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Sliding Mode Control for Pressure Process

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Abstract—Generally Pressure process plant should be controlled in various applications such as Power plants, Chemical Industries, especially in boilers. There are controllers like PID, Model predictive controller, Fuzzy controller, and intelligent controller are used to control the pressure process. Here, the sliding mode controller is implemented to control and observe the pressure process, and then the result of controller is analyzed to give better performance than other controllers.

Keywords — PID, Sliding Mode Control, Process plant, Pressure control.

I. INTRODUCTION

In process control system, sliding mode control (SMC), is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Sliding Mode Control can switch from one continuous structure to another based on the current position in the state space and known as a variable structure control method. The multiple control structures are designed in a way that trajectories always move toward an adjacent region with a different control structure, and the ultimate trajectory will not exist entirely within one control structure. The motion of the system as it slides along these boundaries is called a sliding mode. Sliding mode control evolved from pioneering work in the 1960's in the former Soviet Union [1], [2], [3], [4]. It is a type of Variable Structure System (VSS) which is characterized by a number of feedback control laws and a decision rule. The decision rule, termed the switching function, has its input some measure of the current system behavior and produces as an output the particular feedback controller which should be used at that instant in time. In sliding mode control, Variable Structure Control Systems (VSCS) are designed to drive and constrain the system state to lie within a neighborhood of the switching function. Advantage of this model is that the dynamic behavior of the system may be directly tailored by the choice of switching function essentially the switching function is a measure of desired performance .The closed-loop response becomes totally insensitive to a particular class of system uncertainty.

II. LITERATURE REVIEW

In this chapter, the literature survey conducted on pressure process, model predictive controller for pressure control, fuzzy PID for process control, sliding mode control, SMC for level control and SMC for Antenna Azimuth Position Control are presented.

J. Llanos-Proaño and Marco Pilatasig et al. (2016) describes that the design and implementation of a model predictive control (MPC) applied to a real pressure plant.

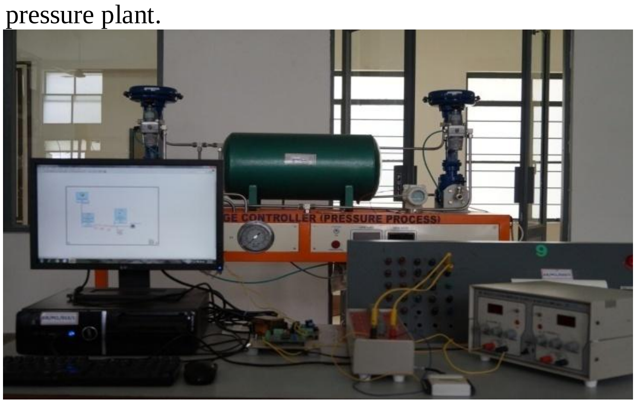

Figure. 1 Experimental Setup of Split Range Pressure Plant

The controller designed is implemented in a PAC device (Programmable Automation Controller), which is used in the industry because PAC has industrial standards and industrial communication protocols. In this work is analyzed the performance of MPC controller, the results are compared with a PID controller. The MPC controller shows a better performance than the traditional PID controller. After the analysis there is less overshot, less setting time, improvement in the actuator operation, which is used to increase the actuator life time. This will improve the operation process using this type of experimental applications.

Yrjo¨ Majanne et al. (2005) describes the control scheme of industrial power plants which leads to a complex multivariable control structure with active constraints. Model Predictive Control (MPC) handles multivariate control problems and optimal control result is calculated actuator limitations and constraints of process variables. MPC is applied to control the pressure stability.

