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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 inFig.1.The inverter currentI_{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.

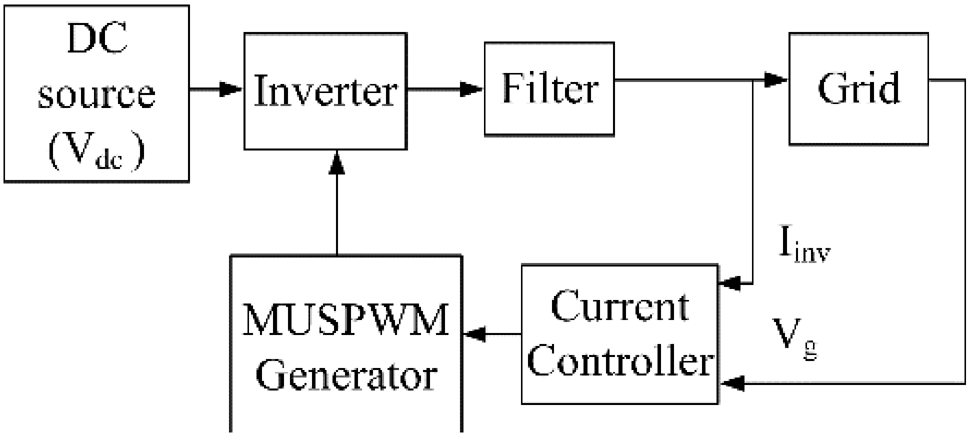

Fig.1.Block diagram of the proposed system.

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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 $V_{g\alpha}$ and inverter quadrature current I_α are computed to transform from stationary reference frame(α-βreference 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,

$$V_{id} = V_{gd} + V_d - \omega L I_q \qquad (1)$$
$$V_{iq} = V_{gq} + V_q + \omega L I_d$$

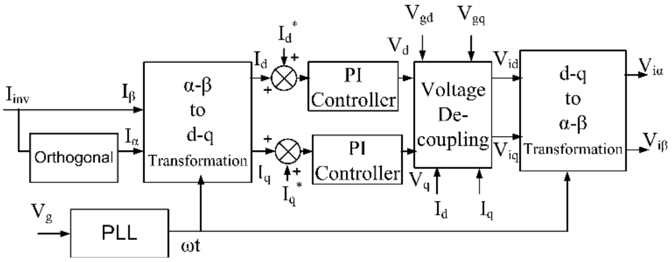

Fig.2.Block diagram of synchronous frame control structure

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

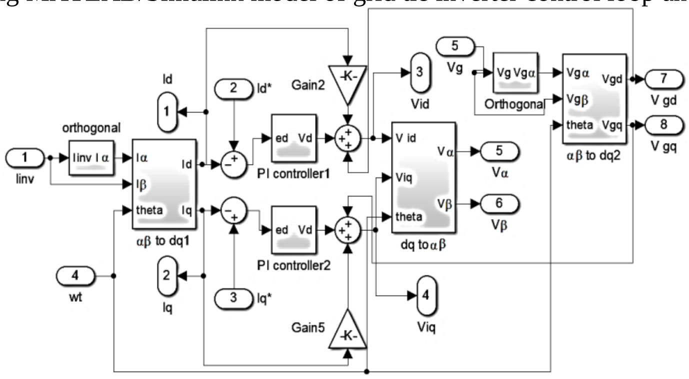

Fig.3.MATLAB/ Simulink model of Grid tie inverter control loop.

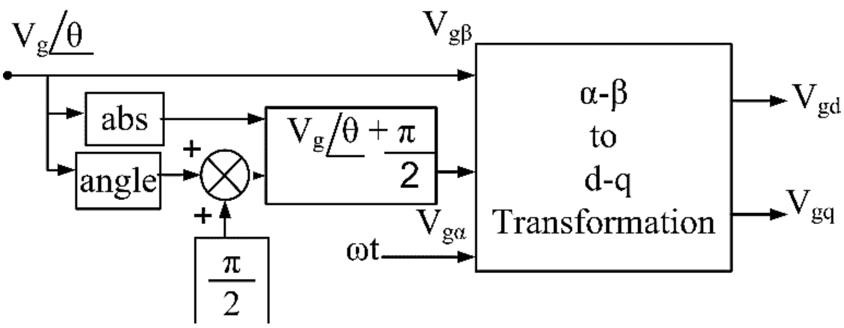

Fig.4.α-β to d-transformation of grid voltage.

