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Controlling Non-linearity at High Voltage using Sliding Mode Controller compared to Proportion Integral Controller

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ABSTRACT:

This paper presents a nonlinear controller for High Voltage DC Transmission system using sliding mode control strategy. It is expected that in future the use of High Voltage DC technology will expanded. The conventional proportional-integral type control system loops for the current and extinction angle controllers in high voltage dc converters are replaced with Sliding Mode based control.. The two approaches are compared on CIGRE benchmark model using simulations on MATLAB/SIMULINK. A method to further refine the sliding mode control to improve the transient response is presented. The results show that the sliding mode control based approach can provide, at the minimum, a marginal improvement over the P-I based controller.

Keywords:

HVDC technology, PI controller, GSMC, SMC, BSM, Monopole

INTRODUCTION:

High voltage direct current (HVDC) transmission is a technology based on high Power electronics and used in electric power systems for long distances power transmission, connection of non-synchronized grids and long submarine cable transmission . It is an efficient and flexible method to transmit large amounts of electric power over long distances by overhead transmission lines or underground/submarine cables. It can also be used to interconnect asynchronous power systems.

The first commercial HVDC connecting two AC systems was a submarine cable link between the Swedish mainland and the island of Gotland.While power lost in transmission can also be reduced by increasing the conductor size, larger conductors are heavier and more expensive. High voltage cannot readily be used for lighting or motors, so transmission-level voltages must be reduced for end-use equipment. There are three types of DC transmission lines. They are mono polar, bi polar and homopolar. This paper aim is to control nonlinearities in the system and insensitive to parameter variations.

PRINCIPLE:

The Benchmark Simulation Model (BSM) is a detailed protocol for implementing, analyzing and evaluating the impact and performance of both existing and novel control strategies applied to wastewater treatment plants (WWTPs). The diagram of benchmark simulation model is shown below fig.1. For interfacing between the two AC systems in that case we are using benchmark model.

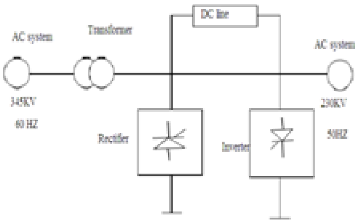

Fig.1: Basic block diagram for Benchmark model.

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PROPORTIONAL&INTEGRAL CONTROLLER:

Integrator will decrease the stability of the system. And variation of gain is toughest task in control system. So we use different types of controllers. In proportion control oscillations are decreases, t_r (rise time) increases, and then peak over shoot is decreases. Here the PI control having two representations according to Benchmarking model that is rectifier side and inverter side which is shown in fig.2 and fig.3.At rectifier side we are controlling current whereas at inverter side controlling voltage.

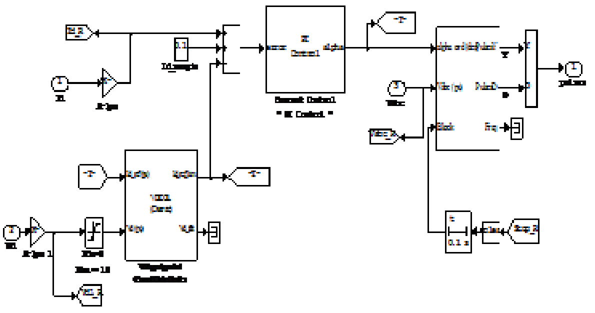


FIG.2.PI control at rectifier side

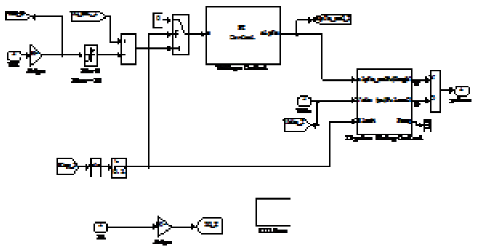


FIG.3.PI controller at inverter side

SLIDING MODE CONTROL:

Generally sliding mode control is a mathematical control. And it is a first order system. And in sliding mode control, no. of types is there. But here we can use the Global Sliding Mode Control for an Uncertain System method is used for HVDC transmission system.

