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RESEARCH ARTICLE

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ENHANCEMENT OF POWER SYSTEM STABILITY USING SLIDING MODE CONTROL BASED HVDC SYSTEM CONTROL

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ABSTRACT

In this paper, investigation is carried out for the improvement of power system by utilizing auxiliary controls for controller model and the line dynamics are considered in the stability analysis. Transient stability analysis is done on a multi-machine system, where, a sliding mode controller is developed to improve the stability and robustness in the power system and to improve the response time of the controller to changing conditions in power system. The results show the application of the sliding mode controller in the AC-DC power systems and case studied under transients.

Key Words—HVDC controller, SMC, CIGRE model, PI controller and ANN.

I. INTRODUCTION

With developing industrialization, power generation and demand are increasing very fast. To handle large bulk amount of power, AC power transmission is not economical over long distances. High Voltage Direct Current (HVDC) transmission is the only alternative to it. The advantages gained by DC power transmission outweigh the complexity of its operation and maintenance.

High Voltage Direct Current (HVDC) transmission is an efficient technology designed to deliver large amounts of electricity over long distances. The technology is a key component in the future energy system based on renewable energy sources. The tradition HVDC classic technology is used to transmit power for long distances via overhead lines or submarine cables with reduced losses. There is a breakpoint between AC and DC transmission distance, where after this point DC transmission is smarter and efficient, which is shown in the Figure 1. The success of HVDC technology applied to the interconnection of AC systems has been confined fast controllability, low transmission losses, suitability for cable transmission, and asynchronous connection, all combine to ensure the future of HVDC in modern power systems. Three main components of HVDC system is show in Figure 1.

HVDC transmission systems, when installed, often form the backbone of an electric power system. They combine high reliability with a long useful life.

High Voltage Direct Current (HVDC) transmission is the preferred method for bulk power transmission over long distances as HVDC systems offer numerous advantages over AC transmission systems, such as:

- More power carrying capacity per conductor.
- Full control over power transmitted.

- Asynchronous interconnection, therefore capable of connecting AC systems with different frequencies.
- No skin effect, therefore resulting in lower transmission losses.
- Less corona loss and interference with neighbouring telephone systems.
- Fast control to limit fault currents in DC lines. This makes it feasible to avoid DC breakers in two terminal DC links.

HVDC systems can transmit more electrical power over longer distances than a similar AC transmission system, which means fewer transmission lines are needed, saving both money and land. In addition to significantly lowering electrical losses over long distances, HVDC transmission is also very stable and easily controlled, and can stabilize and interconnect AC power networks that are otherwise incompatible. The HVDC systems core component is the power converter, which serves as the interface with the AC transmission system

II HVDC Control System

Normally, HVDC system operates in constant power control mode. Power order is given by the user. Current order (I_{order}) derived from the power controller, which is send to the VDCOL (Voltage Dependent Current Order Limiter) and into the Current Control Amplifier (CCA). The alpha order from the CCA is send to the converter firing control which determines the firing instant of valves.

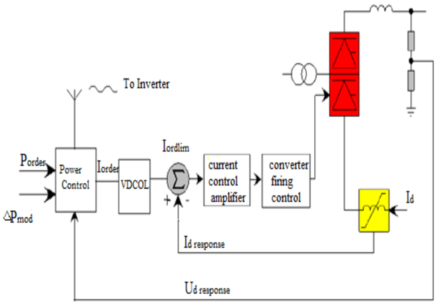


Figure 1 HVDC control overview

The primary function of HVDC controls are:

- Fast and flexible power control between the terminals under steady state and transient operation.
- Better stability of AC system.
- Fast protection of AC and DC system faults.
- Minimizes over voltage across the valves.
- Reduces the short circuit current through the valves and lines/cables
- Reduces the reactive power consumption.
- Avoids repetitive commutation failures.

The above advantages are achieved by varying exact firing instant of valves. The converter firing control determines the firing instants for each valve to obtain the rated DC voltage. The input for the firing control system could be the output of current control, voltage control, minimum alpha control and minimum commutation margin control mode or $alpha_{max}$ control.

The layout of HVDC system is shown in the Figure 2 below:

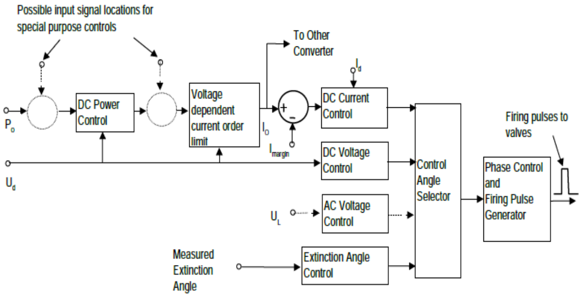


Figure 2 HVDC control system layout

III Conventional controllers

PID controllers use a 3 basic behavior types or modes: P-Proportional, I-Integral and D-Derivative. While proportional and integrative modes are also used as single control modes, a derivative mode is rarely used on its own in control systems.

