International Journal of Research Publication and Reviews, Vol 5, no 6, pp 1667-1676 June 2024

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Optimization of Operational Temperature, Pressure, Mass Flow Rate and Power Output of a Steam Thermal Plant for Performance Improvement

[1]Efosa Obaseki, [2]Nkwor Chimezie Agbafor, [3]Ikegbula Samuel Obi, [4]Ekanem Oto-Obong Aniefiok & [5]Ewurum Tennison. I

[1, 2, 3, 4 &5] Department of Mechanical Engineering, School Of Engineering Technology, Federal Polytechnic Nekede, Owerri, Nigeria

Email & phone number: tennymech@gmail.com, +2348161513849

ABSTRACT

In this paper, optimization of operational temperature, pressure, mass flow rate and power output of a steam thermal plant for performance improvement was successfully investigated. Researchers adopted three set levels for the power input matrix (+0.5MW 2.5MW 20MW) and the operational variables such as temperature, pressure and mass flow rate of steam were used to establish or determine optimal levels using MATLAB software and 3D surface graphical interactions. Results showed that the best maximum real root of the polynomial linear model generated was 2.4179MW and this represented the optimal power output for the thermal steam plant based on the stated conditions. In addition, the 3D surface interactions and optimization of the model for the three input variables required to run the thermal steam plant suggested that the optimal operational values for the thermal plant was 250℃ of temperature, 103bar of pressure and 2.53kg/s of mass flow rate of steam. Also, the linear polynomial model and ANOVA model generated with MATLAB, confirms the correctness of the polynomial linear model equation for the power output response generated by modeling. Researchers recommended based on the study; optimal values of temperature, pressure and mass flow rate should be adopted in the design and operation of steam thermal plant to improve performance, efficiency or functional reliability. Thermal plant parts or machine elements should be designed using optimal values as operational baseline to avoid sudden failure.

Keywords: *Optimization, Thermal plant, Steam, Matlab, Model*

1.0 INTRODUCTION

Over the years, it has been the interest of researchers to improve the operational performances of steam thermal plant due to its importance in electricity generation and other industrial related applications, where steam plays a major role and seems to be environmentally friendly. According to Nworie (2016) steam and green engines are among the effective ways of eradicating environmental pollution. A thermal steam plant is a thermodynamic plant that uses steam as a working fluid through the process of energy conversion following a Ranking cycle processes.

The turbine rotated by the steam power, drives the electrical energy generator that produces electricity that could be fed into consumer cables or wires. The production of steam requires energy transfer from the combustion of fossil fuel such as coal, diesel, gasoline, gas, liquefied petroleum gas or unclear to water in a boiler that generates high temperature and pressure steam.

Amer (2021) studied principles of power plant design and economics of power plants and maintained that; to achieve economy and reliability in the design and operations of steam thermal plant, requires low cost design of plant parts, low operational cost, low maintenance cost and low capital cost. Therefore, to consolidate this recommendations, there is need to have a steam thermal plant that would run at its optimal operational variables such as pressure, temperature, mass flow rate of steam that would yield optimal output. It is on this note that, the researchers aimed to study the optimization of operational temperature, pressure, mass flow rate and power output of a steam thermal plant for performance improvement.

Hamburg (2021) studied the importance of optimization in thermal fluid energy machines (steam power plant) and theoretical fundamentals of the cyclic processes of the steam power plant. He concluded that optimization had improved the electricity generation efficiency of steam power plant up to 45%. He further stated that maintaining the operational variables at the optimal levels, could leverage the overall system performance and operational cost reduction.

According to Mangesh and More (2020) as cited in Olagunju et al(2024) stated that the use of optimization for the determination of actual ratio of material input could drastically reduced production costs. Steam thermal plant optimization could be referred to as the process of improving the efficiency and performance of steam power plant by maximizing its power output and reducing operational cost. The paper aims to ascertain the optimal levels of the operational temperature, pressure, mass flow rate of steam by setting the power output of a steam thermal plant at three levels of matrix input (0.5MW 2.5MW 20MW).

