SIMULATION AND EVALUATION OF A PHASE SYNCHRONOUS INVERTER FOR MICRO-GRID SYSTEM

Tawfikur Rahman, Muhammad I. Ibrahimy, Sheikh M. A. Motakabber, and Mohammad G. Mostafa
Departmental of Electrical and Computer Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia
E-mail: tawfikurr@gmail.com, ibrahimy@iium.edu.my, amotakabber@iium.edu.my

ABSTRACT

The phase synchronous inverter is an electrical inverter device which is synchronizing inverter phase with the micro-grid phase. Generally, DC voltage supply is considered as the input of the DC to AC inverter which is a renewable energy source such as solar panel, wind turbine and battery storage, etc. The three phase three layer phase synchronous inverters are normally utilized in the high power transmission and distribution systems to supply AC voltage to the three phase micro-grid loads. It has a phase synchronous controller, which includes voltage controllers that contain current regulator and DC voltage regulator to get the reference output power for creating the inverter gate pulses. An inverter utilizing a three leg IGBT has been designed and simulated by using MATLAB2014a/Simulink with the Simscape/SimPower-Systems Block Set. The inverter is connected to an input DC source, an output filter and a controller circuit. It has been observed that the output phase of the inverter is synchronized with the micro-grid phase.

Keywords: Three phase three layer inverter, Synchronous inverter control, LC filter, and Micro-grid

INTRODUCTION

Nowadays, the micro-grid system becomes very popular since it is a small region power sharing system between small power sources. The micro-grid system consists of a group of radial feeders such as sensitive-load feeders and non-sensitive-load feeders. The sensitive-load feeders is commonly connected to the domestic loads and the non-sensitive-load feeders is used when the fault occurred due to the main grid. One of the applications of phase synchronous inverter (PSI) is to connect a small module of power source in micro-grid to avoid the phase synchronization problem. Due to the phase synchronization problem, there is a power loss and it also introduces higher order harmonic distortion. As a result, it will produce a low quality and low efficiency power system. Most of the power transmission and distribution systems including micro-grid system, three phase supply has been considered because it has higher efficiency compared to single phase supply. The sometime DC source is utilized to overcome the problem of synchronization problem. However, AC supply is more preferable since the AC equipment is simple and low cost compared to DC system. Whether the source is AC or DC, initially all types of sources are converted into DC supply. Then the DC supply is converted into the AC supply using phase synchronous inverter and its output finally is connected with a micro-grid system for transmission and distribution purposes.

The three phase three level PSI is derived from a stable DC voltage source that can produce a constant phase and frequency including a constant magnitude of AC supply. The inverter utilizes a voltage controller switching circuit for generating and synchronizing the out supply with other sources during feeding the micro-grid system. Generally, three level structure is utilized to reduce the higher frequency harmonic distortion [1] [2]. Different type of DC voltage pattern strategies like current amplitude regulators, voltage amplitude regulator and pulse width modulation has been utilized to produce a sine wave for PSI. On the other hand, selective, higher frequency harmonic reduction is carried out by magnitude modulation patterns on fundamental magnitude control, harmonic distortion and phase synchronization [3].

THREE PHASE THREE LAYER PSI DESIGN

The output voltage of the PSI can be regulated by using a controller. In this design voltage regulator has been used instead of PL regulator. Therefore, that output voltage has been controlled by the voltage regulator. A constant DC input voltage has been given to the inverter. ‘On’ and ‘Off’ duration of the inverter has been regulated to obtain imperturbable output AC voltage and phase synchronization. Voltage controller is represented by fixed a synchronize amplitude pulse. This method is most suitable for controlling the output phase synchronization and output voltage [4] [5].

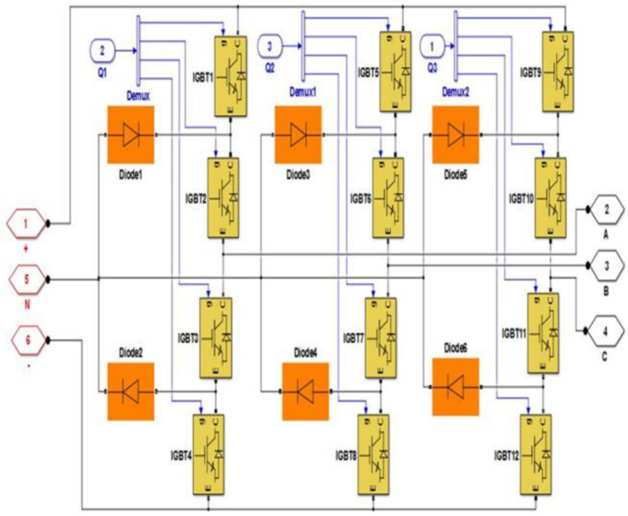

Figure-1. Three phase three layer PSI.