- P Controller
- PD Controller
- PI Controller
- PID Controller

PID Tuning Methods

Tuning is adjustment of control parameters to the optimum values for the desired control response. Stability is a basic requirement. However, different systems have different behavior, different applications have different requirements, and requirements may conflict with one another.

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, some of them

- Manual tuning method,
- Ziegler–Nichols tuning method,
- PID tuning software methods.

Table 1 Overview of tuning methods

Method	Advantages	Disadvantages
Manual tuning	No math work required. Is an online method	Requires experienced personnel
Ziegler-Nichols	Proven method online method	Process upset, some trail-and-error, very aggressive tuning
Software tools	Consistent tuning or offline method. May include value and sensor analysis. Allow simulation before downloading. Can support Non-Steady State NSS) tuning.	Some cost and training involved
Cohen-Coon	Good process models	Some math work required. Is an offline method. Only good for First-order processes

IV Sliding Mode Control

Sliding mode control (SMC) is a nonlinear control method that alters the dynamics of a system by the multiple control structures are designed so as to ensure that trajectories always move towards a switching condition. Therefore, the ultimate trajectory will not exist entirely within one control structure. The main strength of sliding mode control is its robustness. Because the control can be as simple as a switching between two states, it need not be precise and will not be sensitive to parameter variations that enter into the control channel. Additionally, because the control law is not a continuous function, the sliding mode can be reached in finite time (i.e., better than asymptotic behavior). There are two steps in the SMC design. The first step is designing a sliding surface so that the plant restricted to the sliding surface has a desired system response. This means the state variables of the plant dynamics are constrained to satisfy another set of equations which define the so-called switching surface. The second step is constructing a switched feedback gains necessary to drive the plant's state trajectory to the sliding surface. These constructions are built on the generalized Lyapunov stability theory.

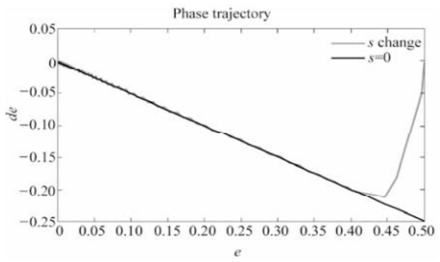


Figure 3 Phase trajectory

1. Sliding Mode Control Based on Reaching Law

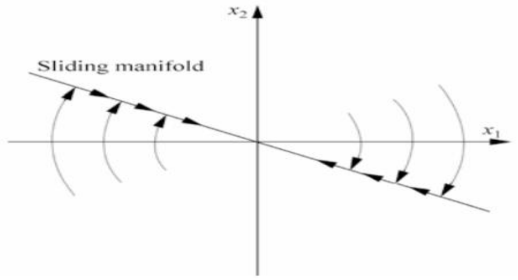


Figure 4 The Idea of Sliding Mode

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. 4

V Modeling of HVDC Controllers

1. Master Control

Master control generates the reference currents for the Rectifier as well as Inverter. To avoid loss of margin, these rectifier and inverter reference currents should be equal.

In the Master control, pulse generators are de-blocked and the power transmission started by ramping the reference current att=20 msec. The reference reaches the minimum value of 0.1pu in0.3 sec. At t=0.4 sec, the reference current is ramped from 0.1 to1pu (2kA) in 0.18s (5pu/s).The DC current reaches to steady state, at the end of the starting sequence at approximately 0.58sec.

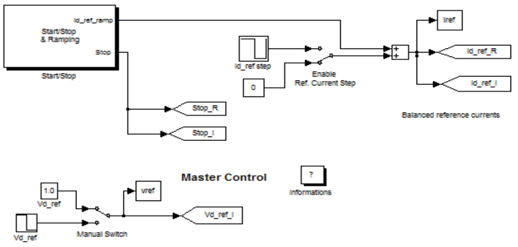


Figure 5 SIMULINK Diagram of Master Control

2. HVDC Control – Sliding Mode Control

There are two steps in the SMC design. The first step is designing a sliding surface so that the plant restricted to the sliding surface has a desired system response. This means the state variables of the plant dynamics are constrained to satisfy another set of equations which define the so-called switching surface. The second step is constructing a switched feedback gains necessary to drive the plant's state trajectory to the sliding surface. These constructions are built on the generalized Lyapunov stability theory.

