

วิธีการเทียบเคียงสมรรถนะจากข้อจำกัดและเกณฑ์ต่าง ๆ
สำหรับเทคโนโลยีการจัดเก็บพลังงาน
MULTI-CRITERIA BENCHMARKING METHOD FOR ENERGY
STORAGE TECHNOLOGIES

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บทคัดย่อ

การเติบโตทางเศรษฐกิจในภาคพลังงานทดแทนจากแหล่งพลังงานที่มีความผันผวนและไม่แน่นอนสามารถทำให้น่าเชื่อถือและมีประสิทธิภาพมากขึ้นโดยผนวกเข้ากับระบบการจัดเก็บพลังงาน วัตถุประสงค์หลักของการศึกษานี้คือ การพัฒนาเครื่องมือวิเคราะห์เทียบเคียงสมรรถนะที่รู้จักกันในชื่อ วิธีมาตรฐานขอบเขตความเป็นเลิศ (NFB; Normalization of frontier of the best method) ซึ่งเป็นหนึ่งในวิธีการเปรียบเทียบเกณฑ์หลายเกณฑ์เพื่ออำนวยความสะดวกในกระบวนการตัดสินใจและใช้ในการเลือกใช้เทคโนโลยีการจัดเก็บพลังงานที่เหมาะสมในการใช้งาน ภายใต้ข้อจำกัดและเกณฑ์ต่าง ๆ วิธี NFB ที่ได้รับการพัฒนาแล้วได้ถูกตรวจสอบความถูกต้องโดยนำไปเทียบกับผลการจัดอันดับของการแข่งขันกีฬาโอลิมปิกปี 2016 ประเภทกีฬาทศกรีฑา และตรวจสอบความแตกต่างโดยใช้วิธี Kendall rank correlation coefficient พบว่า มีค่า z ของทศกรีฑา เท่ากับ 5.3528 ซึ่งมีระดับความเชื่อมั่นสูงกว่า 99% เมื่อผลรับของการตรวจสอบเป็นที่พอใจ วิธีการ NFB จึงได้นำมาใช้เพื่อเปรียบเทียบเทคโนโลยีการจัดเก็บพลังงานภายใต้ 9 เกณฑ์ประสิทธิภาพและ 3 เกณฑ์ต้นทุน

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โดยจำแนกเทคโนโลยีการจัดเก็บพลังงานออกเป็น 5 กลุ่ม ได้แก่ Electrochemical energy storage, Mechanical energy storage, Electrical energy storage, Thermal energy storage และ Chemical energy group storage และผลของการจัดอันดับของแต่ละกลุ่ม เพื่อค้นหาเทคโนโลยีที่ดีที่สุดตามลำดับ คือ Li-ion, PHES (Pumped hydro energy storage), Supercapacitors, Thermal energy storage และ Chemical energy storage

คำสำคัญ: การเทียบเคียงสมรรถนะ, การจัดเก็บพลังงาน, วิธีมาตรฐานขอบเขตความเป็นเลิศ, การจัดอันดับ, เกณฑ์ต่าง ๆ

Abstract

Economic growth in the renewable energy sector from fluctuating and unstable energy sources can be made more reliable and efficient by integrating with energy storage systems. The main objective of this study was the development of comparable performance analysis tools called the Normalization of Frontier of the Best Method (NFB) to facilitate the decision-making process in choosing the most suitable energy storage technology for application under various restrictions and criteria. The developed NFB method was validated against the rankings of the 2016 Olympics, decathlon and the difference was examined by using the Kendall rank correlation coefficient, it was found that the decathlon's z-value was 5.3528 with a confidence level greater than 99%, the NFB method was used to compare energy storage technologies under 9 efficiency criteria and 3 cost criteria by classifying energy storage technology into 5 groups which were Electrochemical energy storage, Mechanical energy storage, Electrical energy storage, Thermal energy storage and Chemical Energy. The results of each group's ranking to find the best technology in each group were Li-ion, PHES (Pumped hydro energy storage), Supercapacitors, Thermal energy storage and Fuel Cells respectively.

Keywords: Benchmarking, Energy storage, Normalization of Frontier of the Best (NFB) method, Ranking, Multi-criteria.

