Study on Potential of Utilization of Retired Gas-Fired Power Plants in Bangladesh by Using Analytic Hierarchy Process

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Abstract

Electric power generation in Bangladesh is dominated by indigenous natural gas. At present, there is an acute shortage of electricity due to rapid increasing demand and derated generation from state owned, aged, less efficient gas or steam turbine power plants. They need to consider proper utilization after retirement to overcome a national problem of power shortages. This study investigates the alternatives of such utilization and decision making criteria. The alternatives are (a) construction of a new combined cycle power plant at the same site, (b) renovation, modernization and conversion into combined cycle to increase efficiency and lifetime and (c) to maintain old power plant as it is. The decision is based on five criteria by using the Analytic Hierarchy Process (AHP). The criteria are forced outage rate, operation age, generation cost, environmental, and social effects. Expert judgments are used for assessing the importance level of each criterion as well as a final decision on the alternatives. Seven case studies from existing power plants in Bangladesh are employed. The findings indicate that generation cost is the most influential factor for making a decision about an aged gas fired-power plant. Moreover, the alternative, construction of a new combined cycle power plant at the same site is the best option in Bangladesh.

Keyword: Potential of utilization, Retired power plant, Expert judgment, Analytic Hierarchy Process, Gas-fired power plants

1. Introduction

Electricity consumption is one of the indicators of living standards of any nation. In Bangladesh, per capita electricity consumption is 170 kWh whereas generation is 200 kWh. Generation capacity in June 2011 was 6727 MW; about one–fourth of the generation comes from power plants which are at least 20 years old [1]. Therefore, capacity deterioration and number of forced outages are high. Around 500, MW capacity plants cannot produce electricity due to a shortage of gas supply. As a result, dependable generation varies around 4600 MW~5000 MW. In 2011, the average power generation was 4105 MW per day against a demand of 5000 MW to 6000 MW [2]. Power outage or failure is a common phenomenon nowadays and people are facing severe load shedding with voltage fluctuation for an entire day. Besides, only 49% of the total population enjoys electricity facilities [3, 1]. More than 82% of electric power is generated from indigenous natural gas [1]. Fig. 1 shows the fuel types of installed capacity in 2010.

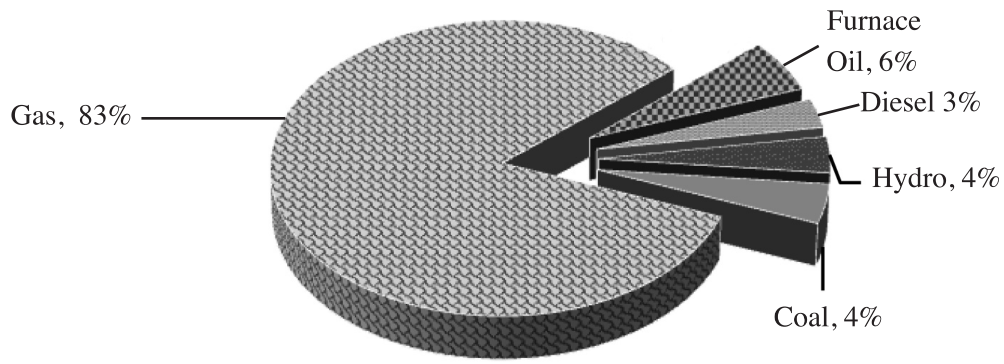

Fig. 1. Installed capacity by fuel type.

The main shortcomings of the power system in Bangladesh are insufficient generation capacity to meet the demand and a large number of aged gas-fired steam turbine or gas turbine power plants with very low efficiency of 25~32%; moreover, the demand is increasing day by day [4]. Fig. 2 shows the plant type generation of electricity in 2010.

The area of Bangladesh is 147500 square kilometers and the present population is 146 million [5]. Government has set the development strategy of electricity generation capacity to 7000 MW by 2013, 8000 MW by 2015, and 20000 MW by 2021, with the vision of electrification of the whole country by 2020. Government hopes to overcome power shortages by implementing ongoing and committed projects of new power plants and renovation and modernization of existing power plants [6]. Most of the projects are dependent on donor agency funding. However, no project has been finished on time due to fund constraints.

