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Life cycle improvement of serially connected batteries system by redundancy based on failure distribution analysis

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ABSTRACT

The utilization of redundant batteries is seen as an effective method to promote battery life cycle. On account of the diminishing marginal effect, it is necessary to reasonably configure redundant batteries quantity according to battery characteristics. Based on failure distribution analysis, an evaluated method for serially connected batteries system is proposed to improve lifetime by redundant batteries. The optimal redundancy quantity with maximum cycle numbers can be obtained against the various number of serially connected batteries and the different shape parameter of battery failure distribution by multivariate rational function with rounding. Besides, the scheduling control strategy for serially connected batteries is presented in light of battery health and cycle times. The proposed method is suitable for different batteries type, battery station as well as other devices with similar characteristics to batteries.

1. Introduction

The electric power generation based on renewable energy [1], such as wind energy [2] and solar energy [3], depends on natural conditions with fluctuation [4] and intermittence [5–7], whose regulation and control are more difficult than fossil energy. Large-scale access of renewable energy will bring significant impact on the safety and stability of power grid [8,9].

For promoting competitive advantage of renewable energy over fossil energy, large-scaled battery energy storage [10] as a critical technology can be used to stabilize their output, which will allow electricity to be produced and stored at a time of relatively low economic value and then be dispatched later. Large-scale energy storage station [11] with the ability to rapidly store and release electrical energy, can support services of power quality management, frequency regulation, and load shifting, so that power supply can be uninterrupted and smoother, and it can realize the maximization of reliability, flexibility and efficiency of system [12–14]. The reduction of battery cost and the gradual implementation of energy storage policy worldwide promote battery energy storage station to increasingly become a new type of functional complex and independent entity in modern power system.

With the wide application of batteries, the design optimization and lifetime improvement of batteries have become challenges and research issues in various fields.

Firstly, battery design can directly affect its lifetime. Battery design involves several levels [15]: material level [16], electrode level [17], cell level [18], and system level [19]. Each level has influence on battery life in applications. Various complex factors and their mutual influence need to be considered in battery design, such as the heat dissipation [20] and the solid electrolyte interface [21] formation.

Secondly, battery production process [22] can have a significant impact on its life cycle. In order to produce high-performance batteries with long-life, it is necessary to develop production technology and optimize the detailed production process reasonably.

Thirdly, battery operation conditions can also affect battery life, including temperature [23], state of charge (SOC) [24], charge/discharge current [25], depth of discharge (DOD) [26], etc. When batteries work on improper operation conditions, there are side effects in the battery, which can reduce the battery life.

Recently, the battery system design has attracted researchers. The system level design should handle mechanical, electrical, and thermal related issues. The design of batteries configuration in the battery system will affect the system performance.

The utilization of redundant batteries and the appropriate design of equalization circuit is regarded as an effective way to enhance the reliability of battery system and extend battery life cycle [27,28]. However, system structure becomes more complicated due to various redundancy configuration and strategy, so that the operation environment of each battery is different, which results in inconsistent

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Nomenclature

Abbreviations

DOD	depth of discharge
SOC	state of charge
SOH	state of health

Symbols

E	expectation of cycle numbers
$F(t)$	failure cumulative distribution function
$f(t)$	probability density function
L	mean lifetime per battery
m_0	the number of working batteries
m_1	the number of redundant batteries
m_2	the number of optimal redundant batteries
R	the reliability distribution
t	cycle numbers
U	voltage
β	shape parameter
λ	scale parameter

temperature distribution [29,30] during operation and affects the performance of battery system. In the field of redundancy configuration, the previous researches are normally based on presupposed configuration of redundant batteries, and rarely discusses its detailed impact on battery life expectancy. Due to the diminishing marginal effect [31,32], the unit lifetime decreases gradually with the growth of redundant batteries after reaching a certain scale, although the total lifetime still rises. Thereby, it is necessary to reasonably allocate redundant batteries in the light of battery characteristics.

For handling above problem, this paper proposed an evaluative method for serially connected batteries system to enhance lifetime by redundancy based on failure distribution analysis. The reliability of serially connected batteries decreases while the series quantity increases. Based on the properties analysis of failure probability distribution, the serially connected batteries lifetime can be raised by redundant batteries. Since the optimal redundancy number is related to serially connected batteries number and shape parameter of single battery failure distribution, the relationship among them can be fitted by multivariate rational function with rounding, thereby, the optimal redundancy number with maximum lifetime can be figured out. In addition, the scheduling control strategy for serially connected batteries is proposed based on battery health and cycle times. This method is able to apply to various batteries type, battery station even other electronic or mechanical equipment similar to serially connected batteries, such as photovoltaic cells.

2. Electrochemical energy storage

The conversion between different energy forms has always been an important research emphasis. Electrical energy [33] can be transformed and stored by mechanical reactions [34–37], chemical reactions [38–44], and electromagnetic field [45–47]. Among them, electrochemical energy storage device is the converter between chemical energy and electrical energy.

Fuel cells [48] can convert chemical energy into electrical energy directly. The fuels involved in electrochemical reaction are oxidizable substances, such as hydrogen, methane, hydrocarbons, etc., and the oxidant is oxygen or air. When the electrochemical potential (Fermi level) of two materials is different, an electrochemical energy storage device can be composed of these two materials theoretically. Taking lithium-ion battery [49] as an example, the voltage is determined by the difference between the positive and negative electrochemical potentials.

Table 1
The chemical reaction equation of different battery technology.

Battery types	Chemical reaction equation Negative electrode	Positive electrode
Lithium-ion battery	$Li_xC_6 \rightleftharpoons xLi^+ + xe^- + C_6$	$Li_{1-x}CoO_2 + xLi^+ + xe^- \rightleftharpoons LiCoO_2$
Sodium sulfur battery	$2Na \rightleftharpoons 2Na^+ + 2e^-$	$xS + 2Na^+ + 2e^- \rightleftharpoons Na_2S_x$
Nickel cadmium battery	$Cd - 2e^- + 2OH^- \rightleftharpoons Cd(OH)_2$	$2NiOOH + 2H_2O + 2e^- \rightleftharpoons 2Ni(OH)_2 + 2OH^-$
Lead-acid battery	$Pb + SO_4{}^{2-} \rightleftharpoons PbSO_4 + 2e^-$	$PbO_2 + 4H^+ + 2e^- + SO_4{}^{2-} \rightleftharpoons PbSO_4 + 2H_2O$
Flow battery	$V^{2+} \rightleftharpoons V^{3+} + e^-$	$V^{5+} + e^- \rightleftharpoons V^{4+}$

The battery capacity is related to the amount of lithium stored in the material. The power density is mainly related to the maximum allowable transmission rate of lithium-ion between the positive and negative electrodes. In lithium-ion batteries, the carrier of energy is movable lithium-ions and electrons.

