Modelling and Simulation of Transformer less Single Phase Grid Tie Inverter Using MATLAB/Simulink

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Abstract: Ever increasing growth of electricity demand and promising growth of renewable energy production has necessitated the requirement of an efficient grid tie inverter. In the proposed system, grid tie inverter control is based on the d-q reference frame controller. Grid voltage and inverter current are transformed through d-q transformation to convert into dc components and the error signal is passed through a PI controller to supply active power to grid. Modified Unipolar Sine Wave Pulse Width Modulation (MUSPWM) is used to reduce switching loss. The simulation of system is carried out using MATLAB/ Simulink. The reactive current reference of d-q based controller is set to zero and active current reference is based on the active power to be supplied to the grid. Simulation results show the effectiveness of the controller in ensuring only active power supply to grid in steady state.

Keywords: Grid tie inverter, d-q reference frame, MATLAB/Simulink, MUSPWM.

I. INTRODUCTION
Demand for electricity and renewable energy generation is constantly increasing which leads to raise in penetration of electrical energy into grid worldwide. Electrical energy produced by renewable energy sources such as PV generator is penetrated to grid using grid tie inverter.

A synchronous frame current control method for single phase grid tie inverter is used to provide an infinite control gain and zero steady state error at fundamental frequency [1]. This paper presents detailed description of synchronous reference frame current control method for a single phase grid tie inverter.

II. PROPOSED SYSTEM
The proposed system block diagram is shown in Fig.1. The inverter current $I_{inv}$ and grid voltage $V_g$ are fed back to Current controller. The synchronous reference frame current control scheme produces the reference signal to Modified Unipolar Sine wave Pulse Width Modulation which generates switching sequence for grid tie inverter. The DC bus voltage $V_{dc}$ is maintained constant and termed as an ideal DC Source.

![Block diagram of the proposed system.](image-url)
III. CONTROL LOOP DESIGN

To supply only active power to grid from renewable energy source grid tie inverter current must be in-phase with the grid voltage. Block diagram of synchronous frame control structure is as shown in the Fig.2. Phase Locked Loop (PLL) is used to determine the instantaneous phase angle(ωt) and frequency of the grid voltage (V_g).

For single phase grid tie inverter control scheme, additional quadrature grid voltage V_α and inverter quadrature current I_α are computed to transform from stationary reference frame(α-β reference frame) to synchronously rotating reference frame (d-q reference frame) using Park’s Transformation.

It is necessary to balance the voltage, else there is a possibility of drawing power from grid which is not acceptable. By applying voltage balance equation we get,

\[ V_{id} = V_{gd} + V_d - \omega L I_q \]
\[ V_{iq} = V_{gq} + V_q + \omega L I_d \]

Equation (1) is realized using MATLAB/Simulink model of grid tie inverter control loop and shown in Fig.3.

The \( \alpha-\beta \) to d-q Transformation of grid voltage is as shown in Fig.4.Here \( V_{g\beta} \) is the grid voltage (AC bus voltage) and \( V_{g\alpha} \) is in-quadrature with \( V_{g\beta} \). \( V_{g\alpha} \) and \( V_{g\beta} \) are DC components computed using Park’s transformation for voltage balance. The \( \alpha-\beta \) to d-q Transformation of inverter current is as shown in the Fig.5. Here \( I_{\beta} \) is the inverter output current \( I_{inv} \) and \( I_{\alpha} \) is in-quadrature with the \( I_{\beta} \). The \( I_d \) and \( I_q \) DC components are computed using Park’s transformation. These DC
components are compared with references $I_d^*$ and $I_q^*$. The $I_d^*$ is current reference to supply active power to grid [4]. $I_q^*$ is the reference current to supply reactive power to grid. This system supplies only active power to grid and hence $I_q^*$ is kept zero. The actual current DC component is subtracted from the reference current which generates error signal. This error signal is compensated using Proportional-Integral (PI) controller.

The $d$-q to $\alpha$-$\beta$ Transformation of inverter current is shown in the Fig. 5. Here $V_d$ and $V_q$ are the output of the PI controller. $V_{id}$ and $V_{iq}$ are the DC components of the inverter voltage are converted to $V_{i\alpha}$ and $V_{i\beta}$.

Voltage balancing voltage Equation (1) is shown in the Fig. 6. Here $V_d$ and $V_q$ are the output of the PI controller. $V_{id}$ and $V_{iq}$ are the DC components of the inverter voltage are converted to $V_{i\alpha}$ and $V_{i\beta}$.

The d-q to $\alpha$-$\beta$ Transformation of inverter current is shown in the Fig 7. Here inverter voltage obtained from Voltage Decoupling is transformed back to stationary reference frame using Inverse Park’s transformation. $V_{i\beta}$ is the reference signal to the MUSPWM generator, which intern generates the switching sequences for grid tie inverter.

