Energy and Power Engineering, 2011, 3, 557-564
doi:10.4236/epe.2011.34069 Published Online September 2011 (http://www.SciRP.org/journal/epe)

Multiple Criteria Analysis for Energy Storage Selection

Alexandre Barin[1*], Luciane Neves Canha[1], Alzenira Da Rosa Abaide[1], Karine Faverzani Magnago[1], Breno Wottrich[2], Ricardo Quadros Machado[3]
[1]*Federal University of Santa Maria, Post-Graduate Electrical Engineering Program, Center for Energy and Environment Studies, Santa Maria, Brazil*
[2]*Comillas Pontifical University, ICAI School of Engineering, Madrid, Spain*
[3]*University of São Paulo, Department of Electrical Engineering, São Carlos, Brazil*
E-mail: *chbarin@gmail.com
Received May 5, 2011; *revised June* 7, 2011; *accepted June* 20, 2011

Abstract

In view of the current and predictable energy shortage and environmental concerns, the exploitation of renewable energy sources offers great potential to meet increasing energy demands and to decrease dependence on fossil fuels. However, introducing these sources will be more attractive provided they operate in conjunction with energy storage systems (ESS). Furthermore, effective energy storage management is essential to achieve a balance between power quality, efficiency, costs and environmental constraints. This paper presents a method based on the analytic hierarchy process and fuzzy multi-rules and multi-sets. By exploiting a multiple criteria analysis, the proposed methods evaluate the operation of storage energy systems such as: pumped hydro and compressed air energy storage, H_2, flywheel, super-capacitors and lithium-ion storage as well as NaS advanced batteries and VRB flow battery. The main objective of the study is to find the most appropriate ESS consistent with a power quality priority. Several parameters are used for the investigation: efficiency, load management, technical maturity, costs, environmental impact and power quality.

Keywords: Multiple Criteria Analysis, Fuzzy Sets, AHP Method, Energy Storage Systems, Power Quality

1. Introduction

In response to the energy crisis and related pollution problems, it is necessary to adopt new means of generating energy that use renewable sources and storage technologies in an efficient and environmentally friendly manner. Renewable hybrid systems receive governmental incentives for their development in many countries. One remarkable example of this tendency occurs in Brazil. The Federal Government recently approved Decree 10438/02, which creates the Incentive Program for Alternative Sources of Energy - PROINFA [1].

Therefore, considering the future scarcity of fossil fuels and the environmental damage caused by them, it is incontestable that the use of hybrid renewable sources of energy is the best choice for providing electricity to end-users [2]. However, an effective method for energy storage management is essential to guarantee the expansion of the use of hybrid energy sources [3]. This method must be able to deal with some trade-offs between power quality, costs and environmental constraints. Accordingly, it is important to select a multiple criteria method that best satisfies the management needs [4]. Today, several authors have achieved excellent results by using a large number of multiple criteria analyses in energy management. ELECTRE [5], PROMETHEE [6], MACBETH [7], AHP [8] and also Fuzzy sets [9] are some familiar tools. This paper presents a method based on the routine developed by Saaty in the AHP method and on multi-rules-based decisions and multi-set considerations applied with fuzzy logic. To analyze the ESS operation, this paper uses AHP and fuzzy logic and then compares and evaluates the final results.

The study focuses on the operational evaluation of some ESS—compressed air energy storage (CA), pumped hydro energy storage (PH), H_2 storage, flywheel and super-capacitor (SUP), lithium-ion and NaS advanced batteries and VRB flow battery storage. Several criteria are used in this analysis: efficiency, load management, technical maturity, costs, environmental impacts and power quality. In addition, the analysis of these criteria also considers transit and end-use ride-through, load leveling, load following, spinning reserve and transmission and distribution stabilization. Thus, the paper has a focal point on power quality management needs, but also evaluates costs and environmental concerns. The paper is organized as follows: Section 2 introduces the application's main characteristics and the purpose of the methods presented for ESS selection. Section 3 presents the previous classification defined by the selected criteria, according to the scenarios under analysis. Sections 4 and 5 introduce the main concepts of AHP and fuzzy logic, respectively. Subsequently, the application of AHP and fuzzy logic is outlined in Section 6, in addition to a comparison of the final results for both methods, concerning the EES selection. Concluding remarks are given in Section 7.