2.0 METHODOLOGY

Researchers choose a three set levels for the power input based on the reviewed literatures. The variable temperatures, pressure, mass flow rate of steam were used to establish or determine optimal levels using MATLAB software and 3D surface graphical interactions. Here, Y *is* a dependent variable or predicted response known as plant power output; *X1, X2 and X3* are independent variables; representing temperature in ℃, pressure in bar and mass flow rate in kg/s respectively. The matrix for the three variables were chosen and varied at 3 levels (+0.5 2.5 20) for power output response prediction. MATLAB (R2015a) was used to generate regression model and 3D graphical analysis of surface interaction to establish the optimal values to be used for maximizing steam thermal plant output.

4.0 RESULTS

```
>> % OPTIMAL VALUES OF TEMPERATURE, PRESSURE AND MASS FLOW RATE IS MODELED AS BELOW

>> % Y = dependent plant output response variable in MW;

% X1 = independent variable, amount of temperature in℃;

% X2 = independent variable, amount of pressure in bar;

% X3 = independent variable, amount of mass flow rate in kg/s;

>> Y = [0.5 2.5 20];

X1 = [200 150 600];

X2 = [10 100 200];

X3 = [1.5 2.5 5];

% the expected relationship for the variables is below;

Y = X1 + X2 + X3;

Y = A; X1 = B; X2 = C; X3 = D;

Undefined function or variable 'A'.

>> A = [0.5 2.5 20];

B = [200 150 600];

C = [10 100 200];

D = [1.5 2.5 5];

>> mdl = fitlm(B,A)

mdl =

Linear regression model:

    y ~ 1 + x1

Estimated Coefficients:

                   Estimate       SE        tStat      pValue
                   ________    ________    _______    _______

    (Intercept)     -5.8459       3.161    -1.8494    0.31556
    x1             0.042671    0.008423      5.066    0.12407

Number of observations: 3, Error degrees of freedom: 1

Root Mean Squared Error: 2.94

R-squared: 0.962,  Adjusted R-Squared 0.925

F-statistic vs. constant model: 25.7, p-value = 0.124
```

```
>> tbl = anova(mdl)

tbl =

          SumSq    DF    MeanSq      F       pValue
          ______   __    ______    ______   _______
   x1     221.53    1    221.53    25.665   0.12407
   Error  8.6318    1    8.6318

>> mdl = fitlm(C,A)

mdl =

Linear regression model:

   y ~ 1 + x1

Estimated Coefficients:

                 Estimate      SE        tStat      pValue
                 ________   _______    ________    _______
   (Intercept)   -3.0766     5.6784    -0.54181     0.6839
   x1            0.10397    0.04394     2.3661     0.25456

Number of observations: 3, Error degrees of freedom: 1

Root Mean Squared Error: 5.91

R-squared: 0.848,  Adjusted R-Squared 0.697

F-statistic vs. constant model: 5.6, p-value = 0.255

>> mdl = fitlm(D,A)

mdl =

Linear regression model:

   y ~ 1 + x1

Estimated Coefficients:

                 Estimate      SE       tStat     pValue
                 ________   ______    _______    _______
   (Intercept)   -9.8718    3.7102    -2.6607    0.22887
   x1             5.8462    1.1103     5.2654    0.11948

Number of observations: 3, Error degrees of freedom: 1

Root Mean Squared Error: 2.83

R-squared: 0.965, Adjusted R-Squared 0.93

F-statistic vs. constant model: 27.7, p-value = 0.119

>> tbl = anova(mdl)

tbl =

          SumSq    DF    MeanSq      F       pValue
          ______   __    ______    ______   _______
   x1     222.15    1    222.15    27.725   0.11948
   Error  8.0128    1    8.0128
```

The response linear regression model for the three input variables required for operational output of steam thermal plant is shown below.

$\boldsymbol{Y = 0.042671X_1 - 5.8459 + 0.10397X_2 - 3.0766 + 5.8462X_3 - 9.8718\ MW}$ .. (4.0)

```
>> % TO OBTAIN THE ROOT OF THE POLYNOMIAL;
```

```
>> E = [0.042671 -5.8459 0.10397 -3.0766 5.8462 -9.8718];

>> sqrt(E)

ans =

  Columns 1 through 4

   0.2066 + 0.0000i   0.0000 + 2.4178i   0.3224 + 0.0000i   0.0000 + 1.7540i

  Columns 5 through 6

   2.4179 + 0.0000i   0.0000 + 3.1419i
```

The best maximum real root of the polynomial is 2.4179MW and this represents the optimal steam thermal plant output.

