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Techno-economic Analysis of Rehabilitating and Repowering of Thermal Power Plants in Iran

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Abstract: Making targeted subsidies and the process of releasing energy market and specified criteria for the quality of energy delivered to consumers shows the necessity for the explanation of energy production in Iran. In the meantime, thermal power plants produce about 85% of electricity in Iran. Steam and gas turbine power plants have created the vast capacity of power generation in thermal plants, but the significant portion of this generated power is not in the sense of new energy policy. Therefore, the reconstructing and improvement of thermal power plants has undeniable importance. In this paper, considering two major methods in reconstructing thermal power plants, eligible power plants are presented. Results are discussed according to important economic parameters like electricity generation costs, capital return rate, cost benefit, annual interest, etc. Further, estimation of changes in target plants in terms of technical and economic characteristics has an effective role in our decisions, i.e. changes are affected by the features of current plants and their potentials. The efficacy of reconstructing average efficiency, capacity, and electricity generation costs can be the effective parameters in future management decisions.

Key words: Thermal power plant, Making targeted subsidies, Repowering, Combined cycle, Economic parameters.

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1. Introduction

Revising the process of production and presentation of energy bearers is necessary by realizing the energy products in market and target-orientation of subsidies. As an example, thermal power plants by considering their restrictions in electricity generation such as reduction of energy consumption and efficiency improvement would require upgrades in their techno-economic properties. According to the subsidy reform rule, the ultimate cost of electricity is measured according to the sum of the expenses of the conversion, transmission, and distribution of energy with the least efficiency of 38% in Iranian power plants[1]. In addition, an efficiency of at least one percent should be added to the country power plants annually until it reaches 45% in the following years[1].Consequently, it would not be economical to construct thermal units with efficiencies of less than 45%. Power plants having lower efficiencies impose a large expense on the government (regarding the considered efficiency computed in consumers' generated electricity bills). Execution of subsidies targeting rule have been estimated by researchers regarding current conditions. Some researches have been carried out according to the present relations in energy conversion [1-3] and field studies [4].Generally, two groups of thermal power plants in Iran have been studied in this project with low efficiencies despite of their effective role in electricity generation. Their energy conversion has been also investigated regarding execution of the mentioned rule and the effect of the conversion on efficiency, capacity, and electricity generation cost by thermal power plants. Nowadays, efficiency in most of Iranian steam power plants is not in an acceptable range due to their age. In addition, efficiency is less than current average in newer steam power plants. Hence, the economical criteria of electricity generation should be investigated more precisely. Structural modification can play a remarkable role in enhancing positive economical and technical properties of network electricity. The chosen power plants are the appropriate ones for full repowering. Their life time is over or is going to be reached to the end. Second group includes the thermal power plants whose modification plays a major role in the quality enhancement of energy generation in gas turbine power plants. A lot of gas turbine power plants are now active in Iran. Low capital investment cost, high flexibility, particular performance at peak load, short startup period, etc. are the main reasons for utilization of this kind of thermal power plants. At the present time, 34% of the total electricity is generated by gas turbine power plants and about 30% of it is generated by steam power plants. About 46% of the steam power plants in Iran are qualified for full repowering and conversion to combined cycle units [3]. About 65% of gas turbine power plants are exposed to change from the current conditions to combined cycles. The changing process in the gas turbine power plants has been investigated in this article.

General capacity to perform such a change is 14.5 GW. This capacity is 35% of the network total power. Hence, improving their properties has a significant effect on the general efficiency of the network power plants. First, appropriate power plants were selected to undergo variations regarding the considered criteria and results have been investigated and compared on the basis of economical and technical criteria. In addition, the effect of variations on economical parameters has been discussed. Price of the electricity generated from these power plants before and after change is a major decision-making parameter. This shows the difference between two initial states and target cycle for cost of generating each kWh of electricity. Another important issue is utilization of the power plants with less than 45% efficiency. Therefore power plants could be utilized to respond network demand up to a definite limit and beyond that limit utilization would not be reasonable and economical. This definition is to display the difference between present and converted cycles regarding the capability of using them from timing viewpoint in the network based on economical estimations. Finally, the present and converted cycles have been compared through figures and diagrams.

Considering the properties of studied steam and gas turbine cycles, an estimation of the effective variables in decision-making at the time of capital return(an important decision-making parameter in privatizing the units) has been performed. Role of consumed fuel price and its effect on the price of generated electricity has been discussed in the next section (all computations have been performed neglecting the effect of peak load on economic components). General estimation of the network efficiency promotion in different states regarding the area of feasible works has been also discussed. Finally, our attempt is to analyzing the process of required changes in the sense of economical and technical point of view. Also by regarding the typical criteria, the current and obtainable status in conversion of units are compared.

2. Electricity Cost and Limit of Thermal Power Plants Utilization

Different expenses are imposed on thermal power plants owing to their particular economical and technical characteristics. The generated electricity cost in different thermal power plants regarding economical and technical parameters has been shown in Table (1).

Various factors are effective in determination of electricity generation costs in current thermal power plants, including the power plant annual working hours, capital return factor (related to the power plant lifetime and interest rate), constant and variable repair and maintenance expenses, power plant power, efficiency, and consumed fuel expense. Owing to the expressed parameters, generated electricity costs function is presented as Relation (1)[3]:

$$Z_{OC} = (\frac{TCI.CRF.\varphi}{\dot{W}.H}) + C_f .HR_{pp} [€¢ / Kwh] \qquad (1)$$

Table 1. Determination of electricity generation costs in current thermal power plants.

