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Voltage Oriented Control Applied to a 3-Φ Bidirectional Inverter for Grid Connected PV System

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Abstract: This paper presents a voltage oriented control (VOC) applied to a 3-Φ Bidirectional Inverter for Grid Connected PV System. The bidirectional inverter can perform the two modes of the operation such as grid connection mode (GC) and rectification mode with power factor correction (PFC) .under low current ranges, inductor current have more ripples, with the help of VOC method improve the current distortion and power transfer can takes place smoothyand the problems of synchronization of current to be injected to the grid can be solved by the phase locked loop (PLL). The model of the grid connected PV system had been implemented in the MATLAB | SIMULINK software and simulation studies have been presented.

Keywords: Voltage Oriented control (VOC), Bi-Directional Inverter, PLL, and PV System.

1. INTRODUCTION

Developing countries are highly dependent on fossil fuels to meet this energy demands. Fossil fuels are non-renewable i.e., they draw on finite resources that will eventual diminish. Making energy too expensive which will damage the environment, to meet the energy demand and to be eco-friendly, natural energy sources should be used. In contrast many types of renewable energy sources such as wind and solar energy are constantly utilized will never runout. Solar energy is one of the most promising renewable energy source. Using photovoltaic (PV) modules solar energy can be directly converted to electrical energy. The PV modules provide a very reliable, pollution free way of extracting solar energy.

From the PV modules we can generate the DC voltage. But that voltage is always varies with temperature and irradiance. To avoid that variations Buck/Boost converter with MPPT technique [1] is proposed in this paper. So that we can maintain the DC bus voltage maximum and constant. Here DC load is my critical load ,whenever DC bus voltage more than the AC grid, bidirectional inverter acts as an inverter(sell power) and DC bus voltage is less than the AC grid voltage , bidirectional inverter acts as a rectifier with PFC(buy power) shown in Figure (1). For making these operations smoothy VOC and PLL is required [2]. In this paper with the help of PLL grid voltage and currents are synchronized, and with VOC buy powerand sell power is easy [9].

2. DYNAMICS OF THE BI-DIRECTIONAL INVERTER

In order to understand dynamics of the PWM Bi-directional inverter with variations of control inputs and disturbance inputs, Grid direct and quadrature axis voltages are following equations

$$V_{gd} = Ri_{gd} + \frac{Ld(i_{gd})}{dt} - \omega Li_{gq} + V_{sd}$$

$$V_{gq} = Ri_{gq} + \frac{Ld(i_{gq})}{dt} - \omega Li_{gd} + V_{sq}$$

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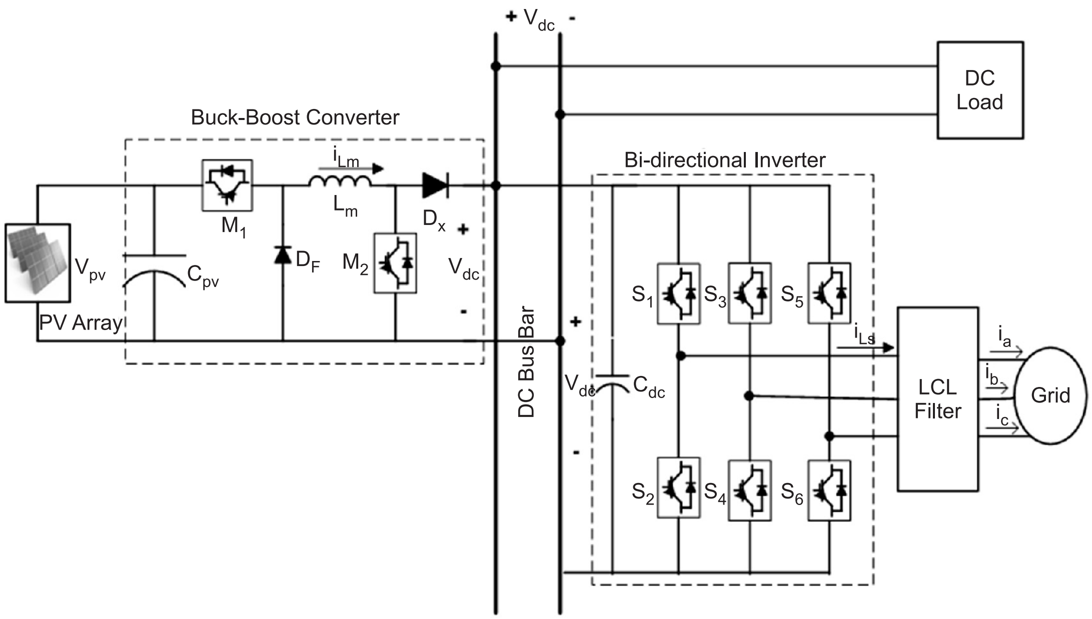

