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A Solar-Photovoltaic Grid Interface Systemusing Smc Based On Lyapunov Function

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Abstract: *A sliding mode control technique (SMC) is used for achieving maximum power point tracking (MPPT) control of solar-PV array. The Lyapunov function-based control technique is designed and developed for the DC-AC inverter to the functions of an active power injection to the grid, balanced grid currents at unity power factor and load currents harmonics compensation.The proposed Maximum Power Point Tracking controller generates current reference directly from the sensorboard, and the current controller uses the sliding mode technique for the tight regulation of theinjected grid current.The sliding mode controller has been designed using a time-varying slidingsurface to control the sinusoidal current injected to the grid. The structure of a proposed system issimple and robust against modelling uncertainties and parameter variations.The mathematicalmodelling is developed and reliable simulations of the proposed controller are presented. The performance of solar-PV power generating system with proposed control algorithms is demonstrated using simulation and experimental studies under various operating conditions.*

Keywords:*Lyapunov-based function, MPT, PV array, power quality improvement sliding mode control approach, stability analysis.*

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I. INTRODUCTION

The photovoltaic solar energy became more attractive these last decades in the present alternatives. There are various sectors whereelectricity was not easily obtained,at that places the solar systems were employed more and more. In someprovinces, where the wind is not enough to produce required demand, a photovoltaic generator (PVG) is composed of a certain number of solar cells connected in series andparallels according to the required demand. Therefore prices decrease, the systems ofPVG always needs expensive investments; consequently, it is very significant to extractthe maximum of energy from PVG. This later can be only employed effectively when itsfunctions at its optimum point of operation. Since the operation point of PhotoVoltaic Grid depends on the temperature, the illumination and the load. It is not possible to use all solar energyavailable in variable atmospheric conditions when the system is not controlled. It is essentialto force the PVG system to operate at the optimum operation point. Consequently, variousmethods for maximum power point tracker (MPPT) are presented in the literature review [1] [2].

The perturbation and observation method is an algorithm which is used in Maximum Power Point Tracking [7].An another algorithm that is neural network was trained with given data, then the optimal operatingpoint is identified and the maximum power from the solar array is estimated [6]. In thispaper we use a simple method which consists in serving the photocurrent of the PVG so asto have optimum current. This result is very important; in fact we can have the optimumvalue of the current thanks to sensor board situated close to a generator in the global systemmodel.

Single-stage grid connected photovoltaic systems have advantages such as simpletopology, high efficiency. The typical Single-stage grid connected photovoltaic systemsconsists of a series-parallel connection arrangement of the available PV modules, inverters(converter DC-AC) and the utility grid. The inverter is the key-component for successfuloperation of the grid connected PV system. It uses various control strategies: powercontrol power-current controlled, [3], power controlled, [8], [9], and current controlled gridconnected PV system, [7]. In this paper the sliding mode controller has been designedto control the sinusoidal current injected to the grid.

II. SLIDING MODE CONTROL

Sliding mode control (SMC), one of the Lyapunov controllers, has been applied to the control of civil engineering structures under earthquake and wind loads, and its effectiveness and robustness were verified through theoretical and experimental studies. SMC determines the sliding surface where the motion of a structure is stable, and Lyapunov function is defined as a scalar function proportional to the distance of states to the sliding surface.

SMC is a kind of non-linear control which is robust in the presence of parameter uncertainties and disturbances. It is able to constrain the system status to followtrajectories which lie on a suitable surface in the sliding surface. The main steps for sliding mode controller design can be summarized, by using an equivalent control concept, as follows:

-Selecting a switching surface s(x,t) = 0 (where x is the system's state vector) that provides the desired asymptotic behavior in steady state.

Obtaining the equivalent control ueqby applying the invariance condition.

$s(x, t) = 0$ and $\dot{s}(x, t) = 0 \Longrightarrow u(t) = u_{eq}(t)$ (1)

The existence of the equivalent control ueqassures the feasibility of a sliding motion over the switching surface s(x,t) = 0

Finally, selecting a non-linear control input n u to ensure that Lyapunov stability criteria.