Effective parameter	Combined cycle	Gas turbine cycle	Steam cycle
Availability (%(hours))	91(8000)	55(4800)	73(6450)
Capital investment cost (€/Kw)	612.2	383.4	742.8
Investment return rate (%)	12	12	12
Plant lifetime (year)	30	15	30
Average cost of fuel in 2009 (€/MBTU)	3.46	3.46	3.46
Thermal efficiency (%)	45	28.7	36
Constant cost of operation & maintenance (€/KW)	3.110	5.040	6.730
Variable cost operation & maintenance (€¢/Kwh)*	0.030	0.060	0.035
Initial investment cost (€¢/Kwh)*	1.014	1.320	1.558
Fuel cost (€¢/Kwh)*	2.623	4.114	3.279
Final price of electricity generation (€¢/Kwh)*	3.637	5.434	4.837
Proposed purchase price of electricity (€¢/Kwh)*	3.808	5.644	4.787

*1 €=100 €¢

Purchase price of the electricity suggested from the power plants has been considered regarding an annual interest of 18% for the initial investment. Considering the above assumptions for the combined cycle power plants, capital return period is 12.5 years according to the objectives of subsidies targeting rule. However, gas turbine and steam power plants with the following specifications do not meet the objectives of subsidies targeting rule as it is shown in Table (1). Since great expense has been allocated to their construction (in comparison to their working life of this type of power plants), their performance characteristics should be promoted. Their utilization degree and their expiry date can also be determined according to their conditions (working life and level of initial investment). According to Table (1), their expiry dates with such features have been determined. To do so, minimum life of 15 and 30 years has been respectively assumed for gas turbine and steam power plants and upgrading technical (and consequently economic) cycle properties would not be possible. In addition, the expenses value has been updated on the basis of annual inflation rate per Iran's domestic and foreign currencies which are 12% and 3% respectively [5]. Relation (2) has investigated to determine the utilization degree of thermal cycles. Where this relation reaches 1 concerning the power plant function degree from the beginning period, the power plant would not be economical.

$$ES = \frac{(Z_{OC} - EGC) \times n_{AS}}{Z_{CC}} [\%] \quad (2)$$

$$EGC = (\frac{C_f}{3.46}) \times 341.1 + 131.8 \quad (3)$$

Here, Z_{OC}, EGC is electricity operation cost and electricity price [$/Kwh], Z_{CC} is the capital cost investment [$/Kw] and C_f is fuel cost in subsidy and un-subsidy conditions[$/MBtu].The effect of subsidies targeting on utilization of gas turbine and steam power plants which are not able to estimate the objectives of subsidies targeting rule could be presented as an important component in determining the efficiency of the cycles in the new conditions of energy market. Statistical averages of economical and technical properties for the utilization of gas turbine and steam power plants has been shown in "Fig. 1"[6]. Considering the acceptable efficiency value of combined cycles in Iran thermal power plants and their accordance with the objectives of subsidies targeting rule, economical properties of the power plants, including their electricity cost price to determine the utilization degree of other thermal power plants, were used for comparison.

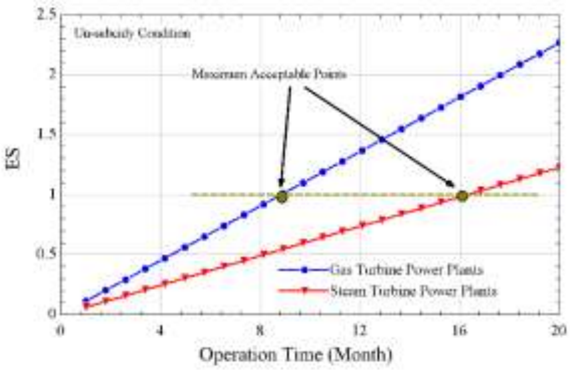

Fig. 1. Comparison of utilization limit in existing and new cycles in un-subsidy condition

Concerning price of the fuel delivered to thermal power plants in 2009, Relation (4) has been used to determine properties of cycles at subsidy state.

$$EGC = (\frac{C_f}{0.103}) \times 10.72 + 131.8 \quad (4)$$

Applying this value on the productivity level of gas turbine and steam cycles, diagram in "Fig. 2"has been obtained. It has been indicated in this diagram that the effect of consumed fuel price is at second position regarding the power plants efficiency and the effect of conducted initial investment has been more effective in constructing the units. At the present state with performing the subsidy targeting rule, this issue is in an inverse state and the effect of delivered fuel price at productivity level is more remarkable.

As it has been seen, gas turbine power plants have low productivity levels. Steam power plants are not at an acceptable state despite of their relative promotion and their performance in the network would not be economically affordable as in the previous state.

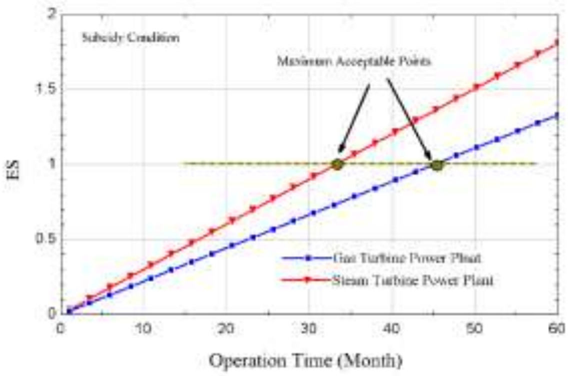

Fig. 2. Comparison of utilization limit in existing and new cycles in subsidy condition

3. Power Plants classification

3.1. Steam Power Plants

Steam power plants in Iran with an average efficiency of 36% generate 30% of the total power generation which play a major role in electricity generation fleet[6]. There are two general methods, including full and partial repowering, to improve the steam power plants with non-solid fuel. Partial repowering methods have been utilized to promote properties which include methods of heating feed water, wind-box repowering, and supplemental boiler repowering in new power plants. It is conducted through adding a cycle of gas turbine to steam turbine, while full repowering methods are utilized in old power plants with expired useful life. Full repowering is done by substituting HRSG[1](converting steam cycle to combined cycle) for the present boiler. It is the commonest way to promote old steam power plants properties. The first index parameter to convert a steam unit to a combined cycle (full repowering) is to have the least age of 25 years [7-9]. This age is 30 [10-12] or 25-30 [13] in some other references. To estimate current potential capability to fulfill future objectives, the age is considered 25 years or more, in this study. This method could be used for units having less than 250MW power and maximum steam pressure of 1800psig [12, 14, 15]; To decrease the probability of infeasibility as a result of current restrictions to access new technologies of HRSG manufacturing which produces such pressures, the value was considered 200MW (as units of 50 to 200 MW power are appropriate for this method [16, 17]). On the other hand, available statistics on Iran power plants [6] indicate that such an assumptionwould not lead to any change in capacities allocated to this method. However, units with capacities more than 300MW which having the first property that is, reaching the expiry date of their useful life have been considered to conduct this operation. In such conditions, repowering is usually conducted by several gas turbines. Sequential order of operational stages should be determined in a way that there would be minimum power plant performance loss in the required time to conduct such projects[18]. In addition to expressed capacities, there are some other upgradable capacities to conduct other repowering methods (feed water heating and wind box repowering [3], but full repowering method has been investigated in the current project owing to the degree of capacity increase, efficiency upgrading, and Iran remarkable capacity to conduct this method. the effect of full repowering method on steam power plants has been shown in Table (2). Following cases were used to estimate future power plants properties after repowering:

- The thermal rate deduction caused by modulation of two cycles has been considered between 15%-30% which is in its actual range and has been dedicated from practical cases [14, 18 and 19]. Efficiencies over 15-20% are mostly related to old repowering operations in about 1985 [18], while recent operations indicate the improvement of thermal rate about 30% or more [14, 19].

- The added power to the cycle has been considered equal to the turbine added gas turbine power.

- Mean efficiency obtained from Relation (5) has been used to estimate the efficiency of the repowered new cycle according to the above cases.

$$\eta_{net} = \frac{\dot{W}_{st,net} + \dot{W}_{gt,net}}{\dot{m}_{fg}.LHV_{gt}} \qquad (5)$$

- Capacity of the new units has been obtained regarding the appropriate range of the added gas turbine power. A common gas turbine has been utilized to enhance the power of repowered cycle for better adaption.

- To determine generated electricity cost (per kwh) efficiency factors (in the current and new cycles), number of annual work hours and degree of initial investment have been fundamental factors in repowering the steam power plants. Expense of consumed fuel has been displayed in a separate column to show the effect of cycle efficiency on the fuel cost used to generate perkwh of electricity.

- Utilization limits of current cycles with efficiencies lower than objectives of the targeting rule also have been investigated in a separate column of Table 2. Period of capital return for plans with acceptable efficiency in targeting rule execution can be seen in this column. This value has been obtained using Relation (6) [20].

$$n_{Payback} = \frac{\log(\frac{A_t}{A_t - i.TCI})}{\log(1+i)}[year] \qquad (6)$$

Capital return period variations and the operation cost of the power plants obtained from combined cycle and repowering cycle according to the variations in initial investment has been shown in "Fig. 3"by using relations 1 and 6. As it has been indicated in this figure, capital investment cost reduction will lead to significant decreases in capital return period. If capital return for combined power plant is assumed about 12.5 years as it

1. Heat Recovery Steam Generator

has been mentioned before, this period would be about 4 years for the repowered steam power plant. This estimation has been made by allocating these power plants to private sector and determining the generated electricity price on the basis of economical and technical properties of combined cycles.

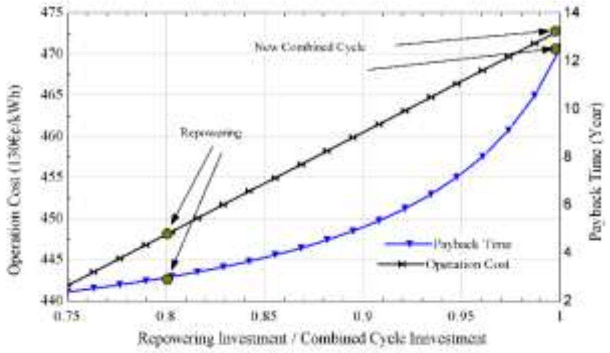

Fig. 3. Comparison between operation cost and time of capital return of existing and new cycles

- Finally, the proportion of generated electricity cost price in each unit for subsidies targeting rule execution to subsidies state by Relation (7) is shown in the last columnof Table 2. Hence, this column displays the computation of generated electricity price at subsidies state.To compute the expense of subsidies fuel, price of the natural gas delivered to power plants is equal to the prior price before targeting rule, that is, 0.38 €¢ per cubic meter. Therefore, the effect of delivered fuel price at subsidies and non-subsidies states has been studied for the current and new cycles.

$$OC_{(NS/S)} = \frac{Z_{OC_{(NS)}}}{Z_{OC_{(S)}}} [\%] \tag{7}$$

- Among the presented steam power plants, BESPP and MASPP did not meet the required criteria of targeting rule despite of conducted variations. As it has been mentioned before, the computations were conducted according to prior operations; considering mean thermal rate upgrading has been considered 15 to 30%, while the conducted related researches have studied the effect of full repowering on BESPP using new technologies. Efficiency has been estimated to be up to 53% for new cycle of the power plant without extra combustion.

