Power Electronics Lab (EE39006)
Autumn Semester 2021-22
Department of Electrical Engineering, IIT Kharagpur

Experiment-6

Title: INSTRUCTION SETS FOR SINGLE-PHASE AND THREE PHASE INVERTERS

Monday Batch

A. *Single phase Inverter:*

Simulate a single-phase inverter with following values: Input voltage Vs = 400V, and Load resistance = 40Ω. Choose MOSFET as switching devices and set its on-state resistance to 20 mΩ. Set the on-state resistance and the on-state voltage drop of the body diode to 1 mΩ and 0.7V respectively.

I. Implement Quasi-square wave modulation for the inverter with parameters given above. Use 50Hz as switching frequency.

a. Plot the following: Output voltage and input current for at least two switching cycles.

b. Perform FFT analysis for output voltage, and report the following: (i)THD and magnitude of fundamental component, and (ii) magnitude of 3^{rd} and 5^{th} order harmonic components and their proportion with respect to fundamental. Compare the theoretically calculated values with the simulation results.

c. Calculate the required phase shift between the two legs of the inverter so that the peak value of the fundamental output voltage will be (i) half and (ii) one fourth of the maximum fundamental output voltage possible. Also show the corresponding output voltage and input current waveforms for at least two switching cycles.

B. *Three phase Inverter:*

II. For a DC input voltage of 700V, and a RL load with R=35Ω, and L=20mH, simulate the three-phase voltage source inverter (VSI) using sine-triangle PWM modulation scheme. Choose IGBT/Diode Simulink block as the switching devices. Consider on-state resistance of the IGBT/Diode block as 20 mΩ.

a. Consider sinusoidal modulating frequency (f_m) as 50Hz and triangular carrier wave frequency (f_c) of 15kHz. For three different modulation indices (m_a) given, (i) $m_a = 0.4$, (ii) $m_a = 0.9$ and (iii) $m_a = 1.3$, plot the output line and phase voltage (V_{ab} and V_{an}) and perform FFT for the same. Also, note down the %THD and the fundamental rms component of the output line and phase voltage (V_{ab} and V_{an}) for all three modulation indices.

b. Now introduce a dead time of 1μs between the switches of the same leg. For $m_a = 0.9$, perform FFT for output phase and line voltage. Compare the fundamental rms components of output line and phase voltages with those of without dead time.

c. Perform FFT Analysis for output line voltage (V_{ab}) for following operating conditions (without introducing dead-time).

   1. Consider $f_m = 61$Hz, $f_c = 15$kHz and $m_a = 1$.
   2. Consider $f_m = 61$Hz, $f_c = 1$kHz and $m_a = 1$.

   Also compare the FFT obtained above with $f_m = 50$Hz, $f_c = 15$kHz, and $m_a = 1$ and comment.

Discussion questions:

1. **What** will happen if you connect a pure inductive load to the square wave modulated Inverter? Draw the input current and output current waveforms for at least two switching cycles. What will be the total active power delivered to the load? What will be the total active power taken from the input source? Assume all components to be ideal.
2. How can you implement variable voltage and frequency drive with the three phase VSI? Also mention for what application it is required and Why?

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Tuesday Batch

B. Single phase Inverter:

Simulate a single-phase inverter with following values: Input voltage Vs = 400V, and Load resistance = 40Ω. Choose MOSFET as switching devices and set its on-state resistance to 20 mΩ. Set the on-state resistance and the on-state voltage drop of the body diode to 1 mΩ and 0.7V respectively.

I. Implement Bipolar SPWM scheme for the inverter with parameters given above. Use 25 kHz as switching frequency. The fundamental component of the output voltage is expected to have frequency of 50 Hz.

a. Plot the following: Output voltage and Switch currents for at least two switching cycles.
b. Perform FFT analysis for output voltage, and report the following: (i) THD and magnitude of fundamental component, and (ii) magnitude of 5^{rd} and 7^{th} order harmonic components and their proportion with respect to fundamental.
c. For the following displacement factor, 0.8 lagging, unity power factor, and 0.2 leading, select the required load impedance for R =40 Ω. Plot the corresponding input current, output voltage and output current waveforms for all the cases and then indicate the interval for which the MOSFETs and the corresponding body diodes are conducting.