III. Design Of Pv System

Due to the requirement for environmental preservation and dramatic increase in energy consumption over the last decades, most countries have decided to strongly promote and develop clean and sustainable power generation sources. Also, governments encourage resorting to such energy solutions through significant tax credits. Nowadays, renewable energy sources are widely used and particularly (PV) energy systems have become widespread everywhere. Indeed, PV systems present several features e.g high dependability, simplicity of allocation, absence of fuel cost, low maintenance and lack of noise due to the absence of moving parts. All these considerations assure a promising role for PV generation systems in the near future. The grid-connected PV systems consist of an array of solar module, a DC-DC power converter, a DCAC converter and a control system, the complete scheme is presented in fig 1

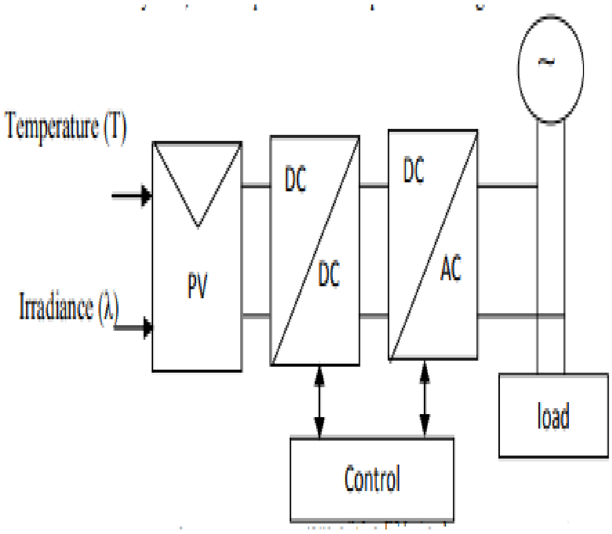


Figure 1: PV single-phase grid system

Proposed system consists of solar-PV array tied to the grid through a DC-DC boost converter and a three-phase DC-AC inverter that show in fig 2. To attenuate the switching ripples at the AC terminals of the DC-AC inverter, a star-connected three terminal RC ripple filter is connected.

The DC-DC boost converter is controlled using SMC approach in order to achieve MPT from PV array with regulating the DC link voltage of PV array. The DC-AC inverter is controlled using Lyapunov-function based approach in order to feed the solar-PV generated power to the grid, to compensate harmonics present in load currents and to ensure balanced grid currents at unity power factor.

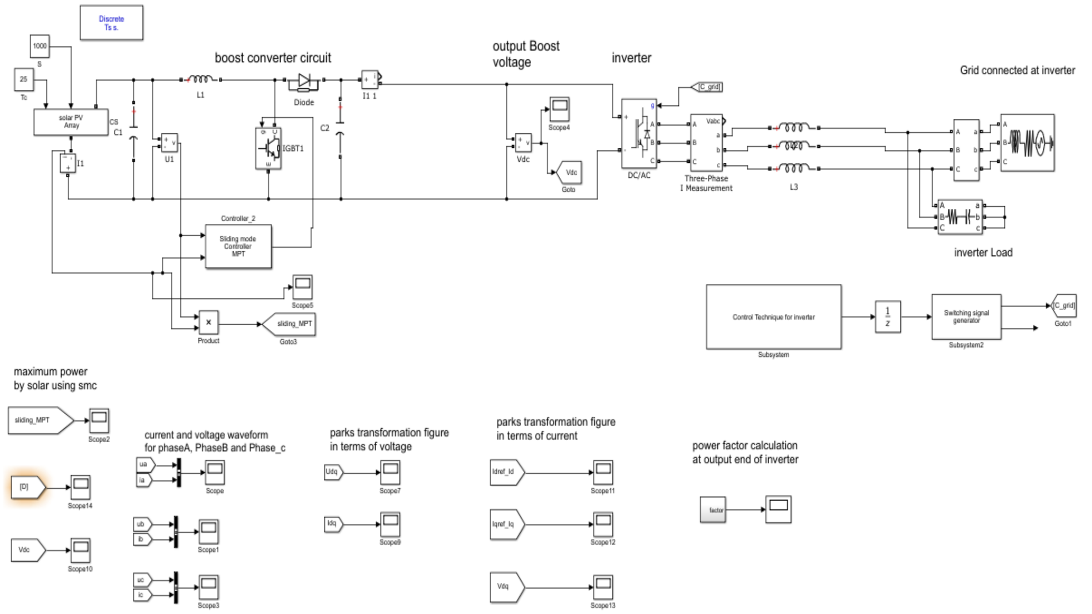


Figure 2:solar-PV power generation model.