Table 2. Technical–economic characteristics of existing and new cycles

	Power plant name	Constructing data	Condition	Efficiency (%)	Capacity (MW)	Electricity generation costs (EGC)*	Fuel cost*	Utilization limit: Capital return(month)	$OC_{(NS/S)}$
Steam units	BASPP	1980-1985	Base	37.2	4×320.0	4.978	3.174	16	2.61
			New	48.5	4×882.0	3.266	2.434	22	3.60
	BESPP	1967-1968	Base	28.7	3×82.50	6.003	4.114	09	2.97
			New	37.4	3×159.4	4.170	3.157	22	3.74
	EASPP1	1974	Base	36.2	2×120.7	4.691	3.262	16	3.06
			New	47.2	2×307.7	3.330	2.502	26	3.67
	EASPP2	1980	Base	36.2	1×320.0	4.691	3.262	16	3.06
			New	47.2	1×882.0	3.330	3.262	26	3.67
	NESPP	1979-1981	Base	34.9	4×440.0	4.899	3.383	14	3.02
			New	45.6	4×1283	3.418	2.589	32	3.75
	MASPP	1973-1974	Base	31.8	2×60.00	4.896	3.712	11	3.76
			New	41.2	2×175.4	3.880	2.865	50	3.51
	MGSPP	1971-1973	Base	34.9	4×156.5	4.846	3.383	14	3.08
			New	45.6	4×434.5	3.418	2.589	32	3.75
	RASPP	1979-1986	Base	39.0	4×315.0	4.908	3.027	17	2.48
			New	50.8	4×877.0	3.154	2.324	18	3.49
	SBSPP	1973	Base	35.7	2×120.0	4.577	3.307	16	3.33
			New	46.6	2×307.7	3.362	2.534	28	3.70
	SMSPP	1984-1986	Base	35.0	4×200.0	4.686	3.373	15	3.30
			New	45.6	4×434.5	3.418	2.589	32	3.75
	TASPP	1986	Base	35.9	1×368.0	4.735	3.288	15	3.05
			New	46.8	1×969.9	3.352	2.522	27	3.69
Gas turbine units	ABGPP	2002-2003	Base	34.1	4×123.4	4.402	3.462	14	4.20
			New	51.1	4×185.1	3.325	2.310	33	3.06
	BAGPP	2002	Base	19.8	2×25.00	8.246	5.962	06	3.34
			New(CC)	29.7	2×37.50	4.989	3.975	09	4.37
			New(CHP)	68.5	2×87.60	3.458	1.724	101	1.93
	CHGPP	2008	Base	20.2	1×159.0	19.808	5.845	10	1.40

		New(CC)	30.3	1×238.5	4.911	3.896	09	4.32
		New(CHP)	67.6	1×527.0	3.481	1.746	114	1.94
DAGPP	2003-2005	Base	30.6	12×159	5.749	3.858	11	2.85
		New	45.9	12×239	3.587	2.572	92	3.27
HOGPP	2004-2005	Base	32.5	6×165.0	4.622	3.632	12	4.18
		New	48.8	6×247.5	3.436	2.422	45	3.15
JAGPP	2007-2008	Base	32.0	6×159.0	5.373	3.689	11	2.98
		New	48.0	6×238.5	3.474	2.459	51	3.18
ORGPP	2006-2007	Base	29.2	4×159.0	6.923	4.043	10	2.30
		New(CC)	43.8	4×238.5	3.710	2.695	170	3.37
		New(CHP)	70.0	4×527.0	3.421	1.687	86	1.91
SBGPP	2007-2008	Base	37.0	4×159.0	7.087	3.191	13	1.77
		New	55.5	4×238.5	2.987	2.127	22	2.90
SHGPP	2005-2007	Base	32.2	6×159.0	5.302	3.666	12	3.03
		New	48.3	6×238.5	3.458	2.445	49	3.17
SNGPP	2005-2007	Base	32.5	6×159.0	5.011	3.632	12	3.35
		New	48.8	6×247.5	3.436	2.422	45	3.15

*** Expenses are in €¢ per kWh.**

3.2. Gas Turbine Power Plants

As it has been mentioned before, gas turbine power plants produce a remarkable part of Iran required power. Convertible Gas turbine power plants to combined cycle power plants have been investigated. They could reach the mentioned efficiency in subsidy targeting rule and the variations effect on them could be measured and discussed. The items mentioned in Table (2) have been determined on the basis of following parameters.

- Gas section of under investigation gas turbine power plants is active now and some plans have been considered for their conversion to combined cycle units [2, 6].

- Other gas turbine power plants would not be qualified to have changes considering the useful life of the gas turbine power plants (which is considered 15 years). In addition, the power plants could not fulfill targeting rule objectives by being converted to combined cycles [2]. Among considered cycles, Gas turbine cycles in BAGPP and ORGPP, because of not achieving the objectives of targeting rule, the method of converting this cycle to a cogeneration cycle has been used. Relation (8) has been used to determine the efficiency of the cycle. As it is obvious from the table values by converting these units to high efficiency units through considering the life (age) of a combined cycle power plant for them and gas turbine power plants mean performance, their capital return period has reached less than 10 years taking into account the price of generated electricity in a combined cycle power plant of 45% efficiency. To achieve gas turbine cycle properties and relate technical specifications relations obtained by Romeo and Escosa have been used [21].The common efficiency of these networks has been also used for added thermal network.

$$\eta_{CHP} = \frac{\dot{W}_{GT}(\eta_{GT}) + \dot{Q}_{GT,Loss}(0.85)}{\dot{W}_{GT} + \dot{Q}_{GT,Loss}} \tag{8}$$

- Power of the new cycle is computed after considering a common combined cycle and attributing double power of gas turbine to the steam section of combined cycle. The obtained efficiency is computed using Relation (9).It should be mentioned that power proportion has been considered by relation (4)[8].

$$\eta_{net} = \frac{\dot{W}_{st,net} + \dot{W}_{gt,net}}{\dot{m}_{fg}.LHV_{gt}} = \frac{\frac{\dot{W}_{gt,net}}{2} + \dot{W}_{gt,net}}{\dot{m}_{fg}.LHV_{gt}} \tag{9}$$

$$\Rightarrow \eta_{net} = 1.5\eta_{GT}$$

- CHGPP conversion to cogeneration cycle has conducted according to the mean annual performance of Iran gas turbine cycles because of partial annual function owing to the present data the and lack of new data on this power plant cycle; while the announced annual function of initial gas turbine cycle has been used in computations of BAGPP and ORGPP cycles. In addition, its capital investment cost has been considered almost equal to the costs of combined cycle power plants.

4. Effect of Variations on Major Economical Parameters

Since useful life of mentioned steam power plants has been finished or almost finished, economical parameters in allocation of these types of thermal power plants can be investigated, owing to the considered 15% to 30% value of the power plant site [12, 16, 17].

Effective parameters in the price of generated electricity include the power plant efficiency, unit price of the consuming fuel, access degree, power plant lifetime, operation and maintenance factor (fixed and variable), initial investment expense of power plant construction, the interest rate considered for initial investment involved in the generated electricity price determination and other economical criteria. Effect of steam repowered power plant useful life variables and capital investment interest rate on SBSPP operation cost has been analyzed in "Fig. 4".

