Implementation of Synchronous-Reference-Frame Theory-based PWM generation for DC to AC conversion

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Abstract—**Many renewable and non-renewable energy sources are being incorporated in the currently used power system. These Distributed Generation (DG) systems involve conversion of different forms of energy to electrical power. The DG systems do not have continuous source of energy, so a power electronic interface must be used to interface them to the grid or to an independent power system. Basically the energy resources generate DC voltage or current which are later converted to AC. This involves DC to AC conversion that are performed using two stage of conversion, where one performs the leveling of DC voltage using a Buck/Boost conversion followed by an H-bridge inverter. The paper proposes a closed loop control for the converter circuit by generating enhanced PWM pulses that drives the converter switches. The closed loop control is based on Synchronous Reference Frame (SRF) theory where a DC voltage can be used as reference to control the AC voltage. The proposed paper contains design and simulation of SRF based control for closed loop control of DC to AC conversion and generation of enhanced PWM signals using PSIM and MATLAB.**

Keywords—Introduction; Implementation of SRF theory; Enhanced PWM.

I. INTRODUCTION

There are many forms of available energy on the earth, but majorly electrical energy is used to perform any sort of productive work. There are different methods to convert the available energy into electrical energy. Many available methods that are incorporated to convert the energy from different systems of renewable energy into the existing power system have been developed. Researches have proved that renewable energy usage provides safe, reliable, clean and cost effective solution or an alternative to the electricity from the grid [4].

The main aspect of research lies in the conversion of power from different levels to a standard AC signal, utilized to drive many loads including household and industrial loads. The power electronic converters are used in these systems where the power generated is incompatible with the distribution system [6]. The conversion process involves DC-DC converter to vary the input to the inverter in the next stage. The majorly used converter among the DC-AC converter is Voltage Source Inverter (VSI) [3].

The traditional method with VSI and a buck-type DC-DC converter can produce output that has magnitude either greater than or less than the given DC voltage. Switched Boost Inverter (SBI) is a converter which can produce voltage higher than or lower than that of the input DC voltage without change in the configuration of the circuit, which is not the case in conventional VSI.This paper involves a Switched SBI [4] to analyze and obtain the results of SRF based closed loop control.

The proposed SBI is derived from Inverse Watkins Johnson topology with the ability to drive simultaneous AC and DC loads. The SBI is found to have many advantages over conventional VSI converter which involves reliability and immunity to Electro Magnetic Interference (EMI) [4].

The different control algorithms are the space vector Transformation and fuzzy logic control [6] which are complex when compared to SRF control. The advantage of the SRF is that a dc signal can be used to map the fundamental signal and it has been shown that it has an effective performance in presence of harmonic distortion. The SRF theory based control has reduced number of computations with simple implementation [5].

The performance of any system depends on the control algorithm designed to obtain the values of the reference current and voltage components, for which many algorithms were developed including the Instantaneous Reactive Power theory, Synchronous Reference Frame theory (SRF) and Symmetrical Component theory (SC) [2] while SRF control algorithm is used because of its advantages previously mentioned.

II. IMPLEMENTATION OF SRF CONTROL

A. Synchronous Reference Frame theory

The inductance of synchronous and induction machines are functions of rotor speed and the coefficient equations of voltage and current are represented in differential equations describing the time varying behavior of these machine.

A change of variable can be used to reduce the complexity of differential equation by representing the equations in another frame called arbitrary reference frame that rotates at any angular velocity or remain stationary. All power system components are represented in synchronously rotating reference frame and the variables associated is transformed on to a synchronously rotating reference frame [1].

This represents the theory of SRF with the equations obtained by Park's transformation matrix, [2] that is transformation from α-β to d-q frame.

The transformation Matrix is given below:

$$\begin{bmatrix} d \\ q \end{bmatrix} \Rightarrow \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \qquad (1)$$

The inverse transformation can be calculated using the equation (2) as below:

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} \Rightarrow \begin{bmatrix} \sin\theta & \cos\theta \\ \cos\theta & -\sin\theta \end{bmatrix} \begin{bmatrix} d \\ q \end{bmatrix} \qquad (2)$$

The equation above is used to obtain the values corresponding to the reference frame by moving at an average of 100Hz [2].