III. GRID PV SYSTEM

The model of the sliding mode controller started from the design of the sliding surface.Usually, the sliding surface is constructed by the linear combination of state variable errors that are known as the differences between the state variables and their references.Therefore, in this case, the sliding surface can be designed with errors of the solar-array voltage and inductor current. In a single-phase grid-connected photovoltaic system, the solar-array voltage is oscillating due to the sinusoidal inductor current, which results in an undesirable sliding mode performance.Because of this ,any attempt has not been made to apply the sliding mode control for a grid-connected photo-voltaic system. The main purpose of a grid-connected photovoltaic system is to transfer the maximum solar-array power into the grid with a unity power factor. Therefore, the sliding surface should be designed to control the inductor current and solar-array power simultaneously. This requirement can be achieved by choosing a sliding surface only using the errors of the inductor current.

The proposed time-varying sliding surface is defined by:

$$\mathrm{s(x,t) = i_{res} - i_{ref} = i_{res} - i_{opt}\sin \omega t} \qquad (2)$$

The current of generator statement, corresponds to the maximum power, noted Iopt(optimal current), and is proportional to the photo current which is proportional toillumination following the relation [9] according to

$$\mathrm{I_{opt} = 0.85\, I_{ph}} \qquad (3)$$

The control input is given as follows:

$$\mathrm{u(t) = u_{eq}(t) + u_n(t)} \qquad (4)$$

The equivalent control ueq can be obtained applying the invariance condition.

$$\mathrm{s(x,t) = 0 \text{ and } \dot{s}(x,t) = 0 \Longrightarrow u(t) = u_{eq}(t)} \qquad (5)$$

The existence of the equivalent control eq u assures the feasibility of a sliding motionover the switching surfaces(x,t) = 0.

Differentiating B(x) = 0 give:

$$\dot{s}(x,t) = \frac{\partial s}{\partial x}\Big(A(x,t) + B(x).u_{eq}(t)\Big) + \frac{\partial s}{\partial t} = 0 \qquad (6)$$

The necessary condition for the existence of a sliding motion of s(x,t) is represented bythe transversality condition and expressed as follows:

$$\frac{\partial s}{\partial t} \times B(x) \neq 0 \qquad (7)$$

Where

$\frac{\partial s}{\partial t} \times B(x) \neq 0$denotes the directional derivative of the scalar function r withrespect to the vector field B(x)

$$^{\cdot}\ s(x,t) = \frac{1}{L}(V_P.u(t) - R.I_{res} - V_{res}) - i_{opt}\ \omega \cos \omega t = 0 \qquad (8)$$

Therefore, the equivalent control-input is given as:

$$u_{eq}(t) = \frac{R.i_{res} + V_{res} + i_{opt}.\omega.\cos\omega t / V_{RM}}{V_p} \qquad (9)$$

Once the desired time varying sliding surface was fixed, the nonlinear switching inputcan be chosen as follows:

$$U_n(t) = -K_i|s|\alpha sgn(s_i) \;\; 0 \propto \alpha \propto 1, i = 1 \dots m \qquad (10)$$

If (25) and (26) are substituted into (20), the range of kiensuring ss< 0 can bedetermined as follows:

$$s\dot{s} = s\left(i_{res} - i_{opt}\ \omega\ \cos\omega t\right) = s\left(\frac{V_p}{L}\left(v_{eq}(t) + u_n(t)\right) - \frac{V_{res}}{L} - i_{opt}\ \omega \cos\omega t\right)$$

$$= s\left(-\frac{V_{res}}{L}.K_i|s|\alpha sgn(s_i)\right) \propto 0 \qquad (11)$$

