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Design and Analysis of a Single Phase Unipolar Inverter Using Sliding Mode Control

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***Abstract-This project is about modeling and simulation of single phase unipolar Pulse Width Modulation (PWM) inverter using sliding mode control. The model was implemented using MATLAB/Simulink with the Sim Power Systems Block Set. In this model Metal Oxide Field Effect Transistor(MOSFET) model was used as switching device. The software used to design, analysis and evaluation of single phase inverter and their controllers in this project is MATLAB/Simulink.In inverter circuit, an AC output is obtained from a DC input by appropriate sequence of switching scheme. For that,in this model Pulse Width Modulation technique is used in control the operation of switches. The switching scheme applied is unipolar. Sliding mode control (SMC) is a robust controller with a high stability in a wide range of operating conditions .It is not possible to apply directly to multi switches power converters. In this paper, a fixed switching frequency sliding mode controller is used for control a single-phase unipolar inverter. The PWM signal is used to control switching states of the MOSFETs will functions in inverter model that create the control scheme. Then, simulation is made from the inverter model in Simulink*.**

Keywords: Pulse width modulator,sliding mode control, uinpolar single phase inverter.

I. INTRODUCTION

Pulse Width Modulation inverters are used in uninterruptible power supplies (UPSs) and driving induction motors (IM). In UPS systems, a 50Hz sinusoidal output voltage is required. It is well-known that sliding mode control (SMC) can give good tracking performance.[2] However, one major drawback of sliding mode control in PWM inverters is the varying switching frequency of the switch. It will generate a lot of high frequency noise and give a high THD (total harmonic distortion).Here a fixed frequency continuous-time sliding mode controller was proposed, this controller works like a bang bang controller. Control signal is generated by applying a signal to a hysteric comparator, which is a function of output current, output voltage and inductor current.Fixed-frequency switching mode inverters are more suitable to be represented by discrete-time state equations.

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It is because the duty cycle of the inverter is unchanged within one switching period.In this derived a better sliding mode controller with a more complete reaching condition. In this, a discrete-time sliding mode controller(SMC) will be applied to control a Pulse Width Modulation inverter. It will be shown that this controller can give good output response under linear and non-linear loads.[1].An inverter is a device that converts DC power into AC power at desired output voltage and frequency.In line commutated inverters Phase controlled converters are operated in the inverter.The line commutated inverters for their commutation at the output terminals an existing AC supply which is used. This means that line commutated inverters can't function as an isolated AC voltage sources or as a variable frequency generators with DC power at the input. Therefore, frequency, voltage level and waveform on the AC side of the line commutated inverters can't be changed.[8] On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable. Based on their operation Inverters can be classified into two types:

- Voltage Source Inverters (VSI)
- Current Source Inverters (CSI)

Voltage Source Inverters(VSI) is one in which the DC source has small or negligible impedance. A CSI is designed with adjustable current from a DC source of high impedance i.e, from a DC current source. In a Current Source Inverter designed with stiff current source, where output current waves are not affected by the load. On view point of connections of semiconductor devices,the inverters are classified as

- Bridge Inverters
- Series Inverters
- Parallel Inverters

Recently, many control methods, hysteresis current mode control [6], multiloop feedback [5],like repetitive control [3], deadbeat control [4], , have been introduced to achieve the demands. Recently, harmonic elimination techniques and nonlinear observer [11] are employed to improve the transient response. It seems that these control methods are based on small signal model of the inverter [12], [07], because the inverter state space equations vary when the switches state changes. This project aims based on Sliding Mode Control theory, a fixed frequency and high-performance controller is proposed to apply to unipolar single-phase unipolar inverter.A PWM is employed to fix the switching frequency and to generate the suitable switching for the four switch inverter.