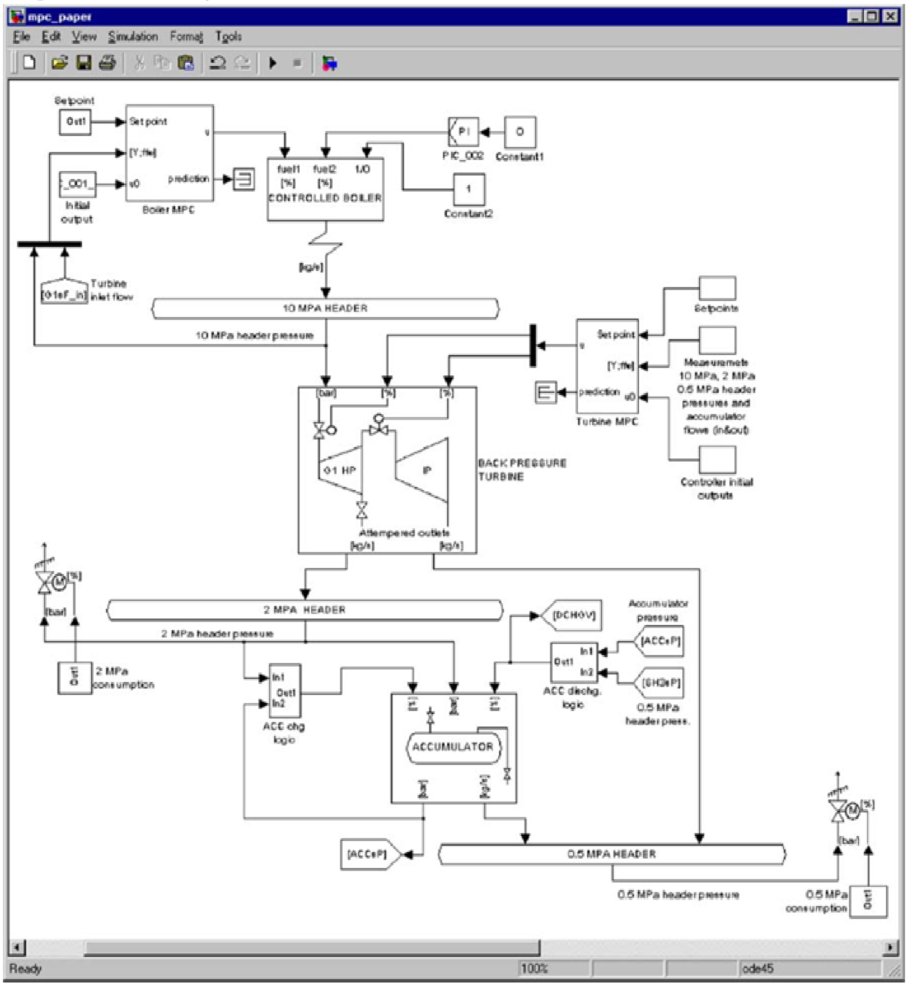

Figure. 2 Power Plant Simulator with the Model Predictive Controllers.

The system is demonstrated in a simulator environment. Model Predictive Control can be used as a convenient tool for analyzing and designing the structure of the steam network. A power plant simulator controlled by MPC helps to decide the location and the capacity of steam level.

CHEN Wei, XING Meixiang and FANG Kangling et al. (2012) describes that the development and designing a fuzzy PID controller using PLC for a set point pressure control problem in the collecting main pressure system. The objective of the controller is to make the collecting pressure attain to the desired range. The collecting main pressure control system uses programmable logic controllers (PLCs) to implement the pressure control action. The proposed fuzzy controller has a combination of a conventional basic PID and a fuzzy compensating controller. There is an inherent interacting effect between two collecting pressure control loops in the collecting main pressure process.

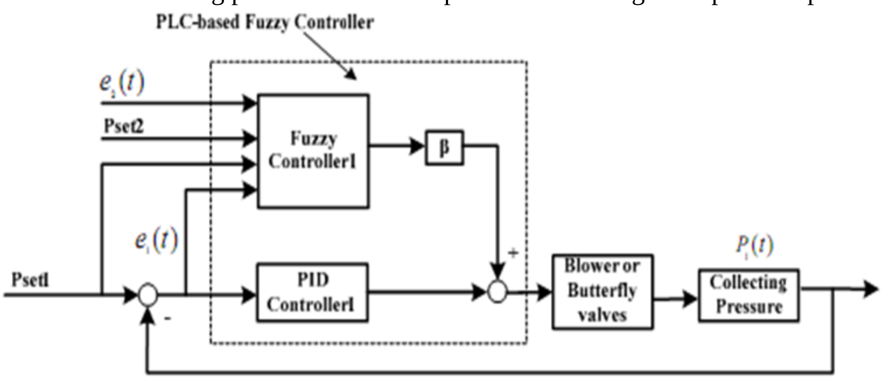

Figure. 3 Structure PLC-Based Fuzzy Controller

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To reduce the pressure error and oscillating in the collection pressures control process, the fuzzy compensating controller configures the control signal based on interacting effect and implement good pressure control performance. The proposed fuzzy PID controller has been tested on a practical collecting pressure control system in Coke-oven. The experience results demonstrate the proposed control method provides an enviable control performance under the practical operating conditions.

