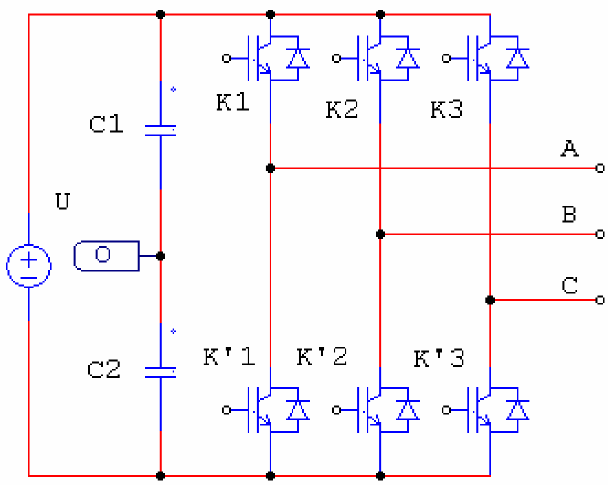
ELECTRICAL ENGINEERING

PULSE WIDTH MODULATION ASSOCIATED WITH THREE-PHASE VOLTAGE SOURCE INVERTERS

1. Elementary structure of the inverter :



We can create a three-phase voltage source inverter by grouping together three single-phase half bridges and a capacitor voltage divider.
The switches should be complimentary two by two (K1 with K'1, etc…).
In order for the output voltages to be identical to a third of a period, it is necessary to shift the controls for the switches of each arm by a third of a period.
For a balanced load with neutral N, it is not necessary to link this N point to the milieu 0 of the source.
On the other hand, this is imperative for an unbalanced load.

2. Different types of PWM:

Pulse width modulation is used to:

- Push the harmonics of the output voltage towards the high frequencies which makes filtering easier.
- Vary the value of the voltage fundamental.

Often the switch angles are determined by using one of the following techniques:

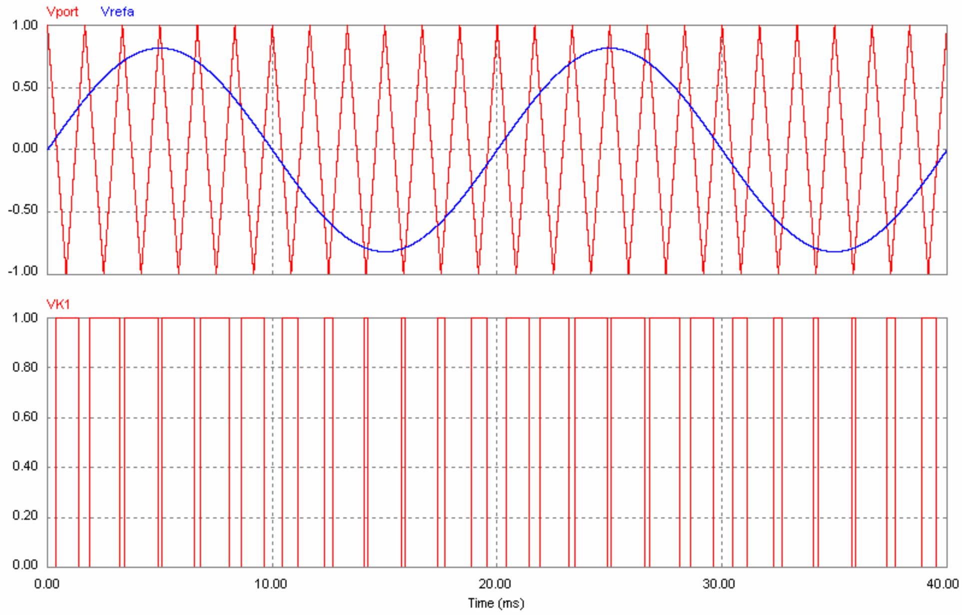
- By using the intersection of a reference or modulating voltage (often sinusoidal) with a carrier (in general triangular). This is called sine-triangle modulation.
- By defining the switch angles with a programmable component. This is called pre-calculated PWM.
- It is also possible to use a register controlled by a reference voltage and the integrated voltage of the output. This is called sigma-delta modulation.

3. Sine-triangle PWM :

3.1 Principle

The goal is to vary the average value of the output voltage of a single phase of the inverter by comparing a reference voltage to a carrier. We can show that the output voltage is directly proportional to the reference voltage (in this case Vrefa). This hypothesis is based on the fact that we consider the value of the reference voltage as constant during switching.

We can see below the carrier and the reference as well as the control signal of a switch that is the result of the comparison of the two.



3.2 Characteristics of the modulation

If the reference is sinusoidal, we can define two parameters :

- The modulation index m is the relation between the frequency of the carrier and the reference.

$$\boxed{m = \frac{f_{car}}{f_{ref}}}$$

- The tuning coefficient r is the relation between the amplitudes of the reference and those of the carrier.

$$\boxed{r = \frac{A_{ref}}{A_{car}}}$$

The modulation is said to be synchronous when f_{car} is an integer multiple of f_{ref}. This is often the case in steady state.

