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Design and control of a Single Phase Synchronous Inverter for Microgrid

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Abstract: Microgrid power system is becoming popular for utilizing renewable energy. This energy should invert to supply AC for microgrid, but inversion of the renewable energy has suffered some issues; inferior quality of waveform, large phase difference, high switching loss and poor power quality. A new scheme of phase synchronous inverter (PSI) has outline in the microgrid system which improve the quality of the power supply. A pulse width modulation (PWM) signal is generated for PSI to precisely synchronize with the grid line frequency. A lowpass LC filter is utilized to reduce the higher harmonics frequency in the inverter. In this research a resistive load of 40 Ω and input DC voltage ± 35 V has been considered. A PWM of 1600 Hz carrier frequency and 95% modulation index with 50 Hz fundamental frequency has been examined in this project. The simulated results show that the proposed PSI overall efficiency is 96%, total harmonic distortion (THD) is 3.9% and phase distortion is about 4 degrees. Therefore, it is highly appreciated that proposed design will improve the microgrid power supply system.

Keywords: Inverter, PWM, microgrid, phase synchronization, THD, power quality

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Currently the energy main sources around the world are the fossil fuel and gas. The fossil fuels and gases reserve are limited and near future these sources will be finished, in this situation renewable energy can be a long-term solution. Some cases due to loss involved in conversion into electric energy from renewable energy makes it useless. For proper and efficient utilizing the renewable energy there is numerous scope to do research in power electronics and relevant engineering sectors (Rahman et al., 2016).-The renewable energy like, solar, wind, tidal wave, etc. are used as the input source for a PSI to be converted into AC electric energy for micro-grid systems (Rahman et al., 2016). The sun is an unlimited energy source for renewable energy; the photovoltaic (PV) cell can be used to convert the solar energy into electrical energy directly (de et al., 2017). However, the energy generates by a PV cell must use instantly otherwise there is needed storage battery systems which is expensive, bulky, and also needs regularly maintains. To overcome the battery storage systems complicity, nowadays, many PV systems are connected through common local networks which are known as a microgrid system. The efficiency and usefulness of the microgrid mostly depend on the electric switching techniques and inverter system (Rahman et al., 2016). Due to high frequency switching loss, higher harmonic frequency distortion and phase mismatching make the system performance very low (Zhou, 2017). Researchers are trying to improve the system efficiency by introducing new switching technology and algorithm (Lee, 2017). A voltage-sustained power electrical inverter is one within that the DC input voltage or current is fundamentally consistent and free of the load current strained (Zare et al., 2017). Although a half H-bridge inverter has better output voltage form factor and improved input power factor compared to a full H-bridge inverter
(Emmanuel, 2017). The output voltage and current wave shape of a full H-bridge inverter and half H-bridge inverter will be same provided the extinction angle is less than 180^0 (Zhang et al., 2017). In the continuous conduction mode, a half H-bridge inverter the output voltage cannot become negative and so it cannot run in the inverter mode (Yahyaoui, 2017).

A Single Phase Synchronous Inverter

The construction and working principle of a single phase synchronous inverter circuit is explained in Figure 1. The single phase inverter has one output terminal and consists of two IGBT

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switches connected in series. The load is connected between the midpoints of the DC voltage sources and the junction of the two switches, these points are marked as ‘0’ and ‘a’ respectively.

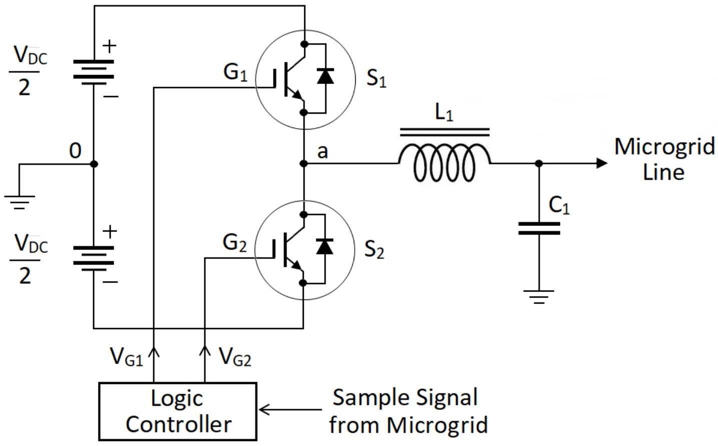


Figure 1. Proposed half phase inverter circuit the food chain.