The α-β 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_{gd} and V_{gq} are DC components computed using Park's transformation for voltage balance. The α-β to d-q Transformation of inverter current is as shown in theFig.5. HereI_β is the inverter output current I_{inv} and $I_\alpha$is in-quadrature with theI_β .The I_d and I_qDC components are computed using Park's transformation.These DC

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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 henceI_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.

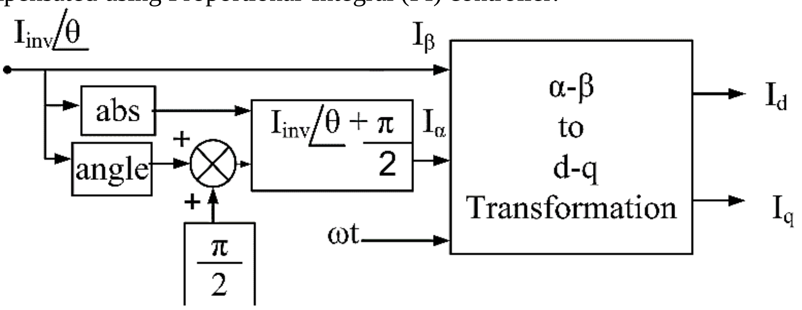

Fig.5. α-β to d-qTransformation of Inverter current.

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$V_{i\beta}$.

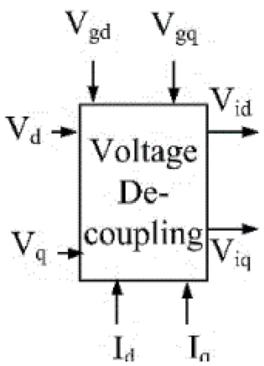

Fig.6.Voltage decoupling.

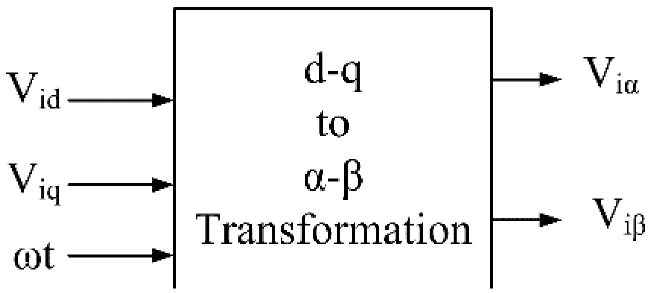

Fig.7.d-qto α-β Transformation of Inverter current.

The d-q to α-β Transformation of inverter current is shown in the Fig 7. Here inverter voltage obtained from Voltage De-coupling 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 T3and 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 T1and T2 are switched at low frequency (50Hz) whereas second leg switches T3 and T4areswitched 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.

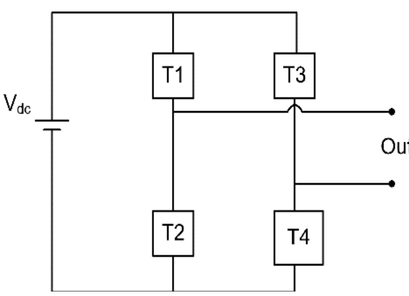

Fig.8. Simple inverter

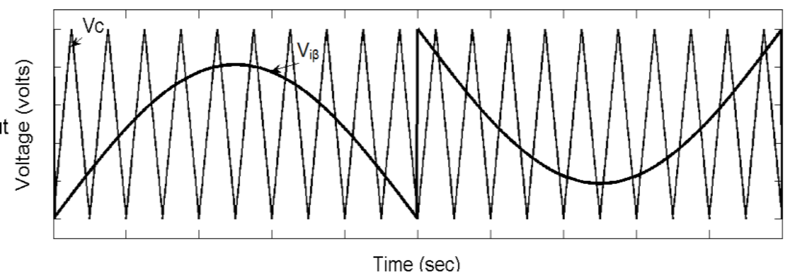

Fig.9.Control and carrier signals of modified unipolar SPWM switching.

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.

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T1 is turned ON when V_r is greater than zero. T2 is ON when $V_{i\beta}$ is less than zero.T3is ON when $V_{i\beta}$ is greater than V_c and T4is 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.

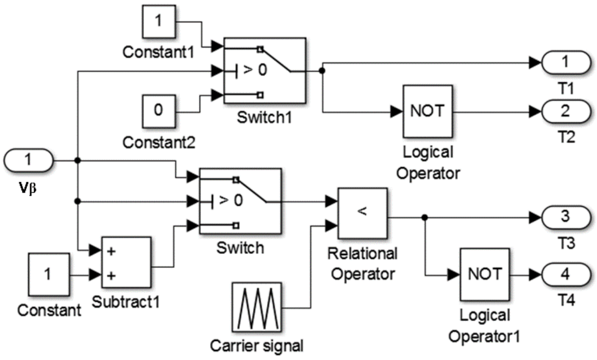

Fig.10. MATLAB/Simulink model of MUSPWM switching sequence generator.