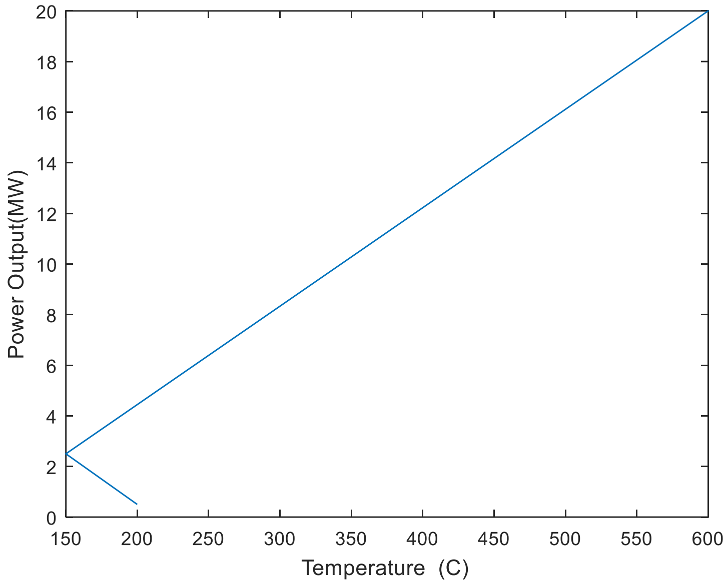

Fig 1.0: Graph of Power Output against Temperature

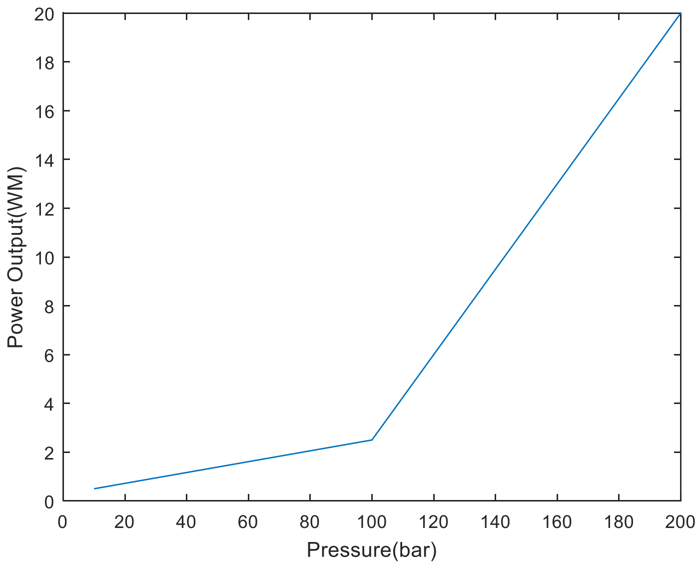

Fig 2.0: Graph of Power Output against Pressure

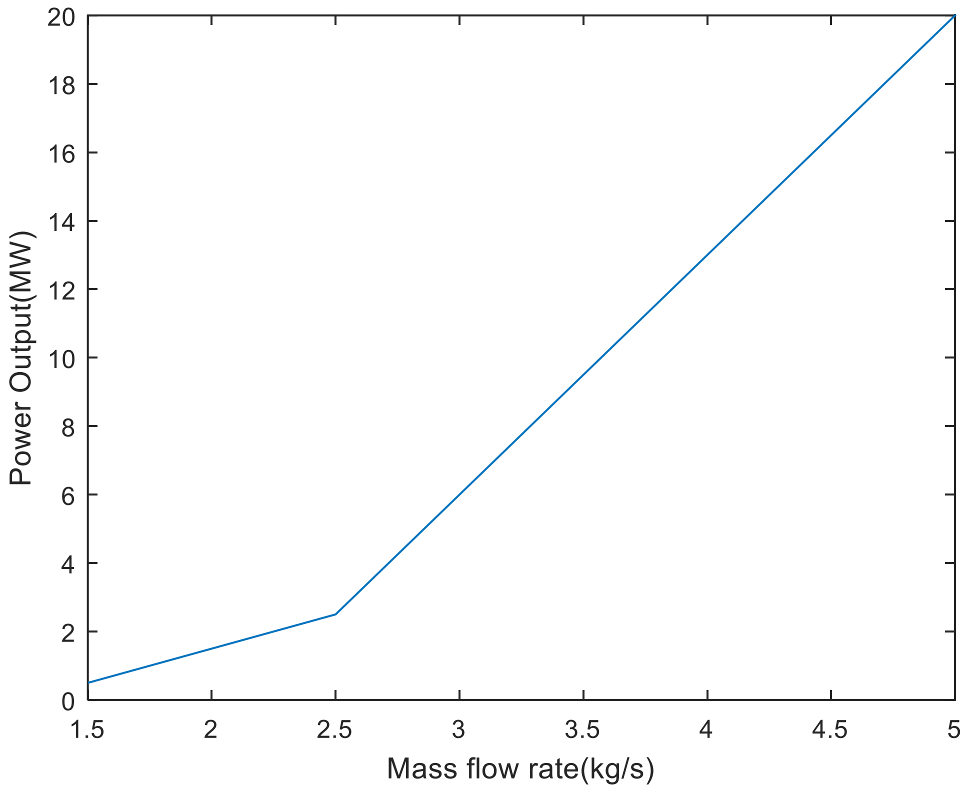

Fig 3.0: Graph of Power Output against Mass flow rate

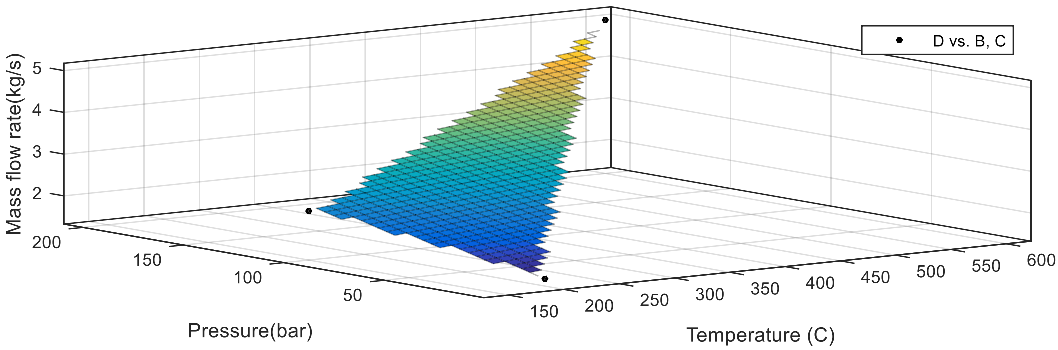

Fig 4.0: 3D Surface Interaction of Input Variables

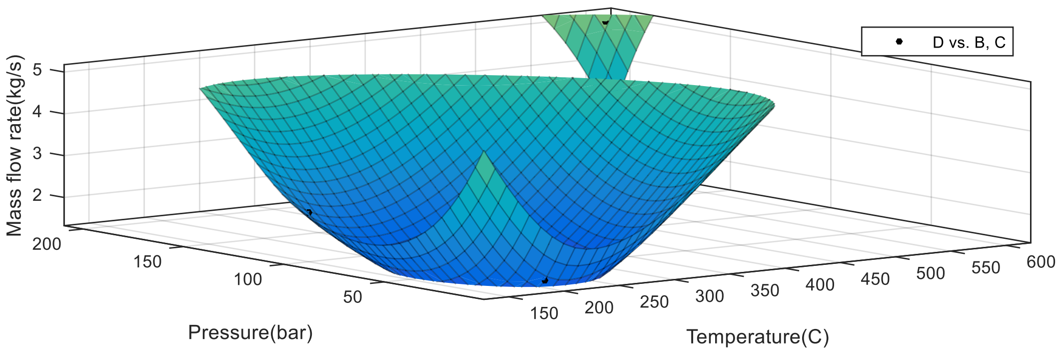

Fig 5.0: 3D Surface Interaction of Input Variables

MATLAB CODES FOR 3D SURFACE INTERACTION GRAPH ABOVE

```
function createfigure1(VertexNormals1, CData1, ZData1, YData1, XData1, XData2, YData2, ZData2)
```

```
%CREATEFIGURE1(VERTEXNORMALS1, CDATA1, ZDATA1, YDATA1, XDATA1, XDATA2, YDATA2, ZDATA2)
%  VERTEXNORMALS1:  surface vertexnormals
%  CDATA1:  surface cdata
%  ZDATA1:  surface zdata
%  YDATA1:  surface ydata
%  XDATA1:  surface xdata
%  XDATA2:  line xdata
%  YDATA2:  line ydata
%  ZDATA2:  line zdata
%  MATLAB on 18-May-2024 17:53:13
% Create figure
figure1 = figure('Tag','Print CFTOOL to Figure',...
    'Color',[0.941176470588235 0.941176470588235 0.941176470588235]);
% Create axes
