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DEVELOPMENT OF AN EFFECTIVE ENERGY MANAGEMENT SYSTEM IN POWER PLANTS OF PAKISTAN

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Abstract

In many regions of the world the management of energy conserves is a challenging task. Numerous factors inclusive of economic, environmental and political are having substantial effects on energy management practices, leading to a variety of reservations in appropriate decision making. Energy Management System (EnMS) provides a standardized roadmap for organization efficiency, effectiveness and profitability. By using the EnMS techniques, energy losses could be reduced, and there is substantial saving of fuel which could be used for further power generation. ISO50001:2011 is the standard that deals with EnMS. The objective of the current research work is to pinpoint the optimal approaches in the development of Energy Management Systems (EnMS) of a Combined Cycle Power Plant (CCPP). In the present study the CCPP was analyzed for a period of six months for the development of an EnMS. Results showed that there were saving of 8.13×10^6 BTUs of energy which means a saving of about USD.4500 per day, which will keep on increasing as a result of the implementation of the developed EnMS. The results obtained from the current research could be utilized as a guide for the further application in industrial energy management system.

Keywords: Energy Management System, EnMS, Power Plants, ISO 50001, Energy Audit

1. Introduction

Energy generation system planning is critical for acquiring environmental friendly and economically efficient EnMS at multiple scales. Rapid industrialization and economic development has led to increase in global demand of energy due to exponential growth in the world population. In this situation, energy management has played its vital role to minimize the energy losses. Energy Management System has got more attention as nonrenewable energy resources are being depleted drastically due to increase in consumption, facilities and energy demand accordingly. If use of energy is efficient in each sector, energy resources can be used for a longer time, cost can be cut down and profitability can be increased [1-4]. Pakistan is facing a prolonged energy crisis. Ideally the installed capacity should meet the energy demand of Pakistan. One of the factors contributing for this gap between installed capacity and energy demand is the efficiency of power plants. In thermal power plants, only 30-40% of the fuel energy is converted into the electrical energy.

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Conventional energy sources are the main energy reservoirs while renewable sources contribute partially to the energy demand and supply strategy. EnMS is a new concept and the first energy management standard (ISO 50001:2011) was developed in 2011[5-8]. General energy saving approaches are mentioned by Enercon Pakistan which is helpful for the development of EnMS. Thermal power plants share is more in the installed capacity i.e. 69%, hydal is the second contributor with contribution of 28% and the share of nuclear is very less i.e. only 3% [8-12]. It indicates that any initiative of improvement in thermal power plants will contribute a lot to the power sector of Pakistan.

Present research was carried out at Halmore Power Plant (combined cycle power plant) for the development of EnMS. IPPs in Pakistan have more share than WAPDA, PEPCO & others available resources. Pakistan is currently relying on the costly resources of energy rather than the cheap ones like hydroelectric, nuclear and other renewables. The power mix of Pakistan is also important from strategic point of view for future strategy. Numerous initiatives in power sector were taken for performance improvement of the energy sector but due to various political, managerial and administrative issues, these did not work effectively. Some of the initiatives were preparation of power policies for IPPs in various years, invitation of government in hydro sector, independence of National Transmission and Dispatch Company (NTDC), Formulation of Distribution Companies (DESCOs), Privatization of Kot Addu Power Company (KAPCO) and Private Power and Infrastructure Board (PPIB). Pakistan Electric Power Company Private Limited was devised to make it responsible for public sector thermal power plants, distribution companies' efficiency and NTDC performance improvement. HR (NEPRA) was formulated for monitoring and regulating all these matters so that competition in case of privatization can be ensured. In the existence of these political and strategic issues, the energy demand is increasing due to an exponentially increase in the country population. On the other hand, due to continues decline in the fossil fuels reserves and their increasingly prices, it is the need of the hour to manage the use of fuels in a much effective manner. This paper suggests an effective management of the existing energy systems to reduce the energy loss as well to reduce the use of fuels in in power plants of Pakistan.

