# ENERGY AUDIT MANUAL FOR THERMAL POWER PLANTS (TPPs)

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# List of Acronyms or Abbreviations

| | |
|---|---|
| AC | Air Conditioning |
| AHP | Ash Handling Plant |
| APC | Auxiliary Power Consumption |
| BDT | Bangladeshi Taka |
| BEECMP | Bangladesh Energy Efficiency and Conservation Master Plan |
| BERC | Bangladesh Energy Regulatory Commission |
| BFP | Boiler Feed Water Pump |
| BNBC | Bangladesh National Building Code |
| BPC | Bangladesh Petroleum Corporation |
| BPDP | Bangladesh Power Development Board |
| BOGMC | Bangladesh Oil, Gas, and Mineral Corporation |
| BTU | British Thermal Unit |
| CA | Compressed Air |
| CAGR | Compounded Annual Growth Rate |
| CAPEX | Capital Expenditure |
| CC | Closed Cycle |
| CCPP | Combined Cycle Power Plant |
| CEP | Condensate Extraction Pump |
| CHP | Coal Handling Plant |
| CRI | Climate Risk Index |
| CWP | Cooling Water Pump |
| DM | Demineralized |
| EAP | Energy Audit Procedure |
| ECM | Energy Conservation Measure |
| EE | Energy Efficiency |
| EE&C | Energy Efficiency and Conservation |

| | |
|---|---|
| ENCON | Energy Conservation |
| ERL | Eastern Refinery Limited |
| ESCO | Energy Service Company |
| ESP | Electrostatic Precipitator |
| FDF | Forced Draft Fan |
| GBG | Green Building Guideline |
| GCV | Gross Calorific Value |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GT | Gas Turbine |
| HFO | Heavy Fuel Oil |
| HR | Heat Rate |
| HRSG | Heat Recovery Steam Generator |
| HSD | High-Speed Diesel |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IDF | Induced Draft Fan |
| kCal | Kilocalorie |
| kV | Kilovolt |
| kWh | Kilowatt Hour |
| LNG | Liquefied Natural Gas |
| MEPS | Minimum Energy Performance Standard |
| MPEMR | Ministry of Power, Energy, and Mineral Resources |
| Mtoe | Million Tons of Oil Equivalent |
| MW | Megawatt |
| NG | Natural Gas |
| OC | Open Cycle |
| OEM | Original Equipment Manufacturer |

| | |
|---|---|
| PAF | Primary Air Fan |
| PF | Power Factor |
| PG | Performance Guarantee |
| PPE | Personal Protective Equipment |
| RTD | Resistance Temperature Detector |
| $Sm^3$ | Standard Cubic Meter |
| SPV | Solar Photovoltaic |
| SREDA | Sustainable and Renewable Energy Development Authority |
| ST | Steam Turbine |
| TPP | Thermal Power Plant |
| TPS | Thermal Power System |
| WHRB | Waste Heat Recovery Boiler |

# 1.0 Executive Summary

The industries in Bangladesh rely primarily on power plants for their energy needs. Thermal power plants (TPPs) offer high-capacity power generation. This energy audit manual for Bangladesh analyzes the country's energy mix and power generation mix, power generation performance, energy prices trend, energy projections master plans, and their commitments. This audit manual serves as a ready reckoner for conducting energy audits for all levels of engineers and managers working in the TPP sector. The manual also helps as a reference base for regulatory bodies like Bangladesh Energy Regulatory Commission (BERC) and others, during their monitoring and verification campaigns, mandatory energy audits, and so on.

This manual provides a brief overview of the Bangladesh Energy Efficiency and Conservation Master Plan (BEECMP) 2030, and information on the functions and support of BERC in price regulations of gas, electricity, and petroleum products. The manual identifies the need for energy audit and energy conservation in TPPs and explores the potential cost-saving options in critical energy-consuming areas. It also offers technical information, energy audit methodologies, and energy audit procedures (EAPs) that are involved while conducting an energy audit in various types of TPPs. To summarize, this energy audit manual serves the following functions:

- Addresses different types of TPPs operational in Bangladesh.
- Provides guidelines to identify energy conservation measures (ECMs).
- Addresses the operational boundary of the energy audit in each TPP type, including energy systems, processes, equipment, and people/functions (to ensure the accuracy of data).
- Provides guidelines for performance evaluation of a TPP.
- Explains "walk-through" EAP.
- Describes different phases of a "detailed" energy audit:
  - pre-audit phase,
  - audit phase, and
  - post-audit phase.

The scope of this audit manual covers the following types of operational TPPs in Bangladesh:

- Coal-fired TPP,
- Natural gas (NG)-fired TPP,
- NG-fired gas turbine (GT) closed cycle (CC) TPP,
- NG-fired GT open cycle (OC) TPP,
- NG-fired gas engine CC TPP,
- NG-fired gas engine OC TPP,
- Diesel-fired engine CC TPP, and
- Diesel-fired engine OC TPP.

The manual provides a comprehensive list of critical energy consuming equipment, processes, and subsystems based on the type of TPPs that are required to be audited as part of the energy performance evaluation process of a typical TPP. The manual also shares an energy audit plan, the main points of which are listed below.

- Review of audit plan with stakeholders, explanation of audit methodologies, and understanding of the expectations of the plant owners.
- A questionnaire covering the energy audit parameters for various subsystems.
- Finalization of audit duration.
- The process of streamlined communication.
- Coverage of a typical energy audit report.
- Budget and timeline of the audit.

- Equipment and machinery that are in constant operation in a TPP.

In addition, the manual illustrates the selection process of energy auditors/energy managers and a qualified support team to conduct an energy audit. The manual lists the necessary areas of expertise and experience that an energy audit team must have. The manual also provides information on tools for professional Certified Energy Auditors and Managers while conducting mandatory or voluntary audits; this is to ensure a degree of uniformity in reporting the results of an energy audit.

The manual provides the means for evaluating the energy performance of TPPs and the main subsystems, such as the boiler and the turbine, using energy performance indicators. In addition, the energy performance assessment of all the other main and auxiliary systems is part of the "Evaluation of Equipment Performance" section of the energy audit manual.

Specifically, the EAPs mentioned in the manual offer scope for practicing shop-floor engineers to conduct a decent and standardized energy audit of energy-related equipment in a TPP, including evaluation of energy performance, identification of potential ECMs, and reduction of greenhouse gas (GHG) emissions accordingly. The manual also illustrates the process of an EAP with an example.

The manual lists the conclusion activities (post-audit phase) that comprise (a) presentation of energy audit findings, (b) general recommendations, and (c) preparation of an action plan. Furthermore, the manual discusses the implementation and follow-up plan in the post-audit phase and the action plan for implementation by the TPP team.

# 2.0 Bangladesh Energy Sector and Energy Efficiency Overview

## 2.1 Bangladesh Energy Efficiency and Conservation Master Plan 2030

**A brief overview**[1]

In Bangladesh, the energy intensity (national primary energy consumption per gross domestic product [GDP]) is expected to be 20% higher in 2030 than it was in 2013. From now until 2030, there exists an enormous potential of saving energy to the tune of 95 million tons of oil equivalent (Mtoe; 113 billion cubic meters of gas equivalent).

Therefore, the government needs to facilitate the implementation, execution, and proliferation of energy efficiency (EE) and conservation (EE&C) programs along with raising public awareness of the need for saving energy.[2] The BEECMP 2030 promotes three EE&C programs, namely the (1) Energy Management Program, (2) EE Labeling Program, and (3) EE Buildings Program. All these programs are targeted at large energy-consuming entities in the industrial, residential, and commercial sectors.

**Action plan**

The action plans under the EE&C programs demonstrate the practical methods to accomplish the goals outlined in the BEECMP. Table 1 summarizes the action plan of the BEECMP 2030.

**Table 1. Action plan of the BEECMP 2030**

| Program | Targets | Scope |
|---|---|---|
| **Energy Management Program** | Large industrial energy consumers | • Notification of large energy consumers as designated entities<br>• Examination for Certified Energy Manager, Certified Energy Auditor, and Accredited Energy Auditor<br>• Energy audit (mandatory/voluntary)<br>• Energy consumption reporting (mandatory)<br>• Benchmarking |
| **EE Labeling Program** | Residential consumers | • Label certification/laboratory accreditation system<br>• Standardization of the EE measurement method and Star label rating criteria<br>• Star label standardization (Unification)<br>• Participation of manufacturers, importers, and retail shops (mandatory/voluntary)<br>• Minimum Energy Performance Standard (MEPS) |
| **EE Buildings Program** | Buildings | • Implementation of a revised Bangladesh National Building Code (BNBC)<br>• Green Building Guideline (GBG) development<br>• Introduction of the manual and assessment system |
| **EE&C Finance Program** | Private companies | • A low-interest loan or subsidy for EE&C investment<br>• Preferential taxation on high-efficiency equipment/appliances and/or EE&C investment<br>• Other incentive mechanisms |
| **Government Initiatives** | Government | • Green purchase program for eco-friendly public procurement<br>• The certification process for ISO14001 and 50001 |
| **Energy Consumption Data Collection** | Government | • Energy consumption data by fuel<br>• Energy consumption data by sector and subsector<br>• Energy intensity data |
| **Global Warming Countermeasure** | All | • Formulation and quantification of a national carbon market<br>• Carbon abatement project as capacity development<br>• Awareness raising |

[1] BEECMP up to 2030
[2] BEECMP up to 2030

Implementation of such targets is a multisector issue, which requires the participation of all interested parties, including the general public and private/public establishments. Various organizations have roles and responsibilities to support and enforce rules. Knowledge dissemination of EE&C is also a key factor.