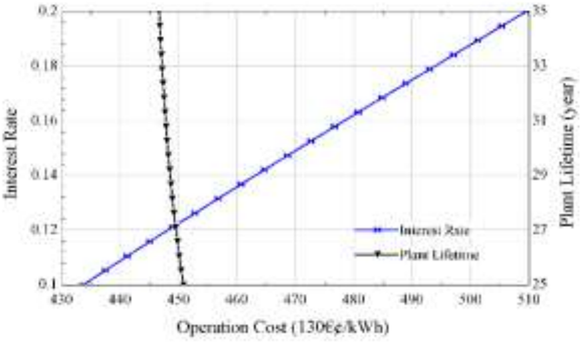

Fig. 4. Effect of interest rate and plant lifetime on operation cost of new cycle

Owing to the obtained diagram, interest rate has a remarkable effect on the generated electricity price. It has a greater effect than the useful life of a modified power plant; an investment interest of 16.5% would be harmful for the power plant and would lead to capital irreversibility. Computation of capital return criteria considering both variables has been shown in "Fig. 5". According to diagram shown in "Fig. 5", considering the interest rate of capital repayment to construct new unit would be an important decision-making parameter, while about 10 years difference of useful life of new power plant did not have remarkable effect on capital return period.

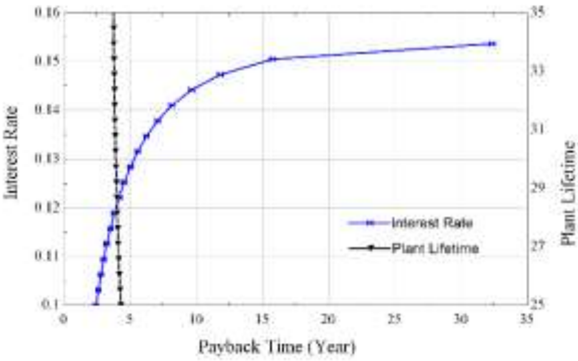

Fig. 5. Effect of interest rate and plant useful lifetime on capital return time

The power plant annual function hours and the required investment for capital return are important parameters which are interrelated as it can be seen in "Fig. 6". Annual interest rate of the capital investment is an important criterion in capital return and conversion of the thermal power plants. Due to decrease in capital investment rate to construct the repowered units, the annual interest rate considered for capital return could be presented as an effective parameter in the case of private sector management.

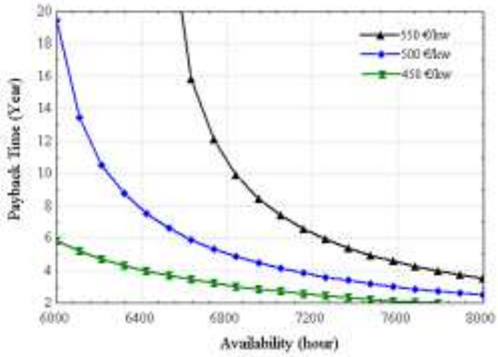

Fig. 6. Effect of capital investment cost and plant availability on capital return time

It can be seen in "Fig. 7" that this variable could have a significant effect on capital return period. According to "Fig. 7" initial investment increase in the discussed plans and its closeness tolerated values of similar combined cycle's results would lead to more sensitive capital return than interest rate. Owing to what has obtained from computations the capital return period reaches 20 years by 7% variation in repayment profit. Intensity of this issue would be lessened by reduction of investment degree.

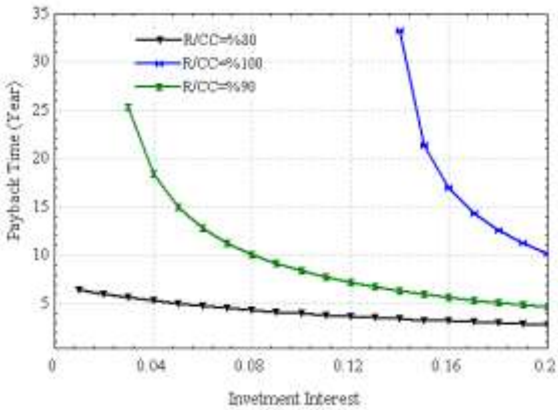

Fig. 7. Comparison of the benefit capital investment cost effect on capital return time

The effect of fuel cost and new cycles efficiency on capital return period is a major decision-making criterion and their effect on capital reversibility can be studied in "Fig. 8". Capital return of such a cycle differs from combined cycle with similar specifications as a result of decrease in its capital investment (R/CC: repowering/ Construction expense for new combined cycle units).

It has been seen in the diagram that the unit efficiency affects capital return period significantly regarding fuel price variations. For example, it is 10 years for a power plant with 45% efficiency and 3.7€.MBTU, while it is 2 years for a power plant with 50% efficiency and the same fuel price. According to policies of sections related to privatizing thermal power plants different parameters may be important to allocate thermal power plants. Concerning the issue, capital return period or annual interest rate could be considered as criteria that would encourage the investor and reduce investment risk in assigning the power plants [1].

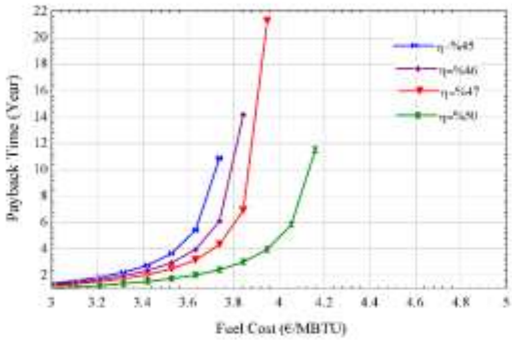

Fig. 8. Effect of efficiency and fuel cost on capital return time

Considering that most of gas turbine power plants concerned for conversion are less than 10 years old, variations considered to change these power plants were conducted assuming that new combined cycle power plants were constructed since the variations have been occurred. Effect of fuel price on the generated electricity price is a major issue in determining the desirability of power plant cycles properties; this parameter is directly affected by the cycle thermal efficiency. The effect of fuel price variation, in a definite range, on cost price of generated electricity could be investigated using Relation (10).