B. Block diagram

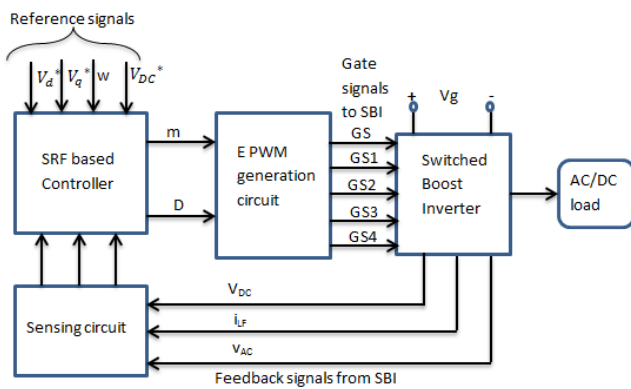The block diagram of the proposed SRF control theory is shown in figure1 below.

Fig 1: The closed loop control of the SBI using SRF theory

The control loop consists of feedback path which senses the voltages and current from the SBI and is fed to the controller. The controller generates a modulating wave 'm' and 'D' which is given to PWM module to generate the PWM pulses.These pulses turn the the switches of SBI ON/OFF for predetermined duration to drive the AC/DC loads connected. 'D' is the shoot through interval of the switches.

The reference signals are given to the controller along with the sensed signal from the DC bus, SBI (AC current and Voltage).The signals V_d^* and V_q^* are directly given to the controller; this reduces the computational burden on the processor used. The dq transformation from $\alpha\beta$ is obtained using the equations 1 and 2.

There are two voltage control loops one to control the DC voltage V_{DC} and other to control the AC voltage v_{AC}. The DC controller is a linear controller which varies the value of 'D' in proportional to the error from the feedback sensing circuit. The DC control loop is not shown in the figure1, while is implememted in the controller. The linear controller is implemented using the Proportional Integrative (PI) controller, which is beyond the scope of this paper.

The controller has inner and outer loop to control current and voltage respectively. The sensed coefficients use PI controller to reduce the non linearities and local dq couplings.

The control block for inner current loop and outer voltage loop is as shown in figure 2(a) and 2(b).

The d-axis and q-axis voltage controller are derived using PI controller. Since DC signals are used as reference to control the AC values, simple linear controller can be used to restrict the sensed value to be within the limits nearer to the reference value.
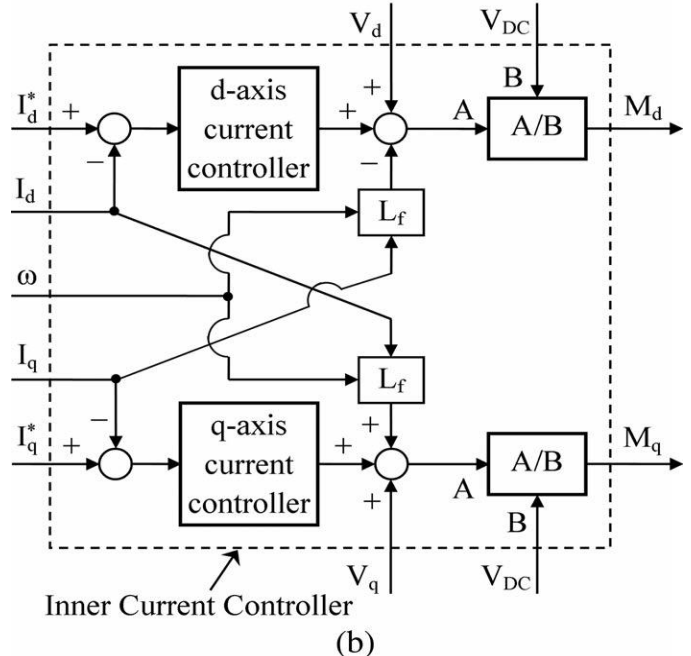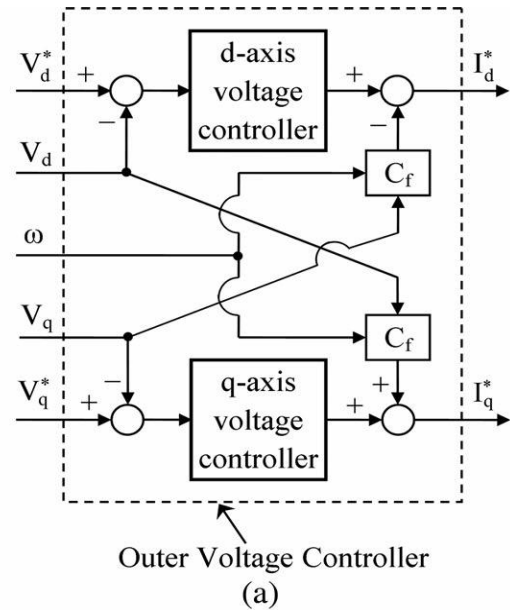

