Impact of Harmonics on RC Filter Design - A Case Study of AC/DC Converter System

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***Abstract :--*Controlled Rectifiers draw non-sinusoidal current from the source and have a poor power factor. For the source with high internal impedance (a weak source), the line current harmonics cause fluctuations of the source voltage. Further more, the temporary short-circuit of the lines during the commutation of thyristors, causes sharp current pulses, which further distort the line voltage. Such voltage fluctuations adversely affect the other loads connected to the same source. The line current harmonics (particularly sharp current pulses) cause electromagnetic interference for nearby communication equipment. The use of RC-filter is the common practice as well as cost effective solution for the AC/DC converter system. A Brief mathematical analysis of harmonic contents in the system at pulsating load condition and its impact on the RC-network has been discussed with designer's point of view in the present work.**

***Key-Words:--*Harmonics(Sinusoidal components of a periodic wave having frequencies as integral multiple of fundamental frequency).**

Filter (Equipment to reduce the harmonic current or voltage flowing in or being impressed upon specific parts of an electrical power system or both), RF (Radio-Frequency)

Jitter (Differences in the firing delay from one device to the next).

Introduction:

As compared to uncontrolled line commutated rectifiers the Controlled rectifiers will have higher harmonic contents in the load voltage. Drive and Phase controller regulates and delays the point of commutation.

In most of the present analysis level dc load current with the assumption of infinite load inductance is not always justified, and harmonic currents do exist in the waveform. The effect of these harmonics has on the load as well as on the source must be judged in respect of the individual application. In practice with regulated high performance current, particularly at large firing delays, the harmonic components are complex and differ from the simple relationship to the fundamental.

In the rectifying device, switching action inevitably results in non-sinusoidal current being drawn from the AC supply system. It can be viewed as the AC supply (Source) delivering a sinusoidal voltage with power flow relating only to the fundamental (mains) frequency. The load then converts some of this power to higher frequencies, and feeds back harmonic power into the supply system. Hence a rectifying load acts in part as a harmonic generator. For analysis purposes the harmonic currents may be taken as reactive in nature and the generated components effectively in series. [7] [8]

Fast switching action of the current can in certain cases result in load transmitting air-borne RF interference signals, which require suppression. The presence of harmonics can distort the supply waveforms and cause problems in respect to firing circuits which rely on the supply voltage zero as reference to the firing delay angle. Such distortion can cause slight differences in the firing delay from one device to the next (Jitter).

The extent of penetration of the harmonics into the supply from the load will depend on how the components of the system react to each particular frequency. Capacitors connected across the lines will absorb harmonic currents due to their reactance falling with frequency. Resonance within the system may occur at a harmonic frequency. At fast-regulated load conditions, in view of the harmonic contents, with mathematical analysis the proper design of the filter network has been checked out.

Main Specifications:

Converter Transformer – 560 KVA, Y/D1, 415/440 V, Sec. cur 735 A., Impedance 4.86 %
Thyristor Converter and DC Motor – 184KW, 900A

Harmonic content analysis:

(Refer fig 2)

K_1 - Constant from (fig 2 diagram)=350
k - order of harmonic
Slope of curve (approx.) = 15
(Function treated as periodic for 2π)
With application of Fourier series,

Let $I(q) = (15q + K_1)$

$$B_{km1} = 1/2\pi \int_0^p (15q + K1)\cos kq\,dq$$

$$= 1/2\pi \left[15 \int_0^p (q \cos kq\,dq + K1\int_0^p \cos kq\,dq\right]$$

$$= -15/\pi k^2$$

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$B_{km2} = 1 / 2\pi \int_{p}^{2p} \left(-15q - K1\right) \cos kqdq$

