 (2021)
9) Southern Water Resources Bureau of the Ministry of Water Resources, Ministry Economic Affairs, https://www.rasb.gov.tw (accessed on September 12, 2021) (in Chinese)
10) Kececioglu, D., *Reliability Growth*, Reliability Engineering Handbook, 4th ed., Vol. 2., Englewood Cliffs, New Jersey: Prentice-Hall, pp. 415-418 (1991)
11) IEC International Standard. Reliability growth—Statistical test and estimation methods, IEC 1164 International Electrotechnical Commission 1995
12) Ishii, T.; Takashima, T.; Otani, M., *Research and Applications*, 19, 170 (2011)
13) Sahu, A.; Yadav, N.; Sudhakar, K., *Renewable and Sustainable Energy Reviews*, 66, 815-824 (2016)
14) Aihara, R.; Yokoyama, A.; Noniyama, F. et al., *IEEJ Transactions on Power and Energy*, 132(1) (2012)
15) Ahmad, O. A.; Habeeb, W. H.; Mahmood, D. Y.; Jalal, K. A.; Sayed, H., *Renewable Energy*, 115, 238-251 (2018)
16) Yang, Z.; Liu, P.; Cheng, L. et al., *Journal of Cleaner Production*, 195, 562-572 (2018)
17) Mahmoudimehr, J.; Shabani M., Optimal design of hybrid photovoltaic-hydroelectric stand-alone energy system for north and south Iran. *Renewable Energy*, 141, 181-194 (2019)
18) Meydbray, Y.; Wilson, K.; Brambila, E.; Terao, A.; Daroczi, S. Solder joint degradation in high efficiency all back-contact solar cells, IEEE Photovoltaic Specialists Conference 2008
19) Piechota, T. C.; Chiew, F. H.; Dracup, J. A.; McMahon, T. A., *Journal of Hydrologic Engineering*, 6, 20-28 (2001)
20) Hayhoe, K. et al., Emissions Pathways, Climate Change, and Impacts on California, Proceedings of the National Academy of Sciences of the United States of America 2004, 101, pp. 12422-12427
21) Grossi, P. Catastrophe Modeling: A New Approach to Managing Risk, Springer Science & Business Media, Springer-Verlag, Berlin, p. 25 (2005)
22) World Economic Forum, Accelerating Sustainable Energy Innovation; WorldEconomic Forum, Cologny, Switzerland, 2018
23) Sahu, A.; Yadav, N.; Sudhakar, K., *Renewable and Sustainable Energy Reviews*, 66, 815-824 (2016)
24) Trapani, K.; Santafé, M., *Progress in Photovoltaics: Research and Applications*, 23, 524-532 (2014)
25) Gangshan Household Registration Office, https://gangshan-house.kcg.g (accessed on March 31, 2021) (in Chinese)
26) Motech Industries, Inc., https://www.motech.com.tw/modules-l.php (accessed on September 18, 2021) (in Chinese)
27) De Brito, M. A.; Sampaio, L. P.; Junior, L. G.; Canesin, C. A., Evaluation of MPPT techniques for photovoltaic applications, 2011 IEEE International Symposium on Industrial Electronics, pp. 1039-1044 (2011)
28) Azli, N. A.; Salam, Z.; Jusoh, A.; Facta, M.; Lim, B. C.; Hossain, S., Effect of fill factor on the MPPT performance of a grid-connected inverter under Malaysian conditions, Proceedings of the IEEE 2nd International Power and Energy Conference (PECon’08), pp. 460-462, IEEE, Johor Bahru, Malaysia, December 2008
29) International Electrotechnical Commission (IEC), Environmental testing- Part 2-52: Tests – Test Kb: Salt mist, cycle (sodium chloride solution) 2017
30) Central Weather Bureau, https://www.cwb.gov.tw (accessed on March 31, 2021) (in Chinese)
31) Japan Dam Foundation, The Yamakura Reservoir, https://www.damnet.or.jp (accessed on April 2, 2021) (in Japanese)
32) Mann, H. B., *Econometrica*, 13, 245-259 (1945)
33) Kendall, M. G., Rank Correlation Methods, Griffin,
34) Box, G. E. P.; Jenkins, G. M.; Reinsel, G. C., Time Series Analysis; Forecasting and Control, 3rd. Edition, Prentice-Hall, Englewood Cliff, New Jersey, 1994
35) Salas, J. D., Analysis and modeling of hydrologic time series. In Handbook of Hydrology, Maidment DR, McGraw-Hill: New York. 19.1-19.72 (1993)
36) Singh, G. K., Energy, 53, 1-13 (2013)
37) Bailey, R. L.; Dell, T. R., Sci., 19, 97-104 (1973)
38) Staehler, D. L.; Wronski, C. R., Applied physics letters, 31(4), 292-294 (1977)
39) Lin, C.; Hsieh, W.; Chen, C.; Hsu, C.; Ku, T., IEEE Transactions on Power Systems, 27(2), 1090-1097 (2012)
40) Staehler, D. L.; Wronski, C. R., Applied physics letters, 31(4), 292-294 (1977)
41) Ang, A. H-S.; Tang, W. H., A Review of: “Probability Concepts in Engineering Planning and Design”, Volume II: Decision, Risk, and Reliability, John Wiley & Sons, New York, 1984
42) Taiwan Power Company, https://www.taiwanstat.com/realtime/power/ (accessed on January 14, 2022) (in Chinese)
43) Sultan, S.; Kim, J. H.; Kim, S. H.; Kwon, Y.; Lee, J. S., Journal of Energy Chemistry, 60, 410-416 (2021)
44) Redón, S. M.; Soler J. B. T; Romero F. J. S. et al., Energy, 67, 246-255 (2014)
45) Shivam, K.; Tzou, J.; Wu, S., Energy Conversion and Management, 237 (2021)