HYBRID MODELING OF POWER PLANT AND CONTROLLING USING FUZZY P+ID WITH APPLICATION

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ABSTRACT

This paper provides a method one can model manufacturing processes in hybrid systems framework utilizing simple bond graph to determine the flow of events and differential equation models that describe the system dynamics. Controlling of these systems can be easy to develop. "Modeling and Simulation of thermal Power generation Station for power control" will be presented by using hybrid bond graph approach. This work includes the structure and components of the thermal electrical power generation stations and the importance of hybrid bond graph to model and control complex hybrid system, controlling of power plant will be presented by using Fuzzy P+ID controller.

KEYWORDS: *Hybrid system, Bond Graph, word Bond Graph and hydraulic system.*

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, chemical and 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 interpreters that 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 sensors and Attemperator.

The paper is organized as follow: In Section 2 the Bond Graph (BG) technique and some related issues. Section 3 deals with the design of word Bond Graph and model of hybrid power plant. Generation of state space equations from Bond Graph will mention in Section 3. Controlling of Hybrid System will be descried in Section 4. The paper results are given in Section 5. A brief summary of some related work to the subject of this paper is presented in section 6. Finally conclusion will be presented in section 7.

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.

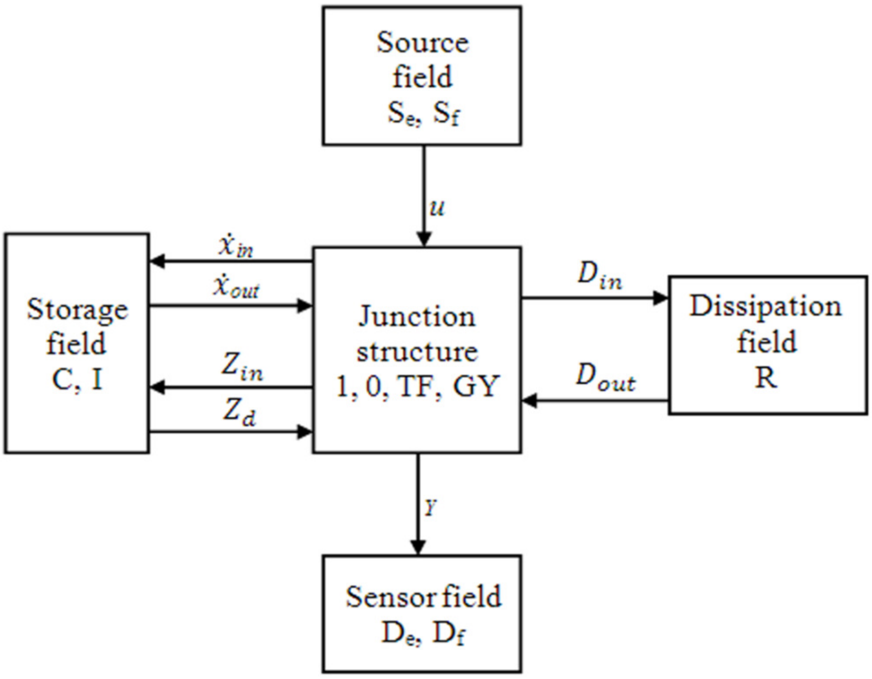

Figure 1: Structure of bond graph

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 (S_e) 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 Sf 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, S_e and S_f, and constitute the junction structure of the Bond Graph model [1]. As shown in Figure (1).

2.1. Power variables in Bond Graph model

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 (1) gives effort and flow variables for some of physical domains [2]. The power exchanged at the port is the product effort and flow:

$$P(t) = e(t) * f(t) \quad (1)$$

Table 1 power variable in 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 Convection	 Temperature Temperature	 Heat flow rate Enthalpy flow rate

III. MODELING OF HYBRID POWER PLANT

In this section we discuss the bond graph of steam generator Figure 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.

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, non linear…) between its inputs and outputs. A signal may not be real; it may be some abstraction made by the user. 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 that 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 Figure 3. Thus, the connections between two subsystems represent only a signal. So the word bond graph represents the physical structure of the system in which the inputs and outputs are the power variables. Thermal and hydraulic energies are coupled; their coupling can be represented by a small ring around the bond.