Introduction

When the nations of the world adopted the Paris Agreement in December 2015, they took a giant step toward reducing the emission of gases that contribute to global warming. In the agreement, all countries agreed to work to limit global temperature rise to well below 2 degrees Celsius. Later in October 2018 The Intergovernmental Panel on Climate Change (IPCC) released a report on the 1.5°C target; it concluded that net anthropogenic carbon dioxide (CO₂) emissions must approach zero by mid-century (2050) to give a reasonable chance of limiting warming to 1.5°C (Gail, 2012). This has put the pressure on research and development, focusing on alternative and clean energy resources and systems. Although they have tremendous advantages in terms of energy security and environmental impact, renewable energy sources have intermittent and discontinuous nature, the imbalance between supply and demand required better management. Hence, most of energy obtained from renewable energy sources need to be stored in ways that are affordable, reliable, flexible, clean, safe, and efficient to ensure stability and quality of electrical systems. As a result, energy storage is becoming a crucial step to build innovative energy systems for a sustainable future.

Energy can be stored in many forms, energy storage technologies (EST) often divided into electrochemical energy storage (ECES) (Andrews & Jelley, 2013) (World nuclear association, 2016), mechanical energy storage (MES) (International Energy Agency, 2016), chemical energy storage (CES) (Hamidreza et al., 2004), thermal energy storage (TES) (Grigorios & Garyfallos, 2016 and electrical energy storage (EES) (Elton, 2004) (Mueller et al., 2015) (IRENA, 2013). Different energy storage technologies have different application potential and limitations, some of which are already commercially mature while others are at early research and development stages. Each of these options can be tailored to meet different end users' needs at different scales.

The need for energy storage technologies (EST) in a future energy system, based on volatile renewable energy sources is widely accepted. The still open question is which technology should be used, in particular in such applications where the implementation of different storage technologies would be possible. Therefore, this study aims to develop methods that will facilitate the decision making based on the normalization of frontier of the best (NFB) method to evaluate and rank the most recent status of energy storage technologies, along with requirement of various criteria of the end users, and characteristics of energy storage systems.

The classification types of energy storage system

With the development of energy storage technology, the main energy storage technology can be classified according to the classification of technology in to five groups of technologies as follows.

A. Electrochemical storage systems such as Li-ion, NaS, Lead-acid, VRB, NiCd, ZnBr and PSB

These are classified into two groups; systems with integrated energy storage e.g., Lead-acid batteries, NiCd batteries, NiMH batteries, Li-ion batteries, NaS batteries, NaNiCl/ZEBRA batteries and systems with external energy storage e.g., V-redox, ZnBr, Zn-air batteries, In systems with external energy storage, there is a physical separation between the energy conversion unit and the charged active material, while in systems with integrated energy storage the charge/discharge reaction takes place directly in the active material, so no spatial separation occurs on this occasion (Andrews & Jelley, 2013). Systems with external storage are capable of being independently sized for power and energy for the storage facility, whereas in systems with integrated energy storage, the power is related to the energy storage capacity (World nuclear association, 2016).

B. Mechanical Energy Storage such as PHEs, CAES and Flywheel

Pumped hydro-energy-storage (PHEs)

This is the oldest kind of large-scale energy storage being used since the 1890's and Currently accounts for 95% of the global storage capacity. These systems have installed capacities in the GW range and are typically used for load leveling on a daily basis (International Energy Agency., 2016). Exhibiting a rapid response speed (0.5-3.0 mins), they also serve as an emergency reserve in case of sudden changes in demand or sudden shutdowns of power plants.

Compressed air energy storage (CAES)

Compressed air energy storage is achieved at high pressures (40–70 bars), at near ambient temperatures. This means less volume and a smaller storage reservoir. Large caverns made of high-quality rock deep in the ground, ancient salt mines, or underground natural gas storage caves are the best options for compressed air storage, as they benefit from geostatic pressure, which facilitates the containment of the air mass (Andrews & Jelley, 2013).

Flywheel energy storage (FES)

Flywheel energy accumulators are comprised of a massive or composite flywheel coupled with a motor-generator and special brackets (often magnetic), set inside a housing at very low pressure to reduce self-discharge losses (IRENA, 2013). They have a great cycling capacity (a few 10,000 to a few 100,000 cycles) determined by fatigue design (International Energy Agency, 2016).

C. Electrical Energy Storage such as Capacitor and Supercapacitor

Conventional Electrostatic Capacitors This is the simplest form of capacitor and works by storing energy in an electric field. Two plates (electrodes) are placed very close together, but not touching, with either air or other non-conductive material (known as a dielectric) in between the plates (Elton, 2004).

