PERFORMANCE ANALYSIS OF THREE-PHASE PARALLEL INVERTER OF PHOTOVOLTAIC SYSTEMS

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Abstract
To balance an electric current I, on three-phase parallel inverter may be difficult due to prerequisite needed for reimbursement of inverter contemporary errors. There are needs to produce a high quality current from the inverters, besides amplifying in switching frequency of the inverter is demeaning the proficiency of power converters. This paper will discuss about performance analysis of three phase parallel inverters in solar plant. Two inverters are connected in parallel to share and transmit a high quality current, and LCL filters are connected in the output of the inverters to filter the current ripples. A modest switching technique is used for the inverters to produce a reference current at very low switching frequency with very high power capacity. SVPWM switching technique is used to control the inverters and was designed in MATLAB/SIMULINK. Simulation finding illustrates that the parallel inverters can be controlled by SVPWM and total harmonic distortion (THD) can be minimally condensed.

Keywords: Three-phase parallel inverter, Total Harmonic Distortion (THD), Space vector pulse width modulation (SVPWM), Inductance Capacitance Inductance (LCL).

Introduction

To generate electricity using photovoltaic system there is need to consider natural phenomenon which is refilled to human timescale. The natural phenomenon includes Geographical Location, Climatic Change, and Direction of Sun Light Radiation. In this paper, three phase parallel inverter is been considered to measure the performance of current I, in PV plant. Output voltage generated from photosensitive material in form of direct current (dc) is supplied to the input terminals of the inverters, which converted it into alternative current (ac) [1][2]. The inverters can be single-phase voltage source inverter or three-phase voltage source inverter. Single-phase voltage source inverters (VSIs) operate at low range power transmission, while three-phase voltage source inverters (VSIs) operate at medium to high power transmission. Three-phase parallel inverters terminals are mainly designed to produce three-phase load current, while other components such as frequency f, phase difference ϕ, and amplitude voltage $V_{p,}$ are control to have different desired goals [3]. The mode of three-phase inverter's switching terminals (IGBTs) are designed as button one (b_1) and button four (b_4), button three (b_3) and button six (b_6), button five (b_5) and button two (b_2). These buttons cannot be ON instantaneously at a time, because it will cause short circuit in the input terminal of the inverters [3][4]. Insulated Gate Bipolar Transistors (IGBTs) or Metal Oxide Semiconductor field-effect transistors (MOSFETs) are the best common switches used to produce sine wave. To turn the switches ON or OFF, Pulse Width Modulation Generator (PWMG) is used as medium that produces pulse signal at switching frequencies in the range of Kilohertz (KHz). The resulting output voltage is in triangular waveform, which is unrefined voltage. Henceforth, the additional power output components (Inductors and Capacitor) are used to refine and filter the output ripples of the waveforms [8]. Three-phase parallel inverters with low pass filters, have key effect of improving the transient reaction of the inverter to a step changer of input reference voltage through the exclusion of overshoot and oscillation [5]. To reduce high switching frequency with harmonic distortion generated by inverters, LCL filters are extensively employed on the output terminals of the inverters [5]. LCL filters have better attenuation capacity, and it require small inductance of inductors to operate with rate current solution than conventional inductors L, filters. There are different methods of controlling inverter with LCL such as; Methodological optimal, Symmetric optimal and elevated design [5][6][7][8][9].

Inverter switching frequency is amplifying for the purpose of distributing a better quality current I, to the load. The aim is to design three-phase parallel inverters with low switching frequency and have the performance analysis results of parallel inverters output voltage. Two inverters are connected in parallel to observe the current I, behavior produced by the switches and how a better quality current can be produced. Both inverters have the high power capacity and operate at very low switching frequency; they have the same parameters as an output reference current. The Space Vector Pulse Width Modulation (SVPWM) technique is commonly popular known as PWM method for three-phase inverter with control technique of Proportional Integral (PI) controller. It has the characteristics of current protection and also has active response which is very fast, while zero voltage vectors can be derived in each button. Unlike conventional sinusoidal pulse width modulation (SPWM) which has constant switching frequency, well defined harmonic range, optimal switching pattern and non-inherent current protection [10][16].

