
Impact of Auxiliary Equipments' Consumption on Electricity Generation Cost in Selected Power Plants of Pakistan

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ABSTRACT

This study focuses on higher generation cost of electricity in selected TPPs (Thermal Power Plants) in Sindh, Pakistan. It also investigates the energy consumed by the auxiliary equipment of the selected TPPs in Sindh, Pakistan. The AC (Auxiliary Consumption) of selected TPPs is compared with that in UK and other developed countries. Results show that the AC in selected TPPs in Sindh, Pakistan exceeds the average AC of the TPPs situated in developed countries. Many energy conservation measures such as impeller trimming and de-staging, boiler feed pump, high voltage inverter, variable frequency drive, and upgrading the existing cooling tower fan blades with fiber reinforced plastic are discussed to overcome higher AC. This study shows that harnessing various available energy conservative measures the AC and unit cost can be reduced by 4.13 and 8.8%; also adverse environmental impacts can be mitigated. Results show that the unit cost of electricity can be reduced from Rs.20 to 19/kWh in JTPP (Jamshoro Thermal Power Plant), Rs.9 to 8.8/kWh in GTPS (Gas Turbine Power Station) Kotri and Rs. 11 to 10.27/kWh in LPS (Lakhara Power Station). Thus, electricity production can be improved with the existing capacity, which will eventually assist to manage the current energy crisis and ensure its conservation.

Key Words: Sources of Electricity, Thermal Power Plants, Auxiliary Consumption, Unit Cost.

1. INTRODUCTION

Energy demand is increasing day by day all over the world due to rapid growth of population, enhanced standard of life and development in technologies [1]. Currently, about two-thirds of world's energy demand is accomplished by harnessing non-

renewable energy sources [2] and its severity towards the environmental destruction is one of the major issues of recent research [3-4]. There are various alternative energy resources available through which world energy demands and its crisis could be coup up without affecting global environment.

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Pakistan is the 6th largest country by population which is over 190 million with GDP (Gross Domestic Production) growth rate of 4.4% and inflation rate of 1.8% [5]. Pakistan is facing electricity short fall of around 23.53-29.41% for last few years. This has negative effects on GDP that in turn causes various socio-economic and political problems. However, annual energy demand of Pakistan is increasing by about 4-5% and that will continue for coming 10 years. The share of different energy sources in electricity generation in Pakistan is oil (35.2%), hydel (29.9%), natural gas (29%), nuclear and others (5.8%) [6]. It is reported that in Pakistan about 67% of electricity is generated by TPPs based on fossil fuels, in which oil, gas and coal contributes 55.96, 43.94 and 0.1%, respectively in 2012-2013 [7-8]. The energy efficiency of CCGT (Combine Cycle Gas Turbine) power plant is as low as 34.41% [9]. There are two major factors of this low efficiency; one is ageing of TPPs and the other is energy losses [10]. The low efficiency of most of the fossil fuel based power plants and higher line losses are estimated to be 23-25% that causes electric power shortfall and higher generation cost [11]. The generation of electricity from different resources in different countries is demonstrated in Fig. 1[12-14].

In Fig. 1 the generation of electricity from various sources such as fossil fuel (oil, gas and coal), nuclear, hydel and other renewable in Pakistan is compared with other developed countries. It is clearly shown in Fig. 1 that most of the electricity is generated from fossil fuel i.e. greater than 65% in Pakistan. Notably, 35% of total electricity is produced from oil which is an expensive source and mostly imported. The coal is regarded as cheapest source for electricity production. However, abundant coal reserves are available in Pakistan yet its use in the country for electricity generation is less than 1%. Natural gas contributes about 30% in electricity production, greatly affecting the ample supply to domestic, commercial and industrial sectors of the country. Consequently, the levelized cost of electricity is also remaining at higher side as compared to neighboring countries.

1.1 Auxiliary Consumption

In TPP the equipment that are not directly generating the power but are assisting in the process of power generation such as pumps, fans and compressors are known as auxiliary equipment and power consumed by them is called AC. It is reported that most of the fossil