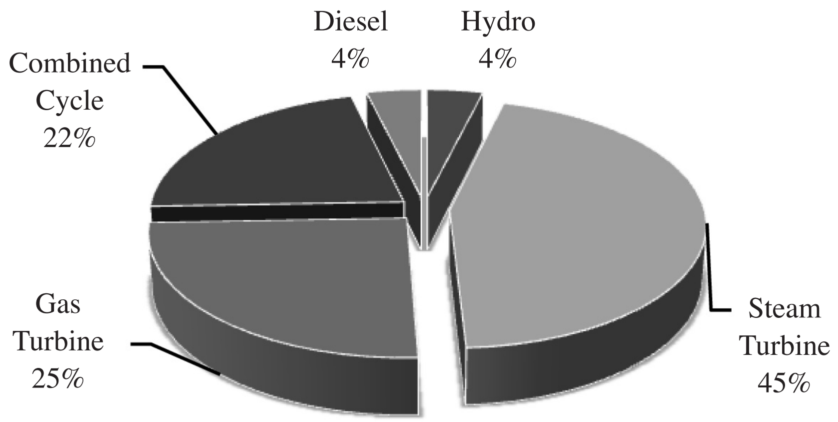

Fig. 2. Electricity generation by plant type.

In this context, there is uncertainty to achieve the electricity addition target within the stipulated time. The power plants which exceed the technical lifetime mentioned in the Power System Master Plan (PMPC) of Bangladesh are treated as retired or decommissioned power plants whether it is in operation or not. According to PMPC-2006, technical age limits of gas turbines, steam turbines, and combined cycle power plants are 20, 25 and 30 years respectively. The total number of gas-fired power plants is 51, of which 28 are state owned. Fig. 3 shows the age-wise distribution of gas-fired power plants of the country.

Bangladesh is one of the most densely populated countries in the world where electricity demand increases by 10% per annum. Moreover, load shedding in 2011 occurred for 354 days. Fig. 4 shows the power sector scenario of Bangladesh.

Therefore, it is difficult to manage the growing demand from the present trend of generation addition [1].

At present, it is not realistic to shut down any old power plants. However, Bangladesh is a unique example of breakdown operation of power plants, for unlimited time. So the best utilization plan is required to make the power supply sustainable.

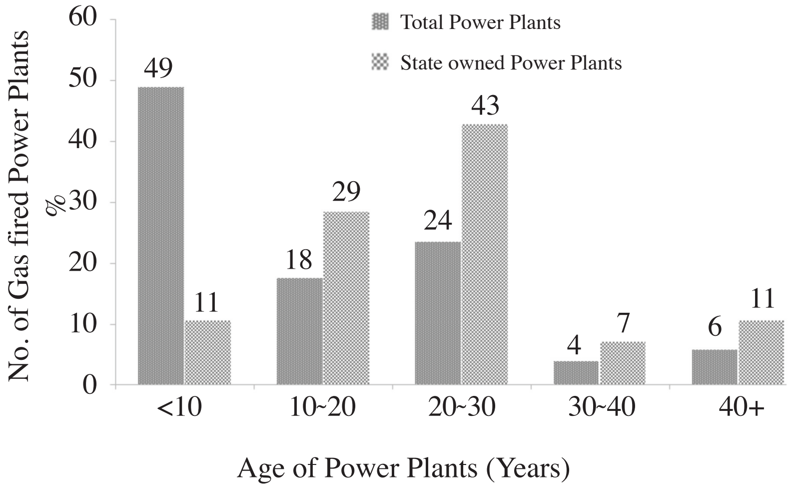

Fig. 3. Age of power plants in Bangladesh.