Configuration of the System

The block diagram of the three-phase parallel system is shown in Fig1. The systems include two parallel inverters, independent DC voltage source, LCL filters, and series equivalent resistance (ESR) for filters. The inverters have high power capacity and operate at low switching frequency.

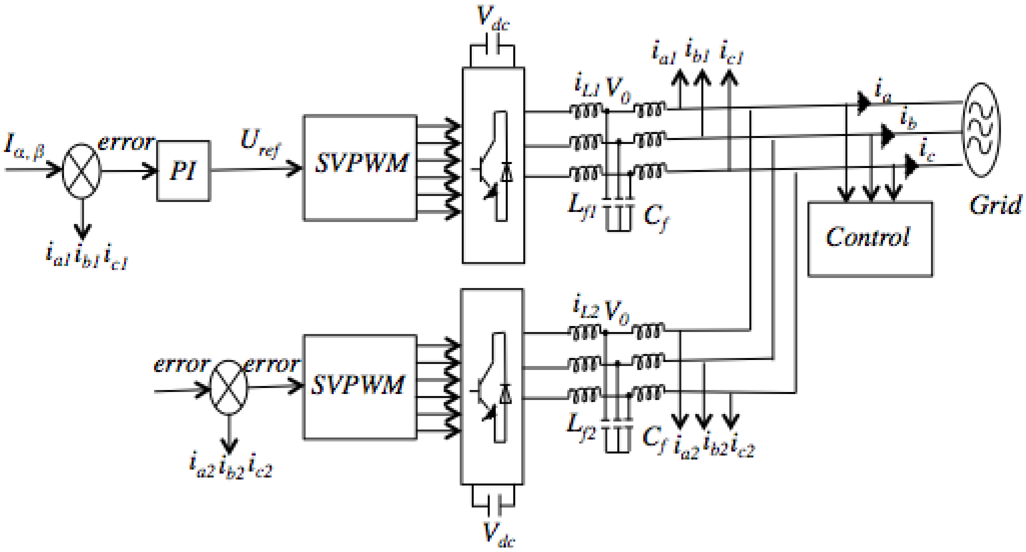


Fig.1. The Block Diagram Three-Phase Parallel Inverters

The inverter efficiency depends on switching frequency and power of level IGBTs. IGBTs operate at low switching frequency, decrease switching losses in high power inverters [2][3][11].

Mathematical Model of the System

To assume balance and stability of three-phase grid voltage, the three-phase LCL values of each inverter are the same, then switches are ideal and DC link voltages are constant.

$$I_1 = \frac{V_{in} - V_{out}}{X_{L1} + R} \qquad (1)$$

$$I_2 = \frac{V_{in} - V_{out}}{X_{L2} + R} \qquad (2)$$

$$I_3 = \frac{V_{in} - V_{out}}{X_{L3} + R} \qquad (3)$$

$$I_c = \frac{V_c}{X_L} \qquad (4)$$

$$X_L = 2\pi f_L \& X_c = \frac{1}{2\pi f_c}$$

X_L is the reactance of the inductor while X_C is the reactance of the capacitance. F is the frequency measured per second (S^{-1}) or Hatz. The output current in an a.c circuit of an inductor is lagging behind the voltage at 90^0 ($\pi/2$), therefore, capacitor would filter the current to be in good sine wave.