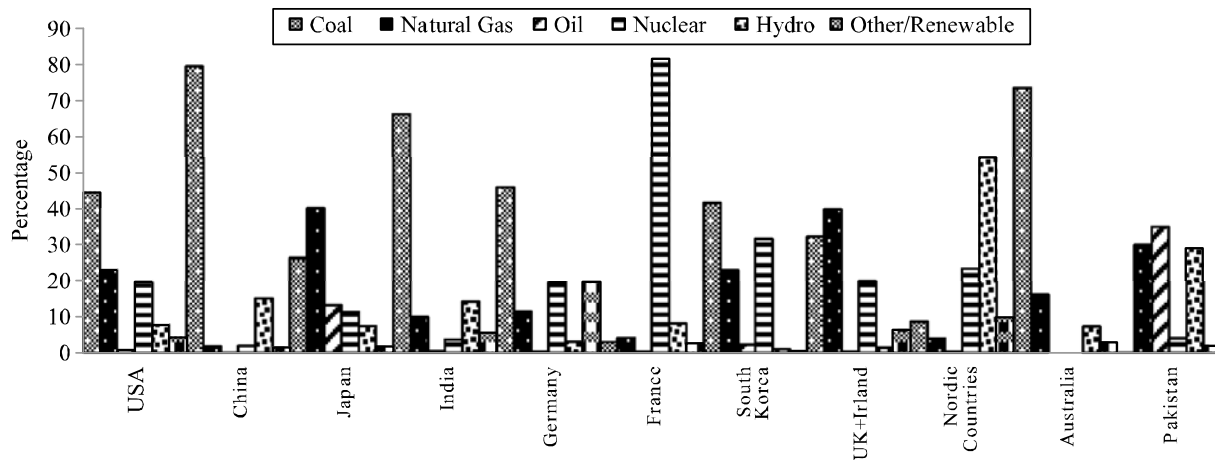


FIG. 1. PERCENTAGE ENERGY GENERATION BY SOURCE

fuel fired TPPs in India have an efficiency ranging from 30-40% [10], which is lower than that in developed countries [14-15]. The decrease of energy conversion efficiency of TPPs in India is due to high consumption of auxiliary equipment that ranges from 6.5-8.5% [16,17]. In 2012 a case study shows that gas based power stations had an AC ranges from 1.4-1.8% while AC ranges from 6.5-9.6% in coal based power stations [18,19]. The mean AC of most of the coal fired power plant in the USA is around 7.97% whereas in India its value is around 11.9% for same year of 2009 [20]. A gas-steam combine cycle co-generation power plant is reported to have a thermal efficiency of about 77.16%, average heat-to-power ratio of 40.65% and AC of 2.1% [21,22].

1.2 Auxiliary Consumption Reduction Measures

There are various methods through which the performance of auxiliary equipment can be improved such as, impeller trimming, de-staging and installation of VFD (Variable Frequency Drives) [23] and operating auxiliary equipment with different load factors. It had been analyzed that about 38% of electric power is produced by harnessing coal in the USA. The thermal efficiency of coal-fired TPPs in USA was enhanced from 32-37.4% in 2007-2008. This enhancement was done by improving plant operation and maintenance scheduling along with refurbishment of equipment and plant up-gradation. It accounts for overall reduction in GHG (Greenhouse Gas) emissions of 175 million metric tons/year. This is around 2.5% of total GHG emissions/year of 2008 in the USA [24]. The AC of 210MW coal-fired TPPs in India is reduced up to 12.05% at 70% PLF (Plant Load Factor) to 8.74% at 100% PLF that decreases energy consumption around 9.1 MU/year and

CO₂ emission around 9500 ton/year [25]. The AC of cooling tower of TPPs can be reduced about 30-35% by up-grading the exiting blade glass reinforced plastic with fiber reinforced plastic [26]. The boiler feed pump energy consumption can be decreased from 2.97-2.32% of gross energy generation by implementing remedial measures. However, it is achieved by reducing re-circulation flow, pressure drop in feed water circuit components and enhancing overall efficiency of feed water pumps [27]. In boiler, ID (Induced Draft) fan is operated by motor accounts for larger proportion of energy consumption as compared with turbine driven. Therefore, the energy is saved from 1.6-2.5 g/kWh by using turbine driven ID fan, which is operated on fourth and fifth stage steam extraction [28].

Use of inverters for variable speed control is relatively small, so there is an incentive to use high voltage inverters. The electric motor power consumption could be decreased up to 70% using high voltage inverter operating on output capacity of 50% [29]. The coal consumption is reduced up to 856grams of coal/kWh by considering financial and economic risk associated with implementation of renovation and modernization program in coal-fired TPPs under available operating conditions and parameters [30]. The efficiency of TPPs is increased by decreasing circulating water flow to AC at high temperatures. The electricity output can also be increased by diverting AC circulating water discharge to main condenser instead of flowing directly to cooling tower [31]. The moisture removals from coal decrease the AC of 550 MW unit of coal-fired TPP is situated in North Dakota, USA. Thus, it increases the performance of coal-fired TPP is situated in North Dakota, USA [32].

2. PROBLEM STATEMENT

The generation cost of electricity is high in selected TPPs of Sindh Pakistan due to multiple reasons which include high auxiliary consumption and use of costlier fuel.

3. OBJECTIVES

This paper aims to focus on the issue of generating electricity at higher price from fossil fuels. For this purpose, some TPPs in Sindh, Pakistan are taken as a case study. The power consumption of the auxiliary equipment's in TPPs is considered. Finally, methods are devised to reduce higher consumption of auxiliary equipment in order to reduce unit cost of electricity generation and CO₂ emission from selected TPPs.

4. METHODOLOGY

In this research work uses the primary data (i.e. related to generation and the type of fuel used) which is obtained from selected TPPs in Sindh, Pakistan. The data is used to ascertain the AC of selected TPPs and compare it with that of TPPs of other developed and under developing countries. The impact of AC on generation cost of electricity was also determined. In addition to that the secondary data, obtained from the literature for the fuel

used by other countries for producing electricity, revealed the impact of type of fuel on the generation cost of electricity. It is noted that in most of the cases, electricity is being generated from costlier fuel (i.e. Oil) in Pakistan. Thus, the impact of the main reasons of higher generation cost of electricity (i.e. fuel and AC) is determined. This study, then discussed different measures required to reduce higher AC in selected TPPs. Finally, the implementation of suggested measures, such as using appropriate fuel for generating electricity or reducing AC, on increasing net electricity generation or mitigating adverse environmental impacts is analyzed.

5. ELECTRICITY GENERATION COST

The electricity generation cost in Pakistan is high due to multiple reasons, including inefficient power plants and production of electricity from costly fuels. These two reasons contribute in raising the unit cost of electricity in Pakistan, while comparing with other developed countries as given in Table 1.

