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Testing of HVDC Transmission using SMC System in Relation to PI Controller

B. Prasanna Lakshmi[1], K. Ramesh[2], R. Kiranmayi[3]
[1]*Research Scholar, Electrical Engineering, JNTUCE, Ananthapur, India*
[2]*Professor, EEE, Kuppam Engineering College, Kuppam, AP, India*
[3]*Professor, Dept. of EEE, JNTUCE, Ananthapur, AP, India*

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 be 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 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, Propagation Integral (PI) controller, Sliding Mode Controller (SMC)

I. INTRODUCTION

In a general power system, the generated electrical runs to customers through the transmission and distribution network. High voltage is used for electric power transmission to reduce the energy lost in the resistance of the wires. For a given quantity of power transmitted, doubling the voltage will deliver the same power at only half the current. Since the power lost as heat in the wires is proportional to the square of the current for a given conductor size, but does not depend on the voltage, doubling the voltage reduces the line losses per unit of electrical power delivered by a factor of 4. 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.

II. BENCHMARK MODEL

The Benchmark Simulation Model No 2 (BSM2) 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 basic block diagram of bench mark model -2 is shown below fig.1.

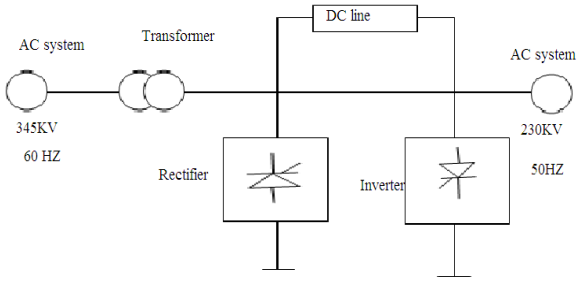


Fig 2.1**:** Basic block diagram for Bench mark model-2

For interfacing between the two AC systems in that case we are using bench mark model. Consider two ac systems as shown in above.AC to AC direct interface is not possible in this system. Here we are using monopolar configuration. So that, here we

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having rectifier and inverter. Generally, rectifier can be converts the AC power into DC power and inverter converts DC to AC power. In this way we are interfacing between the two AC systems. In rectifier we are having more harmonics to reduce the harmonics we are using the transformer. Generally transformers are mainly used for varying voltage and harmonic nullify components elimination and filter purpose also we are using the transformer.

III. CONTROLLERS OF HVDC SYSTEM

The HVDC system is represented by the CIGRE first. HVDC Benchmark model which is mainly used for the simulation study of the HVDC transmission systems .The CIGRE HVDC system is mono-polar and each rectifier and inverter station is rated 500kV, 1000MW.The rectifier side is connected to a relatively strong AC system. The rectifier and the inverter are interconnected through a 300 km distributed parameter line and two 0.5H smoothing inductor.

A. Rectifier and inverter control

Mainly, the CIGRE HVDC benchmark system consists of two control model. The rectifier control is provided with a Constant Current (CC) controller to maintain the DC link current constant and the inverter is equipped with a Constant Extinction Angle (CEA) controller and the CC controller. The DC link current at the rectifier end is compared with reference current which obtained from the inverter controller output to produce error signal. By subtracting the measured current with reference current and input signal $u1$, the error signal is obtained. The error signal is then passed through the PI controller to produce required firing angel α at rectifier valves. The current controller block diagram for rectifier is shown in Figure 1. The rectifier, moreover, is provided with an α limit control. In the CC control mode, tap changer control of the converter transformer brings α within range of 10° to 20°.

The rectifier fringe angle decreases until it reach the min limit, if there is a reduction in voltage at the rectifier end. Under normal conditions, nominal angle in rectifier control (α) is regulated to a value of about 15°.

