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Sliding Mode Control of Dc/Dc Switching Converters for Photovoltaic Applications

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Abstract-Maintaining good voltage regulation at output and having fast dynamic response under sudden load fluctuation are extremely important in distributed generation (DG) as well as uninterrupted power supply (UPS) systems. This paper presents a fixed frequency hysteresis current (FFHC) controller, which is implemented on the basis of sliding mode control (SMC) technique and fixed frequency current controller with a hysteresis band. The controller has the benefit of hysteretic current control having fast dynamic responses and reduces the disadvantages of the variable switching frequency. To overcome elliptical sliding surface was taken. These has been verified and compared with the carrier based pulse width modulated (PWM) voltage controller under the same load fluctuation. The proposed method is then applied to islanded single phase voltage source inverter (VSI) system. The results show that the dynamic response is quite faster than that of widely used PWM-controlled inverter systems. The DC voltage that is required for the inverter input is supposed to be given from the output of PV panel with buck converter. In PV system ,sliding mode control is used to track the maximum power point .Here inverter and buck converter connected to PV array are taken separately.

Keywords— SMC, FFHC,PWM,VSI

I. INTRODUCTION

In recent years, researches have been focused on the distributed generation (DG) systems, powered by renewable energy sources, such as, micro turbines, fuel cells, photovoltaic and wind generation due to the limited fossil fuel and environmental impacts [1]. The above units are interfaced to the utility network through the power electronics converter systems. The DG systems can be operated either in grid connected or in islanded mode. For the sake of simplicity, it is preferable to operate in islanded mode instead of grid connected mode. In the islanded mode, the local loads are supplied by the DG system, which is usually act as a controlled voltage source. A single phase islanded DG system as shown in Fig. 1, supplies the non-linear and critical step changing loads.

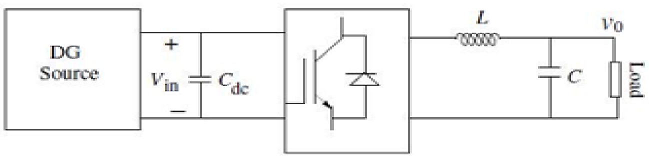

Fig. 1. Single-phase islanded DG system.

The above loads deform the desired sinusoidal output voltage of inverter [2]. For all types of loads, the total harmonic distortions (THD) of the inverter output voltage should be as per the IEEE standard 1547, i.e., less than 5%. Moreover, the closed-loop control system should be capable of achieving high performance in the sense of fast dynamic response and robustness under sudden load-and line fluctuations [3]. In recent past, several control strategies have been suggested for the inverter operations, depending on how the error signal is processed [4]. Out of these available techniques, in maximum cases, the control methodology based on constant-frequency pulse width modulation (PWM) techniques like dead beat control, conventional PI control, repetitive control, and adaptive control have been suggested to improve the robustness and the dynamic response of inverter [5], [6]. However, in all the above cases, the control design is normally based on voltage mode control, which leads to the output voltage waveform sensitive to the load variations. Alternatively, non-linear control scheme, namely, sliding mode control (SMC) strategy has been proposed in dc-dc switching regulators [7] since these are well known for their robustness, guaranteed stability and good dynamic response under wide range of operating conditions.

The switching control law of SMC is to drive the state trajectory from any initial point to a particular surface in the state space called sliding or switching surface, and maintain it on this surface for rest of time. However, SMC operates at variable switching frequency at which an undesirable chattering phenomenon may occur. In order to compensate the above drawback partially, the SMC are realized by means of a hysteresis comparator [8], which also provides a variable switching frequency. Several authors have proposed constant frequency SMC by means of a variable width hysteresis controller [9],[10]. which can however lead to a complex analog implementation, thereby involve more cost. Moreover the width of hysteresis band depends on the converter parameters. Alternatively fixed frequency SMC can also be achieved by comparing an external ramp signal to the switching surface [10]. Hence in these controllers, the switching instant does not depends on the switching surface behavior. In this paper, a fixed frequency hysteretic current (FFHC) controller is proposed to improve the dynamic response of a single phase inverter subjected to a sudden fluctuation of load. The proposed controller is designed on the basis of SMC technique. A hysteresis band is employed to generate the switching law for the inverter circuit and that has been implemented using a simple flip-flop with externally driven constant frequency clock pulses. In spite of this constant frequency switching operation, it has all the properties of an ideal SMC such as simple to design and good transient performance.