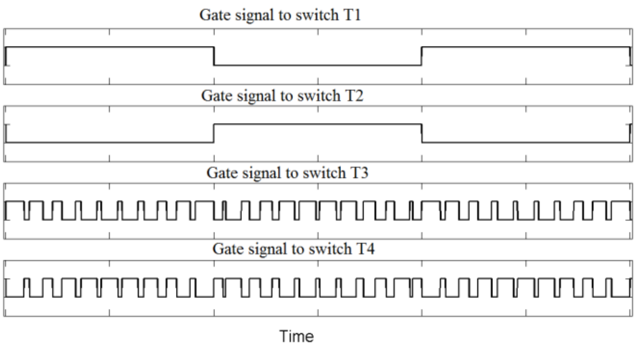

Fig.11.Gate signal to the switches of the inverter

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

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

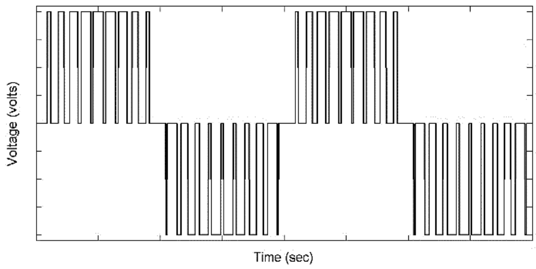

Fig.12. Inverter Bridge output waveform.

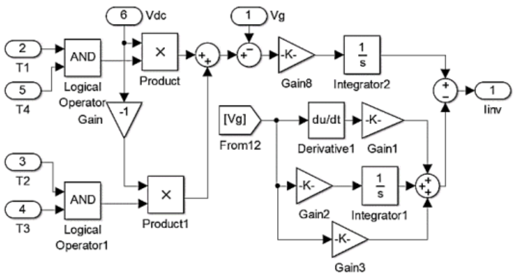

Fig.13.MATLAB Simulink Model of Grid tie inverter With LC Filter and RL load.

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Inductor current and capacitor current can be written as,

$$i_L = \frac{1}{L}\int(V_{inv} - V_g)dt \quad (3)$$

$$i_c = C\frac{d\,v_g}{dt} \quad (4)$$

For RL local loadcurrent can be written as,

$$i_0 = \frac{V_g}{R_L} + \frac{1}{L}\int V_g\,dt \quad (5)$$

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 ωt under dynamic conditions as shown Fig.14.

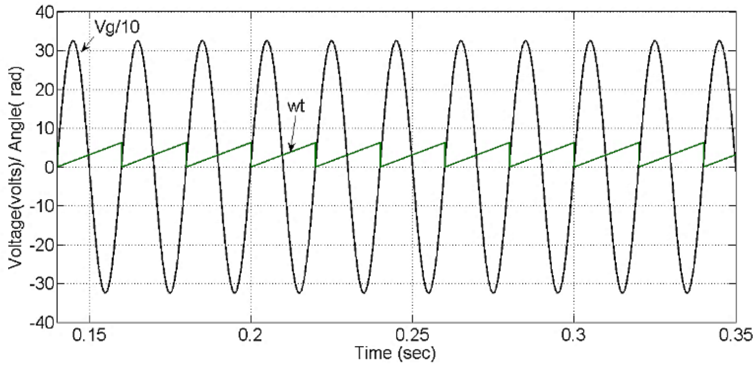

Fig.14. Grid voltage angle tracked by PLL i.e. ωt.

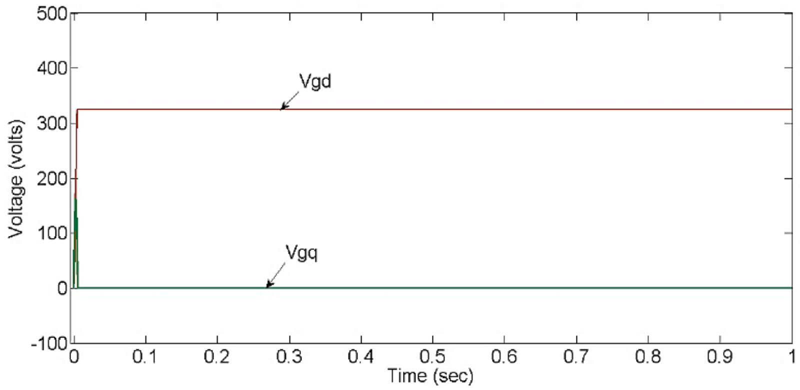

Fig.15.V_{gd} and V_{gq} synchronous reference frame.