Outer Voltage Controller
(a)

Inner Current Controller
(b)

Fig 2: Block diagram of AC bus controller (a) Outer voltage control loop (b) Inner current control loop.

The cross coupling of the terms between dq components results in cancelling of active and reactive components along with the non-linearities. This control scheme has been verified to have high performance along with tracking accuracy at a dynamic state [7].

C. AC Current and Voltage controller

The equations for the controller is developed using the equivalent circuit of SBI.

$$\frac{d}{dt}\begin{bmatrix} I_d \\ I_q \end{bmatrix} \equiv \begin{bmatrix} \dfrac{R_{Lf}}{L_f} & w \\ -w & -\dfrac{R_{Lf}}{L_f} \end{bmatrix}\begin{bmatrix} I_d \\ I_q \end{bmatrix} + \frac{1}{L_f}\cdot\begin{bmatrix} V_{invd} - V_d \\ V_{invq} - Vq \end{bmatrix} \quad (3)$$

The equation (3) represents the current controller equation, while equation (4) represents the voltage controller equation.

$$\frac{d}{dt}\begin{bmatrix} V_d \\ V_q \end{bmatrix} \equiv \begin{bmatrix} \dfrac{1}{R_{AC}.C_f} & w \\ -w & -\dfrac{1}{R_{AC}.C_f} \end{bmatrix}\begin{bmatrix} V_d \\ V_q \end{bmatrix} + \frac{1}{C_f}\cdot\begin{bmatrix} I_d \\ Iq \end{bmatrix} \quad (4)$$

The resistance R_{AC} is the equivalent value of load resistance. The above equations are used to generalize and design the controller for voltage control and current control as in figure 2.

III. ENHANCED PWM

The Pulse Width Modulation (PWM) technique is widely used in control of power electronic switched converters. There are many advantages in using PWM control like increased efficiency, flexibility and reliability.

The SBI proposed has shoot-through condition during which the switches of same leg of H-bridge inverter are turned ON. This is not the case in normally used conventional PWM; the shoot-through condition is avoided in all converters since it causes the direct short circuit of the source. Hence an enhanced PWM (e-PWM) technique is generated for the control of the switches [4].

The waveforms of the e-PWM are shown in figure 3, where there is a single carrier of 10 kHz and 4 reference signals. One modulating signal of frequency 50 Hz along with its phase reversed signal (phase difference=180^0), and two DC signals with opposite signs having same magnitude form the four reference signals shown in figure 3(a) and 3(b).

The modulating wave with 50 Hz frequency is taken as reference. The pulses generated are with respect to the modulating wave and the e-PWM pulses generated is different for positive and negative cycles of the modulating wave (Vm(t)). The waveforms are represented for one cycle of the carrier wave whose period is represented as $T_s=1/f_s$, as shown below.

IV. EXPERIMENTAL VERIFICATION

An experimental model of SBI along with the SRF reference frame control is developed and is verified using MATLAB and PSIM simulations

A. PSIM simulation

The circuit implementation of SRF closed loop control is shown in figure 4. The circuit implementation involves the outer voltage loop and inner current loop control of the SRF controller.