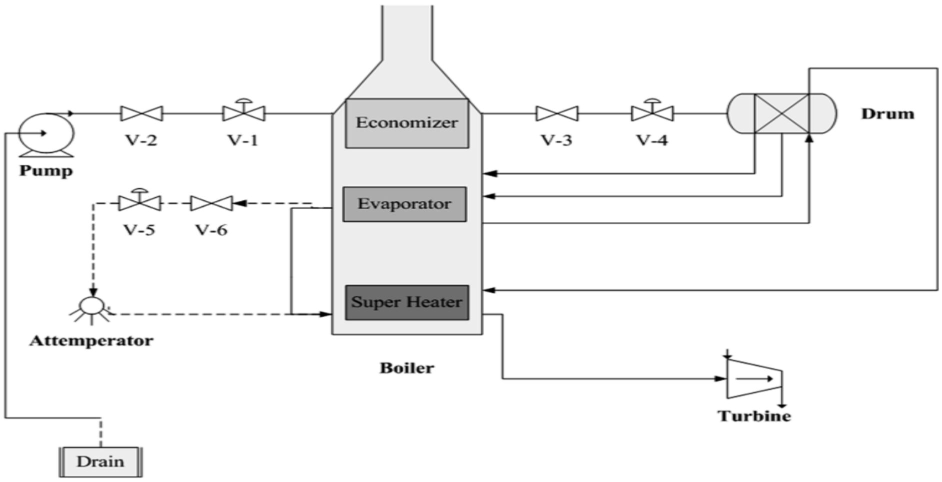

Figure 2: Steam generator

3.1. Bond Graph of Steam Generator

3.1.1. *Bond Graph of pump*

Pump is a hydraulic device that supply the plant with water flow and the required pressure, feeding water from Drain tank, So it can be considered as a source of effort (water pressure), and also the water flow rate can be controlled by valves ,either gate (On/Off) valve or Control valve, So we can simulate the functionality of pump in Bond graph as modulated Source of effort (MSE) that represent source of water pressure, Gate (ON/Off) valve can be modulated by (1 junction) and resistance (R); this resistance is playing the main role in controlling the flow rate, so it acts as a controlled valve and according to its value, the flow rate will be changed.

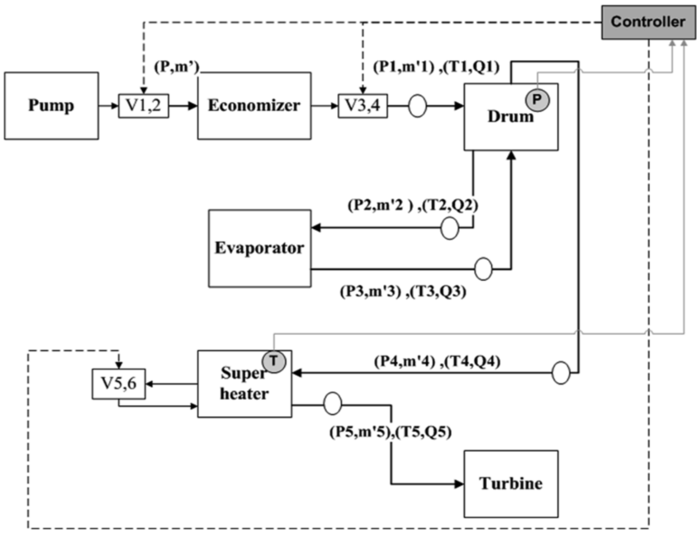

Figure 3: Word bond graph of steam generator

3.1.2.. *Bond Graph of Boiler*

The purpose of this part is to produce super heated steam to drive the main turbine generator, the boiler or super heated steam boiler boils the water and then further heat the steam in a super heated. This provides steam at much higher temperature but can decrease the overall thermal efficiency of the steam generating plant due to the fact that the higher steam temperature requires higher flue gas exhaust temperature so we can solve this problem by using economizer. The function of the economizer is to preheat boiler feed water before it is mixed with water in the steam drum. It is introduced into boiler under water wall. it also enhances boiler efficiency by transferring heat from the boiler flue gases leaving boiler to feed water entering the boiler[3], so the boiler contains three parts, economizer, evaporator and super heated. Each part can be modeled into separate sub-model.

3.1.3. *Bond Graph of economizer*

Economizer is a set of coils made from steel tube located in the top of a boiler. The hot gases leaving the boiler furnace heat the water in the coils. The water temperature is slightly less than the saturation temperature. Then the water will flow from the economizer to drum, So the economizer in the steam generator consists of hydraulic and thermal conjugate flows and efforts, firstly the hydraulic part represents the water flow from pump to the tube of the economizer. This can be modeled by resistance that represents the hydraulic losses, 1 junction to represent common flow and inductance that represent the moment of inertia. The value of this part is changed according to the length, diameter and the material of economizer tube. The output of the hydraulic part of the economizer is water flow rate. Secondly the thermal part of economizer represents the heat flow from exhaust of gas turbine to the water via economizer wall (conduction energy). This can be modeled by a source of flow to represent the heat flow, resistance for thermal losses and storage capacitance that is used to store the heat flow of water, Finally the coupling energy is modeled by multi port resistance element that connect the hydraulic part with thermal part. The flow rate is the same flow rate of pump because this is not a storage media.