$$\frac{(C_f\,HR_f\,)_2}{(Z_{OC}\,)_2} - \frac{(C_f\,HR_f\,)_1}{(Z_{OC}\,)_1} = FCDS\,[\%] \qquad (10)$$

For instance, fuel cost was only 0.08246€¢ per kwh for subsidy state for a power plant with ideal properties of combined cycle in accordance with the objectives of subsidy targeting rule, while it would be 2.62€¢ at non-subsidy state. In other words, the proportion of fuel price to the general expense per every kWh would be only 7.5% for subsidy state and over72.1% at non-subsidy state. Effect of fuel price difference on the cost price of generated electricity for SBSPP at the current and new state is shown in "Fig. 9". As it can be seen in the diagram, sensitivity of the price of generated electricity to fuel price has been increased by efficiency decrease. This difference is 12.7% for the concerning cycle and new steam repowered cycle, while it is 14.9% for steam cycle according to relation (10). The effective role of fuel price and thermal power plants efficiency in the final price of generated electricity is shown by these differences.

Relations (11) and (12) could be used respectively for the current and converted states of SBSPP shown in the diagrams of "Fig. 9".

$$Z_{OC} = 202.5 + 123.1C_f \qquad (11)$$

$$Z_{OC} = 107.75 + 94.78C_f \qquad (12)$$

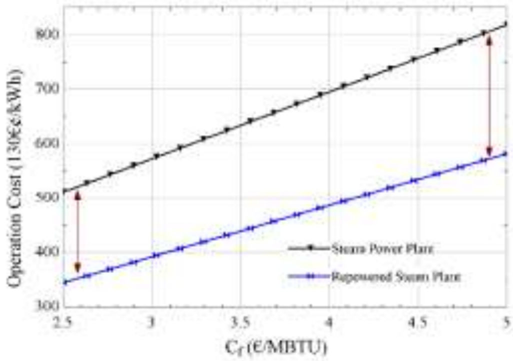

Fig. 9. Effect of fuel cost on operational cost in the existing and new condition

These states can be also compared using these relations. Cost benefit percent on the plans implementation is an important investment factor in the introduced plans to change the system of the current power plants. Effect of economic variables on this parameter is significantly important because variations are possible. Relation (13) has been utilized to determine values of this parameter regarding the current variables.

$$BCP = \frac{Z_{elec,buy} - Z_{OC}}{Z_{OC}}[\%] \qquad (13)$$

This relation indicates that the current steam and gas turbine power plants bring about loss considering the ideal power plants of targeting rule (combined cycles). For repowering cycle of prototype steam power plant, this relation has been investigated to compare converted state of concerning cycles. Some important current variables concerning the present status of the power plants include annual function of the power plant and interest rate to price the generate electricity.

Effect of the variables on the function has been shown in "Fig. 10". As it can be seen in this figure, the effect of interest rate on this function is more steeped.

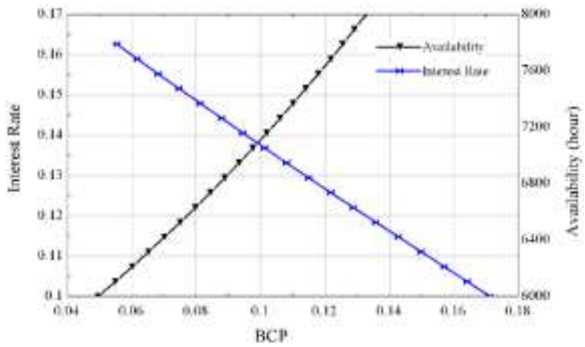

Fig. 10. Effect of plant availability and utilization limit on cost benefit percent

General annual profit could be obtained regarding the values obtained from Relation (14).

$$BC = \dot{W}.H.Z_{elec,buy}.BCP \quad (14)$$

It has been indicated in this relation that annual profit of the converted power plants would be affected by variables including the power plant annual performance hours, cycle power, cost benefit percent, and the price of purchasing generated electricity in the case of estimating the subsidy targeting rule. Hence, the great steam power plants in Iran which their repowering takes a long time would be economically justifiable in the case of utilization.

5. Variations Effect on the Properties of Iran Thermal Power Plant Fleet Thermal power plants

Concerning computed values in the current methods to upgrade the thermal units, Table (3) could be obtained. More precise investigations have been also displayed for each upgrading method in a separate column. A general conclusion has been shown in the last column. It can be seen in the second row that mean efficiency obtained from the methods is used for the power plants. The minimum of this value (obtained for steam power plants) completely agrees with the objectives of targeting rule from the viewpoint of generated electricity mean efficiency. Since the efficiency of CHP units is more than common units efficiency, their effect on the average obtained from thermal power plants upgrade has been significant. Since technical problems can occur in converting such units to CHP cycles, the state of gas turbine power plants mere conversion to combined units have been discussed as a separate capacity. In addition, since converting CHGPP and BAGPP to combined cycle has not affected the converted cycle positively when the capital investment cost is taken into account, this state was studied in two scenarios. Mean value of these methods performed in these present power plants with regard to their final power has been displayed in the third row of the table. The obtained efficiency was at least 45% after using these methods. Owing to the significant capacity and efficiency resulted from change of gas turbine units to CHP power plants, highest obtained efficiency related to the concerning methods and general state efficiency have been shown in third and 5thcolumn, respectively. Added capacity to thermal power plant fleet is shown in the third row. This would be the capacity for steam power plants depending on the variable and upgradable properties of the power plants. The added capacity of this state is about 30% of the thermal power plants network power of the Ministry of Energy until 2009. The costs of the generated electricity methods can be seen in the 4th row. Cost of repowering methods has decreased significantly for the units with technical properties similar to new combined power plants as a result of less initial investment. Its value is about 0.19077€¢ per kWh. Despite of higher efficiency in other power plants, this reduction is greater for the properties of combined cycle. Price reduction of consumed fuel used in comparison with average price of the power plants initial fuel has been shown in the 5throw. This value undergoes more reduction when the efficiency is upgraded.