## 2.2 Energy efficiency institutional framework in Bangladesh

**Bangladesh Energy Regulatory Commission (BERC)[3]**
BERC was established by the Bangladesh Parliament in March 2003 with a mandate to regulate the electricity, gas, and petroleum industries. BERC determines tariffs, issues licenses, and oversees dispute settlement. BERC is tasked with the responsibility of ensuring EE at levels of generation, exploration, production, transmission, and distribution of the related sectors. BERC is also responsible for formulating the EE&C plan on electricity supply.

Most of the petroleum products consumed in Bangladesh are imported. BERC periodically fixes the prices in the market for these products. The government controls the prices of petroleum products and electricity as a result. Thus, energy subsidies primarily result from setting fuel and electricity retail prices below their true market value.

BERC sets electricity prices based on the pricing principles it adopted in January 2004. The guidelines are intended to codify the process of implementing the principles of tariff adjustment and eliminating distortions in the tariff structure. The following points illustrate the role and responsibilities of BERC in setting up electricity prices:

- Each electricity end-user tariff is set to cover the reasonable costs of supplying electricity to that customer class, generating a surplus to expand coverage and supply, and improving customer service.
- Providing subsidies for capital or operating costs to specific customer classes that come directly from the government budget.
- In addition to providing incentives to improve efficiency, generation costs are passed on to end users through tariffs.
- A review of tariffs is conducted at least quarterly and adjusted more than once annually to reflect changes in fuel prices, generation mix, exchange rates, and inflation. If the quarterly review indicates a variation in recognized costs of more than 10%, tariffs are adjusted accordingly.
- Differentiated rates are maintained for peak and off-peak consumption, and a two-part tariff is introduced for Bangladesh Power Development Board's (BPDB) generation plants, including fixed (capacity) costs and variable (energy) costs, and excluding variable renewable energy-based power plants.

BERC arranges public hearings involving stakeholders, policymakers, and government officials to maintain transparency and accountability in the pricing framework.

BERC sets the price of petroleum products in consultation with the Bangladesh Petroleum Corporation (BPC) and considers the changes in the import cost of petroleum products and the volume of losses of BPC. The BPC is the sole agency in Bangladesh for the production and supply of petroleum products throughout the country, with the involvement of Eastern Refinery Limited (ERL) and the distribution companies in the supply chain. However, unlike in the case of electricity, BERC does not offer any public hearings on the pricing mechanism of petroleum products; it determines the price through internal consultation with BPC.

[3] Mustafa K. Mujeri, Tahreen Tahrima Chowdhury, and Siban Shahana "Energy Sector in Bangladesh: An agenda for reforms." Bangladesh Institute of Development Studies. March 2014.
https://www.iisd.org/system/files/publications/energy_sector_bangladesh.pdf

**Bangladesh Oil, Gas, and Mineral Corporation (BOGMC)[4]**
The main regulator for upstream oil and gas in Bangladesh is the BOGMC, also known as PetroBangla, which is governed by the Ministry of Power, Energy, and Mineral Resources (MPEMR). The basic functions of PetroBangla include, but are not limited to:

- Research in the field of oil, gas, and minerals.
- Preparing and implementing programs for the exploration and development of oil, gas, and mineral resources.
- Producing and selling oil, gas, and mineral resources.
- Performing any such other functions as the government may, from time to time, assign PetroBangla.

The Gas Act of 2010 regulates the transmission, distribution, marketing, supply, and storage of NG and liquid hydrocarbons in Bangladesh's land, sea borders, and economic zones. By the preamble to the act, the goal is to ensure the proper and appropriate use of the regulated substance. Exploration and production of NG and related resources, however, are not governed by the Gas Act.[5]

**Sustainable and Renewable Energy Development Authority (SREDA)**
In May 2012, the Bangladesh Parliament established SREDA as a national nodal organization for promoting demand-side EE&C. The roles and responsibilities of SREDA[6] include, but are not limited to, the following:

- Coordination of EE&C policies among all government agencies and nongovernment organizations on a multisectoral/cross-cutting basis.
- Monitoring and implementation of EE&C programs at a national level.
- Report on energy consumption to the public and government.
- Implementation and approval of green building guidelines.
- Advocacy and awareness raising.
- Arrange examinations to obtain Certified Energy Auditors.
- Energy labeling of equipment.

The government must facilitate EE measures in the country, as well as create the momentum to promote energy-saving activities among the public. The following section describes the key drivers for conducting energy audits in power generation facilities in Bangladesh.

## 2.3 Drivers for energy audit in power generation facilities

The country secured the 65th rank on the "Long-term Climate Risk Index (CRI)," covering the period 1996 to 2015. Bangladesh's carbon emissions account for just 0.35% of the combined emissions of all the countries in the world. As things stand, if the world fails to take ambitious action, Bangladesh could see its GDP being reduced by 2% by 2050, and by 9.4% by 2100.[7] Power generation in Bangladesh increased at a compounded annual growth rate (CAGR) of 6.47% between 2015 to 2020. Figure 1 shows the power generation and energy mix of the country.

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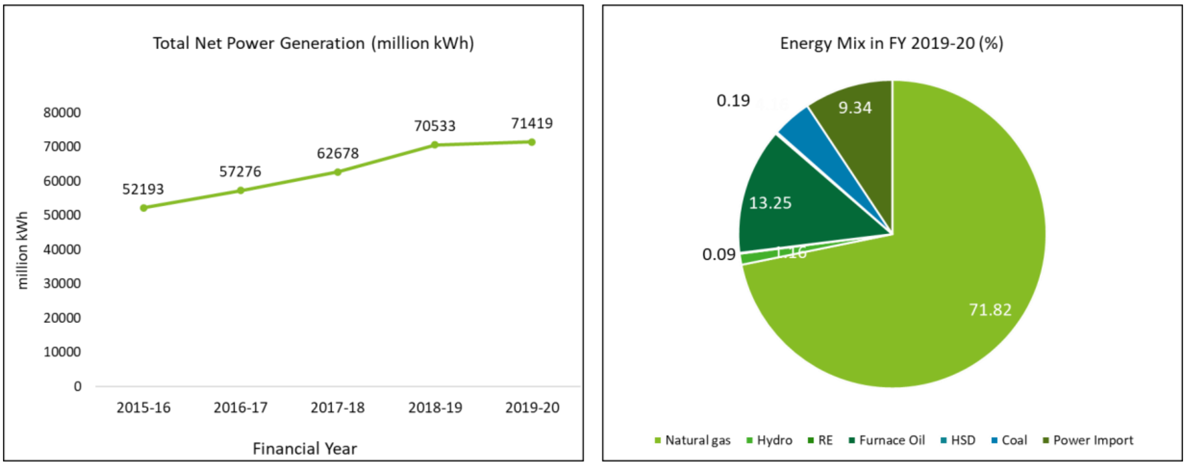
[4] "A general introduction to oil and gas law in Bangladesh." Lexology. November 2021.
https://www.lexology.com/library/detail.aspx?g=79dcf1d4-1936-453a-b838-45b6264ba3d5#footnote-020

[5] Ibid.

[6] Ibid.

[7] Hartley-Louis, Rob, and Salma Islam. "Energy Efficiency and Energy Auditing in Bangladesh." Green Growth Knowledge. October 2018.
https://www.greengrowthknowledge.org/sites/default/files/downloads/resource/EDGG+Paper+10+Energy+Efficiency+and+Energy+Auditing.pdf

**Figure 1. Power generation and energy mix in Bangladesh**




Source: BPDB Annual Reports (2015/16 to 2019/20), IEA

The total net power generation in Bangladesh increased to 71,419 million kilowatt-hours (kWh) in the year 2019/2020 from 70,533 million kWh in 2018/2019. NG formed about 71.82% of the fuel mix in energy generation in 2019/2020. Similarly, furnace oil formed 13.25% of the fuel mix for energy generation, whereas 9.34% of power was imported in the same year. Bangladesh consumed 1.62 quadrillion British Thermal Units (BTUs) of primary energy in 2019. Bangladesh's primary energy consumption rose from 0.51 quadrillion BTUs in 2000 to 1.62 quadrillion BTUs in 2019. The CAGR reached a maximum of 11.81% in 2015 and then decreased to 4.27% in 2019.[8]

The government has used fiscal measures to keep the cost of gas down in recent years; however, this is unsustainable overall, and therefore, the cost of energy would inevitably rise. The concept of EE is widely seen as the most cost-effective and short-term measure of reducing the strain on energy production in a country, with the added benefit of realizing lower emissions. To implement such measures, the regulatory bodies of most countries have three main instruments for maximizing EE; these are regulations, auditing, and certification. The energy audit provides a benchmark for managing energy and planning more effective use of energy throughout the facility.

To improve EE, reduce operating costs, and achieve an effective energy management program, an energy audit is conducted. During an energy audit, a facility's operational practices and energy costs are examined in detail, and recommendations are made for savings on energy bills by optimizing operating practices or retrofitting or upgrading energy-consuming equipment. The objectives of a good energy management program include the following:

- To achieve and maintain optimum energy procurement and utilization, throughout the organization.
- To minimize energy costs/waste without affecting production and quality.
- To minimize environmental effects.

As a result of an energy audit, viable and cost-effective measures can be identified for reducing energy consumption per unit of output, thereby lowering operating costs.

