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Dynamic Matrix Control Technique for Boilers

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Abstract
Increased pressure and limited resources on hydrocarbon based energy resources motivate us to look and investigate control issues of power generation using biofuel fired boiler. In this paper we use industrial data to developed different type of linear model of boiler using MATLAB- system identification tool box. We use DMC (Dynamic Matrix control), and develop and simulated on computational platform. All result work compared with each proposed model. The controller response and relative performance analysis is shown in paper. We observed less overshoot; lesser oscillatory behavior in the Drum pressure of boiler using coal fuel but economy as compared to other conventional fuel. Hence overall efficiency and economy of the power plant increased.

I. Introduction

The boiler-turbine system is an essential part of a power plant. The boiler-turbine system exhibits nonlinear, time-varying, coupling behavior. Hence, the control of such system is complex and challenging and a linear model cannot capture the nonlinear dynamics sufficiently. The major control objective of a boiler-turbine system is to keep the output of mechanical energy in balance with the electrical load demand while maintaining the internal variables such as drum steam pressure, temperature and drum water level within the desired ranges. Due to the variable demand for electricity in a grid the power plants are forced to change load frequently in a large magnitude. As a result, the power plants have to operate in multiple operating regimes and the nonlinear behavior becomes more significant during these transitions between operating points. It is essential that the developed dynamic model can capture the dynamics of the system in different operating while keeping the model relatively simple, suitable for the design of feedback controllers.

Numerous modeling and control methodologies have been applied for boiler-turbine system. In [1] multiple model predictive control methodology where the system is modeled by piecewise linear models is applied for control of a boiler turbine unit. Gain scheduling approach allowing the possibility of large changes in operating conditions has been presented in [2]. PID scheduling model predictive controller where local models are equidistantly distributed in the operating space and the local models parameters are obtained through linearization is discussed in [3]. Neuro-fuzzy network with Controlled Auto-Regressive Integrated Moving Average CARIMA models and interpolation based on the B-splines functions has been successfully applied in [4]. Moon and Lee [5] presented a PID controller that can update the fuzzy rules adaptively by a simple set-point error checking process. The online learning of Radial Basis Function (RBF) neural network has been tested in [6]. In [7] the dynamic fuzzy model, where local models are obtained using Taylor series around the nominal points, is presented. A two level hierarchical control scheme for boiler-turbine system is implemented in [8]. In this paper, the controlled plant under consideration is a 34 MW boiler-turbine system that was reported in [9]. The state is estimated using the bank of Kalman filters each using the parameters from different operating point.

II. Boiler Dynamics

A schematic picture of a boiler system is shown in Fig. 1. The heat, Q, supplied to the risers causes boiling. Gravity forces the saturated steam to rise causing a circulation in the riser-drum-down comer loop. Feed water, Q_F , is supplied to the drum and saturated steam, Q_S, is taken from the drum to the super heaters and the turbine. The presence of steam below the liquid level in the drum causes the shrink-and-swell phenomenon which makes level control difficult. In reality the system is much more complicated than shown in the figure. The system has a complicated geometry and there are many down comer and riser tubes. The outflow from the risers passes through a separator to separate the steam from the water. In spite of the complexity of the system it turns out that its gross behavior is well captured by global mass and energy balances. A key property of boilers is that there is a very efficient heat transfer due to boiling and condensation. All parts of the system which are in contact with the saturated liquid-vapor mixture will be in thermal equilibrium. Energy stored in steam and water is released or absorbed very rapidly when the pressure changes. This mechanism is the key for understanding boiler dynamics. The rapid release of energy ensures that different parts of the boiler change their temperature in the same way. For this reason the dynamics can be captured by models of low order. Drum pressure and power dynamics can, in fact, be represented very well with "first-order dynamics as shown in Astrom and Eklund (1972). At "first it is surprising that the distributed effects can be neglected for a system with so large physical dimensions.

