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Hybrid Modeling and Control of an Electric Power Plant Using Conventional Pidcontrollers

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ABSTRACT:The hybrid bond graph (HBG) paradigm is a uniform, multi-domain physics-based modelling language. It incorporates controlled and autonomous mode changes as idealized switching functions that enable the reconfiguration of energy flow paths to model hybrid physical systems. Building accurate and computationally efficient simulation mechanisms from HBG models is a challenging task, especially when there is no a priori knowledge of the subset of system modes that will be active during the simulation. In this work, we present an approach that exploits the inherent causal structure in HBG models to derive efficient hybrid simulation models as reconfigurable block diagram structures. The implementation of the PID controller to enhance the performance of an electric thermal power station representing the boiler as a hybrid system is discussed. The parameters of the PID controller are estimated using Particle Swarm Optimization (PSO) technique. Results show the adequacy of the introduced technique for the control of hybrid systems.

KEYWORDS:Hybrid system, Bond Graph, word Bond Graph and hydraulic system, PID controller, Particle Swarm**.**

I. INTRODUCTION

The hybrid systems of interest contain two distinct types of components, subsystems with continuous dynamics and subsystem with discrete dynamics that interact with each other. Continuous subsystem represents the plant while discrete subsystem represents the control of the plant. It is important to analyze the behaviors of both modeling and simulation of hybrid systems, and to synthesize controllers that guarantee closed-loop safety and performance specifications. Bond graph is a graphical description of the dynamic behavior of the hybrid systems. This means that systems from different domains (e.g. electrical,mechanical,hydraulic, chemicaland thermo-dynamics) are described in the same way. The basis is that bond graphs are based on energy and energy exchange.

In this paper, Generic Modeling environment (GME) tool is used for modeling hybrid system. It contains integral model interpretersthat perform translation and analysis of model to be simulated, controlled with MATLAB/SIMULINK.This package is used to model and control Boiler Systems. A system model shows the bond graph of each component that represents the plant or continuous dynamics and controls component that represents the discrete dynamics. The continuous components are: Pump, Economizer, Drum, Evaporator, Pipe and Super heater while the discrete components are Controller, valve, level sensorsand Attemperator.

The paper isorganizedas follow: In SectionIIwe introduced the Bond Graph technique and some related issues. Section III deals with the design of word Bond Graph (WBG) and model of power plant. The adaptation of the bond graph model to the Matlab/Simulink environment using the GME/FACT Tool is illustrated in section IV. Controlling of Hybrid System will be described in Section V.The Bond Graph model using GME/FACT is delineated in section VI. Moreover, Control of Hybrid power plant is introduced in section VI. Finally results and conclusion will be presented in section VII and VIII respectively.

II.BOND GRAPH METHODOLOGY

Bond Graph method uses the effort –flow analogy to describe physical processes. A Bond Graph consists of subsystems linked together by lines representing power bonds. Each process is described by a pair of variables, effort (e) and flow (f), and their product is the power. The direction of power is depicted by a half arrow. One of the advantages of bond graph method is that models of various systems belonging to different engineering domains can be expressed using a set of only eleven elements.

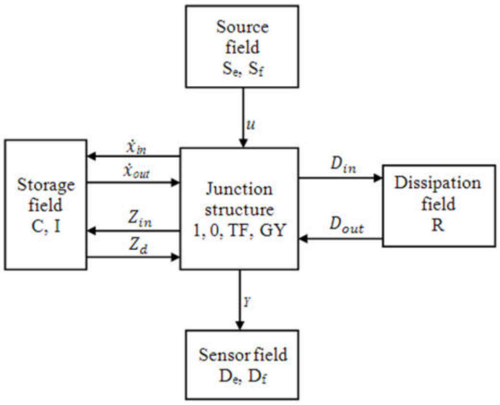


Fig. 1: Structure of bond graph

A classification of Bond Graph elements can be made up by the number of ports; ports are places where interactions with other processes take place.There are one port elements represented by inertial elements (I), capacitive elements (C), resistive elements (R), effort sources (Se) and flow sources (S_f).

