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MEASUREMENT OF PERFORMANCE OF THERMAL POWER PLANT USING PHYSICS TECHNIQUES AND IT'S IMPACT ON ENVIRONMENT IN ENERGY PHYSICS

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Abstract

This study examined measurement of performance of thermal power plant which is possible through physics techniques. As gas turbine with a single shaft is also part of thermal power plant. The performance of an existing gas turbine can be predicted rather accurate by matching the characteristics of the compressor and the turbine coupled with a heat balance of the combustor. In order to make performance predictions one often has to rely on simplified models. The model chosen uses the principle of relating two operating conditions by applying simple laws of physics. A similar approach is presented in (Saravanamuttoo, Rogers et al, 2001).In Nigeria we have TPP as in Egbin power plc in Lagos, Calabar thermal power station etc. Impact on environment can occur during both construction and operation of a thermal power plant (TPP). During construction, impact are caused primarily during site preparation activities such as leveling, excavation, earth moving, de-watering, dredging and / or impounding streams and other water bodies, developing streams and other water bodies, developing areas for other purposes, vehicular movement and transportation and erection of equipment.

Keyword: Performance, impact on environment like site preparation activities, local and regional air quality ,groundwater ,crops ,existing infrastructure.

INTRODUCTION

Impact on environment can occur during both construction and operation of a thermal power plant (TPP).In any construction , impacts are caused initially during site preparation activities such as leveling, excavation, earth moving, de-watering, dredging and impounding streams and other water bodies, developing areas for other purposes, vehicular movement and erection of equipment .

In order to make performance predictions one often has to rely on simplified models. The model used for this study uses the principle of relating two operating conditions by applying **simple laws of physics**. A similar approach is presented in [1].

On the other hand, during operation of a TPP, local and regional air quality, ground water, crops, native vegetation, building & monuments, aquatic ecosystem of certain lakes, forest ecosystem, existing community infrastructure such as school, police, fire protection, medical facilities, demographic patterns, local social and cultural values, living patterns of the residents, local traffic etc. Get affected.

Many of the adverse impacts of a TPP can be foreseen and minimized through judicious siting and amenable to technological control providing necessary preventive and control measures, and finally through effective environmental management of the operating plants.

The following assumptions are made for the model:

1) The gas model is single-shaft and is coupled to a generator running at constant speed(3000/3600 rpm for 2-pole generators)
2) Compressor and turbine efficiencies are constant, independent of load condition.
3) The lines for constant reduced speed in the compressor are vertical.
4) The turbine is assumed to behave like a choked nozzle.

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Compressor:
For constant speed the inlet of the compressor can be assumed to have constant volumetric sucking capacity with respect to velocity v. By combining the equation of continuity and ideal gas law, one obtains a relation between the flow rate $\dot{m}$ and temperature, pressure and gas constant at the compressor inlet, as well as equivalent cross-sectional area A_c , for the compressor[2]. Whenever

$\dot{m}$=flow rate (kg/s)
U=velocity (m/s)
A_c=cross-section flow area (m^2)
R=gas constant (kJ/(kg.k))
W=Power (Kw)
P=Ambient pressure (bar,)
ρ =density(kg/m^3)
MW=molecular weight (kg/kmol)
C_{pk}=specific heat (KJ/Kgk)
T=Temperature (k)
n_p=polytropic efficiency

$$\dot{m}=\rho u\ A_c \quad (1)$$

$$\frac{P}{\rho}=RT \quad (2)$$

$$\dot{m}\ -\ \frac{P}{RT}A_c \quad (3)$$

By relating a known condition (index ref) and the actual condition (no index) .We can write:

$$\frac{\dot{m}}{\dot{m}_{ref}}=\frac{pR_{ref}T_{ref}A_c}{P_{ref}RTA_{cref}} \quad (4)$$