In the first step, the IGBT switches S_1 is ON and S_2 is OFF; so the current flow from upper half DC supply to the load. However, in the second step, the switch S_1 if OFF and switch S_2 is ON; thus, current flow from ground to the load and lower half DC supply. As a result current in the load is alternating. The AC output voltage across the load can be express by the following equations (Lee, 2017 and Zhou, 2017).

$$v_o = (2d - 1) \times V_{DC} - L\,\frac{di_L}{dt} \qquad (1)$$

$$i_L = C \times \frac{dv_o}{dt} + \frac{v_o}{R} \qquad (2)$$

$$d = \frac{v_m}{v_C} \qquad (3)$$

Design of a Switching Controller

A single phase half H-bridge PSI uses two input DC supplies and two switches for converting the DC into AC. Similarly, a full H-bridge PSI also uses two input DC supplies but four switches (Zhang et al., 2017). Generally, a microgrid system uses three phase inverter topology (Rahman et al., 2016 and Lee, 2017). In single phase half H-bridge PSI circuit, two independent PWM signals are used to trigger the two IGBT switches. For phase synchronizing a sample signal is used to control the switching. On the other hand, for a three-phase PSI uses six PWM signals to control six IGBT switches (Rahman et al., 2016). The PWM switching technique uses high frequency carrier signal (1-30 kHz) that leads to use a small value of inductor and capacitor for filtering the higher harmonic frequencies. The duty cycle D is used to control the PWM and can be calculated by using Equation (4).

$$D = \frac{\text{Vin} + \text{Vout}}{2 \times \text{Vin}} \qquad (4)$$

Calculating the inductor and capacitor values of the lowpass LC filters is very complicated because their value depends on many factors such as, duty cycle, load current variation, carrier frequency, DC voltage and switching frequency of the inverter. Equation (5) and (6) can be used to calculate the inductor and capacitor values (Lee, 2017 and Zhou, 2017).

$$L = \frac{2 \times V_{dc} \times D_{max}}{\Delta I_{max} \times f_c} \qquad (5)$$

$$\Delta V_{out} = \frac{\Delta I_L}{C \times f_s} + r_{ESR} \times \Delta I_L \quad (6)$$

r_{ESR} is the equivalent series resistance of the output capacitor.

The percentage of total harmonic distortion can be calculated by the Equation (7).

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 \ldots\ldots\ldots. + V_n^2}}{V_1} \quad (7)$$

The witching sequences and exact “On” and “Off” timing of the inverter switches has been generated by using microcontroller. An advanced zero crossing technique has been used to synchronize the inverter AC frequency and phase with the microgrid frequency and phase. The relative amplitude of the microgrid voltage with phase difference with respect to inverter output voltage can be calculated by trigronomatric formula as Equation (8).

$$A = 2\sin\left(\omega t + \frac{\varphi}{2}\right) cos(\varphi/2) \quad (8)$$

Equation (8) states that at 180 phase difference the relative amplitude becones 0, and it is double at 0 degre

Results and Discussion

Figure 2 shows the frequency domain analysis of voltage and current of the single phase half H-bridge PSI without filtering. From the figure it is clearly seen that the signal contains 50 Hz fundamental frequency including the high order odd harmonic frequencies. One of the major reason for degrading the power quality of the microgrid supply is these higher harmonic frequencies. Therefore, it is one of the key challenging task to the researchers to remove these higher frequencies from the inverter before to feed it to the microgrid.