Two ports element represented by transformer (TF) and gyrator elements (GY).Multi ports element -effort junctions (J0) and flow junctions (J1). I, C, and R elements are passive elements because they convert the supplied energy into stored or dissipated energy. Se and S_f elements are active elements because they supply he power to the system.And TF, GY, 0 and 1-junctions are junction elements that serve to connect I, C, R, Se and S_f, and constitute the junction structure of the Bond Graph model as shown in Fig. 1[1-5].

Power interactions are presenting when two multiport are passively connected. In bond graph languages, the various power variables are classified in a universal scheme so as to describe all types of multiport in common languages. Power variables are generally referred to as effort and flow. Table I gives effort and flow variables for some of physical domains [2]. The power exchanged at the port is the product of effort and flow:

$$P(t) = e(t) * f(t) \tag{1}$$

III. MODELING OF POWER PLANT

In this section we discuss the bond graph of steam generator as depicted in Fig. 2, which is considered as thermodynamics system so the modeling will be in Hydraulic and Thermal domains, The water flow from pump to the group of heaters in the boiler (economizer) to be heated then the heated water flows to the drum that isolate the water and steam by flowing the specific quantity of water to the evaporator that produce steam, then the steam collected in the top of the drum to be flowing through pipe to the super heater that is used to increase the steam temperature to be suitable for turbine.

There are a group of valves that is considered as a device that regulates the flow of fluid. V-1 and V-2 are valves that regulate the water out from pump to the boiler, While V-3 and V-4 is used to regulate the water out from economizer to the Drum and V-5 and V-6 are valves of an Attemperator used to control the steam temperature.

Table1 :Power variable of bond graph

Domain	Effort e(t)	Flow f(t)
Electrical.	Voltage	Current
Mechanical Rotation.	Torque	Angular velocity
Mechanical translation.	Force	Velocity
Hydraulic	Pressure	mass flow rate
Thermal		
Conduction	Temperature	Heat flow rate
Convection	Temperature	Enthalpyflow rate

Any process can be considered to be composed of interconnected subsystems. Engineers are more familiar with block diagram representation, where the input and output are both signals. Every block represents a functional relation (Linear or non-linear) between its inputs and outputs.

Essentially, a signal represents the causal signal to calculate some variables on the left hand side of an equation from the variables on the right hand side of the same equation. These representations neither require nor ensure the relations embedded in the block complied with the first principles of the physics. The block diagram is therefore a computational structure and it does not reflect the physical structure of a system. The word bond graph model of the steam generator process is given in Fig.3. The global Word Bond Graph of the hybrid power plant is shown in Fig. 4. It comprises of the following bond graphs:

- **Bond Graph of pump**
- **Bond Graph of Boiler**
- **Bond Graph of Economizer**
- **Bond Graph of Evaporator**
- **Bond Graph of Super heater**
- **Bond Graph of Drum**
- **Bond Graph of pipe**
- **Bond Graph of Attemperator**
- **Bond Graph of Load (Turbine)**

IV.BOND GRAPH MODEL USING GME/FACT

The Generic Modeling Environment (GME/FACT) is a Windows-based, domain-specific, model-integrated program synthesis tool for creating and evolving domain-specific, multi-aspect models of large-scale engineering systems. The GME/FACT is configurable, which means it can be “programmed” to work with vastly different domains [4-7].

After finishing Bond graph model of hybrid power plant by using GME/FACT interpreter must take place to transform a model constructed in GME using the FACT modeling language to a Simulink model. It outputs are two files of interest, both Matlab .m files to be executed in the Matlab environment:

1. Build script – calls the functions which construct the Simulink model.
2. Data structure script – stores a global flat bond graph structure for model execution.

The Hybrid bond graph of hybrid power plant (HPP) using GME/FACT Tool is shown in Fig.5 each block contain the bond graph of subsystem. These blocks are Pump, Economizer, Pipe, evaporator, Drum and super-heater

V.CONTROL OF HYBRID POWER PLANT

A proportional–integral–derivative controller (PID) is a generic control loop feedback mechanism that is widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs [8].

$$u(t) = K_p\, e(t) + K_i \int e(t)dt + K_d \frac{d}{dt} e(t) \tag{2}$$

Where:

K_p: Proportional gain, a tuning parameter.
K_i: Integral gain, a tuning parameter.
K_d: Derivative gain, a tuning parameter.