3.3 Amplitude of the fundamental

By acting on r we can vary the amplitude of the voltage fundamental U_{1AB}. If m is large enough (superior to 6), we can show that :

$\boxed{V_{1AB} = \frac{1}{\sqrt{2}} r \times \frac{U}{2}}$ (U is the continuous voltage source of the inverter)

If m is large the maximum value of r is equal to 1. We can observe in this case that the maximum value of the fundamental is less than that obtained by full-wave control. We call this voltage drop.

3.4 Generating harmonics

If the receiver is star-connected with no neutral conductor or in a delta, the harmonics of the 3rd order or that are multiples of 3 are eliminated.

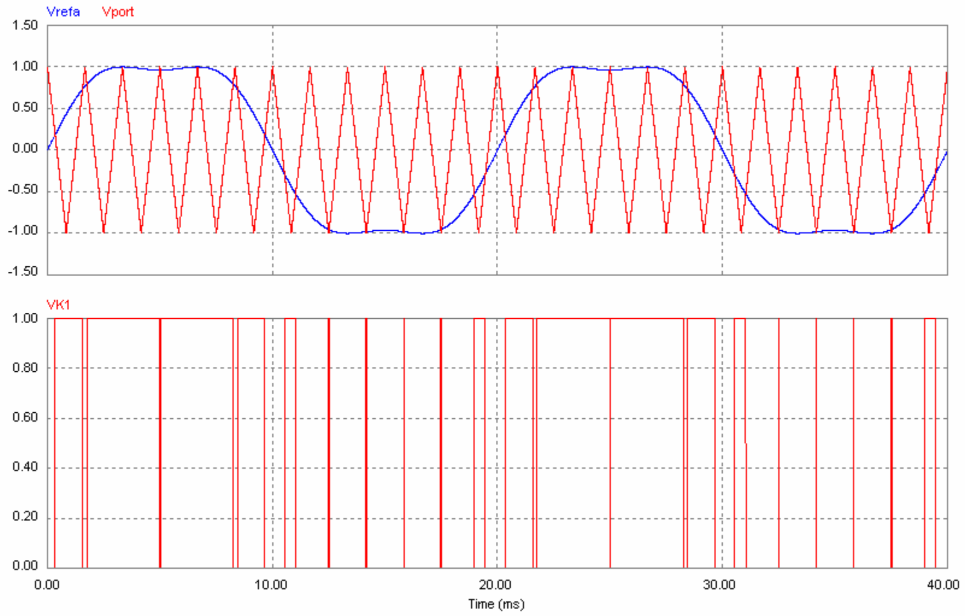
Moreover, if we choose m, multiple of 3, we eliminate (among others) the most important harmonic, the harmonic of the frequency $m \times f_{ref.}$

We can thus show that the only ones left for the two first families are the harmonics of the order:

$$m - 2, m + 2 \text{ and } 2m - 1, 2m + 1$$

3.5 Suboptimal strategy

In three-phase we can reduce the voltage loss by adding a harmonic of the 3rd order in the reference voltage:



In this case the equation of the reference voltage is written: $V_{ref} = r\sin\omega t + k\sin 3\omega t$

We can therefore show that for r = 1.155 and k = 0.1925 voltage loss is reduced to 9.31 % compared to full-wave control.

4. Pre-calculated PWM :

4.1 Principle

In the previous method we considered that the firing angles were calculated in real time. For pre-calculated PWM the switches are controlled by sequences that have been calculated previously or saved to the memory. This technique is used to cancel harmonics that are specific to the application (we call these weighted harmonics).

4.2 Calculating the angles

The value of the angles is determined by the number of harmonics we want to eliminate and the desired amplitude of the fundamental.

We must therefore solve a system of non-linear equations. We calculate n angles that define n holes in order to eliminate the n-1 first order harmonics:

$$\begin{cases} \frac{1}{2} - \cos\theta_1 + \cos\theta_2 - \cos\theta_3 + \ldots \pm \cos\theta_n = \frac{\sqrt{2}\, V_{AN1} \times \pi}{4 \times U} \\ \frac{1}{2} - \cos5\theta_1 + \cos5\theta_2 - \cos5\theta_3 + \ldots \pm \cos5\theta_n = 0 \\ \frac{1}{2} - \cos7\theta_1 + \cos7\theta_2 - \cos7\theta_3 + \ldots \pm \cos7\theta_n = 0 \\ \frac{1}{2} - \cos11\theta_1 + \cos11\theta_2 - \cos11\theta_3 + \ldots \pm \cos11\theta_n = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{cases}$$

The angles θ_n are calculated for 1/4 of a period. The others are determined by symmetry in relation to the first quarter.

As an example, for N = 3 and $V_{AN1} = \frac{4 \times U}{\sqrt{2} \times \pi}$, we find that $\theta_1 = 14.85244°$; $\theta_2 = 37.60198°$ and $\theta_3 = 44.07266°$