

# An Overview of Constant-k Type Filters

<sup>1</sup>Rashmi Vaishya, <sup>2</sup>Ashish Choubey

<sup>1</sup>M.E. Student (HVPS Engg.), <sup>2</sup>Assistant Professor  
<sup>1,2</sup>Deptt of Electrical Engineering, JEC Jabalpur, M.P.

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**Abstract:** Power system are designed to operate at a frequency of 50 or 60 Hz. However, certain types of non linear loads produce current and voltages with frequencies that are integer multiple of the fundamental frequency. These frequency components known as harmonic pollution and is having adverse effect on the power system network. Inverter is the part of day to day life for every individual. Energy adversity is of special attention in recent days. Because of the sine wave output of the inverter, the electronic devices are efficiently operated. Most of the inverters provide square wave output. Electronic devices run by this inverter may be damaged due to harmonic contents. Available sine wave inverters are expensive and their output is not so good. Hence the improvement in the square wave output of the inverter is most essential. For getting pure sine wave output SPWM technique is used in inverter. The PWM inverter has been the main choice in power electronics because of its simplicity. SPWM is the mostly used method in motor control and inverter applications. Most of the harmonics can be removed by the SPWM technique and hence improves the quality of power converter. By using active or passive filters or both, we can improve the power quality .

**Keywords:** Filter, Active filter, Passive filter, Low-pass, High-pass, Band-pass, Band-stop, Characteristic impedance, Cut-off frequency.

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## I. INTRODUCTION

The concept of filters has been an integral part of the evolution of electrical engineering from the beginning. Several technological achievements would not have been possible without electrical filters. Because of this prominent role of filters, much efforts has been expended on the theory, design, and construction of filters. A filter is a circuit that is designed to pass signals with desired frequencies and reject or attenuate the others. As a frequency-selective device, a filter can be used to limit the frequency spectrum of a signal to some specified band of frequencies. Filters are the circuits used to allow to us to select one desired signal out of a multitude of broadcast signals in the environment.

Filters are classified in two types:-

- Active filters
- Passive filters

A filter is a passive filter if it consist of only passive elements R, L and C. It is said to be an active filter if it consists of active elements (such as transistors and op amps) in addition to passive elements R, L and C. LC filters have been used in practical applications for more than eight decades.

Passive filters are widely used in power system for harmonic mitigation. In general, they have shunt branches consisting of passive elements; such as inductors and capacitors which are respectively tuned to the predominant harmonics. Design procedure for this type of filter is also very simple.

The design of a passive filter requires a precise knowledge of the harmonic producing load and of the power system. Because passive filters always provide reactive compensation to a degree dictated by the volt-ampere size and voltage of

the capacitor bank used, they can in fact be designed for the double purpose of providing the filtering action and compensating power factor to the desired level. Thus, passive filter design must take into account expected growth in harmonic current source or load reconfiguration because it can otherwise be exposed to overloading, which can rapidly develop into extreme overheating and thermal breakdown.

There are four types of filters whether passive or active:

- Low-pass filters
- High-pass filters
- Band-pass filters
- Band-stop filters

A low-pass filter passes low frequencies and stops high frequencies. A high-pass filter passes high frequencies and rejects low frequencies. A band-pass filter passes frequencies within a frequency band and blocks or attenuates frequencies outside the band. A band-stop filter passes frequencies outside a frequency band and blocks or attenuates frequencies within the band.

## II. WORKING OF FILTERS

### LOW PASS FILTER:-

It is clear from the figure (1) that with increase in frequency of the signal at the input side, the shunt capacitive reactance decreases. This will allow more current to be returning back to the source through the low impedance path. At a higher frequency, the entire input current returns to the source through the shunt branch which becomes practically a short circuit link at this frequency.