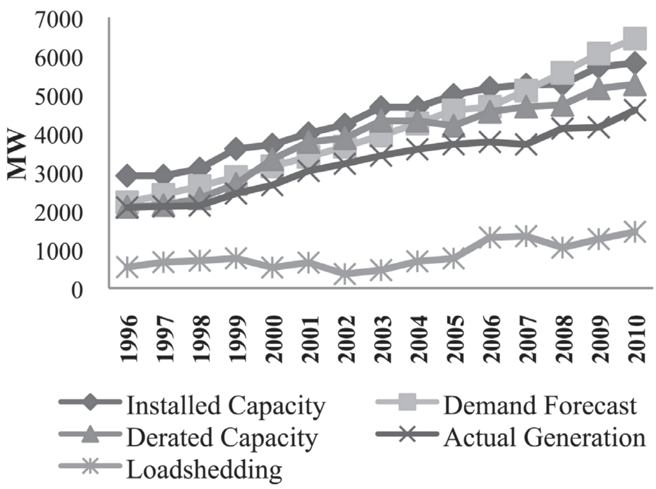

Fig. 4. Trend of Installed Capacity, Demand Forecast, Derated Capacity, Actual Generation, and Load shedding.

This study aims to describe the five influential criteria, find out their importance level for making a decision to retire power plants, and employ the importance levels on seven real case studies. The Analytic Hierarchy Process (AHP) is used to calculate the importance level and select a suitable alternative from three defined alternatives by a group of experts opinion. Nowadays AHP is applied in many research areas, such as accounting and auditing, electric utility industry, medicine, business, and education [7]. The technological, economical, and sustainable evaluation of power plants is analyzed by using the AHP process from ten types of power generation technologies under twelve criteria [8]. It is investigated for defining the most important environmental parameters and their importance to select the least negative method of electricity generation by the AHP method [9]. It is also studied for selection of the best power production option in Jordan by the AHP method [10]. Researchers used the AHP method to develop an assessment framework regarding risk of health, environmental and social benefits of the electric power generation from different renewable sources [11]. The Japan International Co-operation Agency (JICA) study team has re-evaluated the power plants retirement year by using the AHP method in Bangladesh [12]. Other than confining the alternatives of retirement to aged power plants as undertaken in [12], this paper proposes two more alternatives of "renovation, modernization, and conversion to combined cycle power plant" and "maintaining of use as it is", in which the latter represent the normal practice presently in Banglades.

2. Methodology

2.1 Basics of AHP method

Thomas L. Saaty introduced the Analytic Hierarchy Process (AHP) in 1970 [13]. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. In the AHP method, a decision is made in different steps as follows [13, 14]:

Step 1: Define objectives.

Step 2: Structure problem for goal, criteria, sub-criteria, and alternatives.

Step 3: Make a pairwise comparison of elements by AHP ratio scale and put in a reciprocal matrix.

Step 4: Calculate importance level and consistency index by the AHP specified method.

Saaty (1980) suggested that the value of the Consistency Index (C.I.) should not exceed 0.1 for a confident comparison result; the Consistency Ratio (C.R.) should be under 0.1 for a reliable result where 0.2 is the maximum tolerable level [15].

Step 5: Evaluate the alternatives according to importance level and finally get ranking of alternatives.

In the AHP method, for combining individual judgments of a group of experts, if consensus cannot be reached, a good compromise is required. In such a case, the individual pairwise judgments can be combined using a geometric mean of the pairwise comparisons to form one compromise value. A geometric mean is used instead of an arithmetic mean to preserve the reciprocal property of the "pairwise" comparison matrix [16].

2.2 Goal setting and alternative selection

Government has set a target of 100% electricity coverage within 2021, whereas for the last 40 years it has achieved only 49%. Due to increasing demand, huge shortages of electricity, limitations of cultivable land, rapid urbanization, and social conditions, old generation units cannot be left out. These lands with usable infrastructure have to be used positively. Therefore, the best possible use of the old or retired power plants in the Bangladesh power system to ensure energy security is the goal of this study.