The continuous time dynamic model can be denoted by

$$\begin{cases} L_1 \frac{\overrightarrow{di_{in}}}{dt} = \vec{v}_{in} - \vec{v}_{out} \\ C \frac{\overrightarrow{dv_c}}{dt} = i_{in} - \vec{i}_{out} \\ L_2 \frac{\overrightarrow{di_{out}}}{dt} = \overrightarrow{v_{in}} - \overrightarrow{v_{out}} \end{cases} \quad (5)$$

SVPWM CONTROL STRATEGY

One of the reason for using space vector technique is to estimate the line modulating signal space V_C with eight-space vector [3][14]. In order to ensure the generated voltage is on sampling period T is on average equal to the vector V_C,

$V_C x\ T = V_{in} x\ T_{in} + V_{in+1} + T_{in+1} + V_2\ x\ T_{Total}$ (6)

Actual and invented result of equation above for a line-load voltage that features amplitude A, restricted to $0 \leq \hat{V}_c \leq 1$ gives,

$$T_{in} = T\ x \hat{V}_c\ x \sin(\frac{\pi}{3} - \theta) \quad (7)$$

$$T_{in+1} = T\ x\ \hat{V}_c\ \ x \sin\frac{\pi}{3} \quad (8)$$

$$T_{total} = T - \hat{V}_{in} - T_{in+1} \quad (9)$$

The above expression indicates that the determined basic line-voltage amplitude A, is unity as $0 \leq \theta \leq \frac{\pi}{3}$. It brings an advantage to SPWM technique which can attain $\sqrt{3}/2$ maximum basic line-voltage amplitude in the linear operating region [15]. Where θ is the phase difference between amplitude current and voltage. Fig.2. shows the space vector of three-phase grid-connected inverter, assuming the grid current is balanced.