2. General Aspects of the Proposed Analysis

To develop the proposed method, eight types of ESS are analyzed according to six criteria. The main objective of this study is to find the most appropriate type of ESS to be used in the power quality scenario. Accordingly, the availability for use of any of the selected EES is considered for the specific region under analysis. A brief description of the ESS evaluated in this paper [10-12] is presented below.

The CA storage system works by compressing air (CA operates like a gas turbine at high temperatures). CA has a significant technical feasibility and it is considered one of the most efficient engines for converting heat into electrical power, presenting an economically attractive system for load management. In CA, the energy is stored by compressing air via electrical compressors in huge storage reservoirs that usually already exist, such as underground caves, abandoned hard-rock mines, or natural aquifers. CA offers good efficiency and has a high technical maturity. On the other hand, the need for a fuel in the combustion process (usually natural gas) increases greenhouse gas emissions.

Pumped hydro energy storage (PH) is an ESS based on conventional hydroelectric technology. PH uses the potential energy of water, transferred by pumps (charging mode, during off-peaks) and turbines (discharge mode, during peaks) between two reservoirs located at different altitudes. The amount of stored energy is proportional to the height difference between the upper and lower reservoirs and the volume of water stored. PH may be considered extremely expensive in terms of initial costs (installation), it also requires suitable sites and there are long lead-times for construction. The efficiency is usually determined by the efficiency of the pumps and turbines deployed.

Although H_2 storage is an immature technology, it is seen as a promising means of electrochemical storage, attracting huge interest. Since hydrogen is not a primary energy source, its energy storage is based on an electrolyzer to split water into hydrogen and oxygen. Most aspects in the hydrogen-related technology, including generation, storage and utilization in fuel cells, still need further development to be employed on a large scale.

A flywheel can accumulate and store mechanical energy in kinetic form. The stored energy depends on the inertia and speed of the rotating mass (rotor). The flywheel is a rotor placed inside a vacuum to eliminate friction-loss from the air and mounted on bearings for a stabile operation. A flywheel offers high density energy and high efficiency.

Super-Capacitors store energy by means of separating the charge into two facing plates. They use polarized liquid layers at the interface between a conducting ionic electrolyte and a conducting electrode, increasing the capacitance. Super-Capacitors offer high efficiency and high costs.

Batteries are the most common devices used to store electrical energy. Traditionally, they have been used mainly for small scale applications. However, due to the liberalization of electricity markets, battery manufacturers have begun to recognize some potential applications for larger scale energy storage applications. This paper evaluates the sodium-sulfur (NaS) and lithium-ion advanced battery technologies.

Flow Batteries, also known as Regenerative Fuel Cells or Redox Flow Systems, are a new class of battery that has been achieving substantial progress - technically and commercially. Flow Batteries present some features that make them especially attractive for utility-scale applications. The operational principle differs from classical batteries. The latter store energy both in the electrolyte and the electrodes, while flow batteries store and release energy using a reversible reaction between two electrolyte solutions, separated by an ion-permeable membrane. Both electrolytes are stored separately in bulk storage tanks, the size of which defines the energy capacity of the storage system. The power rating is determined by the cell stack. Therefore, the power and energy rating are decoupled, which provides the system designer with an extra degree of freedom when structuring the system. This paper evaluates the vanadium redox (VRB) flow battery.

A description of the criteria evaluated by the proposed method is described below. It is important to observe that the definition and evaluation of both quantitative and qualitative criteria must take into account an actual database and management needs for each specific case. After analyzing these aspects, it is possible to arrange the method for the ESS selection.

The qualitative criteria are expressed through weights stipulated by the decision maker—a group of researchers from The Federal University of Santa Maria—in the intervals from 0 to 1.0, with 1.0 being the highest score.

These weights are defined according to the analysis of the actual database, taking into account social, political and economic aspects related to the particular region under analysis, e.g. EES installation in a specific region of Brazil. In addition, the experience of the selected decision makers is another key aspect in determining the weights. The qualitative criteria considered in this work are:

- load management (LM) related to load leveling and load following;
- technical maturity (TM);
- environmental impacts related to visual and biological impacts and greenhouse gas emissions;
- power quality (PQ) related to transit and end-use ride-through, spinning reserve and transmission and distribution stabilization.