Construction of new power plants usually takes five to six years lead-time, from decision taken to commissioning of the first unit. In principle, a plant is retained in service until it becomes more economical to replace it with new capacity [17]. Modification is needed for improving safety, efficiency, reliability, and performance of existing plants. Plant modification should be initiated when (a) it is obvious that an item of the plant or equipment, or control system, fails to fulfill its required functions, (b) new data, or experience gained at other locations, suggests that the original plant design criteria are no longer valid and (c) improvements in safety standards can be identified.

The three possible uses of existing gas-fired plants are (a) construction of new combined cycle power plants at the same site, (b) renovation, modernization, and conversion to combined cycle to increase efficiency and lifetime and (c) to maintain old power plants as it is. In this paper, alternatives are denoted by A, B and C respectively. The Bangladesh Power Development Board (BPDB) has already taken projects to convert some existing simple cycle gas and steam turbine plants to combined cycle power plants. A number of old power plants are still being used for meeting power crises after retirement from economic life.

2.3 Criteria selection

Nine types of electric power generation plant including a natural gas fueled power plant are evaluated regarding seven criteria of service life, generation cost, O&M cost, capital cost, NOx emission, CO2 emission, and efficiency [18]. Under the aspect of technological and economic point of view, ten types of power plants are assessed depending on the eight criteria of efficiency, availability, capacity, reserve or production ratio, capital cost, O&M cost, fuel cost and external cost [19]. In addition, power systems and energy sectors are evaluated on technical, economic, environmental, and social aspects [20, 21]. The JICA study team has evaluated the retirement of old gas fired power plants in the Bangladesh power system based on four criteria of efficiency, operation age, forced outage rate, and generation cost [12]. This study has proposed five evaluation criteria for old or retired power plants in Bangladesh from technical, economic, service life, environmental, and social aspects. They are (i) reliability (ii) generation cost (iii) operation age (iv) environmental effects and (v) social effects. These five criteria represent all the major evaluation influences.

Forced Outage Rate:

Forced outage rate (FOR) is a performance indicator of a power plant. FOR of a power generation unit is the probability that the unit will not be available for service when required. It is calculated by FOR= [(Forced outage time)/ (Operating time+ Forced outage time)] ×100% and expressed as a percentage.

Operation age:

Operation age or real service life of a power plant is the age of the generation plant (in years) after commissioning. It indicates how old the unit is.

Generation cost of power:

The cost of electricity generation by different sources is the cost of generating net power at terminal bus. It includes fixed cost and variable cost. Fixed cost is the sum of depreciation, interest on loan, and O&M cost. Variable cost is the total of fuel cost and variable O&M cost.

Environmental effect:

Power stations are major emitters of greenhouse gases (GHG). The flue gas discharged from power plants contain carbon dioxide, water vapor, nitrogen, nitrogen oxides, and sulfur oxides. The amount of water usage is often of major concern in electricity generation systems due to increasing population and droughts becoming a major factor. A natural gas fueled power plant uses 100 to 180 gallon water per MWh electricity generation. In Bangladesh, allowable emissions of nitrogen oxides from gas fuel based power plants are 50 ppm for 500 MW and above, 40 ppm for 200 to 400 MW, and 30 ppm for below 200 MW capacities. Standards for sound levels are given in Table 1 [22].

Table 1 Standard for sound in decibel (dB).

Category of area	Day	Night
Silent zone	45	35
Residential area	50	40
Mixed area	60	50
Commercial area	70	60
Industrial area	75	70

Social effects:

Social effects include job creation, social acceptance, resettlement, compensation rate, etc. A power plant consumes many local resources, but creates limited local job opportunities, as plants need specialized persons for operation. For new power plant construction at a new site, creation of employment opportunity has positive impact. For example, during the construction period of a power plant, many skilled and unskilled labors are employed for civil and architectural work, equipment installation work, etc. On the other hand, some negative impacts are conflict of interest, infectious diseases, increased child labor, resettlement, etc. Social impact for construction of a new power plant at an existing site is comparatively less as resettlement is not required and other social issues have already been settled. A generation capacity increase assures a stable supply of power in conjunction with the reinforcement of the power distribution system. This will substantially contribute to the improvement of people's livelihood.