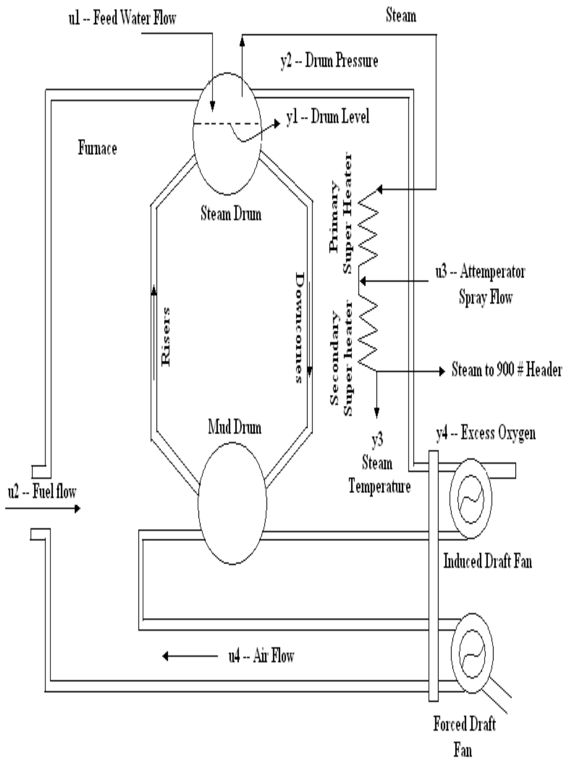

Figure 1: Schematic diagram of the boiler.

2.1. Balance equations

The behavior of the system is captured by global mass and energy balances. Let the inputs to the system be the heat flow rate to the risers, *Q*, the feed water mass flow rate, Q_F , and the steam mass flow rate, q_S . Furthermore, let the outputs of the system be drum pressure, *p*, and drum water level, this way of characterizing the system is convenient for modeling. For simulation and control it is necessary to account for the fact that mass flow rate Q_s depends on the pressure by modeling the turbine and the super heaters.

To write the equations, let V denote volume, ρ denotes specific density, *U* specific internal energy, *H* specific enthalpy, *T* temperature and Q mass flow rate. Furthermore, let subscripts *s*, *w*, *f* and *m* refer to steam, water, feed water, and metal, respectively. Sometimes, for clarification, we need a notation for the system components. For this purpose we will use double subscripts where *t* denotes total system, *d* drum and *r* risers. The total mass of the metal tubes and the drum is m_t and the specific heat of the metal is *Cp*.

The global mass balance is

$$\frac{d}{dt}[QsVst + QwVwt] = Qf - Qs$$

and the global energy balance is

$$\frac{d}{dt}[QsUsVst + QwUwVwt + MtCpTm] \\ = Q - Qfhf - QsHs$$

Since the internal energy is $u=h-p/\rho$, the global energy balance can be written as

$$\frac{d}{dt}[QsHsVst + QwHwVwt - pVt + MtCpTm] \\ = Q - Qfhf - QsHs$$

Where V_{st} and V_{wt} represent the total steam and water volumes, respectively. The total volume of the drum, down comer, and risers, V_t is

$$V_t= V_{st}+V_{wt}.$$

The metal temperature t_m can be expressed as a function of pressure by assuming that changes in t_m are strongly correlated to changes in the saturation temperature of steam t_s and thus also to changes in *p*.

III. Energy source problems

Increased pressure and limited recourses on hydrocarbon based energy resources motivate us to look and investigate control issues of power generation using biofuel and biomass gas fired boiler. Our problem is related with sugar industries having their own captive power plant. In present scenario Indian coal are of grade D, E & F with low calorie value & imported coal with grade A, B & C having high calorie value contribute high cost & lossful feasibility with more hazardous emissions like Sox & NOx including high ash content. In present days sugar industries are in loss due to many Govt Policies & high costing of imported coal. Even in coal fired boilers in power plants, boiler efficiency cannot explored fully; leads to high cost & less steam generation with other environmental problems.

IV. Proposed Model

[1] Baggase fired scheme
[2] Coal fired scheme
[3] Baggase +Coal fired scheme
[4] Baggase+ coal+ Biogas Scheme

4.1 Baggase fired scheme

Baggase is waste material of sugar industry, which can be used as fuel for boilers for steam generation. The chemical composition of Baggase is shown below

Carbon C	47 %
Hydrogen H	6.5 %
Oxygen O	44 %
Ash content	2.5 %

Table1. Composition of Baggase

4.2 Coal fired scheme:

Coal purchased from India as well abroad Coal of Low grade used to achieve required pressure of boiler.