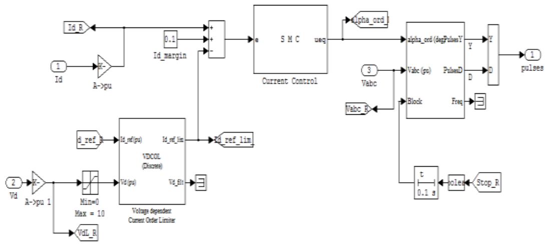


Figure 6 SIMULINK diagram of SMC Rectifier side

This tacitly implies the fact that the input change is also sensed by the ANN through the sudden jump of error, and the input need not necessarily be the reference value, and other signals can be taken as the ANN input.

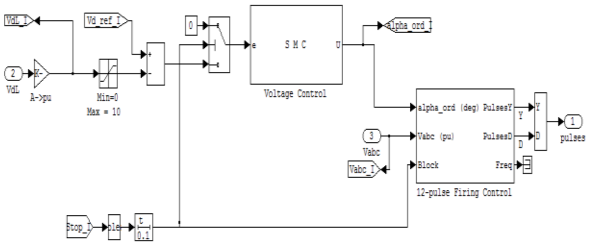


Figure 7 SIMULINK diagram of SMC Inverter side

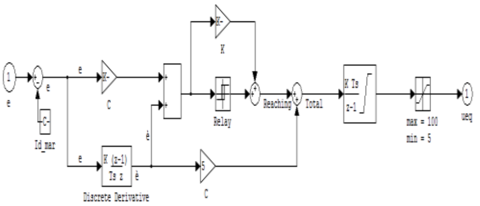


Figure 8 SIMULINK diagram of SMC

VI Simulation Results

The simulation of CIGRE HVDC Benchmark model II system is modeled in MATLAB/SIMULINK. To study the action of the controllers, AC faults at inverter side and rectifier are created. The fault is initiated at the positive zero crossing of the phase. Output response using PI and SMC controllers on rectifier and inverter side are observed. Voltage, current, power responses for particular fault are plotted.

1. Starting of HVDC System: The complete HVDC system reaches stable state after 0.3 sec. The HVDC system controlled by conventional control takes the DC voltage of 0.489 sec to reach steady state at a % overshoot of 36.53 % whereas the sliding mode controller takes 0.2087 sec to reach steady state at a % overshoot of 10.95 % . For DC current conventional controller takes 0.547 sec at a % overshoot of 17.22 % whereas SMC takes 0.342 sec at % overshoot of 0.8 %.

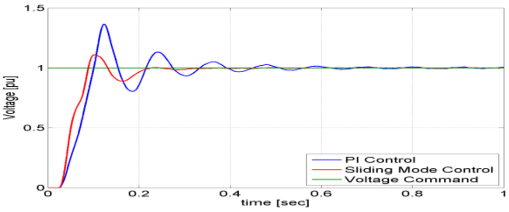


Figure 9 Voltage Response with PI control and SMC for starting the HVDC

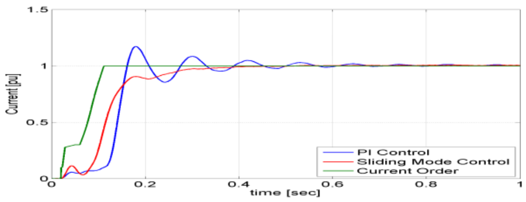


Figure 10 Current Response with PI control and SMC for starting the HVDC

2. DC Fault: Figure 11 and Figure 12 shows the system voltage and current waveforms under DC fault (created at t=2 sec and cleared at t= 2.1 sec) condition, using PI control and Sliding mode control. It is observed that form figure11, conventional controller reaches the steady state for 0.57 sec at a overshoot of 35.48% whereas SMC takes 0.27 sec at overshoot of 17.44 % to reach DC voltage to steady state. From figure 12, the current in transmission line with conventional controller takes 0.632 sec at overshoot of 65.17% to reach steady state whereas sliding mode control takes 0.415 sec at overshoot of 15.44% to reach steady state.