2.4 Hierarchy tree

In order to evaluate the best utilization option of an existing retired power plant, a hierarchy tree is built for the application of AHP. The hierarchy tree for the study is shown in Fig. 5.

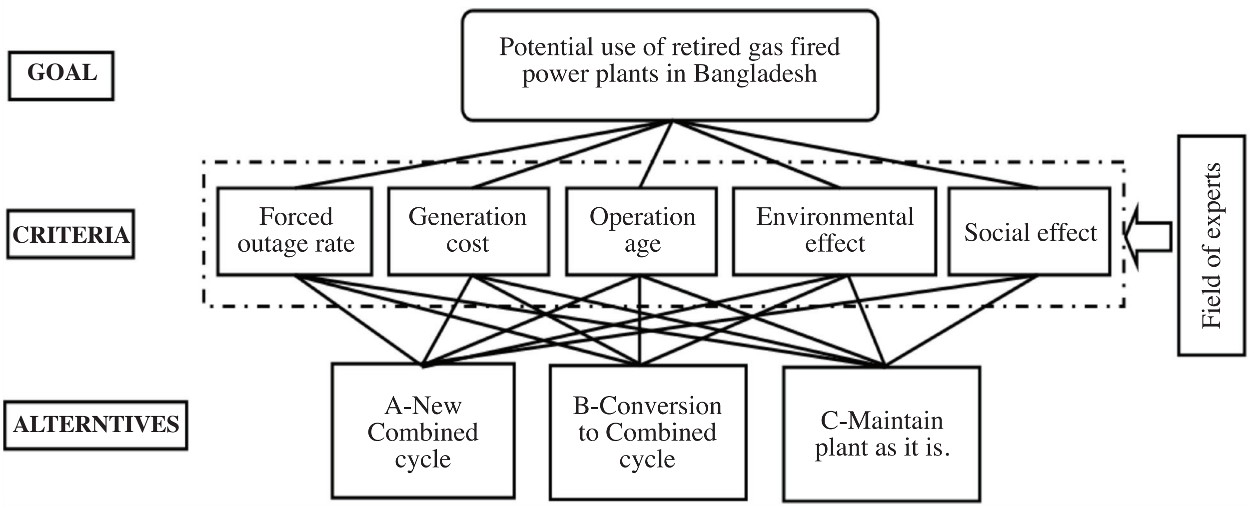

Fig. 5. The hierarchy tree of the study.

2.5 Procedure of the study

For the study, an opinion questionnaire for experts is prepared for criteria evaluation. Twenty-two experts put their judgments in the form of pairwise comparison of the criteria regarding the objective. The experts are power plant planners and construction consultants, engineers of IPP or Public Ltd. Co., rental, and state owned power plants (BPDB), university teachers, economists, sociologists, NGO personnel for public health, and energy security and environment conservation movement activists with professional experience in relevant fields from 10 to 45 years. Judgment sharing is shown in Fig. 6. The expert opinions are then combined and put in the AHP matrix and the priority of each criterion is calculated. Then seven real case studies are employed by using the priority points. Similarly, for the case study, an individual questionnaire is prepared for an individual power plant based on five to ten years reliability, generation cost, and environmental data.

Expert opinions on pairwise comparison of alternatives regarding each criterion are taken from those people who are still working in various power plants because they know the details of the present conditions of the existing plants. There are fourteen expert judgments for case study 1, twelve for case study 2, thirteen for case study 3, eleven for case study 4, twelve for case study 5, twelve for case study 6, and thirteen for case study 7. Then the opinions are combined for each case study and the results are calculated.

It is worth noting that ratio of judging groups or weights may affect the results. And that sensitivity analysis can be employed in AHP. However, with light interest in this study, this paper does not include such analysis.