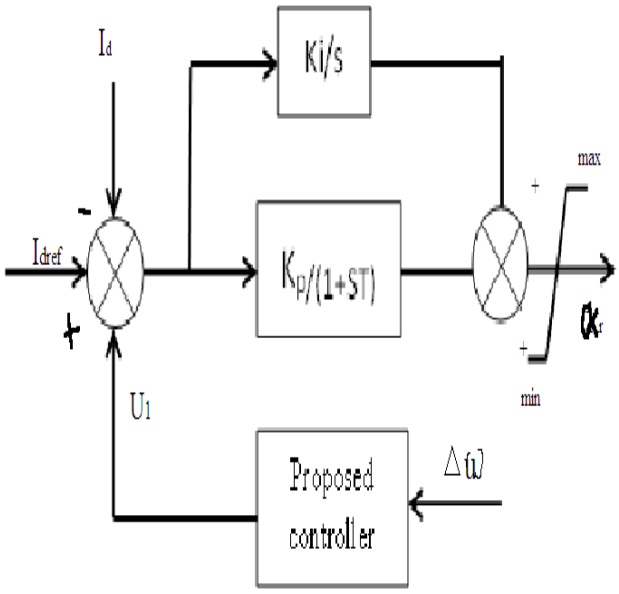


FIG.3.1.Rectifier current controller

Generally, there are many controllers in the control systems. In this HVDC we can use two types controls according to the efficiency, accuracy we can choose sliding mode control and proportion and integral control.

IV. HVDC USING PI CONTROL

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 roportion 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

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shown in fig.4.1 and fig.4.2.At rectifier side we are controlling current whereas at inverter side controlling voltage.

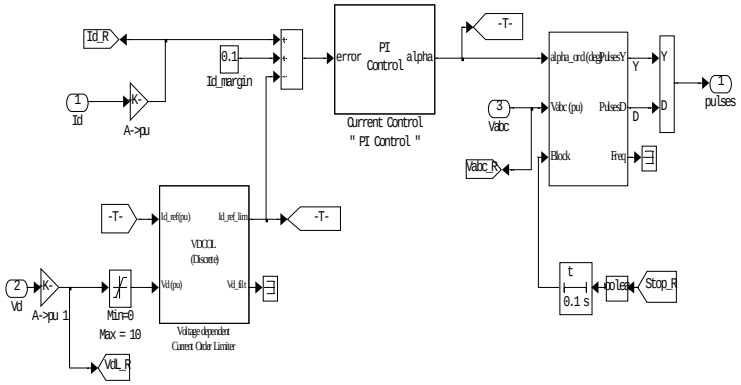


FIG.4.1.PI control at rectifier side

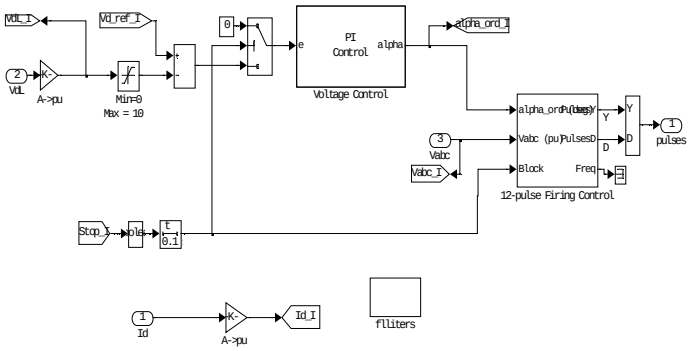


FIG.4.2.PI controller at inverter side

V. 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.

A. 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. 4.1, and the corresponding program diagram of the system is shown in Fig.4.2.

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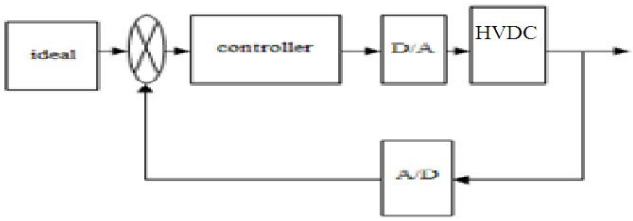