The design of “supercapacitors” is essentially a hybrid between batteries and capacitors. They have two electrode plates and an electrolyte in between

(like batteries) and when a power source is connected, ions make their way to the electrodes with opposite charges due to the electric field (since oppositely charged objects attract) (Mueller et al., 2015). The difference is that a chemical reaction does not occur, merely the ions migrate; so, the storage mechanism is still the electric field (IRENA, 2013).

D. Thermal Energy Storage

There are two types of TES systems, depending on whether they use sensible or latent heat. Latent-fusion-heat TES makes use of the liquid–solid transition of a material at constant temperature. During accumulation, the bulk material will shift from the solid state to liquid and, during retrieval, will transfer back to solid. The heat transfers between the thermal accumulator and the exterior environment are made through a heat-transfer fluid (Grigorios & Garyfallos, 2016).

Sensible heat thermal storage is achieved by heating a bulk material (sodium, molten salt, pressurized water, etc.) that does not change states during the accumulation phase; the heat is then recovered to produce water vapor, which drives a turbo-alternator system.

E. Chemical Energy Storage such as Fuel Cell

Fuel cells are a means of restoring spent energy to produce hydrogen through water electrolysis. The storage system proposed includes three key components: electrolysis which consumes off-peak electricity to produce hydrogen, the fuel cell which uses that hydrogen and oxygen from air to generate peak-hour electricity, and a hydrogen buffer tank to ensure adequate resources in periods of need (Hamidreza et al., 2014).

1. Ranking Method

The ranking method presented here is based on the Normalization of Frontier of the Best (NFB) method which is one of the multiple criteria decision analysis approaches for objective ranking. However, in many practical situations,

the decision maker might not want to use objective ranking but prefers to have some personal preferences and in many circumstances wants to have or set performance targets which need to be met as close as possible. Therefore, the original NFB method has to be modified in order to handle the subjective ranking and target setting.

2. Formulation of NFB ranking

Most multi attribute decision-making (MADM) models require a normalization which has to be done in a decision matrix that has the following parts: alternatives A_i ($i=1,2,3,..,m; m=16$), which decision makers have to choose, criteria C_j ($j=1,2,3,..,n; n=12$), relative importance of criteria (or weightings) W_j , the performance target T_j , and the corresponding criteria values with q_{ij} elements, which are the performance, quality or cost parameters of alternative i with respect to criterion j as shown in Table 2. After all of the relevance parameters in Table 2 are obtained, the ranking is conducted as follows (Holassut, 2006):

1) Set $X_{ij} = q_{ij}$ if there is no setting target for the criteria C_j , however in the case of C_j has set criteria T_j then the q_{ij} needed to be rescaled to reflect the distance from the set criteria T_j by using rescale equation,

$$X_{ij} = (q_{ij} - T_j)^2 \quad (1)$$

If q_{ij} is already on the target, X_{ij} will be zero otherwise X_{ij} is positive.

2) Initialized all X_{ij} for each criteria C_j with a normal distribution with mean zero and standard deviation one using

$$\bar{X}_j = \frac{\sum_{i=1}^m (X_{ij})}{m} \quad (2)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^m (X_{ij} - \bar{X}_j)^2}{m}} \quad (3)$$

$$Z_{ij} = \frac{(X_{ij} - \bar{X}_j)}{\sigma_j} \quad (4)$$

3) In order to have the score for ranking within the range of 0 to 10 with the score value of 5 represented an average score, the Z_{ij} needed to be shifted to

$$S_{ij} = 5 + (K_j)(Z_{ij}) \quad (5)$$

The coefficients K_j in Eq. (5) represent cost-benefit or disadvantage-advantage indicators which defined as $K_j = +1$ if the value of Z_{ij} which is higher than the average is considered to be benefit or advantage, and $K_j = -1$ if the value of Z_{ij} which is lower than the average is considered to be benefit or advantage. For a criteria C_j which has a set target value the coefficient K_j is always = -1 to ensure that the score of ranking is always fall in the range of 0 to 10, any S_{ij} which is lower than 0 or greater 10 needed to be adjusted to either 0 or 10.

4) After step 3 has been completed the score can be calculated for each alternative A_i from

$$SC_i = \sqrt{\frac{\sum_{j=1}^n (W_j \cdot S_{ij}^2)}{\sum_{j=1}^n W_j}} \quad (6)$$

All of the weight $W_j = 1$ for objective ranking and for the subjective the W_j can be vary depending upon the circumstance, but cannot be negative ($W_j \geq 0$)

The score SC_i for each alternative A_i reflects the quality of alternative

A_i under the criteria C_j , the higher the score indicated higher quality and hence the higher rank. The ranking order is determined by sorting the score SC_i . However, the score function as given in the Eq. (6) is a nonlinear function which makes it difficult to determine the actual quality gap between the alternatives considered system to facilitate the problem the linear transformation is required.