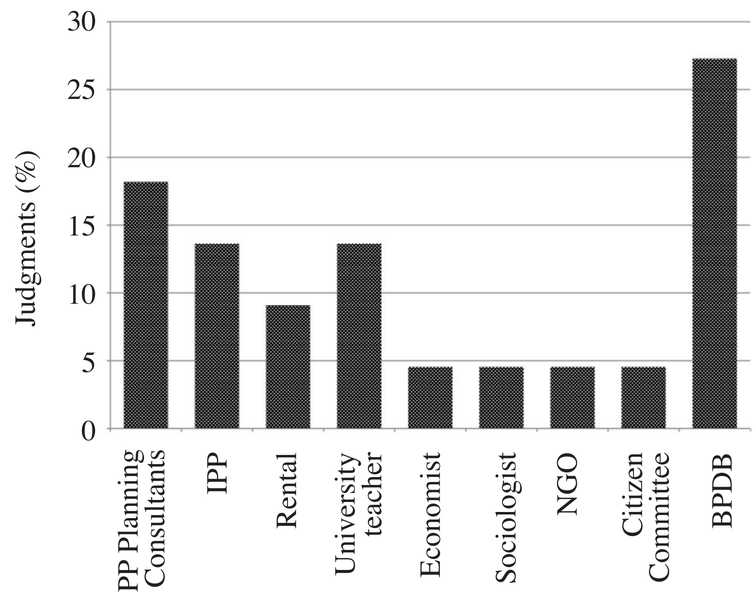

Fig. 6. Expert judgments from various fields.

3. Results and discussion

The combined pairwise comparison matrix for criteria is shown in Table 2.

The importance levels with rank are calculated from the above matrix and shown in Table 3.

The results show that the generation cost is the most important criterion. The second important criterion, operation age, is slightly more important than the third criteria, forced outage rate. The criteria, environmental effect and social effect, are also much closer in importance level.

Table 2 Criteria matrix of pairwise comparison by experts.

Criteria	FOR	OPA	GC	EE	SE
FOR	1	0.73592	0.42796	1.81531	2.28762
OPA	1.35884	1	0.48752	2.03546	2.06948
GC	2.33669	2.05122	1	3.89719	4.40359
EE	0.55087	0.49129	0.25659	1	1.50985
SE	0.43714	0.48321	0.22709	0.66232	1

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

Table 3 Priority points of criteria.

Criteria	Priority points	Rank	Remarks
FOR	0.180952	3	
OPA	0.210444	2	CI=0.0062
GC	0.412717	1	RI=0.0055
EE	0.109457	4	
SE	0.086431	5	

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

3.1 Case study 1

Table, 4 shows the potential utilization pictures of Haripur 3×33 MW Gas Turbine Power Plants.

Table 4 Total priority points of alternatives for Case Study-1.

HARIPUR 3×33 MW GAS TURBINE POWER PLANTS (AGE 22 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.108894	0.046560	0.025497
OPA	0.138852	0.033774	0.037817
GC	0.144647	0.201688	0.066382
EE	0.073695	0.025475	0.010287
SE	0.018517	0.028632	0.039282
Priority points	0.484605	0.336129	0.179266
Rank	1	2	3

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

Alternative-A gets the highest priority. From Table 4, it is seen that the alternative to construct new combined cycle power plants (A) surpasses the alternative of converting to combined cycle power plants (B) with reasons of better reliability (FOR) and operation age (OPA) even though it holds higher generation cost (GC).

3.2 Case study 2

The best utilization of Baghabari 71 MW Gas Turbine Power Plant is shown in Table 5.

Table 5 Total priority points of alternatives for Case Study-2.

BAGHABARI 71 MW GAS TURBINE POWER PLANT (AGE 19 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.076586	0.052859	0.051506
OPA	0.129933	0.057786	0.022724
GC	0.115793	0.245623	0.051300
EE	0.076440	0.022820	0.010196
SE	0.015450	0.025014	0.045966
Priority points	0.414204	0.404103	0.181693
Rank	1	2	3

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

The results show that alternatives A and B have very close importance levels, 0.414 and 0.404. Alternative-C is the lowest option with importance level 0.181. However, conversion to combined cycle power plants (B) is obviously positive for its lower generation cost (GC) when compared to the alternative of constructing a completely new plant (A).