The three phase three layer PSI has produced lower harmonic distortion and better phase synchronization in the inverter output voltage while operating micro-grid load. In addition, extra productive supply voltage related to both phase synchronous modulation and sinusoidal modulation method. The design circuit of three phase three layer PSI is shown in Figure-1. The inverter circuit, PSI consists of three terminals with twelve IGBT switches and six diodes. Each terminal is completed by four IGBTs connected in series.

The input voltage is spliced in two by the connection of equal series connected DC voltage sources. Each terminal is completed by addition, two clamp diodes.

SWITCHING LOGIC DESIGN OF PSI

The three phase three layer PSI generates three voltage levels on the inverter output which are + Vdc/2, 0 and - Vdc/2, respectively. The switches are categorized in two ways: six are main switches which are IGBT1, IGBT3, IGBT9, IGBT4, IGBT8 and IGBT12 and the other six are working as auxiliary switches which are IGBT2, IGBT6, IGBT10, IGBT3, IGBT7 and IGBT11 that design the output, which are controlled by the switching variables. The twelve IGBT switches are a combination of three states (which are 1, 0 and -1) and the main three exciting pulses which are Q1, Q2, and Q3. Each exciting pulse is combined with four IGBT switches such as Q1 (which is IGBT1, IGBT2, IGBT3 and IGBT4), Q2 (which is IGBT5, IGBT6, IGBT7 and IGBT8), Q3 (which is IGBT9, IGBT10, IGBT11 and IGBT12). The layer PSI can only connect the inverter output to either the + Vdc/2, or - Vdc/2. The Q1 switching state has an analysis that is shown in Figure-2.

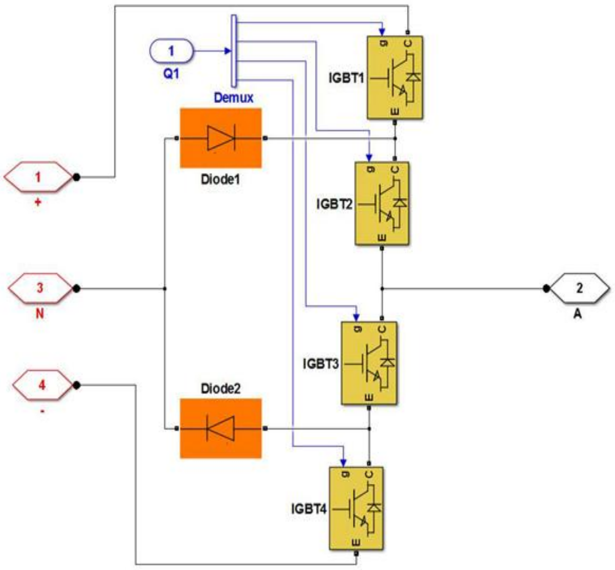

Figure-2. Half leg.

For a half operation: Switching state 1: when IGBT1 and IGBT2 are switched "on" and IGBT3 and IGBT4 are switched ‘off’ then the switching logic is 1100. At this point, IGBT1 and IGBT2 are turned ‘on’ that signifies ‘1’ then terminal ‘A’ is connected to the positive terminal of the DC input voltage. Therefore, the output voltage is + Vdc/2. Conversely, IGBT3 and IGBT4 are turned ‘off’ that signifies ‘0’ and then the output voltage is 0V.

Switching state 0: However, the switching logic is 0110, IGBT1 and IGBT4 are turned ‘off’, IGBT2 and IGBT3 are turned ‘on’ that why this state does not provide any voltage and each phase. So the voltages is 0.