$= -15 / \pi k^2$

$B_{km} = -30 / \pi k^2$

$= -9.55 / k^2$

$C_{km1} = 1 / 2\pi \int_{0}^{p} \left(15q + K1\right) \sin kqdq$

$= 15 / 2k + K1 / \pi k$

$C_{km2} = 1 / 2\pi \int_{p}^{2p} \left(-15q - K1\right) \sin kqdq$

$= 45 / 2k + K1 / \pi$

$C_{km} = 30 / k + 2K_1 / \pi k$
$= 252.9 / k$

$A_0 = 1 / 2\pi \int_{0}^{p} \left(5q + K1\right) dq + 1 / 2\pi$

$\int_{p}^{2p} \left(-5q - K1\right) q dq$
$= -5\pi / 2$

Amplitude for individual harmonic taken as [6]
$A_{km} = \sqrt{(B_{km}^2 + C_{km}^2)}$

The analysis up to 25^{th} should give satisfactory result in this practical case [8]
The constituting harmonic components possess from fundamental to successive up to 25^{th} are
253, 126.5, 84,…10 Amp.

All these components separately create their voltage components on account of source inductance and distort the source voltage and effect circuit components including filters. Practical approach for filter design will be with consideration of few points as follow [1][2].

- Filtering Characteristics is strongly influenced by source impedance.
- At specific frequencies there is the possibility of parallel resonance between a source and a passive filter which causes amplification of harmonic currents on the source side.
- Source may fall into series resonance with a passive filter, so that voltage distortion produces excessive harmonic currents flowing into the passive filter.

Equipment filtering methods:

General: In addressing the means for reduction of harmonic currents it is normally assumed that DC currents are continuous and stable to the extent possible. Thus Drive regulation system should be properly tuned and optimized.

Additional line reactance: Though the reactance increase creates higher voltage drop but at the same time harmonic constant of the converter system decreases. Converter transformer in this case provides this reactance.

Multi Pulse Methods: This involves multiple converters connected in a way that harmonics generated by one converter are canceled by harmonics produced by the other converter. These lead to reduction of ac input line current and voltage ripple.

Active filtering within the equipment: The development of variable frequency drives has led to high performance microprocessor controls. Significant advances have also been made with PWM (pulse width modulated) inverters. Used with an induction motor the speed performance is comparable to dc motor. Similar equipment can also be used to control the power conversion process occurring at the converter input to control the amount of power being drawn or supplied to the dc load. In this fashion converter operates rather like a synchronous generator. Power flow depends on the inverter frequency/phase and VAR on the converter voltage.

