2.6 firing schemes

1. The firing instant for all the valves are determined at ground potential and the firing signals sent to individual thyristors by light signals through fibre-optic cables. The required gate power is made available at the potential of individual thyristor.
2. While a single pulse is adequate to turn-on a thyristor, the gate pulse generated must send a pulse whenever required, if the particular valve is to be kept in a conducting state.

The two basic firing schemes are

1. Individual Phase Control (IPC)
2. Equidistant Pulse Control (EPC)

Individual Phase Control (IPC)

This was used in the early HVDC projects. The main feature of this scheme is that the firing pulse generation for each phase (or valve) is independent of each other and the firing pulses are rigidly synchronized with commutation voltages.

There are two ways in which this can be achieved

1. Constant α Control
2. Inverse Cosine Control

Constant α Control

Six timing (commutation) voltages are derived from the converter AC bus via voltage transformers and the six gate pulses are generated at nominally identical delay times subsequent to the respective voltage zero crossings. The instant of zero crossing of a particular commutation voltage corresponds to $\alpha = 0^{o}$ for that valve.

The delays are produced by independent delay circuits and controlled by a common control voltage V derived from the current controllers.

Inverse Cosine Control

The six timing voltages (obtained as in constant α control) are each phase shifted by 90^{o} and added separately to a common control voltage V.

The zero crossing of the sum of the two voltages initiates the firing pulse for the particular valve is considered. The delay angle α is nominally proportional to the inverse cosine of the control voltage. It also depends on the AC system voltage amplitude and shape.

The main advantage of this scheme is that the average DC voltage across the bridge varies linearly with the control voltage V_c .

Drawbacks of IPC Scheme

The major drawback of IPC scheme is the aggravation of the harmonic stability problem that was encountered particularly in systems with low short circuit ratios (less than 4). The harmonic instability, unlike instability in control systems, is a problem that is characterized by magnification of noncharacteristic harmonics in steady-state.

This is mainly due to the fact that any distortion in the system voltage leads to perturbations in the zero crossings which affect the instants of firing pulses in IPC scheme. This implies that even when the fundamental frequency voltage components are balanced, the firing pulses are not equidistant in steady-state. This in turn leads to the generation of noncharacteristic harmonics (harmonics of order $h \neq np \pm 1$) in the AC current which can amplify the harmonic content of the AC voltage at the converter bus. The problem of harmonic instability can be overcome by the following measures

1. Through the provision of synchronous condensers or additional filters for filtering out noncharacteristic harmonics.
2. Use of filters in control circuit to filter out noncharacteristic harmonics in the commutation voltages.
3. The use of firing angle control independent of the zero crossings of the AC voltages. This is the most attractive solution and leads to the Equidistant Pulse Firing scheme.

Equidistant Pulse Control (EPC)

The firing pulses are generated in steady-state at equal intervals of 1/pf , through a ring counter. This control scheme uses a phase locked oscillator to generate the firing pulses. Thre are three variations of the EPC scheme

1. Pulse Frequency Control (PFC)
2. Pulse Period Control
3. Pulse Phase Control (PPC)

Pulse Frequency Control (PFC)

A Voltage Controlled Oscillator (VCO) is used, the frequency of which is determined by the control voltage V_c which is related to the error in the quantity (current, extinction angle or DC voltage) being regulated. The frequency in steady-state operation is equal to pf_o where f_o is the nominal frequency of the AC system. PFC system has an integral characteristic and has to be used along with a feedback control system for stabilization.

Pulse Period Control

It is similar to PFC except for the way in which the control voltage V_c is handled. The structure of the controller is the same, however, V_c is now summed with V_3 instead of V_1 .

The frequency correction in this scheme is obtained by either updating V_1 in response to the system frequency variation or including another integrator in the CC or CEA controller.

Pulse Phase Control (PPC)

An analog circuit is configured to generate firing pulses according to the following equation

$$\int_{t_{n-1}}^{t_n} K_1 V_1 dt = V_{cn} - V_{c(n-1)} + V_3$$

where V_{cn} and $V_{c(n-1)}$ are the control voltages at the instants t_n and t_{n-1} respectively.

For proportional current control, the steady-state can be reached when the error of V_c is constant.

The major advantages claimed for PPC over PFC are (i) easy inclusion of α limits by limiting V_c as in IPC and (ii) linearization of control characteristic by including an inverse cosine function block after the current controller. Limits can also be incorporated into PFC or pulse period control system.

Drawbacks of EPC Scheme

EPC Scheme has replaced IPC Scheme in modern HVDC projects; it has certain limitations which are

1. Under balanced voltage conditions, EPC results in less DC voltage compared to IPC. Unbalance in the voltage results from single phase to ground fault in the AC system which may persist for over 10 cycles due to stuck breakers. Under such conditions, it is desirable to maximize DC power transfer in the link which calls for IPC.

2. EPC Scheme also results in higher negative damping contribution to torsional oscillations when HVDC is the major transmission link from a thermal station.