II. FIXED FREQUENCY SLIDING MODE CONTROL SINGLE PHASE INVERTER

$$\begin{pmatrix} \frac{di}{dt} \\ \frac{dv}{dt} \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \begin{pmatrix} i \\ v \end{pmatrix} + \begin{pmatrix} \frac{E}{L} \\ 0 \end{pmatrix} u$$

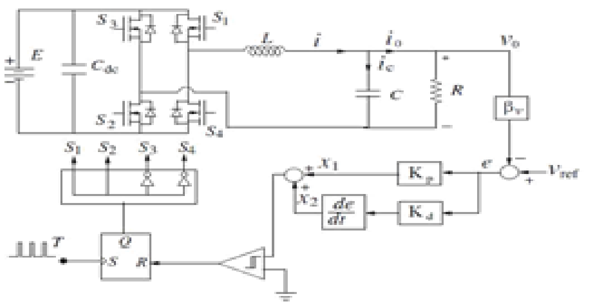

Fig.2. The proposed FFSMC-controlled single-phase inverter

The VSI consists of a dc supply voltage E, a dc linkcapacitor C_{dc}, filter elements L and C, aload resistance R, and four controllable power switches S1 to S4.The switches are controlled by the fixed frequency sliding mode control logic. Assuming all components are ideal, the state space equations of VSI can be written in matrix form, as where i and v are the inductor current and output voltage and control signal, depending on which switches are active, namely, u = -1 corresponds to output inverter voltage equal to –E, u = +1 corresponds to output inverter voltage equal to +E. Moreover, in accordance with the sliding mode theory ,the switching surface can be designed, which leads to a robust output voltage behavior towards any load variation and source fluctuations, due to its independence on converter parameters.

III. SLIDING MODE CONTROL

Normally, SMC is considered as a good alternative to the control of switching converters. The main advantages of such control scheme over classical one are; its robustness, and high dynamics performances under parameter fluctuations. The various steps of this control scheme can be outlined by using the equivalent control concept..The first step is the selection of the switching surface S(x; t) (where x is the system state vector), for the single phase VSI system, so that, it can act as a reference path for the trajectory of the controlled system. It is important to note that for an ideal SMC, it requires an infinite switching frequency, so that, the state trajectories in neighborhood of the switching surface can move precisely along the surface. But operation of such infinite switching in power electronics inverter system is practically impossible. It is therefore necessary a typical control circuit that would require a relay or hysteresis function to restrict the infinite switching frequency as shown in Fig. 3.

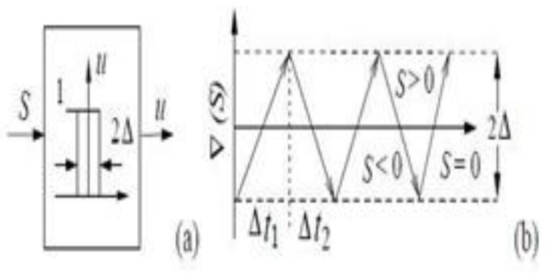

*Fig.3.*Schematic diagram showing the: (a) hysteresis function; and (b) the state trajectory in the vicinity of sliding surface S = 0

A. Constatnt Frequency Operation

The operating switching frequency of the sliding mode control is variable and it depends on various factors, like value of hysteresis band, parameters of inverter and the load condition. So the constant switching frequency operation is highly essential to lock the desired frequency of the VSI. This can be achieved by taking a hysteresis comparator followed by a S-R flip flop which is set by a clock signal running at the desired operating frequency. At every rising edge of the clock, the PWM signal u is set to 1 and it is reset to 0 when the switching surface S(x) reaches the threshold of the comparator. The advantages of this scheme are its quite simplicity and exact operating frequency during steady state. But during the transient operation the switching frequency changes because during this period, two consecutive rising edges of the clock may occur without a reset event. Therefore, after obtaining the mathematical model and constant-frequency switching logic presented, we only discuss some numerical results.

IV. SIMULATION *RESULTS*

In order to verify the proposed control scheme, the above model has been simulated by MATLAB/SIMULINK. The resonant frequency is taken 2.5 KHz to design the low pass LC filter. The sampling frequency is100 μsec . The parameters required for simulation of a 1 kVAinverter are: E = 175 V, V_0 =110 V(rms), f = 50 Hz, f_s = 20 kHz, L =0.75 mH, C = 66μF , load register R = 17 . All the parameters are chosen to attain the best transient performance of the system.. The phase plane plot of the output voltage v and the voltage derivative v are shown under the proposed ellipsoidal surface sliding mode control on full load condition. The system trajectory shown in this Figure moves along the curved switching surface with a switching frequency of the clock pulse.