Battery is a mature energy storage device with high energy density. There are various types, including lithium-ion battery, sodium sulfur battery, nickel cadmium battery, lead-acid battery, flow battery, etc. Tables. 1 and 2 present the chemical reaction equation and characteristic of various battery, respectively.

3. Improvement of serially connected batteries lifetime by redundant batteries

3.1. The lifetime of single battery

Weibull distribution [50] is widely used in reliability engineering and failure analysis, especially for the distribution of wear cumulative failure of mechanical and electrical products. The failure of single battery is in conformity with Weibull distribution [51–54]. The probability density function of Weibull distribution can be expressed by Eq.. (1).

$$f(t) = \frac{\beta}{\lambda}\left(\frac{t}{\lambda}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\lambda}\right)^{\beta}\right] \tag{1}$$

Where, t is cycle numbers, λ is scale parameter, β is shape parameter. In long-term application, there is aging process in batteries, which means that the value of β should be more than 1.

The cumulative distribution function of Weibull distribution can be given by Eq.. (2).

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\lambda}\right)^{\beta}\right] \tag{2}$$

The expectation and variance of Weibull distribution can be calculated by Eqs. (3) and (4), respectively.

$$E(t) = \lambda \cdot \Gamma\left(1 + \frac{1}{\beta}\right) \tag{3}$$

$$D(t) = \lambda^2 \left\{ \Gamma\left(1 + \frac{2}{\beta}\right) - \left[\Gamma\left(1 + \frac{1}{\beta}\right)\right]^2 \right\} \tag{4}$$

Where, $\Gamma(x)$ is Gamma function.

Figs. 1 and 2 show respectively the probability density function of Weibull distribution and its variance against various β value when λ is invariant. The shape parameter β directly impacts the geometrical shape of the failure density distribution curve, which presents the failure mechanism of objects [55]. In Fig. 1, the greater β value leads to the higher curve peak. Fig. 2 presents that the greater β value contributes to lower variance. Thereby, the increase of β value signifies the concentration of the aging process.

Table 2
The characteristic of various battery technology.

Technology parameters Battery types	Energy density (Wh/kg)	Power density(W/kg)	Lifetime (cycles)	Cell voltage (V)	Energy efficiency (%)	Reference
Lithium-ion battery	90~330	100~20,000	1,000~20,000	3~4.5	90~95	[38,39]
Sodium sulfur battery	130~150	90~230	4,000~5,000	2.1	75~90	[40]
Nickel cadmium battery	50~85	150~1,000	1,000~3,000	1.2	50~75	[41]
Lead-acid battery	35~55	75~300	500~5,000	2.1	50~75	[42]
Flow battery	25~40	50~140	5,000~10,000	1.4	65~82	[43,44]

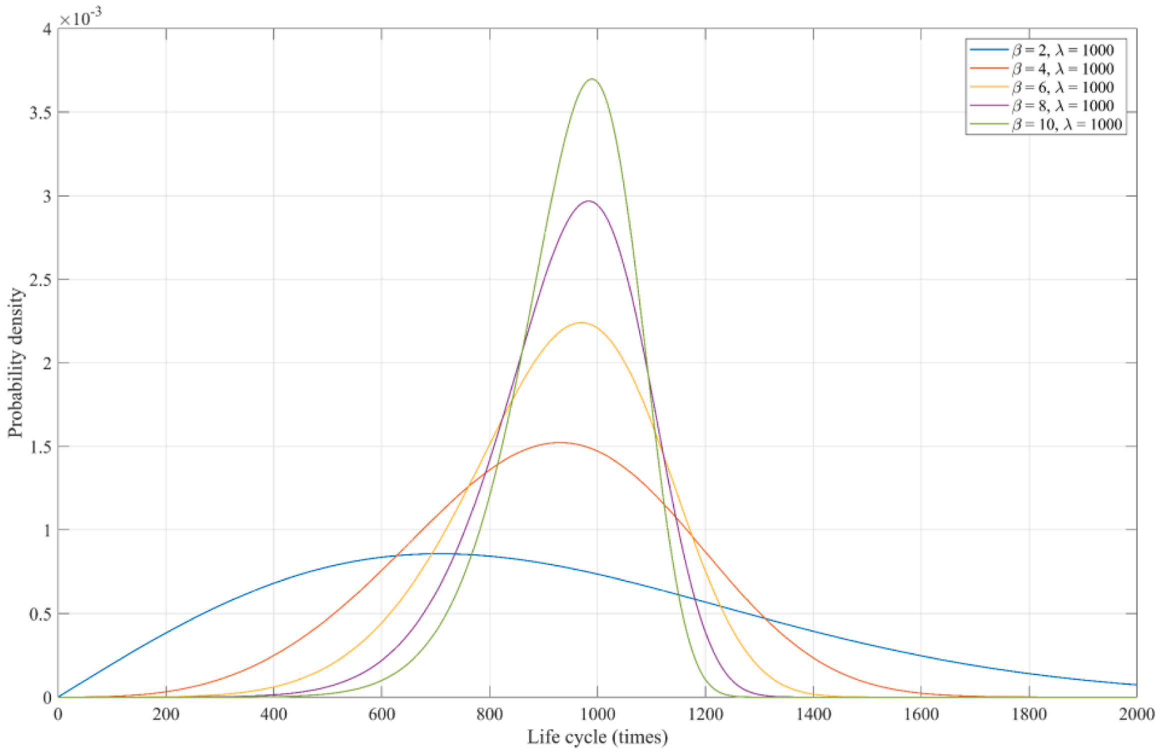

Fig. 1. The probability density function of Weibull distribution against various β value.