From (9), (10) and (11) the control input u(t)=ueq(t)+un(t) is given as follows:

$$u(t) = \frac{Ri_{res} + V_{res} + i_{opt}\ \omega\ \cos\frac{\omega t}{V_{RM}} - Ki|s|\alpha sgn\,(s)}{V_P} \qquad (12)$$

IV. MPPT SYSTEM MODELLING

The system can be written in two sets of state equation depending on the switch position S. If the switch position S=0,the differential equation can be written as

$$i_{L1} = \frac{V_{pv}}{L} - \frac{V_0}{L} \qquad (13)$$

$$V_{o1} = \frac{i_L}{C} - \frac{V_0}{CR_L} \qquad (14)$$

the differential equation if switch is in position S=1

$$i_{L2} = \frac{V_{pv}}{L} \qquad (15)$$

$$V_{o2} = -\frac{V_0}{CR_L} \quad (16)$$

By using state space averaging method eq (13) (14) and eqn (15) (16) can be combined into one set of state eqn to represent the dynamic of the system. Base on the idea of PWM, the ratio of the switch in position in a period is defined as duty ratio. The distinct eqn. sets are weighted by the duty ratio and superimposed

$$\dot{X} = (1-\mu)\dot{X}_1 + \mu\dot{X}_2 \qquad (17)$$

Hence the dynamic equation of the system can be described by

$$i_L = \frac{\mu V_{pv}}{L} - \frac{V_0}{L} + \frac{V_0\mu}{L} \quad (18)$$

$$i_L = -\frac{V_0}{L} + \frac{\mu(V_{pv} + V_0)}{L} \quad (19)$$

$$V_0 = \frac{i_L}{C} - \frac{i_0}{C} - \frac{i_L\mu}{C} \quad (20)$$

$$V_0 = \frac{(i_L - i_0)}{C} - \frac{i_L\mu}{C} \quad (21)$$

$$V_{pv} = \frac{i_{pv}}{C} - \frac{\mu i_L}{C} \quad (22)$$

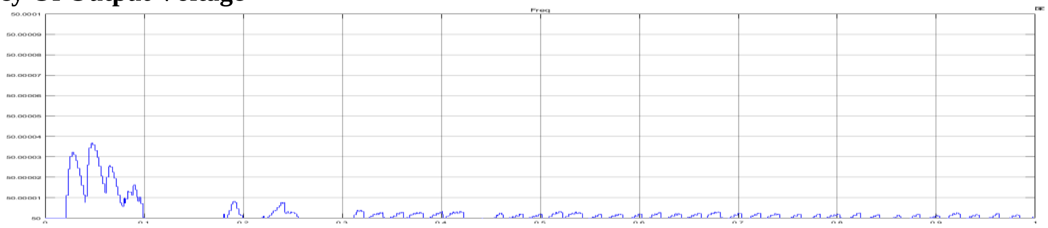
$$\dot{X} = \begin{bmatrix} V_{pv} \\ i_L \\ V_b \end{bmatrix} \quad f(x) = \begin{bmatrix} \dfrac{i_{pv}}{C} \\ \dfrac{-V_0}{L} \\ \dfrac{(i_L - i_0)}{C} \end{bmatrix} \quad g(x) = \begin{bmatrix} \dfrac{-i_L}{C} \\ \dfrac{(V_{pv} + V_0)}{L} \\ \dfrac{-i_L}{C} \end{bmatrix} \qquad (23)$$

The system of equation can be written in general form of the non-linear time system as