The quantitative criteria are expressed through rated data. The quantitative criteria evaluated in this study are:

- efficiency (EF) in %;
- costs represented in US$/kW.

As mentioned previously, the simulations will also consider fast and conventional spinning reserve (FRSR - CRSR), transit and end-use ride-through (T&ER), and transmission and distribution stabilization (T&D) for the power quality parameter. In addition, they consider load leveling (LL) and load following (LF) for load management parameter. Accordingly, it is important to introduce some basic concepts regarding these aspects [11].

The fast response spinning reserve category corresponds to the fast generation capacity response that is in a state of 'hot-stand-by'. Utilities hold it back in case of a failure of generation units. Thus, the required power output for this application is typically determined by the power output of the largest unit operating on-grid. The conventional spinning reserve requires a lesser 'fast as possible' response. Storage systems can provide this application in competition with standard generation facilities.

Transit and end-use ride-through are applications requiring very short durations combined with very fast response times. They cover electric transit systems with remarkable load fluctuations and customer power services such as voltage stabilization and frequency regulation to prevent events that can affect sensitive processing equipment and can cause data and production losses.

Transmission and distribution stabilization are applications that require very high power ratings for short durations in order to keep all components on a transmission or distribution line in synchronous operation.

Traditional load leveling is a widespread application for large energy storages, in which cheap electricity is used during off-peak hours for charging, while discharging takes place during peak hours, providing cost savings for the operator.

In the case of ramping and load following, energy storage is used to assist generation to follow the load changes. An instantaneous match between generation and load is necessary to maintain the generator rotational speed and hence the frequency of the system.

The main characteristics of the ESS under analysis [11,12] according to Power Quality (PQ) and Load Management (LM) are presented in **Table 1**.

The selected criteria analyzed in this section are now presented in **Table 2**. The rated data described in the literature [10-12] are used to determine the values of the quantitative criteria—efficiency and costs. The qualitative criteria—load management, technical maturity, environmental impacts and power quality—are represented by weights stipulated by the decision makers in the intervals from 0 to 1.0, with 1.0 being the highest score.

3. Classification of the Criteria

The scenarios simulated in this study are evaluated by the prior classification of the criteria. This classification is therefore used in both AHP and fuzzy simulations. This classification was thus created according to the different relevance observed among these factors. The purpose of

Table 1. ESS—Power Quality (PQ) and Load Management (LM) characteristics.

	CA	PH	H_2 (FC)	FLY	SUP	LITH	NaS	VRB
LL	X	X	X	X	-	X	X	X
LF	-	-	X	-	-	X	X	X
FRSR	-	-	X	X	-	X	X	X
CRSR	X	X	X	X	-	X	X	X
Back Up	X	-	X	X	-	X	X	X
T&D	-	-	X	-	X	X	X	X
T&ER	-	-	X	X	X	X	X	X
Application	LM	LM	LM, PQ	PQ	PQ	LM, PQ	LM, PQ	LM, PQ

Table 2. Data used in AHP and fuzzy simulations.

Criteria	CAES	PHS	H_2	FLY	SUP	LITH	NaS	VRB
EF	75	80	55	90	95	90	80	85
Costs	450	750	1200	400	3000	1500	2000	2500
LM	0.65	0.60	0.80	0.40	0.25	0.80	0.80	0.80
TM	0.85	0.85	0.50	0.80	0.70	0.75	0.65	0.60
Impacts	0.55	0.75	0.80	0.90	0.90	0.80	0.75	0.70
PQ	0.40	0.40	0.85	0.80	0.65	0.85	0.85	0.85

the proposed arrangement was to facilitate the development of the simulation steps and facilitate understanding of the method. Both these aspects are essential to corroborate the final solutions aligned with the main problem statement. The classification defined for each scenario is presented below:

1) Power Quality Scenario: 1st power quality, 2nd efficiency and load management, 3rd technical maturity, 4th environmental impacts and 5th costs.

2) Costs Scenario: 1st costs, 2nd efficiency and power quality, 3rd load management, 4th technical maturity and 5th environmental impacts.

3) Environment Scenario: 1st environmental impacts, 2nd efficiency and load management, 3rd technical maturity, 4th power quality and 5th costs.