II. DESIGN OF SLIDING MODE CONTROLLER

The output voltage of the single phase four switch inverter is

$$Vout=V_{DC}\times m\times \mathrm{Sin}(2\pi fot) \quad (1)$$

Now consider the state equation of the inverter,

- $L\frac{di_L}{dt} = u * V_{DC}\text{-}V_{out}$
- $C\frac{dV_{out}}{dt} = i_C$
- $i_C=\frac{V_{out}}{R}$

Where Vout is the output voltage, V_{DC}, m, and *fo* represent the input voltage, modulation factor, and output frequency, respectively.The state equations of the inverter Are where inductor current i_L and output voltage *Vout* are selected as state variables. *U* is the discontinuous input of the system. 0 or −1 to provide negative output , 0 or 1 to provide positive output .In addition, *ic*, capacitor current *io*, and *R* are the output current, and load, respectively.To implement the Sliding Mode Control for the inverter, take the output error and its derivative.

$$e = V_{out} - V_{ref}$$
$$\dot{e} = \frac{d}{dt}\left(V_{out} - V_{ref}\right) = \frac{i_c}{c} - \dot{V}_{ref} \quad (2)$$

Where *V*ref is the reference voltage. In the inverter, the output voltage is forced to be equal to *V*ref by appropriate switching.Considering continuous current mode operation of the inverter and, selecting the *e* and *ė* as state variables, the system equations in terms of the state variables x_1 and x_2 can be rewritten as follows

$$x_1 = V_{out} - V_{ref}$$
$$x_2 = \dot{x}_1 = \frac{i_c}{c} - \dot{V}_{ref}$$
(3)

And

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = -\frac{x_1}{LC} - \frac{x_2}{RC} - \frac{V_{in}}{LC}u - \frac{V_{ref}}{LC} \quad (4)$$

Now, the sliding surface can be defined as follows:

$$S(X)=\left(\frac{d}{dt} + \lambda\right) x_1=\dot{x}_1 + \lambda x_1=x_2 + \lambda x_1=0 \quad (5)$$

For the sliding condition of the inverter, λ can be selected by,

$$\lambda\left(\lambda - \frac{1}{RC}\right) > -\frac{1}{LC}$$
(6)

Generally there should be chattering problem in this method in order to eliminate that we are introducing a sliding surface.[8] By using discontinuous control law in the boundary layer, $u(u = -\mathrm{sign}(S(X)))$, is replaced by $S(X)/\Phi$ (see Fig.1). It will helps to reduce chattering problems and the tracking error .So that, selection of Φ is very important in tracking error and the smoothing of control discontinuity.

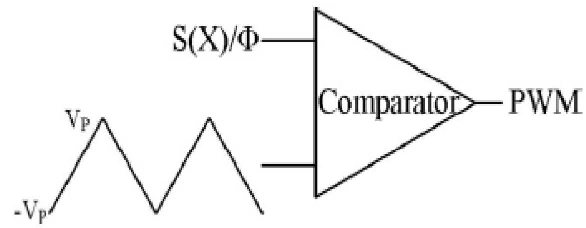

Fig.1. Pulse width modulator.

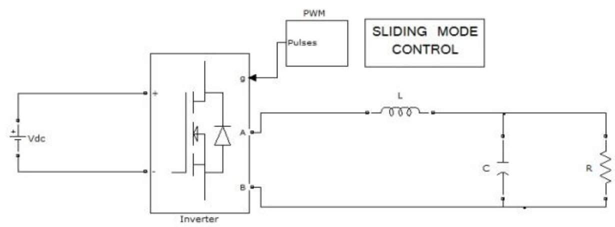

Fig. 2 Proposed controllers for single-phase inverters.

Now, to provide switching law for the inverter, we apply the smooth control law to a pulse width modulator (see Fig. 1). It also results the inverter with a fixed switching frequency.

Our control loop is illustrated in Fig. 2. It consists of two control loops, outer voltage loop and inner capacitor current loop, with a pulse width modulator.In the pulse width modulator, the slope of triangle carrier must be higher than the slope of the input signal.