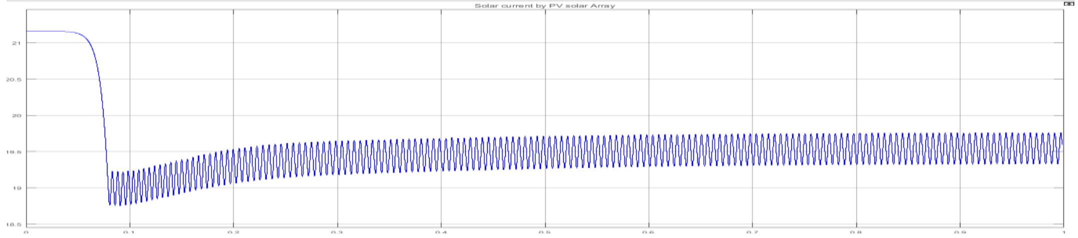
$$\dot{X} = f(x) + g(x)\mu \quad (24)$$

V. SIMULATION AND RESULT-

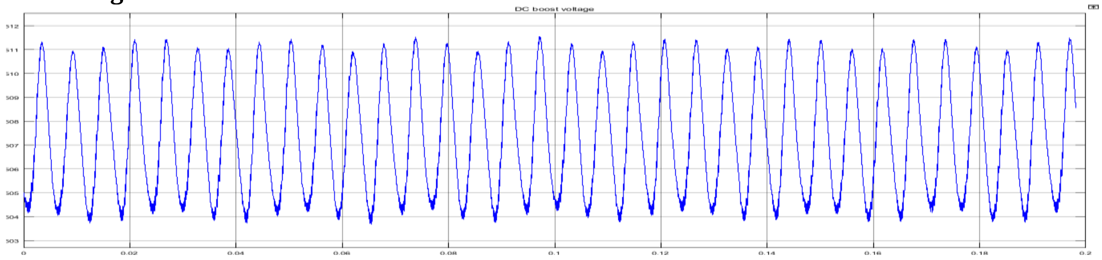
Frequecy Of Output Voltage



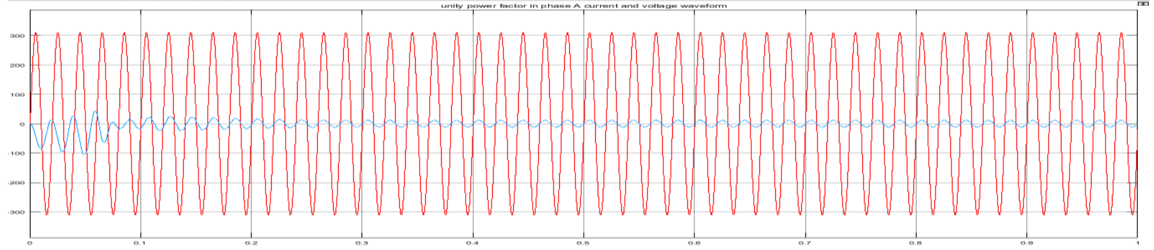
Solar Current By Pv Array



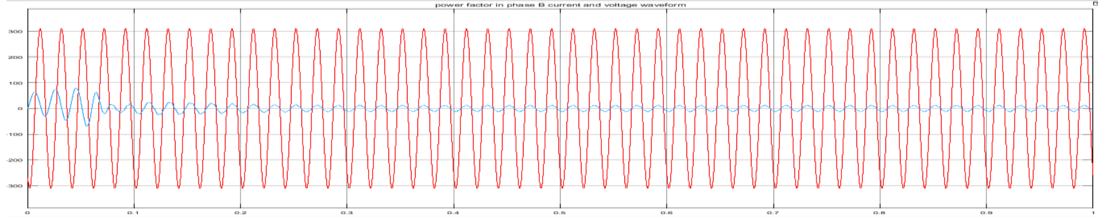
Dc Boost Voltage



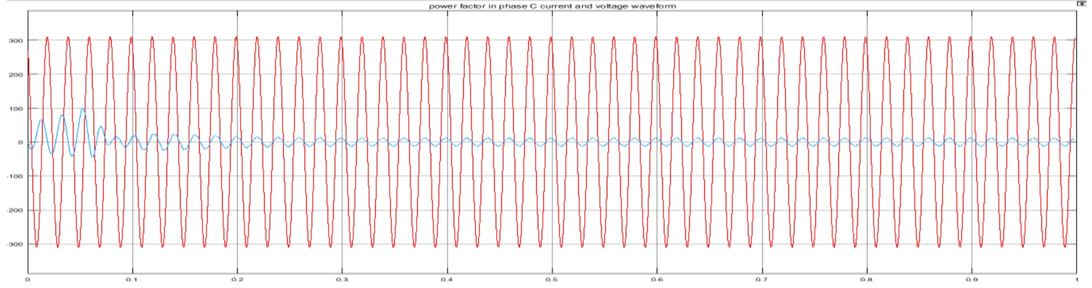
Power Factor In Phase A Current And Voltage Waveform



