International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Optimization of Auxiliary Power Consumption in Supercritical Thermal Power Plant Using Six Sigma DMAIC Methodologies

S.Lingamaiah[1], Dr.R.Ramachandra[2]

[1]Research Scholar, BESTIU, Assistant Professor (Adhoc) SKUCET Anantapuramu, India.
[2]Principal, SKUCET, S.K.University Anantapuramu, India.

Abstract:
Auxiliary Power Consumption (APC) is one of the critical performance indicators in thermal power plants, directly influencing plant efficiency and operational cost. In large supercritical units, auxiliary equipment such as boiler feed pumps, induced draft fans, forced draft fans, cooling water pumps, and coal mills consume significant internal power. This study presents the optimization of auxiliary power consumption in an 800 MW supercritical thermal power plant at Sri Damodaram Sanjeevaiah Thermal Power Station by adopting the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology. Operational data for the period 2023–2024 were analyzed to identify major contributors to APC. Key issues such as inefficient pump operation, air ingress in the condenser, suboptimal combustion conditions, and improper operation of auxiliary equipment were identified. Improvement actions including combustion optimization, mill fine tuning, restoration of low-pressure heater-3, modification of high-pressure heater feed outlet temperature, and condenser vacuum improvement were implemented. As a result, APC was reduced from 6.9% to 6.4%, yielding an annual saving of approximately 25 million units (MUs) of electricity. The study demonstrates the effectiveness of Six Sigma techniques in improving energy efficiency and operational performance in large thermal power plants.

Keywords: Auxiliary Power Consumption, Six Sigma, DMAIC, Supercritical Power Plant, Energy Efficiency, Thermal Power Plant Optimization.

I. Introduction

Coal-fired thermal power plants continue to contribute significantly to electricity generation in India. Supercritical power plants, particularly those with capacities of 800 MW and above, are designed to achieve higher efficiencies and reduced emissions compared to subcritical units [1],[2]. However, a significant portion of generated power is consumed internally by auxiliary systems such as: Boiler Feed Pumps (BFP), Induced Draft (ID) Fans, Forced Draft (FD) Fans, Primary Air (PA) Fans, Cooling Water Pumps, Coal Mills and Pulverizers, Condensate Extraction Pumps. This internal consumption is termed **Auxiliary Power Consumption (APC)** and typically ranges from **6%–9% of gross generation** in large coal-based power plants. Reducing APC improves: Net plant efficiency, Power export to the grid, Economic performance, Fuel utilization [3],[4].

II. Literature Review

Several studies have addressed energy efficiency improvements in thermal power plants.
Bill Smith introduced the Six Sigma methodology to reduce defects and improve process efficiency [5].
Mikel Harry expanded Six Sigma into operational performance improvement.[6]
Studies in coal power plants show that APC reduction significantly improves plant heat rate and reduces coal consumption.[7]. Application of Six Sigma in power plants has proven effective in improving condenser vacuum, turbine heat rate, and boiler efficiency.

III. Problem Statement

In the 800 MW unit of SDSTPS, APC was observed to be higher than the design benchmark.
Design APC: 6.5% **observed APC (2023-24):** 6.9%
Higher APC was caused by:

- Inefficient operation of pumps and fans
- Air ingress in condenser
- Suboptimal mill operation
- Poor combustion conditions
- Inefficient feedwater heating system

IV. Methodology

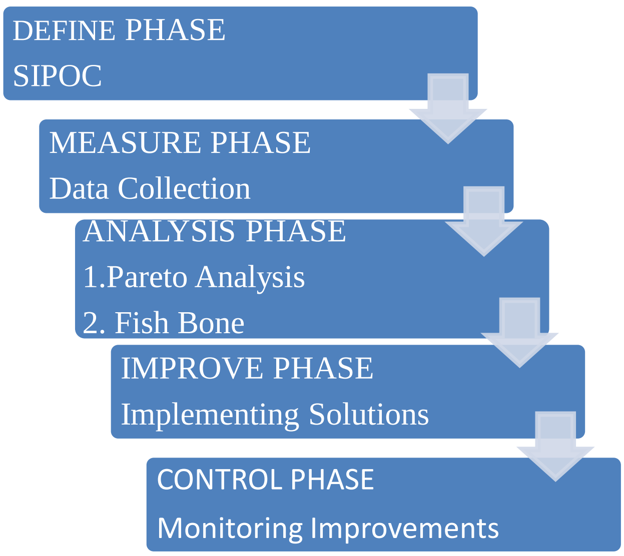

Fig.1: Flow Chart for APC

IV.1. Define Phase

Framing the Problem in this phase establishes the maps out the high-level process to clarify exactly what needs to be fixed and customer requirements, the scope and the "why" of the study. SDSTPS, which uses supercritical technology, should ideally have a lower APC (typically around 5–6%). If it exceeds this, it impacts the Net Heat Rate and profitability.[8]
Critical to Quality (CTQ): A diagram that translates broad customer needs into specific, measurable performance requirements.[9]. Identify the most power-hungry auxiliaries—Boiler Feed Pumps (BFP), Induced Draft (ID) Fans, Forced Draft (FD) Fans, and Cooling Water (CW) Pumps.**Reduce Auxiliary Power Consumption from 6.9% to below 6.5%.**.

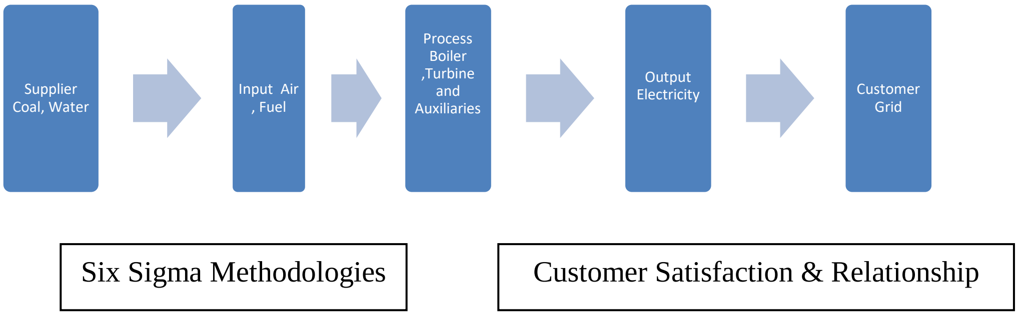

Figure: 2. SIPOC Diagram

SIPOC Diagram (Suppliers, Inputs, Process, Outputs, Customers): A process mapping tool that outlines the major components of a process, helping to establish its scope and identify essential inputs, outputs, suppliers, and customers before improvement activities begin.