The specific gas constant, R, can be replaced by the ratio of the universal gas constant to the molecular weight (MW).
Equation (4) is important in order to understand the sensitivity of various parameters with respect to the flow rate through the compressor. The power output of a gas turbine is proportional to the flow rate $\dot{m}$. It can be noted that reduced air pressure at high altitudes reduces the gas turbine flow rate and power ou tput. The same is the case for high ambient air temperatures. The equivalent cross-sectional area A_c can be regarded as a constant, unless variable guide varies (VGV) are just to control the flow rate through the compressor. VGV's are used quite commonly in most gas turbines and the air flow rate may typically be reduced to 60-70% of the design flow rate. VGV's are used during start-up, and for optimal control of part-load performance in combined cycle operation[3].

Air filter:
The pressure drop through the air filter can be predicted based on the same methodology as for the compressor, by relating two operating conditions. The general expression for frictional drop is [4]:

$$\Delta p=\varepsilon\rho\frac{1}{2}u^2 \quad (5)$$

The friction factor ε depends on the Reynolds number and the relative roughness of the surfaces through which the air is flowing. The typical air filter pressure drop is about 10mbar. There exist a number of equations for calculation of the friction factor, as well as diagrams such as Fanning and moody diagrams. Assuming that the friction factor is constant, one obtains the following relation from Eqn. [2, 1 and 5].For the calculation the pressure drop in an air filter.

$$\frac{\Delta p_{air\ filter}}{\Delta p_{air\ filter_{ref}}}=(\frac{\dot{m}}{\dot{m}_{ref}})^2\frac{TP_{ref}MW_{ref}}{T_{ref}PMW} \quad (6)$$

This expression is very general and can be used for other types of equipment, like for the gas turbine combustor and the heat recovery system, assuming constant friction factor. Now, by setting the reduced flow constant, we get:

$$\frac{\dot{m}\sqrt{T_3}}{P_3}=constant,\frac{\dot{m}\sqrt{T}}{P}\sqrt{\frac{R}{K}}=constant\rightarrow\frac{\dot{m}}{P_3}\sqrt{\frac{T_3}{mW_3}} \quad (7)$$

In equation (7) the left-most expression is a simplified form of the reduced flow rate non-dimensional number, typically used when air is the working fluid, and there is no steam injection in the gas turbine, meaning that the working fluid molecular weight does not change much during operation [5]. In cases where the working fluid composition changes quite a lot, it may be more appropriate to also include the molecular weight in the reduced flow rate expression, as is done in the right-most expression above.
By relating two different operating conditions, the choked nozzle equation is established:

$$\frac{P_3}{P_{3ref}}=\frac{\dot{m}_3}{\dot{m}_{3ref}}\sqrt{\frac{T_3MW_{3ref}}{T_{3ref}\,MW_3}} \quad (8)$$

The above equation states that the pressure in from of the turbine is proportional to the inlet flow rate and to the square root of the temperature, and inversely proportional to the square root of the molecular weight. A more general description of this relation also includes the non-choked regime [6].

In case, of a off-design calculation of a single shaft gas turbine it goes as follows:
Assumptions:

i) Single-shaft constant speed equation
ii) Large axial compressor with vertical speed lines in the compressor map
iii) Constant compressor and turbine efficiency
iv) The turbine operates as choked

COMPRESSOR FLOW RATE

$$\frac{\dot{m}_1}{\dot{m}_{r3}} = \frac{T_{r3}}{T_1} \qquad (9)$$

$$\frac{\Delta P_{af}}{\Delta P_{r,af}} \left(\frac{\dot{m}_1}{\dot{m}_{r,1}}\right)^{1.8} \left(\frac{T_1 P_{r,1}}{T_{r,1} P_1}\right)^{0.8} \qquad (10)$$