3.2. *The lifetime of serially connected batteries without redundancy*

For a serially connected batteries with m_0 working batteries, the reliability and failure distribution can be given by Eq.. (5) and Eq.. (6).

$$R_0(t,m_0) = [1-F(t)]^{m_0} = \exp\left[-\left(\frac{t}{\lambda}\right)^{\beta}\cdot m_0\right] \tag{5}$$

$$F_0(t,m_0) = 1-R(t,m_0) = 1-\exp\left[-\left(\frac{t}{\lambda}\right)^{\beta}\cdot m_0\right] = 1-\exp\left[-\left(\frac{t}{\lambda/\sqrt[\beta]{m_0}}\right)^{\beta}\right] \tag{6}$$

Where, m_0 is determined by ratios of working voltage U_n and single battery cell voltage U_0 by Eq.. (7).

$$m_0 = \frac{U_n}{U_0} \tag{7}$$

Therefore, the lifetime expectancy of a serially connected batteries with m_0 working batteries can be calculated by Eq.. (8). As the result presents, the lifetime decreases with the growth number of working batteries.

$$E_0(m_0) = \frac{\lambda}{\sqrt[\beta]{m_0}}\cdot\Gamma\left(1+\frac{1}{\beta}\right) = \frac{E}{\sqrt[\beta]{m_0}} \tag{8}$$

3.3. *The lifetime of serially connected batteries with redundancy*

A serially connected batteries, including m_0 working batteries and m_1 redundant batteries, can operate by turns (see Fig. 3). When the redundant batteries are not less than the failed batteries, the series circuit is able to work normally. While the failed batteries are more than the redundant batteries, the voltage of the series circuit cannot meet the rated working voltage.

For serially connected batteries with redundancy, the reliability conforms to the binomial distribution [56–58]. Considering that the failures of batteries are uncorrelated, the reliability and failure rate of each battery is characterized by the probabilities $(1-F)$ and F, respectively. The probability that i batteries are faulty and (m_0+m_1-i) batteries are not faulty can be expressed as the product of their probabilities, that is $F^i(1-F)^{m_0+m_1-i}$. The number of cases of selecting i faulty batteries out of (m_0+m_1) batteries can be expressed by Eq.. (9).

$$\binom{m_0+m_1}{i} = \frac{(m_0+m_1)!}{(m_0+m_1-i)!\cdot i!} \tag{9}$$

Since the batteries work alternately, the accumulated operating time of each battery is related to the number of working batteries and

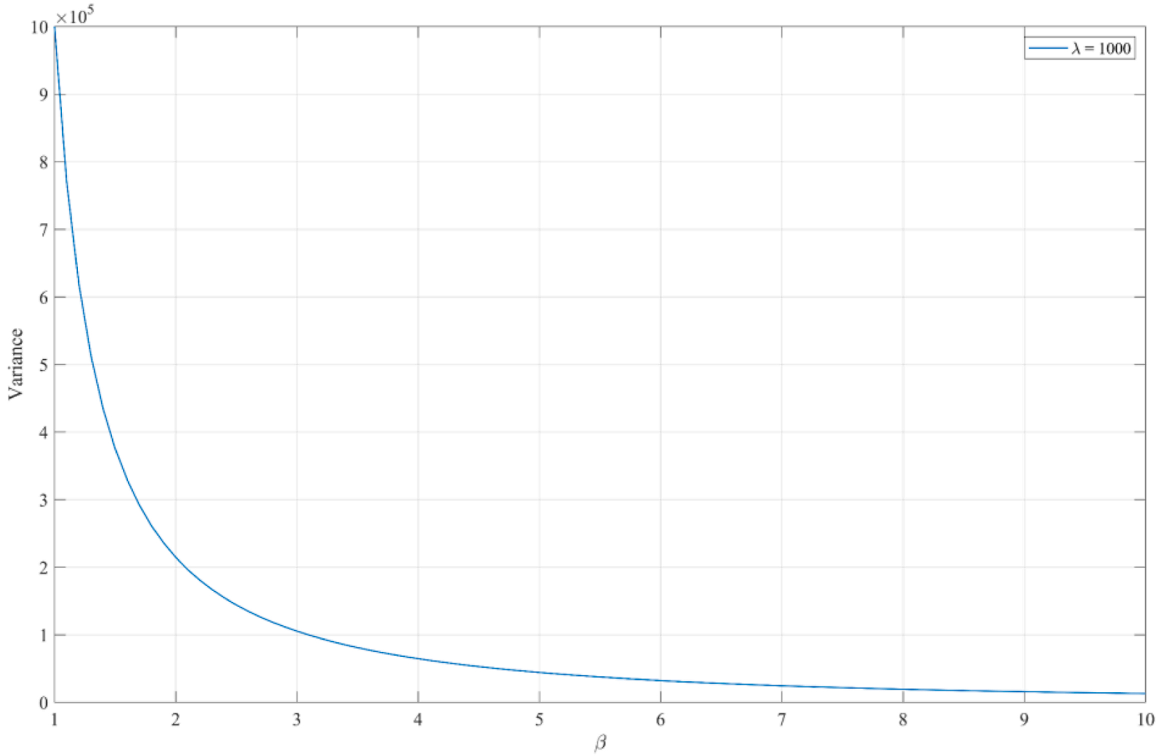

Fig. 2. The variance of Weibull distribution against various β value.

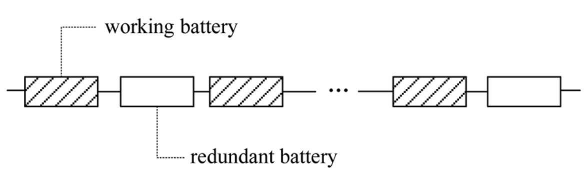

Fig. 3. Batteries operate in rotation.

redundant batteries. When the series circuit operates for a period of time t, each battery runs for $m_0 \cdot t/(m_0 + m_1)$. Thereby, the probability of existing i faulty batteries in the series circuit can be expressed as Eq.. (10).

$$P(i, m_0, m_1) = \binom{m_0 + m_1}{i}\left[F\left(\frac{m_0}{m_0 + m_1}\cdot t\right)\right]^i\left[1 - F\left(\frac{m_0}{m_0 + m_1}\cdot t\right)\right]^{m_0+m_1-i} \tag{10}$$

For the normal operating of serially connected batteries, the failed batteries are not more than redundant batteries, that is, $i \leq m_1$. Therefore, the reliability distribution and failure distribution can be expressed by Eq.. (11) and Eq.. (12), respectively.

$$R_1(t, m_0, m_1) = \sum_{i=0}^{m_1} P(i, m_0, m_1) = \sum_{i=0}^{m_1}\binom{m_0 + m_1}{i}\left[F\left(\frac{m_0}{m_0 + m_1}\cdot t\right)\right]^i\left[1 - F\left(\frac{m_0}{m_0 + m_1}\cdot t\right)\right]^{m_0+m_1-i} \tag{11}$$

$$F_1(t, m_0, m_1) = 1 - R_1(t, m_0, m_1) \tag{12}$$

Supposing that β is 15.1 and λ is 1660.2 [51], when m_0 is 40, the failure distribution of serially connected batteries with different number of m_1 is shown as Fig. 4. Fig. 4 presents that the failure rate under a certain of cycle time decreases with the increase of redundant batteries quantity.