3.1.4. *Bond Graph of evaporator*

The evaporator in the steam generator plays main role in isolating the water and the steam. The mixed (water and steam) flows from drum to the evaporator. It will conduct the surface of evaporator; the water will be evaporated to be steam, this steam will be collected at the top of the Drum. The evaporator, as economizer, is made of a set of tubes that placed in the middle of the boiler and will be exposed to higher temperature than economizer coil. The bond graph of evaporator, as economizer, consists of hydraulic and thermal conjugate flows and energies, the hydraulic part represent the water flow from Drum to the tube of the evaporator. The thermal part represent the heat flow from the burner to the water that pass through tube the coupling energy can be represented by multiport resistance element.

The outputs of this part is steam flow rate and it must be less than water flow rate from pump because of Drum store quantity of water and the pressure will be decreased.

3.1.5. *Bond Graph of Super heater*

The super heat plays main role in heating the steam to reach the specific temperature suitable for the turbine. The steam from the drum passes to the Super heater coils that placed at the bottom of the boiler and will be exposed to highest temperature on the boiler. The bond graph of the super heated as economizer and evaporator.

That consists of Hydraulic part, thermal part and coupling energy, with adding attempertore that is used to maintain the steam temperature at specific range, and both hydraulic and thermal load. This load is considered as source of effort represent the turbine pressure (equal about 48 bar), and source of flow that simulates heat flow. The output of super heater will increase gradually and then saturate at about 530 °C.

3.1.6. *Bond Graph of Drum*

The drum is considered as a large cylinder that functions as the storage and feeding point for water and steam. The water is coming from economizer while the steam is collected at the top of the drum out from evaporator to pass through the super heater, so the bond graph model can be divided in two parts, one for water while the other for steam. Each part contain hydraulic energy modulated by resistance for hydraulic losses, (zero junction) used to represent common effort and capacitor that store the water or steam. The thermal part consists of thermal resistance and capacitors that store the internal thermal energy (convection energy). The Output of the drum are water and steam pressure as hydraulic output a temperature of both water and steam as thermal energy. The bond graph is shown in Figure (4)