Industrial sectors are heavily dependent on energy resources to process raw materials into final products. The technique by which energy is harnessed within industrial processes is crucial to the sustainability of these units. An energy audit is one of the most comprehensive ways to optimize energy consumption in the industry. Industries rely primarily on power plants for their energy needs. TPPs

[8] "Bangladesh - Total primary energy consumption." Knoema. https://knoema.com/atlas/Bangladesh/Primary-energy-consumption

offer high-capacity power generation to meet the needs of the industries. Studies suggest significant energy-saving potential in TPPs.
The next section reveals the total installed capacity (as per fuel type) in power plants in Bangladesh, both in the private and public sectors.

## 2.4 Power plants in Bangladesh

**Inventory of power plants in Bangladesh**
In Bangladesh, the consumption of per capita generation in the year 2021 was low at 220 kWh.[9] Since the 1990s, the government has continuously encouraged industries to install their own captive electricity generating plants so that they could continue uninterrupted production during load shedding periods.

The private power companies were also allowed to produce and supply power to the national grid under agreed terms. Barge-mounted plants were the result of the first such initiative by the private sector. ***Annexure I*** provides details of the operational as well as nonoperational TPPs in Bangladesh.

As of 2022, the total installed power generation capacity in Bangladesh is 25,730 megawatts (MW), including captive and off grid solar as per Power Cell. Table 2 presents the spread of operating power plants by zone and corresponding capacities (as of 2022).

**Table 2. Operating power plants by sector**

| Public sector | Number of power plants | Installed generation capacity (MW) |
|---|---|---|
| BPDB | 38 | 6,013 |
| APSCL | 5 | 1,428 |
| EGCB | 3 | 957 |
| NWPGCL | 7 | 1,401 |
| B-R Power gen | 1 | 149 |
| RPCL | 3 | 182 |
| Subtotal | 57 | 10,130 (45%) |
| **Joint venture** | | |
| BCPCL (JV of NWPGCL & CMC, China) | 1 | 1,244 |
| Subtotal | 1 | 1,244 (6%) |
| **Private sector** | | |
| IPPs | 63 | 8,487 |
| SIPPs (BPDB) | 4 | 99 |
| SIPPs (REB) | 9 | 251 |
| 15-year rental | 4 | 169 |
| 3/5-year rental | 14 | 972 |
| Subtotal | 94 | 9,978(44%) |
| **Power import** | | |
| Bheramara HVDC | | 1,000 |
| Tripura | | 160 |
| Subtotal | | 1,160 (5%) |
| **TOTAL** | **152** | **22,512*** |

***Including captive power and off grid renewable energy total installed capacity (22,512 + 2,800 + 418) = 25,730 MW.**

These nine zones account for 148 power plants, the details of which are listed below.

[9] "Power Plants." Banglapedia. https://en.banglapedia.org/index.php/Power_Plants

- Dhaka zone: 36 plants in operation (17 gas-based power plants, 15 heavy fuel oil [HFO]-based, 3 high-speed diesel [HSD]-based, and 1 solar).
- Cumilla zone: 22 plants in operation (13 gas, 8 HFO, and 1 HSD).
- Chattogram zone: 21 plants in operation (12 HFO, 6 gas, 2 hydro, and 1 solar).
- Sylhet zone: 16 plants in operation (16 gas).
- Khulna zone: 8 plants in operation (1 solar, 2 HSD, 1 gas, and 4 HFO).
- Rajshahi zone: 19 plants in operation (8 gas, 9 HFO, 1 solar, and 1 HSD).
- Barishal zone: 7 plants in operation (3 gas, 2 HFO, 1 coal, and 1 gas/HSD).
- Mymensing zone: 8 plants in operation (2 gas, 4 HFO, and 2 solar).
- Rangpur zone: 8 plants in operation (3 coal, 2 HSD, 2 HFO, and 1 solar).

**Types of power plants in Bangladesh**

There are five kinds of power plants in Bangladesh.

**Steam turbine (ST) plants**

The largest ST power station, based on NG, is situated at Ghorasal, Narsingdi. These power plants are mainly based on NG and to a lesser extent furnace oil. There are four TPPs based on coal. The largest ST power plant operating on coal is Payra 1,320 MW TPP.

**GT plants (OC)**

Currently, in Bangladesh, GT power plants are used as "peaking plants" as well as "base load" plants. The peaking plants are normally OC GT power plants and are kept in operation during peak demand (mainly in the evenings, after sunset, to meet the spurt in lighting loads).

**GT plants (combined cycle)**

A combined cycle power plant (CCPP) system generates electricity, which is based on two thermal units with two separate thermal cycles that include a GT cycle and a ST cycle. The base load plants are mainly combined cycle GT plants.

**Hydropower plant**

The only hydro-based plant in Bangladesh is located at Kaptai in the Rangamati district. Comprising five units, the total capacity of this plant is 230 MW. Installation of another two hydro-based units at the same premises is also in progress. However, the potential hydro capacity for power generation in Bangladesh is insignificant.

**Renewable and nuclear energy-based plants**

Following the crisis of primary fuel, emphasis has been laid on capacity expansion for power generation through alternative sources. The country's first wind-based power plant was installed at Matamuhury under the Feni district, having a total installed capacity of 900 kW (4 x 225 kW). Also, at Kutubdia, 50 wind turbine generators were installed having a total capacity of 1 MW (50 x 20 kW).

To diversify from NG, future power plants have been planned to be run on coal, liquefied NG (LNG), nuclear, and renewable energy (such as solar photovoltaics [SPV] and wind). India has recently made a deal with Bangladesh to develop the transmission lines of Bangladesh Rooppur Nuclear power plant. The plant:[10]

- Is an under-construction 2.4 gigawatt electrical nuclear power plant in Bangladesh.
- Is being constructed at Rooppur (Rupppur) in the Pabna District of Bangladesh.

There are two units of plants that are expected to be completed in 2022 and 2024, respectively. Each will produce 1,200 MW of electricity.

[10] "Rooppur Nuclear Power Plant." GK Today. March 2021. https://www.gktoday.in/topic/rooppur-nuclear-power-plant/

Table 3 summarizes the type-wise spread of installed capacities, alongside the de-rated capacities.

**Table 3. Different types of operating TPPs in Bangladesh**

| Serial. No. | Type of TPP | Installed capacity (MW) | Number | Share of total installed MW (%) | Ranking |
|---|---|---|---|---|---|
| **Gas fuel (NG)-based power plants** | | | | | |
| 1 | Gas-based CCPPs (GT + ST) | 8,598 | 29 | 39.0% | 1 |
| 2 | Gas-based OC gas power plants (GT only) | 1,188 | 12 | 5.4% | 5 |
| 3 | Gas-based conventional TPPs (boiler and ST) | 1,804 | 25 | 8.2% | 3 |
| **Liquid fuel-based power plants** | | | | | |
| 4 | HFO-based conventional TPPs (boiler and ST) | 6,979 | 56 | 31.6% | 2 |
| 5 | HSD-based diesel engine OC TPPs (diesel engine and ST) | 1,110 | 10 | 5.0% | 6 |
| **Solid fuel-based power plants** | | | | | |
| 6 | Coal-based conventional TPPs (boiler and ST) | 1,768 | 4 | 8.0% | 4 |
| **Other types of power plants** | | | | | |
| 7 | Hydro-based power plants | 230 | 1 | 1.04% | 7 |
| 8 | SPV power plants | 229 | 7 | 1.03% | 8 |
| **Miscellaneous** | | | | | |
| 9 | Import of power from India (Tripura) | 1,160 | 1 | 0.73% | 9 |

- **52.6%** of the total installed power (MW) in Bangladesh is based on NG, of which 39% (of total installed MW) are NG-based CCPPs with GT + ST combination, 5.4% are NG GT OC TPPs, and 8.2% are NG-fired conventional TPPs.
- **36.6%** of the total installed power (MW) in Bangladesh is liquid fuel-fired, of which 31.6% (of total installed MW) are HFO-based conventional TPPs (boiler and ST), and 5% (of total) are HSD-based diesel engine OC TPPs (diesel engine and ST).
- **8%** of the total installed power (MW) in Bangladesh are solid fuel, coal-fired, and conventional TPPs (boiler and ST).

Besides the TPPs, the other sources of power feeding the grid are as listed below.

- **1.04%** of the total installed power (MW) in Bangladesh is from hydropower plants.
- **1.03%** of the total installed power (MW) in Bangladesh is from SPV power plants.
- About **0.73%** of the total installed power (MW) is sourced from imports, specifically from Tripura in India.

Currently, 8% of the power generation is based on coal, which is expected to grow to 50% by 2030, whereas 10% (2030) will be based on nuclear power. There are some isolated diesel power stations at remote places and islands, which are not connected to the national grid. The terminal voltage of different generators is 11 kilovolts (kV), 11.5 kV, and 15.75 kV.[11]

In the eastern zone (eastern side of the Jamuna River), electricity is generated from indigenous gas and a small percentage through hydropower. In the western zone, coal and imported liquid fuel are used for the generation of electricity. The fuel cost per unit generation in the western zone is much higher

[11] "Bangladesh Energy Situation." Energypedia. https://energypedia.info/wiki/Bangladesh_Energy_Situation#:~:text=There%20are%20some%20isolated%20diesel,11.5%20kV%20and%2015.75%20kV

than that of the eastern zone. Therefore, as a policy, low-cost electricity generated in the eastern zone is transferred to the western zone through a 230-kV east-west interconnector transmission line.

