Selection of power generation technology in Libya using grey theory approach

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Abstract

With growing world population and rapid industrial economic growth in developing countries, demand for power generation becomes essential. Libya is among these countries and its demand increased as well to fulfil the local needs. There are some research papers carried out about power generation in Libya concentrated in the renewable power generation and treated a single technology to generate power. This paper covers the gap and compare some different technologies to facilitate the decision making process for selecting among these technologies. Selection of an appropriate power generation technology is a complex process. It is necessary to consider and take into account a wide range of parameters. This paper presents the determination of these parameters which influence the selection of power generation technology in particularly for developing countries.

Some parameters were chosen which influence the power generation technology selection. A questionnaire was used to collect the information by some experts in the field of power generation technologies. This paper answers the question of the best suitable technology for Libya because the investment in this field is so costly and making a wrong decision is not allowed, otherwise it will consume the big margin of the initial budget. Four main criteria are included in this paper that are economic, environmental, technical and social. A sub-criteria are also included to support this decision. The performances of six technologies of a power generation are evaluated by grey theory analysis and the best technology is selected.

Key Words: Power Generation, Multi Criteria, Grey Theory, Libya.

1. Introduction

Power generation and the availability of electricity can be considered as the backbone of other industries in all around the world especially in developing countries. The need for electricity is so essential and important in the human life whether in villages or big cities. For developing countries electricity is one of most important because all other needs depend on electricity.

According to Robert Hamweg [1], the main aspects and consideration when thinking of parameters controlling power generation technologies are some of them economic, social, environmental, technological. Integrated resource planning (IRP) got also to be considered for the target countries including the aspects mentioned above. He has divided the major environmental issues of power generation into two categories, one is Global environmental issues and the second is local/ regional environmental issues.

Yildirim and Erkan [2] studied the increasing consumption of electricity exposed countries to build additional power units. There are some technical and economical differences of the energy sources, generation planning is used to determine the best unit type for additional capacity. The assessment of costs in support of decision making should reflect this national policy objectives. The economic parameters vary between countries, even between regions, also change with time.

According to Hipkin [3], south Africa has limited financial resources which restrains technological adoption and expansion. Operations and maintenance staff will be challenged to handle new technology with existing systems and procedures. In technology transfer, the maintenance playing the major factor especially in developing countries. Leonard-Barton's [4] asserted that the maintenance is one of the most problematic issues in the technology management.

Zhouying [5] indicated and pointed out that the economic and technological gap between developed and developing countries can largely be explained by the level of soft technology and soft environments between the two sets of countries. It is well known that the shortage of soft technology experts can be considered as the core problem. Widiyanto [6] draw the attention & importance of set of criteria for optimized selection includes five areas of concern; energy economy, energy security, environmental protection, socio-economic development and technological aspects for electrical power generation.

Breeze [7] reported that, at the beginning of the twenty-first century, the new power plant offering the cheapest source of electricity appears to be the gas-fired combined cycle power station. It is cheap and quick to build and relatively easy to maintain. The fuel is the most significant determinant of electricity price, so while gas is cheap, so is electricity. There are some other factors such as the effect of power production on the environment and on human health, factors which society pays for but not the electricity producer or consumer directly. These factors are called externalities.

Also, Aljamel [8] indicated that the capital, fuel and O&M costs are at top of the criteria which effect the power generation directly in the developing countries.

Khalil and Asheibi [9] presented analytical data for the current and future energy situations in Libya. They concluded that there is a great potential for utilizing, home grid connected photovoltaic systems, large scale grid connected electricity generation using wind farms, and concentrated photovoltaic system CPS. Solar energy resources in particular can be a great source of energy for Libya after oil and natural gas.

Ahmed et. al. [10] investigated the financial and technological challenges and opportunities facing the utilisation of renewable energy resources in Libya. They aim to study and identify the contribution of renewable energy in the mixture of total energy supply in Libya.