Table 3. The effect of changes on network characteristics of thermal power plant

Parameters	Steam power plants	Gas turbine power plants with CHP	Gas turbine power plants without CHP(1)	Gas turbine power plants without CHP(2)	Complex with CHP	Complex without CHP(1)	Complex without CHP(2)
Average of new power plants efficiencies (%)	45	53	47.8	48.3	48.1	46	46.1
Added Capacity to the fleet (MW)	13108.5	5410.4	3867.4	3762.9	18518.9	16975.9	16871.4
Average cost of electricity generation (€¢.Kwh^{-1})	3.447	3.242	3.485	3.458	3.466	3.581	3.571
Average fuel cost reduction* (%)	85.7	193.2	161.7	165	164.1	149.2	150.5
FCE* (subsidized) (%)	9.1	6.4	7.1	7	7	7.3	7.3
FCE* (non-subsidized) (%)	76.1	68.7	70.8	70.6	70.7	71.6	71.6
Network efficiency Without under review existingunits (%)	36.6	37.3	37.3	37.3	37.4	37.4	37.4
Effects of changes on network efficiency (%)	+3.2	+5.1	+3.5	+3.5	+6.7	+5.5	+5.5

*** Expenses are in €¢ per kWh.**
(1): Unit conversion after considering all the converted power plants
(2): Unit conversion without taking the converted cycles of CHGPP and BAGPP into consideration

In addition, effect of fuel cost is shown in sixth and seventh rows for subsidy and non-subsidy states respectively. As it is indicated by mentioned values, about 10% of the spent expense is allocated to consuming fuel for subsidy state. This value would reaches about 70% for the current power plants at non-subsidy state. These values have been obtained using Relation (15).

$$\frac{Z_f}{Z_{OC}} = FCE \tag{15}$$

It is indicated by data in eighth row of the table that omitting these power plants with about 35% of the Ministry of Energy power plants network power would results in less than 1% increase in the efficiency of network power plants, while upgrading the units increases the network efficiency for about 7%. No great difference is seen between the first and the second scenarios values. Hence, the second scenario is superior to the first one. The determined objectives of executing subsidies targeting rule were based on upgrading electricity power plants until 2015 and accomplishment of 45% of them, so this column plays a determinant role in considering such variations. Efficiency of the thermal power plants network of Ministry of Energy has been improved remarkably and these operations plays a significant role in achieving this goal. Having considered these values, final efficiency of thermal power plants has improved according to "Fig. 11".

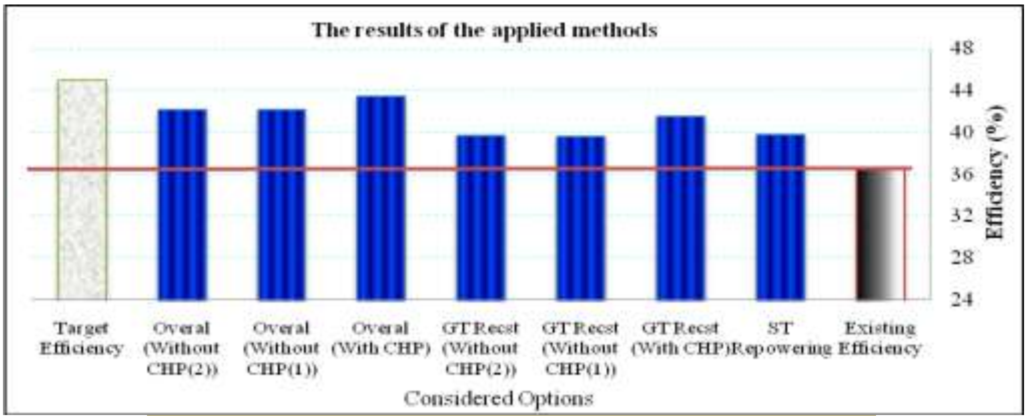

Fig. 11. Network efficiency Changes due to applied considered methods

6. Conclusion

Many gas turbine and steam power plants in Iran apt to be converted into combined cycle power plants. Regarding the obtained results, this conversion plays a remarkable role in general economical technical characteristic of thermal network. Using these methods and increasing the efficiency of thermal power plants will decrease the sensitivity of generated electricity price to the expense of consumed fuel; this fact would be effective in decreasing the variations of generated electricity cost with fuel cost variations. Enhancing thermal power plants Efficiencies from 3.2% to 6.7% and considering each scenario in Table (3) would be an important decision-making parameter in Iran electricity generation fleet regarding the objectives of targeting rule to reach an average efficiency of 45%. In addition, most important results of these methods for steam and gas turbine power plants can be a reduction of 1.385€¢per kWh generated electricity and a decrease over 1.923€¢, respectively. Considering the mentioned issues, a 5.5% increase in the efficiency of thermal power plants could be an efficient way of reaching the objectives of subsidies targeting rule where converting gas turbine units to concurrent production units is not feasible. Besides presented issues, a great capacity of the current gas turbine power plant fleet is not convertible because of their high age and deleting such power plants and replacing the cycles by new combined cycle power plants is not the best way of network upgrading in this respect. Finally and as the result of fulfillment of these changes, it would be possible to achieve one of the major objectives of targeting rule in reaching an efficiency of 45% for the power plants.

Nomenclature

A_t	Sale Benefit (€)
ABGPP	Abadan Gas Turbine Power Plant
BAGPP	Bandae Abbas Gas TurbinePower Plant
BASPP	Bandae Abbas Steam Power Plant
BC	Cost Benefit (€)
BESPP	Besat Steam Power Plant
BCP	Benefit Percent (%)
¢	Cent
C_f	Unit Cost of Fuel (€¢.Kj^{-1})
CHGPP	Chabahar Gas TurbinePower Plant
CHP	Combined Heat and Power
CRF	Capital-Recovery Factor (%)
DAGPP	Damavand Gas TurbinePower Plant
EASPP1	Eslam Abad Steam Power Plant1
EASPP2	Eslam Abad Steam Power Plant2
FCE	Fuel Cost Effect (%)
EGC	Electricity Generation Costs (€¢.Kwh^{-1})
ES	Efficiency Scale (%)
€	Euro
η	Thermal Efficiency (%)
FCDS	Fuel Cost Difference Scale (%)
FCE	Impact of Fuel Costs on Electricity Generation Costs
φ	Operation &Maintenance Factor