COMPRESSOR WORK

$$P_1 = P_0 - \Delta P_{af} \qquad (11)$$

Guessing P_2 and then

$$T_2/T_1 = (P_2/P_1)^{R/C_{PK}\Pi_P} \qquad (12)$$

$$W_{compr} = \dot{m}_1 C_{pk}(T_2 - T_1) \qquad (13)$$

COMBUSTER

$$(\dot{m}_1 + \dot{m}_{fuel})\, C_{pt}(T_3 - T_0) = \dot{m}_1\, C_{pt}\, (T_2 - T_0) + \dot{m}_{fuel}\, \text{LHV} \qquad (14)$$

Estimating combustor pressure drop (neglecting the fundamental loss)

$$\frac{\Delta P_c}{\Delta P_{r,c}} = \left(\frac{\dot{m}_3}{\dot{m}_{r,3}}\right)^{1.8} \left[\frac{T_3 P_{r,3}}{T_{r,3} P_3}\right]^{0.8} \qquad (15)$$

TURBINE INLET (THE CHOKED CONDITION)

$$\frac{P_3}{P_{r,3}} = \frac{\dot{m}_3}{\dot{m}_{r,3}} \sqrt{\frac{T_3 MW_{r,3}}{T_{r,3} MW_3}} \qquad (16)$$

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_{fuel} \qquad (17)$$

$$P_3 = P_2 - \Delta P_c \qquad (18)$$

Check the value of P_2 compared to that guessed before eqn.(12).If different, choose value of P_2 and go back to eqn. (12).

TURBINEWORK

$$\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{R\cap_P}{Cpt}} \qquad (19)$$

$$W_{turb} = \dot{m}_3 P_{pt}(T_3 - T_4) \qquad (20)$$

GAS TURBINE WORK AND EFFICIENCY

$$W_{GT} = W_{turb} - W_{compr} \qquad (21)$$

$$\cap_{GT} = \frac{W_{GT}}{\dot{m}_{fuel\, LHV}} \qquad (22)$$

ENVIRONMENT CONCERNS OF THERMAL POWER STATIONS:

(i) Air Pollution

Particulate matters, So_2,No_x, and Co are emitted from the combustion of fuels in a thermal power plant. If released uncontrolled, these can affect humans, vegetation ,building and monuments, aquatic &forest ecosystem. The emission of large quantities of SO_2 and NO_X from a TPP may result in Acid-rain problems.

(ii) Waste water Discharge

The largest wastewater streams from a TPP are cooling water blow down, which can be either recycled or discharged. If discharged to a surface water body , it's chemical quality gets affected. Associated waste – heat can impact water temperature which in turn can radically alter aquatic plant and animal communities. Other effluents from a TPP, like waste water from de-mineralized backwash and resin regenerator wastewater, ash transport water and runoff from coal piles, ash piles and site, trace metals, acids and other chemicals in various combination in the effluents, oil spills etc have a negative impact on water quality.

(iii) Ash handling and disposal

Ash disposal can have adverse impacts on the environment due to land use diversion, resettlement, water resources allocation and air pollution. Construction of large ash disposal areas results in resettlement issues, loss of agriculture/grazing land/habitat. When the ash gets dried in the absence of water or vegetation cover, fugitive dust from ash pond pollutes the air thereby increasing local concentration of respirable particulate. Once-through slurry disposal systems place additional strain on scarce fresh water resources.

(iv) Land Degradation

The thermal power stations are generally located on the non-forest land and do not involve much Resettlement and Rehabilitation problems. However its effects due to stack emission etc, on flora and fauna, agricultural and other land have to be studied for any adverse effects. Large land requirement for ash disposal and hazardous elements percolation to ground water through ash disposal in ash ponds are the serious effects of thermal power stations.

(v) Noise Pollution

Some areas inside the plant will have noisy equipment such as crushers, belt conveyors, fans, pumps, milling plant, compressors, boiler, turbine etc. Various measures to reduce the noise generation and exposure of workers to high noise levels in the plant area include silencers of fans, compressors, steam safety valves etc..using noise absorbent materials, providing noise barriers for various areas, noise proof control rooms. Provision of green belt around the plant will further reduce noise levels.