They pointed out that solar and wind energy are considered the main sources of renewable energy in addition to wave and tidal energy. In addition, it has been found that energy demand is increasing in Libya and that renewable energy could be the solution to cover some of this demand.

2. Method

2.1 Preliminaries

The Grey system theory, established by Deng in 1982 [11], is a methodology that focuses on solving problems involving incomplete information or small samples. The technique can be applied to uncertain systems with partially known information by generating, mining, and extracting useful information from available data so that the system behaviours and their hidden laws of evolution can be accurately described. It uses a Black-Grey-White colour to describe complex systems [12], the concepts of a grey system can be illustrated as in Figure 1. A grey number is a kind of figure that we only know the range of values, and do not know an exact value. This number can be an interval or a general number set to represent the degree of uncertainty of information. This section describes the basics about Grey systems theory and Grey numbers in order to understand the proposed model.

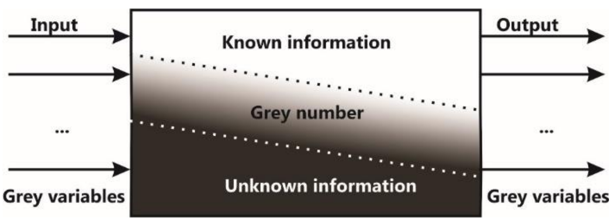

Figure 1: The concept of Grey System

2.1.1 Definition of grey number

Let X is the universal set. Then a Grey set G of X is defined by its two mappings $\overline{\mu}_G(X)$ and $\underline{\mu}_G(X)$: $\overline{\mu}_G(X) : X \longrightarrow [0,1]$ and $\underline{\mu}_G(X)$: $X \longrightarrow [0,1]$ such that $\overline{\mu}_G(X) \geq \underline{\mu}_G(X)$, $x \in X$. Since the lower limit $\otimes G = [\underline{G},\infty)$ and upper limit $\otimes G = (-\infty,\overline{G}]$ can possibly be estimated, G is defined as an interval grey number $\otimes G = [\underline{G},\overline{G}]$ where $\underline{G} > \overline{G}$. Let t be the information, $\overline{G}$ the upper, $\underline{G}$ the lower limit then $\underline{G} \leq t \leq \overline{G}$ if $\underline{G} = \overline{G}$ then $\otimes G$ is a white number with a crisp value which shows the existence of full knowledge. On the contrary, a black number is a grey number one known nothing about it.

2.1.2 Basic operations on Grey numbers

The arithmetic of grey numbers is similar to interval value [13,14] and the operation rules of general grey numbers can be defined as operation rules of real numbers [].

Addition: $\otimes G_1 + \otimes G_2 = [\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2]$

Subtraction:
$\otimes G_1 - \otimes G_2 = [\underline{G}_1 - \overline{G}_2, \overline{G}_1 - \underline{G}_2]$

Multiplication:
$$\otimes G_1 \times \otimes G_2 = \begin{bmatrix} min(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\ \overline{G}_2), \\ max(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\ \overline{G}_2) \end{bmatrix}$$

Division: $\otimes G_1 \div \otimes G_2 = [\underline{G}_1, \overline{G}_1] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\underline{G}_2}\right]$

Length of grey number: $L(\otimes G) = |\overline{G} - \underline{G}|$

Comparison of grey numbers: the possibility degree of two grey number is expressed as:

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{max\left(0, L^* - max\left(0, \overline{G}_1 - \underline{G}_2\right)\right)}{L^*}$$

Where $L^* = L(\otimes G_1) + L(\otimes G_2)$

According to this comparison of two grey numbers there may be four distinct outcomes:

If $\otimes G_1 = \otimes G_2$ then $P\{\otimes G_1 \leq \otimes G_2\} = 0.5$ if $P\{\otimes G_1 > \otimes G_2\}$ then $P\{\otimes G_1 \leq \otimes G_2\} = 1$

