Stability Analysis of Network Control in Smart Grids using SMC

Jyoti [1]*, Charan Jeet Madan[2]
[1]M. Tech. Student, Electrical Engineering
[2]Assitant Professor
HCE, Sonipat
Haryana, INDIA

Abstract: Solar PV array are being applied today to a wider range of applications requiring variable power. Generally, variable power drives for solar PV array require both wide operating range of power and fast operating response, regardless of any disturbances and uncertainties (like load variation, parameters variation and un-modeled dynamics). This leads to more advanced control methods to meet the real demand. In this paper, a sliding mode controller is designed for an induction motor drive. The gain and band width of the controller is designed considering rotor resistance variation, model in accuracies and load disturbance, to have an ideal speed tracking. The chattering effect is also taken into account. The controller is simulated under various conditions and a comparative study of the results with that of PI controller has been presented.

Keywords: MPPT, SMC, MPPT.

I. INTRODUCTION

Sliding mode controller is suitable for a specific class of nonlinear systems. This is applied in the presence of modeling inaccuracies, parameter variation and disturbances, provided that the upper bounds of their absolute values are known. Modeling inaccuracies may come from certain uncertainty about the plant (e.g. unknown plant parameters), or from the choice of a simplified representation of the system dynamic. Sliding mode controller design provides a systematic approach to the problem of maintaining stability and satisfactory performance in presence of modeling imperfections. The sliding mode control is especially appropriate for the tracking control of motors, robot manipulators whose mechanical load change over a wide range. Induction motors are used as actuators which have to follow complex trajectories specified for manipulator movements. Advantages of sliding mode controllers are that it is computationally simple compared adaptive controllers with parameter estimation and also robust to parameter variations. A sliding mode based adaptive input output linearizing control is presented in [2] for induction motor drives. In this case the motor flux amplitude and speed are separately controlled by sliding mode controllers with variable switching gains. A sliding mode controller with rotor flux estimation is presented in [2-3] for induction motor drives. Rotor flux is also estimated using a sliding mode observer. Robust control techniques such as nonlinear adaptive control [9], model predictive control [10], back stepping [11] and sliding mode control [12, 13] have evolved to deal with uncertainties. These control techniques are capable of achieving the specified control objectives in spite of modeling errors and parametric uncertainties affecting the controlled system. Beginning in the late 1970s and continuing till today, the sliding mode control (SMC) [4,5] methodology has received wide attention because of its inherent insensitivity to parametric variations and external disturbances. The sliding mode control (SMC) is a particular type of variable structure control system (VSCS) which uses a discontinuous control input. Recently many successful practical applications of sliding mode control (SMC) have established the importance of sliding mode theory. Design of the SMC involves two key steps, viz. (1) the design of a sliding surface in accordance with the desired closed loop performance and (2) the design of a suitable control law. The sliding surface is to be designed optimally to satisfy all constraints and required specifications. The initial phase when the state trajectory is directed towards the sliding surface is called the reaching phase. During the reaching phase, the system is sensitive to all types of disturbances. However, a control law can be designed which ensures finite time reaching of the sliding surface even in the presence of uncertain-ties and disturbances. For eliminating the non-robust reaching phase, an integral sliding mode was proposed in [19, 20] which naturally allowed SMC to be combined with other techniques. The main advantages of the SMC are the following:

1. During the sliding mode, the system is insensitive to matched model uncertainties and disturbances [1]
2. When the system is on the sliding manifold, it behaves as a reduced order system with respect to the original plant. However, in spite of the claimed robustness, implementation of the SMC in real time is handicapped by a major drawback known as chattering which is the high frequency bang-bang type of control action. Chattering is caused due to the fast dynamics which are usually neglected in the ideal model of sliding mode. In the ideal sliding mode, the control is assumed to switch with an infinite frequency. However, in actual plants, due to the inertia of actuators and sensors as well as the presence of nonlinearities, the switching occurs with high but finite frequency only. The main consequence is that the sliding mode takes place in a small neighborhood of the sliding manifold, whose dimension is inversely proportional to the control switching frequency. In sliding mode, due to the finite switching of control signal, the states would switch about the sliding surface rather than lie directly on it. This switching can occur at a high frequency and is called chattering. The effect of chattering is that the high frequency components of the control propagate through the system and thereby excite the un modeled fast dynamics and give rise to undesired oscillations which affect the system output.