Jayabalan Arunshankar and Elumai Govinda Kumar et al.(2016) the design of a Sliding Mode Controller (SMC), with modified PI-D sliding surface, for the control of First Order Plus Dead Time (FOPDT) process. In the modified PI-D sliding surface, error is connected to the proportional and integral elements of the controller, and the derivative of the system output is connected to derivative element of the controller. The usage of PI-D sliding surface eliminates the discontinuous switching in SMC. In this work, the integro-differential equation used for representing the sliding surface of SMC is replaced with PI-D sliding surface. The controller designed is used to obtain the desired closed loop response of the FOPDT system considered, in simulation. The closed loop performance of SMC with integro-differential equation and SMC with PI-D sliding surface are compared.

Selin Aydm Fandakh et al. describe the most important technology that provides communication without selecting location and time is satellite communications undoubtedly.

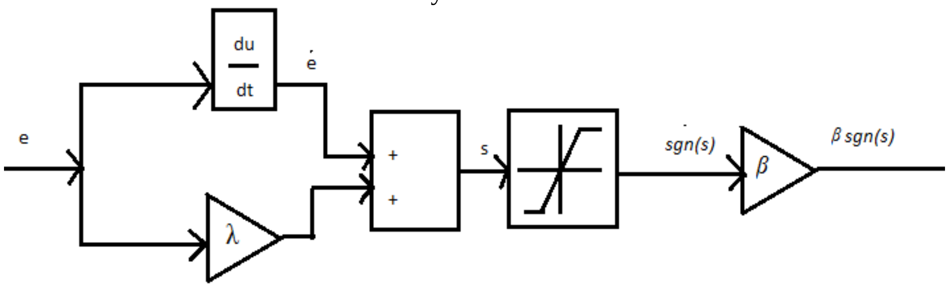

Figure. 4 The block diagram of sliding surface selection

The antenna position control systems are used in providing that communication with high tracing accuracy. The goal of this study is to ensure the minimum angle deviation after the antenna is rotated. For this purpose, the antenna position control system is designed in MATLAB/Simulink and PID, fuzzy logic and sliding mode controllers are performed to the system. The simulation results are compared and the most suitable control method is determined.

III. SURVEY ON CHATTERING REDUCTION TECHNIQUES

The chattering can be eliminated by introducing a boundary layer around the sliding surface. This can be done by continuous approximation of the discontinuous control of sliding mode control using saturation function, tanh function etc. (Husain et al. 2008, Young et al. 1999). However, Slotine and Li (1991) pointed out that this method results in loss of invariance property as the control signal is a linear function of the distance between the actual state and the sliding surface within the boundary layer. Hence, the system possesses robustness that is a function of boundary layer width. This method is highly sensitive to the unmodeled fast dynamics and may lead to unacceptable performance. Also, this method results in a steady-state error that is proportional to the boundary layer thickness (Slotine and Li 1991). Slotine and Li (1991) proposed a class of functions with time-varying parameters to find a compromise between the chattering reduction and the 15 loss of invariance of sliding mode control. However, the tuning of the parameters is cumbersome. Husain et al. (2008) proposed a sliding mode controller with an exponentially decaying function to replace the discontinuous function of the conventional sliding mode controller to reduce chattering while retaining asymptotic stability and robustness. The effectiveness of the proposed approach is verified using its application for stabilization of an active magnetic bearing system. However, the performance of the approach depends on the proper tuning of the exponential function parameters. The tuning of parameters in this method is based on trial and error method. If the parameters are not tuned properly, the method results in unsatisfactory performance.