2. Materials and Methods

2.1. EnMS Model Development Strategy

A Combined Cycle Power Plant (CCPP) was selected to carry out study for the development of an EnMS. The next step was to identify the data points and data acquisition system for running the analysis program and various calculations. This data was taken as base line and results obtained were taken as a reference for improvement. Detailed analyses were conducted for major equipment regarding their operations & maintenance to find out the optimum point of operation for the maximum efficiency. Characteristic curves of pumps and other equipment were plotted to identify the ideal point. After theoretical verifications of the recommendations, these were presented to the management for implementation. These recommendations range from just change of operation/maintenance strategy to some financial actions for performance improvement projects. Most of the recommendations were implemented while remaining is under considerations. A generic flow chart of EnMS is as follows:

Defining Energy Management Structure→ Initial Analysis→ Policy Definition→ Evaluating Technical Potential→ Defining objectives and Targets→ Action Planning→ Execution as per plan→ Reviewing Results

2.2. Process Flow of Analysis Methods

Gas turbines installed at selected site were dual fuel gas turbines. It operates on both gas & high speed diesel (HSD) fuel. Flue gases at the exhaust of gas turbines are at about 550 ^{o}C. These exhaust gases are passed though the HRSG where heat transfer between flue gasses and feed water/condensate occurred. As a result of this heat transfer, feed water is converted into steam which is fed to steam turbine (ST) to generate electricity.

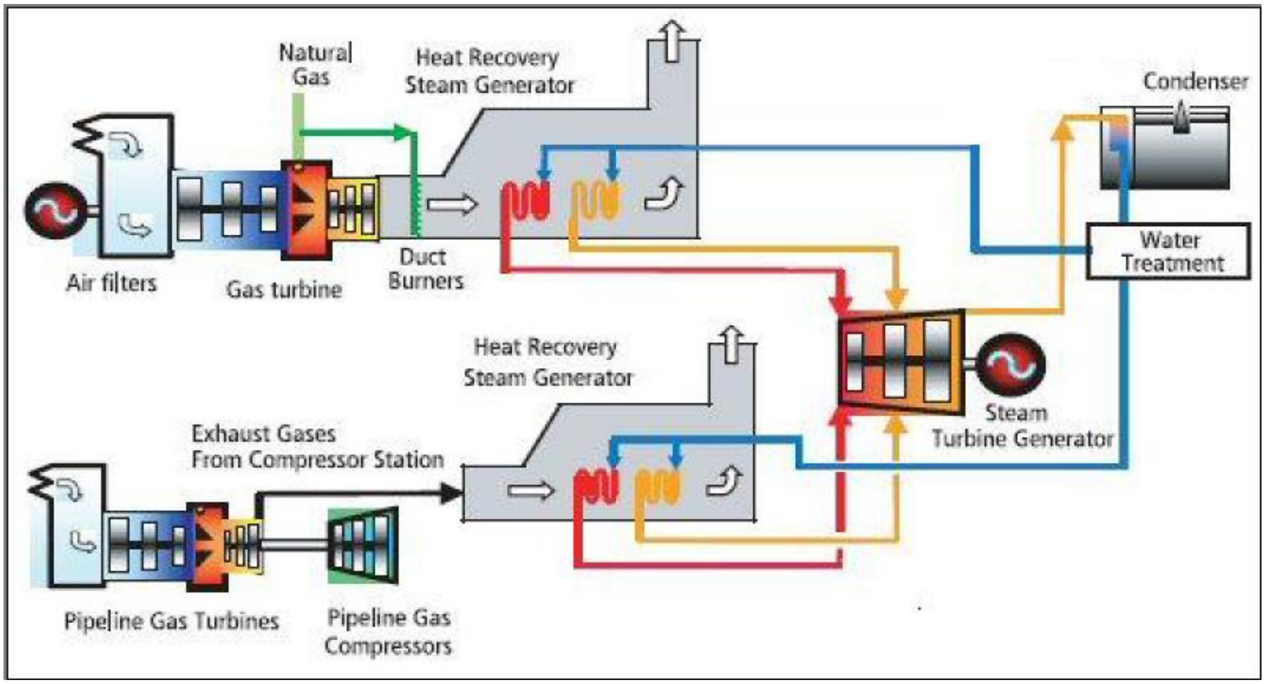

Figure 1. Process flow of combined cycle power plant

Steam from the last stage of steam turbine is sent to the condenser where it is condensed and pumped back to the HRSG. Similarly flue gasses at the end of HRSG are sent to the atmosphere. This process is shown in Figure 1. Major inputs to the gas turbine are fuels and combustion air. A CCPP consists of a gas turbine (GT), HRSG, steam turbine and a steam condenser. The performance of this equipment plays a dynamic role in the overall performance of the system.