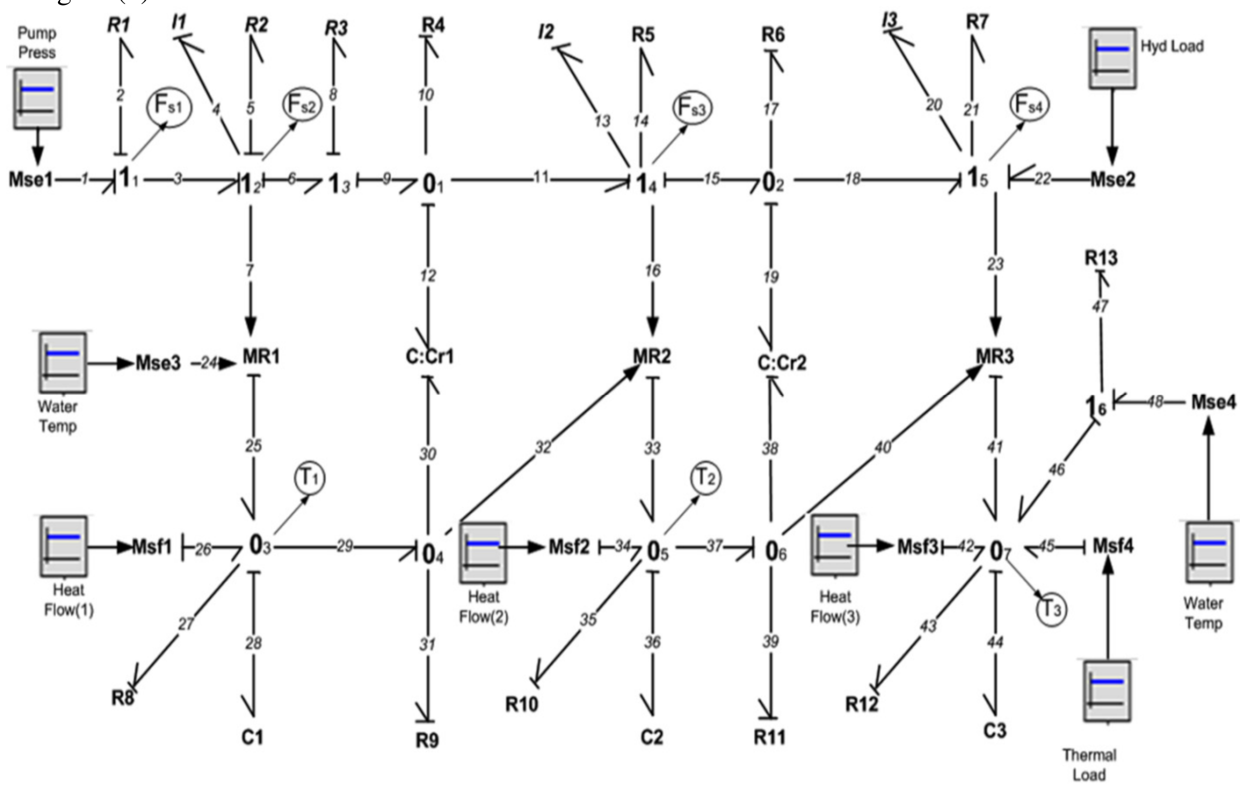

Figure 4: Bond Graph of Boiler Control System

3.1.7. *Bond Graph of pipe*

The pipe is used to transfer water from economizer to drum. The flow inlet to the pipe is controlled by two valves one is gate (On/Off) valve while the other is control valve, that is modeled in bond graph by One junction and R resistance respectively. The value of resistance represents the percentage of the valve opening and closing.

3.1.8. *Bond Graph of Attemperator*

It is a part of super heated sub system used to control the temperature of the steam out from the super heater as shown in Figure 5, the bond graph of the Attemperator will be source of effort to represent the value of temperature of cold water, resistance which represents the control valve of Attemperator and one junction that represent the gate valve. The value of effort source takes minus sign to decrease the steam temperature.

3.1.9. *Bond Graph of Load*

The turbine can be represented by hydraulic load that is modeled by source of effort to represent out pressure with negative sign.

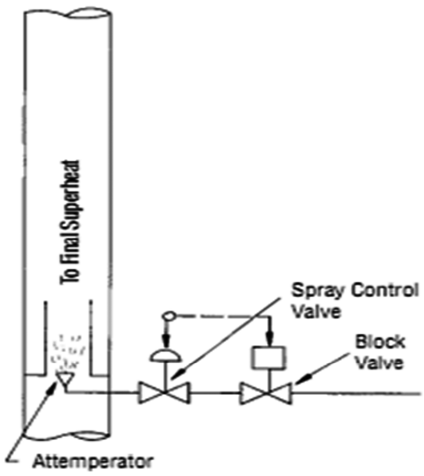

Figure 5: Valves of Attemperator

3.2. State Space Equation

The state variables, *x*, of the global model are the energy variables associated with storage elements, *i.e*. I and C elements are:

1. The momentum of the fluid in the inlet pipe of economizer, evaporator and super Heater are ($[p_4\ \ p_{13}\ \ p_{20}]$) of the elements ($I_1, I_2, I_3$) respectively.
2. The mass stored in the drum, m_{12} and m_{19} from the elements (C_{h1}, C_{h2}) that is the hydraulic part of (Cr_1, Cr_2) to store water and steam respectively.
3. The internal energy of water and steam stored in the Drum, U_{30} and U_{38} from the elements (C_{t1}, C_{t2}) that is the thermal part of (Cr_1, Cr_2) respectively.
4. The thermal energy in metallic body of the tubes of economizer, evaporator and super heater accumulated are Q_{28} , Q_{36} and Q_{44} respectively.

States will be:

$$\boldsymbol{x} = [p_4\ \ p_{13}\ \ p_{20}\ \ m_{12}\ \ m_{19}\ \ U_{30}\ \ U_{38}\ \ Q_{28}\ \ Q_{36}\ \ Q_{44}\ ]^{T} \quad (2)$$

Input vector *u* will be:

$$\boldsymbol{u} = [MSe_1\ \ MSf_1\ MSf_2\ MSf_3\ ]^{T} \quad (3)$$

The measured variables or the outputs:

Reading of Levels sensors: f_{s1} , f_{s2} , f_{s3} and f_{s4} and Reading of Temperature sensors: T_{s1}, T_{s2} , and T_{s3}.

$$\boldsymbol{y} = [f_{s1}\ \ f_{s2}\ \ f_{s3}\ f_{s4}\ T_{s1}\ T_{s2}\ T_{s3}\,]^{\mathrm{T}} \tag{4}$$

$$\begin{aligned}
fs_1 &= \frac{1}{I_1} p_4, \\
fs_2 &= \frac{1}{I_1} p_4, \\
fs_3 &= \frac{1}{I_2} p_{13}\,, \\
fs_4 &= \frac{1}{I_3} p_{20}, \\
Ts_1 &= \frac{1}{C_1} Q_{28}, \\
Ts_2 &= \frac{1}{C_2} Q_{36}, \\
Ts_3 &= \frac{1}{C_3} Q_{44}
\end{aligned} \tag{5}$$