4. AHP Analysis

The Analytic Hierarchy Process (AHP) was proposed by Saaty [13]. As described previously, the AHP method is based on pairwise comparisons. It uses a subjective assessment of relative importance converted into a set of overall scores (weights), classifying in this way the structure of the problem in a hierarchical way. According to [14], the use of AHP as the single decision support tool may be very problematic, largely because this method can, in some cases, overlook the relationship between values and judgments. For this reason, the main considerations observed in [14] and the consistency ratio (C.R.) developed by Saaty [13] are verified in this study. To find the C.R., AHP makes use of a consistency index (C.I.) that prevents priorities from being accepted if the inconsistency level is high. In order to measure the deviation of a pairwise matrix from "consistency", the C.I. is defined by

$$\text{C.I.} = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

where $\lambda_{\max} - n$ is the deviation of the judgments from the consistency approximation.

A random index R.I. (of order n elements) is calculated as the average of the C.I. of many reciprocal matrices randomly generated from the scale 1 to 9, with reciprocals forced. The values of R.I. for matrices can be found in [13]. The ratio of C.I. to R.I. for the same order matrix is called the consistency ratio (C.R.). According to Saaty, "a consistency ratio of 0.10 or less is considered acceptable". That is, an inconsistency is stated to be a matter of concern if C.R. exceeds 0.1, in which case the pairwise comparisons should be reexamined.

It is important to emphasize that the fuzzy sets will be applied in the same practical scenarios previously analyzed by AHP. Thus, it will provide a good comparison of the consistency between the two methods.

Before one applies the AHP method, it is necessary to select the criteria and the alternatives. In addition, it is essential to consider an actual database for the specific case under analysis. Subsequently, criteria and alternatives can be placed into an AHP hierarchy, which is then used to construct the pairwise comparison matrix (PCM). For this, the weights of the criteria need to be estimated. This is done via measurement of AHP, which is based on the theory defined by Saaty, as presented in **Table 3**.

Therefore, as shown in **Table 4**, one weight is assumed for each pairwise comparison defined according to the analysis in **Table 2**. In addition, five more tables are constructed, considering in this way every criteria and each final possible alternative (ESS). Later, as shown in **Table 5**, one weight is assumed for the pairwise comparisons, taking into account only the criteria, and with regard to the priority classification defined earlier for the power quality scenario. This step results in

Table 3. Comparisons defined by saaty.

Weight	Comparisons	Explanation
1	Equal	Two activities contribute equally to the objective
3	Moderate (weak)	Experience and judgment slightly favor one activity over another
5	Essential (strong)	Experience and judgment strongly favor one activity over another
7	Very strong	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute (extreme)	The evidence favoring one activity over another is of the highest possible order of affirmation

Table 4. PCM: Alternative × alternative—power quality criterion.

Criterion 6: Power Quality—C.R. = 0.0399									
	CAES	PHS	H_2	FLY	SUP	LITH	NaS	VRB	RW
CAES	1.00	1.00	0.14	0.20	0.20	0.14	0.14	0.14	0.02
PHS	1.00	1.00	0.14	0.14	0.20	0.14	0.14	0.14	0.02
H_2	7.00	7.00	1.00	1.00	3.00	1.00	1.00	1.00	0.17
FLY	5.00	7.00	1.00	1.00	3.00	1.00	1.00	1.00	0.17
SUP	5.00	5.00	0.33	0.33	1.00	0.33	0.33	0.33	0.07
LITH	7.00	7.00	1.00	1.00	3.00	1.00	0.33	0.33	0.14
NaS	7.00	7.00	1.00	1.00	3.00	3.00	1.00	1.00	0.20
VRB	7.00	7.00	1.00	1.00	3.00	3.00	1.00	1.00	0.20

the construction of two more tables, one for each scenario.

Tables 4 and **5** present the consistency ratio (C.R.) and the relative weights (RW) computed by the simulation of AHP method considering each PCM. According to Saaty, the results of C.R. must be less than 0.1 for the analysis of more than five elements (criteria). To find the RW, the data of each column are summed. Each single data of the PCM is then divided by the sum of the column in which this data is placed. Later, the data resulting from this division is summed to find the RW, considering each line of the matrix separately.

