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Technical Fundamentals of Radiology and CT

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Chapter 12

High frequency technique (multipulse)

12.1 Introduction

For many years, x-ray generation was based on the use of high voltages created from the network frequency, which is 50 Hz or 60 Hz. This concept requires a lot of iron in the transformer core in order to obtain high power. According to the equations used for manufacturing transformers, we obtain that the voltage induced in the transformer secondary depends on several technical factors [1]: the input voltage, the magnetic permeability of the core and the number of turns of wire used ($V_1 = 4$, $N_I = 44, f_1, \varphi_{max}$). Thus when it is necessary to have a high voltage and a high output current, many turns of wire must be used (N_I) with adequate wire gage to handle high currents. This means having enough space in the core geometry for all the wire to fit inside if the system works with a constant low frequency f_1 (50 Hz or 60 Hz).

Now if we consider that the induced voltage depends on the frequency [2], we can have the same voltage with fewer turns of wire if we increase the frequency instead of the number of turns and at the same time if a core of high permeability material is used (superior to iron) for greater magnetic flux (φ_{max}), whereby equivalent power transformers with a much smaller volume and weight are achieved. In the situation described, requiring the creation of a high frequency potential at high power [3] which is not possible with only a conventional oscillator, a system with high frequency oscillation with high power is required as is the possibility to change the output voltage for the range of voltages required for radiographs (between 40 kV and 150 kV).

As explained it is theoretically possible to obtain a high induced voltage if we have a transformer core of high magnetic permeability with an alternating high frequency voltage generated by a variable oscillator that is capable of generating high power. These voltages can be applied to the primary of the transformer, equivalent to those used in conventional x-ray technology, i.e. applying voltages of hundreds of volts to induce thousands of volts in the transformer secondary. In practical terms, the situation is not as straightforward, as in the conventional system

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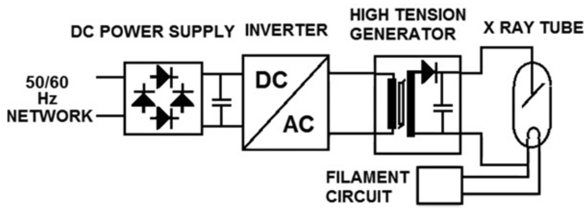

Figure 12.1. A high frequency x-ray generation system. Modified from Electromedica/Siemens.

the voltage intended to be applied on the high voltage transformer, an input autotransformer connected to the conventional electricity network, provides all the power required, which is obtained through its electrical parameters and large physical dimensions from the available mains frequency (50 Hz or 60 Hz). High frequency systems must be designed and constructed with a generator of medium voltages (hundreds of volts), which delivers high voltages (between 40 kV and 150 kV), varying the frequency (in the range of 20–40 kHz), instead of varying the input voltage as a conventional system does.

To generate x-rays with a high voltage at a different frequencies, is necessary to have a system to convert the frequency to an alternating voltage [4], then increase this tension, if possible rectifying and eventually filtering to apply this high voltage on the x-ray tube as constantly as possible.

It should be remembered that in conventional x-ray technology a very high voltage is generated from the 50 Hz or 60 Hz, which can only be rectified with devices that sustain this high voltage, but it cannot be filtered because that would require capacitors with very high voltage and high capacity, which are not commercially available. This marks a major advantage of the technique of high frequency (or multipulse), because it is possible to filter a high frequency and high voltage with capacitors that have a high dielectric strength to withstand high voltage and not a very large capacitance. Figure 12.1 shows a conceptual diagram of the generation of x-rays using a high frequency system.

12.2 How to obtain a high voltage variable frequency

The technical effort to make an oscillator system (inverter) change its frequency so as to achieve the required secondary voltages is too demanding. The solution to the problem was made possible by the existence of solid-state devices that handle high powers as in the case of controlled thyristors (silicon-controlled rectifiers (SCRs)). The circuit shown in figure 12.2 is the conceptual basis for high voltage generating systems for the so-called multipulse technique or medium frequencies. Its basis is as follows.

An RLC circuit supplied with a dc voltage generates an oscillating signal that is damped when a switch is closed. The first part of the circulating current is almost a half-sine which dampens over time, which in figure 12.2 is used as a switch to a thyristor (SCR). On receipt of the appropriate gate voltage this is brought into full conduction. Then the circuit generates a current pulse applied to the resistance which generates a half-sine form voltage.