- *Global Sliding Mode Control for an Uncertain System:*

Global sliding mode control can be obtained by designing an equation of dynamic nonlinear sliding surface. Global sliding mode control eliminates the attaining motion phase and ensures that the whole process of system response is robust. Thus, the drawback of the traditional sliding mode variable structure which has no robustness in the attaining mode is overcome. The digital control system structure is shown in Fig.2, and the corresponding program diagram of the system is shown in Fig.3.

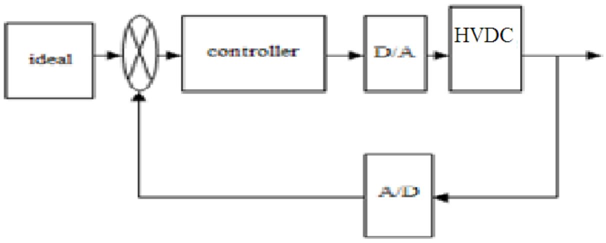


Fig.4. Digital control system structure

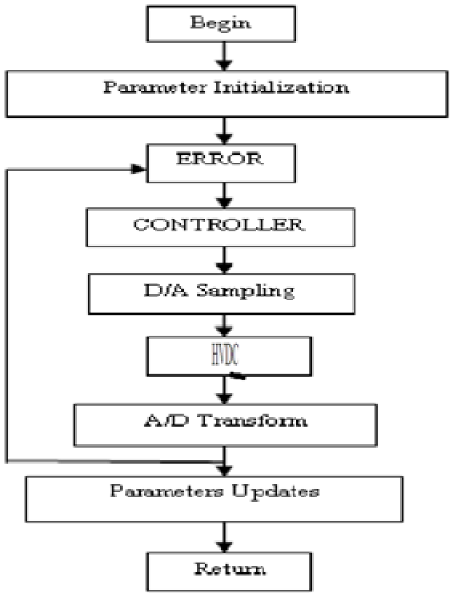


Fig.5. Program diagram of digital control algorithm

Global Sliding Mode Design:

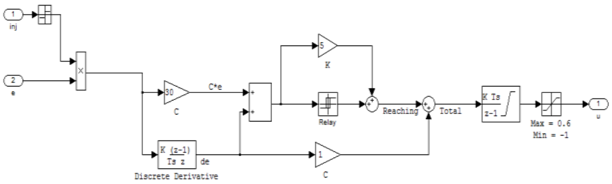


Fig.6. Sliding Mode Control

$$S = ce + \frac{de}{dt} - f(t) \text{ ---(1)}$$

Where s = output of sliding

$\frac{de}{dt}$ = derivative of error = e'

f(t) = sliding surface

c = surface gain

e = error

Where *c* must satisfy Hurwitz condition

c > 0. The tracking error and its derivative value is

$$e(t) = r - \theta(t),\ e^1(t) = r^1 - \theta^1(t)$$

Where *r* = desired quantity or ideal position signal.

θ = measured quantity.

$$S = c.e(t) + \frac{de}{dt} \text{ ---(2)}$$

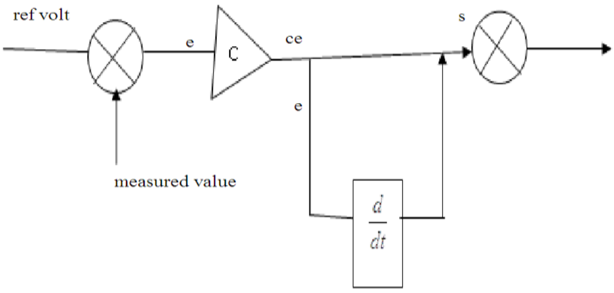


Fig .7. Block diagram of global sliding mode

The global sliding mode controller is designed as

$$u = -\hat{J}\left(c\dot{\theta} - \dot{f}\right) + \hat{J}\,(\ddot{\theta}d + c\dot{\theta}d) \quad -(\Delta J\left|\left(c\dot{\theta} - \dot{f}\right)\right| + D + \Delta J\left|\ddot{\theta}d + c\dot{\theta}d\right|) \text{---(3)}$$