To find the classification of the ESS, the relative weights (RW) presented in **Table 4** are therefore multiplied by the relevant RW estimated in **Table 5**. The Final Relative Weights (FRW) are described by the sum of these multiplications. All the calculated FRWs representing the ESS classification are shown in **Table 6**, according to AHP analysis.

5. Fuzzy Logic

Fuzzy logic was proposed by Zadeh. Fuzzy logic is considered one of the most powerful control methods encompassing many fields of application [15]. Fuzzy logic is tested for the same case study by using MATLAB® software, under multi-rules-based decisions and multi-set considerations.

Table 5. PCM: Criterion × criterion—power quality scenario.

Scenario 1: Power Quality—C.R. = 0.0551							
	EF	LM	TM	COST	EI	PQ	RW
EF	1.00	1.00	3.00	7.00	5.00	0.33	0.20
LM	1.00	1.00	3.00	7.00	5.00	0.33	0.20
TM	0.33	0.33	1.00	3.00	3.00	0.14	0.08
COST	0.14	0.14	0.33	1.00	0.33	0.11	0.03
LC	0.20	0.20	0.33	3.00	1.00	0.14	0.05
PQ	3.00	3.00	7.00	9.00	7.00	1.00	0.44

Table 6. ESS final classification in AHP—power quality scenario.

	EF	LM	TM	COST	IMPAC	PQ	FRW	CL
CAES	0.01	0.02	0.02	0.00	0.00	0.01	0.057	4th
PHS	0.01	0.02	0.02	0.00	0.00	0.01	0.055	4th
H_2	0.00	0.05	0.00	0.00	0.00	0.09	0.148	2nd
FLY	0.04	0.01	0.02	0.01	0.01	0.07	0.167	1st
SUP	0.04	0.00	0.01	0.00	0.01	0.04	0.103	3rd
LITH	0.04	0.04	0.01	0.00	0.01	0.06	0.164	1st
NaS	0.02	0.04	0.00	0.00	0.00	0.09	0.151	2nd
VRB	0.02	0.04	0.00	0.00	0.00	0.09	0.156	2nd

The multi-rules-base used in this work consists of a collection of if-then propositions. Using MATLAB® software, the Mamdani method was applied in the fuzzy inference process and the center of gravity method in the defuzzification process [16].

A basic Mamdani fuzzy system accepts numbers as input, then translates the input numbers into linguistic terms such as low, medium, high (fuzzification). Rules map the input linguistic terms into similar linguistic terms describing the output [17]. Finally, the output linguistic terms are translated into an output number (defuzzification). The main idea of the Mamdani is to describe process states by means of linguistic variables and to use these variables as inputs to control rules. The linguistic terms are represented in fuzzy sets with a certain shape. It is popular to use trapezoidal or triangular fuzzy sets due to their computational efficiency [18].

The number of linguistic terms in each fuzzy set determines the number of rules. In most applications, certain states can be neglected either because they are impossible or because a control action would not be helpful. It is therefore sufficient to write rules that cover only parts of the state space. Definition of linguistic variables and rules constitute the main design steps when implementing a Mamdani controller. In addition, an appropriate classification of the parameters is essential to corroborate the outcome of the fuzzy method.

The choice of Mamdani controller relates to the following aspects [19]:

- it is suitable for engineering systems because its inputs and outputs are real-valued variables;
- it provides a natural framework for incorporating fuzzy rules from human experts;
- there is much freedom in the choices of fuzzifier, fuzzy inference engine, and defuzzifier;
- it provides an effective framework in which to integrate numerical and linguistic information.

Regarding the defuzzification process, there are several choices to be made and many different methods have been proposed [20]. This study used the so-called Center of Area (COA) or Center of Gravity (COG) method. This method chooses the control action that corresponds to the center of the area with membership greater than zero. The area is weighted with the value of the membership function. The solution is a compromise, due to the fuzziness of the consequences. The choice for COG is justified because the use of this method is advisable not only for quantitative but also for qualitative analysis.

To simulate the fuzzy analysis, it is essential to share the six criteria described in two sub-groups, quantitative and qualitative criteria, as already explained in section 2. The data and the weights used to evaluate these criteria were presented in **Table 2**. Qualitative criteria are expressed through weights (defined by the selected specialists in intervals from 0 to 1.0) to be applied in the fuzzy sets.