Switching state -1: Also, switching logic is 0011. If IGBT1 and IGBT2 are turned ‘off’, it implies ‘0’. Similarly, IGBT3 and IGBT4 are turned ‘on’, it implies ‘1’. Then terminal ‘A’ is connected to the negative terminal. As a result, the output voltage is - Vdc/2.

The four IGBTs are listed for switching state in Table-1. Two clamp diodes which are Diode1 and Diode2 supply the connection to the midpoint, which is ‘N’. From the switching logics, it can be assumed that IGBT2 and IGBT3 are turned ‘on’ for most of the cycle, consequential in the higher conduction loss. Alternatively, IGBT1 and IGBT4 are far less switching loss. In most cases, the freewheel diodes which are D2 and D3 (IGBT2 and IGBT3) are soft switched as the parallel to the diode. The diode is turned ‘on’. Thus the diodes across the recovery voltage to the IGBT Vce.

Table-1. The PSI switching logic sequence.

Switching state	IGBT Switching Logic State				
	IGBT1	IGBT2	IGBT3	IGBT4	Output Voltage
1	1	1	0	0	+Vdc/2
0	0	1	1	0	0
-1	0	0	1	1	-Vdc/2

The input DC voltage sources are connected in series and establish the midpoint voltage which is 0V. Also the input filter reduces the DC ripple current. The Figure-3 is shown in the inverter output leg voltage.

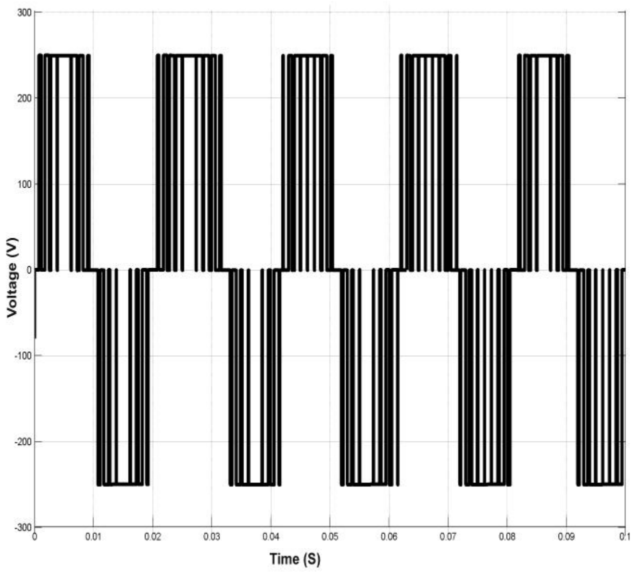

Figure-3. Inverter output leg voltage.

THE OUTPUT FILTER

The inverter has to be synchronized with the micro-grid as the PSI will inject ripple current. Therefore, output filter has been used for synchronization purposes which reduce the higher harmonic distortion (Figure-4). The inverter output LC filter is connected with micro-grid [6] [7]. The components of the LC circuit have presented in Table-2. The value of L and C are chosen based on ripple current and reactive power. It is resulting that lower conduction losses and lower switching for higher ripple current.

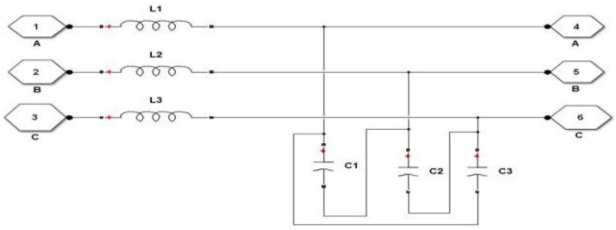

Figure-4. Output LC filter.

Generally, in any design 10% to 20% current ripple is considered of the rated current [8] [9]. However, in this design 10% ripple has been taken. Eqn. (1) has shown the ripple current of an inductor (L),

$$\Delta iL_{\max} = (iL_{\max} - i_{Out\max}) \times 2 \quad (1)$$

To determine the output filter parameter, reactive power is selected of the rated power of 15% that given in Eqn. (1) [3].

$$C = \frac{P_{rated} \times 15\%}{3 \times 2\pi \times V_{2rated}} \quad (2)$$

Table-2. Output filter parameter.