IV.2. Measure Phase

Establishing the Baseline: Collected reliable data to document the current state of the process. Measure the performance and establish specific metrics to track progress against the goal and determine how poorly the current process is performing.[10]

- **Process Mapping / Value Stream Mapping:** A granular, step-by-step visual map of the current workflow to identify bottlenecks and non-value-added steps.
- **Process Capability (Cp and Cpk):** Statistical calculations that measure how well a process performs against its specification limits.

Major APC contributors

Table.1 Auxiliary Power Consumption Elements

Equipment	Current value	Response	Power Consumption (%)
Boiler Feed Pumps	Actual	APC	1.8
ID Fans	Actual	APC	1.2
FD Fans	Actual	APC	0.8
PA Fans	Actual	APC	0.7
Cooling Water Pumps	Actual	APC	1.1
Coal Mills	Actual	APC	0.7
Other Auxiliaries	Actual	APC	0.6
Total APC			6.9%

Table.2. Operational data were collected for one year

Sl No.	Description	Unit	Design (A)	Operating (As Fired Coal) (B)	Deviation (A-B)/A in %
Main stream parameters					
1	Flow	kg/kwh	3.45	3.63	-5.21
2	Temp.	°C	559	562.2	-0.57
3	Pressure	kg/cm^2	139.9	130.58	6.66
4	Condenser	Ksc	0.9585	0.815	14.97

5	DM water flow	t/h	624	657	-5.288	
Flue gas/Air temperature						
6	Flue gas temperature at I/L	°C	355	341.62	3.76	
7	Flue gas temperature at O/L	°C	175	164.33	6.09	
8	Air temperature at I/L	°C	29	35	-20.689	
Other important features						**Other important features**
9	Super Heater spray	t/h	52.22	47.32	9.38	
10	Reheater spray	t/h	0	0	0	
11	Make up water	t/h	13	63.72	-390.15	
12	Cost of fuel	Rs/t	---	4200	---	
13	PLF (Avg. of last 12 months)	%	100	100	0.000	
14	CW inlet temperature	°C	35	30	14.28	
15	CW outlet temperature	°C	38	33	13.15	

