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MODELING OF GAS TURBINE OPERATED BY MUNICIPAL SOLID WASTE TO GIVE ELECTRICITY TO A LOCALITY IN KOLKATA CITY

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ABSTRACT

With passing of time life style of society is improving and waste generation is increasing proportionally day by day especially municipal solid waste(MSW).If MSW is utilized in good way problem of MSW disposal problem could be solved. In this paper gas turbine system is operated by burning municipal solid waste (MSW) as fuel in combustion chamber. The net power output of gas turbine system is 1 MW operated throughout the year in a locality of 214 families in Kolkata city, West Bengal, India for running different electrical appliances depending on season(summer and winter) specific. The excess power generated by gas turbine is used for operating the compressor. The summer and winter month are taken as May and January. In summer(May) month appliances used are fridge, water pump, ceiling fan, air conditioner, water cooler and bulbs. In winter(January) appliances used are fridge, water pump, water heater, and bulbs. The electrical appliances are connected at the exit of gas turbine along with rechargeable battery. Depending on the requirement excess current after meeting the requirement of appliances goes to rechargeable battery and during deficiency current comes from current stored in rechargeable battery. The capacity of battery considered is 23677 Ah. In May and January month electrical energy stored and discharged are 745.55 Ah, 1027.72 Ah and 694.68 Ah, 961.9 Ah respectively.

Keywords

Compressor, Gas turbine, Municipal Solid Waste (MSW), rechargeable battery

1. INTRODUCTION

Gas turbines are engines which provide power by burning fuel in any form such as coal, petroleum, natural gas etc. or any non conventional fuels in combustion chamber. Gas turbines are used for obtaining electrical power and heat energy. In reference [1] performed theoretical studies of combined SOFC(solid oxide fuel cell) and gas-turbine (SOFC/GT) cycles for efficient generation of power and heat. In reference [2] authors presented a discussion about the gas turbine modeling approach and the gas turbine component matching between the compressor and the turbine by superimposing the turbine performance characteristics on the compressor performance characteristics with suitable transformation of the coordinates. The hybrid power cycle, i.e combined SOFC/GT the physical attributes of the hybrid systems, and their performance were presented and discussed in reference [3].In reference [4] authors discussed power obtainable by the coupling of biomass gasifier with gas turbine power system. In reference [5] author discussed the power generation using combined heat and power by gas turbine in the industrial, commercial and residential sectors.

In the present paper 1 MW net power obtained from the gas turbine is being operated by burning municipal solid waste generated by people residing in a locality of 214 families in Kolkata city in West Bengal state in India. The study is made for months of May and January.