The rest of paper is design as follows. The problem statement of research work is described in section II. Modeling of sliding mode controller is described in section III. Simulation results & analysis is described section IV. The overall conclusion of research work describe in section V.

II. Problem Statement

There are two ways to mitigate the power quality problems - either from the customer side or from the utility side. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. Several devices including flywheels, super-capacitors, other energy storage systems, constant voltage transformers, noise filtres, isolation transformer, transitent voltage surge suppressors, and harmonic filters are used for the mitigation of specific PQ problems.

III. Modeling of Sliding Mode Controller

With sliding mode controller, the system is controlled in such a way that the error in the system states always moves towards a sliding surface. The sliding surface is defined with the tracking error (e) of the state and its rate of change ($e^{\cdot}$) as variables. The distance of the error trajectory from the sliding surface and its rate of convergence are used to decide the control input to the system. The sign of the control input must change at the intersection of the tracking error trajectory with the sliding surface. In this way the error trajectory is always forced to move towards the sliding surface [12].

1. The basic equations (1 – 4) of vector controlled induction motor are simplified by assuming, the rotor flux ψ_{dr} to be constant. The steady state value of the rotor flux can be obtained as

$$\Psi^{*}dr = \frac{a_5}{a_4} i^{*}ds \qquad \ldots\ldots\ (1)$$

From 1 we get

$$\frac{a_5}{a_4} = L_m \qquad \ldots\ldots\ (1\ a)$$

Using 1 (a) in 1 steady state value of rotor flux is obtained as

$$\Psi^{*}dr = L_m i^{*}ds \qquad \ldots.\ (1\ b)$$

$The\ speed\ dynamic\ is\ given\ by$

$$\frac{d\omega_r}{dt} = \frac{1}{J}(T_e - T_i - \beta\omega_r) \qquad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Assuming the load torque, T_l to be a disturbance to a system, the speed dynamic equation is simplified as:

$$\dot{\omega}_r = -\frac{\beta}{J}\omega_r + bi_{qs} + \ noise \qquad (3)$$

or

$$\dot{\omega}_r = f_1 + noise \qquad \ldots\ldots\ (3\ a)$$

where

$$f_1 = -\frac{\beta}{J}\omega_r + bi_{qs} \qquad \ldots\ (3\ b)$$

and

$$b = \frac{K_T}{J}\Psi^{*}dr \qquad \ldots\ldots\ldots\ (4)$$

In this vector controlled induction motor drive, speed is taken as the output variable. To track the speed accurately in the second order speed control system, the conditions to be satisfied are:

$$\dot{\omega}_r \ \ |_{\omega_r=\dot{\omega}_r} = 0 \quad and\ \ddot{\omega}_r \ \ |_{\omega_r=\ddot{\omega}_r} = 0 \qquad \ldots\ (5)$$

$$\ddot{\omega}_r = -\frac{B}{J}\dot{\omega}_r + bi_{qs} + noise \qquad (6)$$

$$Substituting\ \omega_e = P\omega_r + a_5.\frac{i_{qs}}{\Psi_{dr}}\ in\ (6),.$$

$the\ following\ equation\ is\ obtained$

$$i_{qs} = -\left(P\omega_r + a_5.\frac{i_{qs}}{\Psi_{dr}}\right) i_{qs} - a_1 i_{ds} - Pa_3\omega_r L_m i_{ds} + cv_{qs} \qquad \ldots\ldots\ldots\ldots\ldots\ (7)$$

$It\ can\ be\ shown\ using\ (4.6)\ and\ (4.7), that$

$$\omega_{si} = a_5\frac{i_{qs}}{\Psi_{dr}} = \frac{R_r L_m}{L_r}\frac{i_{qs}}{L_m i_{qs}} \approx a_4\frac{i_{qs}}{i_{ds}} \qquad \ldots\ (8)$$

$Simplifying\ (8), we\ get$

$$i_{qs} = -(a_1 + a_4)i_{qs} - P\omega_r(1 + a_3 L_m)i_{ds} + cv_{qs}$$

or

$$i_{qs} = f_2 + cv_{qs} \qquad \ldots\ldots\ldots(9a)$$

Starting from the initial condition, E(0) = 0, the tracking task, X & X^{*}, which means x has to follow X^{*} with a predefined precision, is considered as solved, if the state vector, E remains in the sliding surface, S(t) for all t ≥ 0 and also implies that scalar quantity s is kept at zero. A sufficient condition for this behavior is to choose the control law so that

$$\frac{1}{2}\frac{d}{dt}(s^2) \leq -\eta|s| \qquad \ldots\ldots\ (10)$$

Where η is a positive constant. The value of η determines the degree to which the system state is attracted to the switching line. Essentially, equation (10) states that the squared distance to the sliding surface, as measured by s^2 decreases along all system trajectories. Thus it constrains the trajectories to point towards the surface S(t), as shown in the figure below [11].