Another approach to reduce chattering is to use fuzzy logic in the design of sliding mode controllers. In this approach, fuzzy logic control is used to introduce a boundary layer around the sliding surface by fuzzifying the relationship between control signal and the distance between the actual state and the sliding surface, i.e., the sliding surface is fuzzified. As the sliding surface is fuzzified, it is not a hyper-plane anymore. In the two-dimensional case, the sliding surface becomes a band of sliding area, thus introducing a boundary layer around the sliding surface. The control signal changes non-linearly inside the band, thereby retaining the invariance property and robustness. Therefore, this approach reduces the chattering of sliding mode control approach without compromising robustness (Efe et al. 2000, Kaynak et al. 2001, Tao et al. 2010). Palm (1994) proposed a fuzzy logic based sliding mode controller for uncertain systems in which scaling factors of fuzzy variables and rule base are derived using sliding mode control principle. This approach combines the advantages of fuzzy logic 16 control and sliding mode control. The controller assures tracking quality even in the presence of high level of model uncertainties. The chattering in this method is very less compared with sliding mode controller. However, the response and stability of the controller are very difficult to predict. Dotoli (2003) proposed a fuzzy sliding mode controller for a class of second order systems based on a piecewise linear sliding manifold. The controller is robust in the presence of saturated control input and exhibit smooth dynamics without chattering. The effectiveness of the controller is demonstrated through its application for inverted pendulum control. However, fuzzy logic based approaches for eliminating the chattering effect of sliding mode control suffers from the disadvantage of the trial and error design method of the conventional fuzzy logic control. If not designed properly, it may lead to adverse effects. Moreover, the response and the stability of the system with fuzzy logic controllers are not easy to predict (Raviraj and Sen 1997).

IV. SECOND ORDER SLIDING MODE CONTROL

Second order sliding mode control is an effective scheme for the elimination of chattering. Second order sliding mode control generalizes the basic sliding mode idea acting directly on the second order time derivative of the sliding variable instead of first order time derivative as in standard sliding modes (Bartolini et al. 1999, Bartolini et al. 2000, Bartolini et al. 2004, Bartolini et al. 2009, Boiko et al. 2007, Boiko et al. 2008, Capisani et al. 2009, Djemai et al. 2011, Lee and Utkin 2007, Moreno 2012, Pukdeboon 2012, Zong et al. 2010). Bartolini et al. (1999) presented a collection of second order sliding mode control algorithms. Bartolini et al. (2000) pointed out that second order sliding mode control approach in its original 17 formulation is applicable only to single input systems with particular types of uncertainties. They modified this approach to extend for multiple input systems having uncertainties of more general, covering a wide range of real processes. Bartolini and Punta (2000) presented a second order sliding mode control algorithm for the stabilization problem for a mechanical system as a solution to the chattering elimination problem as well as robust against discontinuous disturbances such as friction. The method is effective in avoiding complex stick-slip phenomenon as no oscillations or overshoot take place during the transients. Bartolini et al. (2004) proposed a second-order sliding-mode control approach by explicitly taking into account the presence of measurement error with an unknown upper bound. They presented simulations to highlight the high robustness and the chattering reduction of the proposed approach. Bartolini et al. (2009) presented the implementation of a second sliding mode control algorithm for a class of systems in which the sign of the constant high frequency gain is unknown. The controller is able to deal with uncertain sign and exhibit robust performance. Capisani et al. (2009) presented the effectiveness of second order sliding mode controller as a robust controller for robot manipulators. The controller exhibit good tracking performance. The controller is robust to model uncertainties and perturbations and reduces chattering compared with the conventional sliding mode control. However, the conventional second order sliding mode control suffers from the disadvantage that its implementation demands the increasing information in terms of the first time derivative of the sliding variable in addition to the sliding variable compared with the standard first order sliding mode control (Gonzalez et al. 2012).

Yuanyuan Zhang, Renfu Li, Tao Xue, Zhimin Liu and Zongxin Yao et al. addresses the stability and chattering