Line voltage	25 kV
Modulation index	0.85
DC source voltage	500 V
Nominal frequency	50 Hz
Switching frequency	1.85kHz

DESIGN OF THREE PHASE THREE LAYER PSI

The three phase three layer PSI has been designed and simulated by using MATLAB for verification purposes. This design operates on the basis of switching control logic that is integration of voltage regulator and phase synchronization technique. A basic three phase three layer PSI system, including micro-grid is shown in Figure-5. To verify the system performance, constant input voltage is 500 Vdc. An inverter controller gate pulse is connected to the three phase three layer PSI the control signal frequency (fc) is taken as 50Hz and modulation index is 0.95. The three phase three layer PSI consists of three leg IGBT of internal diode resistance (Ron) and snubber resistance (Rs) which values are $1e^{-4}$ Ω and $1e^{6}$ Ω respectively. The initial switching frequency is 850 Hz and the final frequency is 1.65 kHz has been considered for controlling purposes.

Generally, synchronous inverter control is a technique that is considered by the generation of constant pulse amplitude by changing the duty and the pulse duration. The block diagram demonstration of synchronous inverter control and gate pulse generation is shown in Figure-6. The synchronous inverter controller is normally to take inverter output voltage and current, input DC voltage and PWM switching frequency (Hz). The inverter output, the reference signal is either square or sinusoidal wave, at the same time as the saw, triangle or pure sine waves is the carrier signal at a frequency considerably bigger than the reference signal. There are different types of inverter control techniques and various outputs and the selection of the inverter depend on noise level, power efficiency and proper phase synchronous.

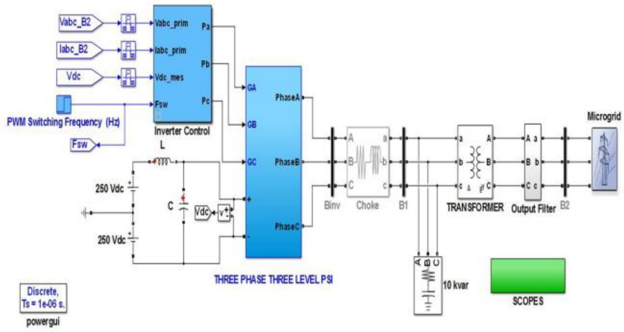

Figure-5. Inverter output leg voltage.

In this paper choice voltage regulator method and it provides phase synchronizing between inverter and micro-grid. It is compatible with digital microprocessors. The output filter is connected to the transformer output to filter the unwanted harmonics. The phase wise current and voltage are measured by the three phase current voltage measurement block. In this design, only the voltage is considering, but not the current. The inverter output current and voltage is in volts and ampere values or per unit.

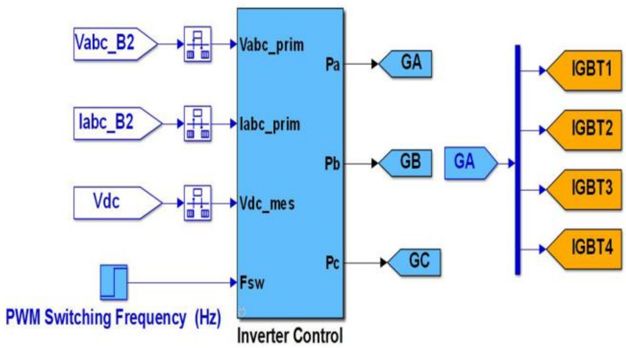

Figure-6. Block diagram of inverter control and gate pulse.

The transformer is connected to inverter output to step up the inverter output voltage. The three phase transformer two winding block the parameters taken nominal power Pn (VA) is $100e^{3}$, frequency (fn) is 50Hz, primary winding which are V_1 Ph-Ph (Vrms) $25e^{3}$, R_1 (pu) 0.001, and L_1 (pu) 0.03 and secondary winding parameter values are V_2 Ph-Ph (Vrms) 260, R_2 (pu) 0.001 and L_1 (pu) 0.03, magnetization resistance Rm (pu) is 500 and magnetization inductance Lm (pu) is 500. The three phase series RLC load block the parameters taken nominal phase-to-phase voltage Vn (Vrms) is 260V, normal frequency (fn) is 50Hz, active power (P) is $5e^{3}$ W, and Capacitive reactive power Qc (negative var) is $10e^{3}$.