axes1 = axes('Parent',figure1,'Tag','sftool surface axes');
%% Uncomment the following line to preserve the X-limits of the axes
% xlim(axes1,[127.5 622.5]);
%% Uncomment the following line to preserve the Y-limits of the axes
% ylim(axes1,[0.5 209.5]);
%% Uncomment the following line to preserve the Z-limits of the axes
% zlim(axes1,[1.325 5.175]);
view(axes1,[-37.5 30]);
box(axes1,'on');
grid(axes1,'on');
hold(axes1,'on');
% Create surface
surface('Parent',axes1,'DisplayName','untitled fit 1',...
    'VertexNormals',VertexNormals1,...
    'EdgeAlpha',0.3,...
    'CData',CData1,...
    'ZData',ZData1,...
    'YData',YData1,...
    'XData',XData1);
% Create line
line(XData2,YData2,ZData2,'Parent',axes1,'DisplayName','D vs. B, C',...
    'MarkerFaceColor',[0 0 0],...
    'MarkerEdgeColor',[0 0 0],...
    'MarkerSize',3,...
    'Marker','o',...
```

```
    'LineStyle','none');
% Create xlabel
xlabel({'Temperature(C)'});
% Create ylabel
ylabel({'Pressure(bar)'});
% Create zlabel
zlabel({'Mass flow rate(kg/s)'});
% Create legend
legend1 = legend(axes1,'show');
set(legend1,'Interpreter','none','EdgeColor',[0.15 0.15 0.15],...
    'Location','northeast');
```