If $\otimes G_1 < \otimes G_2$ then $\{\otimes G_1 \leq \otimes G_2\} = 0$

If $P\{\otimes G_1 \leq \otimes G_2\} > 0.5$ then $\otimes G_2 > \otimes G_1$

Otherwise if $P\{\otimes G_1 \leq \otimes G_2\} < 0.5$ then $\otimes G_2 < \otimes G_1$

2.2 Proposed approach

Step 1. Determine the attribute weights: Attribute weight W_j can be calculated as follows:

$$\otimes W_j = \frac{1}{K}\left[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K\right] \quad (1)$$

$$\otimes W_j^K = \left[\underline{W}_j^K, \overline{W}_j^K\right] \quad (2)$$

Step 2. Alternatives evaluated by the decision makers: decision makers use linguistic or verbal variables when evaluating alternatives according to various criteria.

$\otimes G_{ij}^K, (i = 1,2,\ldots,m; j = 1,2,\ldots,n)$ is the attribute value given by the kth decision maker to any attribute value of the alternative. In grey system this value is shown as, $\otimes G_{ij}^K = \left[\underline{G}_{ij}^K, \overline{G}_{ij}^K\right]$ and computed as:

$$\otimes G_j = \frac{1}{K}\left[\otimes G_j^1 + \otimes G_j^2 + \cdots + \otimes G_j^K\right]$$

Step 3. The construction of Grey Decision Matrix:

$$G = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \cdots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \cdots & \cdots & \otimes G_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1} & \otimes G_{m2} & \cdots & \cdots & \otimes G_{mn} \end{bmatrix} \quad (3)$$

Step 4. The normalization of Decision Matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* & \cdots & \cdots & \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* & \cdots & \cdots & \otimes G_{2n}^* \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1}^* & \otimes G_{m2}^* & \cdots & \cdots & \otimes G_{mn}^* \end{bmatrix} \quad (4)$$

For a benefit attribute $\otimes G_{ij}^*$ is expressed as

$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right]$ where $G_j^{max} = max_{1<i<m}\{\overline{G}_{ij}\}$ and for a cost attribute $\otimes G_{ij}^*$ is expressed as

$\otimes G_{ij}^* = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}}\right]$ where $G_j^{min} = min_{1<i<m}\{\underline{G}_{ij}\}$.

Step 5. Weighted Normalized Grey Decision Matrix normalized D^* matrix is weighted by the

$\otimes V_{ij} = \otimes G_{ij}^* X \otimes W_j$

Process which establishes the weighted normalised grey decision matrix D_W^*.

$$D_W^* = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \cdots & \cdots & \otimes V_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \cdots & \otimes V_{mn} \end{bmatrix} \quad (5)$$

Step 6: Determine the ideal alternative

From a set m alternatives, $S = \{s_1, s_2, \dots, s_m\}$, the ideal alternative S^{max} is determined by

$$S^{max} = \left\{\left[\max_{1\le i\le m} \underline{V}_{i1}, \max_{1\le i\le m} \overline{V}_{i1}\right], \left[\max_{1\le i\le m} \underline{V}_{i2}, \max_{1\le i\le m} \overline{V}_{i2}\right], \dots, \left[\max_{1\le i\le m} \underline{V}_{in}, \max_{1\le i\le m} \overline{V}_{in}\right]\right\}$$

Step 7. Calculate the grey possibility degree

The grey possibility degree can be obtained by comparing ideal alternatives S^{max} and possible alternatives $S = \{s_1, s_2, \dots, s_m\}$.

$$P\{S_i \le S^{max}\} = \frac{1}{n}\sum_{j=1}^{n} P\{\otimes V_{ij} \le G_j^{max}\}$$

Step 8. Rank the order of alternatives

Rank order of the alternatives according to the grey possibility degree determined in the 7th step. Smaller the grey possibility degree $P\{S_i \le S^{max}\}$, better the rank order of Si. Otherwise, the rank order is worse.