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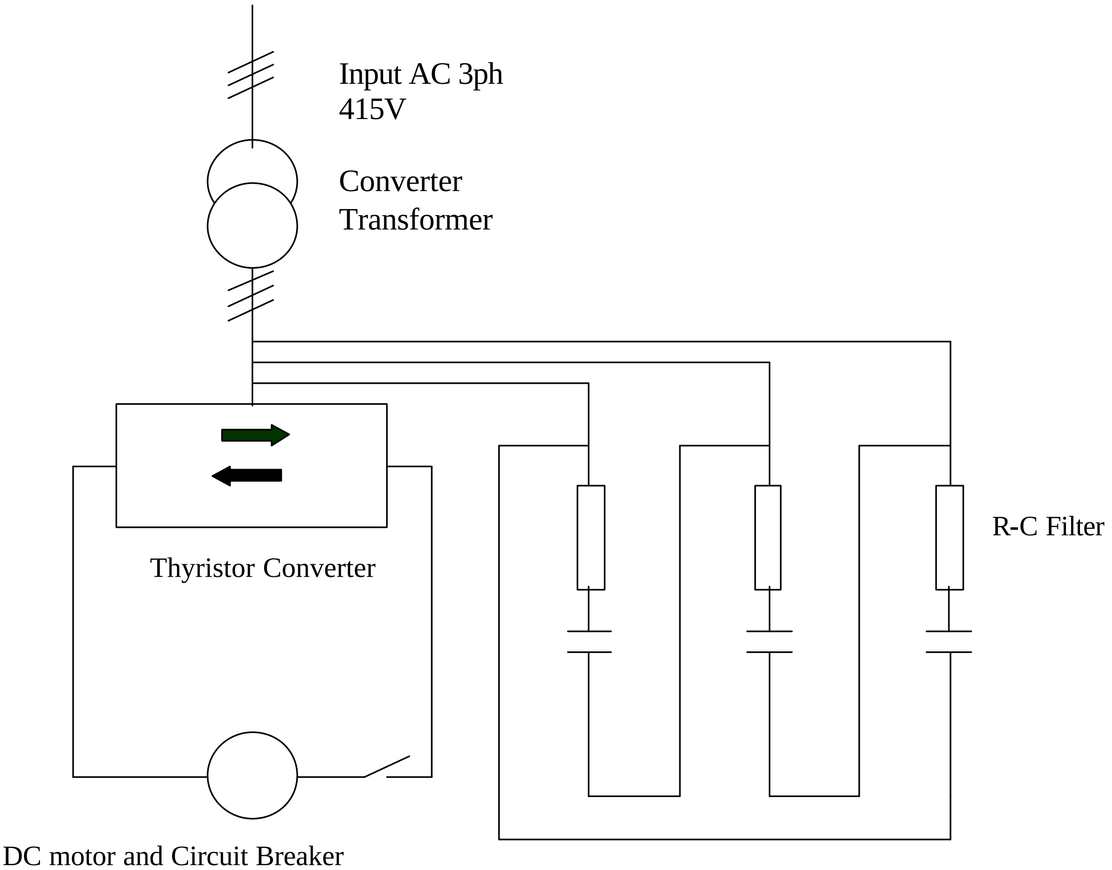

Fig. 1- Thyristor Reversible converter with Filter connection

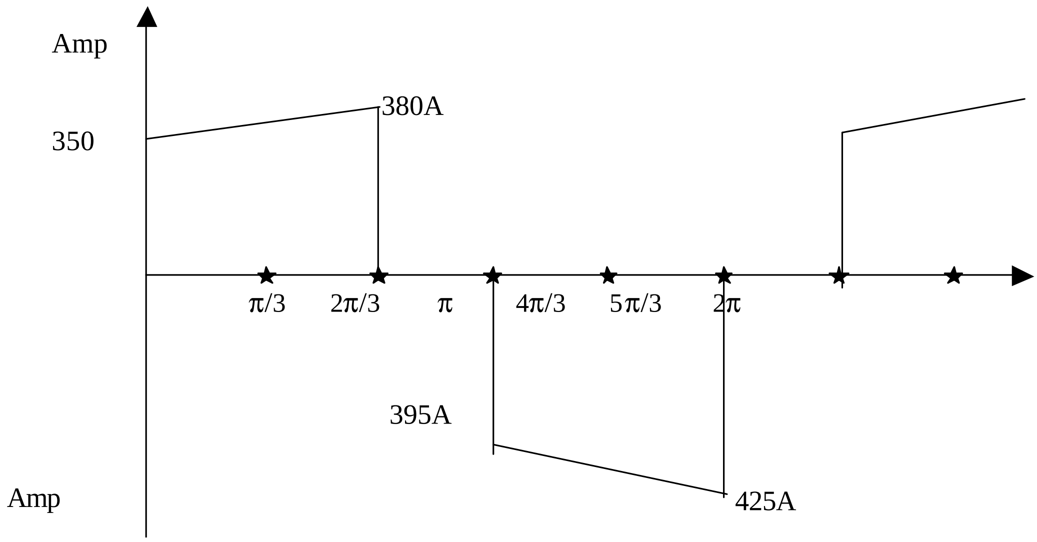

Fig. 2-Equivalent ac line currents (Ia, Ib, Ic) from pulsating regulated dc load Current. These values are approximate and treated as periodic at 2π.