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2.SYSTEM LAYOUT

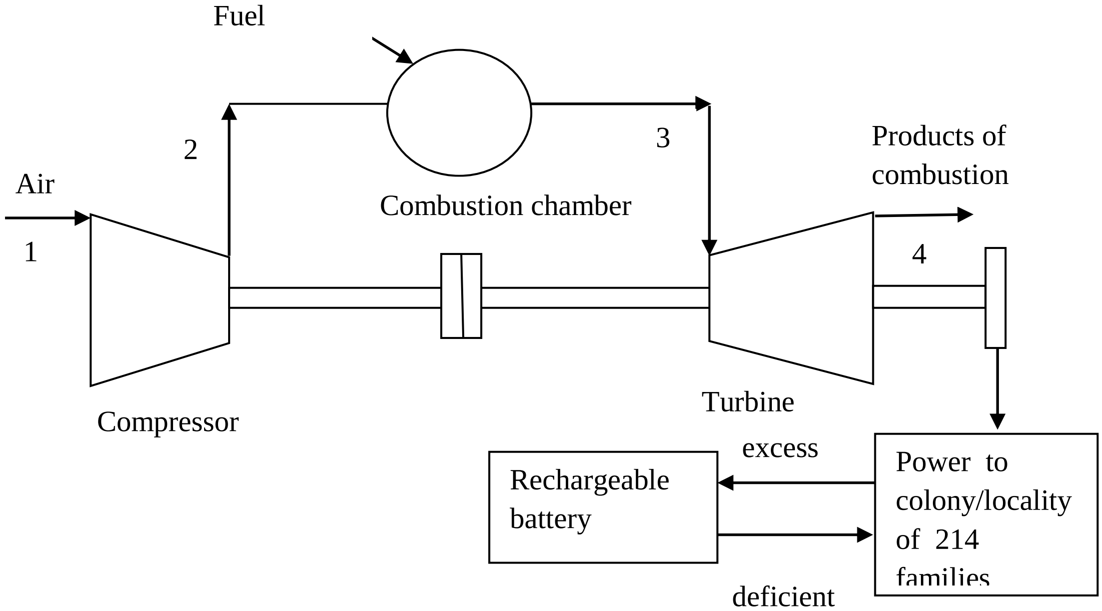

Fig 1: Typical GT plant operated by MSW

In figure no. 1, it shows the typical gas turbine plant operated by municipal solid waste in combustion chamber for generating power throughout the day and year. Required air flow for generating power is passed through air compressor at ambient temperature of Kolkata city throughout the day from 1:00AM to 12:00AM. That air is sent to combustion chamber and required fuel (MSW) in combustion chamber is supplied. The combustion gas formed after burning of MSW with air coming out at a temperature of 1000 K from combustion chamber is sent to GT. Excess power is generated by GT(>1 MW) and hence excess power is sent to compressor for running the compressor. The system is adjusted in such a way that power generated by GT minus power consumed by compressor is always 1 MW throughout the day. The net power (1MW) obtained from gas turbine is sent to locality of 214 families to run different electrical appliances according to the requirement for the month May(summer) and January(winter). The excess power after meeting the locality requirements are sent to rechargeable battery and when power deficient occurs power is obtained from rechargeable battery which stores power during power excess time.

3. MODELING OF GAS TURBINE

Figure 2 shows temperature-entropy (T-S) diagram of GT plant. Process 1-2' shows isentropic compression of air in compressor. T_1 is the air inlet to compressor at ambient temperature of Kolkata city [6]. $T_{2'}$ is the temperature given by equation no.1 [7]:

$$T_{2'} = T_1 \times \left[\frac{P_2}{P_1}\right]^{\frac{\gamma_i - 1}{\gamma_i}} \qquad (1)$$

$\frac{P_2}{P_1}$ =pressure ratio (considered 6 in present study), γ_i=1.4 k J/ kg. K [7].

Process 1-2 shows actual compression of air given by equation no. 2 [7]:

$$T_2 = T_1 + \frac{T_{2'} - T_1}{\eta_C} \qquad (2)$$

η_C= 0.85 [8].

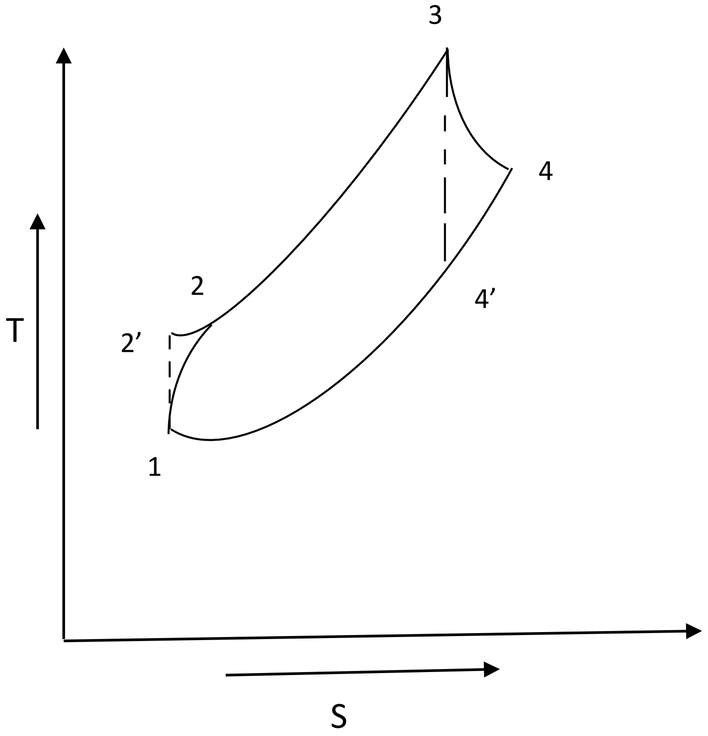

Fig 2: Temperature- entropy(T-S) diagram of figure no. 1

Process 2-3 is the combustion process taking place in combustion chamber. Temperature of combustion gas (T_3) coming out from combustion chamber is considered constant (1000 K).