3.3 Case study 3

The potential utilization of Ashugonj 2×64 MW Steam Turbine Power Plants is shown in Table 6. Results show the priority factors for alternatives A, B, and C. For alternative-A, low generation cost, less forced outage rate, and higher operation age defined the result. Such a clear figure enables confident decision-making.

3.4 Case study 4

Ghorasal 4×210 MW Steam Turbine Power Station (Unit 3), Ghorasal, Norshingdi is the fourth studied plant. Table 7 shows the evaluation results for best utilization. Alternative-A ranks first with importance level 0.466 followed by alternative-C with importance level 0.331 and then alternative-B, with importance level 0.201. From the results, alternative-C, to maintain as it is, becomes more attractive because of its low cost of generation at present.

Table 6 Total priority points of alternatives for Case Study-3.

ASHUGONJ 2×64 MW STEAM TURBINE POWER PLANTS (AGE 40 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.120574	0.037153	0.023225
OPA	0.155728	0.023695	0.031020
GC	0.292222	0.087441	0.033054
EE	0.080362	0.020048	0.009046
SE	0.028188	0.020787	0.037456
Priority points	0.677075	0.189124	0.133801
Rank	1	2	3

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

Table 7 Total priority points of alternatives for Case Study-4.

GHORASAL 4×210 MW STEAM TURBINE POWER STATION, UNIT-3, GHORASAL (AGE 23 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.092965	0.066547	0.021440
OPA	0.137204	0.046128	0.027111
GC	0.137623	0.041396	0.233697
EE	0.074620	0.023077	0.011760
SE	0.024473	0.024587	0.037372
Priority points	0.466885	0.201735	0.331380
Rank	1	3	2

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

3.5 Case study 5

Table 8 shows the evaluation results of Ashugonj 3×150 MW Steam Turbine Power Plants (unit 3) for best utilization plan. The alternative-A is the highest potential utilization option whereas alternative B and C are very close in utilization factors.

Table 8 Total priority points of alternatives for Case Study-5.

ASHUGONJ 3×150 MW STEAM TURBINE POWER PLANTS, UNIT-3 (AGE 23 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.045958	0.036607	0.098387
OPA	0.137641	0.041859	0.030944
GC	0.291760	0.071753	0.049204
EE	0.074587	0.023067	0.011802
SE	0.025208	0.028805	0.032419
Priority points	0.575155	0.202090	0.222755
Rank	1	3	2

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

From the results, it is shown that alternative-A has better position in case of generation cost, operation age, and environmental effect. However, it is revealed that alternative-A, construction of new combined cycle power plants has positive effects on reduction of generation cost.

3.6 Case study 6

Table 9 shows the studied results of Ghorasal 2×55 MW Steam Turbine Power Station, Polash.

From Table 9, alternative-A provides better benefits in almost all criteria, except slightly inferior on social effects.

3.7 Case study 7

Ashugonj Combined Cycle Power Plant was the last case studied plant. In this study, option B means, rehabilitation and modernization of existing power plant.

Table 9 Total priority points of alternatives for Case Study-6.

GHORASAL 2×55 MW STEAM TURBINE POWER STATION, POLASH (AGE 36 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.125987	0.034537	0.020428
OPA	0.162137	0.020996	0.027310
GC	0.202502	0.037655	0.172560
EE	0.076831	0.022835	0.009791
SE	0.019495	0.026262	0.040674
Priority points	0.586952	0.142285	0.270762
Rank	1	3	2

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

Table 10 Total priority points of alternatives for Case Study-7.