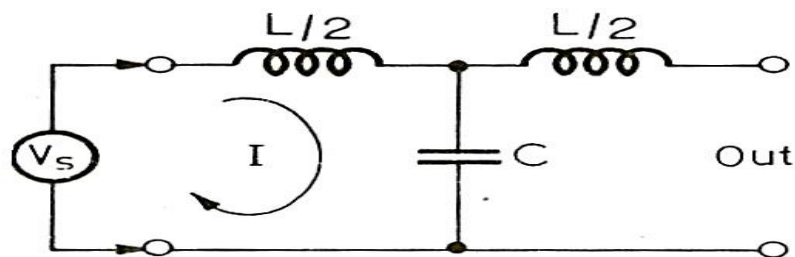


Fig.(1) T-section of Low Pass filter

Thus it is evident that:

- The low pass section can only allow passage of signal through it till the signal frequency is at lower magnitude.
- At higher frequency, the inductive reactance in the series arm also increases to a very high value rendering the blockage of the input signal. In practice, low pass filter operation is said to be satisfactory for increasing frequencies till the voltage gain is 0.707 p.u at cut-off frequency  $f_c$ .

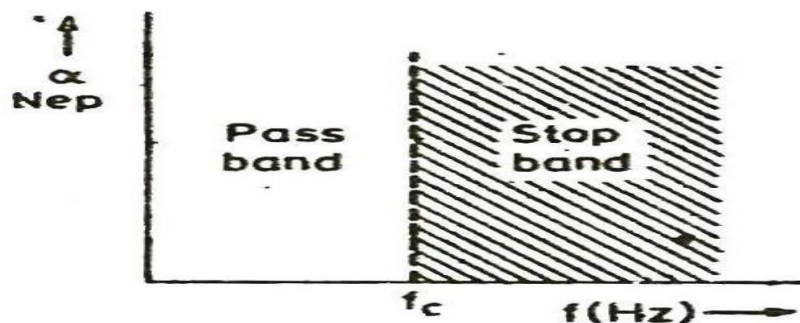


Fig.(2) LPF response at different frequencies

**HIGH PASS FILTER:-**

In case of high pass filter, as shown in fig.(3) the action is just the reverse of and with the increase in frequency, capacitive reactance in the series arm decreases while the inductive reactance in the shunt arm increases. Thus the section knows the passage of the higher order frequencies blocking the lower order frequencies.

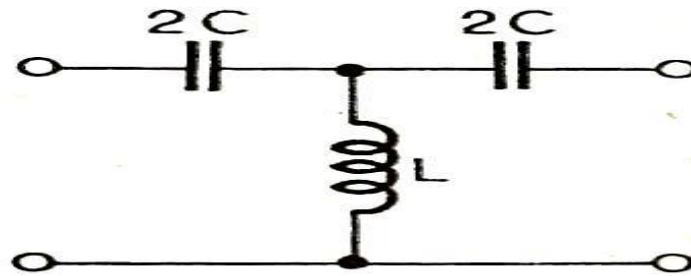


Fig.(3) T-section of High Pass filter

- At lower frequencies, the series capacitor behaves as if a very high reactance while the shunt path offers low reactance. Figure shows the filter section operating at low frequency and in the corresponding gain frequency plot  $f_c$  indicates the cut-off frequency at the point where the voltage gain equals to 0.707p.u.

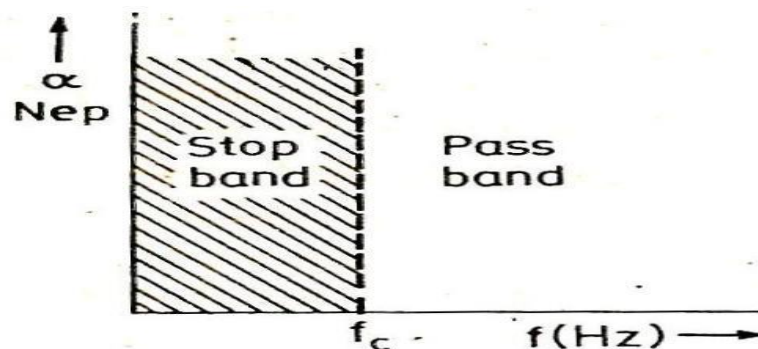


Fig. (4) HPF response at different frequencies

**BAND PASS FILTER:-**

A Band pass filter is combination of two parallel tuned circuits as shown in figure (5). This is a special type of LC filter along-with a particular bandwidth frequency to be allowed through it.