The steady state response of the output voltage and load current are shown. The THD of the output voltage is found about 0.73% at the full load condition.The simulation results of the proposed control scheme under step load changes are verified in phase plane to examine the load fluctuation effect. Fig shows the responses of the controller under step load fluctuation by taking the ellipsoidal switching surface. The system trajectory defined in takes long time to settle when the fluctuation occurs at outside of the existence region where as it will quickly settle at inside the existence region. Similarly the above Fig shows the dynamic response of the controller under step load change of no-load to full load and full load to no load respectively.From the figures, it is observed that the time taken

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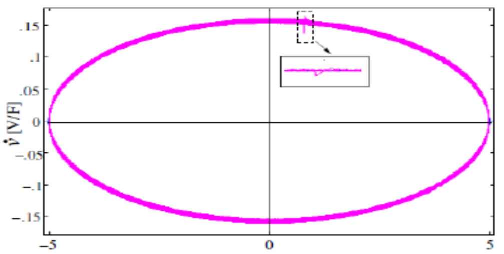
by the proposed controller to attain the steady state after load change is 0.6 msec and 0.85 msec for the above two cases.

$$u = \begin{cases} 1 & \text{when } S > +\Delta \text{ and } \dot{S} < 0 \\ 0 & \text{when } S < -\Delta \text{ and } \dot{S} > 0 \end{cases}$$ [redacted]



limitation and the value 10^{-6} which keep the tracki

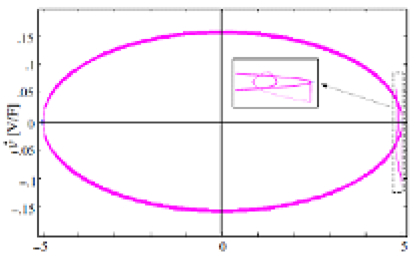


Fig 4.1 The system trajectory under load fluctuation a) hitting in the existence (b) hitting in the non existence region.

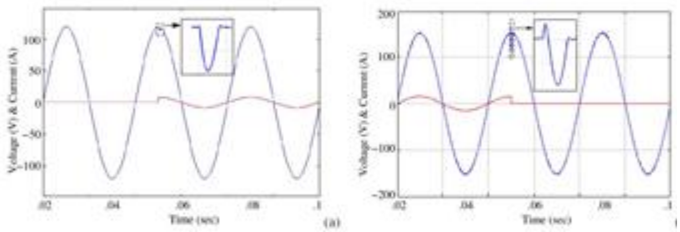


Fig4.2 Transient response of the output voltage and load current of the proposed controller under step load change : (a) from no-load to full load (b) from full load to no-load.

Hence a FFSMC controller is implemented on the basis SMC technique for a single phase full bridge VSI. Since SMC produces a huge chattering problem, so a hysteretic function is employed to generate the switching law. A fixed frequency operation of inverter is achieved by a simple flip-flop with the externally driven constant frequency clock pulse.

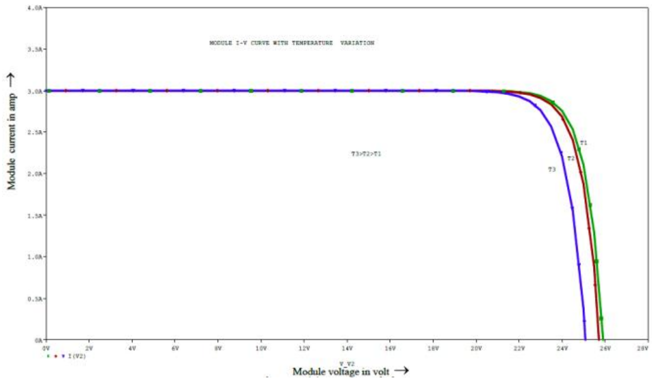


Fig:4.3 PV module I-V Curve.

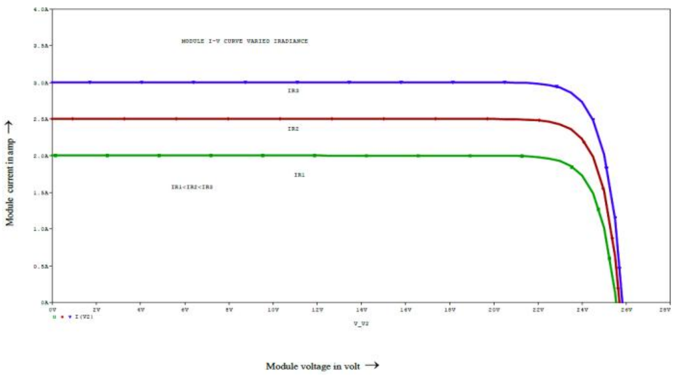


Fig:4.4 PV module I-V Curve.

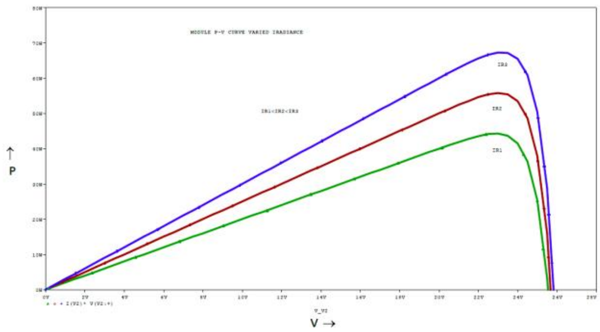


Fig:4.5 PV module P-V Curve.

