Evaluation of Efficiency and Various parameters using Natural Gas Microturbine in Cogeneration Spinning Mill: A Case Study

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Abstract:
In Recent years use of Natural Gas Microturbine for generation of power has increased and is Feasible to Continue to increase. The proportion of generation of power by combining heat and power is effective economical means to save energy and reduce pollution. In this a case study is conducted on 3.5 MW Rice Husk based on Cogeneration Project at Nahar Spinning Mill Ltd Ludhiana for the evaluation of efficiency and various parameters by existing Impulse-Reaction Turbine and Natural Gas Microturbine. Afterwards both the turbines are compared on various parameters. The results show that overall efficiency of plant is increased 12% by replacing Impulse-Reaction turbine with Natural Gas Microturbine which in turn increases the power output. By using Natural Gas -Microturbine Specific Fuel cost saving is about 1.16 $/Mbtu more per month as compared to existing plant turbine. The primary fuel energy saving is 1 ton more than Natural Gas Microturbine but it does not affect so much because overall efficiency of natural gas microturbine is 12 % which is better. It has been found that various parameters are improved by replacing Existing Impulse-Reaction Turbine with Natural Gas Microturbine.

Keywords: Impulse –Reaction Turbine, Natural Gas Microturbine, Combined heat and power Recuperator.

I. INTRODUCTION

The textile industry is one of the most complicated manufacturing industries because it is fragmented and heterogeneous sector dominated by small and medium enterprises (SMEs). Characterizing the textile manufacturing industry is complex because of the wide variety of substrates, processes machinery and components used, and finishing steps under taken .different types of yarns, methods of fabric production and finishing processes (preparation, printing, dyeing, chemical /mechanical finishing and coating) all interrelate in producing a finished fabric [1] The main objective of this work is to calculate overall efficiency and various parameters of one unit in Nahar spinning mill Ltd, Punjab. The evaluation is done on the basis of practical data taken from industry various parameters of one unit for four months has been collected. And thoroughly various parameters analyzed of this unit.

II. CALCULATION OF OVERALL EFFICIENCY AND VARIOUS PARAMETER EXISTING PLANT WITH IMPULSE-REACTION TURBINE

Cogeneration unit in NSMML have one generator and input given to this generator from October 2016 to January 2017.

A. Electrical Efficiency with Existing Impulse-Reaction Turbine:

The electrical efficiency is refers to dividing electrical energy output by fuel energy input.

<table>
<thead>
<tr>
<th>Month</th>
<th>Input Fuel(btu/hr)</th>
<th>Output Power(btu/hr)</th>
<th>Electrical efficiency (ηₑ, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCT -2016</td>
<td>39072000</td>
<td>6563255.1</td>
<td>16.7</td>
</tr>
<tr>
<td>NOV- 2016</td>
<td>38172000</td>
<td>6213851.8</td>
<td>16.2</td>
</tr>
<tr>
<td>DEC- 2016</td>
<td>38772000</td>
<td>6807564.5</td>
<td>17.5</td>
</tr>
<tr>
<td>JAN -2017</td>
<td>38172000</td>
<td>6828719.8</td>
<td>17.8</td>
</tr>
</tbody>
</table>

Figure 1. Graph of Electrical Efficiency Vs Months

B. Thermal Efficiency with Existing Impulse- Reaction Turbine: - The Thermal Efficiency is defined as heat recovered (Q) by the heat recovery unit divided by the fuel input (FI) using (Btu/hr).
Thermal Efficiency = \frac{\text{Heat Recovery}}{\text{Fuel Input}} × 100 \quad(1) \quad[5]

C. Overall Efficiency with Existing Impulse-Reaction Turbine: Overall efficiency refers to the total of both electrical and thermal efficiency.

\[ \eta_e = \text{Electrical Efficiency} \]
\[ \eta_T = \text{Thermal Efficiency} \]

Overall Efficiency \( (\eta) \) = \( (\eta_e) + (\eta_T) \) \quad(2)

D. Power Loss Coefficient (\( \beta \)) with Existing Impulse-Reaction Turbine: It is defined as the production of useful heat results in loss of electrical power.

\[ E_{\text{max}} = \text{Electricity produced in fully Condensing mode} \]
\[ E_c = \text{Electric Power Output} \]
\[ H_{\text{CHP}} = \text{Heat recovered} \]