2.3. Performance Calculation Method

Energy system analysis of the CCPP was conducted to find out the energy losses in the system. Any implementation that is suggested to make was evaluated by this energy audit. Target was set for collection of plant preliminary data, verification of validity of data collection point and analysis of data from performance point of view. Comprehensive energy audit, analysis of energy bills, employees interviews, site walk through tours, breakdown of whole plant system into sub-systems for better understanding and monitoring, identifying the energy saving actions, preparation of action plan based upon the findings of audit and prioritization of the energy saving measures for implementation were conducted. Discussion of the energy management opportunities (EMO) with management was held with implementation point of view and performance evaluation of the suggested actions. Energy analysis of each input and output parameter was conducted for the improvements on the input side. Similarly output energy was also analyzed from efficiency point of view. Change in efficiency with respect to the specific period of the month or the year was highlighted and improved with the help of well-defined strategies. Various operating conditions (start-up, shut down, part load and full load conditions) were also analyzed.

3. Results and Discussion

3.1. Data Analysis

CCPP data analysis shows that 75% of the generation is through natural gas and 25% is by HSD. It means losses on natural gas fuel generation accounts more than HSD fuel generation losses. Figure 2 indicates that there is no uniformity in the operating profile of the units.

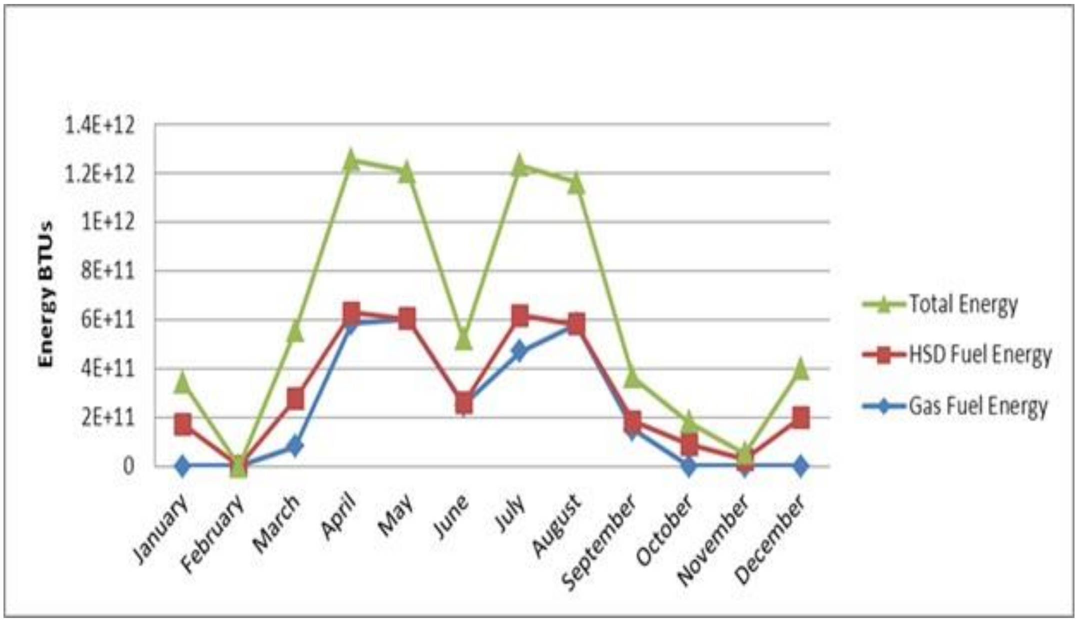

Figure 2. The consumption of energy produced from high speed diesel and gas over the year.