**Comparison of operating parameters of a sample of different TPPs in Bangladesh**
A few TPPs in Bangladesh responded to a questionnaire survey, the details of which are presented in ***Annexure 2***. The operating parameters of the four key types of TPPs (as per the sample survey) are captured in a tabular form. The four different types of TPPs are listed below:

- CCPP: This is the first type of TPP, which is gas-fired, and based on a GT- and ST-based combined cycle.
- GT OC and GT CC presently GT CC on diesel (CCPP): This is the second type of TPP, which has both OC and CC systems. OC is GT only and CC is GT and ST. At present, this TPP is operated with diesel firing on CC mode only.
- Diesel/NG engine CCPP: This is a power plant powered by an engine, which can operate on both diesel and NG in CC.
- GT OC power station: This is purely a GT-based, NG-fired, OC power plant.

These four types of TPPs were compared based on such parameters as (1) the capacity of the power plant, (2) fuel in utilization and their density, (3) average annual gas or fuel oil consumption, (4) average plant load factor, (5) specific fuel consumption, (6) additional fuel used in heat recovery steam generator (HRSG; boiler) annually, (7) fuel gas inlet temperature to HRSG (boiler), (8) annual down time, (9) auxiliary power consumption (APC), (10) lower calorific value of fuels, (11) station generation, (12) operation mode, that is, OC or CC, (13) combined cycle efficiency of the GT or the engine, (14) design and actual gross heat rate and net heat rate, and (15) generation voltage.

Apart from the above technical details, the inlet conditions of the GT compressor, fuel data, exhaust flue gas conditions, generation data, waste heat recovery boiler (WHRB) data feed water inlet parameters, and steam parameters at WHRB exit are also discussed in ***Annexure 2.***

The section below identifies the significance of the energy audit manual by analyzing the operational boundary for the energy audit, the main and subareas where the manual can be utilized, energy use by key equipment in different types of TPPs, and the expected outcome of the energy audit in a TPP.

## 2.5 Significance of Energy Audit Manual

**Scope of the manual**
This audit manual covers not only the main system components of a TPP, but also the utility systems used in a TPP. The key elements of the manual are:

**Main system**

- Boilers and associated systems (in coal-fired and gas-fired TPPs).
- HRSG or WHRB (in NG-fired CCPPs).
- Steam network system.
- Turbines and associated systems (STs, GTs).
- Cooling system (condensers, cooling towers, and cooling water pumps [CWPs]).
- Water pumping systems (boiler feed water pumps [BFPs], condensate extraction pumps [CEPs], demineralized (DM) water pumps, make-up water pumps, raw water pumps, etc.).
- Draft system/fans (induced draft fans [IDF], forced draft fans [FDF], primary air fans [PAF], and other fans).
- Heat exchanger system (economizer, air-preheater, low pressure heaters, high pressure heaters, deaerator).
- Ash handling system.
- Fuel handling system (e.g., coal handling system, coal mills, fuel oil handling).

**Utility systems**

- Compressed air (CA) system
- Air conditioning (AC) system
- Electrical systems
- Electric drives and motors
- Plant lighting system
- Electrostatic precipitators (ESPs)

**Miscellaneous systems**

- Insulation
- Power transformer and auxiliary transformers

This manual attempts to cover the following types of TPPs operating in Bangladesh:

- Coal-fired TPPs,
- NG-fired TPPs,
- NG-fired GT CC TPPs,
- NG-fired GT OC TPPs,
- NG-fired gas engine CC TPPs,
- NG-fired gas engine OC TPPs,
- Diesel-fired engine CC TPPs, and
- Diesel-fired engine OC TPPs.

**The boundary for energy audit**

The boundary of an energy audit at a specific TPP depends upon the given mandate of that exercise. It can vary from the entire TPP to only the main plant's subsystems, to a few key main plant's subsystems, or only the utility's subsystems. Such a mandate covers one or more of the following:

- Boiler subsystem and auxiliaries,
- ST subsystem and auxiliaries,
- Condenser and cooling tower subsystem,
- GT subsystem and auxiliaries,
- HRSG subsystem and auxiliaries,
- Steam subsystem,
- Pumping subsystem,
- Draft subsystem,
- Heat exchanger subsystem,
- Fuel handling subsystem, and
- General subsystem.

**Types of TPPs and their components**

Table 4 provides a comprehensive list of critical components (energy use equipment/system), based on the type of TPP technology, which are recommended to be audited and assessed for their as-run energy performance.

**Table 4. TPP types and components to be energy audited**

| Critical components | Coal-fired TPP | NG-fired TPP | NG-fired GT CC TPP | NG-fired GT OC TPP | NG-fired gas engine CC TPP | NG-fired gas engine OC TPP | Diesel-fired engine CC TPP | Diesel-fired engine OC TPP |
|---|---|---|---|---|---|---|---|---|
| **Main plant** | | | | | | | | |
| Boiler | √ | √ | × | × | × | × | × | × |
| ST | √ | √ | √ | × | √ | × | √ | × |
| Condenser | √ | √ | √ | × | √ | × | √ | × |
| GT (OC) gross efficiency and test rate | × | × | × | √ | × | × | × | × |
| GT compressor | × | × | √ | √ | × | × | × | × |
| HRSG | × | × | √ | × | √ | × | √ | × |
| Power transformer | √ | √ | √ | √ | √ | √ | √ | √ |
| Auxiliary transformers | √ | √ | √ | √ | √ | √ | √ | √ |
| **Pumping system** | | | | | | | | |
| BFPs | √ | √ | √ | × | √ | × | √ | × |
| CEPs | √ | √ | √ | × | √ | × | √ | × |
| CWPs | √ | √ | √ | √ | √ | √ | √ | √ |
| Raw water pumps | √ | √ | √ | √ | √ | √ | √ | √ |
| Clarified water pumps | √ | √ | √ | × | √ | × | √ | × |
| DM water pumps | √ | √ | √ | × | √ | × | √ | × |
| **Fan system** | | | | | | | | |
| FDF | √ | √ | × | × | × | × | × | × |
| IDF | √ | √ | × | × | × | × | × | × |
| PAF/secondary air fans | √ | × | × | × | × | × | × | × |
| Turbocharger | × | × | × | × | × | √ | √ | √ |
| Cooling tower fans | × | × | × | × | √ | × | √ | × |
| **Re-generative heating system** | | | | | | | | |
| LP heaters | √ | √ | × | × | √ | × | √ | × |
| HP heaters | √ | √ | × | × | √ | × | √ | × |
| **Heat exchanger system** | | | | | | | | |
| Economizer | √ | √ | × | × | × | × | × | × |
| Air pre-heaters | √ | √ | × | × | × | × | × | × |
| **Fuel handling systems** | | | | | | | | |
| Mills | √ | × | × | × | × | × | × | × |
| Crushers | √ | × | × | × | × | × | × | × |
| **Energy audit of general systems** | | | | | | | | |
| CA system | √ | √ | √ | √ | √ | √ | √ | √ |
| Cooling towers | √ | √ | √ | × | √ | × | √ | × |
| AC and HVAC system | √ | √ | √ | √ | √ | √ | √ | √ |
| Electric load management | √ | √ | √ | √ | √ | √ | √ | √ |
| Electric motor system—load survey | √ | √ | √ | √ | √ | √ | √ | √ |
| ESP | √ | × | × | × | × | × | × | × |
| Thermal insulation | √ | √ | √ | √ | √ | √ | √ | √ |
| The lighting system of the plant | √ | √ | √ | √ | √ | √ | √ | √ |

## Outcome of an energy audit

An energy audit is a comprehensive study of a plant or a facility to determine how and where the energy is used and to identify the methods for energy savings. The objectives of an energy analysis or audit are to identify and develop modifications that would reduce the energy use and/or cost of operating a facility. Some of the important considerations while conducting an energy audit in a TPP are as follows:

- The result of an energy audit of the abovementioned energy use equipment must provide observations, analysis, and findings on the following:
    - The general operating condition of the equipment.
    - Energy consumption pattern.
    - Specific energy consumption of the equipment.

In the case of TPPs, the heat rate (HR) is the key energy performance indicator and is defined as the amount of energy used by a TPP to generate 1 kWh of electricity.

**Gross HR = Heat input / Power generation = kCal / kWh, and cycle efficiency is the inverse of HR, i.e., Cycle (Effy) = (1 / HR)**

- Where possible, comparisons should be made with benchmark values (performance guarantee [PG] values or equipment design/rated values) for energy performance gap identification.
- Pointers should be given to areas where improvements can be made.
- In short, the present practice/system/equipment should be described in brief, including the background and its impact on energy consumption and EE. The use of a simple process flow diagram or line diagram is encouraged because they can help explain the system in place.
- All ECMs suggested during the energy audit study of a TPP facility should be presented in a separate section, following the above, in serial order, and each of these should include:
    - The title of the recommendation (based on the results identified).
    - Description of the recommendation: Details of the recommendation regarding its technical and operational features, broad benefits expected, and any known risk.
    - The impact of the recommendation, highlighting:
        - Annual energy-saving potential (in kilocalories [kCal] or kWh or tons coal or standard cubic meter [Sm$^3$] NG or kiloliters of fuel oil per year);
        - Annual monetary savings/benefits potential (in Bangladeshi Taka [BDT] per year);
        - Annual GHG-saving potential (in tons of $CO_2$ per year);
        - Envisaged investment (in BDT); and
        - Simple payback period (years or months).
    - Techno-economic evaluation is backed by detailed estimation of energy savings and energy cost reduction over a reasonable technical or economic life of the measure along with envisaged investments (upon selection of ECMs that have been decided to be implemented, comprehensive and detailed prices will be required to be solicited from relevant vendors).
    - When recommending a replacement, retrofitting, or resizing, the auditor must include desired key technical specifications and energy performance parameters (efficiency/specific energy consumption, etc.).
    - A web survey should be done to gather details for implementation in the context of available suppliers/vendors/contractors' details for implementation.
    - Quite often, ECMs can be attractive, but the associated capital expenditure (CAPEX) could be a deterrent in their successful implementation due to the paucity of capital/funds. It would be worthwhile to consider schemes like energy service companies (ESCOs), PG, lease-based financing, and shared savings financing, where the burden of CAPEX would be taken out of the purview of the TPP.
    - If the installation or implementation of any recommended EE measure affects the procedure of operation and maintenance, the deployment of staff, and the budget, the recommendation should discuss these impacts, including their resolution.
    - Cost-effective monitoring and verification protocols should be established.
    - Where different ECM alternatives are available, all options may be compared, and better options suggested.