With Eq.. (13) and Eq.. (14), the lifetime expectation of serially connected batteries with redundancy can be calculated.

$$F_1(t) = \int_0^t f_1(x)dx \tag{13}$$

$$E_1(m_0, m_1) = \int_0^{+\infty} t \cdot f_1(t)dt \tag{14}$$

Where, due to the different redundancy quantity, lifetime expectancy cannot be compared directly. Therefore, it needs to be modified depending on the value of m_0 and m_1 by Eq.. (15).

$$E_2(m_0, m_1) = E_1(m_0, m_1)\cdot\frac{m_0}{m_0 + m_1} \tag{15}$$

The unit lifetime L per battery (including working batteries and redundant batteries) against different working batteries quantity can be calculated by Eq.. (16). When β is 15.1, the mean lifetime curves under different m_0 are displayed in Fig. 5.

$$L = \frac{E_2}{m_0 + m_1} \tag{16}$$

In Fig. 5, hollow circles mark the maximum points of lifetime curves, and the numbers next to the mark represent the abscissa values of these maximum points, defined as the number of optimal redundant batteries m_2. When the redundancies number is more than m_2, there is a diminishing marginal effect, which means the reduction of a unit lifetime. Therefore, these points signify the optimum quantity of redundant batteries whose average lifetimes are more than other numbers of redundancies.

In Fig. 6, the black points show the relationship between the working batteries quantity m_0 and optimal redundant batteries quantity m_2 when β is 15.1. And the red line means trend line. The incremental variation of optimal redundant batteries quantity is a stair-step shape with the growth of working batteries quantity. The fitting function can be expressed by Eq. (17).

$$m_2 = \lfloor 0.069m_0 - 0.0976 \rfloor \tag{17}$$

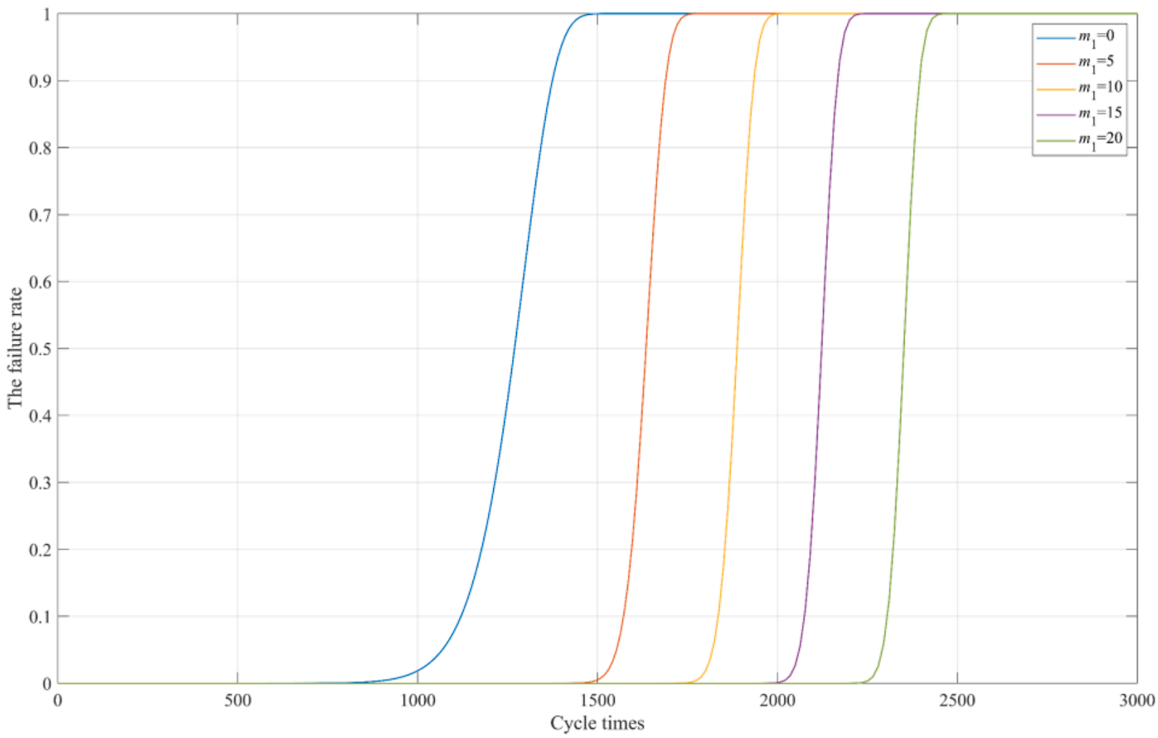

Fig. 4. The failure distribution of serially connected batteries with different quantities of redundant batteries.