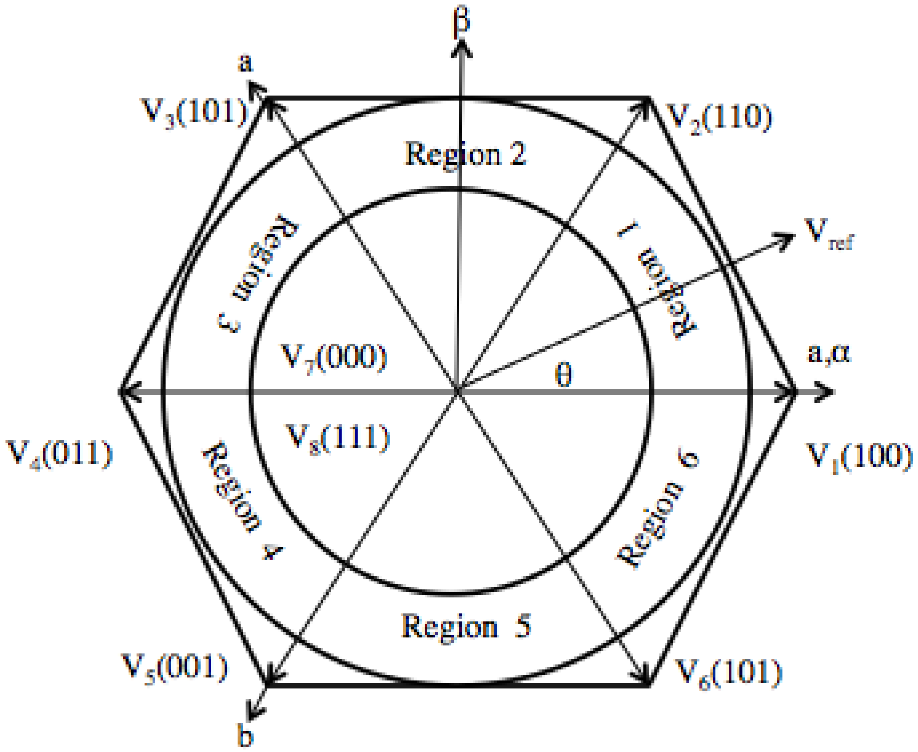


Fig.2. Space Vector Pulse Width Modulation Switching Region

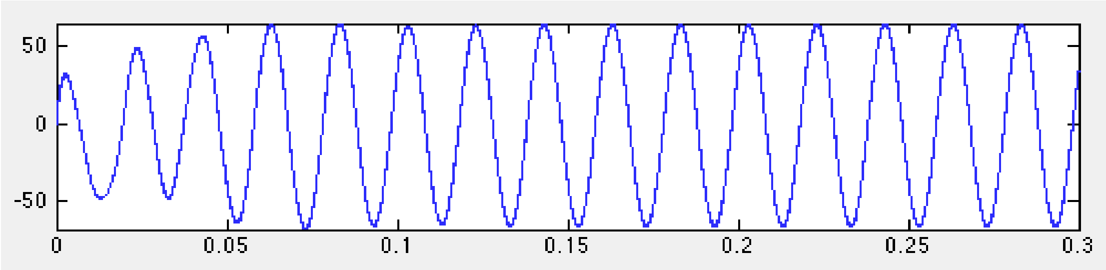
SYSTEM CONTROL ALGORITHM

SVPWM has the advantages of having controlling techniques over three-phase parallel inverters [2]. The inverters operate to produce the output current which can be injected to the load. LCL filters were used to reduce inverters output current ripples and current error because of the behaviors of the IGBT (low switching frequency and high power capacity).

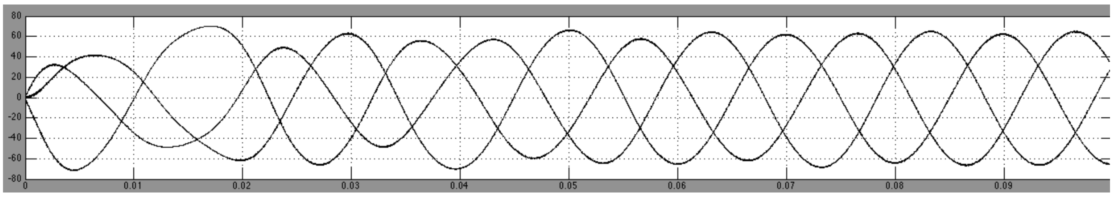
Fig.1. show the controlling algorithm of the inverter. The inverter current i_a, i_b, i_c are used as reference signal that controlled PI controller in order to generate correct PWM signals for closed loop algorithm.

SIMULATION RESULT

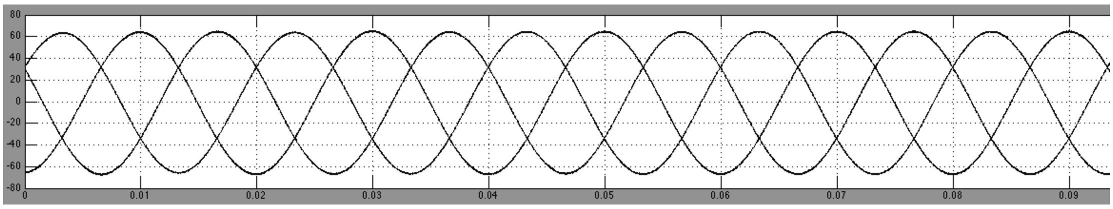
The grid system was simulated in Matlab/Simulink with the following parameters; frequency 50Hz, Vdc = 400V, switching frequency 3KHz or 9KHz, inverter side inductor 850μH, grid side inductor 12mH, and capacitor of LCL filters 2200μF. At starting point the harmonic distortion is very high due to high power capacity of the IGBTs. After then, voltage remains perfect, stable and DC-link remains constant. The simulation results are shown in Fig.3.