ENVIRONMENTAL CLEARANCE PROCESS

The implementation of power projects requires clearance from Ministry of Environment and Forestry. The Environment Impact Assessment (EIA) Notification 1994 states that expansion or modernization or setting up a new power project shall be undertaken after getting environmental clearance from the Ministry of Environment and Forestry (MOEF).

The above EIA Notification sets out procedure for clearance of projects. For site specific projects, such as hydro electric and pit head thermal power stations, the site clearance is to be obtained first from MOEF for initiation of any surveys and investigations, SPCB conducts Public Hearing, issues NOC and forwards the minutes of meeting to MOEF. Thereafter, for such site specific projects Environment Impact Assessment Reports are to be submitted by the proponents to MOEF for clearance. The reports shall be evaluated and assessed by the Impact Assessment Agency and placed before a Committee of Experts. If needed, visits are made to the projects on recommendations of the Committee of Experts, MOEF further process the proposal for clearance/rejection of the project. The cases rejected for non furnishing of complete information may be reopened on the receipt of complete information. The clearance granted is valid for a period of five years for commencement of the construction/operation.

NIGERIA'S GENERATION COMPANIES

1. EGBIN POWER STATION

The installed Egbin thermal power station in Lagos has the capacity of 1320 MW. Edbin thermal station is of reheat type with high intermediate low pressure impulse reaction turbine design and a hydrogen cooled generator.

2. AFAM POWER plc.

Afam Power Station has an installed capacity of 776MW. The plant was commissioned in phases. During the initial phase, 1962-1963, gas turbine units 1-4 were commissioned. During the second phase, 1976 to 1978, gas turbine units 5 to 12 were commissioned. Gas turbine units 13 to 18 were commissioned in 1982.Two gas turbine units were added in 2001 during the final phase of the Afam Power Station extension.

3. SHIRORO HYDRO POWER plc (concession)

Shiroro Power Plant was commissioned in 1990, it has an installed capacity of 600MW. It currently runs at full capacity, generating 2, 100 GWh of electricity annually.

As Nigeria's newest hydroelectricity plant, shiroro hosts Nigeria's SCADA-operated national control centre. Shiroro is also equipped with switch yard facilities that include a technical 'step down' function for enhanced distribution into the national grid, an advanced control room and modern training facilities.

The plant is situated in the Shiroro Gorge on the Kaduna River, approximately 60km from Minna, capital of Niger State, in close proximity to Abuja, Nigeria's federal capital.

4. UGHELLI POWER Plc.

Ughelli Power Plc operates a gas –fired thermal plant located in the Niger Delta region. Ughelli Power is one of the largest thermal generating power stations in Nigeria. The plant has a peak capacity of 972 MW, it can generate 2500 GWh of electricity annually. The plant meets current world specifications for plants of its pipe, and includes an updated control room, a switchgear room, a staff training school and recreational facilities. Ughelli began operations in1966.

5. KAINJI/JEBBA HYDRO ELECTRIC Plc (concession)

Kainji/Jebba Power operates as two hydro generation station plants, each drawing water from the river Niger. The combined installed capacity of the two plants is 1330MW withKainji generating 760MW. Effectively, the plants operate at full capacity. Kainji began operation as Nigeria's first hydro power plant in 1968 while the Jebba plant was commissioned in 1985. Jebba is the smallest of the three generating power plants in Nigeria.

In addition to generation facilities the hydro plants have on –site Medical facilities, a staff school, a recreation centre and a training school. The two plants are in very good condition.

6. **SAPELE POWER PLANT**

Sapele Power Plant is a Thermal generating station in Nigeria's gas rich Delta State. Sapele has an installed capacity of 1020MW Sapele Power's six 120MW steam turbines generate a daily average of 86.72MWI.j/H or approximately2,500GW/H annually Sapele. Power currently operates at a peak capacity of 972MW.