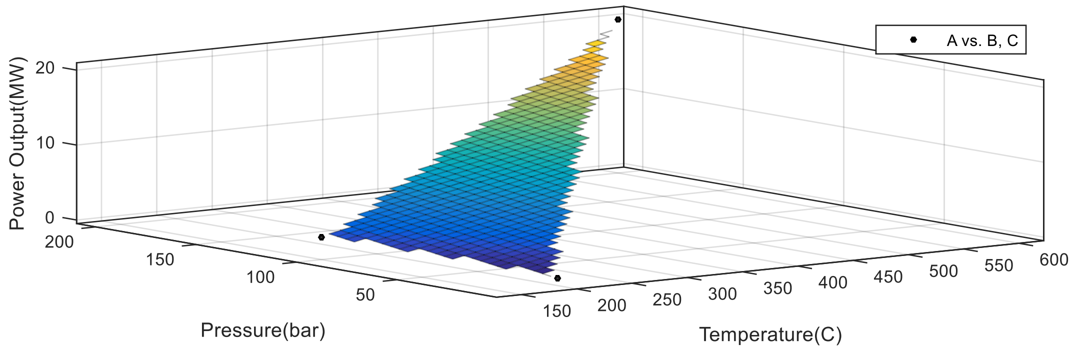

Fig 6.0: 3D Surface Interaction of Input Variables with Power Output

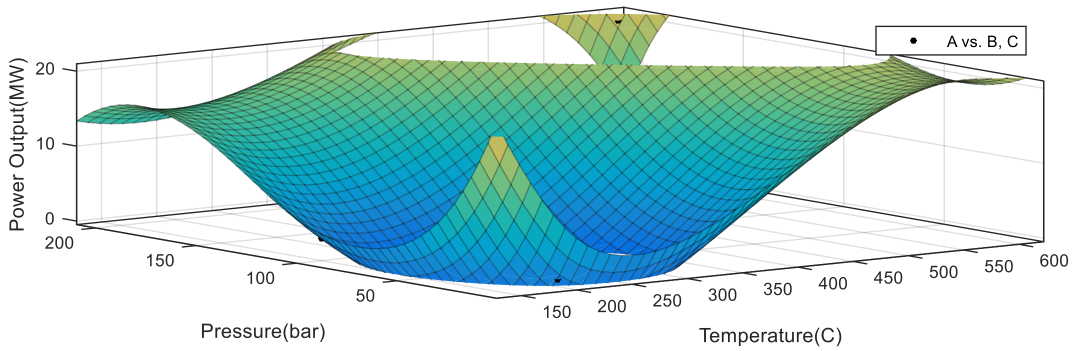

Fig 7.0: 3D Surface Interaction of Input Variables with Power Output

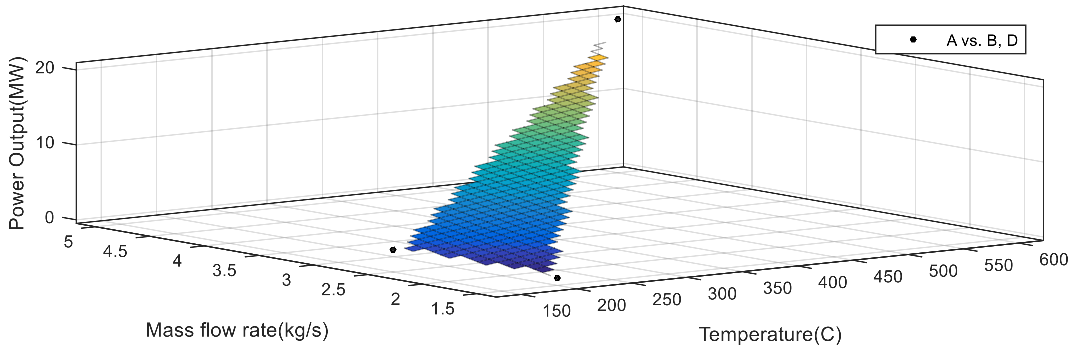

Fig 8.0: 3D Surface Interaction of Input Variables with Power Output