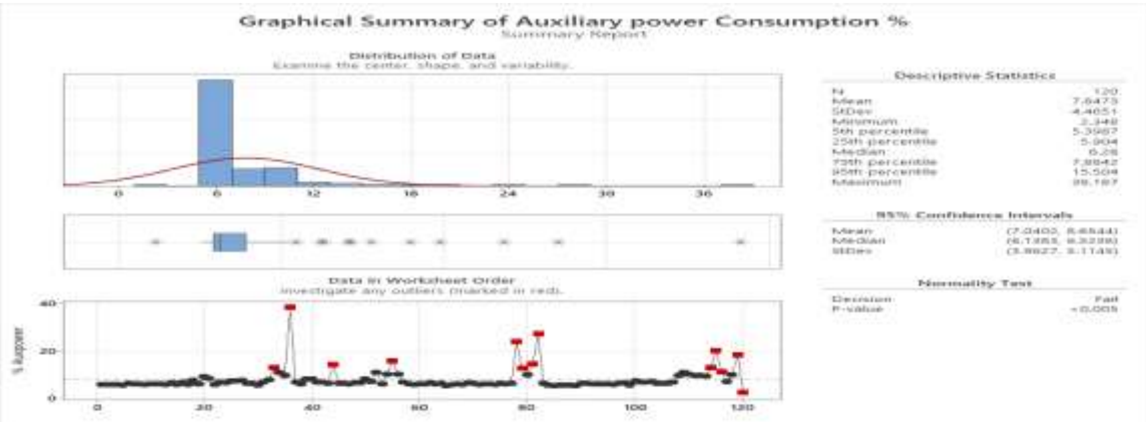

Fig.3. Graphical Summary of APC

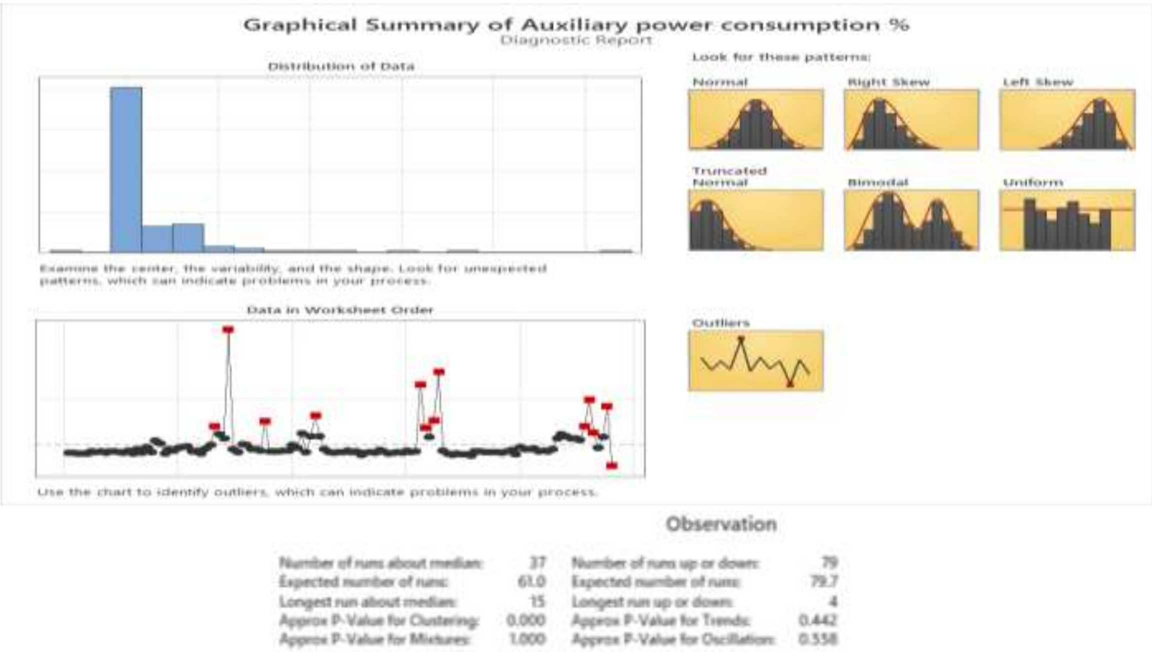

Fig.4. Graphical diagnostic report of APC

IV.3. Analyze Phase

Isolating the Root Cause: Examine the data to identify the gap between current performance and the goal. Tools like fishbone diagrams Pareto. Analyses are used to determine the root causes of defects instead of knowing the symptoms.

Fishbone (Ishikawa) Diagram & 5 Whys: Brainstorming tools used to systematically categorize potential causes of a problem into categories like manpower, machinery, methods, and materials.

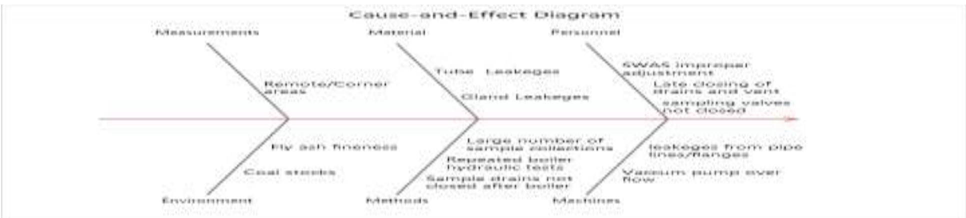

Fig.5. Fish bone Diagram

Fishbone (Ishikawa) Diagram: Categorize causes under Man, Machine, Method, and Material (e.g., low-grade coal leading to increased ID fan loading).

Pareto Analysis

Pareto Chart: A bar graph based on the 80/20 rule, showing that roughly 80% of defects arise from 20% of the causes, helping teams prioritize what to fix first.

Identify the "Vital Few." Usually, BFPs,ID Fans,CWP,FD and CW account for over 80 % of total auxiliary power.

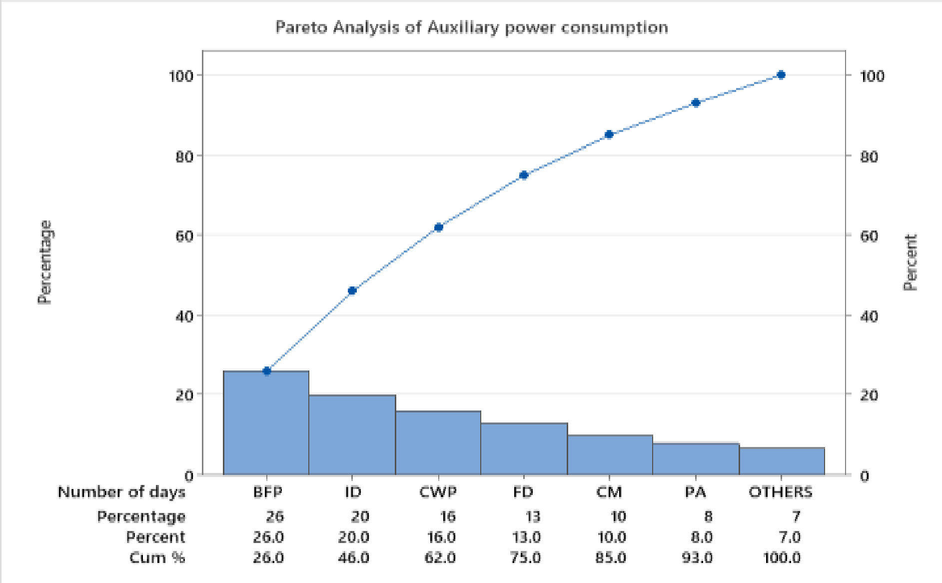

Fig.5. Pareto analysis of APC

IV.3.1 Design of Experiments

A. Boiler Feed Pump DOE

Table.3.Boiler feed pump factors

Factor	**Low (-1)**	**High (+1)**
A: Feed Regulating DP	1.0 bar	2.5 bar
B: Feedwater Flow	90% BMCR	100% BMCR

Factorial Design

Table.4.BFP factorial design

Run	A	B	Response	Expected
1	-1	-1	Boiler Feed Pump Power Consumption	Reduction of Damper Position decreases pump power
2	+1	-1		
3	-1	+1		
4	+1	+1		

B. ID Fan DOE Factors & Factorial Design

Table.5.ID Fan factors

Factor	**Low**	**High**	**Response**	Expected
A: Air Leakage (%)	5	15	ID Fan kW APC %	Air leakage is the dominant factor
B: Fan Speed (%)	80	100		
C: O_2 (%)	3	5		

C. FD Fan DOE Factors

Table.6.FD Pump factors

Factor	Low	High	Response	Expected
A: Air Flow	90%	100%	FD Fan Power Boiler Efficiency	Optimal airflow minimizes excess power
B: Damper Position	50%	100%		
C: Blade Pitch	Min	Max		

D. Coal Mill DOE Factors

Table.7.Coal Mill factors

Factor	Low	High	Response	Expected
A: Ball Loading	70%	100%	Mill Power Fineness APC	Ball loading and classifier settings significantly affect mill power
B: Classifier Setting	Low	High		
C: Coal Moisture	8%	14%		

E. CW Pump DOE factors

Table.8.CW Pump factors

Factor	Low	High	Response	Expected
A: Coating Condition	Without	With	Pump Efficiency kW Consumption	Coating reduces hydraulic losses
B: Flow Rate	90%	100%		
C: Pump Speed	Low	High		

Taguchi DOE Alternative

L8 Orthogonal Array

Table.9.L8 orthogonal array using Taguchi

Experiment	A	B	C
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Factors: Air Leakage, Damper Position, Motor Loading.