Thus, the state equation under non- linear form (because of the coupling of the two energies) $\dot{x}(t) = f(x, u)$ can be written after minor transformation as following:

$$\dot{p}_4 = Mse_1 - \left(\frac{R_1 + R_2 + R_3}{I_1}\right) p_4 \ - \frac{m_{12}}{C_{h1}}, \tag{6}$$

$$\dot{p}_{13} = \frac{m_{12}}{C_{h1}} - \frac{R_5}{I_2}\ p_{13} - \frac{m_{19}}{C_{h2}}, \tag{7}$$

$$\dot{p}_{20} = \frac{m_{19}}{C_{h2}} + (-Mse_2) - \frac{R_7}{I_3}\ p_{20}, \tag{8}$$

$$\dot{m}_{12} = \frac{1}{I_1}\ p_4 - \left(\frac{m_{12}}{R_4 * C_{h1}}\right) - \frac{1}{I_2} p_{13}, \tag{9}$$

$$\dot{m}_{19} = \frac{1}{I_2} p_{13} - \frac{m_{19}}{R_6 C_{h2}} - \frac{1}{I_3} p_{20}, \tag{10}$$

$$\dot{Q}_{28} = \frac{\left(\frac{1}{I_1} p_4 * c_v * T_{In}\right) + Msf_1 - \left(\frac{1}{R_8 C_1} + \frac{1}{R_9 C_1}\right) Q_{28}}{1 + \frac{1}{C_1 * C_v * \dot{m}_{12}}}, \tag{11}$$

$$\dot{U}_{30} = \frac{1}{C_1 * C_v} * \frac{\dot{Q}_{28}}{\dot{m}_{12}}, \tag{12}$$

$$\dot{Q}_{36} = \frac{\left(\frac{1}{I_2} p_{13} * c_v * T_{32}\right) + Msf_2 - \left(\frac{1}{R_{10} C_2} + \frac{1}{R_{11} C_2}\right) Q_{36}}{1 + \frac{1}{C_1 * C_v * \dot{m}_{19}}}, \tag{13}$$

$$\dot{U}_{38} = \frac{1}{C_1 * C_v} * \frac{\dot{Q}_{36}}{\dot{m}_{19}}, \tag{14}$$

$$\dot{Q}_{44} = \frac{1}{I_3} p_{20} * c_v * T_{40} + Msf_3 - Msf_4 - \frac{1}{R_{12} C_3}\ Q_{44} \ - \frac{Mse_4 - \frac{1}{C_3} Q_{44}}{R_{13}} \tag{15}$$

The state space equation will represent the system behavior. It can used also to study the controllability and observability of the system.

IV. CONTROL OF HYBRID POWER PLANT

Combustion control of an industrial boiler is to provide a continuous supply of steam at the desired condition of pressure. In this paper a hybrid fuzzy logic proportional conventional integral-and derivative (FUZZY P+ID) controller is presented to improve the control performance as shown Figure (6).

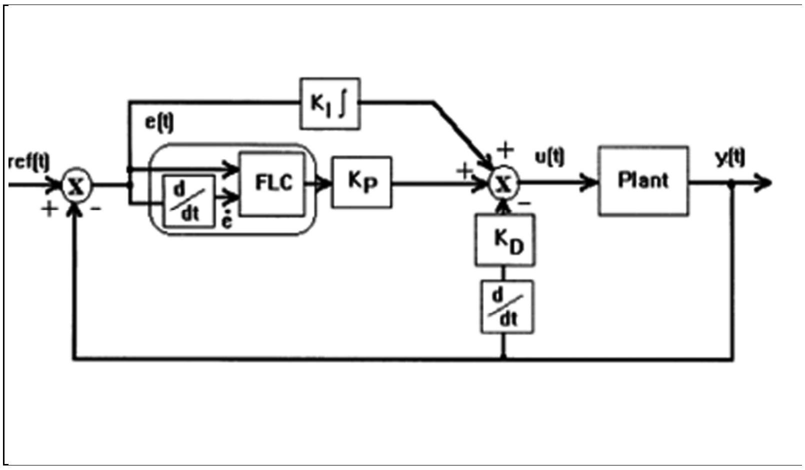

Figure 6: Control scheme of Fuzzy P+ID controller.

Fuzzy P+ID is formed by using an incremental FL in place of proportional term the integral term remains the same where $\Delta u_i(k)$ is the output of the incremental FL controller. The incremental FL controller has two inputs, $e(k)$ and $\dot{e}(k)$, and an output, $u(k)$. Where:

$$\Delta u(k) = u(k) - u(k-1) = k_p^* \, \Delta u_f(k) + k_i^* \int e(k) - k_d^* \dot{y}(k) \tag{16}$$

where k_p^* , k_i^* and k_d^* are the parameters of Fuzzy P+ ID controller. The most important part in the Fuzzy P + ID controller is the fuzzy proportional (P) term because it is responsible for improving the overshoot. The conventional integral (I) term is responsible for eliminating the steady state error and the derivative term is responsible for the flatness of the step response [4].
The fuzzy logic controller is a standard one that has two inputs, e (k) and $\dot{e}(k)$, and an output $\Delta u_f(k)$.
In this thesis, the membership functions of the inputs are defined to be identical.
Using three types of controller:

1. Fuzzy P+ID Controller with three membership functions (N, Z, P).
2. Fuzzy P+ID Controller with five membership functions (NL, NS, Z, PS, PL).
3. Fuzzy P+ID Controller with seven membership functions (NL, NM, NS, Z, PL, PM, PS).