IV. MUSPWM SWITCHING SEQUENCE GENERATION

Inverter with switches T1 and T2 in the first leg and T3 and T4 in the second leg are shown in Fig. 8. In MUSPWM switching sequence generator, the two legs of the single phase H-Bridge grid tie inverter are switched at different frequencies. First leg switches T1 and T2 are switched at low frequency (50Hz) whereas second leg switches T3 and T4 are switched by comparing $V_{i\beta}$ with carrier frequency [7]. The two switches of each leg of single phase H-Bridge grid tie inverter are complementary to each other.

The modulating control signal ($V_{i\beta}$) and carrier ($V_c$) of MUSPWM switching sequence generator are shown in Fig. 9. The firing instants for various devices (T1, T2, T3, & T4) are generated based on the MUSPWM control sequence as given below.
T1 is turned ON when $V_r$ is greater than zero. T2 is ON when $V_{i\beta}$ is less than zero. T3 is ON when $V_{i\beta}$ is greater than $V_c$ and T4 is ON when $V_{i\beta}$ is less than $V_c$. MATLAB/Simulink model of MUSPWM switching sequence generator is designed to generate Switching sequences for T1, T2, T3 and T4 is shown in Fig.10. The resultant gate sequences are shown in Fig.11.

![Fig.10. MATLAB/Simulink model of MUSPWM switching sequence generator.](image)

The inverter bridge output voltage of MUSPWM switching technique is shown in Fig.12. It is observed that, inverter bridge output is same as the unipolar SPWM. Since first leg of the inverter switches are switching at fundamental frequency the switching losses are reduced. MATLAB Simulink model of grid tie inverter with LC filter for RL load is shown in Fig.13. The output current of the inverter with local load can be written as

$$i_{inv} = i_L - i_c - i_o \quad (2)$$

![Fig.12. Inverter Bridge output waveform.](image)

![Fig.13. MATLAB Simulink Model of Grid tie inverter With LC Filter and RL load.](image)
Inductor current and capacitor current can be written as,

\[ i_L = \frac{1}{L} \int (V_{in} - V_g) dt \]  
\[ i_C = C \frac{d}{dt} V_g \]  

For RL local load current can be written as,

\[ i_0 = \frac{V_g}{R_L} + \frac{1}{L} \int V_g dt \]  

V. SIMULATION RESULTS

Modeling and simulation of the system is carried out using MATLAB/Simulink. The PLL tracks the grid voltage and provide the phase angle \( \omega t \) under dynamic conditions as shown Fig.14.

The grid voltage (\( V_g \)) is transformed to \( V_{gd} \) and \( V_{gq} \) based on Park’s Transformations and is shown in Fig.15. It is seen that \( V_{gq} = 0 \) and confirms that PLL is tracking grid voltage.

The Inverter output current \( I_\alpha \) and \( I_\beta \) which is in-quadrature with the inverter output current are shown in Fig.16. These two signals are used for the Park’s Transformation.
\[ I_d \] and \[ I_q \] are the output of Park’s Transformation in synchronous reference frame. The variation of \[ I_d \] and \[ I_q \] following a step change in \[ I_d^* \] is shown in Fig.17. Here active reference current \[ I_d^* \] is increased from 0A to 10A at 0.2s and reactive reference current \[ I_q^* \] is kept zero continuously to supply only active power. It is observed that, there is an overshoot in \[ I_d \] and under shoot in \[ I_q \] following the step change. By choosing suitable PI controller values overshoot, undershoot levels and settling time are found to be within the prescribed limits. It is also observed that \[ I_d \] and \[ I_q \] follows reference current \[ I_d^* \] and \[ I_q^* \] in steady state.

As shown in Fig.18, Inverter current \( I_{\text{inv}} \) is in-phase with the grid voltage \( V_g \) and supplies only active power to the grid in steady state.

The variation in \( P \) and \( Q \) following a step response of active current reference are shown in Fig.19. It is observed that both active as well as reactive power reach steady state with acceptable time response. It is to be noted that the inverter supplies only active power to grid \( (P) \) in steady state as steady state reactive power is zero.

**VI. CONCLUSION**

MUSPWM is used to provide switching sequences to grid tie inverter which reduces switching losses. Synchronous reference frame control of grid tie inverter is designed and simulated using MATLAB Simulink to supply active power to grid. The simulation results show the effectiveness of designed controller which ensure the supply of active power to grid from DC bus.
ACKNOWLEDGMENT

Authors gratefully acknowledge the support received from HEXMOTO Controls, Pvt.Ltd, Mysuru and R&D Centre, Nitte and NMAM Institute of Technology, Nitte Education Trust and VTU, Belagavi in carrying out the research work.

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