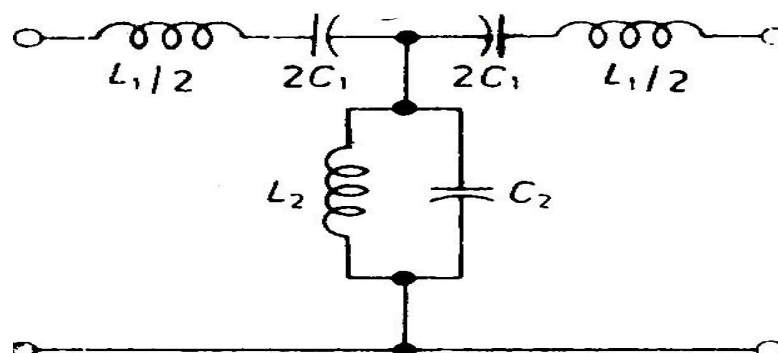


Fig. (5) T-section of Band pass filter

The operation of the filter initiated when the shunt arm as well as the series arms are in resonance. At resonance, the shunt arm behaves as a rejector circuit offering a very high impedance in the shunt arm while the series arm at resonance offers least impedance i.e. a acceptor circuit; thus, any electric signal, incident at the input of the filter allows its transmission through it within the pass band.

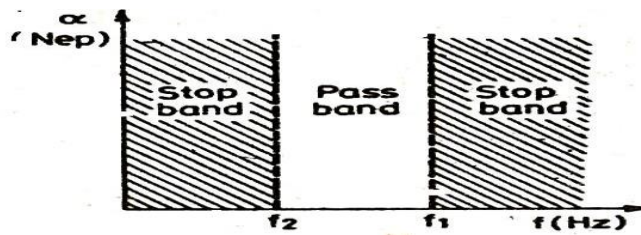


Fig. (6) Band-Pass filter response at different frequencies

**BAND STOP FILTER:-**

A band stop filter as shown in figure (7) in its simplest form, is a tandem of a low pass filter with a high pass filter. Here, the cut-off frequency of high pass filter is higher than the cut-off frequency of the low pass filter. The overlapping attenuation band of the two filters then constitutes the stop band of the band stop filter.

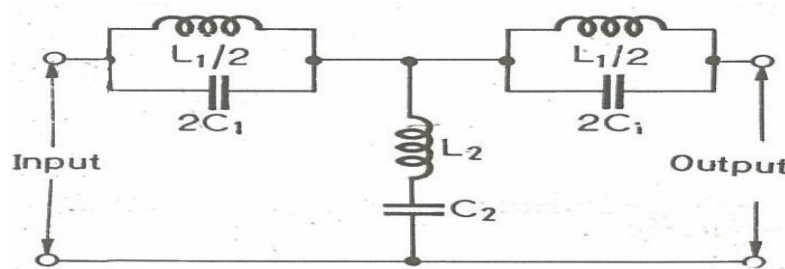


Fig. (7) T-section of Band stop filter

In practice the action of LPF and HPF are combined into a single band stop filter. Operation is initiated when resonance occurs so that shunt impedance becomes minimum and series impedance becomes maximum. Thus incident signal is blocked at this particular condition.