It is given in Table 1 that the highest generation cost of electricity incurred in oil based TPPs in different countries of the globe. However, Pakistan produces over 35% of electricity from oil whereas developed countries have

TABLE 1. A COMPARISON OF ELECTRICITY GENERATION COST (\$/MWH) [33-35]

Resources	Germany	UK	USA	France	India	Pakistan
Gas	58	135	75.2	73	75	90.25
Coal	46	Not Available	95.1	Not Available	60	112
Oil	Not Available	Not Available	Not Available	Not Available	Not Available	199.5
Nuclear	Not Available	127	95.2	57	80	110
Hydro	Not Available	Not Available	83.5	23	60	23

shifted from oil to other resources. Although the cost of electricity generation from gas and nuclear is also not low; Pakistan still produces higher amount of electricity from these two sources. Hydel power is an acceptable power source in Pakistan; its price is equal to the electricity generated in France and less than USA. Average unit cost price of different energy sources in Pakistan is around 15 cent/kWh compared to 12 and 8cent/kWh in USA and Asia-Pacific region in the period of 2010-2013 [11,36].

6. UNIT COST AND AUXILIARY CONSUMPTION

6.1 Jamshoro Thermal Power Station

JTPS is situated in Jamshoro district and fulfills the energy demand of interior Sindh. It consists of one 250MW Japan

based furnace oil fired unit and three 200MW China based dual fired (i.e. Gas and Furnace Oil) units (Table 2).

The data of JTPS for the month of July 2013 shows that 344.5GWh units of electricity was produced at a cost of Rs.6873.46 Million/month i.e. Rs.19.95 per kWh [37]. It is shown in Fig. 2 that AC in JTPS varies from 8.87-12.21%, whereas, the normal range varies from 3-9%. However, the power utilized by auxiliary components is not same for all four units working in JTPS; investigations revealed that considerable amount of AC incurred in auxiliary equipment of Unit-II and Unit-III. The AC of Unit-I and Unit-IV is nearly equal to maximum AC range of thermal power plants. The average AC of JTPS is around 10.4%. The gross unit generated and AC of JTPS is given in Table 3 [38].

TABLE 2. INSTALLATION CHARACTERISTICS OF JTPS JAMSHORO

Unit No	Installed Capacity (MW)	Dependable Capacity (MW)	Fuel Types
ST1	250	205	Furnace Oil
ST2	200	156.6	Dual (Furnace Oil + GAS)
ST3	200	156.67	
ST4	200	156.67	
Total	850	675	

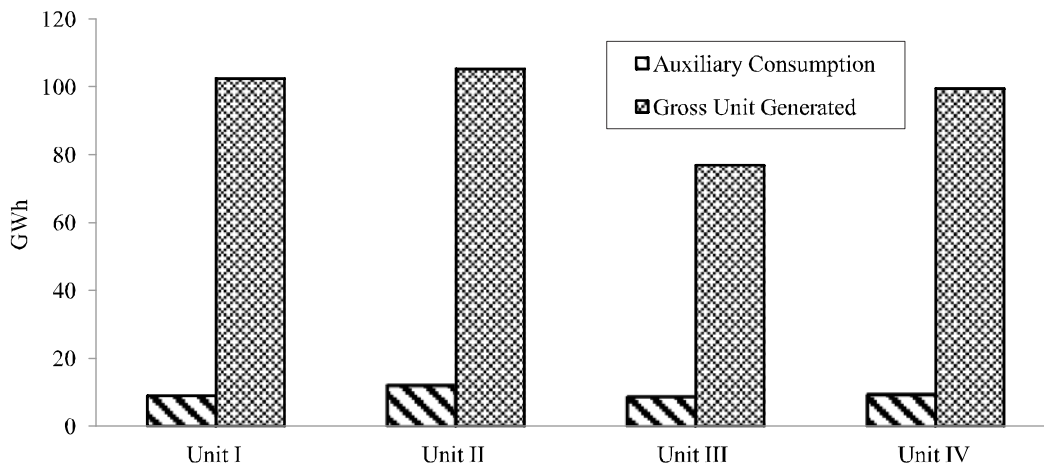


FIG. 2. AC AND GROSS UNIT GENERATED OF FOUR UNITS IN JTPS JAMSHORO

6.2 Gas Turbine Power Station Kotri

GTPS Kotri is situated on the national highway, nearly 8km from Hyderabad city. This power station is the first GTPS built in the province of Sindh. It was constructed in four different phases having a total capacity of 174 MW. Two CEM France units of 15 MW each, two Thomson Holland units of 25 MW each, two Hitachi Japan units of 25 MW each and one combined cycle unit of 44 MW from Harbin Turbine Works China are installed. The installation characteristics of GTPS Kotri are given in Table 4.

According to the data available for the month of November 2013, the total operating hours were

calculated as 446hrs, during that nearly 15.32GWh units of electricity was generated with the expenditures on fuel cost as Rs.138.24 million. Accordingly, leveled cost of the plant in that month is calculated as Rs. 9/ kWh. The data regarding AC in GTPS Kotri is summarized in Table 5 and Fig. 3. It is clear that AC in GTPS Kotri is within permissible limits except unit CCP-VII which has the highest AC among all remaining units [19,23]. However, AC can be reduced if remaining two units are also brought into operation. The operational units of GTPS Kotri had a designed efficiency of 24.5% with natural gas as main fuel. However, the efficiency of these units has been falling

TABLE 3. A VIEW OF GROSS UNIT GENERATED AND AUXILIARY CONSUMPTION IN DIFFERENT UNITS OF JTPS JAMSHORO

Unit	Gross Unit Generated (GWh)	AC (GWh)	AC (%)	Average of AC (%)
	a	b	$c=(b/a) \times 100$	$?c/4$
Unit-I	102.46	8.95	8.74	10.37
Unit-II	105.31	12.21	11.59	
Unit-III	76.88	8.87	11.54	
Unit-IV	99.41	9.54	9.60	

TABLE 4. INSTALLATION CHARACTERISTICS OF GTPS KOTRI

Unit No	Installed Capacity (MW)	Dependable Capacity (MW)	Fuel Type
GT-1	15	8.5	Dual (Gas + High Speed Diesel)
GT-2	15	8.5	
GT-3	25	18	
GT-4	25	18	
GT-5	25	18	
GT-6	25	18	
CC-7	44	34.5	
Total	174	123.5	

consistently and it is fallen to 14.22% only for the fiscal year of 2010-2011. The efficiency of GTPS Kotri is considerably lower than IPPs (Independent Power Producers) which have operating efficiency of 50-52%. Thus it leads to higher costing to CPPA (Central Power Purchasing Agency) of NTDC (National Transmission and Dispatch Company Limited) averagely around Rs.8.3/kWh for fiscal year of 2010-2011 and 11.20 for the month of November 2013.