3. Case study

Before taking any decision to select a power generation technology to generate electricity, it is very important to carry out research to determine all parameters which they influence and support the correct decision for such selection. There is no permittivity to take any mistake or misleading decisions which may adversely affect the economies for developing countries. The information data where provided from some power stations in Libya. The results are collected and gathered taking into account the economical, environmental, social and technical parameters. Some of these parameters effect the population around the power plant, others may have some effect on the safety of society in developing country such as a nuclear power plants.

Some of these parameters can be considered in some countries but are not a vital & important affect because some technologies can not be applicable due to the absence of climatic causes such as hydropower or other reasons.

Table 1.: Different attributes

Qi	Attributes	Sub-attributes
Q1	Economic	Investment cost
		Operation & maintenance cost
		Plant life
		Development
Q2	Environmental	Emissions
		Land use
		Noise
		River and floodways
		Archaeological and historical sites
Q3	Technological	Efficiency
		Safety
		Reliability
		Power transmission
		Power demand
Q4	Social	Job creation
		Public acceptance
		social benefits

Where Qi is the criteria index.

Some technologies are more appropriate than others for developing countries:

- T_1: Oil fired power generation.
- T_2: Gas fired power generation.
- T_3: Wind power generation.
- T_4: Solar photovoltaic power generation.
- T_5: Thermal power generation (solar)
- T_6: Geothermal power generation.

Due to some reasons the technologies are excluded from methods and technologies of power generation such as:

- Diesel engines are normally used at small scale (Villages) or emergency cases.
- Fuel cells power generation technology cannot compete with its high installation costs compared with other generation technologies. With the exception of the PAFC (Phosphoric Acid Fuel cell). Fuel cells are unproven commercially.
- Some of developing countries are far from the sea and oceans, which prevents them from usage of tidal phenomenon for electric power generation.

4. Results and discussion.

In this research work, the different parameters (economic, environmental, technological and social) have been analysed in the following steps:

Step 1: The attributes are rated according to the scale given in table 2 to determine the attribute weights. This step was justified by the experts. The ratings and their evaluation results are clearly illustrated in table 3.

Table 2. The scale of attribute ratings *G* [2]

Scale	⊗ w
Very Low **VL**	[0.0,0.1]
Low **L**	[0.1,0.3]
Medium Low **ML**	[0.3,0.4]
Medium **M**	[0.4,0.5]
Medium High **MH**	[0.5,0.7]
High **H**	[0.7,0.9]
Very High **VH**	[0.9,1.0]

Table 3. Ratings and the evaluation results

Attribute ratings and the results					⊗ w
Qj	D1	D2	D3	D4	
Q1	VH	VH	H	H	[0.75 0.95]
Q2	VH	M	L	VH	[0.58 0.70]
Q3	VH	H	H	H	[0.68 0.93]
Q4	VH	L	M	M	[0.45 0.58]

Table 4. The scale of attribute ratings $\otimes G$

Scale	⊗ G
Very Poor **VP**	[0,1]
Poor **P**	[1,3]
Medium Poor **MP**	[3,4]
Fair **F**	[4,5]
Medium Good **MG**	[5,6]
Good **G**	[6,8]
Very Good **VG**	[8,10]

Step II: Evaluate the different technologies' attributes considering the attribute ratings given in Table 4. The evaluation results are given in Table 5. This step also done by the experts.

Step III: By the assessment of the consequences, grey decision matrix D is generated.