RESULTS AND DISCUSSION

The simulation has been done using MATLAB2014a/Simulink for a three phase three layer PSI micro-grid connected inverter. In this PSI inverter design, the input DC source voltage ± 250V has been converted into peak to peak 1000V AC. A pure resistive load has been considered to maintain unity power factor for the simplicity of the analysis. To generate pulse width modulation, the switching frequency of the circuit has been started from 750Hz and progressively increased up to 1.85kHz. In this simulation voltage and frequency of the micro-grid are 600V (rms) and 50 Hz respectively. The unfiltered output voltage waveform of the inverter is shown in Figure-7.

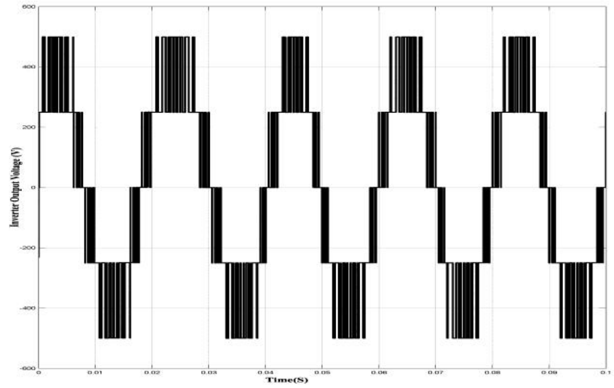

Figure-7. Unfiltered output voltage of the inverter.

Figure-8 shows the modulation index effects on the waveform of three phase three layer PSI.

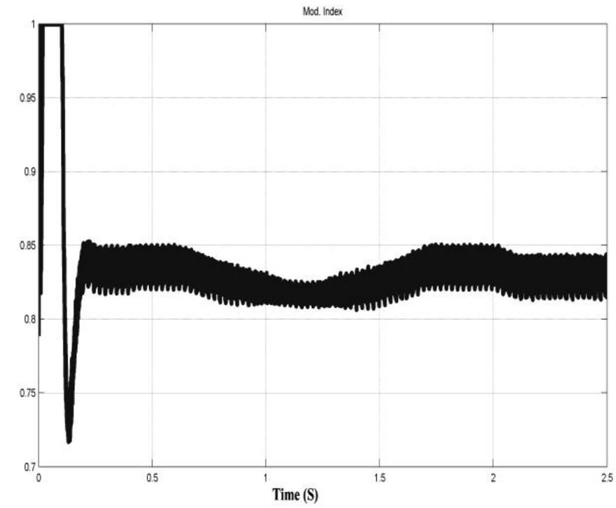

Figure-8. The modulation index of the PSI.

The total harmonic distortion (THD) and the frequency spectral voltage of the PSI are shown in Figure 9 and Figure 10 respectively. From Figure 9 it is found that the stable THD of the inverter is around 4.45%.

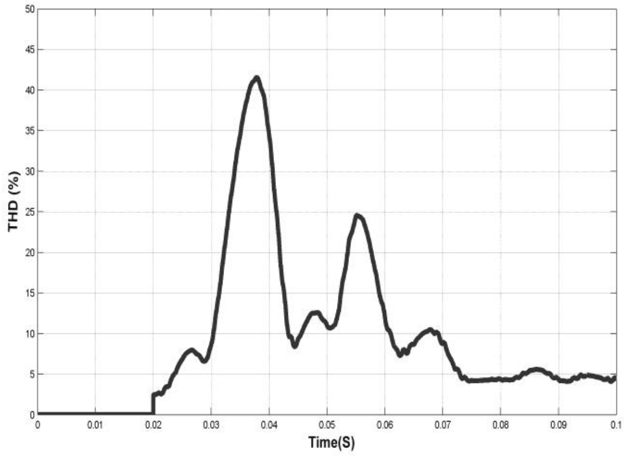

Figure-9. PSI output % THD voltage waveform.

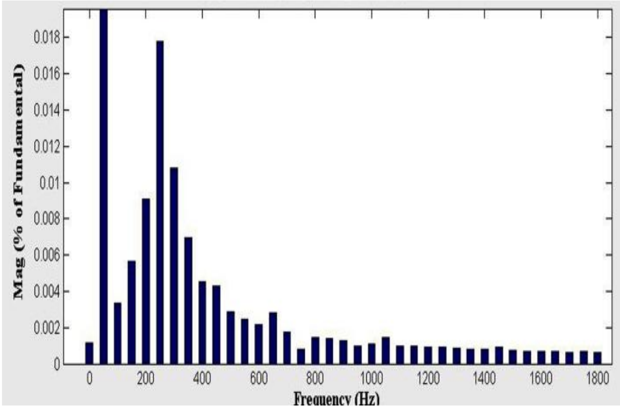

Figure-10. The graphical higher frequency harmonic distortion waveform in inverter.