Fig.5.1. Digital control system structure

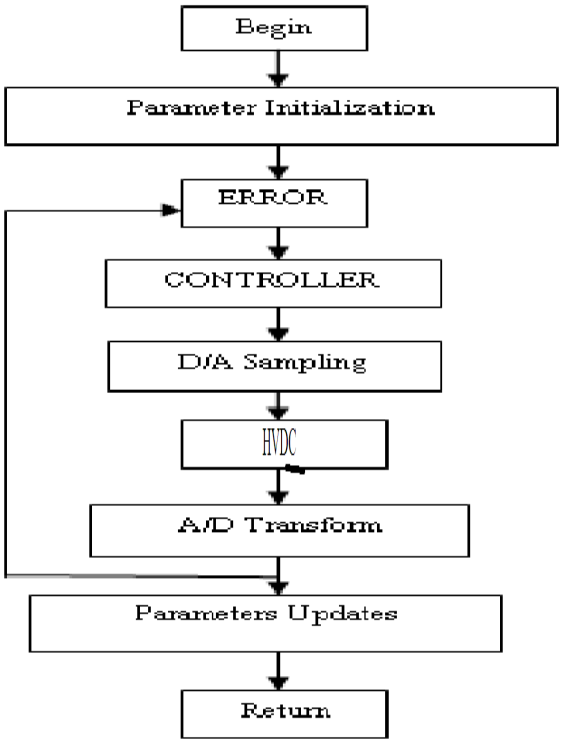


Fig.5.2. Program diagram of digital control algorithm

B. Global Sliding Mode Design

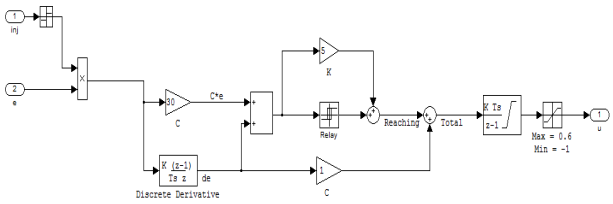


Fig.5.3. Sliding Mode Control

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

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.

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

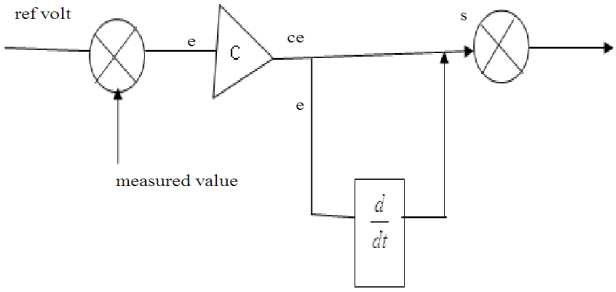


Fig .5.4. Block diagram of global sliding mode

The global sliding mode controller is designed as

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

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

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

Let the Lyapunov function be

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

From Eq. (2), we have

$$\dot{s} = \ddot{e} + c\dot{e} - \dot{f}$$

$$= (\ddot{\theta} - \ddot{\theta}d) + C(\dot{\theta} - \dot{\theta}d) - \dot{f}$$

$$= bu - bd + (c\dot{\theta} - \dot{f}) - (\ddot{\theta}d + c\dot{\theta}d) \quad \textbf{-(4)}$$

$$= b[b^{-1}(c\dot{\theta} - \dot{f}) - b^{-1}(\ddot{\theta}d + c\dot{\theta}d) + u - d)$$

and from Eq. (3), we have

$$b^{-1}\dot{s} = b^{-1}(c\dot{\theta} - \dot{f}) - b^{-1}(\ddot{\theta}_d + c\dot{\theta}_d) - \hat{J}(c\dot{\theta} - \dot{f}) + \hat{J}(\ddot{\theta}_d + c\dot{\theta}_d) - \{\Delta J\left|c\dot{\theta} - \dot{f}\right| + D + \Delta J\left|\ddot{\theta}_d + c\dot{\theta}_d\right|sgn(s) - d$$

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

Therefore,

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

From Eq. (a), we get

$$b^{-1} - \hat{f} = f - \frac{fmax + fmin}{2} \leq \frac{fmax - fmin}{2} = \Delta f > 0$$

Therefore,

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

i.e.,

$\dot{V} < 0$ ----(8)

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

$$sat\left(\frac{s}{\phi}\right) = \begin{cases} \frac{s}{\phi} & \left|\frac{s}{\phi}\right| \leq 1 \\ 1 & \frac{s}{\phi} > 1 \\ -1 & \frac{s}{\phi} < 1 \end{cases} \quad \text{-----(9)}$$

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(2 Π t).