The chemical composition of coal are given below

Table 2

Parameter	Indian coal %	Indonesian coal %
Moisture	5.98	9.43
Mineral matter	38.63	13.99
Carbon	41.11	58.96
Hydrogen	2.76	4.16
Nitrogen	1.22	1.02
Sulphur	0.40	0.56
Oxygen	9.89	11.88

Table. 2 Composition of Coal

4.3 Baggase + coal + scheme:

In this scheme we use two fuels baggase and coal. Biogas is the in-house waste material produced from distillery unit. In all three proposed model water is converted in to steam by burning the fuel in boiler furnace.

4.4 Baggase+ coal+ Biogas scheme

In this scheme we use three fuels baggase, coal and Biogas. Biogas is the in-house waste material produced from distillery unit. In all four proposed model water is converted in to steam by burning the fuel in boiler furnace.

V. System Identification:

System identification deal with the problem mathematical model of dynamical system based on observed system data. The identification of model from data involves decision making on the part of person in search of model, as well as fairly demanding computation furnish bases for these decisions. Typically goes through several iteration in the process of arriving final model where each step earlier decision is revised. Interactive software is natural tool for approaching system identification.

The procedure to determine a model of dynamic system from observed input –output data involves three basic ingredients

1 Input-out data
2 Set of candidate model (the model structure)
3 Criterion to select a particular model in the set, based on the information in the data(identified method)

5.1 Real time data from the plant:

	STEAM TEMP.AT SSH O/L HD	DRUM PRESSURE-A	COMPENSATED STEAM FLOW	FEED WATER FLOW CONTROL
	DEGC	Kg/cm2	TPH	TPH
3/26/13 8:00	512.9	91.9	96.5	98.9
3/26/13 9:00	513.4	91.2	96.3	98.6
3/26/13 10:00	519.0	91.1	95.6	99.4
3/26/13 11:00	520.7	91.2	94.8	97.4
3/26/13 12:00	518.3	92.7	96.2	98.5
3/26/13 13:00	518.2	91.3	96.3	98.5
3/26/13 14:00	515.7	92.8	96.4	98.8
3/26/13 15:00	515.8	92.1	96.3	98.4
3/26/13 16:00	515.6	92.0	96.8	99.4
3/26/13 17:00	516.5	93.3	97.6	100.0
3/26/13 18:00	510.9	92.8	97.2	99.9
3/26/13 19:00	513.4	93.1	97.1	99.9
3/26/13 20:00	514.8	92.1	97.5	100.1
3/26/13 21:00	510.9	92.2	97.6	100.3
3/26/13 22:00	513.2	92.9	97.5	100.3
3/26/13 23:00	514.4	92.3	97.4	100.2
3/27/13 0:00	514.2	92.4	97.5	103.0
3/27/13 1:00	514.6	92.0	96.9	102.0

3/27/13 2:00	511.7	92.2	97.0	103.0
3/27/13 3:00	515.1	91.4	97.2	102.7
3/27/13 4:00	515.6	93.3	97.6	102.1
3/27/13 5:00	513.5	92.1	97.4	100.4
3/27/13 6:00	511.3	91.5	78.6	86.6
3/27/13 7:00	516.6	91.0	95.9	98.2
Average	514.8	92.1	96.1	99.4

Table 3 Real time Data

VI. Dynamic Matrix Control (DMC) For Boiler System.

DMC is a control algorithm designed explicitly to predict the future response of a plant. This algorithm was first developed by Shell Oil engineers in late 1970's and was intended for its use in petroleum refineries. Now-a-days its applications are found in a wide variety of areas including chemicals, food processing, automotive, and aerospace applications.

It is a form of control algorithm in which the current control action is obtained by solving a finite horizon of open loop optimal control problem using the current state of the plant as the initial state. This process is repeatedly done for each sampling point. The optimization yields an optimal control sequence and the first control in this sequence is applied to the plant.