VI.PROPOSED DESIGN OF PID CONTROLLER

The tuning of the conventional PID controller is an expert based process. To determine the PID parameters particle swarm optimization is used. Particle swarm optimization (PSO) is a population (swarm) based stochastic optimization algorithm which is first introduced by Kennedy and Eberhart in 1995 [9]. It can be obtained high quality solutions within shorter calculation time and stable convergence characteristics with PSO algorithm than other stochastic methods such as genetic algorithm [10]. Because of these specifications, Particle swarm optimization uses particles which represent potential solutions of the problem. Each particles fly in search space at a certain velocity which can be adjusted in light of proceeding flight experiences. The projected position of i^{th} particle of the swarm x_i, and the velocity of this particle v_i at $(t+1)^{th}$ iteration are defined as the Following two equations in this study:

$$v_{iD}^{t+1} = K.(v_{iD}^{t} + c_1 r_1 (p_{iD}^{t} - x_{iD}^{t}) + c_2 r_2 (g_i^{t} - x_{iD}^{t})) \tag{3}$$
$$x_{iD}^{t+1} = x_{iD}^{t} + v_{iD}^{t+1} \tag{4}$$

where, $i = 1, ..., n$ and n is the size of the swarm, D is dimension of the problem space, c_1 and c_2 are positive constants, r_1 and r_2 are random numbers which are uniformly distributed in [0, 1], t determines the iteration number, p_i represents the best previous position (the position giving the best fitness value) of the i^{th} particle, and g represents the best particle among all the particles in the swarm. The algorithm of PSO can be depicted as follows:

1. Initialize a population of particles with random positions and velocities on D-dimensions in the problem space,
2. Evaluate desired optimization fitness function in D variables for each particle,
3. Compare particle's fitness evaluation with its best previous position. If current value is better, then set best previous position equal to the current value, and p_i equals to the current location x_i in D-dimensional space,
4. Identify the particle in the neighborhood with the best fitness so far, and assign its index to the variable g,
5. Change velocity and position of the particle according to Equation (3) and (4).
6. Loop to step 2 until a criterion is met or end of iterations.

At the end of the iterations, the best position of the swarm will be the solution of the problem. It is not possible to get an optimum result of the problem always, but the obtained solution will be an optimal one. It cannot be able to an optimum result of the problem, but certainly it will be an optimal one.

$$\Delta u(k) = u(k) - u(k-1)$$

$$= k_p^* \, \Delta u_f(k) + k_i^* \int e(k) - k_d^* \dot{y}(k) \tag{5}$$

Where k_p^* , k_i^* *and* k_d^* are the parameters of the PID.The most important part in the PID controller is the proportional (P) term because it is responsible for improving an overshoot.The conventional integral (I) term is responsible for reducing a steady state error and the derivative term is responsible for the flatness of the step response [4-7].

The controller performance may be judged through some error estimation criterion given as [8]

$$J_n(\theta) = \int_0^\infty [t^n e(\theta,t)]^2 \, dt \tag{6}$$

where is the set of PID controller's parameters k_p^* , k_i^* *and* k_d^* and e(t) is the controller error as depicted in Fig. 6. The index n is

given as
n = 0 for Integral Square Error (ISE) criteria,
n = 1 for Integral Square Time Error (ISTE) criteria.

Or in another way

$$J_n(\theta) = \int_0^\infty \left| t^n e(\theta,t) \right| dt \tag{7}$$

whereindex n is given as

n = 0 for Integral Absolute Error (IAE) criteria,
n = 1 for Integral Absolute Time Error (IATE) criteria.