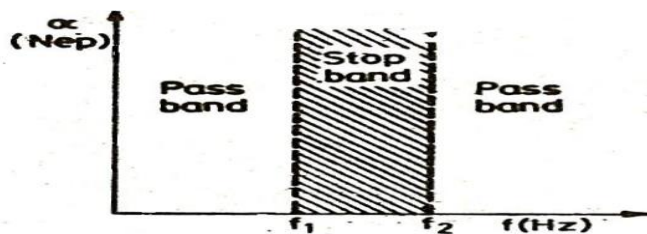


Fig. (8) Band-Stop filter response at different frequencies

**III. CHARACTERISTIC IMPEDANCE AND PROPOGATION CONSTANT**

In a two-port network, as shown in fig. (9) if two impedances  $Z_{i1}$  and  $Z_{i2}$  are such that  $Z_{i1}$  is the driving point impedance at port 1 with impedance  $Z_{i2}$  connected across port 2, and  $Z_{i2}$  is the driving point impedance at port 2 with impedance  $Z_{i1}$  connected across port 1, then the impedances  $Z_{i1}$  and  $Z_{i2}$  are called image impedances of the network. For symmetrical network, image impedances are equal to each other i.e. ( $Z_{i1} = Z_{i2}$ ) and is called the characteristic impedance of the filter  $Z_0$ .

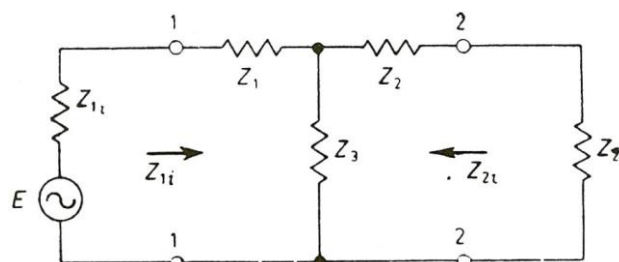


Fig. (9) T-network interposed between source and load

For symmetrical T network, the value of input impedance when it is terminated by characteristic impedance  $Z_0$  is given by

$$Z_{in} = Z_0 = \sqrt{\left(\frac{Z_1^2}{4} + Z_1 Z_0\right)}$$

As input and output impedances are equal under  $Z_0$  termination,

$$Z_0 = V_1/I_1 = V_2/(-I_2)$$

$$\text{then } V_1/V_2 = I_2/(-I_1) = e^\gamma$$

where  $\gamma$  is a complex number and is defined as  $\gamma = \alpha + j\beta$

$\gamma$  = propagation constant

$\alpha$  = attenuation constant

$\beta$  = phase constant

The purpose of a filter network is to transmit or pass a desired frequency band without loss and stop or completely at attenuate all undesired frequencies.