Signal-to-Noise Ratio: Smaller-the-Better (Power Consumption)

$S/N = -10\log(\sum y^2/n)$

$S/N = -10\log(n\sum y^2)$. Higher S/N ratio indicates better performance with lower variability.

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

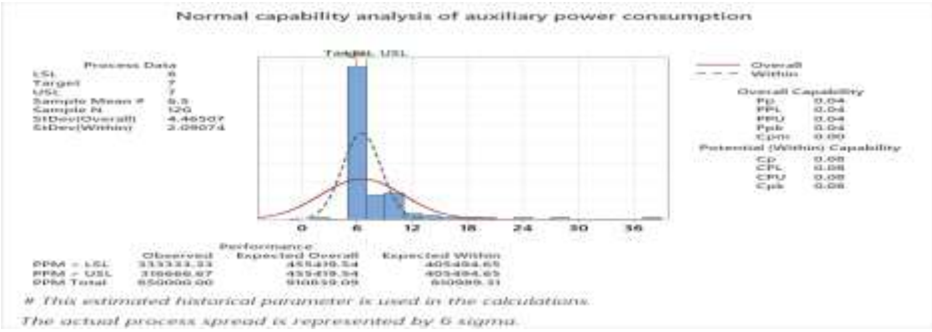

Fig.6. Normal Capability analysis of APC

Capability Analysis for % Auxiliary power consumption

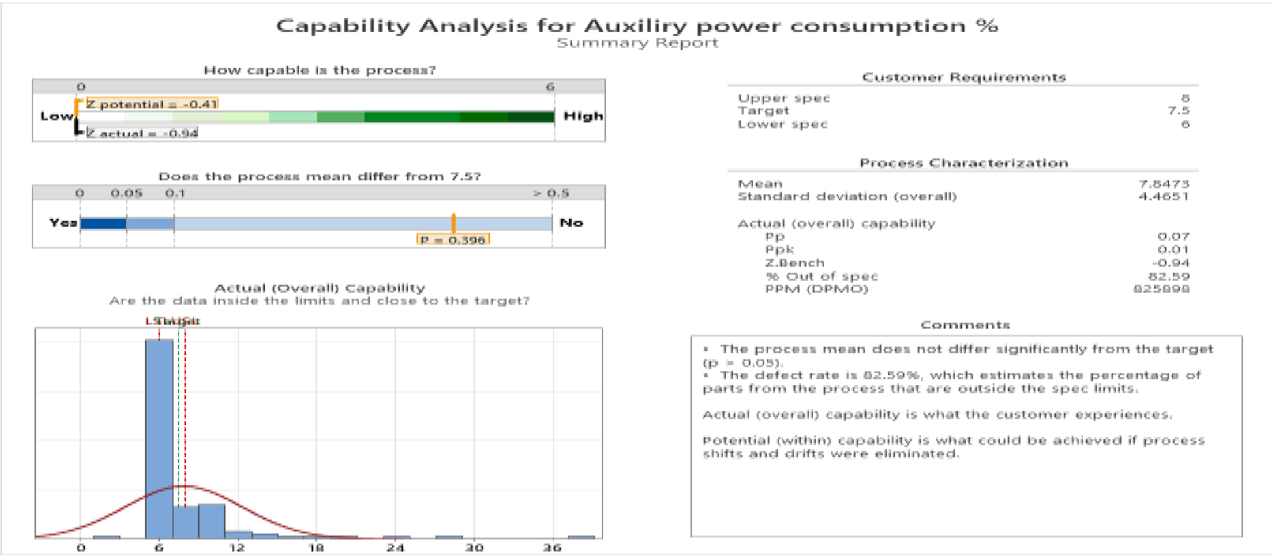

Fig.7. Capability analysis of %APC

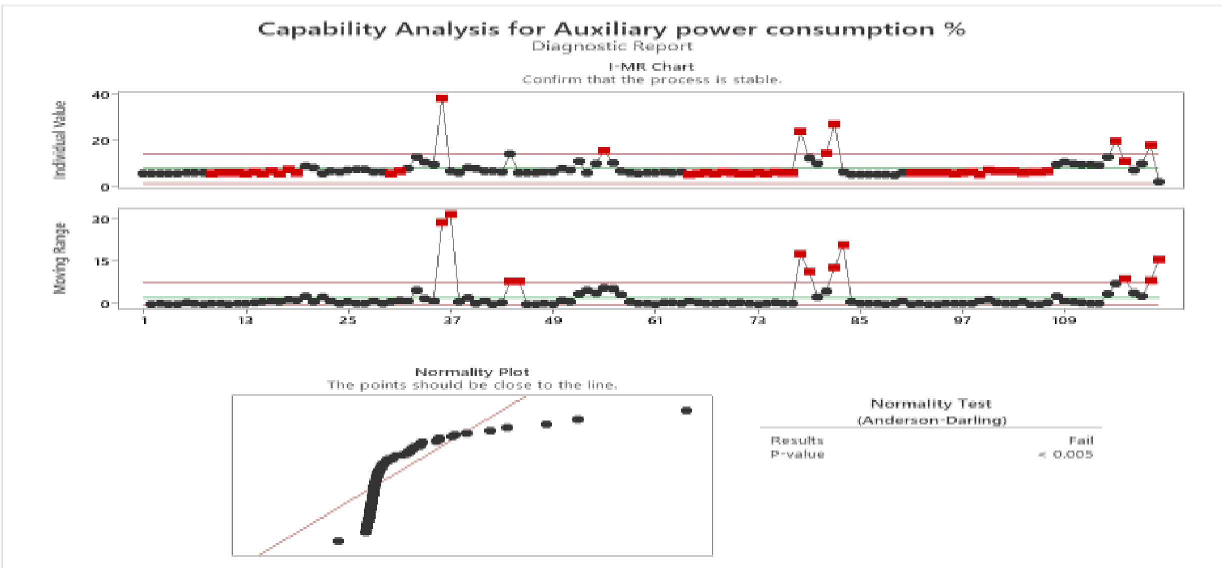

Fig.8. Capability analysis of APC diagnostic report

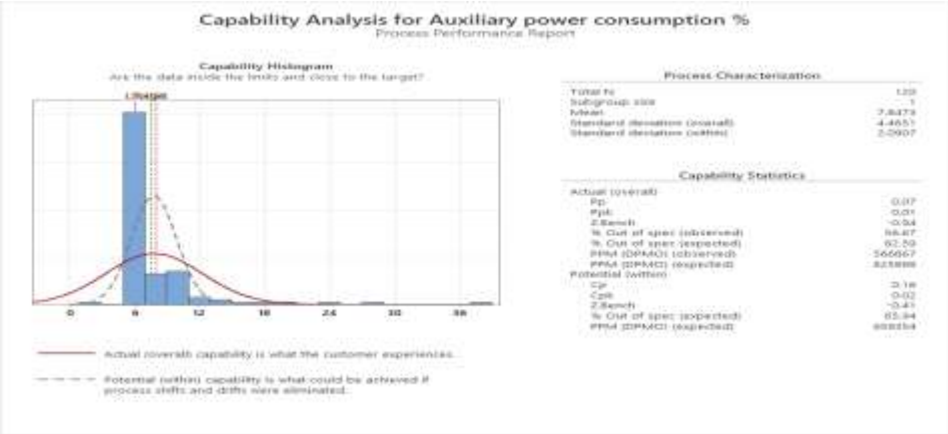

Fig.9. Capability analysis for APC process performance report

IV.4 Improve Phase:

Designing and Validating Solutions

Implementation of solutions to eliminate the root causes which are found in the analysis phase. Operational improvements which are implemented.

DOE (Design of Experiments): A structured statistical method used to test multiple variables simultaneously, determining the absolute optimal settings for a process.

IV.4.1 Major improvement actions

1. **Arresting air ingress in condenser**
   - Improved condenser vacuum
   - Reduced turbine back pressure
2. **Combustion optimization**
   - Reduced unburnt coal
   - Optimized air-fuel ratio
3. **Fine tuning of coal mills**
   - Balanced mill loading
   - Reduced mill power consumption
4. **Reinstallation of Low Pressure Heater-3**
5. **Modification of High Pressure Heater outlet temperature**
6. **Cooling water pump optimization**
   - Improved pump efficiency
   - Reduced unnecessary pump operation
   - **VFD Installation:** Analyze the energy savings from installing Variable Frequency Drives on ID fans or Condensate Extraction Pumps (CEP).
   - **Operational Optimization:** Adjusting excess air ratios to reduce fan loading or optimizing the number of running CW pumps based on ambient temperature.
   - **Maintenance Solutions:** Highlighting the impact of overhauling pumps to restore efficiency or cleaning condenser tubes to improve vacuum (reducing BFP load)

IV.4.2 Major factors effecting APC

- The final feed water temperature at HPH-6 outlet was observed as **236.6°C**, whereas the design value is **241°C**. Due to this lower feed water temperature, the unit heat rate is increased by about