5) The linear approximation of score function is determined essentially because after the transformation, all of the scores are balanced deviations with the reference point or the average value, and hence the quality gap between the alternatives can be obtained directly after linearization. In this case the linear approximation function is

$$SL_i = 10 \left[\frac{e^{1.7(SC_i - 5)}}{1 + e^{1.7(SC_i - 5)}} \right] \quad (7)$$

If only the ranking order is concerned, the linearization of score can be omitted since the linearization process has no effect on ranking order.

3. Verification of the NFB method

The NFB method developed needs to be verified against the best and well-known methods. One of the best methods used for multi-criteria ranking is the method adopted by International Association of Athletics Federations (IAAF) for the scoring and ranking of the Men's Decathlon, this method has been used since 1984 after extensive discussion. The committee involved were well aware of most ranking methods at that time but decided to develop a specific method which had to be most objective based on an abundant amount of empirical evidence, the result is the scoring method for each discipline is cover by a mathematical expression of the type (Sportcalculators, 2016).

Table 1 The decathlon results of the 2016 Olympics rankings and NFB method ranking.

Rank	Country	Ranking by Olympic 2016	Ranking by NFB method
1	US	Ashton Eaton	Ashton Eaton
2	FRA	Kevin Mayer	Kevin Mayer
3	CAN	Damian Warner	Damian Warner
4	GER	Kai Kazmirek	Kai Kazmirek
5	ALG	Larbi Bourrada	Larbi Bourrada
6	CUB	Leonel Suarez	Leonel Suarez
7	US	Zach Ziemek	Jeremy Taiwo
8	BEL	Thomas Van Der Plaetsen	Kurt Felix
9	GRN	Kurt Felix	Zach Ziemek
10	United States	Jeremy Taiwo	Adam Sebastian Helcelet
11	Czech Republic	Adam Sebastian Helcelet	Thomas Van Der Plaetsen
12	France	Bastien Auzeil	Lindon Victor
3	Grenada	Lindon Victor	Bastien Auzeil
14	Spain	Pau Tonnesen	Yordani Garcia
15	Cuba	Yordanis Garcia	Dominik Distelberger
16	Austria	Dominik Distelberger	Keisuke Ushiro
17	Japan	Keisuke Ushiro	Pau Tonnesen
18	Poland	Pawel Wiesiolek	Pawel Wiesiolek
19	Estonia	Karl Robert Saluri	Karl Robert Saluri

From the results in Table 1 we can see that the top 6th ranks of both methods are identical. However, there are discrepancies at the lower ranks, the maximum discrepancy or the different of ranking between the two methods is 3, which is the case of Pau Tonnesen, he is ranked at 14th and 17th in the ranking of IAAF and the ranking obtained by NFB method respectively. The Kendall's Tau (Kendall rank correlation coefficient) between these two ranking methods is equal to 0.8947 with the corresponding z-score of 5.3528 which implied that the two methods have very strong relationship with statistically significantly greater than 99% (for z-score greater than 2.58). The significant of the value of

Kendall's Tau is that the two methods are identical if Kendall's Tau = 1.0 (Maurice, 1970).

The NFB method uses only the actual performances which can be timed or measured directly of the athletes to determine the ranking, in contrast to the ranking of IAAF which has to reliance on particular constants, without the correct values of these constants the accuracy of the method is lost.

Comparing electrical energy storage technologies

1. Methodological approach

Characteristics of energy storage techniques and data, the technical data and various factors of each energy storage technology are obtained from publication databases and organized into 5 key areas (12 factors) for the analysis, including,

a. Durability (1. Lifetime, 2. Cycling time) This refer to the number of times the energy storage can retribute, after each discharge. Cycling time is expressed as the maximum number of cycles N (one cycle corresponding to one charge and one discharge).

b. Available power (3. Energy density, 4. Power density, 5. Specific energy) These parameters show the size of electric components (motor and generator) in the stored energy conversion chain. It is generally expressed as an average value as well as a peak value, it often used to represent maximum power of charge and discharge. Energy density represent the maximum amount of energy that the energy storage can be accumulate per unit of mass or volume. This parameter demonstrates the sizing of energy storage (mass or volume) which is importance for certain applications especially in mobile applications.