Figure 1: Proposed Schematic Diagram

Where, V_{gd}, V_{gq}, i_{gd}, i_{gq} utility voltages and currents are in synchronous reference frame ω is the angular frequency in rad/sec. Conversion of *abc* to *dq* axis is given by

$$T_{abc\text{-}dq}(abc \text{ to } dq) = \frac{2}{3}\begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix}$$

Inverter direct and quadrature axis voltages are following equations

$$V_{sd} = -Ri_{gd} - \frac{Ld(i_{gd})}{dt} + \omega L i_{gq} + V_{gd}$$

$$V_{sq} = -Ri_{gq} - \frac{Ld(i_{gq})}{dt} - \omega L i_{gd} + V_{gq}$$

3. CONTROL METHOD

As the current is oriented along with direct axis voltage component, the control structure is called as the voltage oriented control (VOC). VOC derived from field oriented control (FOC) of Induction machine.

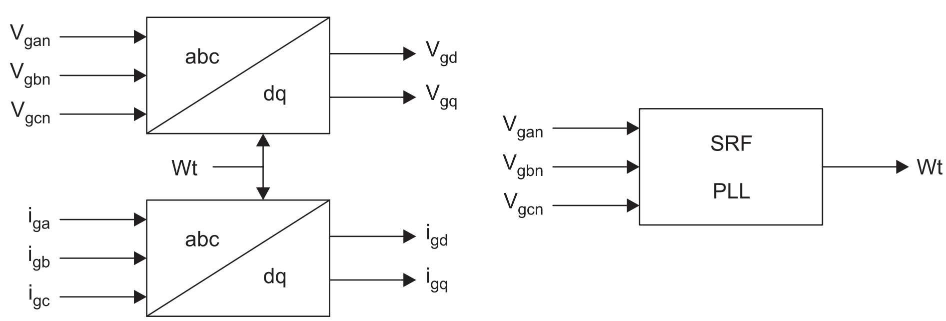

Figure 2: *abc* to *dq* Transformation & Synchronous Reference Frame of Phase locked loop

The PLL is an important and critical part of the system. Its aim is to give the voltage angle of the three-phase system [3]. This angle is then used for all the *dq*-transformations in the model. The line voltages *abc* need to feed the PLL and the voltage angle calculated is used for three-phase to *dq*-coordinate transformation of line current and voltage.