3.13 kcal/kWh. It was also observed that both HP Heater-5 and HP Heater-6 are underperforming, as the TTD and DCA values are higher than the design values and the feed water temperature rise is lower than expected.

- The calculated cooling water (CW) flow through the condenser is **27,066 m³/hr**, which is lower than the design flow of **28,500 m³/hr**. This reduction may be due to partial blockage of condenser tubes by debris or deterioration in pump performance. Therefore, condenser tube cleaning and regular monitoring of CW pump performance are recommended. If a significant reduction in flow is noticed, pump overhauling should be carried out.
- During the energy audit, the unit auxiliary power consumption (APC) was found to be **9.79%,** which is higher than the **8.5%** recommended by the Central Electricity Regulatory Commission (CERC) for units with natural cooling towers. Hence, suitable measures are required to bring the APC within the recommended limit.
- The performance of Boiler Feed Pumps (BFP), Condensate Extraction Pumps (CEP), Cooling Water (CW) Pumps, and ID/FD fans was evaluated under the existing operating conditions. A slight reduction in the performance of BFP, CEP, PA fans, and CW pumps was observed. Proper inspection and overhauling of the FD fans are expected to reduce auxiliary power consumption
- Inspection and maintenance of the ID fans, along with rectification of external air leakage, can reduce the loading on the fans. This may also allow operation with one less ID fan, resulting in a noticeable reduction in auxiliary power consumption
- Auxiliary power consumption at the unit, stage, and plant levels should be monitored regularly on a monthly or annual basis to understand the performance trend. An Online Energy Management System (EMS) can be used to continuously measure, record, and display the power consumption of HT motors and transformers. The recorded data can be analysed and presented through customized reports for effective monitoring and decision-making.

The expected savings after implementing the proposed recommendations have been estimated based on the operating conditions of the plant. The auxiliary power consumption can be reduced by about **108.4 MU/Yr,** which corresponds to nearly 8.3% compared to the previous year's consumption. Based on this reduction, the estimated annual cost saving is approximately Rs. **49.41cr**. The overall energy and cost savings are summarized in Table 10.