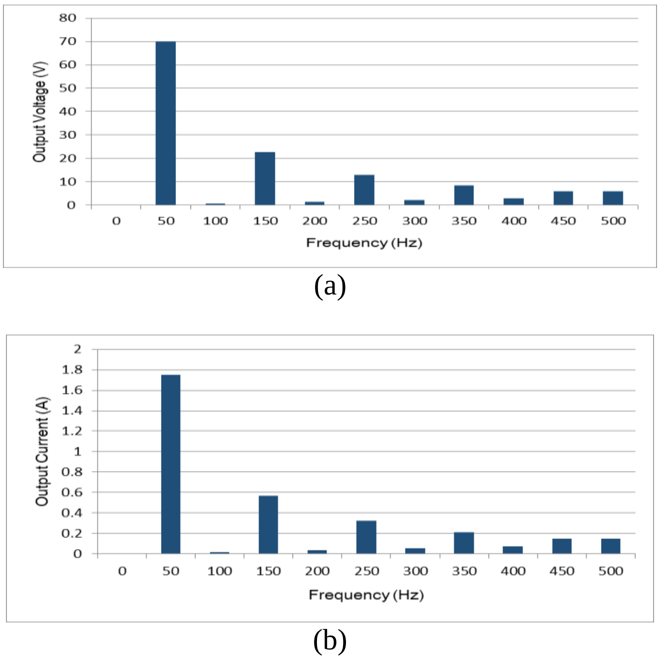
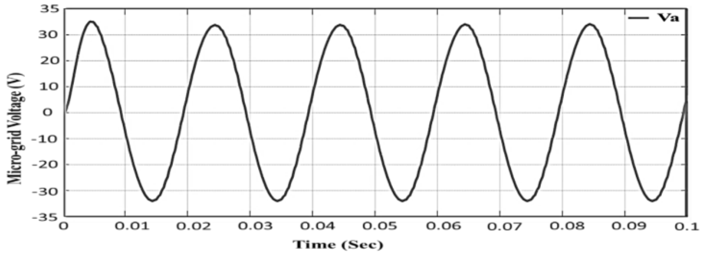
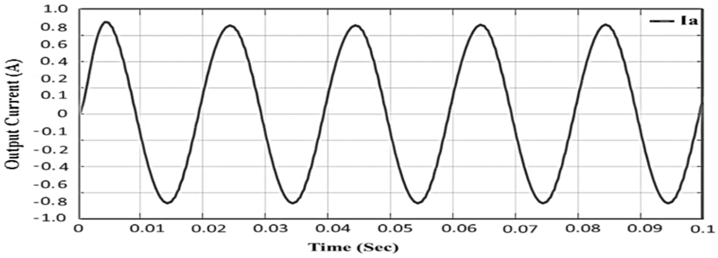


Figure 2. FFT analysis of the output wave without filtering, (a) voltage and (b) current

Before connecting to the microgrid line these signal ate passed through the LC lowpass filter to reduce the high order harmonic frequencies. After filtering, the time domain response of the PSI output voltage and current are shown in Figure 3 (a) and (b) respectively. Finally the frequency domain analysis of the output voltage and current of the inverter is shown in Figure 4. It is realized from the figure, the inverter output voltage and current have a little amount of harmonic signals with the fundamental frequency 50 Hz. From this analysis, it is found that the percentage of THD distortion for both the voltage and current is 47.8% before filtering and it is only 3.9%.

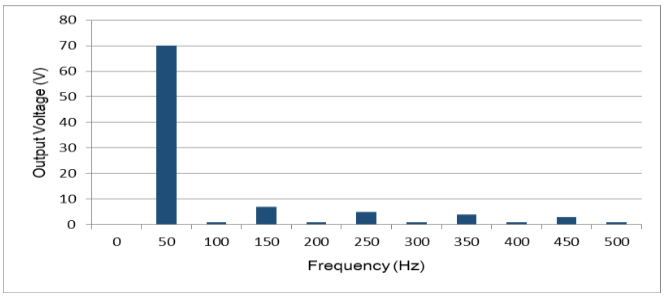


(a)

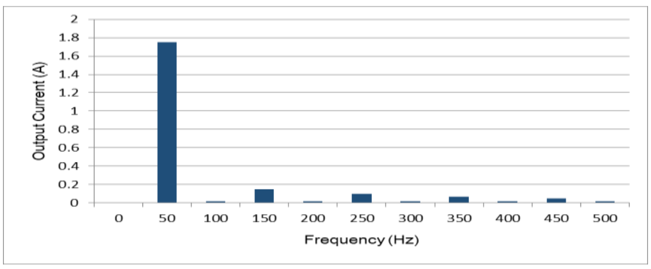


(b)

Figure 3. Time domain response of the the output after filtering (a) voltage and (b) current



(a)



(b)

Figure 4. Frequency domain response of the output after filtering (a) voltage and (b) current

Conclusions

A phase synchronous inverter interface circuit, especially switching controller, output filter and zero crossing circuit have been designed and investigated for microgrid system. The simulated results show the total harmonics distortions of the output signal is 3.9%, which is lower than the maximum permissible distortion (< 5%) as per requirements of IEEE standard. The overall PSI system efficiency is 96.01%. A modified zero crossing technique has been used to reduce the phase mismatch between the inverter and grid line frequencies and it has been achieved about 3.35 degrees which is less than the IEEE permissible standard value 4 degree

Acknowledgements

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