Non-Linear Sliding Mode Control of Three Phase AC-DC PWM Converters

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ABSTRACT

A fast voltage control strategy of three phase AC-DC PWM converters applying a nonlinear sliding mode control technique is proposed in this report. Incorporating the power balance of the input and output sides in the modeling of the PWM converter, a nonlinear model is derived with state variable such as ac input current and dc output voltage. Then by input-output feedback Linearization, the system is linearized and a state feedback control law is obtained by a sliding mode control theory. With this control scheme, output voltage responses become faster than those than the responses found in a conventional cascade control structure like PI control.

KeyWords: Sliding Mode Control, PI Control, PWM Converter

1.0 Introduction

Power semiconductor devices constitute the heart of modern power electronic apparatus. The term Converter System in general, is used to denote a static device that converts ac to dc, dc to ac, dc to dc, ac to ac. Recent development in semiconductor device technology has witnessed many developments in the converter topology. They are used in power electronic converters in the form of a matrix of on-off switches, and help to convert power from ac-to-dc (rectifier), dc-to-dc (chopper), dc-to-ac (inverter), and ac-to-ac at the same (ac controller) or different frequencies (cyclo-converter). High-frequency switch-on and switch-off semiconductor devices allow switching circuit to have the advantages of a) High efficiency due to low loss in power semiconductor devices. b) High reliability of power-electronics converter systems. c) Long life and less maintenance. d) Small size and less weight. so less installation cost. Converters are widely used in applications such as heating and lighting controls, ac and dc power supplies, electrochemical processes, dc and ac motor drives, static VAR generation, active harmonic filtering, etc.

1.1 Configuration of the experimented system

The experimented system consists of a stiff voltage source. The converter is connected to the source through an AC cable. Here the converter is used to meet the DC load in an industrial environment. For the sake of simplicity during the analysis only one converter is considered. Success of which encourages to apply the proposed control theory to multi converter environment. The system studied is shown in Fig 1.
2.0 Mathematical Modeling of AC-DC converters

A general mathematical model of the converter which is discontinuous, time variant and nonlinear is first established. To obtain the closed form solutions the following three techniques are used. a) Fourier analysis b) Transformation of reference frame c) small signal modeling. The Fourier analysis is used to get rid of discontinuities states whereas the transformation of reference frame is used to make the system time invariant. The small signal model is to linearize the system within a small neighborhood around any one of the stable operating points.

The system studied is shown in Fig.1. This model is analyzed under following assumption. a) The utility is a three phase balanced sinusoidal voltage source. b) The filter inductors are linear, saturation is not considered c) The DC load is equivalent to a resistance Rdc.

\[
\frac{dI_{d}}{dt} = -\frac{R_{r}}{L_{r}}I_{d} + \omega_{t}I_{q} + \frac{V_{2d}}{L_{r}} - \frac{V_{rd}}{L_{r}}
\]

\[
\frac{dI_{q}}{dt} = -\frac{R_{r}}{L_{r}}I_{q} - \omega_{t}I_{d} + \frac{V_{2q}}{L_{r}} - \frac{V_{rq}}{L_{r}}
\]

\[
\frac{dV_{dc}}{dt} = \frac{V_{2d}I_{d} + V_{2q}I_{q} - R_{r}I_{d}^2 + I_{d}I_{q}}{C_{d}V_{dc}} + \frac{V_{dc}}{C_{d}R_{dc}}
\]

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Where Rr is resistance of converter, Xr is reactance of converter, I_{rD} and I_{rQ} are the direct and quadrature axis current flowing to the converter, V_{rD} and V_{rQ} are the direct and quadrature axis voltage across the converter, V_{2D} and V_{2Q} are the direct and quadrature axis voltage across the reference bus, Vdc is the voltage across dc load, Rdc and Cdc are the dc side load resistance and dc link capacitance which maintain a constant dc voltage. \(\omega_1\) is the angular frequencies.

### 2.1 Different Modes of Converter

A VSC converter generally operates in many modes when connected to ac system. The major control modes are a) Constant DC voltage control and reactive power control mode b) Active and reactive power control modes and c) Constant DC voltage and AC voltage control modes. Out of these three major modes, mode (a) and mode (b) are widely used whereas mode (c) is explicitly used for interconnected A.C system. Since a stiff voltage source is taken at the sending end, so no need to control AC voltage and constant DC voltage control is there in mode (a).