Table.10. Summary report for main plant Auxiliaries

S.No	**Recommendations**	**Energy Savings (2022-23)**	**Saving in Rs. Crores(2022-23)**	**Energy Savings(2023-24)**	**Saving in Rs. Crores(2023-24)**
Auxiliary Power Consumption study					
I. **Main Plant Auxiliaries**					
1. **Boiler Feed Pump**					
1.1	Reduction in DP across feed regulating station	0.3	0.082	1.524	0.58

2. Induced Draft Fan					
2.1	Arresting Air ingress in flue gas ducts from APH outlet to ID fan inlet facilitating stoppage additional ID fan	8.4	2.17	15.768	6
3. Forced Draft fan					
3.1	Optimizing air low and inspection/ Maintenance of Forced draft fan A & B	0.4	0.103	11.542	4.38
4. Coal Mills					
4.1	Overhauling of Mills & ball feeding frequency	2.4	0.61	5.676	2.15
5. Circulating water pump					
5.1	Providing polymer coating on CW pump internals	0.7	0.186	0.946	3.6
5.2	Provision of Online energy monitoring system	0.796	0.204	71.482	27.16
6. Other auxiliaries AHP,BCW, HP Water and other pumps					
6.1	Polymer/ceramic coating on pumps	0.19	0.05	1.46	5.54
Total		**13.186**	**3.386**	**108.4**	**49.41**
Remark: (i) Saving has been calculated taking power sale rate of Rs.3.8 /kwh					

IV.4.3 CW pumps modification

There are three CW Pumps in unit 1, three as main & one as standby. Pump designed flow is 33,333 m^3/hr and motor capacity is 3450 kw. Pump efficiency and can be improved by applying polymer coating on pump internals. There are manufacturers, who claim that pump efficiency can be improved by 3-6 % by coating.

Energy consumption by such coating can be reduced by 4-5 %.

Total Power Drawn by two pumps = 10350 kW Expected Power after improvement in efficiency = (1-.04)* 10350 (Assuming 4 % improvement in power consumption) = 9936 kw Expected Running Hours (assumed) = 8000 Hrs

Power saving = (10350-9936) =414 KW

Energy saving (Units) = 414 * 8000 = 33,12,000 kWh = 3.3 MUs

Cost of annual energy saving (Rs) = 33,12,000 *3.8 = 1,25,85,600= Rs.125.8 Lakhs Approximate cost of polymer coating on three pump internals = (Rs) 40Lakhs

Pay Back Period = One Year

IV.4.4 Timely replacement of BFP cartridges

The Boiler Feed Pump (BFP) is an important component of the boiler system that supplies feed water to the boiler drum at the required pressure. Since the BFP consumes a considerable amount of auxiliary power, its performance should be monitored regularly. Increased power consumption may indicate inter-stage leakage or deterioration in pump performance. Therefore, periodic inspection of the BFP cartridge and timely maintenance are essential to improve pump efficiency and reduce auxiliary power consumption.

Impact of Implementation

After replacing the BFP cartridge, the pump performance improved, resulting in reduced power consumption and energy savings.