Power loss Coefficient (\( \beta \)) = \frac{E_{\text{max}} - E_c}{H_{\text{CHP}}} \quad(3) \quad[3]

= 37.8

E. Power to Heat ratio with existing Impulse-Reaction Turbine: It is ratio of electricity required by energy consuming facility to thermal energy.

\[ Q = \text{Heat Recovered} \]
\[ \omega_Q = \text{Electrical Net power} \]

Power to Heat Ratio = \frac{\omega_Q}{Q} \quad(4)

= 0.37

F. Calculation of primary energy fuel saving cogeneration with existing turbine: Fuel energy saving is calculated separate for production of electricity and heat.

(a) Fuel energy saving for production of electricity: It is ratio of electric power output to efficiency for production of electricity.

\[ \eta_{P_e} = \text{Efficiency for production of electricity} \]

\[ F_e = \frac{E_c}{\eta_{P_e}} \]

= 393009.3 Btu/hr

= 32.7 Ton

= 33 Ton

(b) Fuel energy saving for production of heat: It is ratio of heat recovery to thermal efficiency.

\[ F_H = \frac{H_{\text{CHP}}}{\eta_T} \]

= 391518.3 Btu/hr

= 32.6

= 33 Ton

(c) Primary energy Fuel saving due to cogeneration system: Primary fuel energy saving is total of fuel energy saving for production of electricity and fuel energy saving for production of heat.

\[ \text{P.E.S} = F_e + F_H \]

= 66 Ton

G. Specific fuel cost (SFC) with existing Impulse-Reaction Turbine: -

\[ \text{S.F.C} = \frac{P_f (1)}{P_o (\text{Net})} \text{fuel cost in$/Mbtu} \quad(8) \quad[10] \]

= 3.37$/Mbtu

= 0.98 $/Kwh

H. Electric Heat rate with existing Impulse-Reaction Turbine: Electric heat rate defined as the amount of Btu of heat required to produce a kilowatt-hour of energy (Btu/kwh).

\[ P_f (1) = \text{fuel input of plant} \]
\[ P_o (\text{Net}) = \text{power output of plant} \]

\[ \text{E.H.R} = \frac{P_f (1)}{P_o (\text{Net})} \quad(9) \quad[10] \]

TABLE II. CALCULATION OF ELECTRIC HEAT RATE WITH EXISTING PLANT IMPULSE-REACTION TURBINE

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Fuel input (Btu/hr)</th>
<th>Net power (kw)</th>
<th>E.H.R (Btu/Kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCT 2016</td>
<td>39072000</td>
<td>1923.5</td>
<td>20313</td>
</tr>
<tr>
<td>NOV 2016</td>
<td>38172000</td>
<td>20961</td>
<td>20961</td>
</tr>
<tr>
<td>DEC 2016</td>
<td>38772000</td>
<td>1995.1</td>
<td>19434</td>
</tr>
<tr>
<td>JAN 2017</td>
<td>38172000</td>
<td>2001.3</td>
<td>19073</td>
</tr>
</tbody>
</table>

Average E.H.R = 19945 Btu/Kwh

Figure 2 - Graph of Electric Heat Rate Vs Months

I. Capital cost factor of existing Impulse-Reaction Turbine: - C.C.F refers to the cost of purchasing the generating system itself divided by the life time energy production.

\[ \text{C.C.F} = \frac{\text{capital cost factor}}{\text{C=C}} \]
\[ L_d = \text{Design life or the expected life of impulse turbine operations in hrs.} \]

\[ \text{C.C.F} \left( \$/KWh \right) = \frac{\text{C.C}}{L_d \times P_o} \quad(10) \quad[5] \]

= 0.101$/KWh
III. CALCULATION OF OVERALL EFFICIENCY AND VARIOUS PARAMETER EXISTING PLANT WITH NATURAL GAS MICROTURBINE

Introduction of Microturbine: - A new small gas turbine technology is being developed which promises to bring the economic, environmental and convenience benefits, advancements in automotive sector, generation of electricity and mechanical power need of the commercial sector [6]. The microturbine use primary fuel such as liquefied petroleum, biogas or industrial gases for generation of electricity.