The response of each fuzzy rule is weighted according to the degree of membership of its input conditions. The inference engine provides a set of control actions according to fuzzified inputs. The commonly used inference engine is the MAX-MIN method. In the rule base only Zadeh's logical &&AND [5], that is, the MIN operator is used. Since the control actions are described in a fuzzy sense, a defuzzifcation method is required to transform fuzzy control actions into a crisp output value of the fuzzy logic controller. For the incremental fuzzy logic controller, a widely used defuzzifcation method is the “center-of mass " formula [6-9].

V. RESULT

As mentioned before the main goal of controller is to maintain the steam pressure in the drum at specific value (83 Bar) to protect the turbine blades from damage.

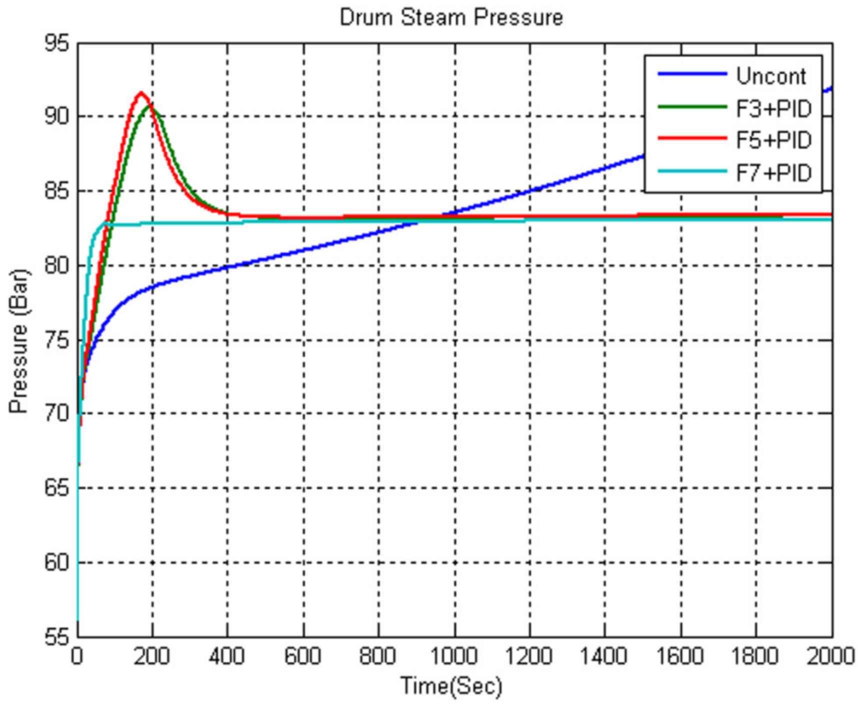

Figure 7: Steam pressure by using Fuzzy P+ID controller

As shown in Table 1 and Figure 7 the response of the steam pressure with Fuzzy P+ID 7 membership is the best one due to lack of overshoot and small settling time.

5.1. *Comparison between controllers*

The comparison between the different Fuzzy P+ID controllers with different number of membership functions (3, 5, and 7) is summarized in Table 2 with respect to the IAE, ISE, IATE dynamic error constants as well as the maximum percentage overshoot and settling time [9].

Table 2: Errors of Controller

Controller	*IAE*	*ISE*	*IATE*	*Overshoot (%)*	*Settling Time (Sec)*
F3 +PID	0.3240	0.1050	647.9211	9.02	425.3
F5 +PID	0.3826	0.1464	765.2219	10.25	426.9
F7 +PID	0.0243	5.9057e-004	48.6032	0	88.59

The water level in the Drum settled at 1.3 m as shown in Figure 8 the Fuzzy P+ID with 7 membership functions give an accurate value.