6.3 Lakhra Power Station

LPS is situated in Jamshoro district. It is the only power generation company based on coal in Pakistan. The installed capacity of LPS is 150 MW but unfortunately, out of three only one unit of 50MW capacity is operating. The only operational unit has a capacity of 30MW while remaining two units are out of operation. All three units are based on coal, which is being recovered by

TABLE 5. GROSS UNIT GENERATED AND AUXILIARY CONSUMPTION IN GTPS KOTRI [39]

Unit	Gross Unit Generated (GWh)	Auxiliary Consumption (GWh)	Bus Bar Line Loss (GWh)	Auxiliary Consumption (%)
G-I	-	-	-	-
G-II	-	-	-	-
G-III	8.41	0.010	-	0.12
G-IV	0.76	0.005	-	0.62
G-V	1.88	0.019	-	1.03
G-VI	0.83	0.008	-	0.97
CCP	4.51	0.865	-	19.18
Total	16.39	0.907	0.18	6.63

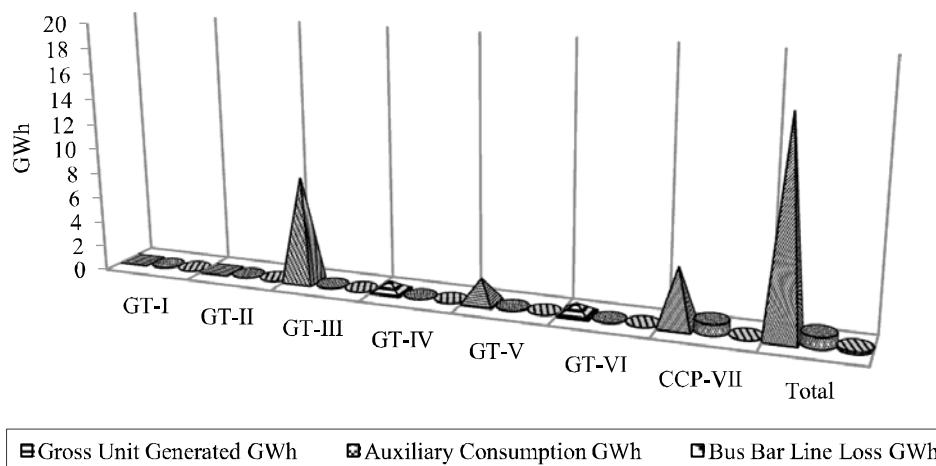


FIG. 3. GROSS UNIT GENERATED (GUG) AND AUXILIARY CONSUMPTION AT GTPS KOTRI [39]

primitive underground mining method from Lakhra coal mines, 25 kilometers from LPS. However, the gross electric power generated from LPS could be increased from 30-90MW by operating the closed units. It is reported that cost incurred on rehabilitation of closed unit is estimated around Rs.2 billion and it could be recovered with payback period of 9 month [40].

According to the available data for the month of October 2013, the total operating hours were calculated as 650hrs, during that nearly 13.78GWh units of electricity were generated with the expenditures on fuel cost as Rs.154.4 Million. Accordingly, levelized cost of the plant in that month is calculated as Rs.11.20 per kWh. Data shows that AC in LPS is around 27% which is higher than the permissible limits of the AC of coal based TPPs in developed countries.

7. RESULTS AND DISCUSSION

It is clear that based on previous discussion that generation cost of electricity is very high in Pakistan due to higher AC. Furthermore, with appropriate measures to overcome AC the current power crisis may be mitigated. The reasons behind these losses may be classified as:

7.1 Primary Reasons

- (a) Power plants are not working to their full capacity.

- (b) The AC of TPPs is too high

It is given in Table 6 that AC of TPPs situated in Sindh Pakistan is beyond the allowable limit of AC of TPPs situated in developed countries.

7.2 Secondary Reasons

- (a) The operation of power plant is frequently aborted by shortfall of water in rivers for long period. Thus, in this period net electric output of TPP is negative i.e. considered as loss. This loss is accomplished when power plant is in operation.
- (b) Improper maintenance gradually degrades performance of plant equipment. Therefore, plant becomes less efficient with higher generation cost.
- (c) Low care for rehabilitation of closed units of power plants. Thus, the assets deplete without production.
- (d) Inefficiency
- (e) Costly fuels are used e.g. oil accounts for 35% of total electricity generation as compared to only 0.1% of coal.
- (f) Improper utilization of renewable energy resources.

TABLE 6. COMPARISON OF AUXILIARY CONSUMPTION OF THERMAL POWER PLANTS SITUATED IN SINDH PAKISTAN WITH THE DEVELOPED COUNTRIES

No.	Plant	Source	AC (%)	AC of TPPs in Developed Countries (%)
1.	JTPS	Oil + Gas	10.38	3-9
2.	GTPS	Gas + HSD	6.6	1.4-1.8
3.	LPGC	Coal	26.73	6.5-9.6

8. REMEDIAL SOLUTIONS

From above analysis it is concluded that the selected power plants in Sindh, Pakistan, are not working on their dependable capacity and even some has units out of operation. The closed units of TPPs cause major contribution to higher percentage of AC because some auxiliary equipment (cooling tower fan and condensate feed pump) would not operate at their full capacity. In addition, energy is consumed by plant building (lighting, cooling etc.) also has significant impacts on its AC. The AC could be decreased to an acceptable level by operating the power plant to their dependable capacity which will increase gross generation.