The move weights are the step response coefficients. Mathematically the step response can be defined as the integral of the impulse response; given one model form the other can be easily obtained. Multiple outputs were handled by superposition. By using the step response model one can write predicted future output changes as a linear combination of future input moves. The matrix that ties the two together is the so-called *Dynamic Matrix.*

The objective of a DMC controller is to drive the output as close to the set point as possible in a least-squares sense with a penalty term on the MV moves. This is equivalent to increasing the size of the diagonal terms in the square solution matrix prior to inversion. This results in smaller computed input moves and a less aggressive output response.

6.1 DMC Tuning:

Every controller design has some design parameters, which can be tuned to get the desired response of the controller. These parameters are called the tuning parameters of the controller.

VII. Simulation Results

The control system and the process model were simulated with MATLAB in a personal computer environment. In the figures, the horizontal axis in time [seconds] and vertical axis is [kilogram per centimeter square] figure 3, 5, 7 shows the process value of drum pressure and 4, 6, 8 shows the error in drum pressure. Comparatively we observed less deviation in drum pressure in proposed model 3 hybrid fuel types. Hence constant pressure maintained in turbine system so power plant overall efficiency increased.

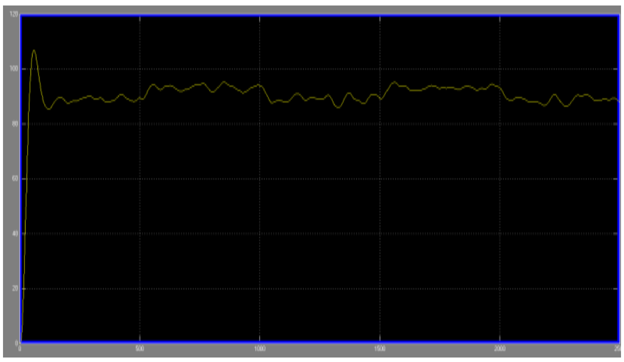

Figure 3: Baggase fired scheme shows the drum pressure using MPC

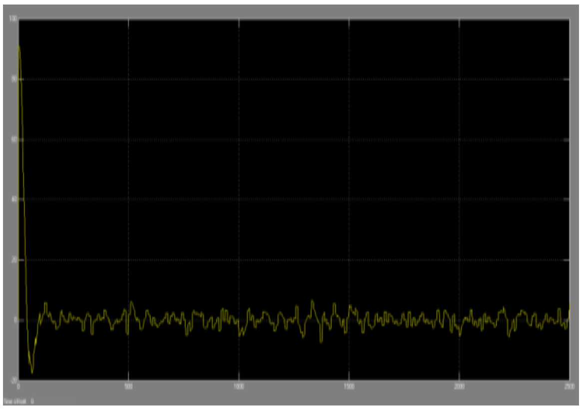

Figure 4: Baggase fired scheme shows the drum pressure error using MPC

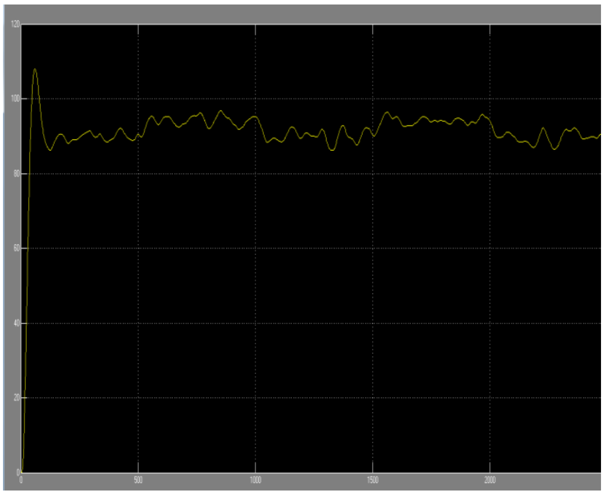