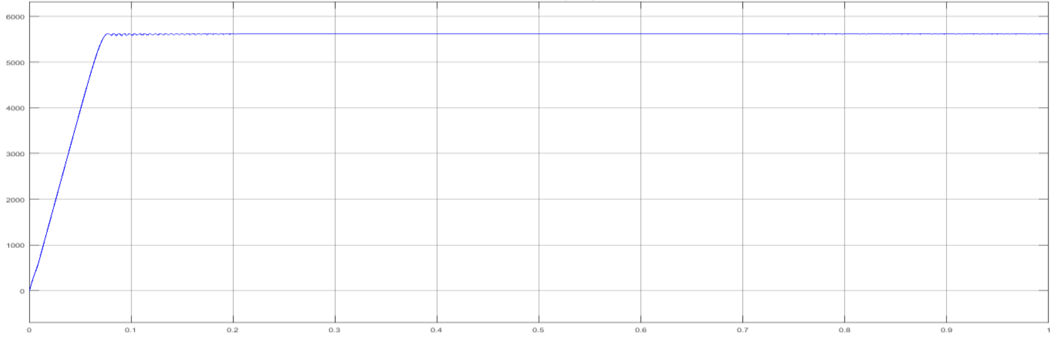
Power Factor In Phase B Current And Voltage Waveform



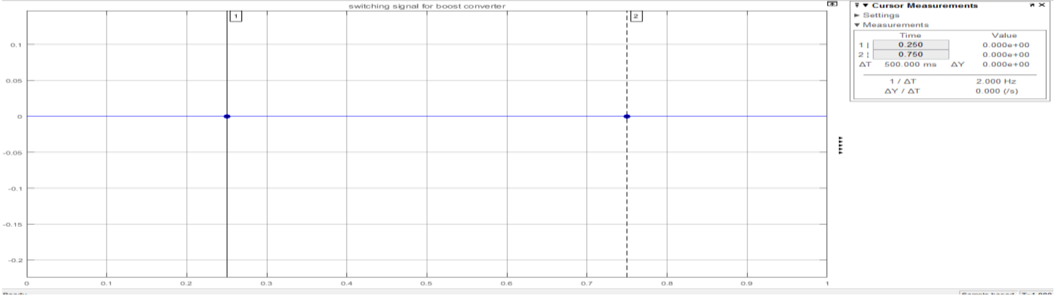
Power Factor In Phase C Current And Voltage Waveform