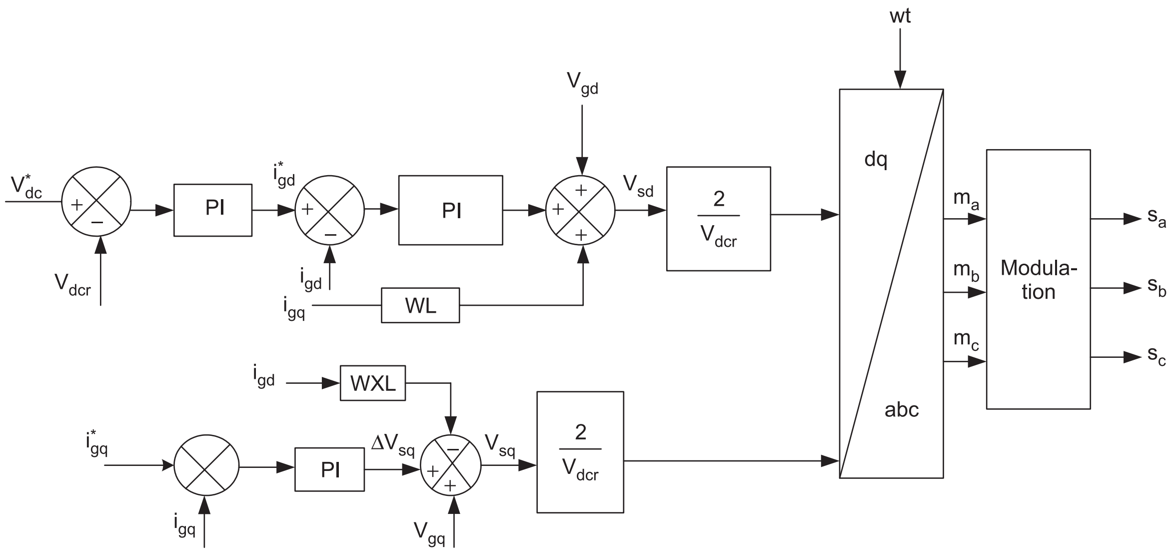

Figure 3: Control Circuit of VOC

VOC is originated on the idea of decoupling direct and quadrature axis components of grid current. As the control method uses synchronous *dq* frame theory, it ensures zero steady state output current error. The control scheme ensures good steady state and transient responses. The control method employs outer voltage loop (to control DC Voltage with inner current loop to control utility currents). The direct axis and quadrature axis currents are controlled independently with decoupled current control method. A reference voltage V^*_{dc} is given to DC voltage control loop, based on the error between reference and actual voltages, voltage controller generates reference to current control loop. The inner loop generates modulation signals in *dq* domain. The modulation signals are converted back to 3 phase coordinate and fed to PWM, which drives bidirectional inverter.

4. LCL FILTER DESIGN

Even though the structure and parameter of LC filters are simple, the harmonic attenuation is not good because of the uncertainty of network impedance. LCL filter has inherently high cutoff innate nature of the LCL filter allows high cut off frequency and strong penetrating capabilities at low frequencies [5-7]. In the LCL filter, the fundamental component, lower order harmonics and higher order harmonic current could be decoupling the input current of converter. The current ripple is reduced because of inductor (L_i), that the current flow through the capacitance behaves such that low resistance path to higher order harmonic quantities but the inductance (L_g) offers high impedance to the same. So that higher order harmonics can only flow through the capacitance. The fundamental lower order harmonics flow through L_g. In the low frequency range the LCL filter operates similar to L filter, Hence in the high frequency range the LCL filter has the good filtering choice.

Since the filter main purpose is to attenuate higher order harmonics for converter the transfer function is derived with grid shortened. For grid injected current to converter terminal voltage

$$T(s) = \frac{v_{pwm}(s)}{i_g(s)}$$

It is nothing but impedance of the system from output to input. The filter can be drawn given as follows.

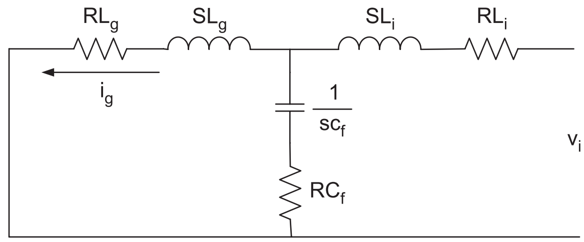

Figure 4: Equivalent circuit of LCL Filter

$$\text{Series combination of capacitance} = R_{cf} + \frac{1}{SC_f} = \frac{R_{cf}SC_f + 1}{SC_f}$$

$$\text{Voltage across shunt branch} = \frac{\dfrac{SC_fR_{cf} + 1}{SC_f}}{RL_i + SL_i + \dfrac{SC_fR_{cf} + 1}{SC_f}}$$

$$\frac{SC_fR_{cf} + 1}{SR_{L_i}C_f + S^2L_iC_f + S(R_{cf}C_f) + 1} = \frac{SC_fR_{cf} + 1}{S^2L_iC_f + S(R_{cf}C_f + R_{L_i}C_f) + 1}$$

The current through

$$L_g = i_g$$

$$i_g = \frac{V_{ct}}{\text{impedance}} = \frac{V_i \cdot \text{ratio}}{\text{impedance}}$$

$$\frac{i_g(s)}{V_i(s)} = \frac{\text{ratio}}{\text{impedance}}$$

$$\frac{i_g(s)}{V_i(s)} = \frac{SC_fR_{cf} + 1}{S^2L_iC_f + S(R_{cf}C_f + R_{L_i}C_f) + 1}\;\frac{1}{R_{L_g} + C_{L_g}}$$

$$\frac{i_g(s)}{V_i(s)} = \frac{SC_fR_{cf} + 1}{S^3L_iC_fL_g + S^2(R_{cf}C_fL_g + R_{L_i}C_fL_g + L_iC_fR_{L_g}) + S(L_g + R_{cf}R_{L_g}C_f) + R_{L_g}}$$