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

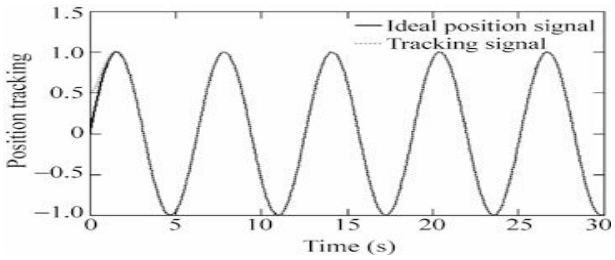


Fig .5.5. Position tracking

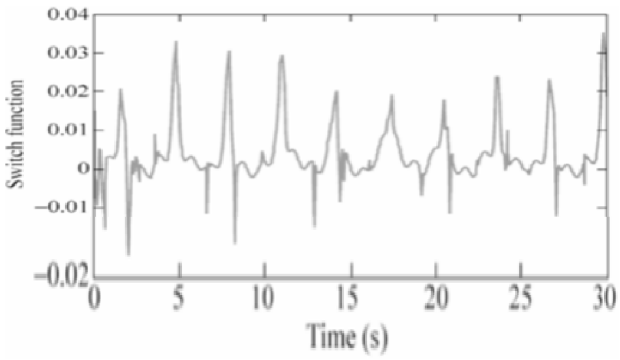


Fig.5.6. Switch function

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C. Surface representation of pi and smc