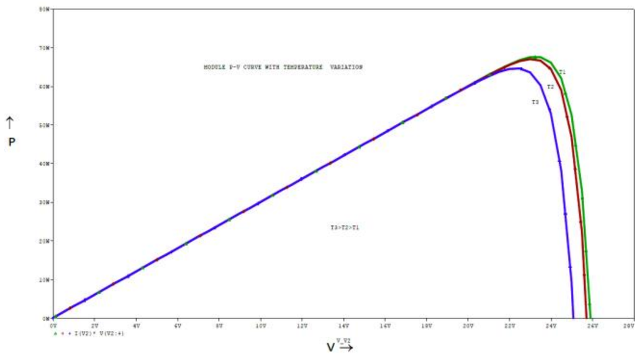


Fig:4.6 PV module P-V Curve.

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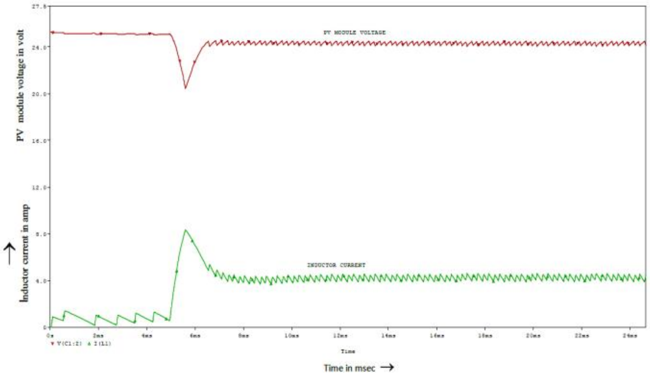

Fig4.7 PV module voltage and converter inductor current without any variation

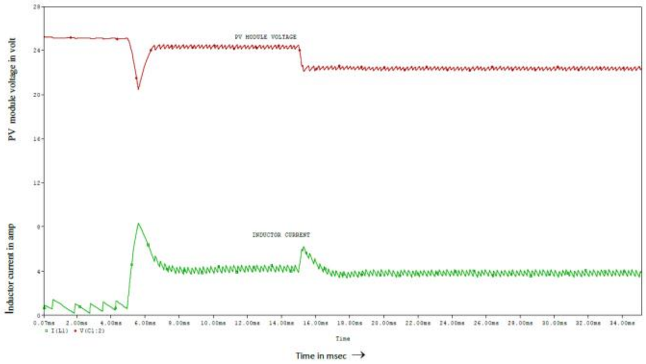

Fig4.8 PV module voltage and converter inductor current with variation

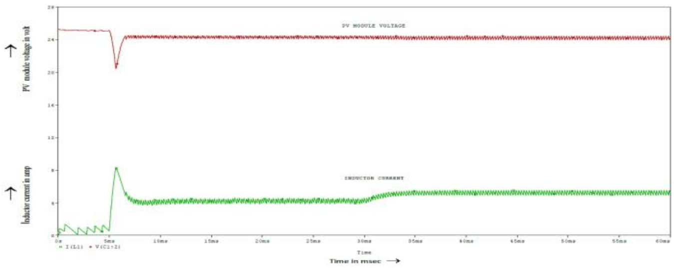

Fig 4.9 PV module voltage and converter inductor current with variation of load

V. CONCLUSION

In this paper, a FFSMC controller is proposed on the basis of Sliding Mode Control for a single phase full bridge VSI. Since SMC produces a huge chattering problem, so a hysteretic function is used to generate the switching law. A constant frequency operation of inverter is achieved by a simple flip-flop with the externally driven constant frequency clock pulse. A ellipsoidal swiching surface is derived in the phase plane. From the simulation results, it can be concluded that the proposed FFSMC controller not only give better voltage regulation, but also exhibits good dynamic performance under sudden load fluctuation. The total harmonic distortion of the inverter output voltage is 0.73% at the rated load. The voltage regulation of 0.8% is measured for step load change from zero to 100%. For the sake of simplicity, it have taken a dc voltage source as the inverter input supply. Moreover, this control scheme is also applicable to the islanded distribution generation (DG) system, powered by the the renewable energysources like pv system, fuel cell system etc. The applications of this controller can also be extended to the grid connected. DG systems to mitigate the problems related to load fluctuation.. Also the MPP of PV system is tracked successfully sources like pv system, fuel cell system etc. The applications of this controller can also be extended to the grid connected DG systems to mitigate the problems related to load fluctuation.Also the MPP of PV system is tracked successfully.

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