# 3.0 Pre-Audit Preparation

## 3.1 Audit plan

Preparing an audit plan is the first step in the process of an energy audit. A comprehensive audit plan, involving all stakeholders and components, will not only help navigate the implementation of the audit but also manage the whole process without time and cost overrun while delivering the desired results. Given below is a complete list of activities that make up a fool-proof audit plan.

## 3.2 Stakeholder identification

The stakeholder identification process begins with an initial meeting with the head of the facility and officers to apprise them about the study. The energy audit team should consist of an energy manager, energy auditor, technicians, and a maintenance team. This team should remain available throughout the conduct of the energy audit.

The energy audit team should identify:

- the involved parties who are relevant to energy performance and the energy conservation mechanism,
- the relevant requirements of these interested parties, and
- the needs and expectations that are to be addressed by the audit team.

Involved parties (stakeholders) comprise company management, plant heads, plant managers, site engineers, maintenance personnel, workers and other employees, and other relevant stakeholders, such as external contractors/workers, original equipment manufacturers (OEMs), and so on.

The parties should share relevant energy performance data and information with the energy audit team for detailed analysis. All the relevant data obtained should be processed to yield information about the facility's performance.

**Initial kick-off meeting**
An initial kick-off meeting would aim to facilitate the following:

- A formal introduction among the key stakeholders (the TPP team and the third-party energy audit team).
- An announcement by the third-party energy audit team about the commencement of the energy audit of their TPP.
- A brief presentation about the energy audit scope and approach/methodologies that would be adopted during the conduct of the energy audit.
- A plea to all the concerned TPP departments soliciting their complete and whole-hearted cooperation and support throughout the energy audit; for example, to share their experiences/concerns in the interest of the energy audit study.
- Solicit responses from the TPP team about their expectations from the energy audit of their TPP and ensure clarity in understanding these expectations.
- A request to the TPP team to designate one officer as the leader of the TPP energy audit team who will be responsible for coordination, smooth conduct, and progress of the energy audit.
- Request the TPP management to arrange a quick walk-through of the TPP, as a next step after the kick-off meeting, for the benefit of the third-party energy audit team, with the key purpose of:
    - Equipment identification and location familiarization.
    - Introduction to each department's key personnel whose assistance could be sought during the energy audit study.

- Spotting and listing glaring and obvious energy losses (for instance, visible leakage of fuel oil, steam, CA, bare and un-lagged hot and cold pipelines, idle operation of plant equipment, open inspection doors, sampling points, seals, etc.).
- Identification and listing of locations where measurement of sampling provisions is required to be made. This list must be handed over to the TPP coordinator requesting for earliest compliance.

**Streamline communication**

The process of streamlined communication should comprise the following points:

- One person each from both teams, that is, the third-party energy auditing team and the internal TPP energy audit team, need to be designated as the “pivot person” for each team. This will be the person in a rank around whom the others wheel and maneuver. The pivot person’s responsibility will be to receive and convey information/queries/clarifications/requests from the respective energy team to the other. The pivot person will also make decisions in respect of issues related to the energy audit to facilitate the smooth progress of the energy audit assignment.
- Each team should share with the other their team members’ names, contact numbers, and roles and responsibilities.
- They should also share the name, designation, and contact numbers of the final authority of each party with each other.
- Quite often, there will be a requirement to conduct field trials/measurements. On such occasions, it will be required to get “permits” issued, and a prior intimation is necessary.
- Similarly, the need to conduct site measurements, to capture “as-run” parameters, calls for special arrangements and provisions to be made, all of which need prior intimation from the departments concerned.

**Questionnaire finalization**

The energy audit team needs to prepare a questionnaire covering the energy audit parameters for the various subsystems and discuss the same with the TPP management/concerned site engineers, supervisors, operators, and so on. The questionnaire should include:

- General details about the TPP.
- Details about the energy-consuming equipment and processes.
- Energy consumption pattern generation and sales and operating load of the TPP equipment vis-à-vis rated load.

This should be finalized between the plant team and energy audit team before circulating it among the relevant stakeholders.

**Finalization of audit duration**

The energy audit duration should be determined based on the following activities:

- Plant capacity/size,
- Detailed scope of the energy audit, and
- The amount of equipment to be covered.

The energy audit duration should cover both the “walk through” or “preliminary” energy audit (short duration—only a few days, depending on the size of the TPP) and the “detailed” energy audit (much longer duration). Both these energy audits will have a “field study” component and an “analysis and report preparation” component. The latter component need not involve presence in the TPP/field; it can be done in the consultants’ office.

**Budget and timeline**

The energy audit budget should rely on the below-mentioned parameters.

Third-party energy auditor's standpoint:

- The number of days required for the energy audit.
- The number of energy audit team members and external consultants (if any).
- Number and type of measuring instruments required for the energy audit.
- Cost of sample testing in external laboratories.
- Travel and lodging/boarding expenses for the audit team.

Some additional parameters would include the engagement of external experts, if required, for the energy audit assignment.

TPP team standpoint:

- Travel and lodging/boarding expenses for the third-party energy audit team.
- Vehicle for local transportation of the third-party energy audit team, from the guest house to TPP and back, as also for their movement within the TPP.
- The labor force needed to assist the third-party energy audit team during site measurements.
- Presentation hall and other paraphernalia required during presentations.
- Sample testing in external laboratories.

The total timeline, including a timeline for each activity, should be determined beforehand, based on the activities listed out by the third-party energy audit team and those suggested by the TPP management. Table 5 illustrates a typical timeline for energy audit of a 300-MW TPP.

**Table 5. Timeline for an energy audit (phase 2 and phase 3) of a 300-MW TPP**

| S. No. | Activity | On-site and off-site person days | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Week Ref → | 2 Weeks | 1 Week (No Activity) | 1 & 2 | 3 & 4 | 5 & 6 | 7 & 8 | 9 & 10 | 11 | 12 |
| 1. | Walk through audit<br>• Tour the site accompanied by engineering/production staff.<br>• Identify major energy-consuming areas/processes to be audited.<br>• Identify existing instruments and data available in the facility.<br>• Identify the list of parameters to be measured and the instruments needed during the energy audit. | | | | | | | | | |
| 2. | Detailed Energy Audit<br><u>Audit activity</u><br>*(Site/field-activity phase)*<br>• Preparation of field study plan.<br>• Submission of this plan to all the concerned departments, in advance.<br>• Ensuring that all the measurement sampling points are in place; if not, follow up and ensure compliance.<br>• Detailed investigation of major energy-consuming areas/processes, which were | | | | | | | | | |

| S. No. | Activity | On-site and off-site person days |
|---|---|---|
| | identified during the preliminary or walkthrough audit.<br>• Performance assessment trials with measurements.<br>• Critical observation to pinpoint pointers that indicate energy conservation potential.<br>• Identification of existing instruments and data available in the facility.<br>• Identification of the list of parameters to be measured and the instruments needed during the energy audit. | |
| 3. | Data collection and sorting<br>*(Site/field-activity phase)*<br>• Plant layout.<br>• Technical specifications, drawings, and PG test reports.<br>• Sources of energy supply.<br>• Overall energy consumption, cost, and tariff data (month-wise energy consumption data for 1–3 years).<br>• Energy consumption by type of energy, by department, by major items of process equipment, and by end use.<br>• Generation data (1–3 years).<br>• TPP outage hours reports (planned outage, unplanned outage, reasons; 1–3 years).<br>• Plant start-up reports (number of start-ups, time taken for each start-up, additional fuel consumed for each start-up, loss of generation; 1–3 years), and TPP HR reports (gross station HR, unit HR, turbine HR).<br>• Tabulation and plotting of data | |
| 4. | Data analysis<br>*(Site/field-activity phase)*<br>• Preparation of process flow diagram and listing the process steps.<br>• Identification of unit operations, key process steps, areas of material and energy use, energy losses, and waste generation.<br>• Comparing performance with design specifications/PG test values and establishing gaps. Identification of energy conservation (ENCON) opportunities.<br>• Reconfirmation trials presenting energy audit findings to management. | |
| 5. | *Nonsite/field-activity phase:*<br>• Draft report preparation and submission of draft energy audit report. | |
| 6. | *Nonsite/field-activity phase:*<br>• Review of the draft report by the TPP team and their comments/feedback. | |
| 7. | *Nonsite/field-activity phase:* | |

| S. No. | Activity | On-site and off-site person days | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | • Preparation of final report, after considering TPP teams' comments/feedback | | | | | | | | | |
| 8. | • Submission of final detailed energy audit report | | | | | | | | | |

*The above timeline is suitable for a TPP of a size of approximately 300 MW.