This non-uniformity of generation as shown in Figure 3 impacted the overall performance of the system. As the power plant is designed to operate on base load, operating at any load that is not base load impacted negatively the performance of the complex. Figure 3 show that power plant is started/ stopped quite often which impacted plant performance in a negative fashion. Figure 4 directs that power plant is operated with discontinuity in each month that affected the plant performance [12]. Online hours mean the hours during which power plant remained in operations while period hours are the total hours of that period. Figure 4 illustrates that online hours are much less than period hours. Further it can be seen that power plant starts/stops are more frequent in the period where online hours are less. These two factors i.e. less online hours combined with frequent starts/stop impacted much in a negative fashion. This factor neutralizes the positive impact of base load operations.

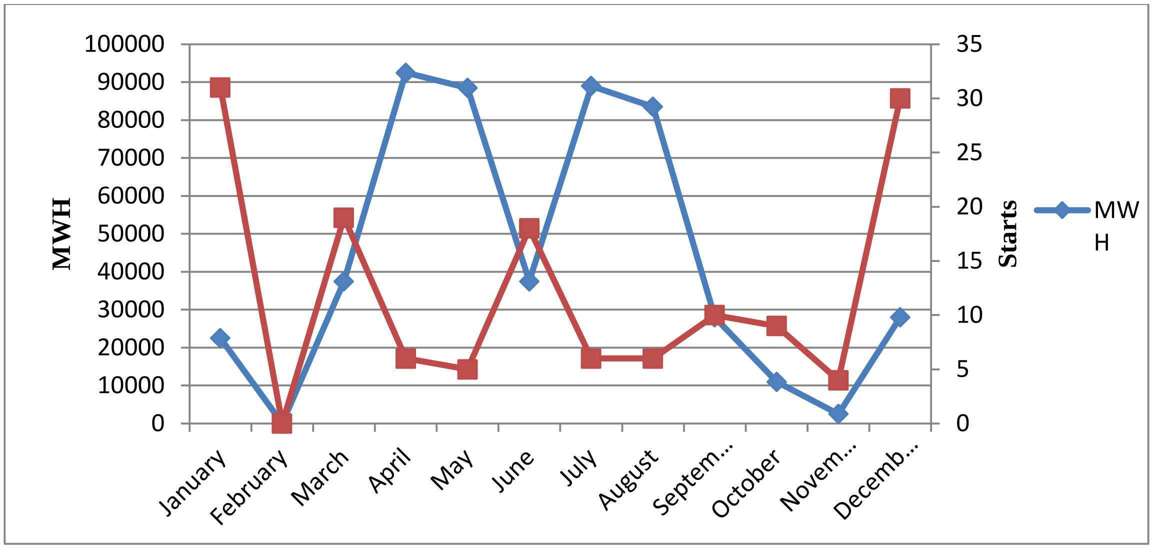

Figure 3. Electricity Generation Detail & Number of starts of plant

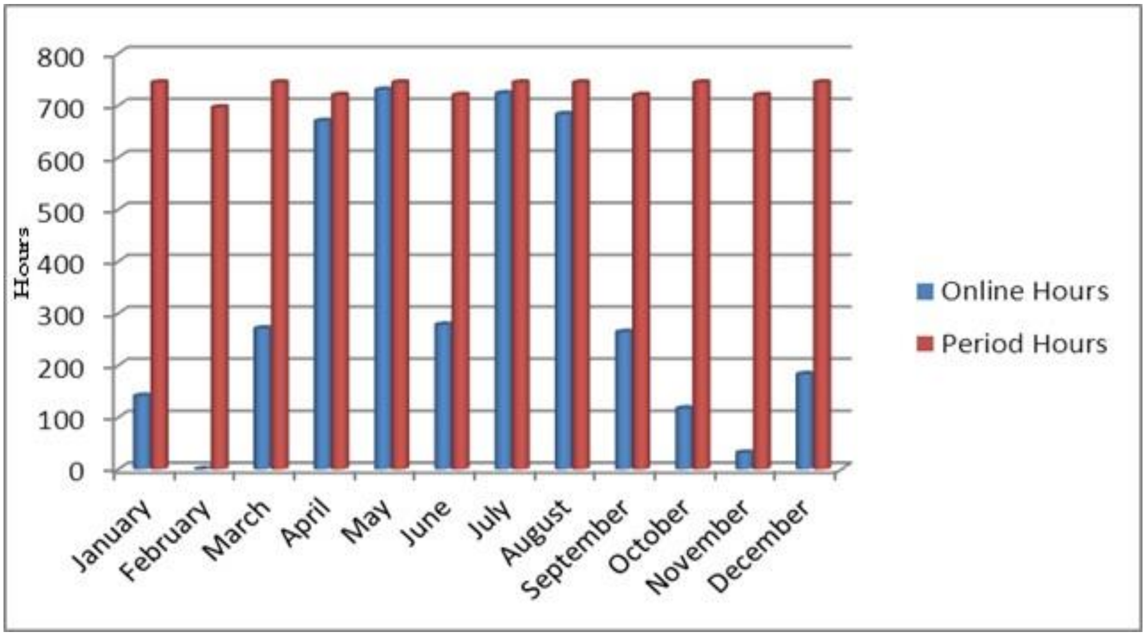

Figure 4. Online hours VS period hours

3.2. Gas Turbine Performance Analysis

Project specific Gas Turbine (GT) performance curves were provided by GE Energy Application Engineering/Operability & Performance Services for the estimation of GTs performance. The performance calculations of gas turbine 1 (GT1) and gas turbine 2 (GT2) are shown in Table 1.

3.2.1. Full Load Performance of GTs by Application of Correction Curves

The output in KW and heat rate can be calculated using following relations;

$$\text{Estimated Output } (kWs) = (kWi) \times A1 \times A2 \times A3 \times A4 \times A5 \times A6 \times A7$$

$$\text{Heat Rate } (HRs) = (HRi) \times B1 \times B2 \times B3 \times B4 \times B5 \times B6 \times B7$$