It is suggested that the implementation of comprehensive preventive maintenance for all power plants, improvement in plant operation, up-gradation with latest technologies can reduce the AC to acceptable level. In addition to that rehabilitation of closed units of LPS and GTPS and ensuring proper supply of water to the plant can reduce AC. Optimum load factor shall be worked out for reducing AC. Above measures could be summarized as:

- (1) Retrofitting of various inefficient auxiliary equipment with most efficient one.
- (2) Operating TPPs on optimum load factor.
- (3) Installation of variable frequency drive along with impeller trimming.
- (4) Operating boiler induced draft fan with bleed-steam from turbine instead of motor drive boiler induced draft fan.

- (5) Minimizing pressure loss in condenser components.
- (6) Eliminating steam and condensate water leakage losses in various fitting and joint with proper maintenance.
- (7) Replacing the existing blade of cooling tower fan with fiber-reinforced plastic material.
- (8) Replacing low voltage VFD inverter with high voltage.
- (9) Implementing innovative and modernize techniques.

8.1 Reduction in Generation Cost in Jamshoro Thermal Power Station

The AC in Jamshoro thermal power station contributes a major share towards the levelized cost of the plant. Considering above recommendations, the AC can be limited to within the prescribed limits for steam power plant of developed countries. The effects of different remedial measures, suggested in the light of a review of literature, on the unit cost of electricity are given in Table 7.

The effects of different remedial measures on auxiliary consumption and unit cost of electricity generated in JTPS are given in Table 7. It is demonstrated in Fig. 4 that unit cost of electricity generated in JTPS is linearly related to its AC. The line in Fig. 4 shows the variation of unit cost generated in JTPS with variation of its AC within the prescribed limit AC in developed countries. The AC of TPPs based on oil varies from 3-9% in developed countries. The present AC of JTPS is around 10.34% and it is higher than permissible limit of AC of

TPPs based on oil in developed countries. The AC of JTPS could be reduced from 10.34-8% by considering suitable remedial measures, which are given in Table

7. Thus, it will decrease unit cost of electricity generated in JTPS averagely up to 2.5% i.e. unit cost reduces from 20-19.5 PKR/kWh.

TABLE 7. EFFECTS OF REMEDIAL MEASURES ON UNIT COST (PKR/kWh) IN JTPS

Remedial Measures	Reduction in AC (%)	GUG (GWh)	Present AC		NEO (GWh)	UC (PKR/kWh)	AC after Remedy		NEO (GWh)	Total Cost Incurred (M PKR)	Modified UC (PKR/kWh)	Decrease in UC (%)
			(%)	(GWh)			(%)	(GWh)				
Impeller trimming & Destaging of Feed Pump	2.0	384	10.4	40	344	20	8.4	32	352	6874	19.5	2.2
Operating on different load factor PLF=70%	1.2	384	10.4	40	344	20	9.1	35	349	6874	19.7	1.4
Operating I.D fan on bled steam	2.1	384	10.4	40	344	20	8.3	32	352	6874	19.5	2.2
Reducing recirculation of feed water and its pressure drop in feed water circuit	2.6	384	10.4	40	344	20	7.7	30	354	6874	19.4	2.9
Replacing Cooling Tower fan bled with fiber reinforced plastic	3.4	384	10.4	40	344	20	7.0	27	357	6874	19.2	3.7
Average	2.3	384	10.4	40	344	20	8	31	353	68734	19.5	2.5

Note: GUG= Gross Unit Generation, NEO = Net Electric Output and UC = Unit Cost

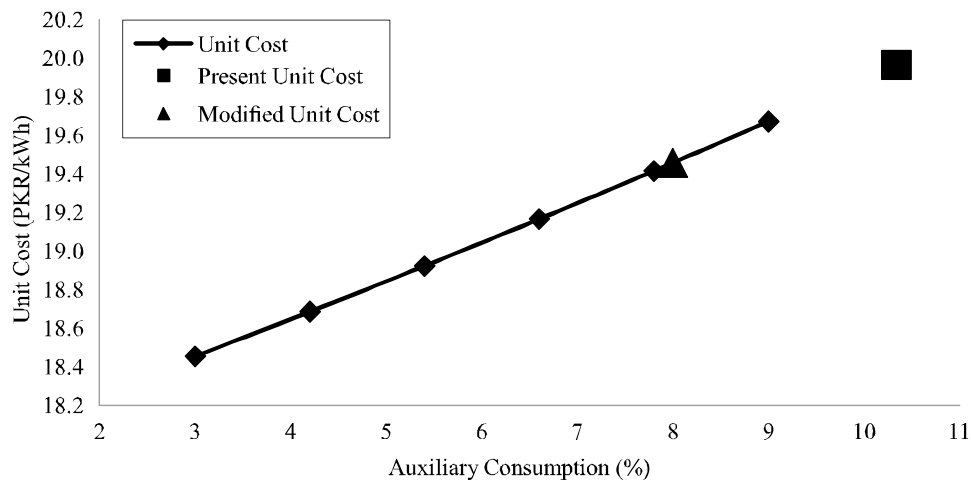


FIG. 4. EFFECT OF AUXILIARY CONSUMPTION ON UNIT COST (PKR/kWh) IN JTPS JAMSHORO

8.2 Reduction in Generation Cost in Gas Turbine Power Station Kotri

Since generation cost of electricity in GTPS Kotri is very high. It is mainly because of the fact that power consumption within the power plant is outside the acceptable limits. If the AC is decreased to the average AC prescribed limit for GTPS of developed countries. The generation cost of electricity can be reduced significantly in GTPS Kotri. The effects of AC on electricity generation cost in GTPS Kotri are analyzed. The AC in GTPS contributes a major share towards the levelized cost of the plant. Considering above recommendations, the AC can be limited to within the prescribed limits for gas turbine power plant of developed countries. The effects of different remedial measures, suggested in the light of review of literature, on the unit cost of electricity are given in Table 8.