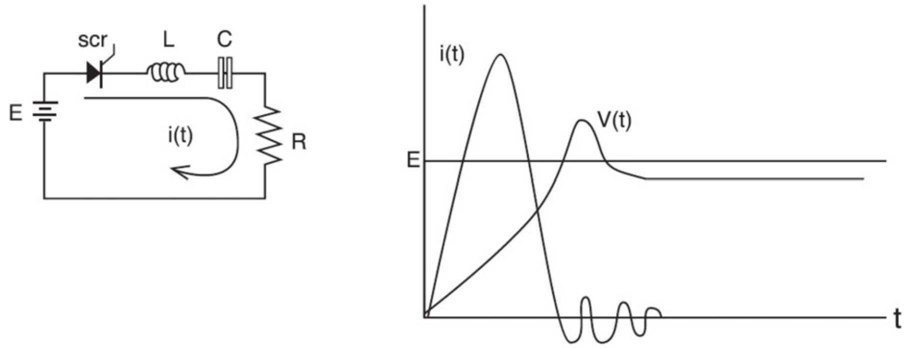

Figure 12.2. The basic circuit of damped wave generation.

We can see that the waveform of the current in its first part corresponds to a half-sine, so that if this current is applied to the primary of a transformer producing a voltage induced in the secondary with the same waveform, the system requires a complete cycle with a second half-sine but with the opposite direction, i.e. with a negative value. If this is a circuit that alternately generates these half-sines, we have a suitable waveform and the voltage required depends on the number of laps in the secondary.

The frequency at which the electronic switch (SCR) is closed determines the oscillation frequency that is generated [5]. Therefore, it is necessary to have a trigger circuit of the gates of the thyristors with the possibility of varying the frequency of pulse emission, and obviously a suitable combination of components that allows the generation of the pulses comprising the sequential damped high frequency wave oscillating circuit to alternate. The circuit shown in figure 12.3 is a conceptual diagram of this process [6].

Both triggers 1 and 3 generate positive sign waves, and triggers 2 and 4 generate negative waves. The sequence is shown on the right of the figure and gives rise to the current $i(p)$, with a sinusoidal shape to result in a current in the same way and frequency in the secondary but with a much higher voltage level.

The electronic implementation of these circuits is shown in figure 12.4, in which the thyristors are triggered in sequence so that the current follows a path that involves developing a voltage on both sides of the primary in the transformer of high frequency. Initially two thyristors opposite each other in the first bridge are shorted and current flows are damped by the upper primary of the transformer. The dashed line shows the path of the wave when it is in the first half cycle of the damped wave where the transformer alternately looks like a sine wave [7]. The resulting waveforms are shown in figure 12.5 with the pulse sequence.

12.3 A complete multipulse circuit

The initial system of x-ray generation by a high frequency ac, called ‘multipulse’, was created by Siemens with a conceptual scheme as shown in figure 12.6. In this block diagram we have a part of the network which feeds the three-phase converter which supplies both systems. The high frequency voltage for the anode circuit on

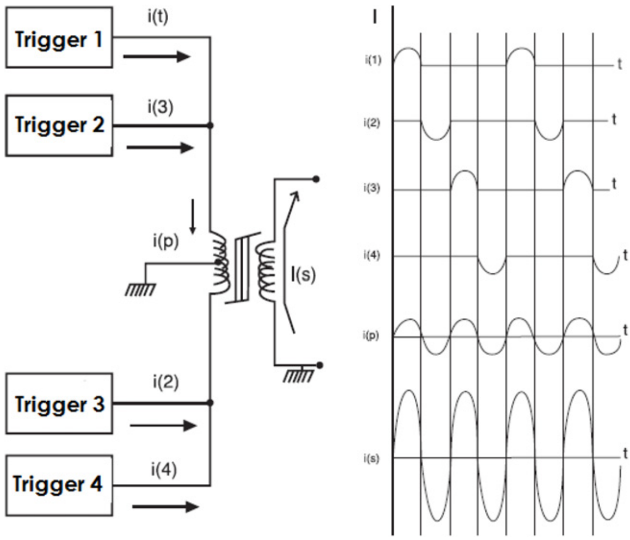

Figure 12.3. The circuit generator of a multipulse wave.