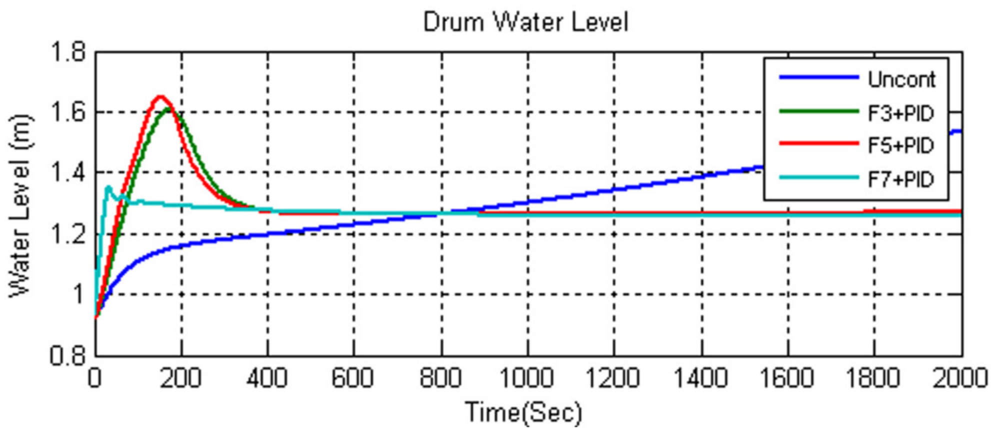

Figure 8: Drum Water Level

VI. RELATED WORK

Firstly, bond graph theory is introduced by Paynter for modeling a basic hydroelectric plant [10]. Kundur [11] and Anderson [12] describe the modeling of a hydroelectric using block diagrams and each block contains the transfer function. However, if it is necessary to change the connection of the elements or introduce new elements or reduce the model, this is difficult. Also, the analysis and control of a hydroelectric plant using block diagrams and simulation are obtained in [13] and [14]. The bond graph approach is applied to model the power system on board a supply vessel [15].

Moreover, the conventional modeling method of thermodynamics is obtained by using the mass balance equation and the energy balance equation and simplifying amounts of variables [16-18]. Because power bond graph based energy conversation law employs generalized power variables to describe different physical process and has advantages for modeling process which couples mechanic, electric, hydraulic and thermal energy [19]. A hybrid bond element named multi-ports C is introduced synchronously coupling hydraulic energy and thermal energy. Then divide the vaporization system to several bond graph subsystem using multiports C to overcome disadvantages with lumped parameters model and integrate them to obtain a complete model of boiler vaporization system [20].

Furthermore, the modeling of power electronic systems using the bond graph formalism is presented in [21]. The switching components are modeled using an ideal representation so that a constant topology system is obtained. The purpose of this study has been the introduction of a technique that combines bond graph energy-flow modeling and signal-flow modeling schemes for simulation and prototyping of signal processing algorithms in power electronics systems.

In addition, the report introduced by Manwell describes the theoretical basis for Hybrid2, a computer simulation model for hybrid power systems [22]. Hybrid power systems are designed for the generation and use of electrical power. They are independent of a large, centralized electricity grid and incorporate more than one type of power source. This manual describes the operation of hybrid power systems and describes the theory behind the Hybrid2 computer code. It is intended to allow the user to understand the details of the calculations and considerations involved in the modeling process. The individual module algorithms in the code (including power system, loads, renewable resource characterization, and economics) are described. In addition, major sections of the report are devoted to detailed summaries and documentation of the code component and subsystem algorithms.

Also Geyer et al. have presented an emergency control scheme capable of predicting and preventing a voltage collapse in a power system, that is modeled as a hybrid system incorporating nonlinear dynamics, discrete events and discrete manipulated variables. Model Predictive Control in connection with the Mixed Logical Dynamical framework is used to successfully stabilize the voltage of a four bus example system [23].

Liu and Wang have introduced an approach toward the design of a hybrid speed control with sliding-mode plus self-tuning PI for induction motors. Simulation results show that good transient and steady state responses can be obtained by applying the proposed control, ie, the system achieves fast response, overshoot suppression, zero steady-state error, and strong robustness [24].

Lastly, in the report given by Alberto Bemporad, a comprehensive study on the application of model predictive control on hybrid systems has been illustrated. This covers state space modeling and control of hybrid systems together with their optimization techniques based on the reachability analysis [25-27].

VII. CONCLUSION

It is very important to have good software tools (HBG) for the simulation, analysis and design of hybrid systems, which by their nature are complex systems. A controller also can be added to the model made by Bond graph that simulate the real system. Fuzzy P+ID controller can be used in the Hybrid Boiler application; by using this controller a good performance in both transient and steady-state periods can be achieved. The structure of the Fuzzy P+ID controller is very simple, since it is constructed by replacing the proportional and integral term in the conventional PID controller with an incremental fuzzy logic controller also particle swarm optimization algorithm is used to obtain the gains of Fuzzy P+ID.