ASHUGONJ COMBINED CYCLE POWER PLANT (AGE 28 YEARS)			
CRITERIA	**Alternatives**		
	A	**B**	**C**
FOR	0.102572	0.060677	0.017703
OPA	0.135076	0.045713	0.029655
GC	0.294498	0.063994	0.054225
EE	0.075314	0.021367	0.012776
SE	0.016548	0.028694	0.041189
Priority points	0.624007	0.220445	0.155548
Rank	1	2	3

Note: FOR-Forced Outage Rate, OPA-Operation Age, GC-Generation Cost, EE-Environmental Effects, and SE-Social Effects.

Table 10 shows the study results. From the results, final importance levels clearly indicate that the alternative to reconstruct combined cycle power plant (A) is more attractive over other alternatives due to lowest generation cost.

3.8 Overall discussion of seven case studies

Fig. 7 shows the position of alternatives according to priority points of case studied power plants.

From the case studied results, it shows that alternative-A, construction of new combined cycle power plants at the same site, is the best utilization option. However, in case study 2 alternative-B, renovation, modernization, and conversion to combined cycle power plant, is very close to alternative-A. In case study one, two, three, and seven, alternative-B, is in second position. On the other hand, in case study four, five, and six, alternative-C, maintain power plant as it is, is in second position.

4. Conclusions and recommendations:

The retired gas-fired power plants have been evaluated by using the AHP method based on five criteria of forced outage rate, operation age, generation cost, environmental, and social effects. It is found that generation cost is the most important decision-influencing factor with the importance level of 41.27%. The second is operation age (21.04%), which is followed by forced outage rate (18.09%), environmental effects (10.95%), and social effects (8.65%). The seven case studies results revealed that the alternative-A (construction of a new combined cycle power plant at the same site) is in all cases the best alternative. This is because, in general, a new power plant can provide better reliability with power generation cost and better service life. Additionally, a large capacity power plant can be built. Hence, the results do not support the present nonstop operational practice as if they have an unlimited lifetime. Exceptions are cases of gas turbine power plants, in which conversions to combined cycle power plants have a comparable attractiveness. The results emphasize that in Bangladesh the power sector needs new combined cycle power plants, taking over any aged and inefficient power plants. Further study is recommended to conduct research with fixed detail sub-criteria for each criterion.

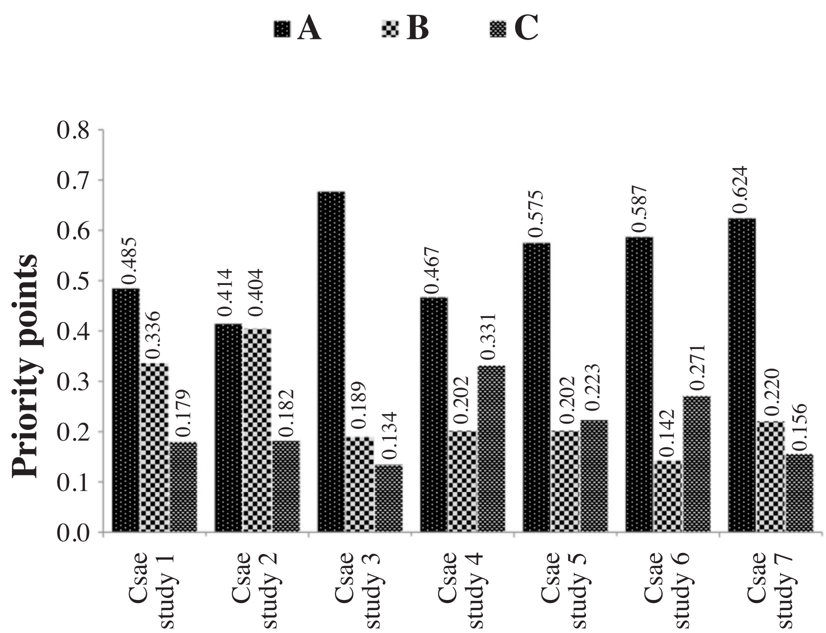

Fig. 7. Position of alternatives according to priority points.

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