The obtained waveform is as shown in figure 5, where modulated wave generated by the SRF control method. The figure provides comparison between the signal independently produced to generate e-PWM pulses and that generated by SRF controller.
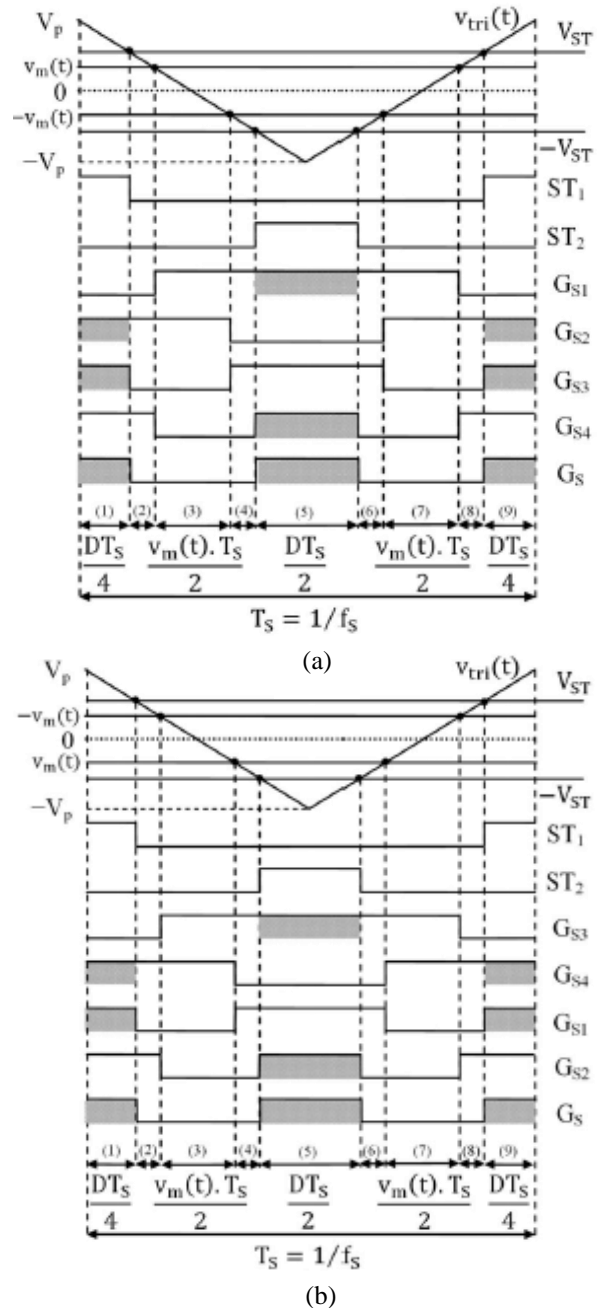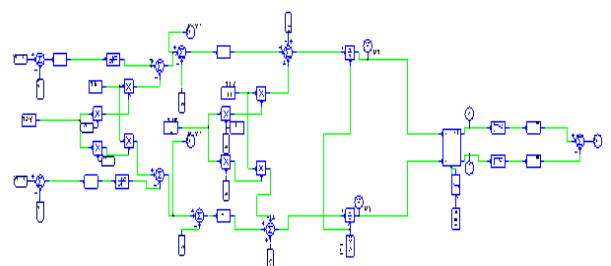

(a)

(b)

Fig 3: Enhanced-PWM waveforms (a) Schematic of PWm pulses for $V_m(t)>0$ (b) Schematic of PWm pulses for $V_m(t)<0$
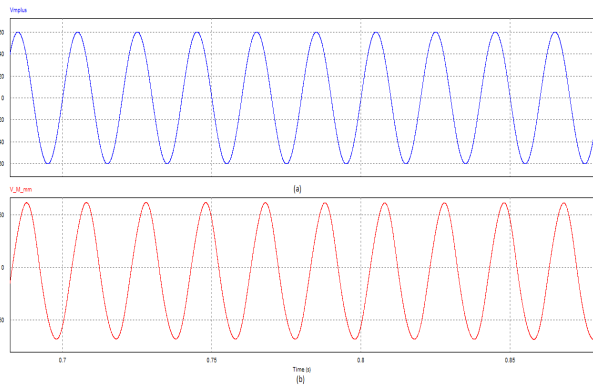
Fig 5: Modulating wave generated (a) independently (b) using SRF control

The Root Mean Square value of the generated modulating wave is comparable with that generated independently.