REFERENCES

[1] Monica Roman , "Pseudo Bond Graph Modeling of some prototype Bioprocesses" Department of automatic control, university of Craiova. A.I Cuza no 13, 200585
[2] Belkacem Ould Bouamama, "Model-Based Process Supervision, Springer, Arun K. Samantaray" ,2008.
[3] Mohamed Ahmed "Modeling And Simulation Of Thermal Power Generation Station For Power Control" , 2009.
[4] W. Li, X. G. Chang, Jay Farrell, and F. M. Wahl, "Design Of An Enhanced Hybrid Fuzzy P+ ID Controller For A Mechanical Manipulator", IEEE Transactions On Systems, Man, And Cybernetics—Part B: Cybernetics, Vol. 31, No. 6, December 2001
[5] L.A. Zadeh, "Fuzzy Sets, Inform. And Control", 8, 1965, pp.338-353.
[6] H.A. Malki, H.D. Li, G. Chen, "New Design And Stability Analysis Of Fuzzy Proportional-Derivative Control Systems", IEEE Trans.Fuzzy Systems, 2, 1994, pp 245-254.
[7] D. Misir, H.A. Malki, G. Chen, "Design And Analysis Of Fuzzy Proportional Integral-Derivative Controller", Fuzzy Sets and Systems, 79, 1996, pp. 297-314.
[8] H. Ying, W. Siler, J.J. Buckley, "Fuzzy Control Theory: A Nonlinear Case", Automatica, 26, 1990, pp. 513- 520.
[9] Marwa M. Abdulmoneim, "Modeling, Simulation and Control of Hybrid Power Plants with Application", Unpublished M. Sc. Thesis, Cairo University, Faculty of Engineering, 2011.
[10] H. M. Paynter, "Analysis And Design Of Engineering Systems", MIT press, Cambridge, Mass, 1961.
[11] John R. Kundur, "Power System Stability and Control", Mc-Graw-Hill, 1994
[12] P. M. Anderson, "Power System Control and Stability"", The IOWA state University Press, 1977.
[13] F. Irie, M. Takeo, S. Sato, O. Katahira, F. Fukui, H. Okada, T. Ezaki, K. Ogawa, H. Koba, M. Takamatsu and T. Shimojo, "A Field Experiment on Power line Stabilization by a SMES System", IEEE Transactions on Magnetics, Vol. 28, No. 1 January 1992.
[14] D. B. Arnautovic and D. M. Skataric, "Suboptimal Design Of Hydroturbine Governors", IEEE Transactions on Energy Conversion, Vol. 6, No. 3, September 1991.
[15] Toma Arne Pedersern and Elif Pedersen, "Bond Graph Model Of A Supply Vessel Operating In The North Sea", Proceedings of the 2007 International Conference on Bond Graph Modeling, 2007.
[16] Wang G.J., G.H. Xin, "Thermodynamics And Application", Science press, Beijing, 1997.
[17] H. Rong, Z.Y. Quan, and C.C. Yan, "The Building Of A Natural Circulation Boiler Model For 300MW Thermal Power Plant And Analysis Of The Boiler Dynamic Characteristics", Journal of Engineering for Thermal Energy&Power, 18(4), pp. 399-401, 2003.
[18] L.J. Chen, Z.C. Wang. "A New Model For Two Phase Flow Of Power Plant Boiler System", Journal of System Simulation, 2001,13, 3, pp.370-372.
[19] Karnopp D.C., D.L. Margolis, and R.C. Rosenberg. "System Dynamics: Modeling And Simulation Of Mechatronic Systems", John wiley and sons Inc, New York, 2000.
[20] Xiyun Yang, Yuegang lv, and Daping Xu, "Research On Boiler Drum Dynamic Model With Bond Graph", Proceedings of the First International Conference on Innovative Computing, Information and Control, 2006.
[21] Rui Esteves Araújo, Américo Vicente Leite, Diamantino Silva Freitas, " Modelling And Simulation Of Power Electronic Systems Using A Bond Graph Formalism", Proceedings of the 10th Mediterranean Conference on Control and Automation - MED2002 Lisbon, Portugal, July 9-12, 2002.
[22] J. F. Manwell, A. Rogers, G. Hayman, C. T. Avelar, J. G. McGowan, U. Abdulwahid, K. Wu, "HYBRID2- A Hybrid System Simulation Model Theory Manual", Renewable Energy Research Laboratory, Department of Mechanical Engineering, University of Massachusetts, 2006.
[23] T. Geyer, M. Larsson, and M. Morari, "Hybrid Control Of Voltage Collapse In Power Systems", Technical report, AUT02-12, Automatic Control Laboratory, ETH Zurich, Switzerland, July 2002.
[24] Ziqian Liu and Qunjing Wang, "Hybrid Control With Sliding Mode Plus Self Tuning PI For Electrical Machines", Journal of ELECTRICAL ENGINEERING, VOL. 59, NO. 3, 2008, 113–121.
[25] Alberto Bemporad, "Model Predictive Control Of Hybrid Systems", University of Siena, Italy, Technical Report, 2005.
[26] Wolfgang Borutzky, "Bond Graph Methodology: Development And Analysis Of Multidisciplinary Dynamic System Models", Springer, 2010 , 662 pages
[27] Breedveld, P.C., "Concept-Oriented Modeling Of Dynamic Behavior", In: Bond Graph Modeling Of Engineering Systems : Theory, Applications and Software Support. Springer, New York, 2011, pp. 3-52.

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