A Comparison In Performance Of Circulating Current And Non Circulating Current Cycloconverter

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ABSTRACT
Cycloconverter performs the power converting function in a single stage without any intermediate d.c link i.e the cycloconverter can produce adjustable voltage, adjustable frequency ac power from an ac source of fixed voltage and frequency. The production of harmonics in the output of a cycloconverter as a result of the process of voltage synthesis is unavoidable. The direct process of frequency changing makes the harmonics as a function of both the input and output frequencies. As a result the cycloconverter input current and output voltage waveform contain harmonics, non-standard harmonics and sub-harmonics. The harmonic spectrum of cycloconverter input and output waveform depends upon its control strategy, pulse number and structure. In this paper the comparative frequency spectrum analysis of two major cycloconverter structures i.e circulating current (CC) and non circulating current cycloconverter (NCC) are made using FFT and DWT. Hence it establishes the acceptability of wavelet transform in detecting the harmonics in the input and output voltage and current waveform. Further using the power quality indices a comparison in performance of NCC and CC are made.The analysis are performed in MATLAB/SIMULINK environment.

General Terms
Frequency Spectrum, Wavelet Transform, Discrete Wavelet Transform.

Keywords
circulating current cycloconverter(CC); non circulating current cycloconverter(NCC) ; harmonics; power quality indices; fast fourier transform(FFT); discrete wavelet transform(DWT**)**

INTRODUCTIONA

naturally commutated cycloconverter is a static frequency changer capable of bidirectional power flow. It produces nearly sinusoidal output waveform. It convert an ac source of any voltage and frequency to a rather lower but adjustable voltage and frequency source. It has a large field of application in variable speed drive of large ac machines [1, 2, 3]. It has high efficiency due to the simple construction of main circuit, no force commutation circuit is required. Because of the process of direct frequency change, the presence of harmonics in the input and output of cycloconverter is inevitable. This unwanted frequency component are function of both the input and output frequency. This constitutes the beat frequencies which are both sum and difference of multiples of input and output frequency [4].

Because of the process of direct frequency change the input and output of cycloconverter are contaminated with harmonics, thus degrade the power quality. To improve power quality these harmonic, sub-harmonics and interharmonics need to be detected and then removed by suitable filtering technique. Fourier transform is a popular tool to detect these harmonics. This paper shows that DWT emerged as a stronger tool not only to detect but to eliminate these harmonics. The harmonic spectrum of cycloconverter input and output waveform depends on a number of factors like pulse number, control strategy and structure. The impacts of harmonics on cycloconverter performance were discussed in [1, 4, 5] The impact of cycloconverter control strategy and pulse number on power quality are discussed in detail in [2] and [6]. [7] Discuss the effect of harmonic spectrum of different cycloconverter structure. In all this work FFT is used as a mathematical tool for analysis. The failure of FFT to detect frequencies in non stationary waveforms has laid to the use of other tools. Though STFT can overcome the disadvantage of FFT, it also suffers from the disadvantage of fixed window length. Wavelet transforms [8, 9, 10, 11, 12] overcomes the limitations of Fourier. In this paper, Discrete Wavelet Transform is used to analyze the harmonic spectrum of cycloconverter input and output waveform. Using DWT the impact of different cycloconverter structure are studied.

1. Wavelet Transform

1.1 Continuous Wavelet Transform (CWT)
Wavelet Transform is a mathematical tool to analyze the signal. It decomposes a signal into different scales and with different levels of resolution. Let x(t) is a signal defined in L2(R) space, where R is any real number. L2(R) denotes a vector space in finite energy signal. The signal has to satisfy the admissibility condition for finite energy.

CWT of x(t) [10] is given by

$$cwt_{\psi}x(a,b) = \int_{-\infty}^{\infty} x(t)\psi^{*}_{(a,b)}(t) \qquad (1)$$

Here $\psi(t)$ is the mother wavelet function

1.2 Discrete Wavelet Transform (DWT)

If $a=a_o^m$, $b=na_0^m b_0$ and t=KT [10] be chosen in eqn. 1 where T=1.0 and k, m, n are integer values, then the discrete wavelet transform is given by

$$DWT(m,n) = \frac{\sum_k x(k)\psi^*[\frac{k - na_0^m b_0}{a_0^m}]}{a_0^m}$$

(2)

1.3 Multiresolution Signal Decomposition

The multiresolution signal decomposition (MSD) technique decomposes a given signal into its detailed and smoothed versions. By using the MSD technique, the power quality (PQ) disturbance signal is decomposed into two other signals, one is the smoothed versions of the PQ signal, and the detailed version of the PQ disturbance signal that contains the sharp edges, transitions and jumps. Therefore, the MSD technique discriminates disturbances from the original signal and then analyzes them separately.