where, $\hat{J} = \frac{Jmax+Jmin}{2}$

$$\Delta J = \frac{Jmax-Jmin}{2} \quad \text{-------(a)}$$

Let the Lyapunov function be

$$V = \frac{1}{2}s^2$$

From Eq. (2), we have

$$\begin{aligned}\dot{s} &= \ddot{e} + c\dot{e} - \dot{f}\\ &= (\ddot{\theta} - \ddot{\theta}d) + C(\dot{\theta} - \dot{\theta}d) - \dot{f}\\ &= bu - bd + (c\dot{\theta} - \dot{f}) - (\ddot{\theta}d + c\dot{\theta}d) \qquad \textbf{-(4)}\\ &= b[b^{-1}(c\dot{\theta} - \dot{f}) - b^{-1}(\ddot{\theta}d + c\dot{\theta}d) + u - d)\end{aligned}$$

and from Eq. (3), we have

$$\begin{aligned}b^{-1}\dot{s} = {} & b^{-1}(c\dot{\theta} - \dot{f}) - b^{-1}(\ddot{\theta}_d + c\dot{\theta}_d) - \hat{J}(c\dot{\theta} - \dot{f})\\ & + \hat{J}(\ddot{\theta}_d + c\dot{\theta}_d) - \{\Delta J|c\dot{\theta} - \dot{f}| + D\\ & + \Delta J|\ddot{\theta}_d + c\dot{\theta}_d|\mathrm{sgn}(s) - d\end{aligned}$$

$$= (b^{-1} - \hat{J})(c\dot{\theta} - \dot{f}) - \Delta J|c\dot{\theta} - \dot{f}|sgn(s) - (b^{-1} - \hat{J})(\ddot{\theta}_d + c\dot{\theta}_d) - \Delta J|\ddot{\theta}_d + c\dot{\theta}_d|sgn(s) - d - Dsgn(s) \quad \text{-----(5)}$$

Therefore,

$$b^{-1}\dot{V} = b^{-1}s\dot{s} = (b^{-1} - \hat{J})(c\dot{\theta} - \dot{f})s - \Delta J|c\dot{\theta} - \dot{f}||s| - (b^{-1} - \hat{J})(\ddot{\theta}_d + c\dot{\theta}_d) - \Delta J|\ddot{\theta}_d + c\dot{\theta}_d||s| - ds - D|s| \quad \text{------(6)}$$

From Eq. (a), we get

$$b^{-1} - \hat{J} = J - \frac{Jmax + Jmin}{2} \le \frac{Jmax - Jmin}{2} = \Delta J > 0$$

Therefore,

$$b^{-1}\dot{V} = -ds - D|s| < 0 \quad \text{--------(7)}$$

i.e.,
$\dot{V} < 0$ ----(8)

In order to reduce the chattering phenomenon, the saturated function can be
Used, i.e.,

$$sat\left(\frac{\sigma}{\emptyset}\right) = \begin{cases} \frac{\sigma}{\emptyset} & \left|\frac{\sigma}{\emptyset}\right| \le 1 \\ 1 & \frac{\sigma}{\emptyset} > 1 \\ -1 & \frac{\sigma}{\emptyset} < 1 \end{cases} \quad \text{-----(9)}$$

Simulation Example

Let the plant be

$$J\ddot{\theta} = u(t) - d(t)$$

where J =1.0 + 0.2sin t, $d(t)$ =0.1+sin(2Π t).

The use of saturated function can reduce the chattering phenomenon effectively.