Power saved per pump= 8000*3%= 240 KWH

Power saved per year= 240*7800 KWH=1,872,000

Saving of cost= 1,872,000 *3.8= Rs7,113,600

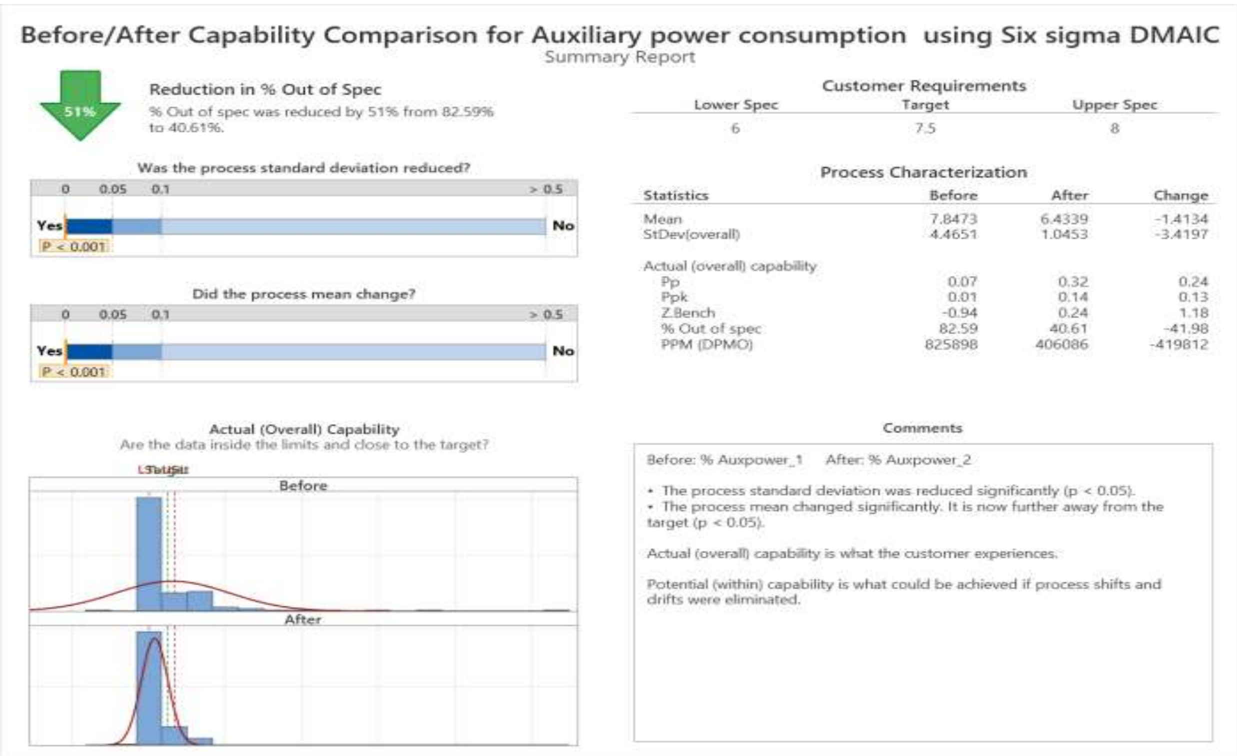

Fig.10. Before & After Capability comparison for APC using DEMAIC

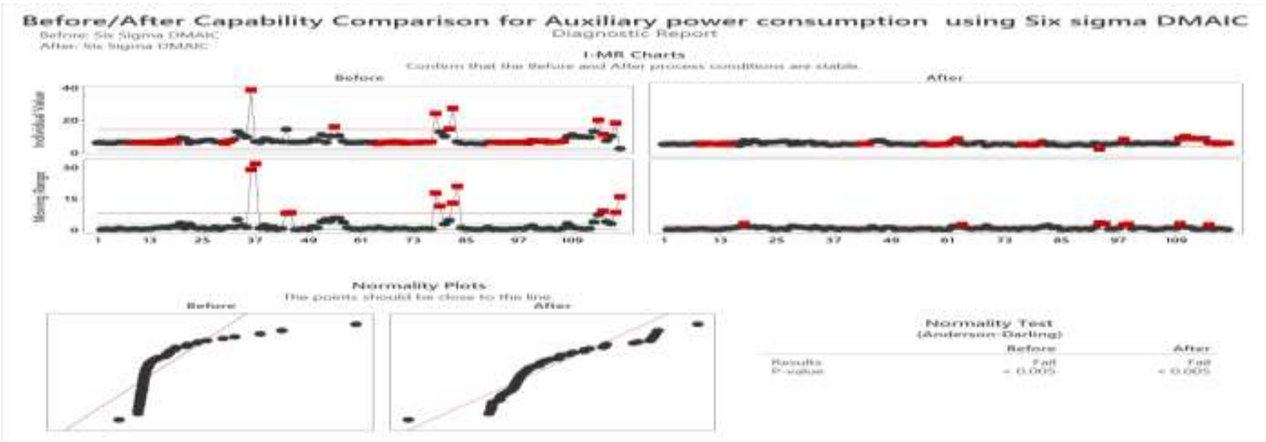

Fig.11. before & after Capability comparison for APC using DMAIC Diagnostic report

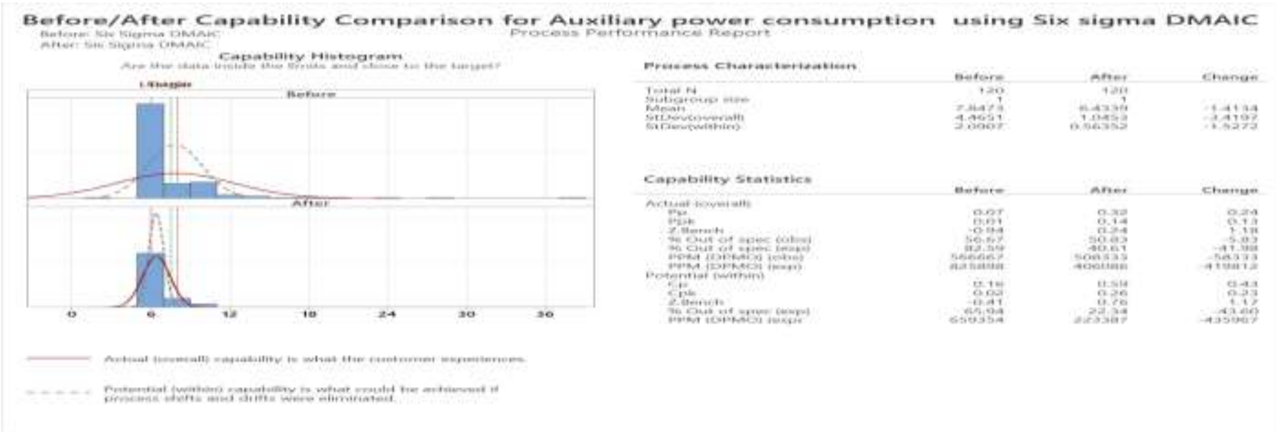

Fig.12. before & after Capability comparison for APC using DMAIC process performance report

Using DOE results:
Predicted Improvements

Table.11. Predicted improvements

Equipment	**Saving (kWh/day)**
BFP	4,175
ID Fan	43,200
FD Fan	31,622
Mills	15,552
CW Pumps	198,432
Other Pumps	4,000
Total	**296,981 kWh/day.**

IV.5. Control Phase:

Standardizing and Sustaining

Developing monitoring plan to ensure the improvements last. Standardize the new process, document workflows, and set up control charts so that if the process goes out of control the team can take action immediately.

To sustain improvements:

- Online APC monitoring system implemented
- Periodic Six Sigma reviews
- Preventive maintenance schedule introduced
- Control charts used to monitor APC variation

Table.12. Control Plan for APC parameters

Parameter	Control Method
APC %	Daily dashboard
Fan Power	SPC Control Charts
Pump Efficiency	Monthly performance test
Air Leakage	Quarterly thermography
Mill Performance	Weekly fineness test

V. Results and Conclusion

Fig.13. before & after improvements for APC

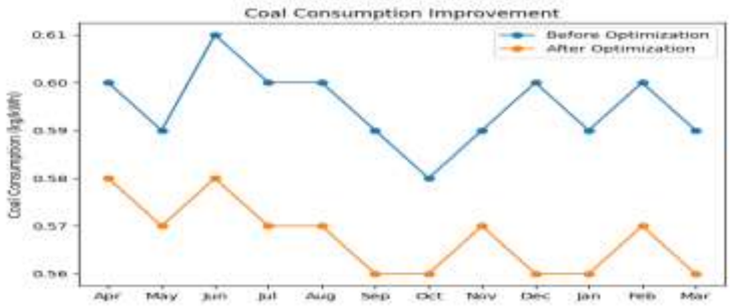

Fig.14. before & after coal consumption improvements

Table.13. summary report for plant performance

Parameter	Before Improvement	After Improvement
Auxiliary Power Consumption	6.9%	6.4%
Net Generation	93.1%	93.6%
Annual Energy Saving	13.2MU	25 MUs
Coal Saving	~1554tonnes/Year	~2500 tonnes/year
Sigma Level	3.2	4.1

Six Sigma Metrics
Assuming:

- Opportunities/day = 7 major auxiliary systems
- Defect = APC exceeds target

Calculation:

- Total opportunities/year = 2555
- Defects observed = 8

DPMO= $(8X10^6)/2555=3131$
Sigma Level = **4.2 σ**
The improvement resulted in:

- Reduced internal power consumption
- Improved turbine heat rate
- Increased plant efficiency

Implementation of Energy Conservation Measures
The energy management approach was implemented in the thermal power plant with the following objectives:

- Optimization of operating parameters.
- Identification of equipment performance deterioration and areas for improvement.
- Reduction of auxiliary power consumption.
- Adoption of suitable energy-saving technologies for auxiliary equipment.