To determine the PID parameters particle swarm optimization is used [8]. It can be obtained high quality solutions within shorter calculation time and stable convergence characteristics with PSO algorithm than other stochastic methods such as genetic algorithm [8]. Because of these specifications, Particle swarm optimization uses particles which represent potential solutions of the problem. Each particles fly in search space at a certain velocity which can be adjusted in light of proceeding flight experiences. The projected position of ith particle of the swarm x_i, and the velocity of this particle v_i at (t+1)th iteration are defined as the following two equations in this study:

$$v_{iD}^{t+1} = K.\left(v_{iD}^{t} + c_1 r_1 \left(p_{iD}^{t} - x_{iD}^{t}\right) + c_2 r_2 \left(g_i^{t} - x_{iD}^{t}\right)\right) \tag{8}$$

$$x_{iD}^{t+1} = x_{iD}^{t} + v_{iD}^{t+1} \tag{9}$$

where, $i = 1, \dots$, n and n is the size of the swarm, D is dimension of the problem space, c_1 and c_2 are positive constants, r_1 and r_2 are random numbers which are uniformly distributed in [0, 1], t determines the iteration number, p_i represents the best previous position (the position giving the best fitness value) of the ith particle, and g represents the best particle among all the particles in the swarm. The algorithm of PSO can be depicted as follows:

1. Initialize a population of particles with random positions and velocities on D-dimensions in the problem space, D here is 3
2. Evaluate desired optimization fitness function in D variables for each particle,
3. Compare particle's fitness evaluation with its best previous position. If current value is better, then set best previous position equal to the current value, and p_i equals to the current location x_i in D-dimensional space,
4. Identify the particle in the neighborhood with the best fitness so far, and assign its index to the variable g,
5. Change velocity and position of the particle according to Equations (3) and (4).
6. Loop to step 2 until a criterion is met or end of iterations.

VII.RESULTS

As mentioned before, the main goal of controller is to maintain the steam pressure at specific value (83 Bar) to protect the turbine blades from damage. By applying PSO techniques on the Simulink model of Fig. 6, with different dynamic error criterion as described by equations (6) and (7), we can have the gains of the PID as shown in Table 3[9-10].

Fig. 7 shows the output flow rate with and without PID controller. Optimum values of the PID controller parameters tuned by PSO are shown in Table 3. As shown in Table 4 the response of the drum level pressure with PID has a reasonable overshoot and settling time. The water level in the Drum settled at 1.3 m as shown in Fig. 8 the PID give an accurate value.

VIII.CONCLUSION

There are many reasons for using Bond graph techniques in analysis and design of control systems. The overall motivation for hybrid methods is significant interaction between the continuous and the discrete parts of a system, as can be the case in the discrete planning of continuous processes. Another important reason for hybrid techniques is the need for hierarchical organization of controls in many of today's complex technical systems, such as Hybrid Power Plant. Hybrid system theory also provides a convenient framework for modeling engineering systems in multiple domains.