The effects of different remedial solution on AC and unit cost of electricity generated in GTPS are given in Table 8. The variation of unit cost with respect to AC of GTPS is demonstrated in Fig. 5. As seen in Fig. 5, the unit cost increases as the AC of GTPS increases. The present unit cost of electricity generated in GTPS Kotri can be reduced from Rs.9/-Rs.8.8/kWh by implementing the various remedial measures, which are given in Table 9. The unit cost of electricity can be averagely reduced up to 2.3% by reducing the average AC around 4.4%. However, it can be further reduced if two closed unit of GTPS are brought into operation. Hence it is highly recommended for GTPS Kotri to take suitable remedial measures in order to decrease AC and reduce the electricity generation cost.

TABLE 8. EFFECTS OF REMEDIAL MEASURES ON UNIT COST (PKR/kWh) IN GTPS KOTRI

Remedial Measures	Reduction in AC (%)	GUG (GWh)	Present AC		NEO (GWh)	UC (PKR/kWh)	AC after Remedy		NEO (GWh)	Total Cost Incurred (M PKR)	Modified UC (PKR/kWh)	Decrease in UC (%)
			(%)	(GWh)			(%)	(GWh)				
Impeller trimming & De-staging of Feed Pump	2	16.40	6.6	1.08	15.3	9.02	4.6	0.75	15.6	138.24	8.84	2.10
Operating I.D fan on bled steam	2.05	16.40	6.6	1.08	15.3	9.02	4.5	0.75	15.6	138.24	8.83	2.15
Operating I.D fan on bled steam	2.65	16.40	6.6	1.08	15.3	9.02	3.9	0.65	15.7	138.24	8.78	2.75
Reducing recirculation of feed water and its pressure drop in feed water circuit	2.1	16.40	6.6	1.08	15.3	9.02	4.5	0.74	15.6	138.24	8.83	2.20
Implementing Renovation and Modernization Techniques	2.2	16.4	6.6	1.1	15.3	9.02	4.4	0.72	15.7	138.2	8.8	2.3
Average		384	10.4	40	344	20	8	31	353	68734	19.5	2.5

Note: GUG = Gross Unit Generation, NEO = Net Electric Output and UC Unit Cost

8.3 Reduction in Generation Cost at Lakhra Power Station Lakhara

With the help of available results it is concluded that two units of LPS are closed, which in turned increases AC of the plant. Charges other than fuel charges (i.e. Depreciation charges, Water charges, Overhead expenditures and etc.) are considered for all three units, even though two units remain closed. Thus if remaining two units are also brought into operation, the generation cost of electricity may be decreased considerably.

The AC in LPS Lakhara contributes a major share towards the levelized cost of the plant. Considering above recommendations, the AC can be limited to within the prescribed limits for coal based TPPs of developed countries. The effects of different remedial measures, suggested in the light of review of literature, on the unit cost of electricity are given in Table 9.

The effects of different remedial measures on AC and unit cost of electricity generated in LPS are given in Table 9. The variation of unit cost with AC of coal based thermal power plants is demonstrated on Fig. 6. As seen in Fig. 6, the AC of TPP based on coal in developed countries varies

from 6.5-9.6%. The present AC of LPS is around 26.7% and it is beyond the prescribed limit of AC of TPP based on coal in developed countries. The AC of LPS could be reduced averagely up to 19.7% by considering suitable remedial measures, which are given in Table 9. Thus it will decrease unit cost electricity generated in LPS averagely up to 8.1% i.e. unit cost reduces from Rs.11.2/-Rs.10.2/kWh. Although incorporating the remedial measures in LPS yet its AC is beyond the prescribed limits for coal based TPPs in developed countries. It can be further reduced by rehabilitation of the closed unit of the LPS and ensuring the proper supply of feed water to the plant. It is suggested that constructing a storage tank within the periphery of the plant would reduce the AC of LPS. Implementing these measures will also help to increase output to a dependable capacity of the plant.

8.4 Overall Impacts on Generation Cost of Electricity Due to Recommendations

Here analysis is carried out to investigate the impacts of different proposed remedial measures on generation cost of electricity from fossil fuels and energy crisis in Pakistan. It is estimated that based on different remedial measures