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_i + L_g}{L_iL_gC_f}}$$

(a) LCL Filter Design Conditions

The Peak to peak of ripple current will be within 10% of the rated current of the converter. For the best performance of LCL filter, Low frequency current should as smooth as possible while the high frequency filtering as much as possible. Capacitor reactive current should be less than 5% of rated current.

(b) Design Procedure

1. Design the capacitor on condition that it takes less than 5% reactive power from, Let Rated Power = P Watts, Frequency = f, Phase Voltege = V_{ph} then I reac ≤ 0.05 I rated

$$V_{ph} 2\pi_f \times C_f \leq \frac{0.05 \times P_{rated}}{3 \times V_{ph}}$$

$$C_f \leq \frac{0.05 \times P_{rated}}{V_{ph}^2 \times 6\pi f}$$

2. Based on the condition to reduce harmonic ripple in the current L_i is calculated

$$L_i = \frac{V_{dc}}{6 f_{sw} \times \Delta i_{L\,max}}$$

3. On the basis of desired frequency $f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_i + L_g}{L_i L_g C_f}}$, L_g value $L_g = \frac{L_i}{(w_{res}^2 L_i C_f - 1)}$

   The damping resistance is chosen such that the capacitive impedance at triple the resonant frequency matches with damping resistor. $R_{cf} = \frac{1}{3 w_{res} C_f}$

5. RESULT ANALYSIS

The performance of designed controller has been verified through simulation of closed loop inverter. Simulation analysis has been carried out for the bidirectional inverter in MATLAB SIMULINK platform.