Figure 5: Baggase + coal fired scheme shows the drum pressure using MPC

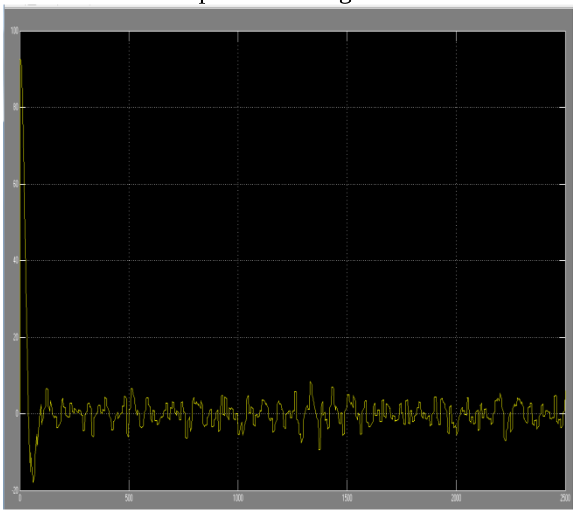

Figure 6: Baggase + coal fired scheme shows the drum pressure error using MPC

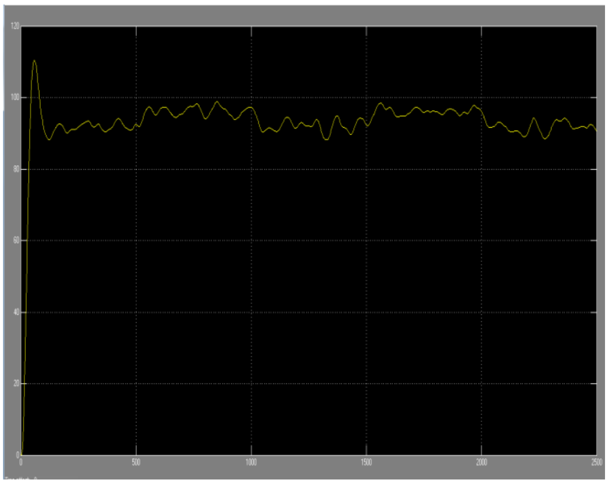

Figure 7: Baggase +coal+ biogas scheme shows the drum pressure using MPC

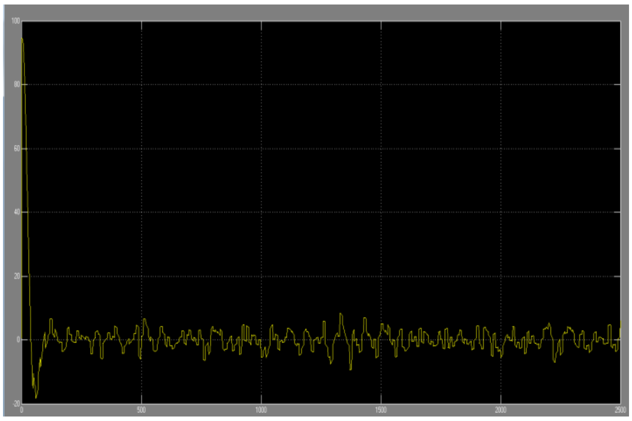

Figure 8: Baggase + coal+ biogas scheme shows the drum pressure error using MPC

Comparative Analysis

Fuel type	Boiler Effciency	Control effort	Cost of fuel	Drum pressure fluctuation
Pure Coal	81 %	lowest	highest	Lowest
Pure baggase	70 %	moderate	lowest	Very high
10%coal+90%Baggase	74%	Less than moderate	moderate	High
10%coal,86%baggase,4%Bbiogas	76%	More	Less than moderate	Low

Overall favourable operating including optimization of control effort,cost,boiler drum fluctutation .we can sayin sugar industry capative poewer plant may be run on mixed fuel model mainlyin agrobased industry

VIII. Conclusion:

This paper present the application of DMC to drum type boiler system .Four possible Model are investigated ,we observed less deviation in drum pressure in proposed model 3 hybrid fuel types. Hence constant pressure maintained in turbine system. it also show good tracking performance and has benefit when considering the input/out constraints, which is often the case of real industrial system. The novel contribution of this paper is as follow: it has been shown that the wide-range operation of drum-type boiler system can be effectively controlled by a direct application of DMC .Until now, the direct application of DMC to drum type boiler system was found to be difficult due to drum level dynamics.Therefor, a careful validation of the model is necessary by using the DMC.These result can provide a good practical guidance in implementing the DMC.

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