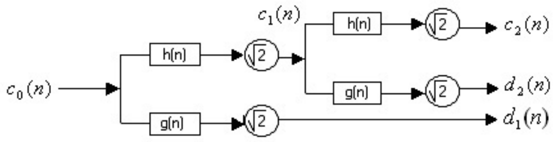


Fig 1: Decomposition of $c_0(n)$ into two scales

Here co(n) is a recorded discrete time signal at scale 1. They are defined as follows:

$$c_1(n) = \sum_k h(k-2n)c_0(k)$$

(3)

$$d_1(n) = \sum_k g(k-2n)c_0(k)$$

(4)

where h(n) and g(n) are the associated filter coefficients that decompose $c_0(n)$ into the smooth and detail coefficients, $c_1(n)$ and $d_1(n)$ respectively at 1st level of decomposition .These filters determine the type of wavelet used for analysis e.g. Haar. After the signal $c_0(n)$ is filtered by h(n) and g(n), it is then decimated by a factor of two according to eqn.3 and eqn.4 respectively. $c_1(n)$ is the smooth version of the original signal $c_0(n)$ because filter h(n) has low pass frequency response. $d_1(n)$ can be thought of as difference between the discrete values of the original signal $c_0(n)$ or we can say that $d_1(n)$ contain detail that have been removed from the signal.

2. Cycloconverter

2.1 Basic modes of operation

A naturally commutated cycloconverter has two basic modes of operation, circulating current and circulating current free mode of operation. It has positive and negative group of converter. Positive converter operates when load current is positive and negative converter operates when load current is negative. In circulating current free mode of operation converter is allowed to conduct during its associated half cycle of load current. During the other half cycle the converter is completely blocked. The basic principle of circulating current cycloconverter is to apply firing pulses continuously to both the converters. Here a circulating current reactor is used to limit the circulating current.

Control scheme

A control strategy is required to produce a set of firing pulses that triggers cycloconverter thyristor to produce a specific output voltage. Different control strategy leads to different characteristics in input current and output voltage. Several control strategy has been developed through the years including cosine wave control, integral control etc. In this work cosine wave control is selected for producing firing angle as Pelly [6] proves that this control method gives the least total harmonic distortion (THD) in the output voltage and load current.

Unwanted frequency in cycloconverter input and output

The extrabasal frequency components of the input current wave of a naturally commutated cycloconverter supplying a mean sinusoidal output (for a balanced three phase output) are [6].

$$f_E = f_I \pm 6nf_o, \quad f_E = (pk-1)f_I \pm 3nf_0,$$

$$f_E = (pk+1)f_I \pm 3nf_0 \qquad (5)$$

The unwanted frequencies in the output voltage are [6]

$$f_v = p_k f_I \pm (n-1) f_0 \qquad (6)$$

Where p is the pulse number, k is any integer from 1 to ∞, n is any odd integer from 1 to ∞ for p_k odd, n is any even integer from 0 to ∞ for p_k even.

3. CIRCULATING CURRENT AND NON CIRCULATING CURRENT CYCLOCONVERTER STRUCTURE

The two basic 3-phase to 3-phase, cycloconverter structure i.e. circulating current and non-circulating current cycloconverter (circulating current free) structure are simulated in MATLAB/SIMULINK environment. The two cycloconverter structures are given a supply of 230V, RMS, 50Hz (phase voltage) from a 3-phase star connected supply system. fi (Frequency of the ac source i.e. input frequency) =50 Hz, fo (wanted output frequency of the frequency changer) = 10 Hz, ø0(output or load phase angle)= -300, modulation index(m)= 1. In CC, a circulating current reactor of inductance 0.09H is used to limit the circulating current.

3.1 MATLAB/SIMULINK result of a 3-phase to 3-phase NCC cycloconverter,load phaseangle=-30^0, modulation index=1, f_I =50Hz, f_0 =10Hz.