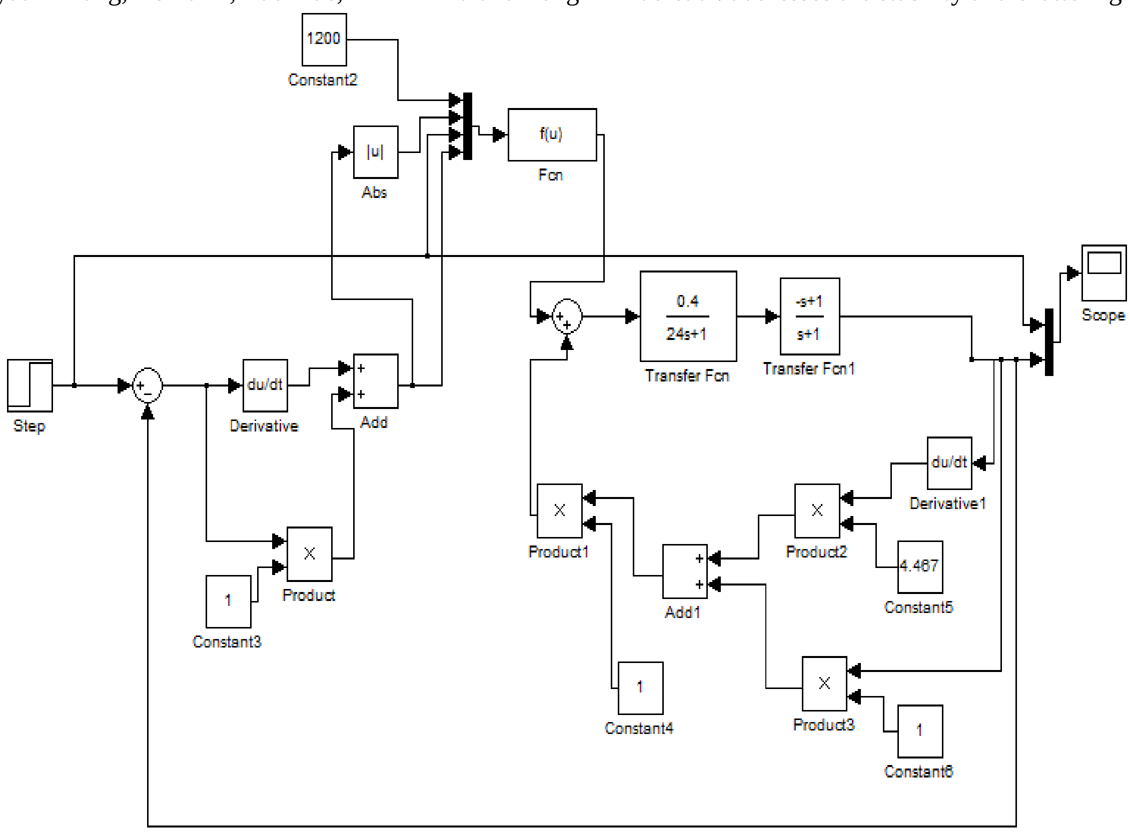

Figure. 5 Block Diagram of Sliding Mode Control

Reduction issue of the high-order slid- ing mode tracking control for a hypersonic vehicle. Quasi-continuous third order mode (Q3OSM) and fourth order sliding mode (Q4OSM) controllers are proposed for the track- ing control of velocity and altitude of the aircraft, respectively. To alleviate the chattering phenomena, a method incorporating the idea of artificial increase of the relative degree in quasi-continuous high-order sliding mode (QHOSM) is introduced. In the meanwhile, the transient time function is constructed using the initial values of the output and their derivatives through the homogeneous technique. Comparison of the results by QHOSM control with those by classical sliding mode control

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(SMC) is presented. It is shown that QHOSM controller delivers a high dynamic tracking performance and can reduce chattering phenomena significantly. It is also shown that the resulting controller has strong robustness to parameter uncertainties. Simulation results demonstrate the effectiveness of the controller design methodology.

V. CONCLUSION

From the literature review, it is concluded that sliding mode control scheme is a well known robust control scheme for dynamic uncertain systems. However, sliding mode control suffers from the dangerous chattering effect which prevents them from being extensively used in practice. Also, the performance of sliding mode control depends heavily on the sliding surface. If the sliding surface is not designed properly, it may lead to adverse effects. Though, there are many methods in the literature to improve the performance of sliding mode controller using time-varying sliding surface, including fuzzy logic control based time-varying sliding surface, these methods do not address the problem of the chattering effect. Second order sliding mode control scheme is an effective scheme for eliminating the chattering effect. However, the increased information demand in terms of the time derivative of the sliding variable is the main disadvantage which prevents the conventional second order sliding mode control scheme from being extensively used in practice. Super-twisting 22 sliding mode control scheme is a modified approach which solves the increased information demand of the conventional second order sliding mode controller. Super-twisting sliding mode control scheme does not require the time derivative of the sliding variable and eliminates the chattering effect. However, the performance of super-twisting sliding mode control heavily depends on the sliding surface. If the sliding surface of super-twisting sliding mode controller is not designed properly, it may lead to unacceptable performance. The selection of optimum sliding surface is tedious and a complicated task. Thus, the method of adjusting sliding surface online is an important topic in the super-twisting sliding mode controlled systems.

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