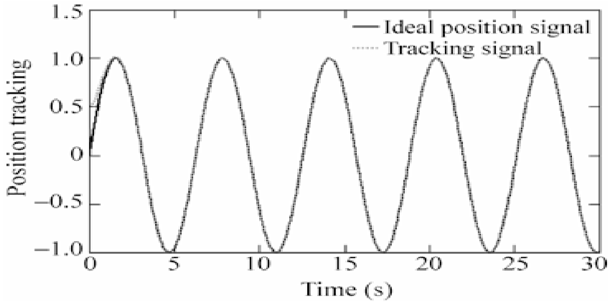


Fig .8. Position tracking

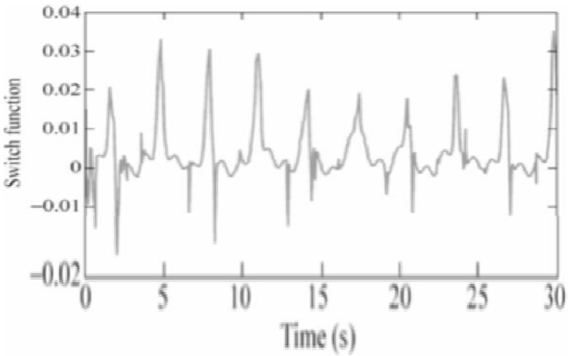


Fig.9. Switch function

Surface Representation of PI and SMC:

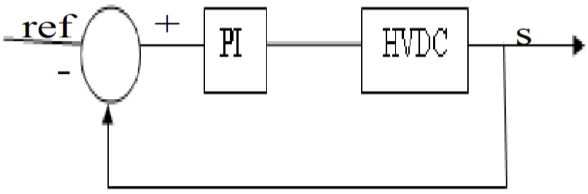


Fig.10. Diagram of Surface Representation

Sliding Mode Control Based On Reaching Law:

Sliding mode based on reaching law includes reaching phase and sliding phase. The reaching phase drive system is to maintain a stable manifold and the sliding phase drive system ensures slide to equilibrium. The idea of sliding mode can be described as Fig

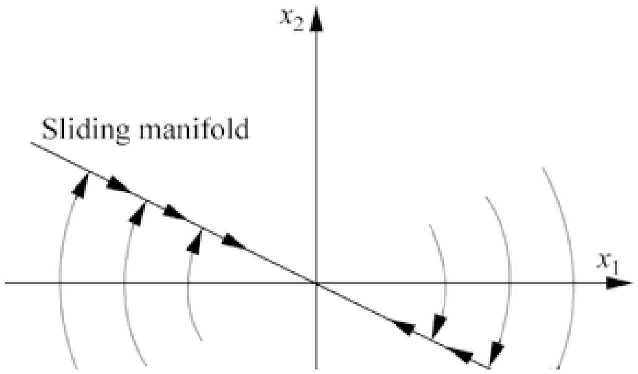


Fig.11. The idea of sliding mode

Sliding surface + reaching law = sliding mode control

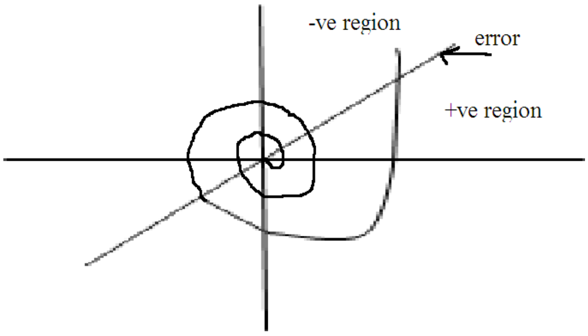


Fig.12. The idea of sliding mode

RESULTS:

There are two situations are demonstrated they are steady state and step response. For Easier viewing, only the waveforms of single phase are shown.

Per Unit System comparing PI and SMC:

1 pu voltage = 500 kV DC , 1pu Current = 2000A

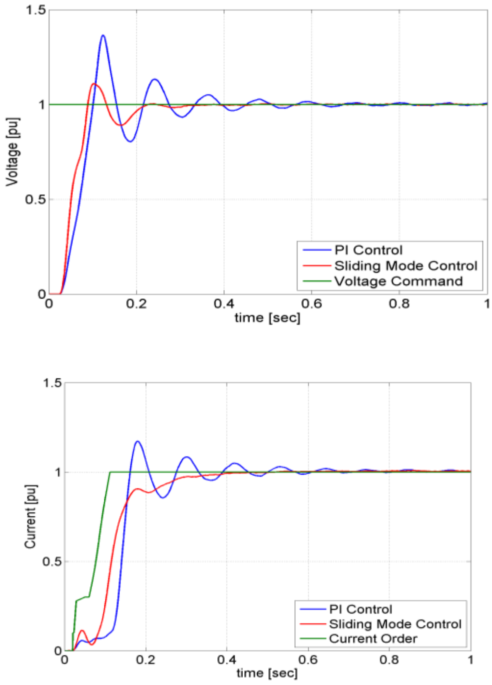


Fig.13.1. The DC Voltage and current response in P.U system

Figure.13.1. plots are DC Voltage and Current response in p.u. These are the response at the time of starting [0 sec to 1 sec]. which show how HVDC starts and ramp up. In the above diagram of Voltage and current response we are comparing proportional and integration control & sliding mode control in per unit. Here one p.u voltage is considered as 500kv and one p.u current is considered as 2000A at the time of starting[0 sec to 1sec].

AC FAULT comparing PI and SMC:

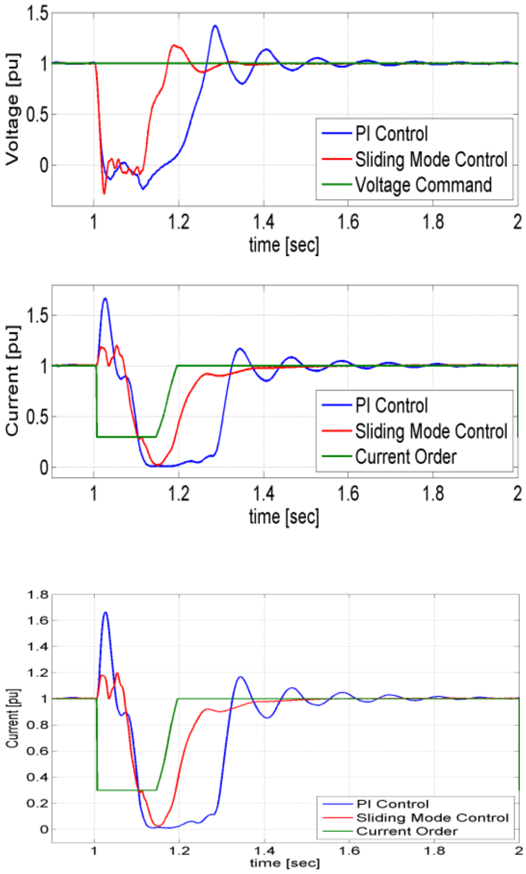
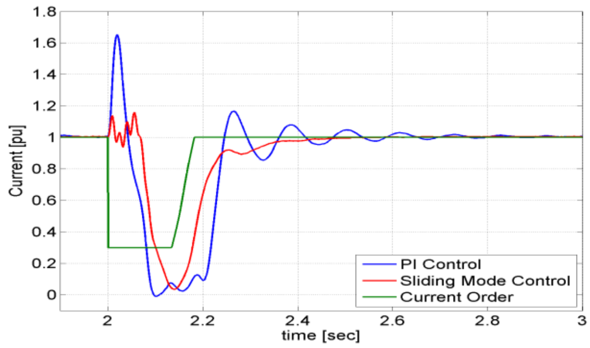


Fig.13.2. voltage and current response of the ac fault system

Fig.13.2 shows at t= 1 sec 3ph fault is created. Above are voltage and current responses. In the above diagram of AC Voltage and current response we are comparing proportional and integration control & sliding mode control in three phase system.

DC FAULT comparing PI and SMC:

According to fig.15 at t= 2 sec DC fault is created. Above are voltage and current response with pi and Sliding Mode Control. In the above diagram of the Voltage and current response we are comparing proportional and integration control & sliding mode control in dc system.Here at 2 sec time the dc fault is created.