Where KWi, HRi, are the input power and heat rate, at ISO conditions i.e. 15°C, 60% RH & 14.7 psi. A1, A2, A3, A4, A5, A6, A7 & B1, B2, B3, B4, B5, B6, B7 are the correction factors for output and heat rate respectively and are presented in Table 2. The estimated output was calculated as 78.936MW corresponding to the actual output of 77.5MW.

Table 1. Performance Analysis of Gas Turbine

Parameters	Units	GT1	GT2	Difference
Generator Net Output (Gross - Excitation)	kW	72872	71929	943
Fuel Flow	lb/hr.	44033	43622	411
Fuel Heating Value (LHV)	BTU/lb	18436	18436	0
Heat Consumption(LHV)	Mbtu/hr.	802.68	796.20	6.49
Generator Net Heat Rate (LHV)	BTU/kWh	11015	11069	-54
Generator Net Efficiency	%	30.98%	30.83%	0.15%
Exhaust Temperature	F	1120.0	1117.8	2.2
Exhaust Flow	lb/hr.	1587040	1591282	-4242
Compressor Pressure Ratio	Ratio	15.459	15.494	-0.035
Compressor Airflow	lb/s	419.88	420.45	-0.57
Compressor Efficiency	%	88.58%	87.88%	0.70%
Ambient Pressure	psia	14.356	14.367	-0.012
Inlet Pressure Loss	"H2O	4.458	5.918	-1.460
Compressor Inlet Temperature	F	64.00	62.42	1.58
Compressor Inlet Specific Humidity	lb/lb	0.0084	0.0083	0.0001
Compressor Inlet Relative Humidity	%	64.8%	68.0%	-3.2%
IGV Angle	deg	85.97	85.98	0.00
Shaft Speed	rpm	5159.7	5159.6	0.1
Compressor Airflow	lb/s	422.2	423.3	-1.1
Compressor Discharge Pressure	psig	207.7	208.4	-0.7
Compressor Pressure Ratio	psia/psia	15.602	15.695	-0.093
Compressor Discharge Temperature	F	746.5	750.3	-3.8
Compressor Efficiency	%	88.66%	87.97%	0.69%
Liquid Fuel Temperature (At Contract Boundary)	F	84.7	84.3	0.3
Liquid Fuel Flow	lb/hr.	44033	43622	411
Liquid Fuel LHV	BTU/lb	18436	18436	0
Water Injection	lb/sec	9.619	9.474	0.145
Exhaust Gas Temperature	F	1113.0	1109.2	3.8
Exhaust Gas Flow	lb/hr.	1593527	1598930	-5403