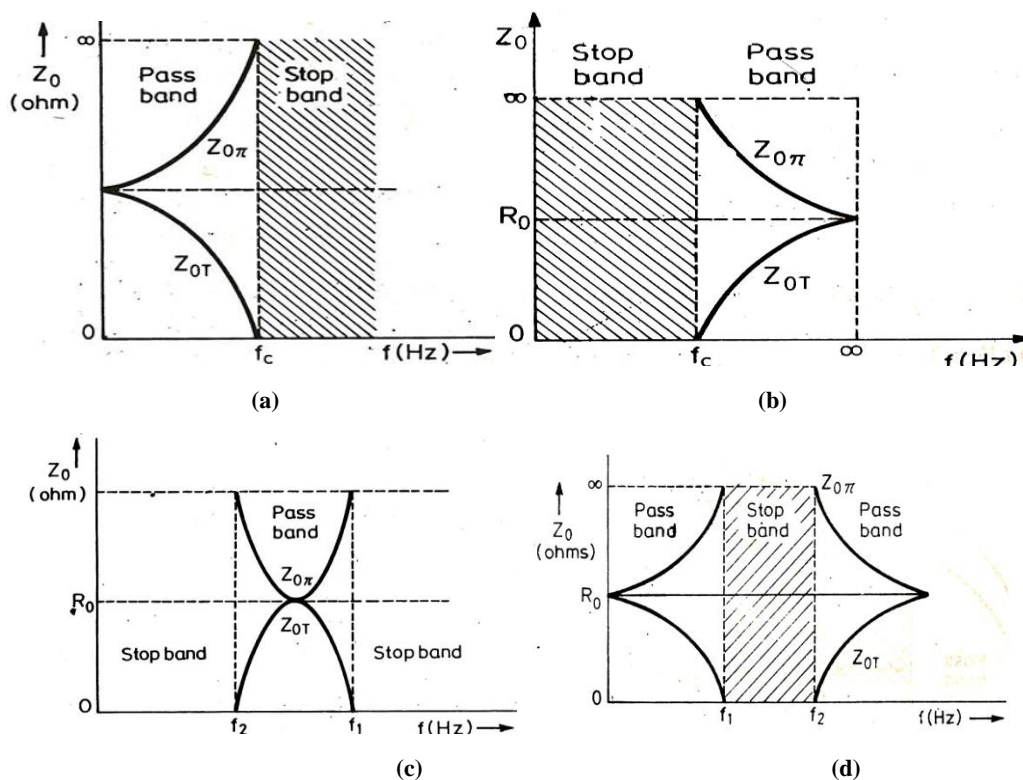


Fig.(10) Characteristic impedance profile of (a) LPF (b) HPF (c) BPF (d) BSF

#### IV. DESIGN OF CONSTANT-K FILTERS

In constant-k type filter, the series and shunt impedances ( $Z_1$  and  $Z_2$ ) are such that  $Z_1 Z_2 = R_0^2 = K$

Where  $R_0$  is a real number and independent of frequency. It is known as design impedance of the section. Any filter, where this relationship is maintained is known as constant  $K$  or prototype filter.

The design values of elements for different types of constant-k prototype filters are as follows:-

#### Low-pass section

$$R = \sqrt{\frac{L}{C}} ; f_c = 1/\pi\sqrt{LC} ; L = R/\pi f_c ; C = \frac{1}{\pi f_c R}$$

#### High-pass section

$$R = \sqrt{\frac{L}{C}} ; f_c = 1/4\pi\sqrt{LC} ; L = R/4\pi f_c ; C = \frac{1}{4\pi f_c R}$$

#### Band-pass section

$$R = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}} ; L_1 = \frac{R}{\pi(f_2 - f_1)} ; C_1 = \frac{(f_2 - f_1)}{4\pi f_1 f_2}$$

$$L_2 = \frac{R(f_2 - f_1)}{4\pi f_1 f_2} ; C_2 = \frac{1}{R\pi(f_2 - f_1)}$$

#### Band-stop section

$$R = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}} ; L_1 = \frac{R(f_2 - f_1)}{\pi f_1 f_2} ; C_1 = \frac{1}{4\pi R(f_2 - f_1)}$$

$$L_2 = \frac{R}{4\pi(f_2 - f_1)} ; C_2 = \frac{(f_2 - f_1)}{R\pi f_1 f_2}$$

## V. QUALITIES AND LIMITATIONS OF CONSTANT-K FILTER

The constant-k filters have qualities and limitations:-

#### Qualities:

- They are easy to design (the configurations and relations are very simple).
- The attenuation in the stop band tends to infinity at frequencies that are too far away from the cut-off frequency.

#### Limitations:

- The attenuation increases very slowly in the stop band, near the pass band; therefore the stop band and the pass band not clearly enough delimited.
- In the pass band the characteristic impedance varies a lot with frequency, so the filter is far away from being matched; as a consequence, the attenuation will not be zero in the pass band.

There are the few ways to eliminate these limitations:

- A way is to replace the constant-k filters with more complex filters (for example, the m-derived filters).
- Another way is to use more sections connected in chain. The sections must have the same characteristic impedance (in order to reduce the non-matching attenuations), therefore they will have the same cut-off frequency. Unfortunately, using more sections in chain won't solve the problem of correct matching; when the attenuation increases in the stop band(desired effect), it also increases in the pass-band too(non-desired effect).

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