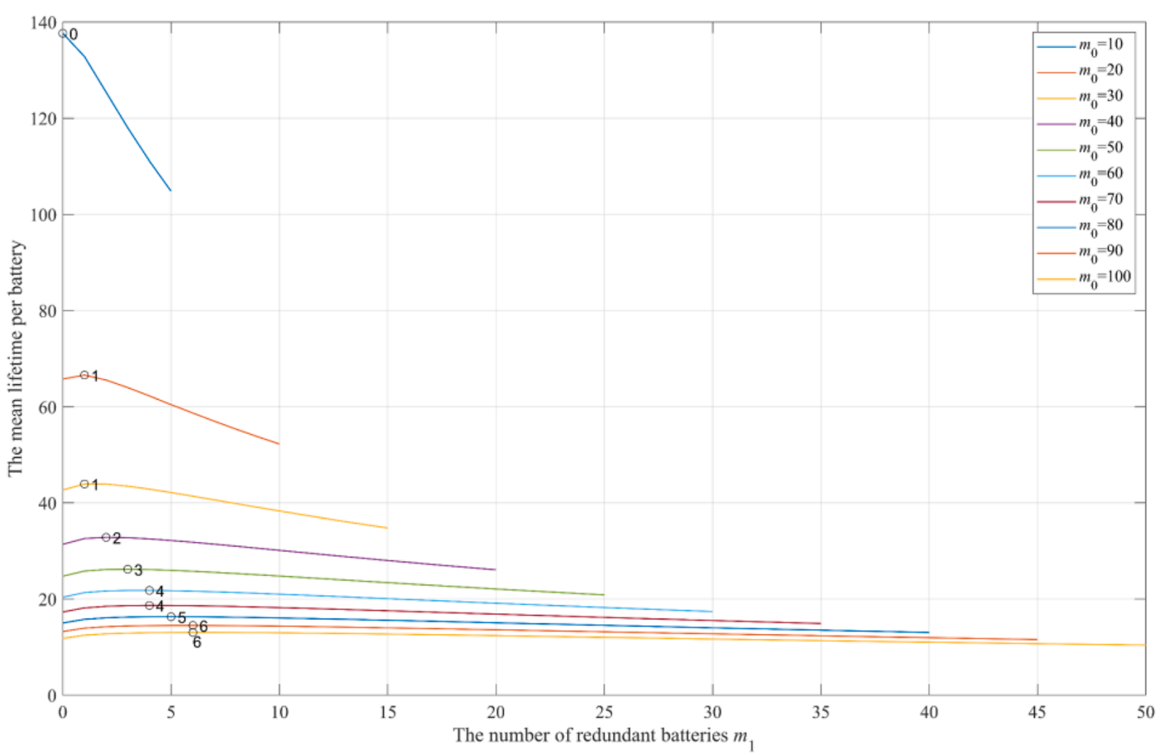

Fig. 5. The mean lifetime against the number of redundant batteries under different working batteries quantity.

Where, $\lfloor x \rfloor$ means that x is rounded down.

In the condition of different β values, there are various relationships between m_0 and m_2. When β is set from 2 to 20, the relationship among β, m_0, and m_2 is displayed in Fig. 7. When m_0 is a certain value, the value of m_2 increases with the reduction of β. When the scale of serially connected batteries system and the characteristic of single battery is known, the optimal number of redundancies can be figured out.

Fig. 7 suggests that the relationship among β, m_0, and m_2 can be expressed by multivariate rational function with rounding. Taking β and m_0 as the independent variable and m_2 as the dependent variable, the fitting function can be expressed by Eq.. (18).

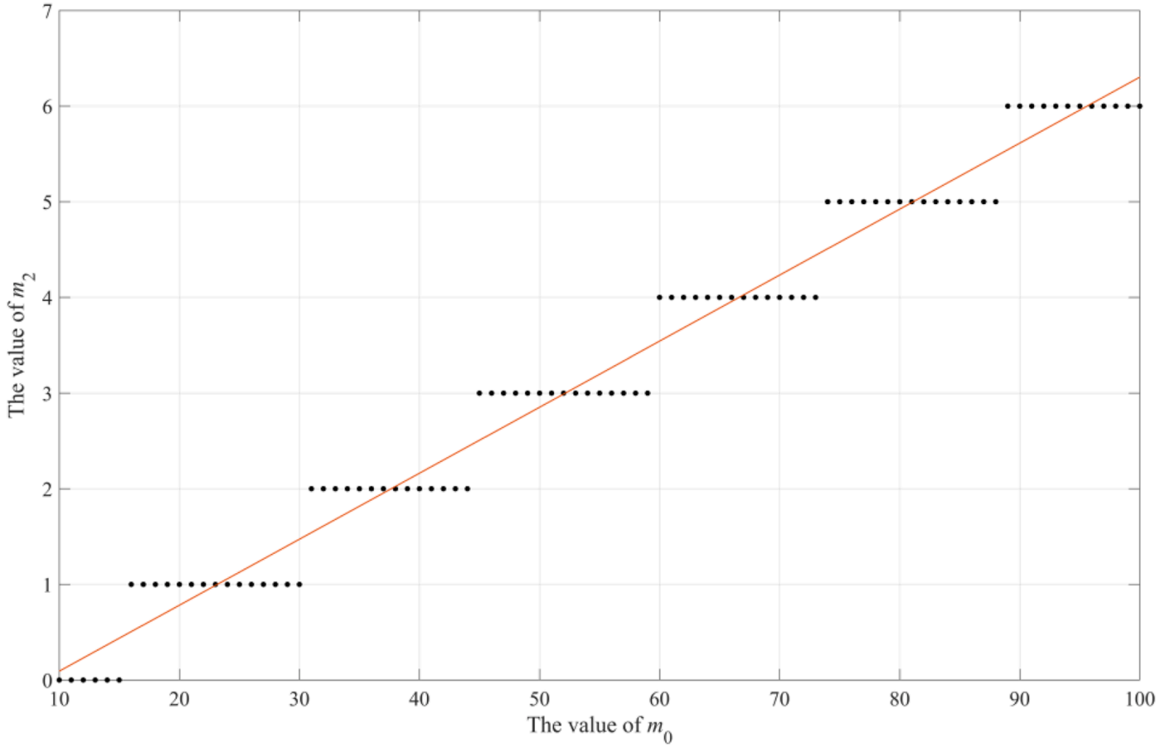

Fig. 6. The optimal redundancy batteries quantity with various quantity of working batteries.

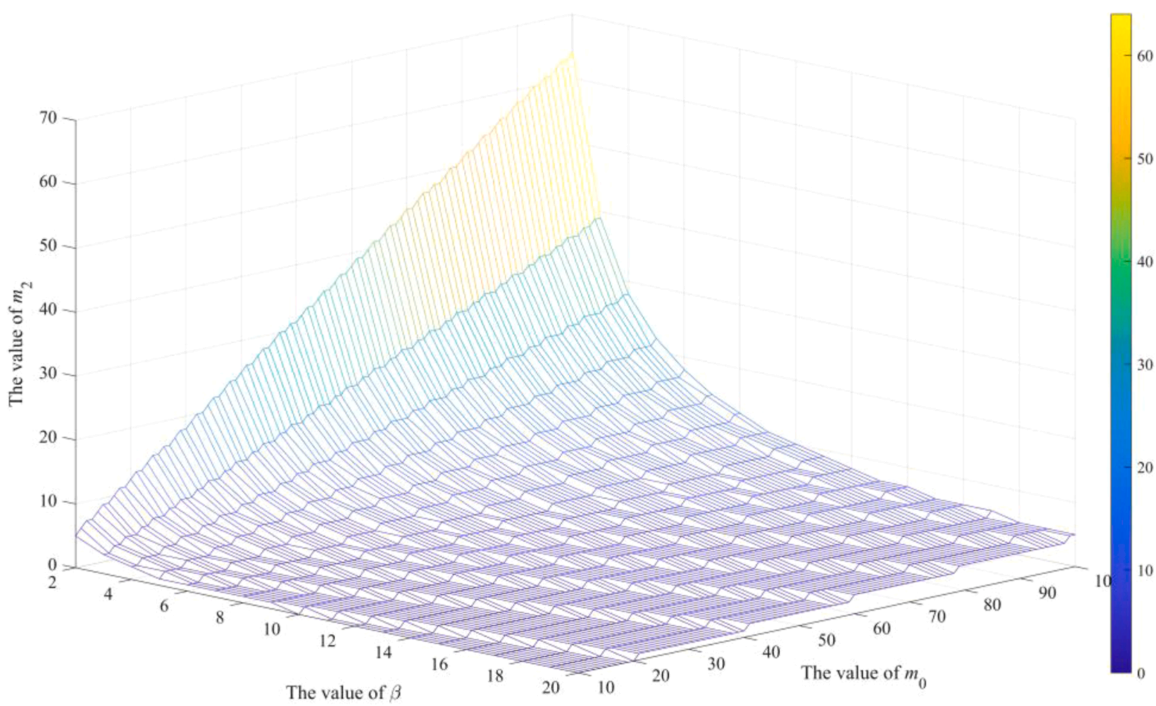

Fig. 7. The relationship among β, m_0, and m_2.