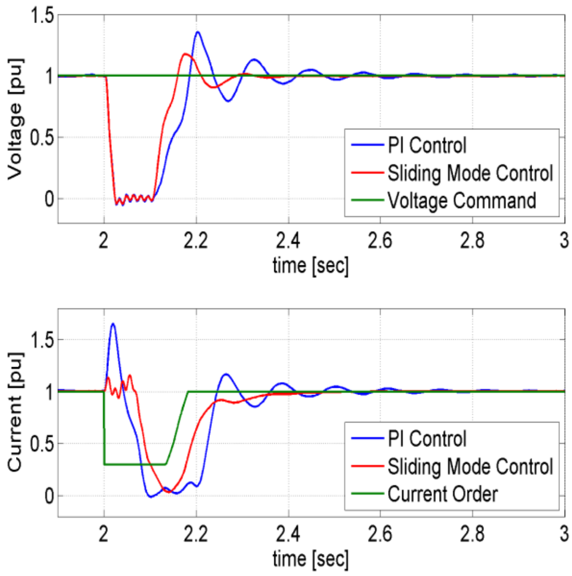


Fig.13.3. DC voltage and current response of the sytem

LOAD:

At t=3 sec current order changes from 1 pu to 0.5 puie., 50% change in Load and at t=4 sec current Order again increases to 1 pu. From Above Fig.16 plots sliding Mode control Shows best performance and better non linearity

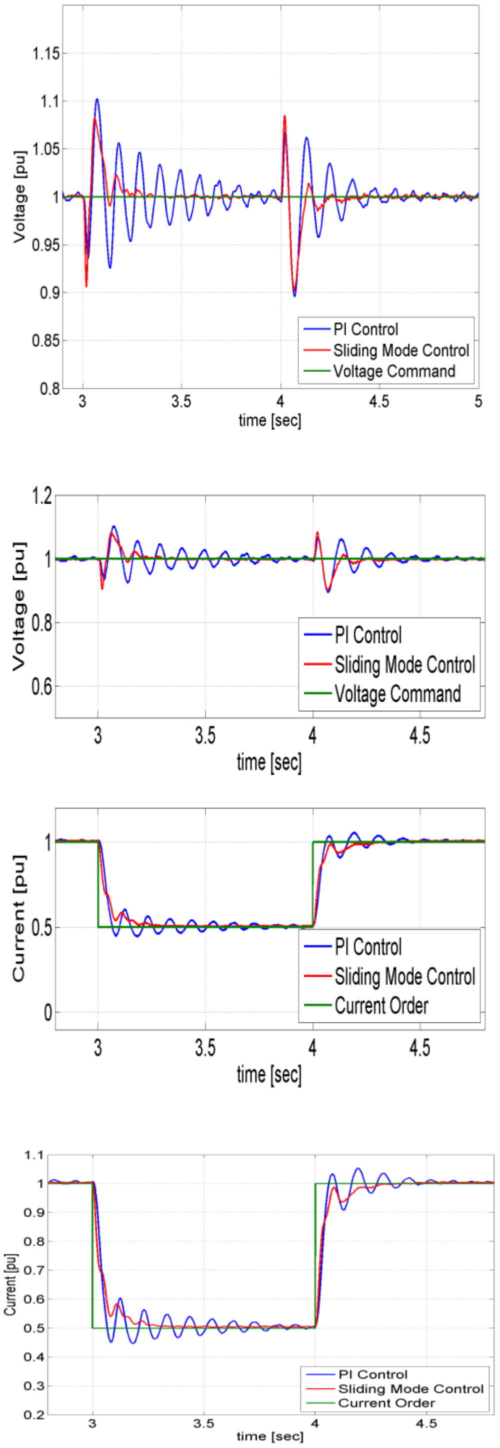


Fig.13.4.The load voltage and current response

CONCLUSION:

In paper the application of the sliding mode control was studied and presented. Sliding Mode control of HVDC systems was investigated. The effectiveness of the proposed controller is tested on CIGRE benchmark model. This proposed controller takes care of nonlinearities in the system and insensitive to parameter variations. This proposed strategy is very effective and guarantees good robust performance both in steady state and transient stability. HVDC system based on sliding mode algorithm shows good performance compared with convectional control.

FUTURE SCOPE:

The scope of this work is the modeling and simulation of HVDC transmission system with sliding mode controller. In this sliding mode controller the drawback is chattering. We have to nullify the chattering in Experimental investigations will be done in future.

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