2.4 Phase-Shifted Multi carrier Modulation (PS-PWM)

Phase-Shifted Multicarrier Modulation (PS-PWM) is a specific type of pulse width modulation technique, mainly used in **multilevel inverters**. It is a form of **multicarrier PWM** where multiple carrier signals (such as triangular or saw tooth waves) are phase-shifted relative to one another to achieve desired switching behavior.

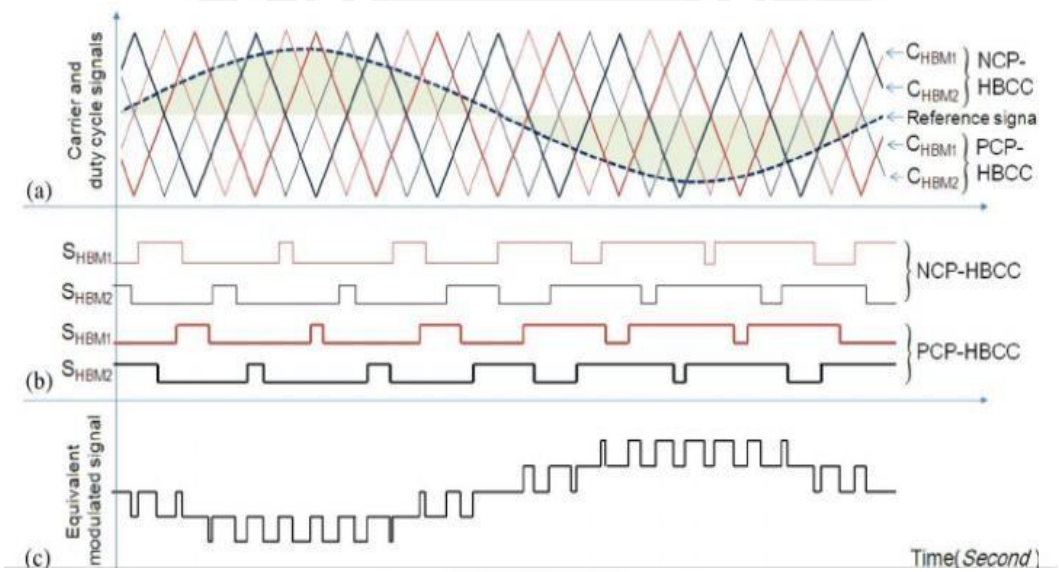

Figure 2.4.1 Phase-Shifted Multi carrier Modulation

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 394]

Key Concepts in Phase - Shifted Multicarrier PWM

1. **Multi level Inverters:**
   - Multi level inverters are converters that generate an output with multiple voltage levels, as opposed to just two levels (positive and negative) as in traditional inverters. These additional voltage levels help reduce harmonic distortion and improve output waveforms.

- Common multilevel inverter topologies include **Cascaded H-Bridge Inverters**, **Neutral Point Clamped (NPC) Inverters**, and **Flying Capacitor Inverters**.

2. **Phase-Shifted Carrier Waves**:
   - In PS-PWM, multiple carriers are used, each phase-shifted by a specific angle relative to the others. For example, in a three-level inverter, each carrier wave could be phase-shifted by 360◦n\ frac {360^\circ}{n}n360◦, where n is the number of carriers (or inverter levels minus 1).
   - Each inverter level (or bridge) has its own carrier signal that controls the switching devices.
3. **Modulating Signal**:
   - Therefore modulating signal is usually a sinusoidal waveform, common to all phases of the inverter.
   - The modulating signal is compared to the phase-shifted carrier waves to generate switching pulses.

Working Principle of PS-PWM

- In multilevel inverters, PS-PWM operates by comparing a single modulating reference signal (usually sinusoidal) with multiple carrier signals, each of which is phase-shifted relative to the others.
- The result is a set of switching pulses that correspond to different inverter levels, with each level contributing to a portion of the total output waveform.

- The phase shift between the carriers helps **distribute the switching events** evenly across the devices, reducing switching losses and improving output wave form quality.

Benefits o f Phase-Shifted PWM

1. **Improved Harmonic Performance**:
    - By using multiple carriers with phase shifts, the inverter can generate output waveforms that more closely approximate a sinusoidal waveform, reducing Total Harmonic Distortion (THD).
2. **Reduced Device Stress**:
    - The phase shift helps in distributing switching events among the different power devices, reducing switching losses and thermal stress on individual devices.
3. **Scalability**:
    - PS-PWM is particularly useful in **modular multilevel inverters**, where the number of voltage levels can be scaled up by adding more H-bridges or other power converter modules. This makes it highly suitable for high-power applications.
4. **Lower Switching Frequency**:
    - Because of the phase shift between the carriers, the effective switching frequency for each individual device is lower than the combined output frequency, which reduces switching losses.

Applications of Phase-Shifted Multicarrier PWM

1. **High-Power Industrial Drives**:
    - Multilevel inverters with PS-PWM are widely used in high-power variable frequency drives(VFDs) for motor control in industrial applications, where efficiency and low harmonic distortion are critical.
2. **Renewable Energy Systems**:
    - Used in photovoltaic (PV) systems and wind turbines, multilevel inverters with PS-PWM can convert DC energy from solar panels or wind turbines into clean AC power for grid integration.
3. **HVDC Transmission**:
    - PS-PWM is applied in high-voltage direct current (HVDC) transmission systems, where multilevel converters play a key role in efficiently converting and transmitting electrical power over long distances.
4. **FACTS Devices**:
    - Flexible AC Transmission Systems (FACTS) devices, such as static synchronous compensators (STATCOMs), utilize multilevel inverters with PS-PWM to provide reactive power compensation and improve power quality in electrical grids.