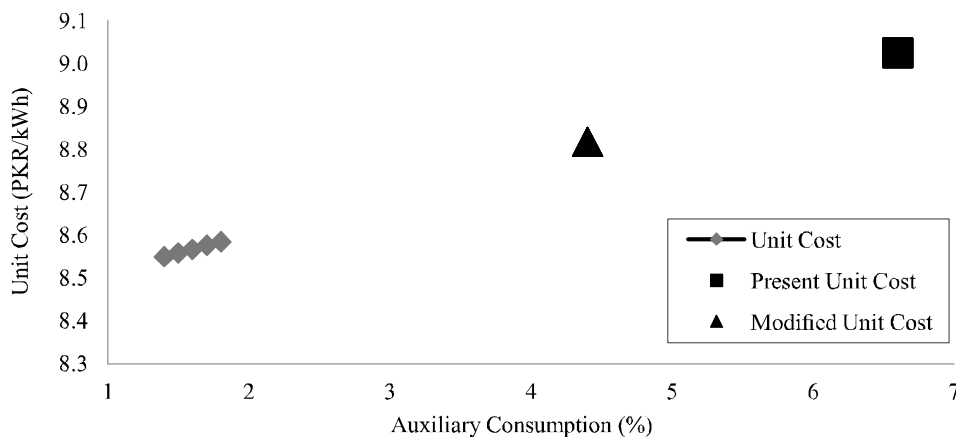


FIG. 5. EFFECT OF AUXILIARY CONSUMPTION ON UNIT COST (PKR/kWh) IN GTPS KOTRI

the generation cost of electricity in JTSP, GTPS and LPS can be reduced by 2.5, 2.3 and 8.12% respectively. The generation cost of electricity in all three units can be averagely decreased by 4.31%.

As shown in Fig. 7 that present unit cost of electricity generated in selected TPPs is compared with its modified value of unit cost. As seen in Fig.7 that the maximum unit cost occurs in oil based TPP i.e. Rs.20/kWh, minimum

TABLE 9. EFFECTS OF REMEDIAL MEASURES ON UNIT COST (PKR/kWh) IN LPSLAKHARA

Remedial Measures	Reduction in AC (%)	GUG (GWh)	Present AC		NEO (GWh)	UC (PKR/kWh)	AC after Remedy		NEO (GWh)	Total Cost Incurred (M PKR)	UC Modified (PKR/kWh)	Decrease in UC (%)
			(%)	(GWh)			(%)	(GWh)				
Impeller trimming & Destaging of Feed Pump	2	18.81	26.7	5.03	13.78	11.2	24.7	4.65	14.16	154.3	10.91	2.7
Operating on different load factor PLF=70%	12.05	18.81	26.7	5.03	13.78	11.2	12.0	2.27	16.54	154.3	9.33	17
Operating on different load factor PLF=100%	8.74	18.81	26.7	5.03	13.78	11.2	8.7	1.64	17.16	154.3	9.00	20
Operating I.D fan on bled steam	2.05	18.81	26.7	5.03	13.78	11.2	24.6	4.64	14.16	154.3	10.90	2.7
Reducing recirculation of feed water and its pressure drop in feed water circuit	2.645	18.81	26.7	5.03	13.78	11.2	24.1	4.53	14.28	154.4	10.81	3.5
Moisture removal from Coal	2.7	18.81	26.7	5.03	13.78	11.2	24.0	4.52	14.29	154.3	10.81	3.6
Average	5.03	18.81	26.7	5.03	13.78	11.2	19.7	3.71	15.10	154.4	10.29	8.14

Note: GUG = Gross Unit Generation, NEO = Net Electric Output and UC Unit Cost

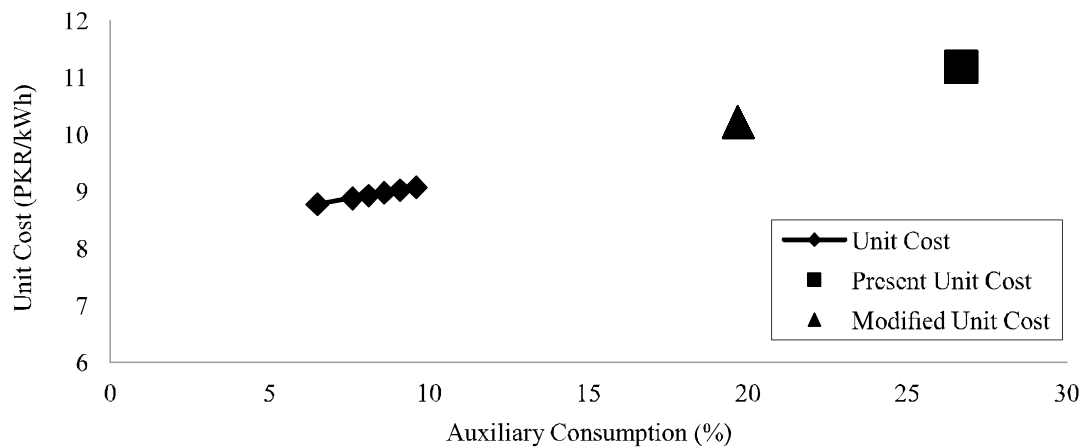


FIG. 6. EFFECT OF AUXILIARY CONSUMPTION ON UNIT COST (PKR/kWh) IN LPS

value occurs in GTPS i.e. Rs.9/kWh and intermediate unit cost incurred in coal based TPP i.e. Rs.11.2/kWh. The value of unit cost of electricity produced from different resources can be reduced from Rs.20/-Rs.19.5/kWh for oil, Rs.11.2/-Rs.10.3/kWh for coal and Rs.9.0/-Rs.8.8/kWh for gas. If proposed remedial measures are incorporated then unit cost can be averagely reduced from Rs.13.4/-Rs.12.9/kWh.