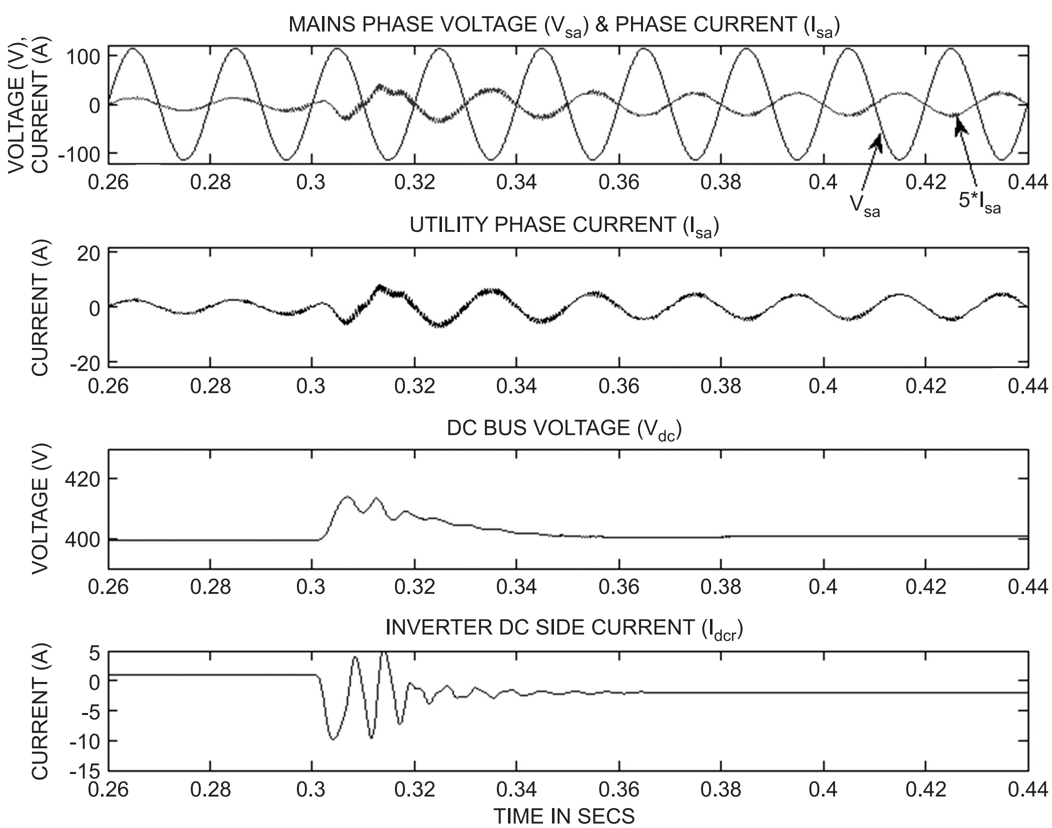

Figure 5: Simulation results of bidirectional inverter with PV source turned on

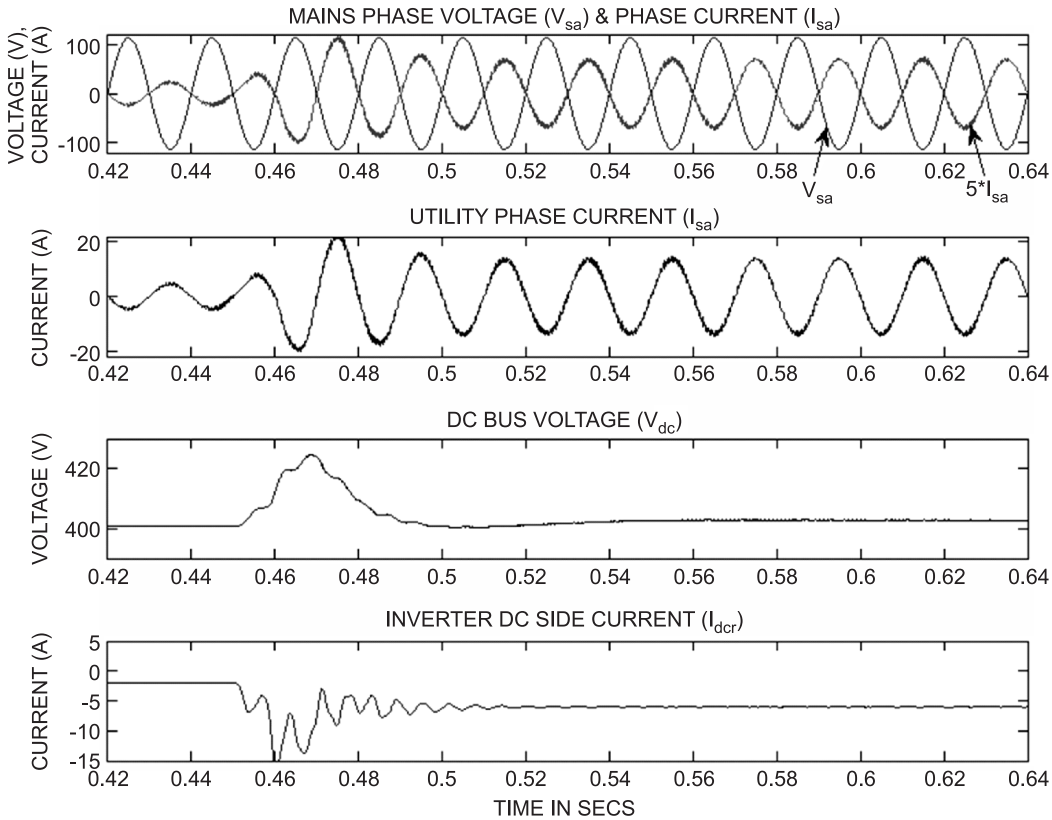

Figure 6: Simulation results of bidirectional inverter with PV source & MPPT turned on