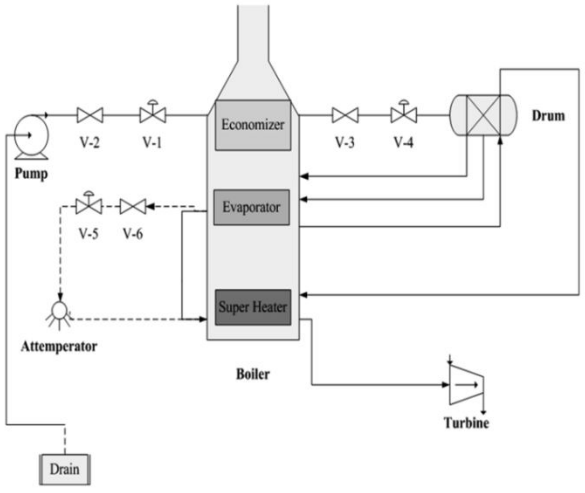


Fig.2: steam generator

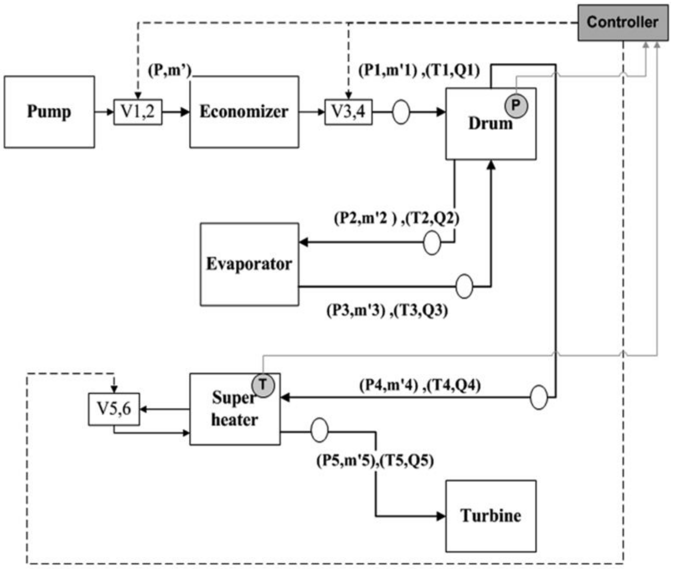


Fig.3: word bond graph of steam generator

Table 3: The best calculated controller gains

Controller	k_p^*	k_i^*	k_d^*
PID	6.7844	1.0516	9.6310

Table 4: **Errors of the PID Controller**
(∫ : Integral, |.|: absolute value, E: error, T_s : settling time)

Controller	*IAE* |*E*|	*ISE* E^2	*IATE* ∫|*E*|	*Over shoot (%)*	T_s *(Sec)*
PID	0.0034	1.149*10^{-5}	6.7804	5.48	821.6

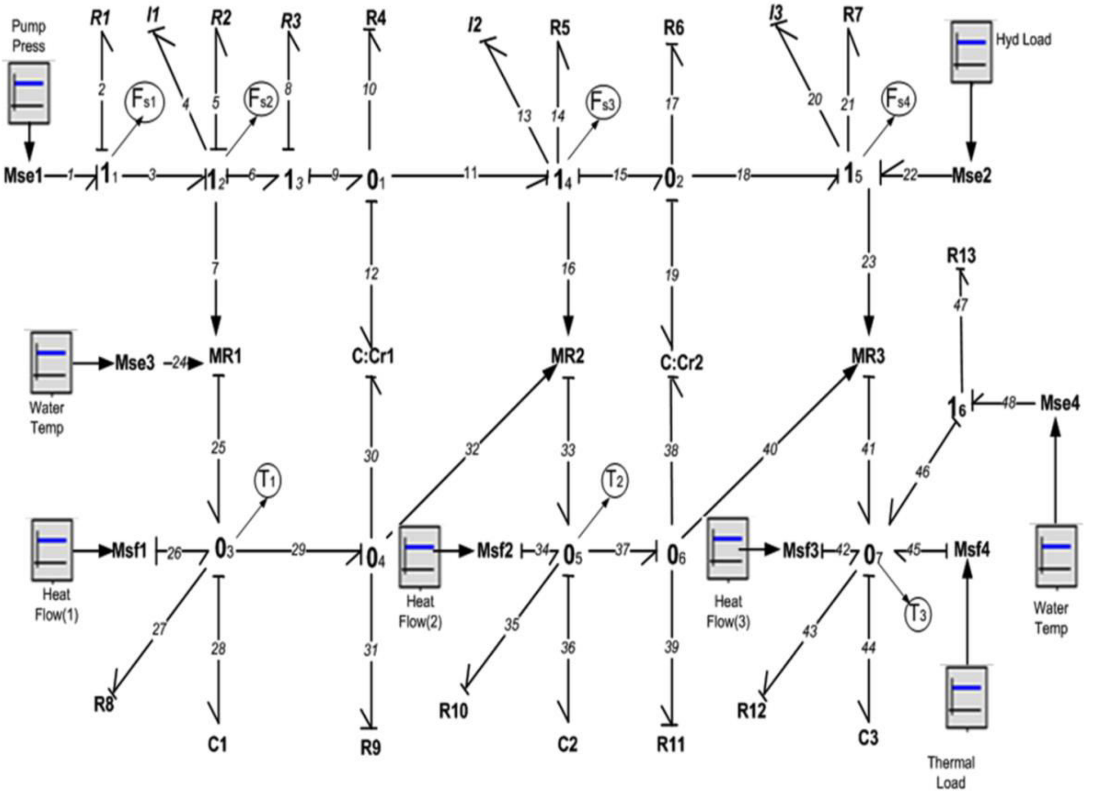
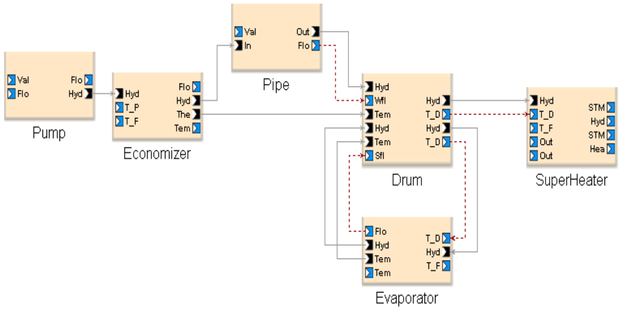