Table 3
The statistics of fitting deviation.

Amount	Deviation					Accuracy
	≤ -2	-1	0	$+1$	$\geq +2$	
1729	0	17	1699	13	0	98.3%

$$m_2 = \left\lfloor \frac{1.021m_0 - 0.9034}{\beta - 0.4361} - 0.072 \right\rfloor \tag{18}$$

The statistics of fitting deviation are listed in Table. 3. There are 1699 fitting-correct points in total 1729 points, and the fitting accuracy is 98.3%. Moreover, 30 other deviation values are only -1 or $+1$.

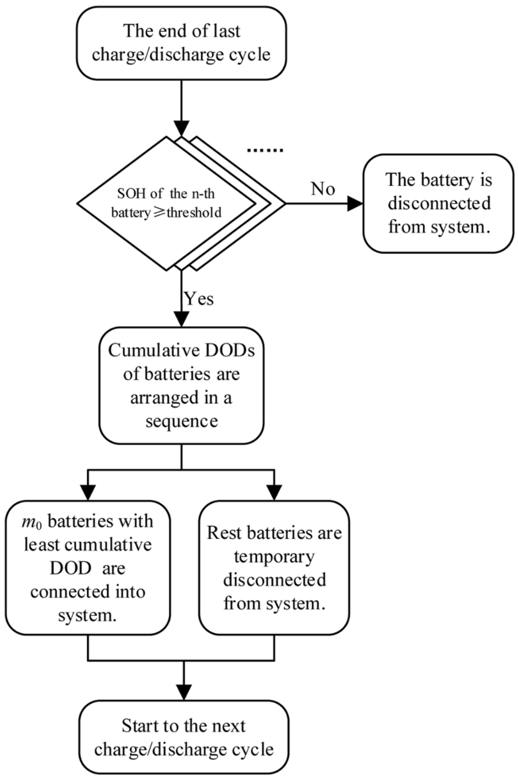

Fig. 8. The scheduling control strategy of battery system.

3.4. The strategy of batteries scheduling

For the realization of batteries in operation in turn, it is necessary to obtain the relevant operational parameters of each battery, including state of health (SOH), cumulative DOD, etc. SOH of each battery is evaluated by a battery management system. And then SOH is compared to the preset threshold, to determine the suitability of the battery to a given application. Cumulative DOD is used to estimate how long a battery has operated. Since the charging strategy of battery power station is usually once a day, battery management system can control whether each battery participates in the next cycle according to SOH and cumulative DOD of the battery. The following flowchart (Fig. 8) presents the detailed scheduling control strategy.

4. Conclusion

The proposed assessed method for serially connected batteries system can enhance life cycle by redundant batteries based on failure distribution analysis. Against the different number of working batteries, the proposed method is able to find out optimal redundant quantity with maximum mean lifetime. In addition, the variation of the shape parameter of battery failure distribution has influence on optimal redundant batteries. Optimal redundancy quantity against shape parameter and working batteries number can be fitted by multivariate rational function with rounding. Finally, the scheduling control strategy for serially connected batteries system is put forward based on battery health and cycle times. The method can be utilized for different batteries type, battery station as well as other devices with similar characteristics to batteries.

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Author statement

Zhe Yan: Methodology, Formal analysis, Software, Writing - original draft, Writing - review & editing. Yongming Zhang: Funding acquisition, Supervision. Jiesheng Yu: Investigation. Bowen Ran: Conceptualization.

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] H. Zheng, M. Song, Z. Shen, The evolution of renewable energy and its impact on carbon reduction in China, Energy 237 (2021) 121639, https://doi.org/10.1016/j.energy.2021.121639.

[2] M.R. Islam, S. Mekhilef, R. Saidur, Progress and recent trends of wind energy technology, Renew. Sustain. Energy Rev. 21 (2013) 456–468, https://doi.org/10.1016/j.rser.2013.01.007.

[3] S. Mekhilef, R. Saidur, A. Safari, A review on solar energy use in industries, Renew. Sustain. Energy Rev. 15 (2020) 1777–1790, https://doi.org/10.1016/j.rser.2010.12.018.

[4] L. Olatomiwa, S. Mekhilef, M.S. Ismail, M. Moghavvemi, Energy management strategies in hybrid renewable energy systems: a review, Renew. Sustain. Energy Rev. 62 (2016) 821–835, https://doi.org/10.1016/j.rser.2016.05.040.

[5] X. Deng, T. Lv, Power system planning with increasing variable renewable energy: a review of optimization models, J. Clean Prod. 246 (2019), 118962, https://doi.org/10.1016/j.jclepro.2019.118962.

[6] A. Zakaria, F.B. Ismail, M.S.H. Lipu, M.A. Hannan, Uncertainty models for stochastic optimization in renewable energy applications, Renew. Energy 145 (2020) 1543–1571, https://doi.org/10.1016/j.renene.2019.07.081.

[7] J. Lian, Y. Zhang, C. Ma, Y. Yang, E. Chaima, A review on recent sizing methodologies of hybrid renewable energy systems, Energy Convers. Manag. 199 (2019), 112027, https://doi.org/10.1016/j.enconman.2019.112027.

[8] S. Liu, Z. Bie, J. Lin, X. Wang, Curtailment of renewable energy in Northwest China and market-based solutions, Energy Policy 123 (2018) 494–502, https://doi.org/10.1016/j.enpol.2018.09.007.

[9] D. Fang, C. Zhao, Q. Yu, Government regulation of renewable energy generation and transmission in China's electricity market, Renew. Sustain. Energy Rev. 93 (2018) 775–793, https://doi.org/10.1016/j.rser.2018.05.039.