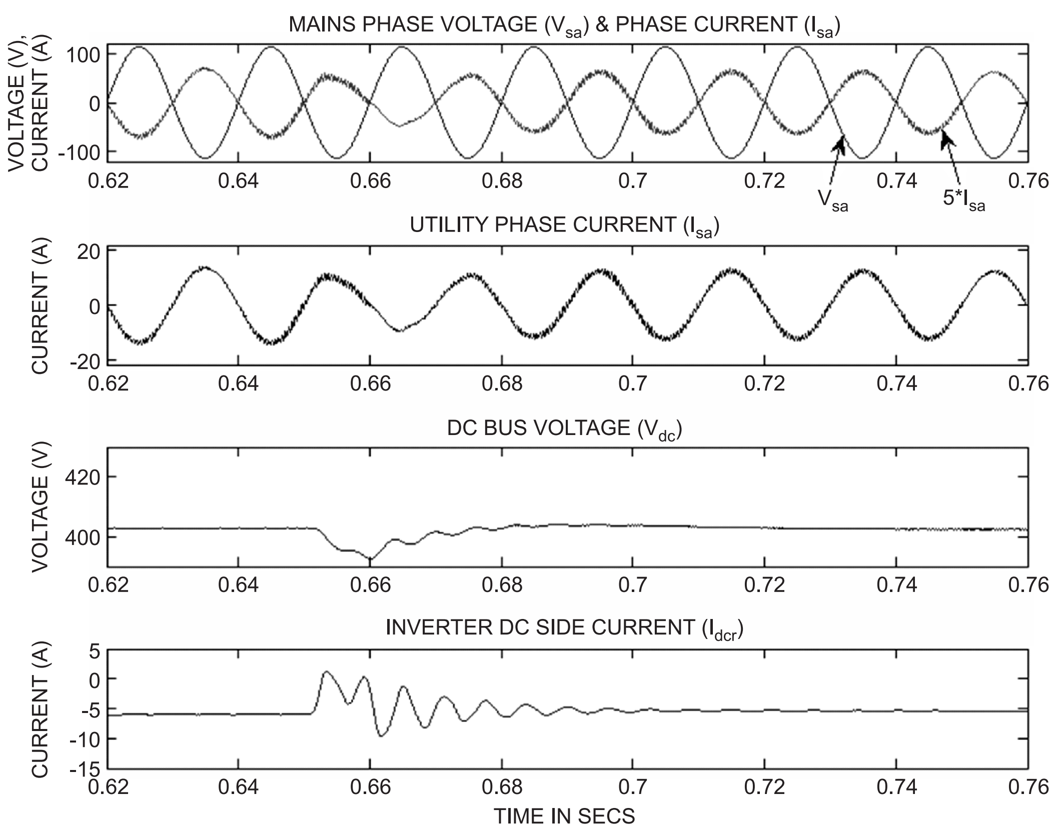

Figure 7: Simulation results of bidirectional inverter with Step change in irradiation on one Panel