**Finalize report format**

The energy audit team should share the report format with the plant head/team. The table of contents of a typical energy audit report is as follows:

TABLE OF CONTENTS

i. Acknowledgements
ii. Energy Audit Team
iii. Executive Summary
Summary of Recommended ECMs
- ✓ Energy Conservation Options with Cost Benefits
  Measure Reference / Annual energy savings (kWh per year and/or $Sm^3$ gas per year and/or tons fuel oil per year and/or tons coal per year) / Annual monetary savings (BDT per year) / Investment (BDT) / Simple payback period (year) / GHG reduction potential (tons of $CO_2$ per year)
- ✓ Prioritized List of Energy Conservation Options
  Low or no-cost options with high return; medium-cost options with medium return; high-cost options with high return

1.0 Introduction to the TPP
- General TPP details and description
- Approach/methodology followed during the conduct of the energy audit

2.0 Energy Scenario and Baselines
- Major energy use (thermal- and electrical-driven) equipment and auxiliaries
- Fuels used and their annual consumption trends
- Energy generation annual trends
- Availability factor trends and plant load factor trends
- Auxiliary Power Consumption (APC) trends and support fuel oil consumption trends
- Break-up of APC, unit-wise (Boiler Feed Pump (BFP)%, Condensate Extraction Pump (CEP)%, Cooling Water Pump (CWP) %, Induced Draft Fan (IDF) %, Forced Draft Fan (FDF) %, Primary Air Fan System(PAF) %, Coal Mining System (CoM)%, Contribution of Station Lighting (STN-LGT)%, Compressed Air System (CA)%, Air Conditioning System (AC)%, Coal Handling Plant (CHP) %, Ash Handling Plant (AHP%)
- Specific fuel consumption trends
- Landed cost and gross calorific value (GCV) of fuel trends
- Water consumption trends and cost
- Station and unit-wise HR and efficiency trends
- TPP process description
- Brief description of the power generation process
- Process flow diagram and major unit operations

3.0 Energy System Description
- Main plant systems and a brief description of each (make, number of, number on standby, and tech specs) of boilers, GTs, HRSG, GT compressor, and STs and condensers
- Main plant auxiliaries and a brief description of each (make, number of, number on standby, and tech specs) of BFPs, CEPs, IDF, FDF, PAF, coal mills, and CWPs
- Other plant auxiliaries and a brief description of each (make, number of, number on standby, and tech specs) of coal handling plant [CHP], ash handling plant [AHP], CA system, AC system, ESP, and station lighting)

4.0 Detailed Process Flow Diagram and Energy and Material Balance
- Flow chart showing flow rate, temperature, and pressures of all input/output streams

5.0 Energy Audit and Energy Performance Assessment

- Introduction, total installed, total in stand-by mode, technical specifications, as-run trial measurements, observations, and comments, and recommendations/ECMs for each of the following main plant energy-use equipment and auxiliaries:
- Boilers, HRSG, GT, GT compressor, STs and condensers, steam system, BFP CEP, IDF, FDF, PAF, coal mills, CWPs, CHP, AHP, CA system, AC system, ESP, and station lighting

6.0 Water Balance of TPP (optional)
- Total input water quantity and break-up of sources (quantified)
- The quantified break-up of in-plant water users

7.0 ECMs and Recommendations
- List of options in terms of no-cost/low-cost, medium-cost, and high investment cost, annual energy and cost savings, and payback
- Each stand-alone ECM identified should feature: Title of the ECM/background or description of the ECM with single line diagram of the current process/recommendation statement/annual energy and monetary savings impact, investment, and payback period, and GHG emission reduction potential/rationale (calculation sheets) of the ECM/other related, expected benefits

8.0 List of Technology Providers/Vendors for Proposed ECMs
9.0 Implementation Plan for ECMs/Projects
10.0 Annexures
11.0 List of Tables
12.0 List of Software Used
13.0 List of Figures

## 3.3 Audit resources

**Key stakeholders**

The key stakeholders would comprise the TPP head, and department heads, and the next in command. These crucial category stakeholders would include operations and maintenance groups (of boiler group, turbine group/generation group, off sites, ash handling plant (AHP), fuel handling plant), performance and efficiency group, control and instrumentation, finance group, water treatment group, and laboratory group. The other crucial category stakeholder would be the energy audit consultant group comprising the lead consultant, expert advisor, consultant team members, and the back-office support team members. Other stakeholders would include the energy efficient equipment suppliers/vendors, the process equipment OEMs, ESCOs, financial institutions, and concerned government departments/agencies.

**Selection of competent energy auditors/energy managers**

The energy auditors in the third-party auditing team must have an energy auditor qualification certification or at least have more than 10 years of experience in energy auditing. SREDA has formulated the Energy Audit Regulation 2018. Based on this regulation, SREDA conducts the energy auditor certification examination with an objective to create a workforce of energy auditors and energy managers in Bangladesh.[12]

However, until such time that a sufficiently large band of competent and qualified certified energy auditors/energy managers are created, the in-house thermal power system (TPS) personnel may be identified to conduct the energy audits, using this manual as a reference guide along with their own considerable experience in the TPS. The services of currently active independent energy audit consulting firms and independent consultant energy auditors may also be used.

For wider penetration of energy audits in TPPs in Bangladesh, it would become necessary to designate an energy manager as the focal person who would be responsible for all energy audits, energy conservation, and energy management activities in the TPS. The energy manager should be of high

[12] "Module One: Fundamentals of Energy Management and Energy Audit." Sustainable and Renewable Energy Development Authority.
http://sreda.portal.gov.bd/sites/default/files/files/sreda.portal.gov.bd/page/37bfe2c3_aaaa_459d_91ec_0c56adc4eb5d/2021-12-07-07-10-d157ddd2327b562343e20afe4446fe2b.pdf

rank in the hierarchy of the TPS and should be capable of holding sway over senior and junior executives of the TPS.

**Qualified support team**

An energy audit team will consist of "core" team members who will be responsible for the conduct of the energy audit from start to finish, and the "support" team members will comprise personnel drawn from different departments of the TPP. The core group, including 3–5 employees from the support group, will be tasked with the bulk of the energy audit work. The group usually consists of at least one energy auditor (if not more), one domain expert, 2–3 engineer consultants experienced in energy auditing, the energy manager, and maintenance personnel, who will be intimately familiar with the TPP systems and equipment.

The energy audit team will possess the following combined experience, relating to a power plant:[13]

- Power plant operations;
- Power plant maintenance;
- Power plant environmental control and reporting requirements;
- Power plant instrumentation, control, and metering;
- Determination and reporting of power plant key performance indicators;
- International power plant efficiency and performance benchmarking;
- Conducting power plant energy audits; and
- Financial review and analysis.

**Team distribution**

In the interest of speedy completion of the energy audit, especially if the entire TPP is in the coverage scope, the composite team will be required to be split into two or three splinter groups, each operating in parallel and independently, and each tasked with energy audit coverage of different subsystems. In the case of multiple teams, the energy audit team leader will keep close tabs on the progress of each team (debriefing after each day and chalking out the action plan for the next day).

**Calibrated instruments**

Portable instruments form the key resource used in an energy audit. Some of the important considerations related to the calibration of instruments are listed below:

- Equipment and machinery that are in constant operation are inherently prone to wear and tear, causing a dip in their performance over time; especially so in the case of equipment in a TPP. Besides, the requirement for an energy audit is to identify and quantify where energy is being used. It, thus, becomes necessary to measure and monitor a variety of as-run parameters to assess their performance.
- In a TPP energy audit, control room/distributed control system/supervisory control and data acquisition instruments, as well as on-site instruments will be relied upon for recording relevant as-run parameters. The calibration frequency of these instruments is normally once every 6 months, which needs to be ensured by the in-house control and instrumentation department. Calibration certificates for instruments should be verified before the conduct of the energy audit.
- In addition to these fixed instruments, portable energy audit instruments, which are not only accurate but also sturdy, will also need to be used, as per the requirement. The selection, accuracy, scale, and end-use applicability of these portable instruments must be carefully and sensibly done.

[13] "Bangladesh Energy Regulatory Commission Regulatory Energy Audit of Generation Facilities Regulations, 2017. BERC. http://berc.portal.gov.bd/sites/default/files/files/berc.portal.gov.bd/page/a250b6fc_8bcf_4c96_bb20_3c3de230467a/BERC%20Regulatory%20Energy%20Audit%20Regulations%202017%20_Draft_.pdf

- The instruments utilized in a TPP energy audit can be classified into the following categories, which include:[14]
    - Mechanical measurement:
        - Temperature measurement: thermocouples, resistance temperature detector (RTD), liquid-filled thermometer, gas-filled bulb and tube thermometer, pyrometer, and so on.
        - Pressure measurement: C-type bourdon pressure gauge, bellows, and so on.
        - Flow measurement: steam, air, and water flow meter, and atomized steam meter (based on the principle of "differential pressure," magnetism, ultra-sonic).
        - Fuel measurement: Coal measurement (belt speed with load/min-load cell and tachometer), gas meter (gas meter, positive displacement type nutating disk), and oil meter (rotameter, nutating disk, etc.).
        - Gas analysis: CO, $H_2O$, SOx-NOx, $O_2$, $CO_2$, and calorific value of fuels measurement. Both lab-grade and portable instruments are used for this purpose.
        - Fuel analysis: GCV, proximate analysis, ultimate analysis (to be executed by an in-house lab, preferably accredited, and cross-checked with a reputed and accredited external lab at a frequency of at least once in three months, if not more frequently, monthly). It would be good to have a bomb calorimeter and a lab-scale furnace as a part of the in-house lab instruments.
    - Electrical measurement:
        - Current measurement: ammeter (generator load, feeder circuits, aux power, field circuit, etc.).
        - Voltage measurement: voltmeter (generating and transmitting voltage, feeding voltage, motor voltage, etc.).
        - Energy measurement: wattmeter (power generated, power exported, feeder power).
        - Other meters: power factor (PF), synchroscope, frequency, reactive power meter, harmonics, and so on.
- A detailed list of site measurement provisions is to be prepared and provided to the plant maintenance group with detailing, location, numbers, and specifications.
- Key portable instruments (with calibration validity of no less than 6 months) for energy audits are presented in Table 6.