The multi-sets that characterize each criterion are displayed in **Figure 1**. The number of membership functions used in each criterion of the fuzzy set and the multi-rules is determined according to the relevance criteria (section 3). In addition, both shape and position of fuzzy set are chosen taking into account the need of each analysis criterion for this study case.

The final classification of the ESS is presented in **Table 7**. It is calculated using fuzzy logic and is associated with the power quality scenario.

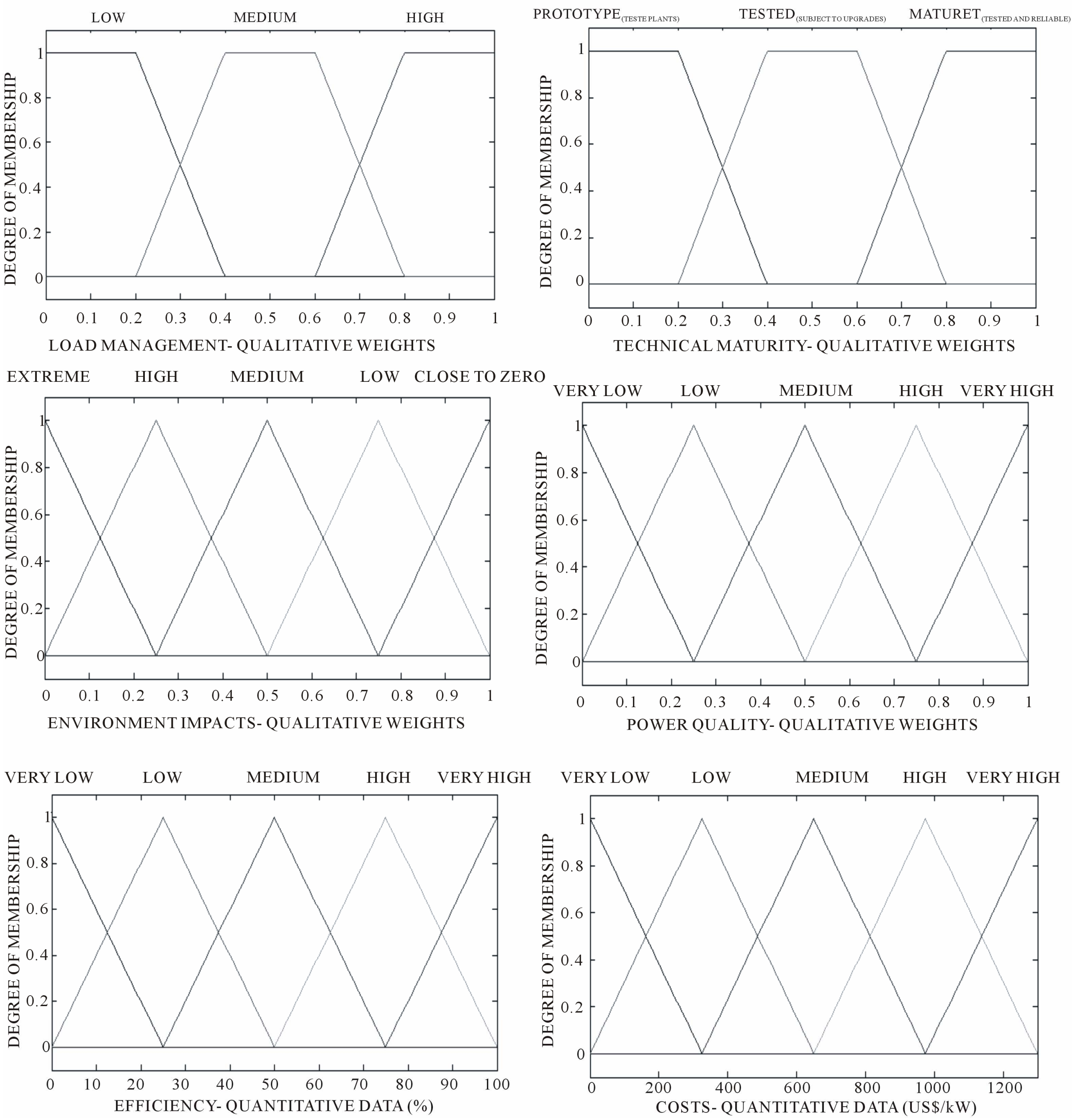

Figure 1. Fuzzy sets for each criterion—ESS analysis.