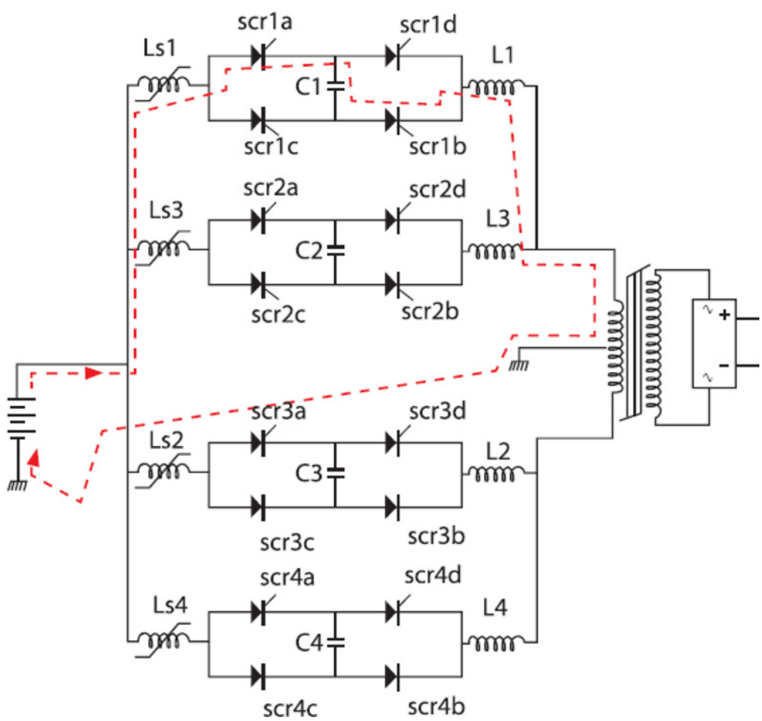

Figure 12.4. Electronic circuit of switching.

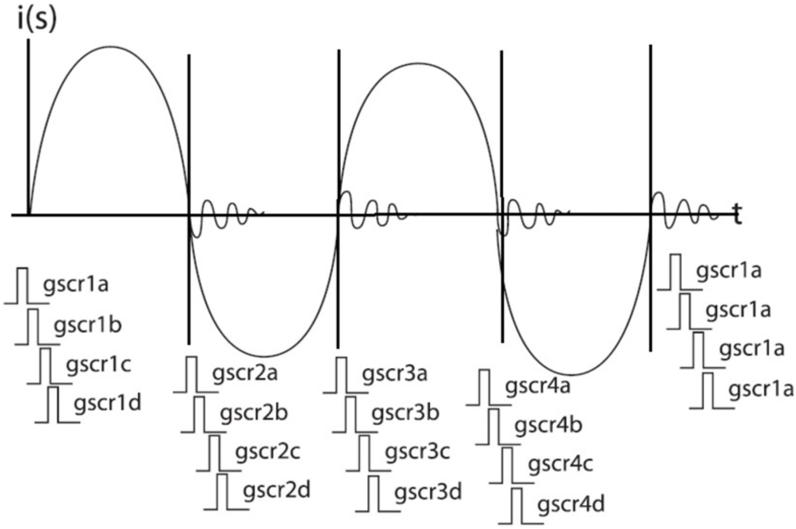

Figure 12.5. Combined resulting waveforms.

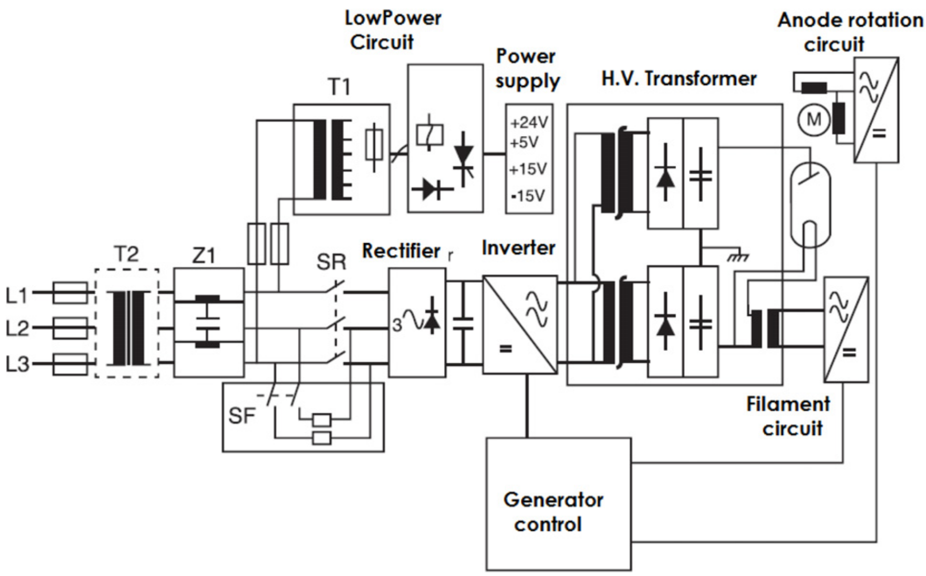

Figure 12.6. A complete multipulse generation system. Modified from Electromedica/Siemens.

the tube and the tube filament power supply circuit are provided through high frequency transformers and their respective rectifying and filtering circuits [8]. This stage has the option of applying tension in fluoroscopy or radiography. At the same time the power is supplied to the conventional low voltage source intended for electronics and the connection to the central control with which the current values, voltage and duration of the radiographic shot are selected, and finally the rotation control circuit, a condition necessary to authorize emission of x-rays.

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