### 3.0 Control Strategies

Various control strategies have been proposed for these types of PWM converters. The main objectives in the control of PWM ac-dc converters are to achieve a high power factor and minimum harmonics distortion of input line currents. In each mode to achieve the best performance of the converters the controller needs more attention. Earlier many researchers have proposed various controllers for ac-dc converter. But in few cases they have tested the controller in the presence of disturbances. But here the focus of our study is to get the optimum energy efficiency under various operating condition to propose a valid controller that will have the ability to reject the disturbances. The dynamic equations of the converters are quite non-linear as the state variables are multiplied by the control inputs and sometimes with disturbances. For converter controllers are mostly PI type which does not reject the various disturbances and interfaces those exist in the power system. The major disturbances are like imprecise mathematical model, measurement error, input disturbances and stochastic fluctuation in the loads. In practice the speed signal or the frequency also changes which affects the performance of the converter controller.

#### 3.1 PI Control

A PI controller is a feedback controller which drives the plant to be controlled with a weighted sum of errors and integral of that value. PI controllers are particularly common, since derivative action is very sensitive to measurement noise and the absence of an integral value prevent the system from reaching its target value due to the control action. The proportional value determines the reaction to the current error. It can be adjusted by multiplying the error by a constant Kp (proportional gain, tuning parameter). A increase in the value of Kp causes a large change in the output for a given change in error and the system can become unstable. If Kp is too low, the control action may be too small for responding system disturbances. Integral value determines the reaction based on the sum of recent errors and the control action is determined by integral gain (Ki). The integral term when added to the proportional term, accelerates the movement of the process towards the set point and eliminates the residual steady state error.

#### 3.1.1 Disadvantages
a) It introduces a phase-lag which decreases the stability margin. So it needs more attention and care during the tuning.
b) As it is linear. Performance in the presence of nonlinearity is not satisfactory.
c) Performance of a feed forward system can be improved with PI controllers only by using a feedback loop.
d) Conventional PI controllers offer a very slow response to any transient disturbance because of its fixed gains.

3.2 Sliding Mode Control

When the system is stable, change in state is zero. When the system undergoes transient disturbances, change in state is driven away from the origin. So it is the ability of the controller to drag the derivative towards the origin, when the system touches a particular surface. When the system touches that particular surface, it is forcibly made to zero. Generally it is a hard-switch controller. It can be made soft-switch by introducing some fuzzy-logic.

3.2.1 Advantages of the sliding mode controller

a) The controller is based upon the exact feedback linearization theory.
b) Considers the zero dynamic situation of the controller.
c) Strong approach towards the disturbance rejection.
d) Stable performance in the presence of exogenous inputs.

Challenges

a) Exact Linearization
b) Choice of suitable sliding surface

4.0 Transient State of Nonlinear Model

Though there are many ways to check the Transient state stability of the system, only few factors are taken into account. Here the system is tested under the worst fault conditions i.e. the Symmetrical fault in A.C side as well as in D.C side. Here the comparison is made between the conventional PI controller and Sliding mode controller for two different modes a) DC voltage and Reactive power control mode b) Active and Reactive power control mode.

4.1 LLLG fault at Converter bus

a) DC voltage and Reactive power control mode
4.2 LG fault in DC side

a) DC voltage and Reactive power control mode

Fig. 2 & 3 depicts about the performance of the plant when there is LLLG fault and it is clearly seen that in case of PI controller peak overshoot is larger. So Non-linear control is better than PI controller.
b) Reactive and Active power control mode

From Fig 4 & 5 it is clear that Quick control is possible with Non-linear control. So it is better than linear

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control.

5.0 Conclusion

The sliding mode control is used to calculate the modulation index and the firing angle of the converter module to get the maximum efficiency. A Nonlinear model is derived and a comparison is made between linear control law and Nonlinear control law. The simulation result is given depicts that with Nonlinear control law, the converter is more stable than that of linear one.

References

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Pr=0.3
Q= -62.832 + 314.16i
-93.522 + 636.36i
-6.654

Pr=0.2
Q= -0.1
-62.832 + 314.16i
-92.754 + 636.47i
-6.2537

Pr=0.5
Qr=0.2
-62.832 + 314.16i
-94.553 + 636.11i
-8.4624

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-92.754 + 636.47i
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Control Mode  Operating Point  Linear  Non Linear

Model

Pr=0.5  Qr=0.2  -62.832 + 314.16i  -62.832 -314.16i  -94.553 + 636.11i  -94.553 -636.11i  -8.4624

Pr=0.3  Qr=0.1  -62.832 + 314.16i  -62.832 -314.16i  -93.522 + 636.36i  -93.522 -636.36i  -6.654

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