Maximum Solar Power By Using Smc

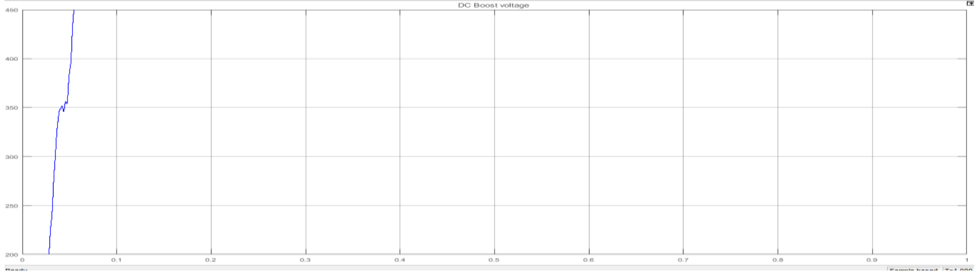


switching signal for boost converter

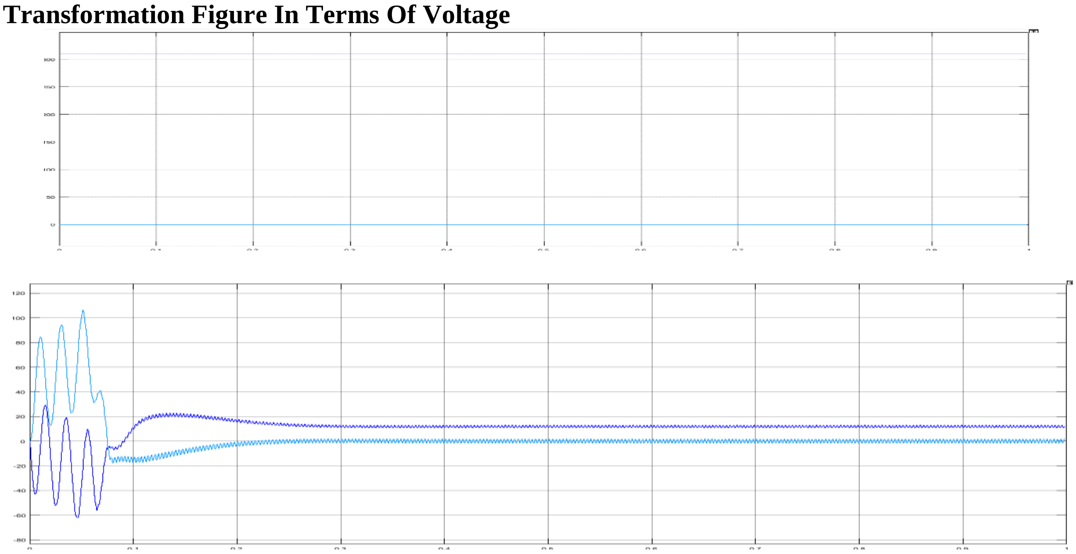


	Time		Value
1	0.250		0.000e+00
2	0.750		0.000e+00
ΔT	500.000 ms	ΔY	0.000e+00
	1 / ΔT		2.000 Hz
	ΔY / ΔT		0.000 (/s)