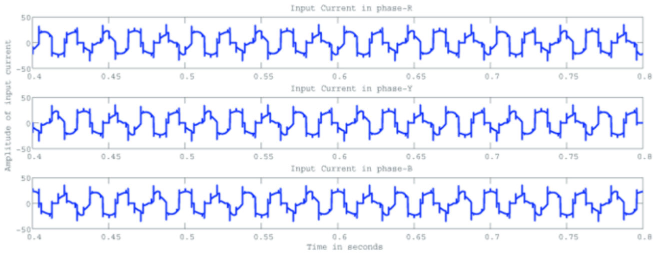


Fig 2: Input current in phase RYB

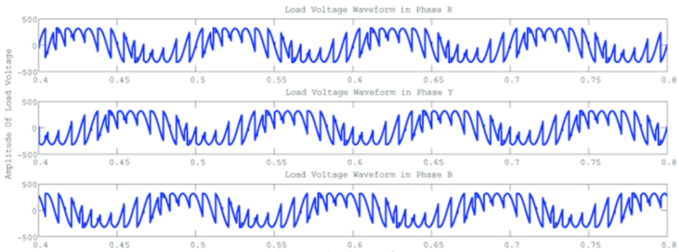


Fig 3: Load voltage in phase RYB

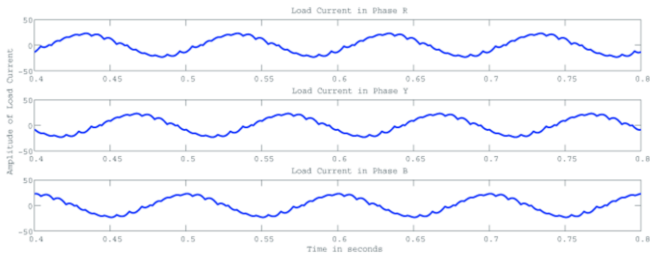


Fig 4: Load current in phase RYB

3.2 MATLAB/SIMULINK result of a 3-phase to 3-phase CC cycloconverter, load phase angle=-30^0, modulation index=1, f_I =50Hz, f_0 =10Hz.