E-PWM implementation in PSIM involves the comparison of four reference signal with one carrier wave to generate the pulses to drive the switches of the converter. The implemented circuit in PSIM and waveform obtained is shown below in figure 6.
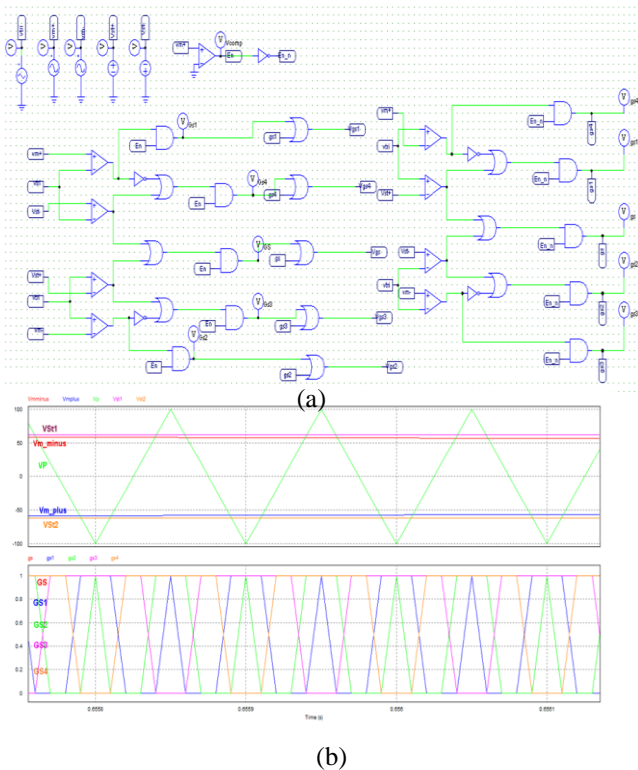

(a)

(b)

Fig 6: (a) Implemented circuit of e-PWM   (b) E-PWM pulses obtained

B. MATLAB Simulations

The simulations in PSIM are verified by programming in MATLAB. The programming involves the generation of PWM pulses by e-PWM technique, and developing a control loop to control the variation in the voltages on AC and DC side.

The SRF generation of the Modulating wave is as shown in figure 7, where a signal of 50 Hz is generated by SRF control algorithm.
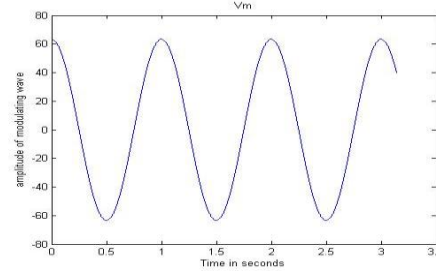

Fig 7: Waveforms obtained after simulations in MATLAB.

A program was developed for e-PWM generation on MATLAB, which generated the pulses for different switches, shown in figure 8 and is satisfactorily comparable to that obtained from PSIM.
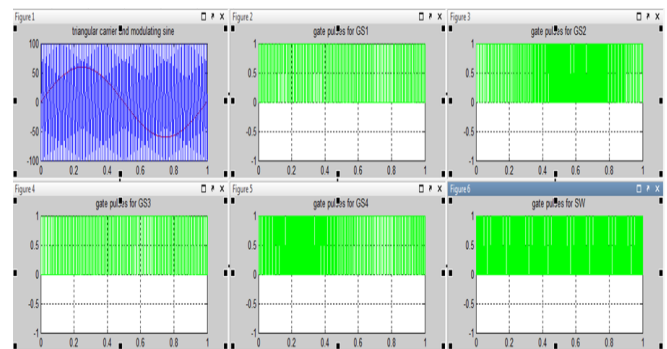

Fig 8: E-PWM pulses for switches of SBI generated using MATLAB.

V.   CONCLUSION

The paper presents a control algorithm for the control of the AC voltage and current levels from an inverter circuit. The SRF control method is simpler and requires fewer computations. It is seen that SRF theory for control circuits can be easily implemented in different tools. The e-PWM method for generation of pulses to drive the switches has proven to be effective and is compatible with SRF control algorithm.

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