To achieve these objectives, a detailed plant survey was carried out along with discussions with the plant personnel. Various operating parameters, including auxiliary power consumption of major equipment, lighting levels, air-conditioning load, and thermal insulation, were assessed. Based on the collected data, important plant performance parameters such as boiler efficiency, boiler losses, air heater efficiency and leakage, turbine heat rate, cylinder efficiency, heater performance, condenser performance, and auxiliary power consumption were evaluated. The observed values were compared with the available design data to identify performance deviations. Based on the gap analysis, suitable measures were suggested to improve plant performance and reduce energy losses. Continuous monitoring of the important process parameters helps in identifying performance deterioration at an early stage so that corrective actions can be taken in time. Regular monitoring also helps in checking the accuracy of instruments and identifying the instruments that require calibration or replacement.
The major benefits of implementing the energy management measures are:

- Reduction in fuel consumption, thereby lowering the overall cost of power generation.
- Identification and rectification of the factors responsible for higher auxiliary power consumption, leading to improved net power output.

The estimated annual energy savings achieved after implementing the proposed energy management measures are summarized below.

a. Auxiliary power consumption reduction –
    - **Saving – 296981.1kwh/d**
    - **Cost saving – Rs 4941lakhs**
b. **Energy saved:** 25 Million Units
c. **Monetary savings:** Approx ₹12–15 Crores/year

d. **Coal saving:** ~2500 MT/year

VI. Conclusion

This study successfully applied the DMAIC Six Sigma methodology to address the high Auxiliary Power Consumption (APC) in an 800MW at SDSTPS. By identifying the Boiler Feed Pumps (BFP) and ID fans as the "Vital Few" in the Analyze phase, targeted interventions such as VFD retrofitting and condenser vacuum optimization were implemented. The project achieved a reduction in APC from 6.9% to 6.4%, resulting in an annual energy saving of approximately 42 MU. This not only improves the plant's operational profitability but also reduces the carbon footprint by approximately 35,000 tons of CO_2 annually. The improvements resulted in significant energy savings, reduced fuel consumption, and improved overall plant efficiency. The methodology presented in this study can be effectively applied to other large thermal power plants to enhance operational performance and sustainability.

VII. Future Scope:

- **Digital Twins:** Future research could involve developing a Real-time Digital Twin of the SDSTPS thermal cycle to predict APC fluctuations based on varying coal grades.
- **AI Integration:** Utilizing Machine Learning (ML) algorithms for predictive maintenance of HT motors to further reduce "forced" auxiliary consumption during equipment failure.
- **Hybridization:** Investigating the integration of solar thermal or floating PV systems within the SDSTPS premises to offset the auxiliary load.

Nomenclature

DOE : Design Of Experiment
APC : Auxiliary Power Consumption
VFD : Variable Frequency Drive
ID : Induced Draft
FD : Forced Draft
CTQ : Critical To Quality
BFP : Boiler Feed Pump
CW : Cooling Water
PA : Primary Air
EMS : Energy Management System
CEP : Condensate Extraction Pump
CERC : Central Electricity Regulating Combustion
C_p : Process Capability
C_{PK} : Process Capability index

Funding: This research received no external funding.

VIII. References

1. N. K. Gavirineni and E. Gundabattini, “Enhancing the Energy Efficiency of a Supercritical Thermal Power Plant,” International Journal of Design & Nature and Ecodynamics, vol. 17, no. 2, pp. 177–187, 2022. [Online]. Available: https://iieta.org/download/file/fid/72351nopr.niscpr.res
2. L. B. Sah, “Boiler & Aux - HR, FIN, Others,” presentation, May 24, 2012. [Online]. Available: https://www.scribd.com/presentation/94663962/Boiler-Aux-HR-FIN-Others

3. M. S. Bhatt and R. P. Mandi, “Performance enhancement in coal-fired thermal power plants. Part III: Auxiliary power,” International Journal of Energy Research, vol. 23, no. 9, pp. 779–804, 1999, doi: 10.1002/(SICI)1099-114X(199907)23:9<779::AID-ER514>3.0.CO;2-P.
4. D. Buddhi and R. Kumar, “Auxiliary Power Analysis of a Coal-based Thermal Power Plant,” International Journal of Research and Analytical Reviews, vol. 6, no. 1, 2019. [Online]. Available: https://ijrar.org/papers/IJRAR1BLP064.pdfrenewconnect
5. W. B. Smith, “Bill Smith (Motorola engineer),” Wikipedia. Accessed Jul. 31, 2026. [Online]. Available: https://en.wikipedia.org/wiki/Bill_Smith_(Motorola_engineer)
6. M. J. Harry, “Mikel Harry,” Wikipedia. Accessed Jul. 31, 2026. [Online]. Available: https://en.wikipedia.org/wiki/Mikel_Harry
7. S. Banerjee, “Thermal Power Plant Performance Improvement Using Quality Initiatives,” 2025. [Online]. Available: source indexed in search results
8. N. K. Gavirineni and E. Gundabattini, “Enhancing the Energy Efficiency of a Supercritical Thermal Power Plant,” International Journal of Design & Nature and Ecodynamics, vol. 17, no. 2, pp. 177–187, 2022. [Online]. Available: https://iieta.org/download/file/fid/72351
9. D. Buddhi and R. Kumar, “Auxiliary Power Analysis of a Coal-based Thermal Power Plant,” International Journal of Research and Analytical Reviews, vol. 6, no. 1, 2019. [Online]. Available: https://ijrar.org/papers/IJRAR1BLP064.pdf.
10. “Improving Energy Usage in Commercial Buildings Using Six Sigma DMAIC,” search result listing.