6. Results and Comparison: AHP and Fuzzy

Table 7 presents the final relative weights and the classification according to the results achieved by AHP and fuzzy logic, regarding the power quality scenario.

By observing the data presented in **Table 7**, it can be seen that the ESS classification is the same, whether compared with the AHP method or fuzzy logic outcome. These results corroborate the use of both methods for the analysis of the main characteristics of ESS. Accordingly, the flywheel and the lithium-ion battery are the most appropriate choices for the power quality scenario. Furthermore, the environmental and costs scenarios were also evaluated by the AHP method and fuzzy logic. As predicted, the most appropriate choices for these scenarios computed by the two methods were the same. In these analyses, the Flywheel was selected again for both environmental and costs scenarios. The final results are presented in **Table 8**, according to the three situations analyzed.

It is important to emphasize that this study may consider several criteria and scenarios. This can be done simply by evaluating and changing the AHP and the fuzzy method (sets and rules) for each case under analysis.

Table 7. Final classification in AHP and Fuzzy—power quality scenario.

	AHP		Fuzzy	
	FRW	CL	FRW	CL
CAES	0.057	4th	0.381	4th
PHS	0.055	4th	0.383	4th
H_2	0.148	2nd	0.751	2nd
FLY	0.167	1st	0.757	1st
SUPERC	0.103	3rd	0.528	3rd
LITH	0.164	1st	0.756	1st
NaS	0.151	2nd	0.751	2nd
VRB	0.156	2nd	0.751	2nd

Table 8. Most appropriate ESS in AHP and Fuzzy—all scenarios in analysis.

Scenario	AHP		Fuzzy	
	FRW	ESS	FRW	ESS
Power Quality	0.167	FLY	0.757	FLY
Power Quality	0.164	LITH	0.756	LITH
Costs	0. 201	FLY	0.863	FLY
Environment	0.145	FLY	0.741	FLY

7. Conclusions

This paper presented a study for finding an appropriate ESS, by evaluating its key operational characteristics in the context of the power quality scenario. To achieve this objective, the AHP and fuzzy logic related to quantitative and qualitative criteria were used. During the AHP simulation, the considerations observed in [14] were verified. It may be concluded that the AHP method respects the relationship between values and judgments in the majority of analyses, considering the previous set of decision makers' weights and the final results obtained by the simulations.

A prior classification of criteria was defined in relation to each scenario. This arrangement facilitated the development of the simulation steps and led to better understanding of the method. The final results offered the same ESS classification for both AHP method and fuzzy logic. These outcomes corroborate the effectiveness of AHP and fuzzy logic, and also validate the use of the prior classification of the criteria for both methods. In addition, they confirm that the relationship between values and judgments is respected by the AHP analysis in this case study.

The outcome achieved by both methods for the power quality scenario—flywheel and the lithium-ion battery as the most appropriate choices—is corroborated because these technologies support the Quality and Load Management characteristics as a whole, such as load leveling, fast response spinning reserve, conventional spinning reserve, transmission and distribution stabilization, among others.

Regarding ESS selection for costs and environment scenarios, the flywheel is selected again as the most appropriate technology. It is easily justified because the flywheel offers high density energy, high efficiency, high life cycle, low costs and it does not entail any kind of negative environmental impact.

To summarize, this paper presents essential aspects of the potential of storage energy systems for the improvement of system management, taking into account not only power quality, but also costs and environmental constraints

8. Acknowledgements

The authors would like to thank CAPES for its financial support.

9. References

[1] National Regulatory Agency of Electrical Energy, ANEEL—Incentive Program for Alternative Sources of Energy, Law 10.438/2002.

http://www.mme.gov.br/programs_display.do?chn=877.

[2] A. Farret and M. G. Simoes, "Integration of Alternative Sources of Energy," John Wiley & Sons, Hoboken, 2006.