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.

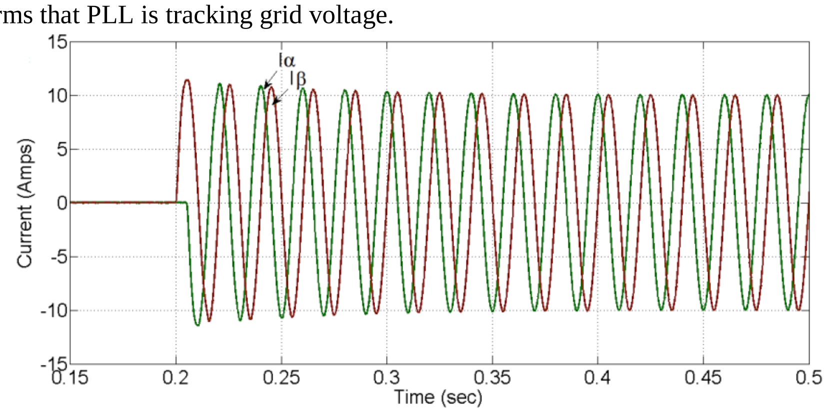

Fig.16.I_α and I_β stationary reference frame.

The Inverter output current I_β and I_α which is in-quadrature with the inverter output current are shown in Fig.16. These two signals are used for the Park's Transformation.

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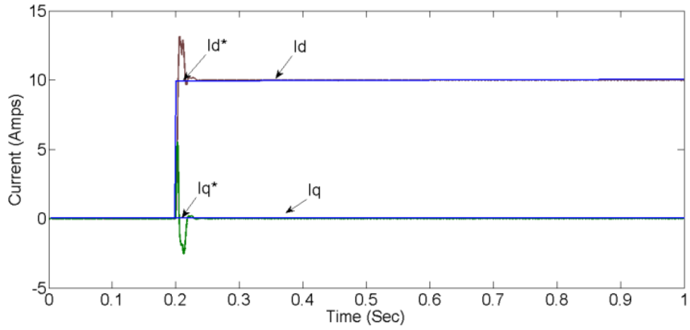

Fig.17.I_d and I_q synchronous reference frame

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 to10A 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 followingthe step change. Bychoosing 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.

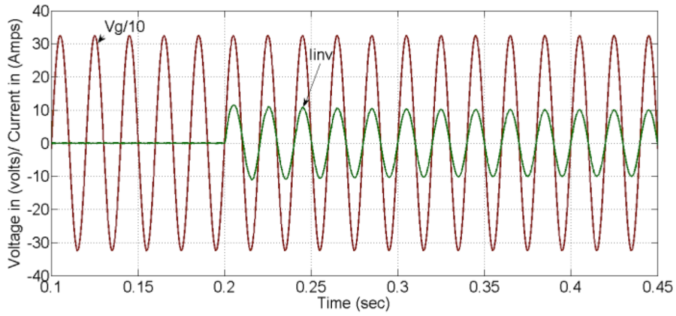

Fig.18.Grid voltage (V_g) vs grid tie inverter current (I_{inv}).

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

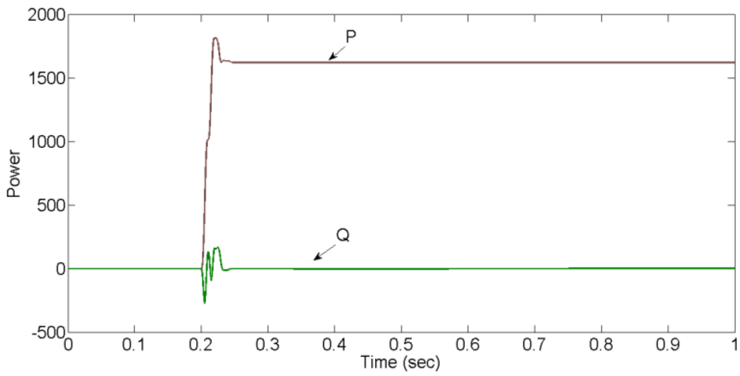

Fig.19. Active power(P) and reactive power(Q).

The variation in P and Q following a step response of active current reference are shownFig.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.

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