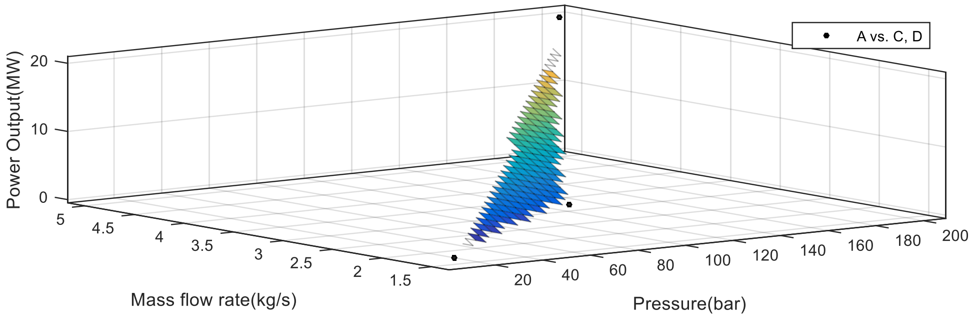

Fig 9.0: 3D Surface Interaction of Input Variables with Power Output

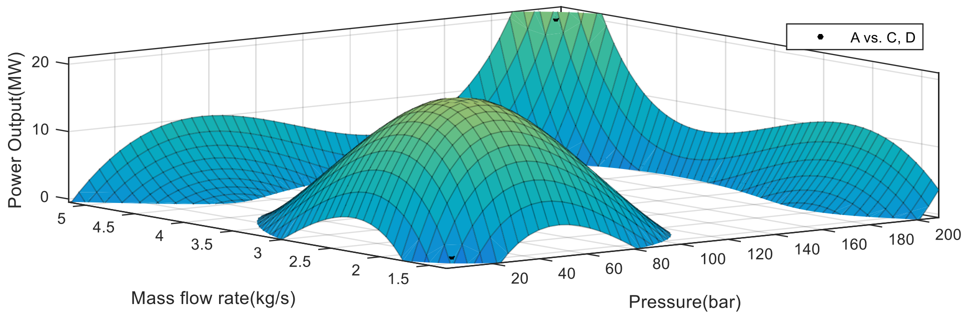

Fig 10.0: 3D Surface Interaction of Input Variables with Power Output

LINEAR MODEL POLY11

f(x,y) = p00 + p10*x + p01*y

Coefficients:

p00 = 0.8242

p10 = 0.002747

p01 = 0.01264

Goodness of fit:

SSE: 2.465e-31

R-square: 1

Adjusted R-square: NaN

RMSE: NaN

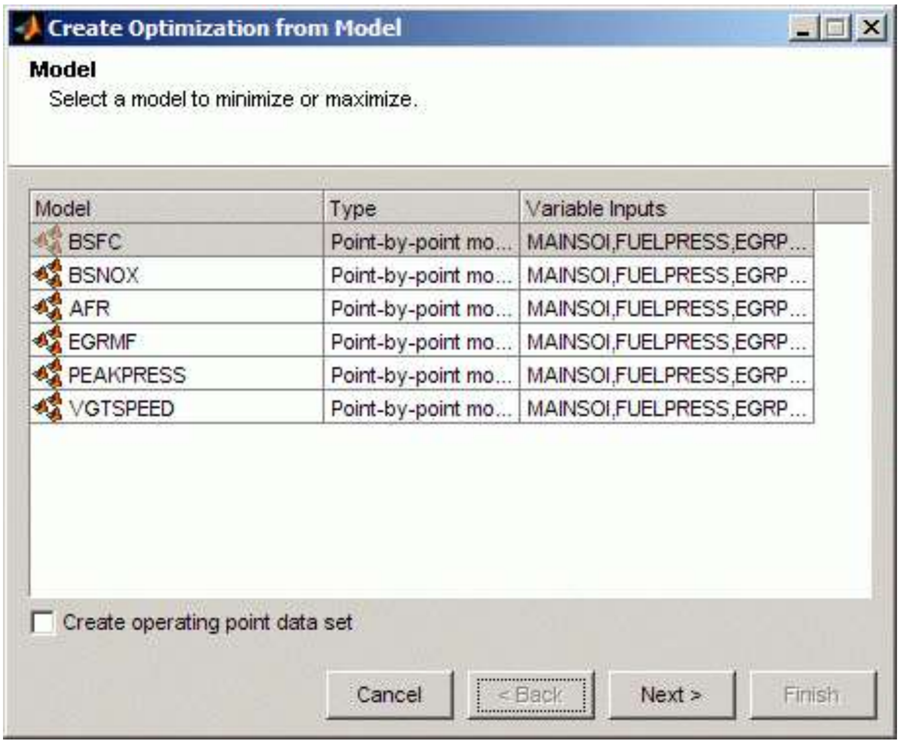

Fig 11.0: Optimization box for polynomial model

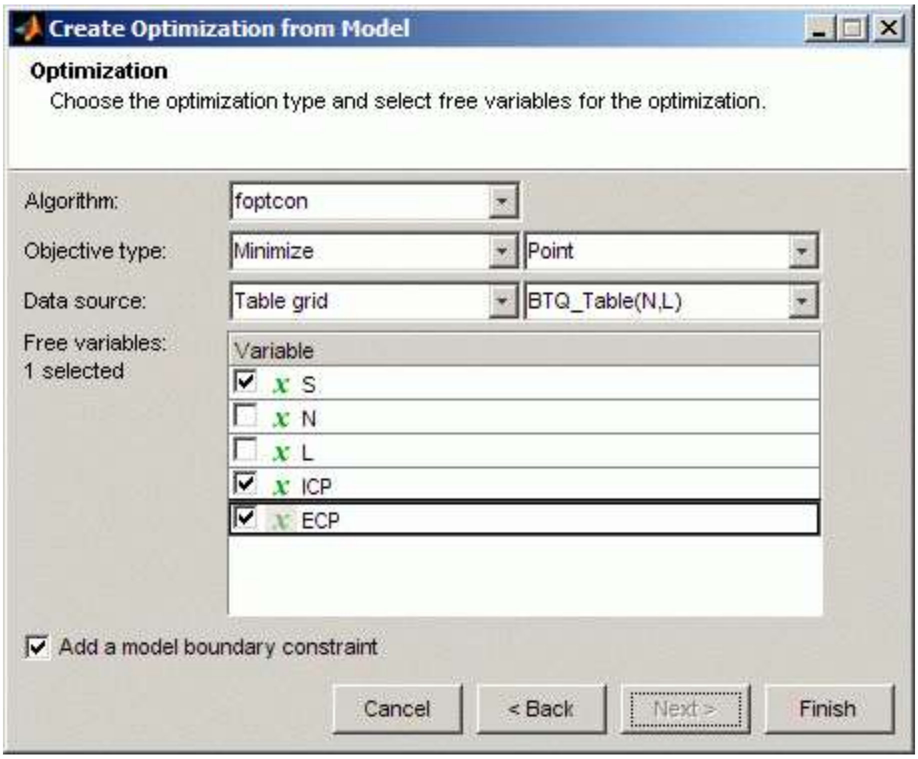

Fig 12.0: Optimization box for polynomial model

The best maximum real root of the polynomial was 2.4179MW and this represented the optimal power output for the thermal steam plant based on the stated conditions. MATLAB (R2015a) was used to generate regression model and 3D graphical analysis of surface interaction to establish the optimal values of input variables; temperature, pressure and mass flow rate as shown in **fig 1.0 to fig 10.0**. According to **fig 4.0 to fig 12.0**, the 3D surface interactions and optimization of the model for the three input variables required to run the thermal steam plant suggested that the optimal operational values for the thermal plant are 250℃ of temperature, 103bar of pressure and 2.53kg/s of mass flow rate of steam. This yielded optimal thermal plant output of 2.4179MW, as suggested by the best root of the polynomial model. Also, the linear polynomial model generated with MATLAB, confirms the correctness of the linear model equation for the power output response generated by modeling.

5.0 CONCLUSION

The results of the study suggested that the optimal operational values of temperature, pressure and mass flow rate required to run a thermal steam plant are 250℃ of temperature, 103bar of pressure and 2.53kg/s of mass flow rate of steam. This yielded optimal thermal plant output of 2.4179MW. Hence, to maximize plant power output and to minimize operating cost, steam thermal plant should be run at the