C. ***Three phase Inverter:***

II. For a DC input voltage of 800V, and a RL load with R=40Ω and L=20mH, Simulate the three-phase voltage source inverter (VSI) using sine-triangle PWM modulation scheme. Choose IGBT/Diode Simulink block as the switching devices. Consider on-state resistance of the IGBT/Diode block as 20 mΩ.

a. Consider sinusoidal modulating frequency (f_m) as 60Hz and triangular carrier wave frequency (f_c) of 20kHz. For three different modulation indices (m_a) given, (i) m_a = 0.3 (ii) m_a = 0.8, and (iii) m_a =1.2, plot the output line and phase voltage (V_{ab} and V_{an}) and perform FFT for the same. Also, note down the %THD and the fundamental rms component of the output line and phase voltage (V_{ab} and V_{an}) for all three modulation indices.

b. Now introduce a dead time of 3 μs between the switches of the same leg. For m_a= 0.8, perform FFT for output phase and line voltage. Compare the fundamental rms components of output line and phase voltages with those of without dead time.

c. Keeping f_c constant at 20kHz and without introducing dead-time, implement a PWM scheme such that V/f ratio is maintained constant by varying f_m as the function of m_a. Consider f_m = 60Hz at m_a = 1. plot the output line voltages for (i) m_a = 0.1 (ii) m_a = 0.5 (iii) m_a = 1. Perform FFT for the same and find out the fundamental rms component of the output line voltage (V_{ab}) for all three modulation indices.

Discussion questions:

1. Implement unipolar sine triangle modulation for the single-phase inverter with following values: Input voltage V_s = 400V ohms, R = 47Ω, L= 100 mH. Use 50Hz as modulation frequency and 10 kHz as carrier frequency.

a. Calculate the filter inductance and capacitance, such that inductor current ripple is 20% in the full load inductor rms current, and the cutoff frequency is at $1/10^{th}$ of the switching frequency.

b. Implement the filter obtained in part (a) in the single-phase inverter. For ma= 0.9, Plot the current through each MOSFETs and its body diodes and find their average and rms values. Calculate the total conduction loss for the given operating condition. Also, compare this with the theoretical results.

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Wednesday Batch

C. Single phase Inverter:

Simulate a single-phase inverter with following values: Input voltage Vs = 500V, and Load resistance = 25Ω. Choose MOSFET as switching devices and set its on-state resistance to 20 mΩ. Set the on-state resistance and the on-state voltage drop of the body diode to 1 mΩ and 0.7 V respectively.

I. Implement unipolar modulation scheme for the inverter with parameters given above. Use 20 kHz as switching frequency. The fundamental component of the output voltage is expected to have frequency of 50 Hz.

a. Plot the following: Output voltage and input current for at least two switching cycles.
b. Perform FFT analysis for output voltage, and report the following: (i) THD and magnitude of fundamental component, and (ii) magnitude of 3^{rd} and 5^{th} order harmonic components and their proportion with respect to fundamental.
c. For the following displacement factor, 0.7 lagging, unity power factor and 0.1 leading, select the required load impedance for R =25 Ω. Plot the corresponding input current, output voltage and output current waveforms for all the cases for the modulation index of 0.9. and then calculate the total conduction loss of the system.

D. *Three phase Inverter:*

II. For a DC input voltage of 750V, and a RL load with R=37.5Ω and L=20mH, Simulate the three-phase voltage source inverter (VSI) using sine-triangle PWM modulation scheme. Choose IGBT/Diode Simulink block as the switching devices. Consider on-state resistance of the IGBT/Diode block as 20 mΩ.

d. Consider sinusoidal modulating frequency (f_m) as 50Hz and triangular carrier wave frequency (f_c) of 25kHz. For three different modulation indices (m_a) given, (i) $m_a = 0.35$ (ii) $m_a = 0.85$, and (iii) $m_a = 1.25$, plot the output line and phase voltage (V_{ab} and V_{an}) and perform FFT for the same. Also, note down the %THD and the fundamental rms component of the output line and phase voltage (V_{ab} and V_{an}) for all three modulation indices.

e. Now introduce a dead time of 2 µs between the switches of the same leg. For $m_a = 0.85$, perform FFT for output phase and line voltage. Compare the fundamental rms components of output line and phase voltages with those of without dead time.

f. Keeping f_c constant at 25kHz and without introducing dead-time-, implement a PWM scheme such that V/f ratio is maintained constant by varying f_m as the function of m_a. Consider $f_m = 50$Hz at $m_a = 1$. plot the output line voltages for (i) $m_a = 0.1$, (ii) $m_a = 0.5$, and (iii) $m_a = 1$. Perform FFT for the same, and find out the fundamental rms component of the output line voltage (V_{ab}) for all three modulation indices.

Discussion questions:

1. Is it possible to connect a pure capacitor at the output of a VSI? Justify your answer.

2. In a three-phase inverter operated using sine-triangle modulation scheme, calculate the fundamental output line voltage theoretically, and compare it with the simulation counterpart for $m_a = 0.9$.