[3] E. Løken, "Use of Multicriteria Decision Analysis Methods for Energy Planning Problems," *Renewable and Sustainable Energy Reviews*, Vol. 11, No. 7, 2007, pp. 1584-1595. doi:10.1016/j.rser.2005.11.005

[4] C. Zopounidis and M. Doumpos, "Multicriteria Classification and Sorting Methods: A Literature Review," *European Journal of Operational Research*, Vol. 138, No. 2, 2002, pp. 229-246. doi:10.1016/S0377-2217(01)00243-0

[5] M. Beccali, M. Cellura and M. Mistretta, "Decision-Making in Energy Planning-Application of the ELECTRE Method at Regional Level for the Diffusion of Renewable Energy Technology," *Renewable Energy*, Vol. 28, No. 13, 2003, pp. 2063-2087. doi:10.1016/S0960-1481(03)00102-2

[6] M. Behzadian, R. B. Kazemzadeh, A. Albadvi and M. Aghdasi, "PROMETHEE: A Comprehensive Literature Review on Methodologies and Applications," *European Journal of Operational Research*, Vol. 200, No. 1, 2010, pp. 198-215. doi:10.1016/j.ejor.2009.01.021

[7] F. Montignac, I. Noirot and S. Chaudourne, "Multi-Criteria Evaluation of on-Board Hydrogen Storage Technologies Using the MACBETH Approach," *International Journal of Hydrogen Energy*, Vol. 34, No. 10, 2009, pp. 4561-4568. doi:10.1016/j.ijhydene.2008.09.098

[8] B. A. Akash, R. Mamlook and M. S. Mohsen, "Multi-Criteria Selection of Electric Power Plants Using Analytical Hierarchy Process," *Electrical Power System Research*, Vol. 52, No. 1, 1999, pp. 29-35. doi:10.1016/S0378-7796(99)00004-8

[9] I. J. Ramírez-Rosado and J. A. Domínguez-Navarro, "Possibilistic Model Based on Fuzzy Sets for the Multiobjective Optimal Planning of Electric Power Distribution Networks," *IEEE Transactions on Power System*, Vol. 19, No. 4, 2004, pp. 1801-1810. doi:10.1109/TPWRS.2004.835678

[10] W. Clark and W. Isherwood, "Distributed Generation; Remote Power Systems with Advanced Storage Technologies," *Energy Policy*, Vol. 32, No. 14, 2004, pp. 1573-1589. doi:10.1016/S0301-4215(03)00017-X

[11] The Electricity Storage Association, Technology Comparisons, Electricity Storage Association, 2003. http://electricitystorage.org

[12] A. Gonzalez, B. Gallachóir, E. McKeogh and K. Lynch, "Study of Electricity Storage Technologies and Their Potential to Address Wind Energy Inter. in Ireland," 2004. http://www.seai.ie/Grants/Renewable_Energy_RD_D/Projects_funded_to_date/Wind/Study_of_Elec_Storage_Technologies_their_Potential_to_Address_Wind_Energy_Intermittency_in_Irl/

[13] T. L. Saaty, "The Analytic Hierarchy Process," McGraw-Hill, New York, 1980.

[14] A. Bana e Costa and J. Vansnick, "A Critical Analysis of the Eigenvalue Method Used to Derive Priorities in AHP," *European Journal of Operational Research*, Vol. 187, No. 1, 2008, pp. 1422-1428. doi:10.1016/j.ejor.2006.09.022

[15] L. A. Zadeh, "Fuzzy Logic," University of California, Berkeley, 1988.

[16] W. Pedrycz, F. Gomide, "An Introduction to Fuzzy Sets: Analysis and Design," The MIT Press, Cambridge, 1998.

[17] W. Siler and J. Buckley, "Fuzzy Expert Systems and Fuzzy Reasoning," John Wiley & Sons, Hoboken, 2005.

[18] H. Zimmermann, "Fuzzy Set Theory and Its Applications," Springer, Berlin, 2001. doi:10.1007/978-94-010-0646-0

[19] L.-X. Wang, "Adaptive Fuzzy Systems and Control: Design and Stability Analysis," Prentice Hall, Upper Saddle River, 1993.

[20] L. C. Barros and R. C. Bassanezi, "Tópicos de Lógica Fuzzy e Biomatemática," Unicamp-Imecc, Campinas, 2006.