stated optimal plant operational variables. The following recommendations were suggested based on the study; optimal values of temperature, pressure and mass flow rate should be adopted in the design and operation of steam thermal plant to improve performance, efficiency or functional reliability. Thermal plant parts or machine elements should be designed using optimal values as operational baseline to avoid sudden failure; this research could also be done in future using different levels of matrix inputs and other advanced software like computational fluid dynamics for generalization.

REFERENCES

Amer, A. (2021). Power Plants: Economics of Power Plants. Retrieved from www.researchgate.com, 28th May, 2024.

Gandla, P & Chandra, P. K (2018). Evaluated the Design and Experimental Analysis on Car Bumper with Composite Materials. International Research Journal of Engineering and Technology, (5)10.

Hamburg, G. (2021). Thermal Fluid Energy Machines: Theoretical Fundamentals of the Cyclic Process of a Steam Power Plant. Retrieved from www.researchgate.com, 28th May, 2024.

Mangesh, P.W & More,O.A. (2020). Investigated Vibration and Impact Analysis of Optimized Automotive Front Bumper. International Journal of Engineering Research and Technology, (9)07.

Nworie, N.N. (2016). Analysis of Green Engine. Oasis International Journal of Research in Science and Engineering Technology, (1)1, pp.23-26.

Olagunju, S.J., Ibearugbulem, C. N., Uchendu, E.E., Nwachukwu,C .P, & Ewurum, T.I. (2024). Actual Ratio of Cow Bone, Snail Shell and Epoxy Resin Material Composite For the Production of Automobile Front Fender. *International Journal of Advance Research and Innovative Ideas in Education 10(3), pp. 2788-2796.*