Process 3-4' is the isentropic expansion of combustion gas in GT and temperature ($T_{4'}$) is given by equation no. 3 [7]:

$$T_{4'} = T_3 \times \left[\frac{P_4}{P_3}\right]^{\frac{\gamma_f - 1}{\gamma_f}} \qquad (3)$$

$\frac{P_4}{P_3}$ = pressure ratio (considered $\frac{1}{6}$ in present study), γ_f=1.33 k J/kg. K [7].

Process 3-4 shows actual expansion of combustion gas in GT given by equation no. 4 [7]:

$$T_4 = T_3 - \eta_T \left(T_3 - T_{4'}\right) \qquad (4)$$

η_T=0.9 [9].

Now mass flow rate of air, fuel flow rate, turbine work, compressor work, net work and thermal efficiency are given by equations 5,6,7,8,9 and 10 respectively [7]:

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$$\dot{m}_a = \frac{1000}{\left[C_{pg}\times(T_3-T_4)+\frac{C_{pg}\times(T_3-T_2)}{LHV_{MSW}\times\eta_{comb}}\times C_{pg}(T_3-T_4)\right]-\left[\frac{C_{pa}}{\eta_m}\times(T_2-T_1)\right]} \quad (5)$$

C_{pg}=1.147 k J/ kg. K [7], η_{comb}=0.98 [7], η_m=0.95 [8].

The composition of MSW is as follows taken from [10]: carbon-25%, hydrogen-3%, oxygen-20%, sulphur-0.3%, nitrogen-0.5%, ash-25%, moisture -25%. The LHV_{MSW} is calculated from [11].

$$\dot{m}_f = \frac{\dot{m}_a\times C_{pg}\times(T_3-T_2)}{LHV_{MSW}\times\eta_{comb}} \quad (6)$$

$$W_T = \dot{m}_a\times C_{pg}(T_3-T_4)+\dot{m}_f\times C_{pg}(T_3-T_4) \quad (7)$$

$$W_C = \left[\frac{\dot{m}_a\times C_{pa}\times(T_2-T_1)}{\eta_m}\right] \quad (8)$$

C_{pa}= 1.005 k J/kg.K [7].

$$W_{net} = W_T - W_C = 1000kW \quad (9)$$

$$E_{bc} = \frac{1000-P_{appliuances}}{230\times 0.8}\times 0.9 \quad (10)$$

Where $P_{appliances}$=power needed for appliances in locality in kW, 230-AC voltage, 0.8-power factor, 1000-net power obtained from gas turbine in kW, 0.9-battery charging efficiency

$$E_{bd} = \frac{P_{appliances}-1000}{230\times 0.8} \quad (11)$$

Battery capacity($E_{capacity}$) is given by [12]:

$$E_{capacity} = \frac{P_L\times autonomy}{DoD\times 1.3} \quad (12)$$

Where P_L-current for battery in a day (8208 Ah), DoD-depth of discharge(0.8 or 80%)[12], 1.3-expected battery capacity[12].

4.RESULTS AND DISCUSSIONS

The electrical appliances used by locality of 214 families obtain power from gas turbine. In the month of May and January different electrical appliances are used which have different power ratings. Table no.1 shows different power ratings of electrical appliances and their usability period in May and January.