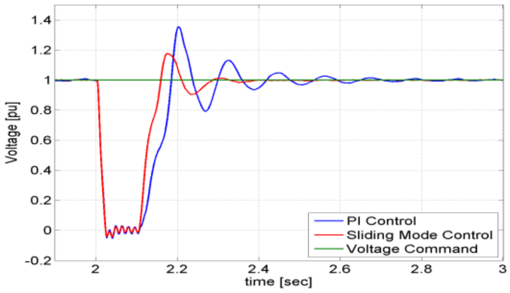


Figure 11 Voltage Response with PI control and SMC under DC fault Condition

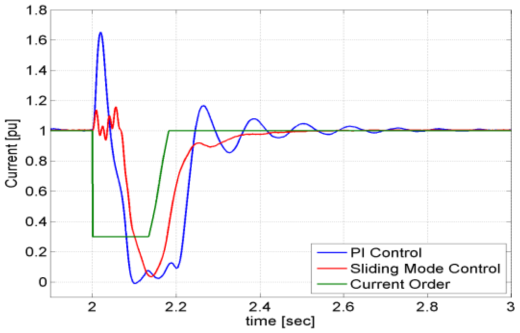


Figure 12 Current Response with PI control and SMC under DC fault Condition

3. AC Fault: Figure 13 and Figure 14 shows the system voltage and current waveforms under AC fault (created at t=1 sec and cleared at t= 1.1 sec) condition, using PI control and Sliding mode control. It is observed that form figure 5.26, conventional controller reaches the steady state for 0.65 sec at an overshoot of 36.88% whereas SMC takes 0.29 sec at overshoot of 28.44 % to reach DC voltage to steady state. From figure 5.27, the current in transmission line with conventional controller takes 0.713 sec at overshoot of 66.52% to reach steady state whereas sliding mode control takes 0.42 sec at overshoot of 20.15% to reach steady state.

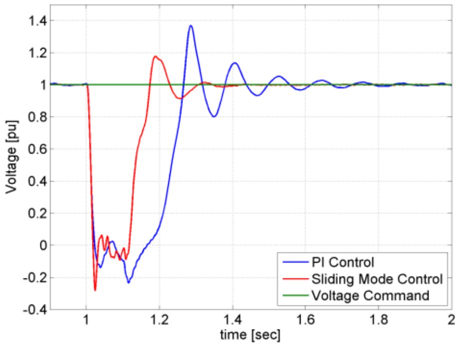


Figure13 Voltage response with PI control and SMC for Single phase fault

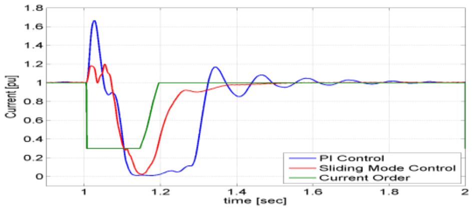
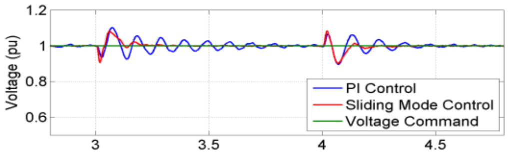


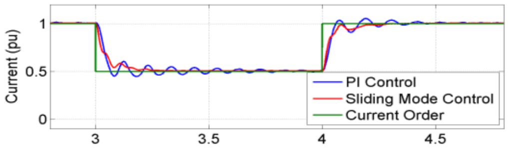
Figure14 Current response with PI control and SMC for Single phase fault

4. Change in Current Order

Figure 15 shows the system voltage and current waveforms for 50 % change in current order (created at t=3 sec and cleared at t= 4 sec) condition, using PI control and Sliding mode control. It is observed that form figure 5.26, conventional controller reaches the steady state for 0.925 sec with rise time of 0.0417 sec whereas SMC takes 0.4 sec with a rise time of 0.0014 to reach DC voltage to steady state. The current in transmission line with conventional controller takes 0.921 sec at rise time of 0.0419 sec to reach steady state whereas sliding mode control takes 0.27 sec at rise time of 0.0654 to reach steady state.



(a) Voltage Response for 50% Change in Current Order



(b) Current Response for 50% Change in Current Order

Figure15 System voltage and current response

All the time response calculation are done for 2% tolerance. By using SMC the outputs obtained are accurate and the transient response of the system is improved in all the considered specifications ie.,T_r,T_s, OS%,POS.

The SMC has the capability to adjust the firing angle such that the DC current follows the reference change. The current reference change response shows that the SMM is capable of controlling the rectifier and inverter for simple current order change.

VIII CONCLUSION

In this project, a HVDC system is designed to control the power flow between two converter stations with conventional (PI) controller and Sliding Mode Control. For rectifier side, current control is used and for inverter side both current and extinction angle control is implemented. In order to transfer maximum power in the DC link, we have to maintain minimum alpha. The error signal is passed through a PI and Sliding Mode Controller, which produces the necessary firing angle order. The firing circuit uses this information to generate the equidistant pulses for the valves in the converter station. Here, SMC is designed for both rectifier and inverter control and its performance is compared with conventional (PI) controller. The simulation results show that the HVDC with Sliding Mode based controller have great advantage of flexibility when compared with PI controller. The implementations outline the basics of the method, and the results show significant improvements in the system performance.

In this project, the CIGRE model is developed for improving the performance of the system. The proposed and the conventional models are simulated using MATLAB-SIMULINK software as a fault occurs in system and are compared with each other. Simulation results show clearly that the proposed method performs significantly to improve the behavior of system.

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