**Table 6. Key portable instruments for energy audit**

| S. No. | Key portable instruments | Description |
|---|---|---|
| 1. | Power analyzer (3-phase, 1 Current Transformer (CT), and 2 Potential Transformer (PT)) | Power analyzers are used for field testing of (protective current) P class CT and PT. The test items include excitation characteristics, transformation ratio, polarity, Degauss 5% and 10% error curves, and secondary circuit checks. Test items must also withstand the test of power frequency alternating current and secondary load. |
| 2. | Power analyzer (3-phase, 4 CT, and 4 PT) | These devices measure parameters such as true power (watts), PF, harmonics, and efficiency. |
| 3. | Digital pressure gauge for water, air, and gas pressures | Digital pressure gauge is used for general industrial applications and for use in the field of testing and calibration. |
| 4. | Pipe thickness gauge | Pipe thickness gauge is used for measuring wall thickness of pipe or plate and serve as a constant guide for judging the condition of pipe. |

[14] "Classification of Instruments in Power Plant." Power Plant Instrumentation Control. http://www.powerplantinstrumentationcontrol.yolasite.com/power-plant-details/1-classification-of-instruments-in-power-plant

| S. No. | Key portable instruments | Description |
|---|---|---|
| 5. | CA flow meter | The function of a CA flow meter is to carry out accurate CA consumption measurements, consumption and leak monitoring, and flow measurements in CA systems. |
| 6. | CA dew point meter | The use of a CA dew point monitoring system allows reliable maintenance of the desired moisture level in a CA system. |
| 7. | Flue gas analyzers ($O_2$, $CO_2$, CO, $NO_x$, $SO_x$) | A flue gas analyzer enables the measurement of the concentrations of various gases and adjusts burners on a boiler to help achieve optimal combustion. |
| 8. | High pressure digital manometer | Digital manometers, also known as electronic manometers, do not rely on hydrostatic balance of fluids to determine pressure. A transducer converts observed pressure levels into an electrical signal whose characteristic value reflects or is a proxy for the magnitude of the pressure. |
| 9. | Low pressure digital manometer | To perform measurements on low pressures, there are additional types of pressure transducer styles used, including a Pirani gauge, thermocouple type transducer, and ionization gauge. Low-pressure manometers are also called micro-manometers. |
| 10. | Pitot tube (S-type) | Pitot tubes are used in climatic engineering, ventilation, dust removal, and pneumatic transportation. Specially designed for measurements in warm air, charged with particles and for high speed. The two hollow metal tubes in a pitot tube S should be all the same shape and required to open the holes in two directions, and the cross section of the opening is strictly parallel. The pitot tube S is more sensitive to alignment errors than the pitot tube L. |
| 11. | Pitot tube (L-type) | With the use of the traverse method, the L-type pitot tubes have a modified ellipsoidal head with one forward-facing hole (sensing total pressure) and a ring of side holes (sensing static pressure). |
| 12. | Vane type anemometer | A vane anemometer consists of several light vanes supported on radial arms rotating on a common spindle. The vane anemometer is a classic wind speed meter that is now common indoors as well as outdoors. With the impeller anemometer, airspeed can be measured quickly and easily. |
| 13. | Hot wire anemometer | A hot wire anemometer is a thermal transducer that is widely used for measuring instantaneous flow velocity. Electric voltage measurements can be used to calculate instantaneous flow velocity using the hot wire anemometer. |
| 14. | Thermal imager | Plant maintenance staff can regularly inspect pipes, valves, and traps to identify problems early and control costs by using a thermal imager. |
| 15. | K-Type thermocouple with a digital thermometer | K-type thermocouple with a digital thermometer are digital thermometers used for contact temperature measurements. They have one input for K-type thermocouples and can display the temperature in 0.1° steps. |
| 16. | IR Thermo gun | These thermometers are sometimes referred to as laser thermometers as a laser aid in aiming, or as noncontact thermometers or temperature guns because of their ability to measure temperature from a distance. |
| 17. | Ultrasonic leak detector (steam and CA) | The ultrasonic leak detector is used to trace leaks on CA lines. |
| 18. | Hygrometer | Hygrometer is used in to measure the humidity or amount of water vapor in the air. |
| 19. | Lux meter | Lux meter is used to measure the amount of light in a space/on a particular work surface. |
| 20. | Tachometer | Tachometer is a device for indicating the angular (rotary) speed of a rotating shaft. |
| 21. | Stroboscope | In a stroboscope, intermittent illumination of a rotating or vibrating object is provided to study its motion or to determine its rotary speed or vibration frequency. |
| 22. | Leak detectors | The leak detector detects combustible gases and emits a vibrating alarm and an audible alarm once a combustible gas has been detected. |

**Personal protective equipment**

Personal protective equipment (PPE) acts as a safety defense net for the workers in TPPs. The substations, turbines, and panels are always energized in a TPP; therefore, the energy audit team must always wear proper PPE, which can prevent any hazardous incident that can cause potentially serious and fatal injuries. The PPE kit should include the following equipment:

- Head protector/hard hats: A hard hat is used to protect the head from falling objects, impacts from falls, and other types of workplace hazards.
- Insulating gloves: Insulating gloves (also referred to as electrical gloves) offer personal hand protection for workers against electrical shocks when working near or on live wires, cables, and electrical equipment.
- Face shields: Face shields protect against potential splashes or sprays of hazardous liquids.
- Nonconductive safety glasses: Nonconductive safety glasses are nonconductive frames and contain zero metal parts that reduce the risk of injury in the case of electrical exposure.
- Arc flash suit: Arc flash suits are used to protect electrical workers from serious injuries and arc flash hazards.
- Safety shoes: A pair of safety shoes (also known as safety boots) is PPE for foot protection at workplaces.
- Earplugs/earmuffs: Earplugs/earmuffs are used to protect the wearer's ears from excessive noise pollution, dust, or temperature variations, especially cold.
- Face masks: The use of face masks reduces the airborne droplet transmission and protects the wearer from the droplets expelled.
- Boiler suit: Boiler suits are used to protect against flashovers. However, they do not prevent arc flash hazards.
- Reflective jacket: By using reflective safety, engineers and other workers can avoid injuries.

# 4.0 Energy Audit Methodology

## 4.1 Energy management

The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect. Energy management is a strategy of adjusting and optimizing energy by using systems, procedures, and techniques that result in the reduction of energy requirements per unit of output. The objectives of energy management include:

- achieving and maintaining optimum energy procurement and utilization throughout the facility,
- minimizing energy costs and wastes without affecting production and quality, and
- minimizing detrimental environmental effects.

**Energy audit**

An energy audit in a TPP provides a detailed plan for implementing energy-saving projects. Determining the TPP's baseline energy use and current energy performance is only a starting point. Subsequently, the operating energy performance of all major and significant energy-consuming systems is comprehensively evaluated to assess the actual performance against desired performance or the best available technology. The differences indicate the potential for actual savings.

The energy audit report is prepared after the completion of the energy audit. The report should contain a detailed summary of actual steps that can be taken to reduce energy use. The report should also carry out recommended actions ranging from simple adjustments in operation to complete equipment replacement. An estimate of investments for completing actions should also be included. The energy audit plan for a TPP consists of two steps:

- Walk-through energy audit and
- Detailed energy audit.

**Walk-through energy audit**

A walk-through energy audit (also known as preliminary energy audit or diagnostic energy audit) is a quick exercise and uses existing or easily obtained data. The scope of the preliminary energy audit is a little wider as the list below shows.

- Tour the site accompanied by engineering/production staff.
- Identify existing data available in the facility.
- Identify existing instruments available in the facility.
- Identify the list of parameters to be measured during the detailed energy audit.
- Identify the list of additional on-site and portable instruments needed (during the detailed energy audit).
- Identify existing sampling points with location details and make a list of additional sampling points that need to be made afresh (for the detailed energy audit).
- Establish energy consumption in the plant (sources: energy bills and invoices).
- Set up a baseline (or reference level) for energy consumption and water consumption.
- Obtain related data such as generation/production for relating to energy consumption.
- Identify the obvious and easiest areas for immediate attention, especially the no-cost and low-cost improvements (for instance, idle running equipment, unnecessary lighting, higher temperature settings, leakages of fuel oil, steam, CA, water, etc.).
- Make a list of potential energy-saving measures that show promise (to be studied in depth during the detailed energy audit).
- Estimate the scope for energy saving.
- Make a detailed checklist of various activities that must be carried out during the detailed energy audit, which would also help in preparing the time frame and the timeline sheet for each activity.

- Prepare and submit a short energy-saving potential assessment report that requires to be dealt with in depth during the detailed energy audit.

Some examples of no-cost ECMs:
- Arresting leaks (oil, steam, CA, water).
- Controlling excess air by adjusting the fan damper.