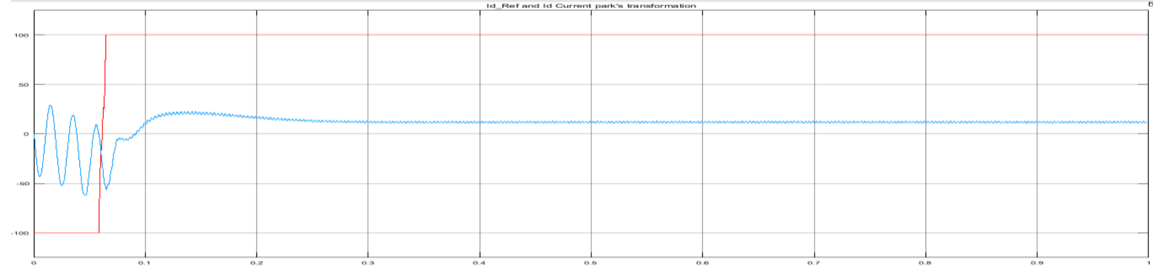
Dc Boost Voltage

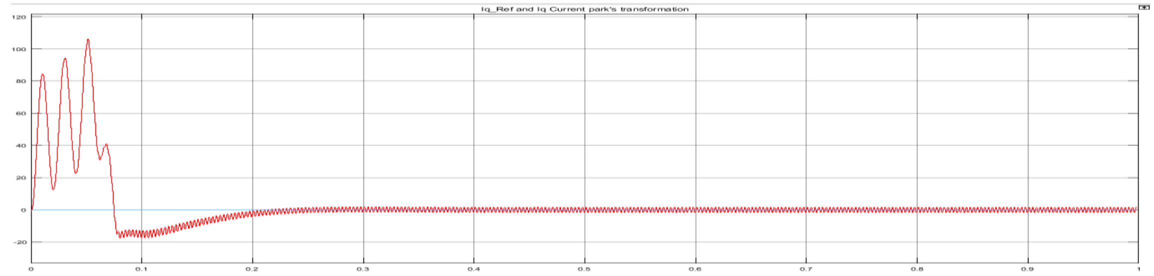


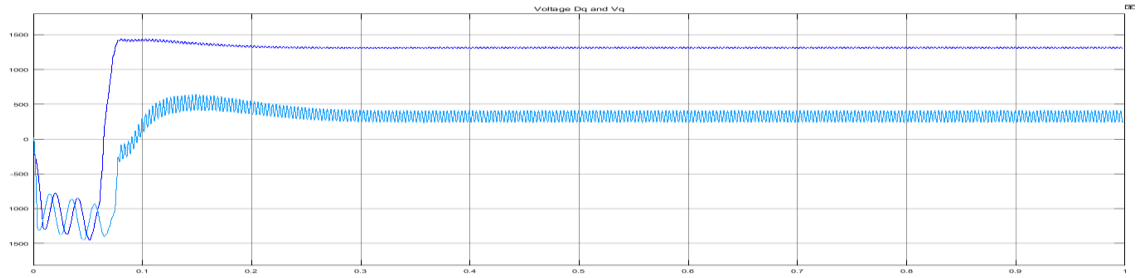
Parks Transformation Figure In Terms Of Voltage



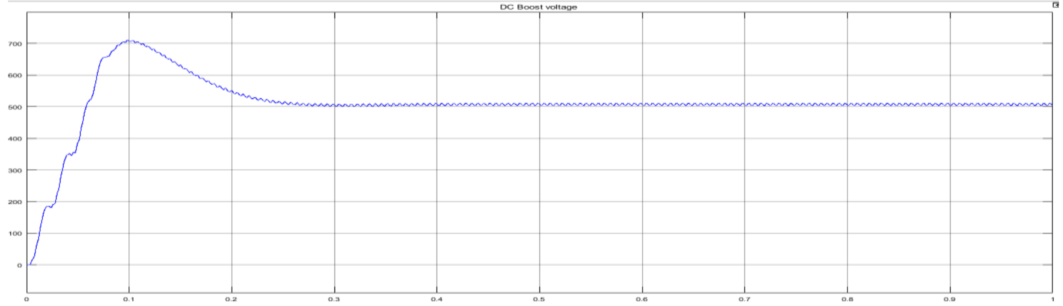
Parks Transformation Figure In Terms Of Current



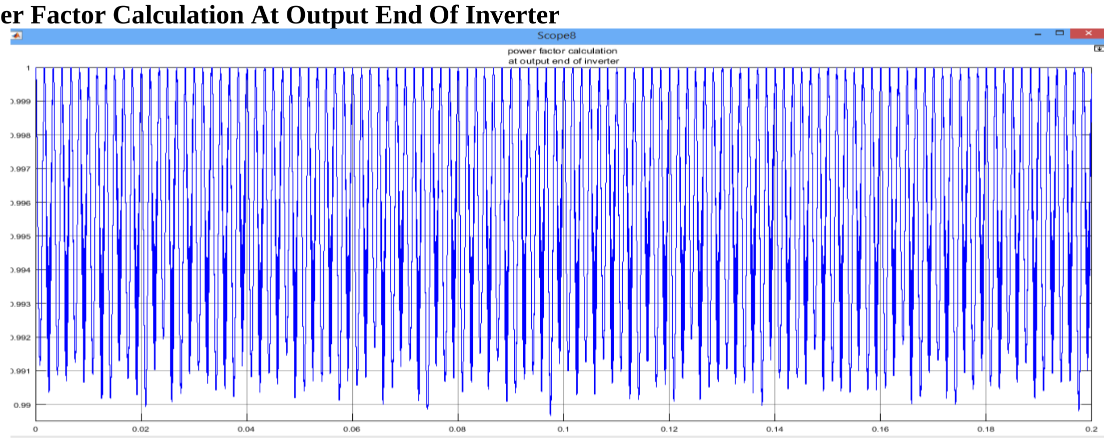




Dc Boost Voltage



Power Factor Calculation At Output End Of Inverter



VI. CONCLUSION

A sliding mode control and Lyapunov function based control algorithms have been presented for the boost converter andDC-AC inverter used for solar-PV power generating system array of solar panels tied with the grid. Detailed design and stability analysis for both control techniques have been discussed to confirm its applicability under various operating conditions.A Sliding mode controller for photovoltaic system connected to the grid has been proposed. The current reference is directly generated from the sensor board. The sliding mode controller was used as a current controller for the tight regulation of the current injected to the grid. The proposed control system is simple, efficient and the control signals are chattering free. In this new controller there is an importing reduction of the chattering phenomenon and improved power factor obtained in this model.

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