[10] S. Chapaloglou, A. Nesiadis, P. Iliadis, K. Atsonios, N. Nikolopoulos, P. Grammelis, et al., Smart energy management algorithm for load smoothing and peak shaving based on load forecasting of an island's power system, Appl. Energy 238 (2019) 627–642, https://doi.org/10.1016/j.apenergy.2019.01.102.

[11] H. Zhang, C. Sun, Cost-effective iron-based aqueous redox flow batteries for large-scale energy storage application: a review, J. Power Source. 493 (2021), 229445, https://doi.org/10.1016/j.jpowsour.2020.229445.

[12] J. Li, F. Liu, Z. Li, C. Shao, X. Liu, Grid-side flexibility of power systems in integrating large-scale renewable generations: a critical review on concepts, formulations and solution approaches, Renew. Sustain. Energy Rev. 93 (2018) 272–284, https://doi.org/10.1016/j.rser.2018.04.109.

[13] M.I. Alizadeh, M. Parsa Moghaddam, N. Amjady, P. Siano, M.K Sheikh-El-Eslami, Flexibility in future power systems with high renewable penetration: a review, Renew. Sustain. Energy Rev. 57 (2016) 1186–1193, https://doi.org/10.1016/j.rser.2015.12.200.

[14] Z. Yan, Y. Zhang, R. Liang, W Jin, An allocative method of hybrid electrical and thermal energy storage capacity for load shifting based on seasonal difference in district energy planning, Energy 207 (2020), 118139, https://doi.org/10.1016/j.energy.2020.118139.

[15] X. Han, L. Lu, Y. Zheng, X. Feng, Z. Li, J. Li, et al., A review on the key issues of the lithium ion battery degradation among the whole life cycle, ETransportation 1 (2019), 100005, https://doi.org/10.1016/j.etran.2019.100005.

[16] F. Wu, Q. Zhu, R. Chen, N. Chen, Y. Chen, L. Li, Ionic liquid electrolytes with protective lithium difluoro(oxalate)borate for high voltage lithium-ion batteries, Nano Energy 13 (2015) 546–553, https://doi.org/10.1016/j.nanoen.2015.03.042.

[17] M. Doyle, J. Newman, The use of mathematical modeling in the design of lithium/polymer battery systems, Electrochim. Acta 40 (1995) 2191–2196, https://doi.org/10.1016/0013-4686(95)00162-8.

[18] U.K. Das, P. Shrivastava, K.S. Tey, M.Y.I. Bin Idris, S. Mekhilef, E. Jamei, et al., Advancement of lithium-ion battery cells voltage equalization techniques: a review, Renew. Sustain. Energy Rev. 134 (2020), 110227, https://doi.org/10.1016/j.rser.2020.110227.

[19] M. Zhang, M. Ouyang, L. Lu, X. He, X. Feng, L. Liu, et al., Battery internal short circuit detection, ECS Trans. 77 (2017) 217–223, https://doi.org/10.1149/07711.0217ecst.

[20] P. Kumar, D. Chaudhary, P. Varshney, U. Varshney, S.M. Yahya, Y. Rafat, Critical review on battery thermal management and role of nanomaterial in heat transfer enhancement for electrical vehicle application, J. Energy Storage 32 (2020), https://doi.org/10.1016/j.est.2020.102003.