Table 1.Equipments showing power ratings and operation in summer (May) and winter (January)

Equipments	Power ratings	Operation hours(May)	Operation hours(January)
Fridge	200 W[13]	24 hours	24 hours
Water pump	500 W[14]	6:00 pm to 8:00pm	6:00pm-8:00pm
Ceiling fan(48 inch)	75 W [15]	24 hours	Nil
Water heater	4000 W[16]	Nil	6:00am to 6:00pm and 6:00pm to 4:00 am
Air conditioner(1.5 ton split AC)	1550W[17]	24 hours	Nil
Water cooler	12.5 W[18]	24 hours	Nil
Bulbs	100W	6:00pm to6:00am	6:00pm to6:00 am

The number of fridges, water pump, ceiling fan, water heater, air conditioner, water cooler and bulbs used by a family are 2, 1, 8, 1, 2, 2, and 10 respectively.

Figure no. 3 and 4 shows the pattern of rechargeable battery charging and discharging for the month of May and January.

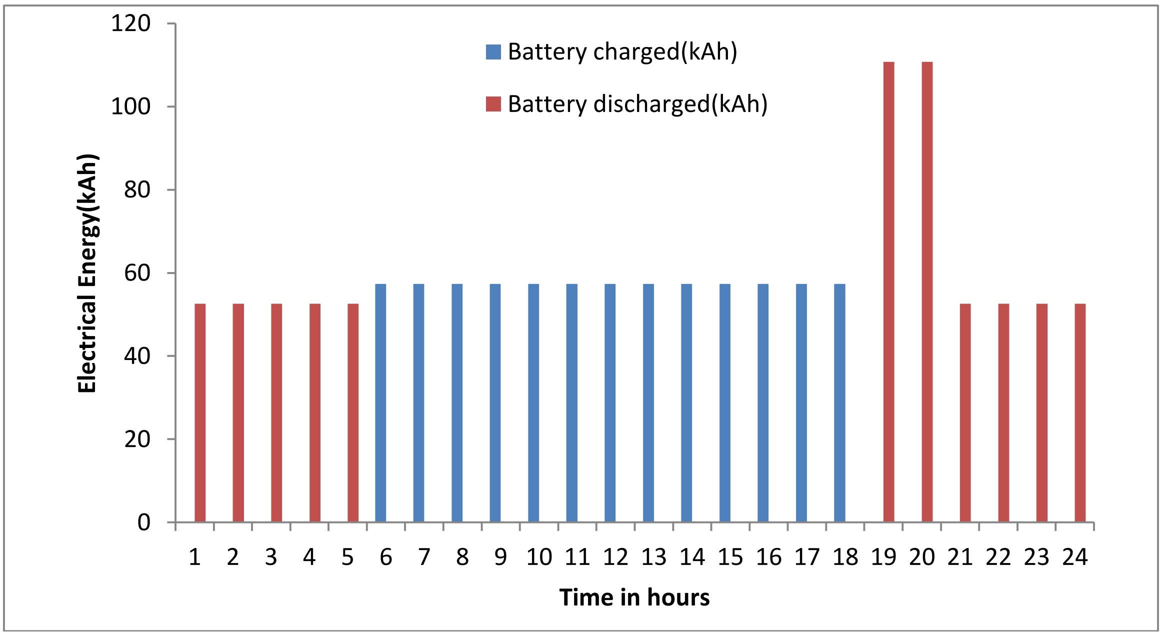

Fig 3:Battery charging and discharging due to electrical appliances used in the month of May

In figure 3 it is seen that battery charging during 6:00 am to 18:00 hours is more(57.38Ah) than during 21:00 hours to 5:00 hours(52.58 Ah) due to extra use of bulbs that can be seen in table no. 1.Battery discharge is more in 19:00-20:00 hours due to extra use of bulbs and water pump.