Table 5. Technology attributes evaluated by experts

Qj	Tj	D1	D2	D3	D4	⊗ Gij
Q1	T1	F	VG	MP	G	[5.50 7.00]
	T2	F	VG	P	VG	[5.75 7.00]
	T3	MG	G	F	F	[4.75 6.25]
	T4	MG	G	MG	MG	[5.25 6.75]
	T5	MG	G	VG	MG	[6.25 7.75]
	T6	MG	MG	G	F	[5.00 6.50]
Q2	T1	G	VG	VG	VG	[8.25 9.75]
	T2	G	G	G	G	[6.00 9.00]
	T3	VP	P	MG	MG	[2.75 4.00]
	T4	VP	P	F	P	[1.50 3.00]
	T5	P	P	P	P	[1.00 3.00]
	T6	P	F	MP	VP	[2.00 3.25]
Q3	T1	G	VG	MP	VG	[6.75 8.25]
	T2	G	VG	F	VG	[7.00 8.50]
	T3	G	MG	MG	F	[5.00 6.50]
	T4	VG	MG	G	G	[6.50 8.50]
	T5	G	MG	VG	F	[6.00 7.50]
	T6	MG	F	G	F	[4.75 6.25]
Q4	T1	G	G	P	VG	[5.50 7.75]
	T2	G	G	MP	VG	[6.00 8.00]
	T3	G	F	F	G	[5.00 7.00]
	T4	G	G	F	VP	[4.00 6.00]
	T5	G	G	F	P	[4.25 6.50]
	T6	G	F	F	VP	[3.50 5.00]

Step IV: Grey decision matrix D is normalized and results expressed in normalized grey decision matrix D*

$$D = \begin{bmatrix} [5.50\ 7.00] & [8.25\ 9.75] & [6.75\ 8.25] & [5.50\ 7.75] \\ [5.75\ 7.00] & [6.00\ 9.00] & [7.00\ 8.50] & [6.00\ 8.00] \\ [4.75\ 6.25] & [2.75\ 4.00] & [5.00\ 6.50] & [5.00\ 7.00] \\ [5.25\ 6.75] & [1.50\ 3.00] & [6.50\ 8.50] & [4.00\ 6.00] \\ [6.25\ 7.75] & [1.00\ 3.00] & [6.00\ 7.50] & [4.25\ 6.50] \\ [5.00\ 6.50] & [2.00\ 3.25] & [4.75\ 6.25] & [3.50\ 5.00] \end{bmatrix}$$

$$D^* = \begin{bmatrix} [0.68\ 0.86] & [0.10\ 0.12] & [0.79\ 0.97] & [0.69\ 0.97] \\ [0.68\ 0.83] & [0.11\ 0.17] & [0.82\ 1.00] & [0.75\ 1.00] \\ [0.76\ 1.00] & [0.25\ 0.36] & [0.59\ 0.76] & [0.63\ 0.88] \\ [0.70\ 0.90] & [0.33\ 0.67] & [0.76\ 1.00] & [0.50\ 0.75] \\ [0.61\ 0.76] & [0.33\ 1.00] & [0.71\ 0.88] & [0.53\ 0.81] \\ [0.73\ 0.95] & [0.31\ 0.50] & [0.56\ 0.74] & [0.44\ 0.63] \end{bmatrix}$$

Step V: considering each attribute importance, then the normalized decision matrix was weighted by the attribute weights according to results in the weighted normalized grey matrix D^*_w.

$$D_W^* = \begin{bmatrix} [0.51\ 0.82] & [0.06\ 0.08] & [0.54\ 0.90] & [0.31\ 0.56] \\ [0.51\ 0.78] & [0.06\ 0.12] & [0.56\ 0.93] & [0.34\ 0.58] \\ [0.57\ 0.95] & [0.14\ 0.25] & [0.40\ 0.71] & [0.28\ 0.50] \\ [0.53\ 0.86] & [0.19\ 0.47] & [0.52\ 0.93] & [0.23\ 0.43] \\ [0.46\ 0.72] & [0.19\ 0.70] & [0.48\ 0.82] & [0.24\ 0.47] \\ [0.55\ 0.90] & [0.18\ 0.35] & [0.38\ 0.68] & [0.20\ 0.36] \end{bmatrix}$$

Step VI: The grey possibility degree of technologies for each criterion is determined with reference to the ideal Technology Tmax. The Tmax is obtained as shown below:
Tmax = {[0,57 0,95], [0,19 0,47], [0,56 0,93], [0,34 0,58]}
Step VII: Each technology is compared with the Tmax to determine the grey possibility degree. The result of such comparison is as follows:

$P\{T_1 \leq T^{max}\}$ = 0.68	$P\{T_2 \leq T^{max}\}$ =0.67	$P\{T_3 \leq T^{max}\}$ =0.69
$P\{T_4 \leq T^{max}\}$ =0.60	$P\{T_5 \leq T^{max}\}$ =0.62	$P\{T_6 \leq T^{max}\}$ =0.74

Step VIII. Sort the technologies according to their grey possibility degree in descending order.
The smaller the grey possibility degree, the better the rank order.
According to the probability degree obtained in step seven, the rank order will be as follows:
T4 > T5 > T2 > T1 > T3 > T6
As it is seen from the rank order, technology T4 is the best technology, while T6 is the worst. The second best technology out of six is T5 and so on.

5. Conclusion

Power generation is an important field to focus in Libya because it will help other sectors to develop and make some contribution to the national economy of developing countries. Technology management was the key to link limited resources, science and knowledge, engineering, economic aspects, social information and communication technologies.

In this paper quantitative and qualitative criteria are used, some of them may include uncertainty and some times may be complex and difficult. The grey theory is a suitable to solve and handle this problem.
The results show that the solar photovoltaic power generation is the best among others to generate power, followed by solar thermal technology. The renewable methods have won and this is agreed with the environmental concern about the climate. Third, the gas fired power generation technology has this rank and its widely available in Libya as a fuel.

6. References

[1] Ropert Hamwey, (1997), Power Generation Technology Guide, International Academy of the Environment, Research for sustainable Economics and Trade, Geneva, Switzerland.

[2] Yildrim, M., and Erkan, K., 2005, Determination of acceptable operating cost level of nuclear energy for Turkey's power system, Energy, University of Kocaeli, Turkey.

[3] Hipkin, I., and Bennett, D., 2003, Managerial perceptions of factors influencing technology management in South Africa, Technovations, University of Exter, UK.

[4] Leonard-Barton D (1995), Wellsprings of knowledge, Boston: Harvard Business School Press

[5] Zhouying, J., 2005, Globalization, technological competitiveness and "catch-up" challenge for developing countries: some lessons of the experience, International journal of Technology Management and Sustinable Development, Chinese Academy of Social Science, 4, pp 35-46.

[6] Widiyan To, A. & Kato, S. (2004), Development of decision model model for selection of appropriate power generation system using distance based approach method, International Journal JSME. Series B, 47, No. 2.

[7] Breez, P., 2005, Power generation technologies, Third edition, Newnes, Book Aid International.
[8] Aljamel, S, A. (2010), Conceptual Framework for Power Generation Technology Management for Deveveloping countries, PhD, Sheffield Hallam University, UK.
[9] Ahmed M. A. Mohamed, Amin Al-Habaibeh, Hafez Abdo and Mohammad Juma R. Abdunnabi, "The significance of Utilizing Renewable Energy Options into the Libyan Energy Mix", Energy Research Journal, 4 (1), 15-23, 2013.
[10] Ashraf Khalil, Ali Asheibi, The Chances and Challenges for Renewable Energy in Libya, 4th International Conference on Renewable Energy Research and Applications, Palermo, Italy, 22-25 Nov 2015.
[11] J.-L. Deng, "Control problems of grey systems," Systems & Control Letters, vol. 1, pp. 288-294, 1982.
[12] S. Liu, et al., "A brief introduction to grey systems theory," in Proceeding of IEEE International Conference on Grey Systems and Intelligent Services 2011, Nanjing, 2011, pp. 1-9.
[13] S. Liu, et al., Grey systems: theory and applications vol. 68: Springer, 2010.
[12] F. Cengiz Dikmen , "Grey theory approach in selection of the best supplier", IJBFMR 3 (2015) 44-52.