The slope of triangle carrier S_C is

$$S_C = 4V_P\times f_S \quad (7)$$

Where V_P and *fs* are the triangle carrier amplitude and frequency, respectively. In the proposed control method, the input of pulse width modulator, $S(X)/\Phi$, consist of two terms: error of the output voltage and the error of the capacitor current

In the steady state, the inverter output voltage can be assumed a pure sinusoidal waveform and its error is very close to zero .Since the inductor ripple current ΔIL is entered to the capacitor, the capacitor current error is equal to the inductor ripple current,

$$\frac{S(X)}{\Phi} = \frac{x_2+\lambda x_1}{\Phi} = \frac{i_C}{C\Phi} - \frac{\dot{V}_{ref}}{\Phi} + \frac{\lambda}{\Phi}\left(V_{out} - V_{ref}\right) \quad (8)$$
$$= \frac{1}{C\Phi}\left(i_C - i_{ref}\right) + \frac{\lambda}{\Phi}\left(V_{out} - V_{ref}\right)$$
(9)

In the steady state, the inverter output voltage can be assumed a pure sinusoidal waveform and its error is very close to zero.

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Since the inductor ripple current ΔIL is entered to the capacitor, the capacitor current error is equal to the inductor ripple current, and (9) can be reduced to

$$\frac{S(X)}{\Phi} \approx \frac{1}{C\Phi}\left(i_C - i_{ref}\right) = \frac{\Delta I_L}{C\Phi} \quad (10)$$

Since the capacitor ripple current is very low, the input signal of the pulse width modulator may be very high slope. So, proper selection of Φ can aim to reduce the rapid slope of the PWM input signal.[13]

$$\Delta I_L = \frac{(V_{out} - V_{ref})}{L} DT \quad (11)$$

and

$$D = m \times \mathrm{Sin}(2\pi f o t) \quad (12)$$

Where D and T are time-dependent duty ratio and period of triangle carrier, respectively. Substituting (1), (11), and (12) in to (10), then derivation on T, the slope of the input signal S_{IN} yields

$$S_{IN} = \frac{V_{DC}}{4LC\Phi} \quad (13)$$

Now, according to the limitation on the pulse width modulator[14],the minimum of Φ is obtained as follows:

$$\frac{V_{DC}}{4LC\Phi} < 4V_p \times f_s \quad (14)$$

Then

$$\frac{V_{DC}}{16LCV_p f_s} \ll \Phi \Rightarrow \frac{10V_{DC}}{16LCV_p f_s} \approx \Phi_{min} \quad (15)$$

III. SIMULATION RESULTS AND ANALYSIS

This project is focus on modeling and simulation of single phase unipolar inverter using Sliding Mode controllers (SMC).Inverter is a circuit that converts DC input to AC sources.Pulse Width Modulation is a method that use as a way to decrease total harmonic distortion in inverter circuit. Sliding Mode controllers (SMC) are well known for their stability and robustness.The nature of the controller is to ideally operate at an infinite switching frequency such that the controlled variables can track a certain reference path to achieve the desired dynamic response and steady-state operation.This is because extreme high speed switching in power converters results in excessive switching losses, inductor losses,transformer core losses and electromagnetic interference (EMI) noise issues.In this project, based on SMC theory, a fixed frequency and high-performance controller is proposed to apply to unipolar single-phase inverters. A pulse width modulator is employed to fix the switching frequency and to generate the suitable switching law for the four switch inverter.

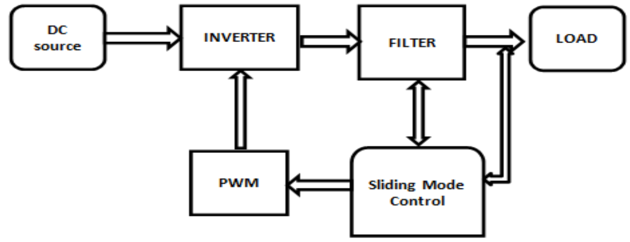

Fig.3 Block diagram of power electronic system

IV. SIMULATION RESULTS

The proposed control method has been simulated by Simulink Toolbox in MATLAB for an inverter whose main characteristics are mentioned in Table.1, in which *fs* and *fr* are switching frequency and cutoff frequency, correspondingly. Controller parameters of the simulated inverter are listed in. β_V is selected considering the electronic circuit's limitation. In the inverter dynamic response is of first order with time constant $\tau = 1/\lambda$. Moreover, the response time of inverter cannot be faster than a period of switching; therefore, we chose λmax = *fs*.