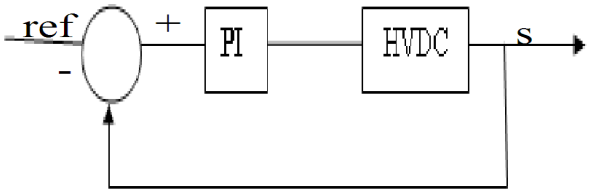


Fig.5.7. Diagram of Surface Representation

D.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

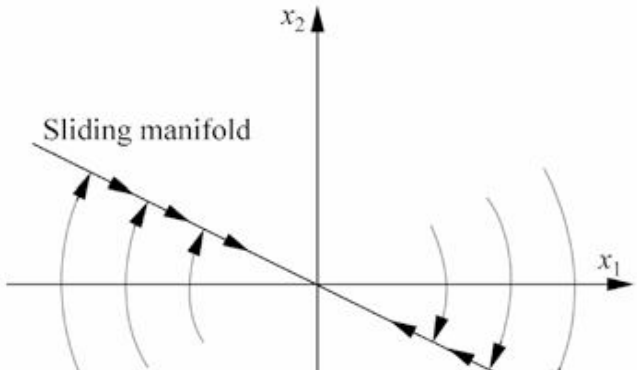


Fig.5.8**.** The idea of sliding mode

Sliding surface + reaching law = sliding mode control

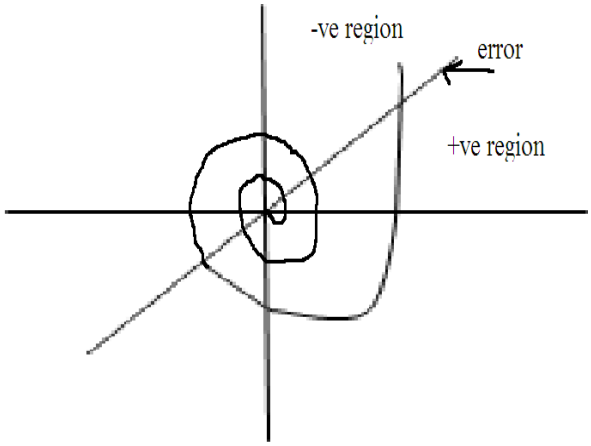


Fig.5.9. The idea of sliding mode

VI. RESULTS AND DISCUSSION

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

A. Per Unit System comparing PI and SMC

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

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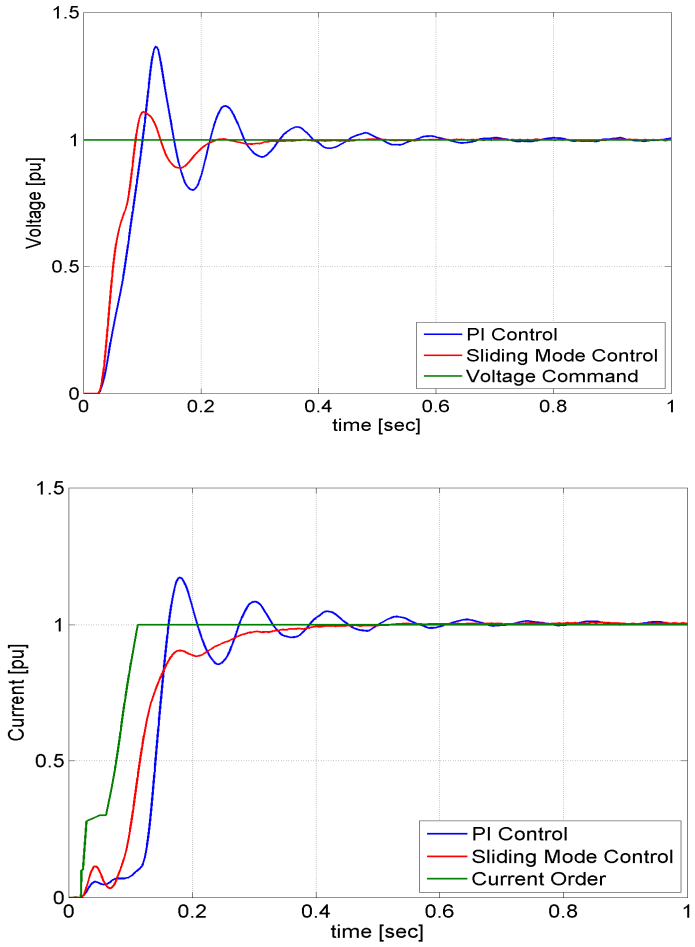
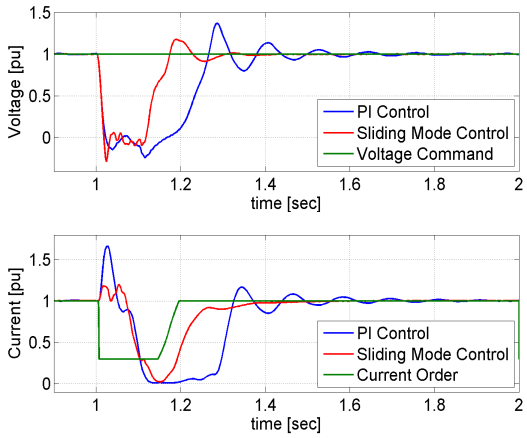


Fig.6.1. The DC Voltage and current response in P.U system

Figure.6.1. 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].

B. AC FAULT comparing PI and SMC



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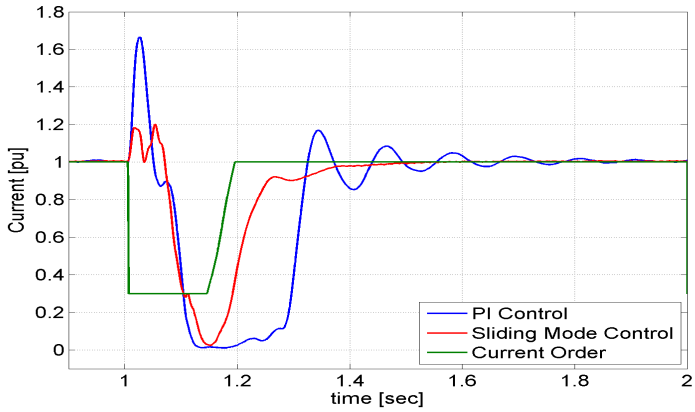


Fig.6.2. voltage and current response of the ac fault system

Fig.6.2 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.