Some examples of low-cost energy management measures:
- Shutting equipment when not needed (e.g., idle running of motors).
- Replacement with appropriate energy-efficient lamps and luminaires.

A sample of areas for the detailed study could include the following activities:
- Converting from direct to indirect steam-heated equipment and recovery of condensate.
- Incorporating EE technologies like variable frequency drive in pumps and fans, efficient boilers, and so on.
- Installing/upgrading insulation on equipment.
- Modifying the process to reduce specific energy demand.
- Investigating scheduling of process operations to reduce energy and water demands.
- Evaluating waste heat streams for potential waste heat recovery, and so on.

**Detailed energy audit**

A detailed energy audit is a comprehensive audit and results in a detailed energy project implementation plan for a TPP facility, as it accounts for the energy use of all major and significant energy-using equipment. It considers the interactive effects of various projects and offers the most accurate estimate of energy savings and cost. It includes detailed energy cost-saving calculations and project implementation costs.

One of the key elements in a detailed energy audit is the energy balance. This is based on an inventory of energy-using systems, assumptions of current operating conditions, measurements, and calculations of energy use.

Detailed energy auditing is carried out in three phases:

- Pre-audit phase,
- Audit phase, and
- Post-audit phase.

Table 7 summarizes the 10-step methodology for conducting a detailed energy audit. However, the methodology is flexible and can be adapted by the prevailing setup/facilities.

**Table 7. Methodology for conducting a detailed energy audit**

| Phase | Step | Plan of action | Purpose/results |
|---|---|---|---|
| **Phase I** | Step 1 | • Plan and organize<br>• Walk-through audit<br>• Interview with energy manager and production/plant manager | • Resource planning and establishing/organizing an energy audit team<br>• Organize instruments and time frame<br>• Macro data collection (suitable to the type of industry)<br>• Familiarization with process/plant activities<br>• First-hand observation and assessment of the current level of operation and practices |
| | Step 2 | • Conduct of brief meeting/awareness program with all divisional heads and persons concerned | • Building up cooperation<br>• Issue questionnaire for each department<br>• Orientation and awareness creation |
| **Phase II** | Step 3 | • Primary data gathering, | • Baseline data collection and analysis of |

| Phase | Step | Plan of action | Purpose/results |
|---|---|---|---|
| | | process flow diagram, and energy utility diagram | historical data<br>• Prepare process flow charts<br>• All service utility system diagram<br>• Design, operating data, and schedule of operation<br>• Annual energy bill and energy consumption pattern |
| | Step 4 | • Conduct survey and monitoring | • Measurements of in-use instruments for the collection of more accurate data<br>• Confirm and compare operating data with design data |
| | Step 5 | • Conduct detailed trials/experiments for selected or all major end-use energy-consuming equipment | • Trials/Experiments:<br>○ 24 hours power monitoring (Maximum Demand, PF, kWh, harmonics, etc.)<br>○ Load variation trends in pumps, fans, Refrigeration &Air Conditioning, air compressors, etc.<br>○ Boiler/efficiency trials for 4–8 hours<br>○ Equipment performance experiments, etc. |
| | Step 6 | • Analysis of energy use | • Energy and material balance and energy loss/waste analysis |
| | Step 7 | • Identification and development of ENCON opportunities | • Identification and consolidation of ECMs<br>• Develop and refine ideas<br>• Review the previous ideas suggested by the unit's personnel<br>• Review the ideas suggested in any recent energy audit<br>• Use brainstorming, value analysis, and 5-W (Who, What, Where, When and Why) techniques<br>• Contact vendors for new/efficient technology |
| | Step 8 | • Cost-benefit analysis | • Assess technical feasibility, economic viability, and prioritization of energy conservation options for implementation<br>• Select the most promising projects<br>• Prioritize low-, medium-, and long-term measures |
| | Step 9 | • Reporting and presentation to the top management | • Presentation of findings to the plant management after completion of site/field studies<br>• Documentation<br>• Draft report submission<br>• Report review and feedback comments by plant<br>• Submission of the final report—after incorporating necessary changes in accordance with the plant's feedback received—to the top management |
| Phase III | Step 10 | • Implementation and follow-up | • Assist in implementing accepted recommended ECMs and monitoring the performance<br>• An action plan and schedule for implementation to be prepared<br>• Follow up on implementation activities with periodic review |

**Phase I—Pre-audit phase**

An initial study of the site should always be conducted because proper planning is a prerequisite for an effective audit. An initial site visit should take around 1 to 3 days. It allows the energy auditor to meet the personnel concerned, familiarize himself/herself with the site, and assess the number of equipment EAPs required to be conducted during the energy audit. It also allows the energy auditor to plan for the resources and logistics required to facilitate the preparation of a techno-economic proposal for conducting an energy audit. During this visit, the main goals are:

- Finalize the energy audit team.
- Identify the main hot spots and equipment to be surveyed as part of the audit.
- Determine if any existing instrumentation or additional metering is required.
- Determine whether any meters need to be installed before the audit (e.g., electricity, steam, oil, or gas meters).
- Determine the instrumentation required for the audit.
- Plan with a timeline.
- Collect macro data on the plant's energy resources and major energy consumers.
- Create awareness through public meetings/programs.

**Phase II—Detailed energy audit phase**
Depending on the nature and complexity of the site, the time taken for a detailed energy audit could be 3 to 6 months (start to closure). Detailed studies would involve the investigation and establishment of material and energy balance for specific plant departments or process equipment. Whenever possible, checks of plant operations are conducted over extended periods, at night and weekends, as well as during normal daytime working hours to ensure that nothing is overlooked.

The audit report should include a description of energy inputs and product outputs by major departments or by major processing functions and should evaluate the efficiency of each step of the manufacturing process. The means to increase these efficiencies should be outlined in the audit report, and at least a preliminary assessment of the cost of the improvements should be performed to determine the expected return on any capital investment necessary.

The following baseline data should be collected by the audit team during this phase:

- Technology, processes used, and equipment details;
- Other inputs such as CA and cooling water;
- Amount and type of input materials used;
- Capacity utilization;
- Water consumption;
- Percentage rejection/reprocessing;
- Fuel consumption;
- Electrical energy consumption;
- Steam consumption;
- Quantity and type of waste generated; and
- Efficiencies/yield.

The EAPs for conducting an energy audit of key main plant and utility energy-consuming equipment are detailed in Annexure 3.

**Phase III—Post-audit phase**
In the post-audit phase, it is important to chart out the plan for carrying out action on the findings and take appropriate action for the implementation of energy conservation and efficiency programs. Hence, to conclude the activities of the energy audit, the following can be considered.

- Concluding activities

    - Presentation of energy audit findings of field study: The findings should be consolidated in the form of a report, which should include the baseline assessment, current efficiency and ENCON opportunities, and ECMs.
    - General recommendations: Post audit phase should include the recommendations for various EE measures in the processes and equipment. This should also be separated into low-cost, medium-cost, and high-cost measures with prepared payback periods.
    - Preparation of an action plan: Post identification of measures, the implementation of measures should be planned as per their feasibility. They should be segregated into short (1–3 years), medium (3–5 years), and long-term (5+ years) measures.

- Implementation and follow-up
  - This is the stage when the energy audit baton will be taken over by the TPP management-designated energy audit implementation team. However, if the energy audit study is to be undertaken by an ESCO, then they will remain until all the agreed implementation activities are installed and commissioned.
  - Every power plant needs to be ensured by the counterpart of the energy auditor team through the efficiency department like BPDP. The concerned department shall then implement the suggestions of the energy auditor.

The details for each of the three phases mentioned above are presented in Annexure 4. Further, relevant details are covered in the following annexures:

- Annexure 5: Sample report
- Annexure 6: Best practices
- Annexure 7: Combined cycle TPP
- Annexure 8: Useful information
- Annexure 9: Data collection and fuel analysis

**Conclusion**

- Analysis of the overall improvement potential of the plant.
- Short-, medium-, and long-term EE milestones should be planned which must include the resources and budget requirements.
- Environmental and cost savings impact should be analyzed and recorded as per the suggested timeline (impact of the implementation of ECMs on the environment and the total budget as per different time intervals).
- Key takeaway in data collection:
  Listed below are some basic tips to avoid wasting time and effort:
    - Measurement systems should be easy to use and provide the information to the accuracy that is required.
    - The quality of the data must be correct to draw accurate conclusions (what grade of the product is on, is the production normal, etc.).
    - Frequent data collection should be defined.
    - Measurement exercises over abnormal workload periods (such as start-ups and shutdowns).
    - Design values should be taken where measurements are difficult (cooling water through heat exchanger).

## 5.0 Annexures Link

Please follow this link to access this manual's annexures: https://pubs.naruc.org/pub/36F8C4FE-1866-DAAC-99FB-1DB8A5FF20B7

This document includes the following information:

- Annexure 1: Details of different types of power plants in Bangladesh
- Annexure 2: Sample of key operating parameters of a few types of TPPs in Bangladesh
- Annexure 3: Energy audit procedures for key energy consuming equipment in TPPs
- Annexure 4: Energy Audit Methodology
- Annexure 5: Sample Energy Audit Report
- Annexure 6: Energy Audit Tips, Checklist, and Best Practices in a TPP
- Annexure 7: Combined Cycle Thermal Power Plant
- Annexure 8: Useful Information while Conducting Energy Audits in Thermal Power Plants
- Annexure 9: Useful Information Regarding Data Collection, Fuel Details, and Power Plant Efficiency Calculations in TPPs

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