c. Efficiency (6. Discharge efficiency, 7. Cycle efficiency) This is the ratio between extracted energy and stored energy. This definition is often oversimplified because it is based on a single operation point. The definition of efficiency must,

therefore, be based on one or more realistic cycle for a specific application. These parameters also reflect self-discharge when the initially stored energy has dissipated over a given time and without any useful work.

d. Performance (8. Discharge time at power rating, 9. Power rating). These indicate the maximum-power discharge duration. It depends on the depth of discharge and operational conditions of the system.

e. Cost (10. Power capital cost, 11. Energy capital cost, 12. Operating and maintenance cost.) The capital invested which are the cost of power, energy and the cost of operation and maintenance are the most important factors to take into account for the entire lifecycle of the system.

2. The ranking procedures

Total of 16 energy storage technologies ($i = 1, 2, 3, \dots, m; m = 16$) which can be classified into 5 groups (A to E) as follow:

A. Electrochemical Energy Storage ($i = 1, 2, 3, \dots, 7$) including of Li-ion, NaS, Lead-acid, VRB, NiCd, ZnBr and PSB.

B. Mechanical Energy Storage ($i = 8, 9, 10, 11$) including of L-CAES, S-CAES, PHES and Flywheel.

C. Electrical Energy Storage ($i = 12, 13, 14$) including of Capacitor, Supercapacitors and SMES.

D. Thermal Energy Storage ($i = 15$) including of Thermal Energy Storage.

E. Chemical Energy Storage ($i = 16$) including of Fuel Cell.

These 16 technologies are compared under 12 criteria including performance, quality and cost. The comparisons have been performed under both objective and subjective conditions. In the case of the objective ranking, all the weight W_j are set to 1, while in the case of subjective ranking, the focus in on the residential energy storage technologies with 10 kWh energy capacity [10] as the target, since the main constrains in the residential applications are space and the budget only electrochemical energy storage is considered.

Table 2 The data of energy storage technology ($l = 1, 2, 3, \dots, m; m = 16$) of each factor ($j = 1, 2, 3, \dots, n; n = 12$).

Group	No. (i)	Criteria	a			b			c		d		e		
		(j)	1	2	3	4	5	6	7	8	9	10	11	12	
		Energy storages technology	Life time (years)	Cycling time (cycles)	Energy density (W.h/L)	Power density (W/L)	Power rating (MW)	Discharge time at power rating (hr)	Discharge efficiency (%)	Cycle efficiency (%)	Specific energy (W.h/kg)	Power capital cost (\$/kW)	Energy capital cost (\$/kW)	Operating and maintenance cost (\$/kW year)	
A	1	Li-ion	5	4,000	500	1,500	100	8	85	97	97	1,590	3,800	65	
	2	NaS	10	4,500	300	180	34	1	85	90	240	3,000	500	80	
	3	Lead-acid	5	1,800	90	400	40	10	85	90	50	600	400	50	
	4	VRB	20	13,342	35	2	50	24	82	85	30	1,500	1,000	70	
	5	NiCd	5	3,500	150	600	40	8	85	83	80	1,500	2,400	20	
	6	ZnBr	10	2,000	65	25	10	10	70	80	80	2,500	1,000	60	
	7	PSB	15	1,000	30	2	15	10	60	75	30	2,500	1,000	55	
B	8	L-CAES	40	12,000	6	2	1,000	24	79	70	60	1,000	120	25	
	9	S-CAES	23	30,000	9	4	10	3	90	65	300	1,550	250	15	
	10	PHES	60	30,000	2	1.5	5,000	24	87	85	1.5	4,300	100	3	
	11	Flywheel	20	20,000	80	5,000	20	0.15	93	95	100	350	14,000	20	
C	12	Capacitor	10	50,000	10	100,000	0.05	1	90	70	5	400	1,000	13	
	13	Supercapacitors	30	100,000	30	100,000	0.3	1	98	97	15	450	2,000	6	
	14	SMES	30	100,000	6	4,000	10	0.3	95	98	75	489	10,000	18.5	
D	15	Thermal	30	20,000	500	2	300	24	30	60	250	400	60	14	
E	16	Fuel cells	20	20,000	3,000	500	58.8	24	59	66	10,000	3,000	15	16.64	

3. Comparative analysis of Normalization Frontier of the Best method (NFB method)

There are 6 steps as follows.