The filtered output of the three phase three lear PSI voltage and current waveforms for the micro-grid line are shown in Figure-11 and Figure-12 respectively. It is found that the waveform is almost free from harmonic distortion.

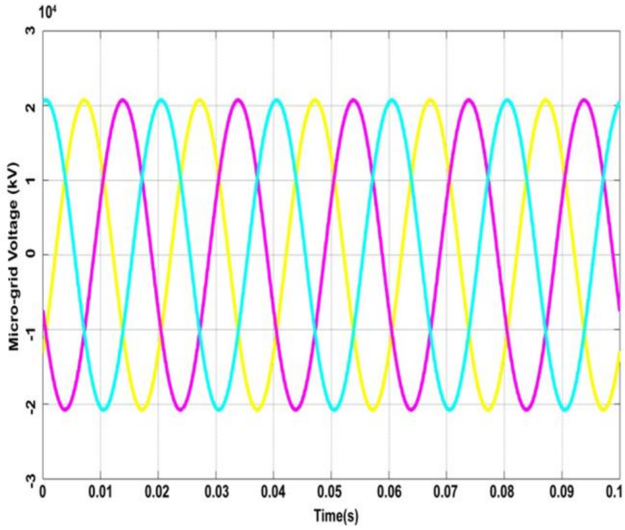

Figure-11. The micro-grid voltage waveform.

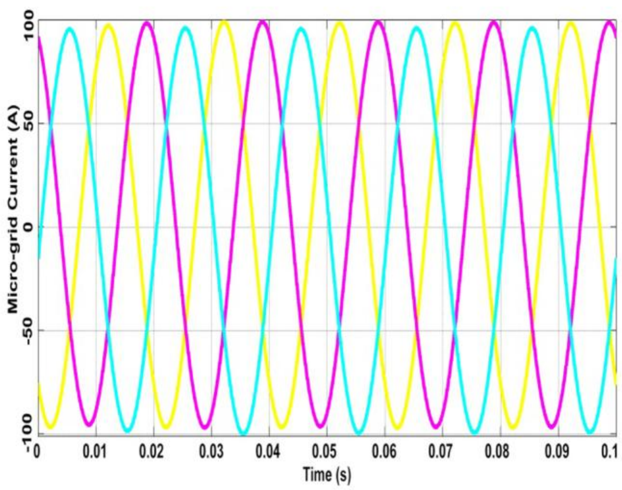

Figure-12. The micro-grid current waveform.

Figure-13 shows the result of the three phase three layer synchronization waveform. The signals Vab, Vbc and Vca represent the micro-grid sampling signal while the signals Vab', Vbc', Vca' represent the three phase three layer inverter controller signal. Also it can be seen that inverter and microgrid phase has been almost synchronized.

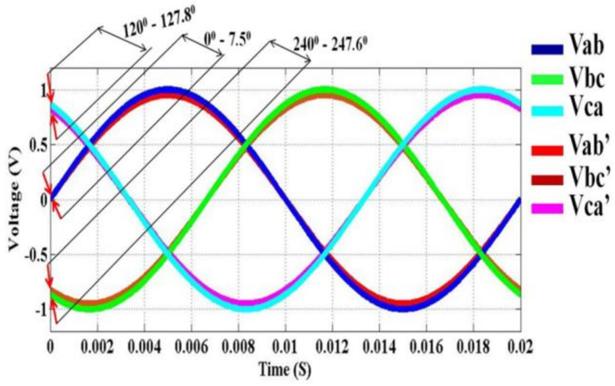

Figure-13. The phase synchronization waveform.

CONCLUSION

This design shows a phase synchronous DC to AC inverter. It has been observed from the simulation results that the designed three phase three layer PSI has better performance in terms of circuit simplicity, cost and power efficiency in micro-grid application to integrate different types of renewable energy sources together.

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