Generator Net Output	kW	74488	73421	1067
Generator Power Factor	ratio	0.9741	0.9569	0.0171

It can be seen from Table 2 that the actual output of the gas turbine is less than the estimated value which considered due to external and internal factors. External factors include system voltages, system frequency, ambient temperature, ambient humidity and ambient pressure. Internal factors are the factors that can be controlled and called controllable factors. These factors impact the gas turbine output and performance. With the passage of time gas turbine get old and its performance deteriorates due to aging. Some factors of these aging are controllable and some are uncountable. Examples of uncontrollable factors are increase of clearances, material stresses and material aging.

Examples of controllable factors are inlet filters clogging, fuel filters clogging, fuel heating system faults, GT washing, various leakages, valve passing, generator & transformer losses. Controllable losses can be covered by different steps. For example, if power output is less due to high DP of inlet air filter, by replacement of these filters output can be improved and loss can be covered. As a thumb rule, the 4 inches H_2O drop in the inlet pressure reduces the power output by 1.42% and increase the heat rate by 0.45%. Similarly if compressor discharge temperature is high, by conducting GT offline water wash, this loss of output can be recovered.

Table 2. Full Load Performance Calculation of Gas Turbine with Correction Curves

External Parameters	Output	Actual Readings	Heat Rate	Actual Readings
Ambient Air Temp	A1	1.11	B1	0.968
Ambient Air Humidity	A2	1.00	B2	1.0005
Shaft Speed	A3	0.980	B3	1.005
Fuel Temperature	A4	1.00	B4	1.00
Inlet Pressure Loss	A5	0.9996	B5	1.0001
Barometric Press	A6	1.040	B6	0.9985
Water Injection	A7	1.058	B7	1.0290

Following are the recommendations of GTs for the improvement of the whole complex; Monitoring and maintenance of GTs inlet filter cleaning system, inspection and replacement of inlet air filters if required, GTs offline and on-line water washing and monitoring of various valves like IBH, Bleed valves, installation of evaporative coolers for power augmentation and operating the GTs at designed fuel temperature for better combustion efficiency. By doing this the output of GTs will be increased by 4 to 5MW. By comparison of GTs data, it is found that GTs exhaust temperature is less than the GTs exhaust temperature of other sites. This temperature is directly linked with the performance of the HRSGs and the whole complex. Exhaust mass flow of GTs of the site is less than that of other site of the same model. This less exhaust flow can be due to either less air flow or less fuel flow. This can be investigated and the matter can be taken up with the OEM engineering team for the betterment of the complex.

3.2.2. HRSG Performance Analysis

Steam flow must be corrected for the superheated steam outlet temperature in order to compare measured and predicted steam flows. It is not the intent of this correction to adjust the steam temperature for the purpose of comparison to a predicted steam temperature, rather only to adjust the flow on a consistent energy basis. The predicted steam capacity will be dependent upon all of the factors necessary to originally design the HRSG. The performance factors would include gas flow, gas temperature and composition and BFW inlet temperature. Predicted steam temperatures and flows for a test will serve as comparative values to what is actually measured. The measuring results required for comparison with the guaranteed values are calculated from the measured values, taking into account all test conditions involved. If the test conditions differ from the data on which the guarantees are based the HP, LP steam flows & HP, LP steam temperatures at test conditions must be converted to the guarantee conditions with the aid of the performance correction factors as follows:

Steam flow at guarantee condition = Steam flow at test conditions x (1 + Correction factors)

Steam temp at guarantee condition = Steam temp at test condition x (1 + Correction factors)

If the corrected steam flow & steam temperature of the acceptance test plus their overall test uncertainty is greater than or equal to the guaranteed values, the boiler performance fulfilled.