Sapele Power is strategically located in the Niger Delta region, close to sources of both natural gas feedstock and a river for cooling its steam turbine generators.Sapele Power includes an updated control room, a switchgear room , a staff training school, and medical recreational facilities. Sapele Power began operations in 1978.

NON OPERATING ASSETS

7. **CALABAR THERMAL POWER STATION**

Calabar Power Station has an installed capacity of 6.6MW derived from three units of 2.2 MW each. Currently, it supply 4.4MW to the national grid and primarily serves as a booster station to the Afam and Oji River power stations. The Calabar Power Station was built in 1934.

8. **OJI RIVER POWER STATION**

Oji river thermal power station was originally built to take advantage of plentiful nearby deposits of high-gra5 coal. Oji generates 10MW of power from five coal-fired boilers and four steam turbines originally installed in 1955.

The plant is the only coal-fired steam power station in Nigeria. Water from the nearly Oji river is used to feedthe steam turbines and also for cooling purposes.

9. **IJORA THERMAL POWER STATION**

Ijora power plant was commissioned in 1956 with coal-fired boilers which are no longer operational. The plant has a132/331 transmission station that is in good condition, but its 33/11KV transformers need replacement. Although the plant is currently nonoperational, current demand for power the availability of natural gas, and the government programme for gas utilization give Ijora power a competitive advantage. The location of the plant makes it ideal for an independent power plant project.

10. **AJAOKUTA STEEL THERMAL POWER PLANT**

It has an installed capacity of 110MW.

Fig. 1 Showing the available components of the Ajaokuta Steel Thermal Plant

As the nation battles to improve power supply to Nigerians, the 110MW Thermal Power Plant of the Ajaokuta Steel Plant has commenced operations after months of rehabilitation by the company engineers. The power plant commenced rehabilitation in July 2014 through a Memorandom of Understanding (MoU) with messrs 3D Hitech systems Ltd and has now been hooked to the National Power Grid system.

<u>ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS/ASSESSMENT THAT CONCERNS THERMAL POWER PLANT</u>

We have to identify impact to environment as positive and negative, because whenever a thermal power plant is constructed on a particular region of a nation, the are expected:

The **positive impacts** identified include the following:

1. Employment opportunities during construction, operation and decommissioning phases.
2. Strengthening and enhancing power supply and reliability in the region.
3. The local economy will benefit from the presence of migrant workers who will seek services and goods that can be availed locally .
4. The power supply will improve the education and health standard .Since primary, secondary and health facilities will be able to attract and retain qualified personnel. Similarly, students will be able to devote more time to study at night as opposed during the daylight only.
5. Open up the area to internet services where residents will have access to information.
6. With the establishment of the plant, the value of land will increase thus benefiting the land owners in the vicinity of the project.
7. A strong power transmission backbone will enhance development of information communication technology (ICT) facilities in key centres around the proposed thermal power plant.

8. Small scale traders and businesses in centres located around the thermal power plant will flourish from the increased volume of trade due to increased demand of basic commodities and services such as food, construction materials and accommodation during construction stage.

NEGATIVE IMPACTS

The consultant identified several negative impacts likely to arise during the proposed projects cycle. These included the following:

1. Hazardous wastes arising from various materials used in the construction.
2. Workers accidents during construction.
3. Air pollution from the construction machinery.
4. Loss of vegetation cover and habitat.
5. Soil disruption arising from excavation of foundation.
6. Increased cases of sexually transmitted infections (STIs) due to the influx of migrant workers and the resulting changes in sexual behaviours.
7. Pollution of surface water by damping of construction wastes.
8. Noise and vibration due to movement of vehicles and machinery.
9. Disruption of traffic due to movement of heavy machinery such as excavators.
10. Competition for water resources.

CONCLUSION

This paper was able to determined the equation necessary to measure the performance of thermal power plant and the expected impact on the environment. This paper also provide identified negative environmental impacts which can be mitigated and monitored during the construction of any thermal power plant. So that, significant adverse impacts, mitigation measures and action required would have to be considered, also develop thermal power plant information plan.

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