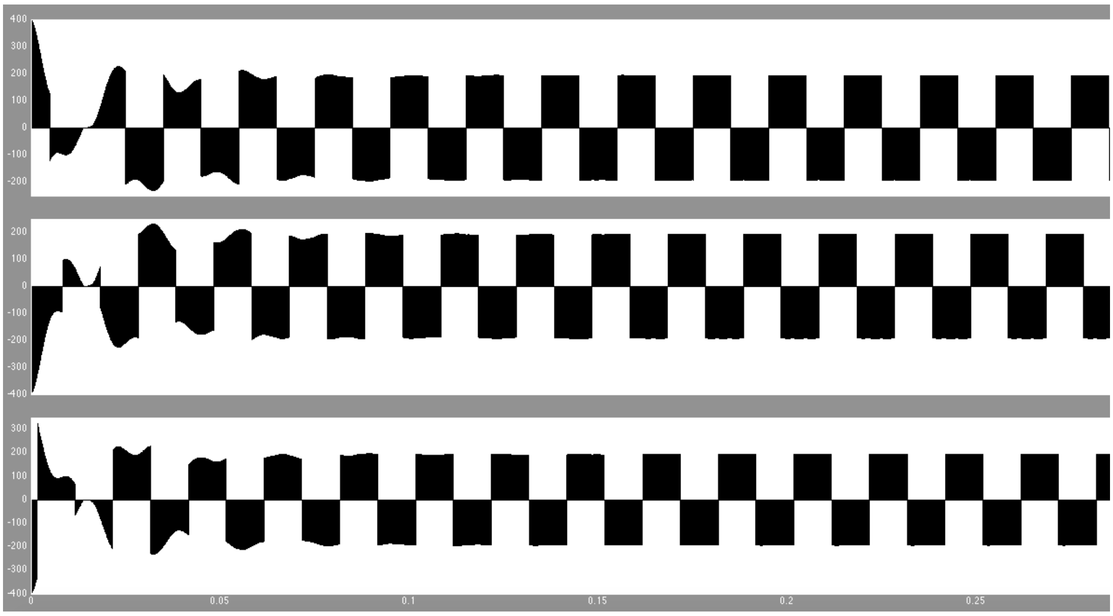
(a)



(b)

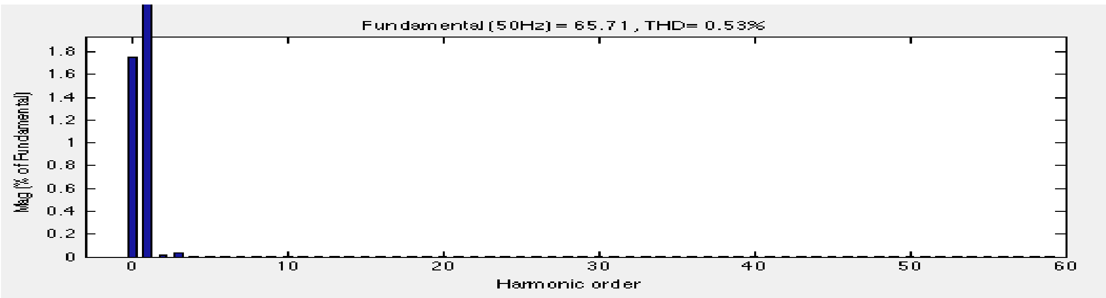


(c)



(d)

Fig. 3. (a) Inverter Phase A Current (b) Three-Phase Output Current at Starting Point (c) Three-Phase Output Current after it Stabled (d) AC Line Load Voltage



(e)

Fig. 4. Harmonic Spectrum of the Grid Current

As shown in Fig. 4, the inverter current ripples are quite high at starting point, and then balanced to stable load current.

Conclusion

The performance analysis of the three-phase parallel inverters was analyzed. SVPWM control technique was used to control both inverters; these techniques make it differ with some parallel inverters controlling techniques. Here each inverter has its own controller or separated as Main Inverter (produced reference output current) and Supplementary Inverters (reimburse output current error of main inverter). The inverters produced reference output current and then distribute the same output power under SVPWM control techniques algorithm. The sum of currents from the parallel inverters produce the reference output current with very low ripples, therefore, the total harmonic distortion was very low in order to meet the standard. At a starting point, the current harmonic noise is quite high, but after some seconds the output current remained balance and stable.

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