Steam flow, at guarantee conditions + overall test uncertainty ≥Steam flow guaranteed.

Steam temp at guarantee conditions + overall test uncertainty ≥Steam temp guaranteed.

Formulae used for actual performance estimation of HRSG are as follows;

Steam flow at guarantee condition = Steam flow at test conditions x (1 + Correction factors)

Steam temp at guarantee condition = Steam temp at test condition x (1 + Correction factors)

If the corrected steam flow & steam temperature of the acceptance test is greater than or equal to the guaranteed values, the performance of the boilers fulfilled.

Steam flow, at guarantee conditions ≥Steam flow guaranteed.

Steam temp at guarantee conditions ≥Steam temp guaranteed

Steam flow at guarantee condition=Steam flow at test conditions x (1 + Correction factors)

Steam flow at guarantee condition =97.4 x (1+0.058-0.04) =97.4 x 1.018 =99.15TPH

Steam Flow guaranteed= 114TPH

It means that the actual steam flow is less than the guaranteed value.

Steam temp, at guarantee condition = Steam temp at test condition x (1 + Correction factors)

Steam temp, at guarantee condition =523(1+0.009) =527 ^{o}C*

Steam Temperature Guaranteed=539 ^{o}C

Steam temperature is also less than guaranteed value. HRSG is basically the waste heat recovery of GTs exhaust but in case of CCPP, GTs performance is compromised for the performance improvement of the whole complex. During analysis of the operating data, it was observed that HRSGs outlet stack temperature was being maintained well within range. Similarly analysis of feed water/steam temperature/flow gives satisfactory results. If performance analysis of the HRSGs is carried out with respect to design values, it can be seen that the input energy required to HRSGs is never met and that's why output is not up to the mark.

Following are the few recommendations regarding HRSGs; Most of the valves of HRSGs are of passing nature. This passing is one of the factors of performance degradation of HRSGs. These passing valves must be identified and passing valves should be either repaired or replaced. Once valve passing matter is fixed, demin water makeup to the system will be reduced and this will enhance the HRSGs efficiency. There are few areas from where flue gasses are leaking, for example expansion joints of GTs exhaust and HRSGs. These flue gasses leaking from the system are the loss. By repairing the expansion joints, this loss can be recovered and performance of HRSG will be improved. It has been observed that sometimes continuous blow down valve is kept opened as per recommendations of plant chemist to maintain the water chemistry but as per drawing of the system this blow down is not effective rather intermittent blow down (IBD) valve should be operated for the effective chemistry control.

When unit is not in operation, various drums (DA, LP & HP) are preserved by wet preservation method. In this method, drums are filled 100% by chemical water. When complex is required to be started, these drums are drained down to operating level. By drain down chemicals and demin water is wasted. To minimize this wastage, this chemical treated water should be taken into the demin water storage tanks where the concentration of chemicals will also get low and this water will be again used as per requirement.

3.2.3. Actual Performance Analysis of Steam Turbine

Steam consumption diagram for the estimation of Steam Turbine (ST) output at different steam flow was used. As per this diagram, ST output should be 65 MW while the actual output is 63 MW. It means ST output is 2 MW less than the expected value. Although from a turbine standpoint, condenser vacuum is very important. Very simply stated, condenser performance is the comparison of real heat transfer rate to an expected heat transfer rate. Actual heat transfer rate is found from the equation 1:

$$U\ Test = Q / (A \times LMTD) = Q / (A \times [(T2 - T1) / [\ln (TS - T1) / (TS-T2)]) \qquad (1)$$

The heat duty Q is found to be108.682 MW corresponding to the condenser effective heat transfer surface area A of 5407 m^2. In the heat transfer equation the U Test is actual heat transfer coefficient, LMTD is logarithmic mean temperature difference, T2, T1 and TS are circulating water out, in and incoming steam temperatures respectively. The expected heat transfer coefficient is found from equation 2 of the HEI (Heat Exchanger Institute) Standards.