C. 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

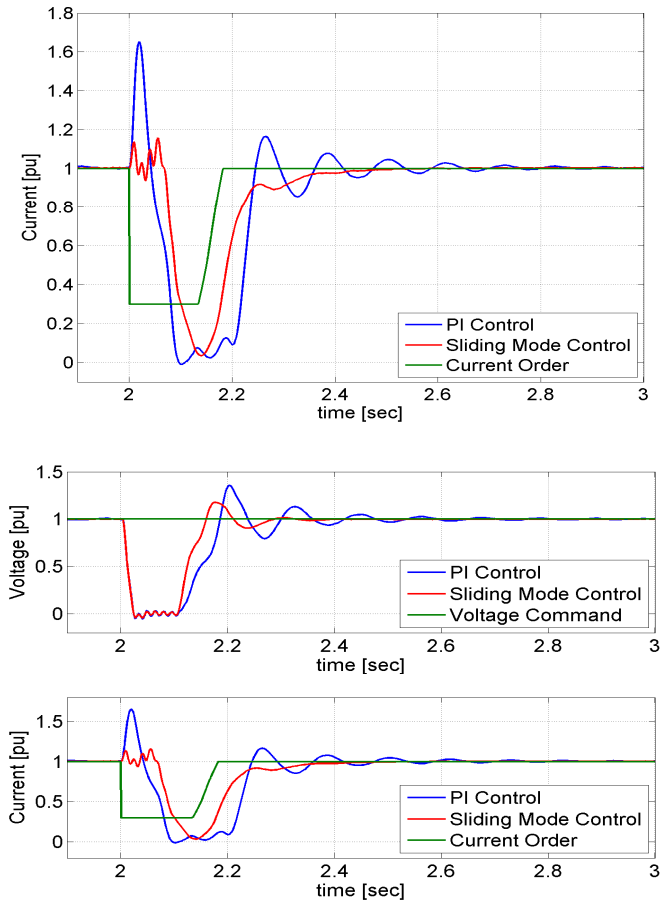
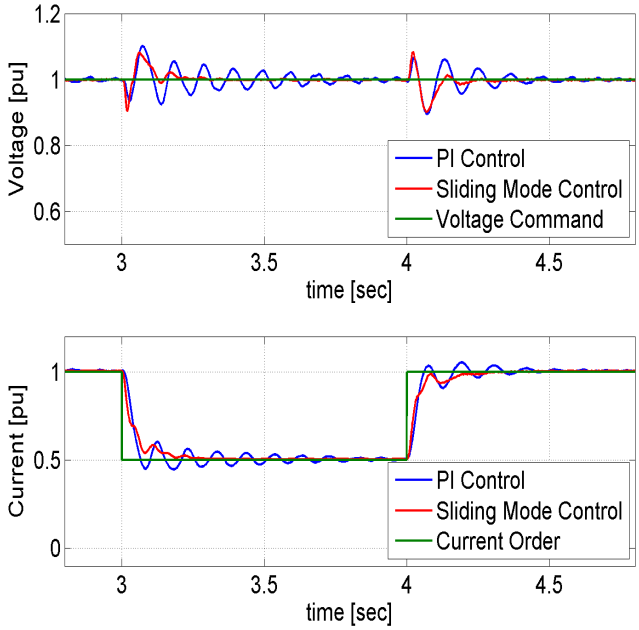


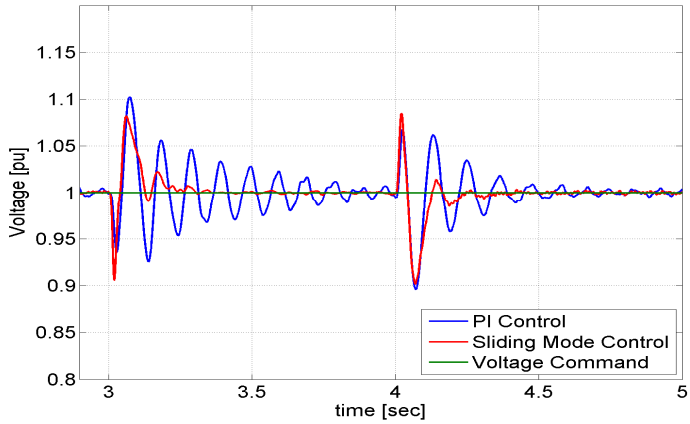
Fig.6.3. DC voltage and current response of the sytem comparing proportional and integration control & sliding mode control in dc system. Here at 2 sec time the dc fault is created.

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D.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





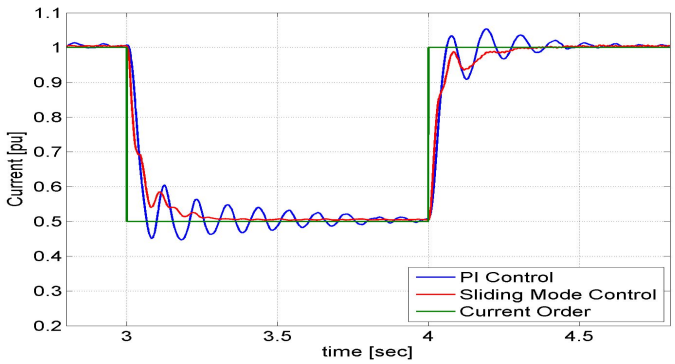


Fig.6.4.The load voltage and current response

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III. 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.