H	Plant Annual Performance(hours)
HOGPP	HormozganGas TurbinePower Plant
HR	Heat Rate(kJ kW^{-1} h^{-1})
I	Annual Interest Rate
JAGPP	JahromGas TurbinePower Plant
LHV	Low Heat Value (kJ.kg^{-1})
MASPP	Mashhad Steam Power Plant
MBtu	Millions Btu
MGSPP	MontazerGhaem Steam Power Plant
N,n	Duration (year)
NESPP	NekaSteam Power Plant
OC	Operation Cost (€.Kwh^{-1})
ORGPP	OromieGas TurbinePower Plant
PEC	Purchased equipment cost (€)
$\dot{Q}$	Heat Transfer Rate (MW)
RASPP	RaminSteam Power Plant
r_n	Inflation Rate (%)
SBGPP	SabalanGas TurbinePower Plant
SBSPP	ShahidBeheshti Steam Power Plant
SHGPP	ShiravanGas TurbinePower Plant
SC	Social Cost (€.Kwh^{-1})
SMSPP	ShahidMontazeri Steam Power Plant
SNGPP	SanandajGas TurbinePower Plant
TASPP	Tabriz Steam Power Plant
TCI	Total Capital CostInvestment (€)
$\dot{W}$	Power (MW)
X	Capital Investment Factor (%)
Z	Cost (€¢.Kwh^{-1})

Subscripts

AS	AfterSubsidies
CC	Combined Cycle
f	Fuel
GT	Gas Turbine
OC	OperationCost
PP	Power Plant
ST	Steam Turbine

References

[1] Mehrpanahi, A., Hosseinalipour, S. M., Rezapor, K.,"*The Effect of Targeted Subsidies on Economic Characteristics of Steam Power Plants*". Conference on Energy Management and Optimization, Tehran, Iran, 2010.

[2] Mehrpanahi, A., Hosseinalipour, S. M., Rezapor,K.,"*Analysis of Situation of Gas Turbine Power Plant on Making Targeted Subsidies Process*", 25TH International Power System Conference on Electrical, Tehran, Iran, 2010.

[3] Hosseinalipour, S. M., Mehrpanahi, A., "*Economic Study of Repowering of Steam Power Plant Compared with Construction of Gas Turbine Power Plant*", Iranian Journal of Energy, No. 33, page: 41-62, 2009.

[4] Solamian, Z., Kordbacheh, M., SadeghiShahdani, M., Mokarizadeh, V.,"*Total Cost Calculations Based on on Making Targeted Subsidies Process in Iran*", 20TH International Power System Conference on Electrical, Tehran, Iran, 2009.

[5] Ghahramani, S., Fateh, A.,"*Economic Comparison of Cost of Energy Production in Distributed Generation in Iran Power Plants*", 23TH International Power System Conference on Electrical, Tehran, Iran, 2008.

[6] Tavanir Organization", Iran Detailed Statistics of Electricity Industry, for Strategic Management in 2008", [online]. Available from: www.amar.tavanir.org.ir. Accessed 21 November 2013.

[7] Kudlu, N., "*Major Options and Considerations for Repowering with Gas Turbines*", Electric Power Research Institute, BETCHEL Project Report. 1989.

[8] Mehrpanahi, A., Hosseinalipour, S. M., Mobini, K.,"*Investigation of The Effects of Repowering Options on Electricity Generation Cost on Iran Steam Power Plants*", International Journal of Sustainable Energy, Vol. 32 No.4, pp.229-243, 2013.

[9] Sanaye, S., Hamzee, Y., "*Techno-Economic Modeling and Optimization of Recovery of Steam Power Plants Using Gas Turbine*", 20TH International Power System Conference on Electrical, Tehran, Iran, 2005.

[10] Brandr, J. A., Chase, D. L.,"*Repowering Application Consideration"*, ASME – Journal of Engineering for Gas Turbines and Power, 114, 643–652, 1992.

[11] Chase, D. L., Kovacik, J. M., Stoll, H. G.,"*Theeconomic of Repowering Steam Turbines*", GE Company, 1991.

[12] Moore, T., Repowering as Competitive Strategy. EPRI Journal, September, 6–13, 1995.

[13] Sarabchi, K., Nabati, H.,"*Thermodynamics Investigation of Steam Power Plant Conversion to Combined Cycle Power Plant*", 8th Iranian Annual Mechanical Engineering Conference, Tehran, Iran, 2000.

[14] Pace, S., Graces, D., Stenzel, W.,"*Strategic Assessment of Repowering*", Interim Report. Electric Power Research Institute, 1997. Available from: http://my.epri.com/portal/server.pt?Abstract_id=TR-106908.

[15] Stenzel, W., Sopocy, D. M., Pace, S.,"*Repowering Existing Fossil Steam Plants*", EPRI, 1997. Available from: http://www.soapp.com/papers/Repowering_Fossil_Plants.pdf.

[16] Ploumen, P. J., Veenema, J. J., Epon, N. V.,"*Dutch Experience with Hot Wind-Box Repowering*", ASME, 96-GT-250, 1996.

[17] Shahnazari, M. R., Foroughi, D., Fakhrian, H.,"*Repowering of Lowshan Power Plant*", IGTC Conference, Tokyo, 2003.

[18] Walters, A. B., Craig, J. R., Herbster, R. E., Van laar, J.,"*Repowering Options Study*", Florida Power & Light Company Report, 1988.

[19] Stoll, H. G., Smith, R. W., Tomlinson, L. O., "*Performance and Economic Considerations of*

Repowering Steam Power Plants". GE Company, 1994.

[20] Sanaye, S., Hamziei, Y, Malekian, M. R."*Thermal and Economic Analysis of Besat Steam Power Plant Repowering*", ASME Turbo Expo. doi:10.1115/GT2006-90720. pp:777-783, 2006.

[21] Escosa, J. M., Romeo, L. M.,"*Optimization CO_2 Avoided Cost by Means of Repowering*", Applied Energy Journal, Vol. 86, 2351–2358, 2009.