$$U = U1 \times FW \times FM \times FC \qquad (2)$$

Hence the performance is represented by equation 3;

$$Performance = (U\ Test / U) \times 100\ [\%] \qquad (3)$$

In equation 2, U is expected heat transfer coefficient, U1 is uncorrected heat transfer coefficient (HEI Standards), FW, FM and FC are circulating inlet water temperature correction factor (HEI Standards), Tube material and gauge correction factor (HEI Standards) and Cleanliness factor, from design value respectively. As ST is working on the Rankine cycle, so following parameters are very important for the performance of ST;

i. pressure of steam inlet to the ST,
ii. temperature of steam inlet to the ST,
iii. degree of superheat of steam inlet to the ST,
iv. flow of steam inlet to the ST,
v. exhaust pressure/vacuum of the ST, and
vi. exhaust temperature of the ST.

All of the above parameters play a vital role for the ST performance. When the data has been analyzed, it revealed that ST output remained short than the required at the operating conditions by 2 to 3 MW. There can be various reasons for the less output. Some factors are related to the operations while most are relevant to engineering.

Following are the observations along with recommendations regarding steam turbine; there was no flow meter at the inlet of ST to meter the actual steam inflow to the turbine. One flow meter should be installed at HP steam line while other should be installed at LP steam line. By using these flow meters, actual steam flow can be measured. Although HP and LP steam flow meters are installed at each HRSG but quantity of steam leaking from the system will also be measured by these flow meters. Bypass line shutoff valves and conditioning valves of both LP and HP lines are passing. Due to this passing, leaking steam goes directly to the condenser without doing any work. This leakage also adds load on the condenser. ST exhaust pressure/condenser vacuum is also observed on the lower side. Due to low vacuum, ST output became less than at higher vacuum. There can be various reasons for fewer vacuums. Some are as follows; Air ingress to the condenser, less flow of cooling water to the condenser, higher ambient temperature, condenser tube fouling, and higher temperature at the condenser inlet and less work done by the steam on the turbine blades. LP steam pressure is less than the design value.

While being conservative side, overall improvement of complex efficiency was 0.5%. This increase in efficiency means 0.5% more energy from the fuel as compared to previous one. The savings in terms of energy, fuel & money are 8.13×10^6 BTUs, Rs. 200 per liter and Rs. 20,000 per hour respectively, while Table 3 is illustrating the performance comparison of the system.

Table 3. Performance comparison

Before				After			
	Complex Efficiency	GT-1 Efficiency	GT-2 Efficiency		Complex Efficiency	GT-1 Efficiency	GT-2 Efficiency
	%	%	%		%		
9-Sep-14	47.10	32.20	32.23	30-Dec-14	47.98	33.50	33.00
16-Sep-14	46.80	31.80	32.16	12-Jan-15	47.85	33.51	33.13
12-Oct-14	46.70	31.65	32.05	4-Mar-15	47.89	33.53	33.45
21-Oct-14	46.88	32.12	32.10	13-Mar-15	47.98	33.56	33.49
Average	46.87	31.94	32.14	Average	47.93	33.53	33.27

4. Conclusions

The increasing demand of energy with ever increase in population, rapid declining trend in the reserves of the fossil fuels and their increasing prices are pushing an effective energy management system in the power plants of Pakistan. This paper identifies the major sources of energy loss and propose an effective energy management strategy. The core finding and improvements of the present research are concluded here.

Identified passing bleed valves were replaced that resulted into half MW increase in output of Gas Turbine. Offline water wash monitoring was enhanced that resulted into prolonged duration of high efficiency of compressor. Water injection flow was decreased that resulted into heat rate improvement of 250 BTUs/KWh. Evaporative coolers were installed that resulted into about 4 to 5 MW increase in GTs output that much more. By comparison of data, overall improvement of GTs efficiency after these entire implementations is 1 % more than previous one. Previously it was about 32% but after implementations of few corrective actions its 33%. For the effect of BOP equipment on the efficiency and economics of power plant, designing an economical model of power plant and its validation from construction and operation point of view are the future recommendations.

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