Parameter	*Value*
V_{DC}	*350V*
Vout	*240V*
f_s	*15KHz*
F	*50Hz*
L	*3.57µH*
C	*9.4mF*
R(load)	*27.5Ω*

Table .1

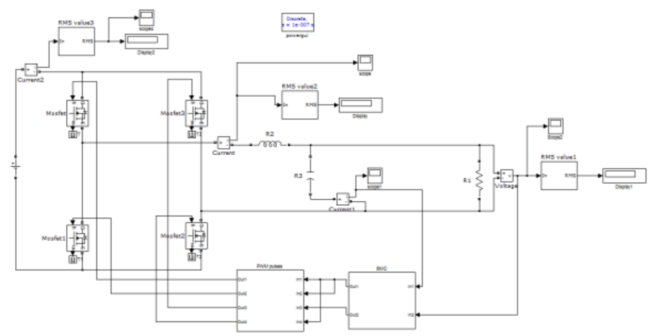

Fig 4. Implemented circuit in MATLAB

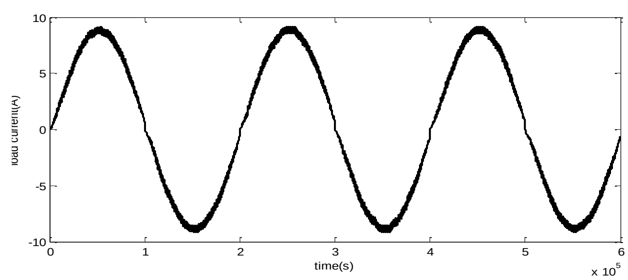

Fig. 5 Simulation result of Output current

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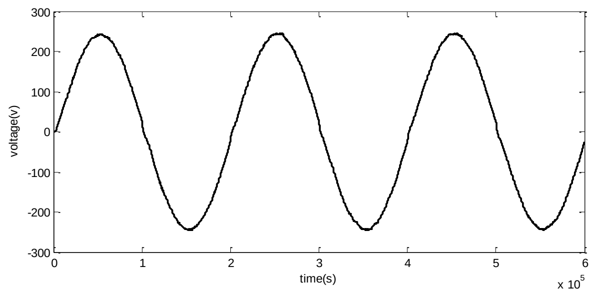

Fig. 6 Simulation result of Output voltage

The unipolar inverter was implemented with a resistive load, (Fig. 4) The simulation is done by MATLAB. Fig. 5 and Fig. 6 experimental waveforms of the inverter output current and voltage for a resistive load with a total harmonic distortion (THD) equal to 2.92%. The average load voltage is 240 V, the average load current is 9A.

V. CONCLUSION

General discussion on the inverter operation and its switching scheme has been made.Natural sampling and regular sampling is two PWM switching scheme.Nowadays regular sampling PWM is the popular technique to be implemented in digital technique. SPWM with Unipolar voltage switching scheme has better harmonic profile compare to Bipolar voltage switching.Because of that, SPWM with unipolar voltage switching will use as a switching scheme for the single phase inverter.This analysis has reported a successful application of a sliding mode controller(SMC) to control a PWM inverter. This controller has been applied to a PWM inverter with a linear resistance load.It is shown that the sliding mode controller can give good responses in both kinds of load. As compared with a proportional controller when using the phase-controlled load,the proposed sliding mode controller shows a better performance. The simulation is done by MATLAB/Simulink. The simulation responses of the inverter with a phase-controlled load are shown in Fig. 5 and Fig. 6 shows the output voltage and load current of an inverter with resistive load under the control of the sliding mode controller. As a comparison, shows the response of the inverter under the control of a proportional controller. It can be seen that the sliding mode controller can give better responses in the output voltage and load current.

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