IV. Simulation & Result Analysis

Proposed Simulink Model is represented in Fig 1. The proposed model having boost converter, grid inverter & other different component. The power factor calculator is also used at the output end of inverter.

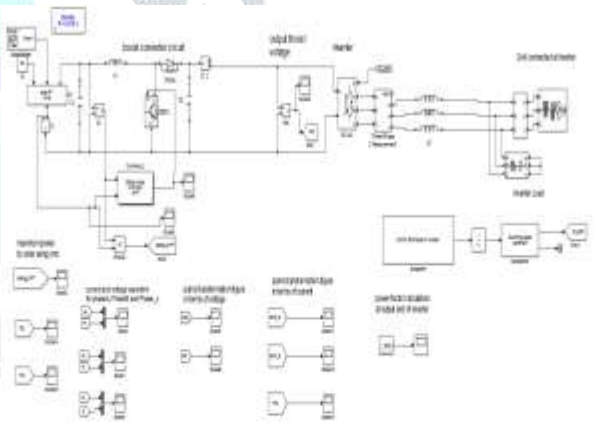

Fig 1 Proposed Simulink Model

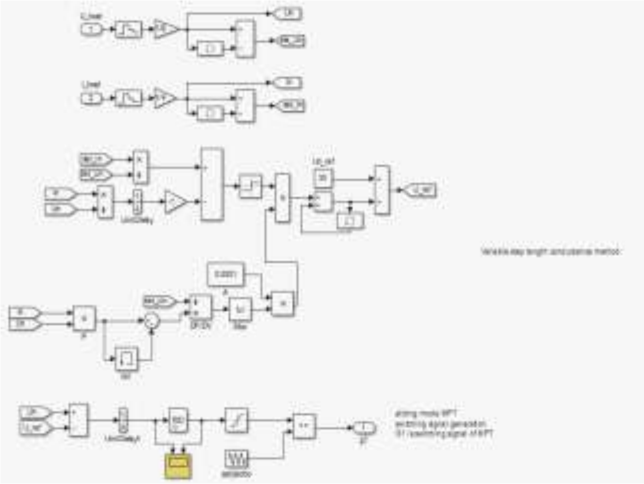

Fig 2 Sliding Mode Controller

The Sliding Mode controller is used in the proposed model for switching signal generation. The PID Controller is used to design the SMC

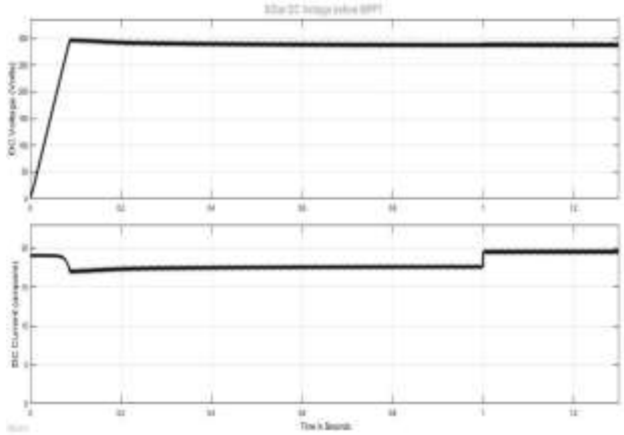

Fig 3 Solar DC voltage and Current before using sliding mode MPPT

Solar DC voltage and current before sliding mode MPPT is defined in fig 3. In the1st graph Dc voltage is increase linearly with respect to time. It is increase with time up to 0.1 sec then voltage become constant to 295 V. Similarly DC Current gives flat portion 0.1 sec to 1 sec.