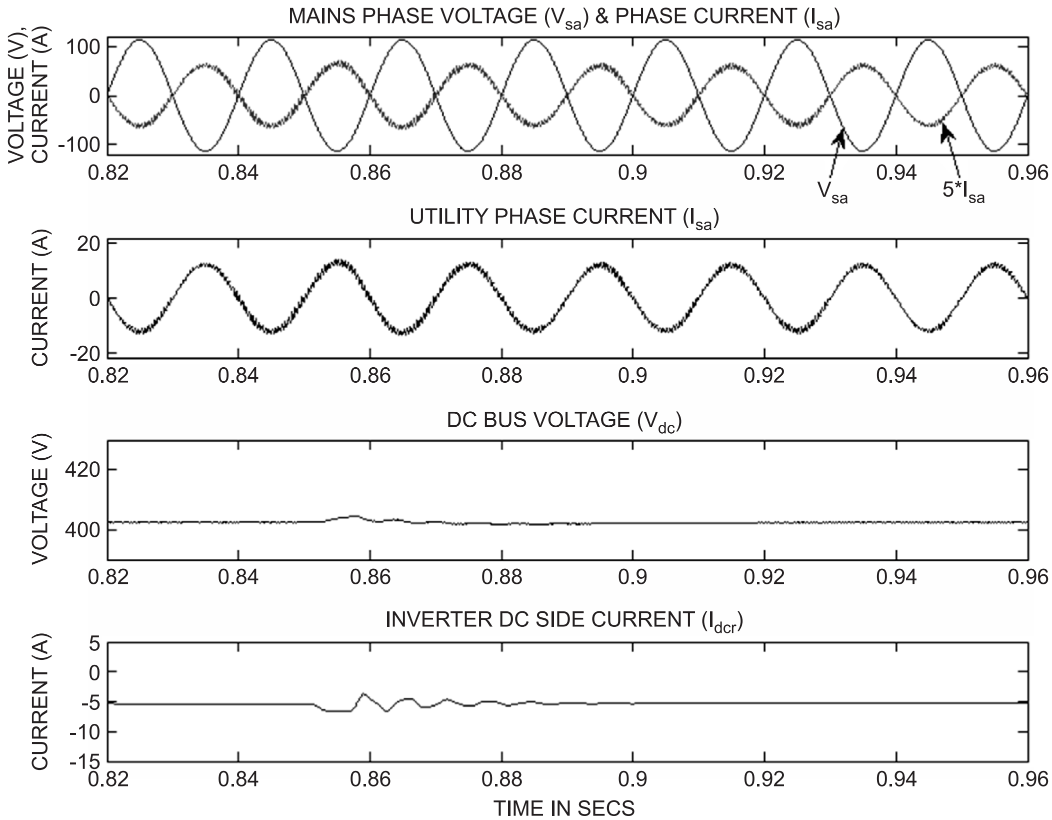

Figure 8: Simulation results of bidirectional inverter with Step change in irradiation on Two Panels

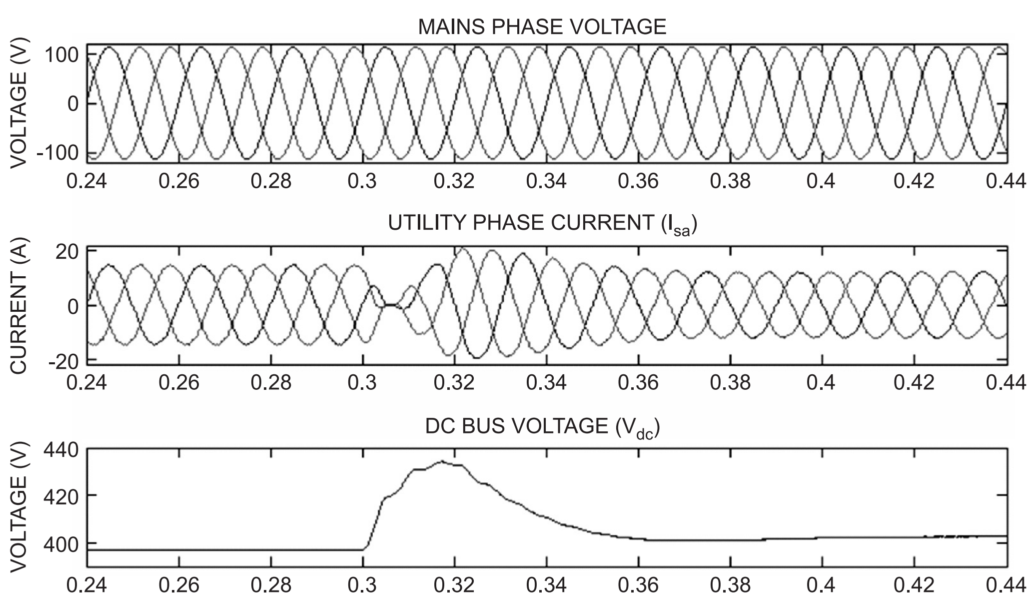

Figure 9: Simulation results of bidirectional inverter with three phases

Figure 5 shows the simulation of result for transient responses of three phase bidirectional inverter. Initially the bidirectional inverter act as rectifier up to 0.3 sec, at 0.3 sec PV source is turned on then the current direction is –ve see in Figure 5, at 0.45 sec MPPT turn on then observe that current magnitude is increases so that power capability increases in Figure 6. Figure 7 shows the grid per phase voltage & current, DC bus voltage and Inverter current in different irradiations observe in Figure 7 & 8. Figure 9 shows the simulation of result for transient responses of three phase bidirectional inverter act as rectifier with PFC up to 0.3 sec after 0.3 sec PV converter MPPT is initiated then it is acts as a inverter send the power to grid.

6. CONCLISION

In this paper, voltage oriented control (VOC) to a 3-Φ Bidirectional Inverter for Grid Connected PV System has been simulated. The utility interface converter has to inject power (generating mode) to mains grid under excessive power conditions in dc distributions system and it has to draw power (rectifying mode) from the mains grid when power deficit occurs in the dc distribution system. This process has been done by bidirectional inverter with VOC method and obtained simulated results with MATLAB Simulation.

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