1) Arrange data by using the electrochemical storage which show as examples (Table 2) of comparable performance of energy storage. The related data of electrochemical energy storage technology factors has been arranged in order to compare performance.

2) Determine the maximum, minimum, average and standard deviation (σ_j) in each factor.

3) Finding Normalized in each factor from Eq. (4).

4) To separate the data to 2 parts one is

- Less than the average (The less the better) must be multiplied by -1

- More than the average (The more the better) must be multiplied by +1

5) Shift the co-ordinate. This method is a method that takes the standard values that have been adjusted by +5 in the received value in No. 4 to give a positive value.

6) Find the sum of normalized values by including all normalized values of each energy storage technology.

7) Sort the sums that are obtained from descending order then will get the sequence of energy storage technology. By applying the same procedure to the remaining types of technology and the ranking of 16 energy storage technology.

Result

The results of energy storage technology ranking were shown in the Table 3 by ranking in each group and by ranking all together in the same weight ($W_j = 1$). By ranking in each group, there are 5 groups (A-E). The A group or Electrochemical Energy Storage ($l = 1, 2, 3, \dots, 7$) including of Li-ion, NaS, Lead-acid, VRB, NiCd, ZnBr and PSB. It was found that Li-ion is the most suitable, the next was VRB, which is a promising technology and the third is lead acid, which we are familiar with. Which the advantages of Li-ion are light weight, long service life, High power, stable in energy, fast charging and is dry cell that does not contain harmful components such as liquid, acid or lead, therefore can guarantee the safety of humans and the environment more than other types of batteries. Besides battery Lithium-ion is already a step further in the development of energy sources in the automobile industry. Also friendly to nature as well Especially in the situation that the world has to face global warming Choosing a lithium-ion battery as the energy core of an electric vehicle is a useful option for the world.

Other groups B and C which are the “Mechanical Energy Storage”(B) resulted to PHES (Pumped hydro-energy storage) as the best technology compared with CAES (Compressed air energy storage) and Flywheel by the specific criteria, and finally the “Electrical Energy Storage” (C) resulted for the Supercapacitors compared with capacitor and SMES (Superconducting magnetic energy storage).

Table 3 The ranking of energy storage technology.

Group	No.	Energy storages technology	Rank in each group	Rank all together in the same weight ($W_j=1$)
A	1	Li-ion	1	13
	2	NaS	4	14
	3	Lead-acid	3	11
	4	VRB	2	8
	5	NiCd	5	12
	6	ZnBr	6	15
	7	PSB	7	16
B	8	L-CAES	4	6
	9	S-CAES	3	10
	10	PHES	1	1
	11	Flywheel	2	9
C	12	Capacitor	3	5
	13	Supercapacitors	1	2
	14	SMES	2	4
D	15	Thermal	1	7
E	16	Fuel cells	1	3

However, the ranking of all 16 energy storage technologies by using 12 criteria, the No. 1 is PHES (Pumped hydro-energy storage) because water is a natural occurrence and circulates for endless use. Water is considered a factor Important for the living of all living things. Especially humans use water for both consumption and consumption. In addition, water is used as an energy source for electricity generation to replace the use of fossil fuels. Energy obtained from water is clean energy without causing air pollution. Therefore, making the world promote the use of waterpower to produce electricity.

Conclusion

The Normalization of Frontier of the best method (NFB method) can be applied to investigate the suitability of energy storage technology under multi-criteria. Benchmarking by using NFB method mentioned above to analyze the performance of energy storage technology. In this research, 16 energy storage technologies were investigated under 12 criteria. These criteria contain performance, capability, durability and cost, there is no environment aspects in the criteria. The objective ranking by the NFB method for 5 groups of energy storage technologies results in obtaining the best of each group as list below.

- A. Li-ion is the best of Electrochemical Energy Storage.
- B. PHES is the best of Mechanical Energy Storage.
- C. Supercapacitors is the best of Electrical Energy Storage.
- D. Thermal Energy Storage is the best of Thermal Energy Storage.
- E. Fuel Cells is the best of Chemical Energy Storage.

And the results for the top rank of the over all ranking is PHES.

From this ranking result will be used as a guideline for choosing the technology that is available to suit the current usage and the most effective. For an evaluation of the energy storage technology that is best suited depending on a variation of given demand situations such as size, capacity, mobility and budget. In addition, the NFB can also indicate the ability of a given requirement to improve the energy storage technology required.

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