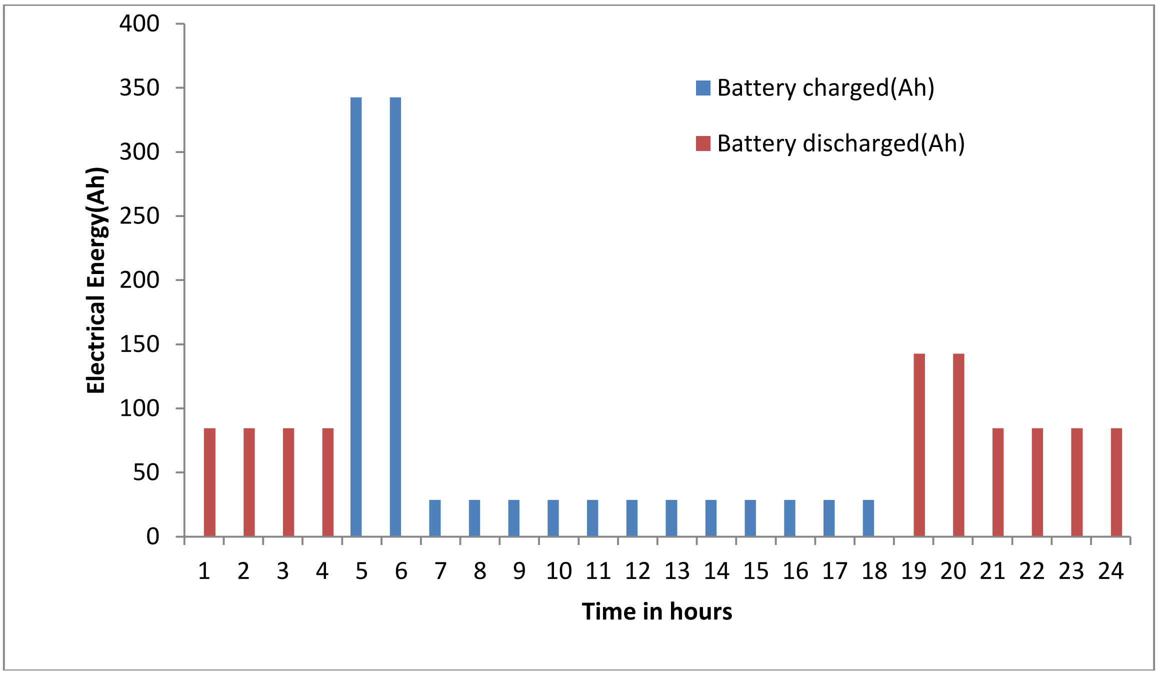

Fig 4:Battery charging and discharging due to electrical appliances used in the month of January

In figure 4 it is seen that battery charging from 7:00 hours to 18:00 hours is less (28.56Ah)than discharge of battery from 21:00 hours to 4:00 hours(84.56 Ah) due to use of bulbs. Battery discharge is more from 19:00-20:00 hours (142.71 Ah) due to use of water pump. Battery charging is more from 5:00-6:00 hours due to absence in use of water heater which draws huge power (4000 W).

It is seen that although electrical appliances usage is less in winter(January) than summer (May), but still battery charging is less and discharging is more in January due to use of water heater in January which draws large power.

It is seen that by using 23677 Ah batteries it fulfills the energy requirement for May and January. It is found that cumulative battery charging and cumulative battery discharging for May and January are 745.55 Ah, 1027.72 Ah and 694.68 Ah, 961.9 Ah respectively.

5.CONCLUSION

The work presented in this paper is to operate a GT plant with MSW as fuel to operate electrical appliances depending on the month of May and January. The reason for choosing month May and December is due to the fact that month May have maximum temperature and minimum temperature in January month. Hence if it works well in these two months the whole gas turbine plant will work perfectly. It is also seen that battery charging is more than battery discharging, hence the system will work perfectly to supply power to a locality of 214 families in Kolkata city, West Bengal, India.

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NOMENCLATURE

C_{pa}	specific heat of ambient air (k J/kg. K)
C_{pg}	specific heat of combustion gas (k J/kg. K)
E_{bc}	energy stored in battery (Ah)
E_{bd}	energy discharged from battery (Ah)
GT	gas turbine
LHV	lower heating value
$\dot{m}_a$	mass flow rate of air (kg/s)

$\dot{m}_f$	mass flow rate of fuel (kg/s)
MSW	municipal solid waste
P	pressure (bar)
T	temperature (K)
W_C	compressor work (k W)
W_T	turbine work (k W)
γ_i	ratio of specific heat of air
γ_f	ratio of specific heat of combustion gas
η_c	isentropic efficiency of compressor
η_T	isentropic efficiency of turbine
η_{comb}	combustion efficiency of combustion chamber
η_m	mechanical transmission efficiency of power from turbine to compressor