[21] S. He, S.P. Jiang, Electrode/electrolyte interface and interface reactions of solid oxide cells: recent development and advances, Prog. Nat. Sci. Mater. Int. (2021), https://doi.org/10.1016/j.pnsc.2021.03.002.
[22] J. Smekens, R. Gopalakrishnan, N. Van den Steen, N. Omar, O. Hegazy, A. Hubin, et al., Influence of electrode density on the performance of Li-ion batteries: experimental and simulation results, Energies 9 (2016) 1–12, https://doi.org/10.3390/en9020104.
[23] T. Waldmann, M. Wilka, M. Kasper, M. Fleischhammer, M. Wohlfahrt-mehrens, Temperature dependent ageing mechanisms in Lithium-ion batteries e A Post-Mortem study, J. Power Source. 262 (2014) 129–135, https://doi.org/10.1016/j.jpowsour.2014.03.112.
[24] Z. Li, J. Huang, B. Yann, V. Metzler, J. Zhang, A review of lithium deposition in lithium-ion and lithium metal secondary batteries, J. Power Source. 254 (2014) 168–182, https://doi.org/10.1016/j.jpowsour.2013.12.099.
[25] J.C. Burns, J. Electrochem, A. Soc, Situ Detection of Lithium Plating Using High Precision, Coulom. In-Situ Detect. Lithium Plat. Using High Precis. (2015), https://doi.org/10.1149/2.0621506jes.
[26] N. Omar, M. Abdel, Y. Firouz, J. Salminen, J. Smekens, O. Hegazy, et al., Lithium iron phosphate based battery – Assessment of the aging parameters and development of cycle life model, Appl. Energy 113 (2014) 1575–1585, https://doi.org/10.1016/j.apenergy.2013.09.003.
[27] Q. Xia, Z. Wang, Y. Ren, B. Sun, D. Yang, Q. Feng, A reliability design method for a lithium-ion battery pack considering the thermal disequilibrium in electric vehicles, J. Power Source. 386 (2018) 10–20, https://doi.org/10.1016/j.jpowsour.2018.03.036.
[28] Manenti A., Abba A., Geraci A., Savaresi S. A new cell balancing architecture for Li-ion battery packs based on cell redundancy. vol. 44. IFAC; 2011. https://doi.org/10.3182/20110828-6-IT-1002.00280.
[29] T.M. Bandhauer, S. Garimella, T.F. Fuller, A critical review of thermal issues in lithium-ion batteries, J. Electrochem. Soc. 158 (2011), https://doi.org/10.1149/1.3515880. R1.
[30] M.R. Palacín, A. De Guibert, Batteries: why do batteries fail? Science (80-) 351 (2016) https://doi.org/10.1126/science.1253292.
[31] T. Weckesser, D.F. Dominković, E.M.V. Blomgren, A. Schledorn, H. Madsen, Renewable energy communities: optimal sizing and distribution grid impact of photo-voltaics and battery storage, Appl. Energy 301 (2021), 117408, https://doi.org/10.1016/j.apenergy.2021.117408.
[32] B. Zakeri, S. Cross, P.E. Dodds, G.C. Gissey, Policy options for enhancing economic profitability of residential solar photovoltaic with battery energy storage, Appl. Energy 290 (2021), 116697, https://doi.org/10.1016/j.apenergy.2021.116697.
[33] W. Yang, T.N. Cong, Y. Ding, H. Chen, C. Tan, Y. Li, Progress in electrical energy storage system: a critical review, Prog. Nat. Sci. 19 (2009) 291–312, https://doi.org/10.1016/j.pnsc.2008.07.014.
[34] S. Rehman, L.M. Al-Hadhrami, M.M. Alam, Pumped hydro energy storage system: a technological review, Renew. Sustain. Energy Rev. 44 (2015) 586–598, https://doi.org/10.1016/j.rser.2014.12.040.
[35] M. Budt, D. Wolf, R. Span, J. Yan, A review on compressed air energy storage: basic principles, past milestones and recent developments, Appl. Energy 170 (2016) 250–268, https://doi.org/10.1016/j.apenergy.2016.02.108.
[36] H. Liu, J. Jiang, Flywheel energy storage-An upswing technology for energy sustainability, Energy Build. 39 (2007) 599–604, https://doi.org/10.1016/j.enbuild.2006.10.001.
[37] G.S.M Mousavi, F. Faraji, A. Majazi, K Al-Haddad, A comprehensive review of Flywheel Energy Storage System technology, Renew. Sustain. Energy Rev. 67 (2017) 477–490, https://doi.org/10.1016/j.rser.2016.09.060.
[38] K. Zaghib, M. Dontigny, A. Guerfi, P. Charest, I. Rodrigues, A. Mauger, et al., Safe and fast-charging Li-ion battery with long shelf life for power applications, J. Power Source. 196 (2011) 3949–3954, https://doi.org/10.1016/j.jpowsour.2010.11.093.
[39] A.G. Ritchie, Recent developments and future prospects for lithiumnext term rechargeable previous termbatteriesnext term, pdf 96 (2001) 6–9.
[40] Z. Lin, J. Cao, X. Xu, Z. Gu, Z. Wen, F. Zhang, Research on sodium sulfur battery for energy storage, Solid State Ion. 179 (2008) 1697–1701, https://doi.org/10.1016/j.ssi.2008.01.070.
[41] V.G. Lacerda, A.B. Mageste, I.J.B. Santos, L.H.M. da Silva, C.H. da Silva M do, Separation of Cd and Ni from Ni-Cd batteries by an environmentally safe methodology employing aqueous two-phase systems, J. Power Source. 193 (2009) 908–913, https://doi.org/10.1016/j.jpowsour.2009.05.004.
[42] G.J. May, A. Davidson, B. Monahov, Lead batteries for utility energy storage: a review, J. Energy Storage 15 (2018) 145–157, https://doi.org/10.1016/j.est.2017.11.008.
[43] C. Ponce de León, A. Frías-Ferrer, J. González-García, D.A. Szánto, F.C. Walsh, Redox flow cells for energy conversion, J. Power Source. 160 (2006) 716–732, https://doi.org/10.1016/j.jpowsour.2006.02.095.
[44] Y. Shi, C. Eze, B. Xiong, W. He, H. Zhang, T.M. Lim, et al., Recent development of membrane for vanadium redox flow battery applications: a review, Appl. Energy 238 (2019) 202–224, https://doi.org/10.1016/j.apenergy.2018.12.087.
[45] Sharma K Poonam, A. Arora, S.K Tripathi, Review of supercapacitors: materials and devices, J. Energy Storage 21 (2019) 801–825, https://doi.org/10.1016/j.est.2019.01.010.
[46] Y. Zhang, Z. Yan, F. Yuan, J. Yao, B. Ding, A novel reconstruction approach to elevator energy conservation based on a DC micro-grid in high-rise buildings, Energies 12 (2018) 33, https://doi.org/10.3390/en12010033.
[47] X.S. Zhou, B. Lu, Y.J. Ma, Superconducting magnetic energy storage summarize, Adv. Mater. Res. (2012) 535–537, https://doi.org/10.4028/www.scientific.net/amr.535-537.2057, 2057–60.
[48] Y. Wang, S. Luo, H.Y.H. Kwok, W. Pan, Y. Zhang, X. Zhao, et al., Microfluidic fuel cells with different types of fuels: a prospective review, Renew. Sustain. Energy Rev. 141 (2021), 110806, https://doi.org/10.1016/j.rser.2021.110806.
[49] P. Lyu, X. Liu, J. Qu, J. Zhao, Y. Huo, Z. Qu, et al., Recent advances of thermal safety of lithium ion battery for energy storage, Energy Storage Mater. 31 (2020) 195–220, https://doi.org/10.1016/j.ensm.2020.06.042.
[50] H. Rinne, The Weibull distribution: a Handbook, CRC press, 2008.
[51] M. Johnen, C. Schmitz, M. Kateri, U. Kamps, Fitting lifetime distributions to interval censored cyclic-aging data of lithium-ion batteries, Comput. Ind. Eng. 143 (2020), 106418, https://doi.org/10.1016/j.cie.2020.106418.
[52] Y. Mekonnen, H. Aburbu, A. Sarwat, Life cycle prediction of sealed lead acid batteries based on a Weibull model, J. Energy Storage 18 (2018) 467–475, https://doi.org/10.1016/j.est.2018.06.005.
[53] C.I. Ossai, N. Raghavan, Statistical characterization of the state-of-health of lithium-ion batteries with weibull distribution function—A consideration of random effect model in charge capacity decay estimation, Batteries 3 (2017), https://doi.org/10.3390/batteries3040032.
[54] J. Xiong, S. Wang, X. Li, Z. Yang, J. Zhang, C. Yan, et al., Mechanical behavior and Weibull statistics based failure analysis of vanadium flow battery stacks, J. Power Source. 412 (2019) 272–281, https://doi.org/10.1016/j.jpowsour.2018.11.060.
[55] T. Mouais, O.A. Kittaneh, M.A. Majid, Choosing the best lifetime model for commercial lithium-ion batteries, J. Energy Storage 41 (2021), 102827, https://doi.org/10.1016/j.est.2021.102827.
[56] C.T. Yeh, L. Fiondella, Optimal redundancy allocation to maximize multi-state computer network reliability subject to correlated failures, Reliab. Eng. Syst. Saf. 166 (2017) 138–150, https://doi.org/10.1016/j.ress.2016.08.026.
[57] C.T. Yeh, L. Fiondella, C. Kim, S. Lee, Villela lucia maria aversa, Nanoscale memory repair, Electron 53 (2017) 526–537, https://doi.org/10.3390/electronics4030526.
[58] C. Kim, S. Lee, Redundancy determination of HVDC MMC modules, Electron 4 (2015) 526–537, https://doi.org/10.3390/electronics4030526.