The Microturbine operates on a thermodynamic cycle is known as the Brayton cycle. In the Brayton cycle, the atmospheric air is compressed by the compressor then preheated in a recuperator. The high pressure air passes through the combustion chamber, where fuel is added and burned at the same pressure as the compressed air. The resulting hot gas increases both in pressure and temperature due to heat energy of burning fuel, and it is allowed to expanding section. The gas expansion causes the turbine blades to spin, which then turns the rotor of a high speed permanent magnet generator. The permanent magnet converts rotation of rotor into electric power. The frequency of the electricity produced by the permanent magnet is very high (255 HZ); to make this electric power commercially usable it is rectified to direct current, and then inverted to 60/50 Hz alternating current. All the rotating components of the microturbine are mounted on a single shaft supported by air bearings. The exhaust gas exits the turbine to the atmosphere through a recuperator that pre-heats the atmospheric air entering the combustor to improve the efficiency of the system. The efficiency of microturbines depends on the temperature of the pre-heated air entering the combustor, the higher the temperature, the higher the power generation. To sustain a very high temperature, the hot sections of the microturbines require special materials. However to make gas microturbine cost effective, so far alloy steel is used in the microturbines, which can only sustain temperature of well below 700°C. The microturbine can operate as a power system or as a combined heat and power (CHP) system. In CHP system, a heat exchanger is placed after the recuperator that recovers energy from the exhaust gas. The heat exchanger has little impact on the power generation of microturbine. The recovered energy can be used for heating water or spaces [4]. They are actually single shaft machines, in which turbine, compressor and generators are mounted on the single shaft. This unit can be used for distributed power, stand-alone, stand-by-power and vehicle application like turbocharger. The commercial customer requirement for small prime mover is that they be very clean (NOx, Co and unburned hydrocarbon [6].

A. Electrical Efficiency with Natural Gas Microturbine: - The electrical efficiency is refers to dividing electrical energy output by fuel energy input.

<table>
<thead>
<tr>
<th>Month</th>
<th>Input Fuel (btu/hr)</th>
<th>Output Power (btu/hr)</th>
<th>Electrical Efficiency (η_e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCT-2016</td>
<td>39072000</td>
<td>10005492.2</td>
<td>25.6</td>
</tr>
<tr>
<td>NOV-2016</td>
<td>38172000</td>
<td>9985155.9</td>
<td>26.1</td>
</tr>
<tr>
<td>DEC-2016</td>
<td>38772000</td>
<td>9924146.8</td>
<td>25.5</td>
</tr>
<tr>
<td>JAN-2017</td>
<td>38172000</td>
<td>9985155.9</td>
<td>26.1</td>
</tr>
</tbody>
</table>

B. Thermal Efficiency with Natural Gas Microturbine: - The Thermal Efficiency is defined as heat recovered by the heat recovery unit divided by the fuel input (F1) using (btu/hr), substitute into equation (1) we get:

Thermal Efficiency = 47.8%

C. Overall Efficiency With Natural Gas Microturbine:- Substitute into equation (3) we get;

Overall Efficiency = 73.9%

D. Power Loss Coefficient (β) with Natural Gas Microturbine:- It is defined as the production of useful heat results in loss of electrical power.

Power Loss Coefficient (β) = 100 % efficiency – overall efficiency

= 26.1

E. Power to Heat ratio with Natural Gas Microturbine: - It is ratio of electricity required by energy consuming facility to thermal energy. Substitute into equation (4), we get:

Power to Heat Ratio = 0.54

F. Calculation of primary energy fuel saving cogeneration with Natural gas Microturbine: - Fuel energy saving is calculated separate for production of electricity and heat.

Fuel energy saving for production of electricity: - It is ratio of electric power output to efficiency for production of electricity. Substitute into equation (5), we get;

(e) Fuel energy saving for production of heat: It is ratio of heat recovery to thermal efficiency. Substitute into equation (6), we get;

\[ F_e = 33 \text{ton} \]

(c) Primary Fuel energy saving due to cogeneration system: Primary energy saving is total of fuel energy saving for production of electricity and fuel energy saving for production of heat. Substitute into equation (7), we get;

\[ \text{PES} = 65 \text{Ton} \]

J. Specific fuel cost (SFC) with Natural Gas Microturbine: Substitute into equation (8), we get;

\[ \text{SFC} = 0.64 \$/\text{kWh} \]