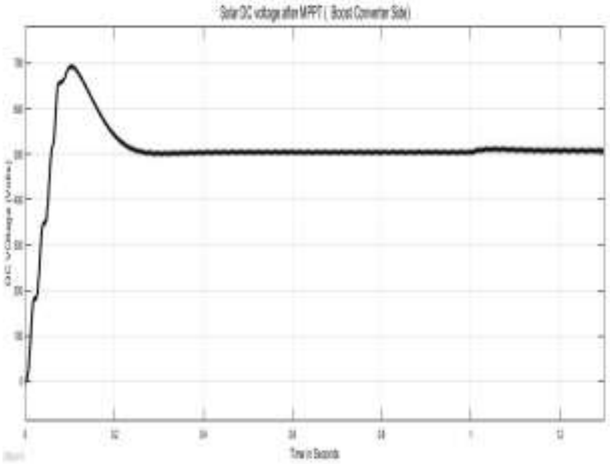

Figure 4 Solar DC Voltage Using Sliding Mode MPPT

Solar Dc Voltage using sliding mode MPPT is shown in fig 4. The graph is increases upto 0.1 sec then it will be decreases then become constant 5000v after 0.3 sec.

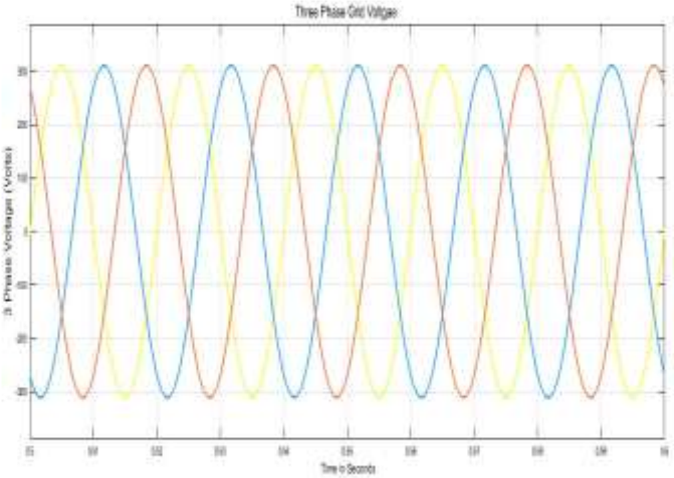

Figure 5 Three phase Grid Voltage 50 Hz Voltage magnitude 300 Volts

Three phase grid voltage is represented in fig 5. The amplitude of three phase voltage is 300 V. Three voltages are aligned by 120 degree phase angle.

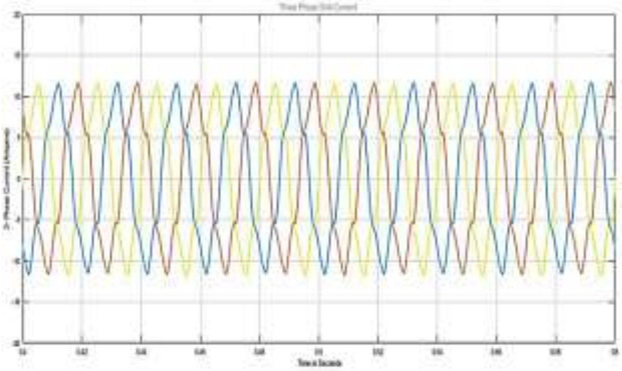

Figure 6 Three Phase Grid Current 50 Hz

3 phase grid current is shown in fig 6. The amplitude of grid current is 12 ampere. The time is varied for 6 sec.

V. Conclusion

In this thesis the theory of sliding mode controller is studied in detail. The equations of the induction motor model are reorganized so as to apply the control technique. The controller gain and band width are designed, considering various factors such as rotor resistance variation, model in accuracies, load torque disturbance and also to have an ideal speed tracking. Considering the case such as load disturbance, the response of the designed sliding mode controller is satisfactory. It also gives good trajectory tracking performance. The final conclusion of the model is

1. Minimum ripple in solar PV model DC current and Voltage by using Sliding mode controller
2. The sliding mode controller based MPPT technique boost the voltage up to 500 volts which is ripple free
3. Track maximum power in solar PV mode
4. MPPT Controlled algorithm is Sliding mode controller
5. Voltage source inverter is controlled by Space vector pulse width modulation and having two control loop
    (a) Inner current control loop which is used to Reduce total harmonics distortion up to 3%
    (b) Outer voltage loop is used to attain unity power factor

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