It is clearly demonstrated on Fig. 8 that the amount of CO₂ emission is released by different fossil fuel varies

from one another throughout the globe. As seen in Fig. 8, the maximum amount of CO₂ emission is produced by coal based power plants i.e. 948g/kWh. The minimum amount of CO₂ is produced in gas TPPs i.e. 452g/kWh. However, intermediate amount of CO₂ is emitted by oil based TPPs i.e. 823g/kWh. The global average CO₂ emission value is assumed for selected TPPs in Sindh, Pakistan. It is suggested that remedial measures increase the net electric power produced by selected TPPs. It can decrease the amount of CO₂-emission per unit of electricity is generated in

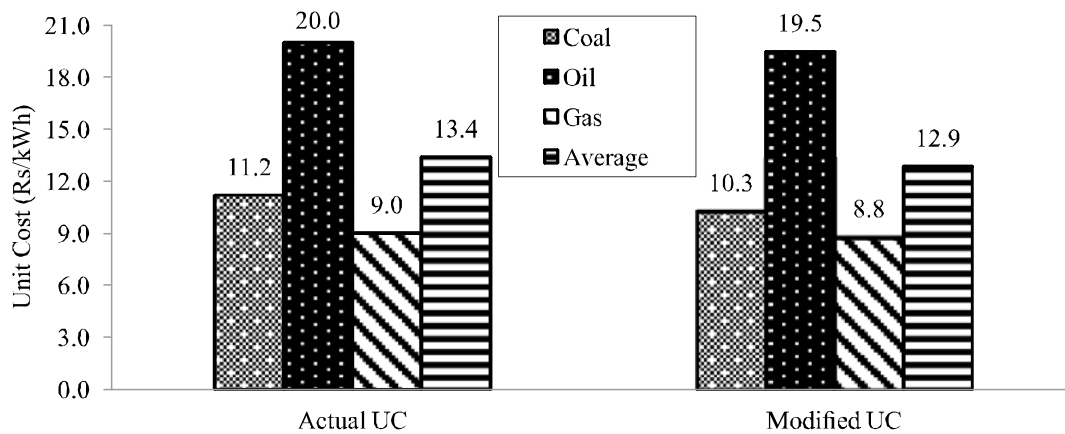


FIG. 7. COMPARISON OF PRESENT UNIT COST TO MODIFIED UNIT COST

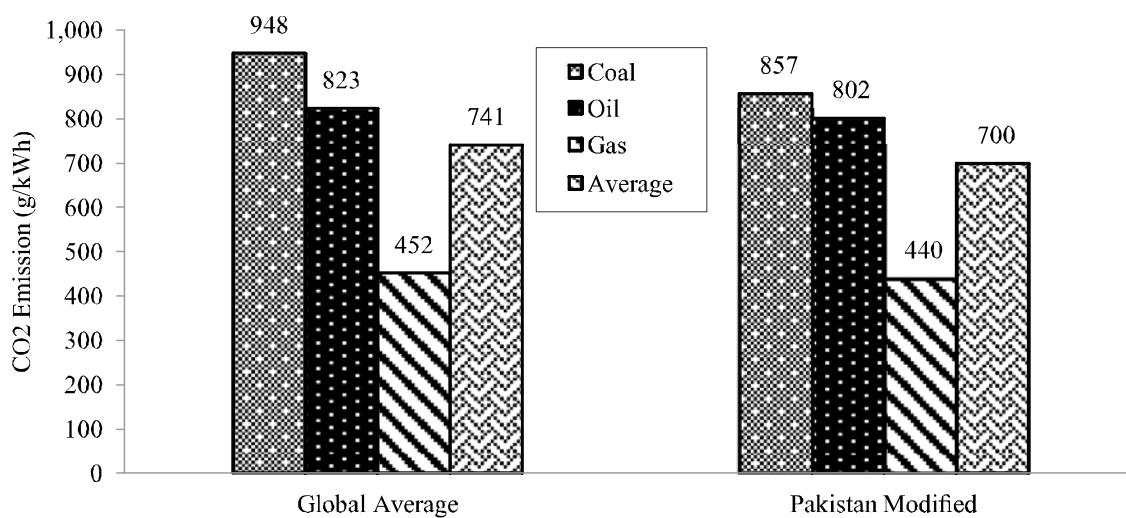


FIG. 8. CO₂ EMISSION FROM THERMAL POWER PLANTS BASED ON FOSSIL FUEL [14]

selected TPPs by enhancing their net electric output. Therefore, it is concluded on the basis of Fig. 8 that globally assumed average value of CO₂ emission can be reduced to 857g/kWh for coal, 802g/kWh for oil and 440g/kWh for gas. Considering suitable remedial measures the CO₂ emission can be averagely reduced from 741-700g/kWh in selected TPPs in Sindh, Pakistan. That means the average quantity of CO₂ emission can be reduced by 5.9% of currently CO₂ emission quantity of selected TPPs.

9. CONCLUSIONS

It is concluded that implementation of proposed remedial solution such as retrofitting, up-gradation and renovation of plant, impeller trimming, reducing re-circulation of feed water flow, feed water loss in feed pump, high voltage inverters and variable frequency drives can get following results:

- (i) The AC of JTSPS can be reduced from 40-31GWh.
- (ii) The unit cost of JTSPS can be reduced up to Rs. 20/- Rs. 19.5/kWh.
- (iii) The NEO of JTSPS can be enhanced from 344-353GWh.
- (iv) The CO₂ emission from JTSPS can be reduced from 823-802g/kWh.
- (v) The AC of GTPS can be reduced from 1.08-0.72 GWh.
- (vi) The unit cost of GTPS can be reduced up to Rs.9.0/-Rs.8.8/kWh.
- (vii) The NEO of JTSPS can be enhanced from 15.3-15.7 GWh.

- (viii) The CO₂ emission from JTSPS can be reduced from 452-440g/kWh.
- (ix) The AC of LPS can be reduced from 5.03-3.71GWh.
- (x) The unit cost of LPS can be reduced up to Rs.11.20/-Rs.10.27/kWh.
- (xi) The NEO of LPS can be enhanced from 13.78-15.10GWh.
- (xii) The CO₂ emission from LPS can be reduced from 948-857g/kWh.
- (xiii) The average unit cost can be reduced by 4.4% whereas CO₂ emission can be reduced by 5.9% in selected power plants.

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