Fig.4: Global bond graph



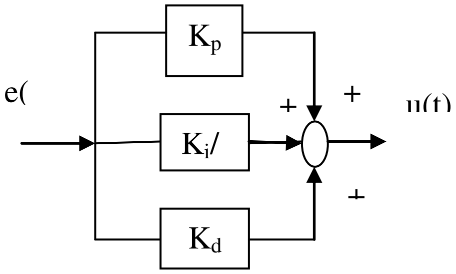


Fig. 5: Bond graph model of HHP using GME/FACT

Fig. 6: control scheme of PID controller

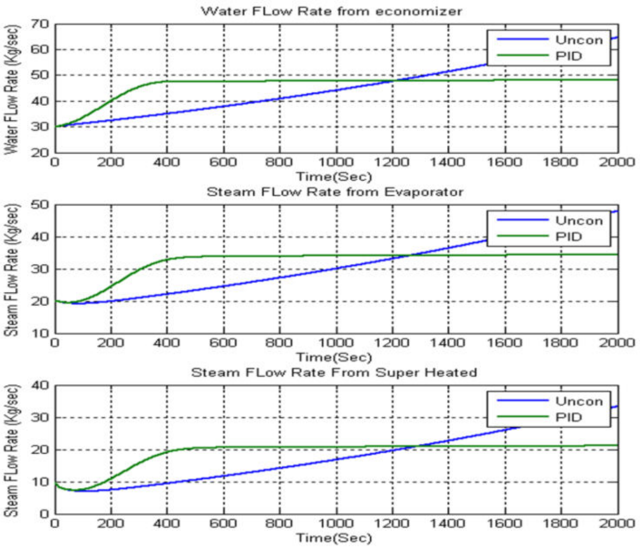


Fig. 7: output Flow Rate

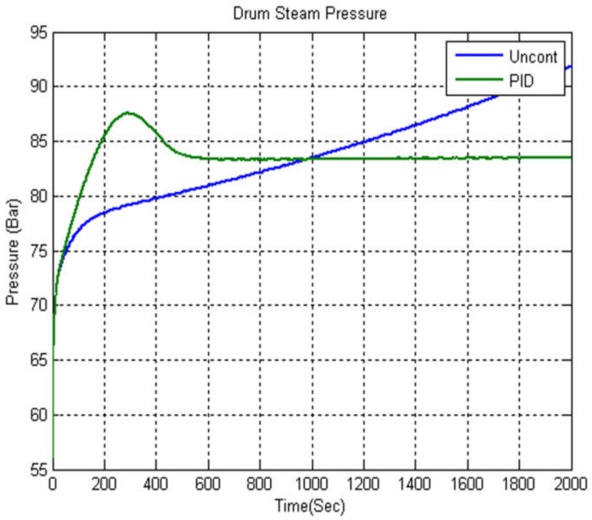


Fig. 8: Drum Water Level.

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