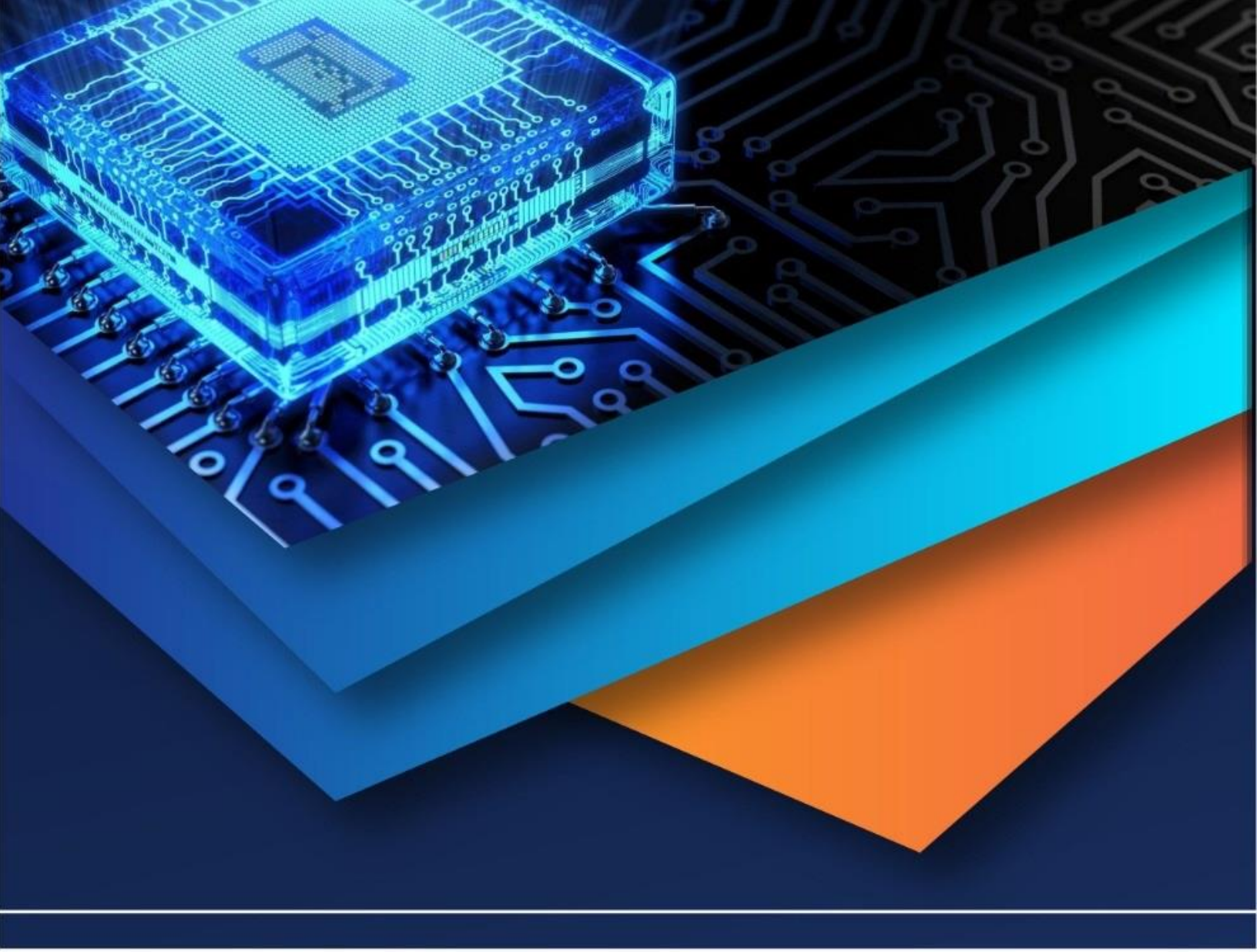
IV. FUTURE SCOPE

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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