K. Electric Heat rate with Natural Gas Microturbine: Electric heat rate defined as the amount of Btu of heat required producing a kilowatt-hour of energy (Btu/kwh). Substitute into equation (8), we get:

Table IV. Calculation of Electric Heat rate with Natural Gas Microturbine

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Fuel input (P_f(Net)) Btu/hr</th>
<th>Net power (P_d(Net)) kw</th>
<th>EHR(Btu/Kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCT 2016</td>
<td>39072000</td>
<td>2932.32</td>
<td>13325</td>
</tr>
<tr>
<td>NOV 2016</td>
<td>38172000</td>
<td>2926.36</td>
<td>13044</td>
</tr>
<tr>
<td>DEC 2016</td>
<td>38772000</td>
<td>2908.48</td>
<td>13331</td>
</tr>
<tr>
<td>JAN 2017</td>
<td>38172000</td>
<td>2926.36</td>
<td>13044</td>
</tr>
</tbody>
</table>

Average E.H.R= 13186 Btu/Kwh

C.C.F=0.05$/kWh

IV. COMPARISON BETWEEN BOTH TURBINES

The various parameters of existing Impulse turbine compared with Microturbine C-60 and plot graph between few parameters of existing plant turbine and microturbine.

TABLE V. IMPULSE REACTION TURBINE VS C-60 MICROTURBINE

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameters</th>
<th>Existing Impulse – Reaction Turbine</th>
<th>C-60 Microturbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Electrical efficiency</td>
<td>16.2%</td>
<td>26.1%</td>
</tr>
<tr>
<td>2.</td>
<td>Thermal Efficiency</td>
<td>45.4%</td>
<td>47.8%</td>
</tr>
<tr>
<td>3.</td>
<td>Overall Efficiency</td>
<td>61.6%</td>
<td>73.9%</td>
</tr>
<tr>
<td>4.</td>
<td>Power Loss coefficient</td>
<td>37.8%</td>
<td>26.1%</td>
</tr>
<tr>
<td>5.</td>
<td>Power to Heat Ratio</td>
<td>0.37</td>
<td>0.54</td>
</tr>
<tr>
<td>6.</td>
<td>Primary fuel energy saving</td>
<td>66 Ton</td>
<td>65 Ton</td>
</tr>
<tr>
<td>7.</td>
<td>Specific Fuel cost</td>
<td>3.37 $/Mbtu</td>
<td>2.21 $/Mbtu</td>
</tr>
<tr>
<td>8.</td>
<td>Electric Heat Rate</td>
<td>19945 Btu/Kwh</td>
<td>13186 Btu/Kwh</td>
</tr>
<tr>
<td>9.</td>
<td>Capital cost Factor</td>
<td>0.101$/kWh</td>
<td>0.05$/kWh</td>
</tr>
</tbody>
</table>

Plot graph of between various parameters:-

(A) Plot a Graph between Electrical Efficiency of Impulse-Reaction Turbine and Microturbine C-60:-

Figure. 5. Electric heat rate vs months

I. Capital cost factor with Natural gas Microturbine: C.C.F refers to the cost of purchasing the generating system itself divided by the life time energy production. Substitute this into equation (10), we get;

\[ \text{PES} = 65 \text{Ton} \]
Plot a Graph between Electric Heat rate of Impulse reaction Turbine and Microturbine C-60:

![Electric heat rate graph](image)

Figure 6. Electric heat rate of Impulse Reaction Turbine Vs Microturbine C-60

Plot a Graph between overall efficiency and power loss coefficient of Impulse-reaction turbine and Microturbine C-60:

![Overall efficiency and power loss coefficient graph](image)

Figure 7. Overall Efficiency and Power loss coefficient of Impulse Reaction turbine vs. Microturbine C-60

V. CONCLUSION:

The overall efficiency of plant is increased 12% by replacing Impulse-Reaction turbine with Natural Gas Microturbine C-60 which in turn increases the power output. By using Natural Gas -Microturbine Specific Fuel Cost saving is about 1.16 $/Mbtu more per month as compared to existing plant turbine. The primary fuel energy saving is 1 ton more than Natural Gas Microturbine but it does not affect so much because overall efficiency of natural gas microturbine is 12 % which is better . It has been found that various parameters are improved by replacing Existing Impulse-Reaction Turbine with Natural Gas Microturbine C-60.

VI REFERENCES