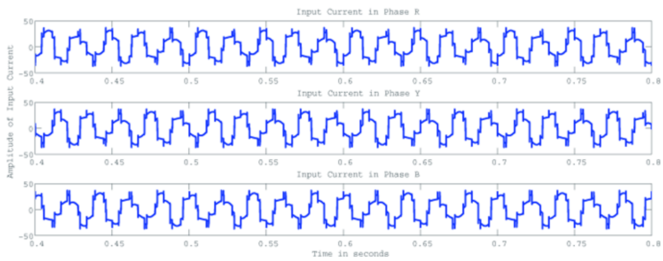


Fig 5: Input current in phase RYB

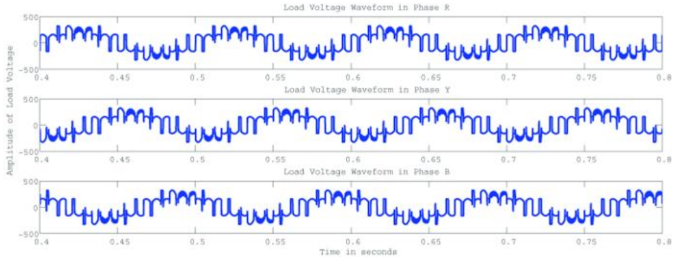


Fig 6: Load voltage in phase RYB

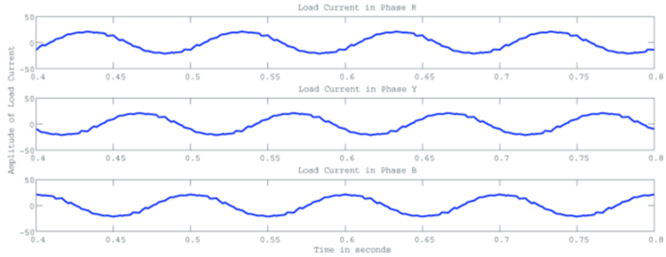


Fig 7: Load current in phase RYB

3.3 DWT analysis of input and output waveform of CC and NCC

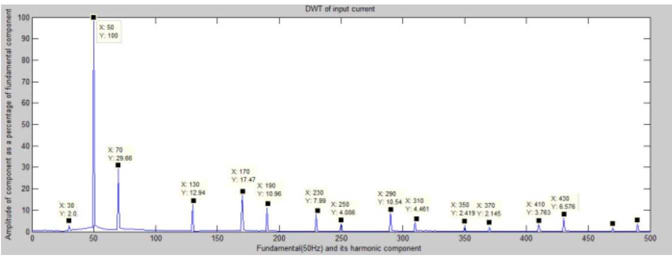


Fig 8: DWT of input current of a CC cycloconverter

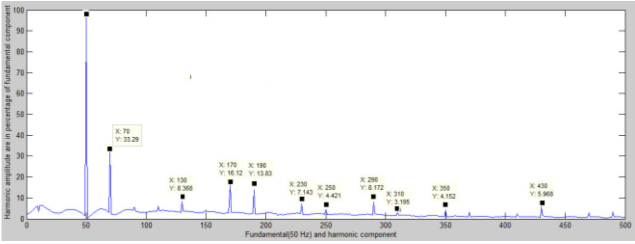


Fig 8: DWT of input current of NCC cycloconverter

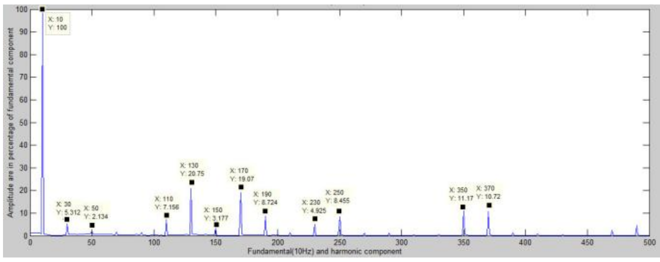


Fig 9: DWT of load voltage of CC cycloconverter

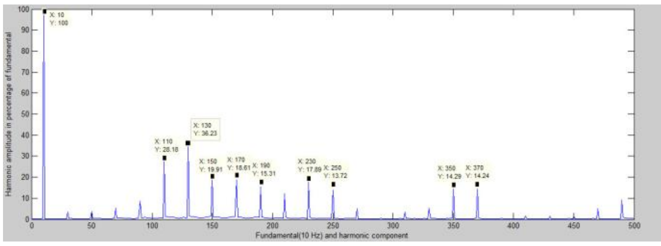


Fig 10: DWT of load voltage of NCC cycloconverter

4. POWER QUALITY ANALYSIS OF OUTPUT AND INPUT WAVEFORM

The performance of frequency changer i.e. circulating and non circulating type is compared on the basis of power quality indices. The power quality indices used are total RMS distortion (TRD), total demand distortion (TDD), input current distortion factor (ICDF).

The output voltage [6] of the cycloconverter of phase p can be written as

$$v_{op} = V_O \sin(w_o t - (p-1)\frac{2\pi}{m}) + \sum_{l=1}^{\infty} V_{vl} \sin(w_{vl} t - \phi_{vl})$$

Where $V_O \sin(w_o t - (p-1)\frac{2\pi}{m})$ represents the fundamental component.

$\sum_{l=1}^{\infty} V_{vl} \sin(w_{vl} t - \phi_{vl})$ represents all the unwanted output voltage component.

V_{vl} is the amplitude of the l^{th} unwanted component.

ϕ_{vl} is the phase of the l^{th} unwanted component.

From [6] the input current may be written as ensemble of sinusoidal component given by

$$i_{Ip}(t) =$$

$$I_I \sin((w_I t - (q-1)\frac{2\pi}{n} + \phi_I) + \sum_{l=1}^{\infty} I_{El} \sin(w_{El} t - \phi_{El})$$

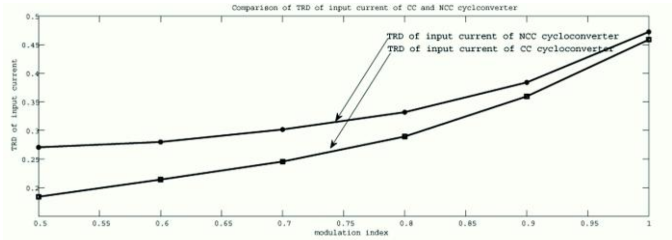
Where I_I , w_I and ϕ_I represents the amplitude, frequency and phase of fundamental component.

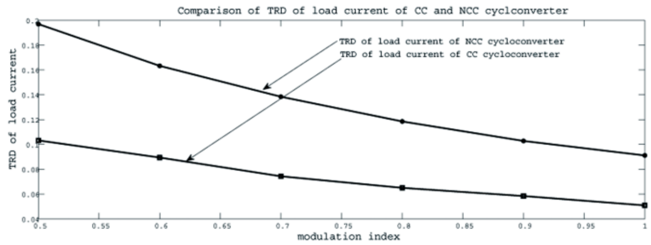
$\sum_{l=1}^{\infty} I_{El} \sin(w_{El} t - \phi_{El})$ represents the ensemble of extrabasal input current component.

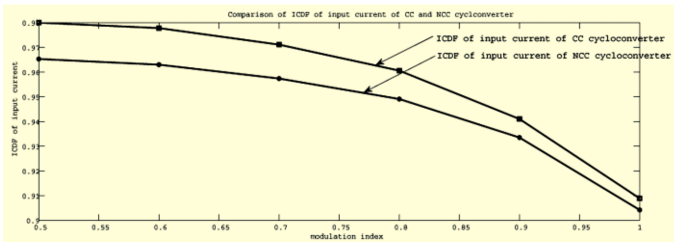
$$\text{TRD}= \sqrt{\frac{\sum_{l=1}^{\infty} V_{vl}^2}{V_o}} \quad , \qquad \text{TDD}= \sqrt{\frac{\sum_{l=1}^{\infty} V_{vl}^2}{V_o^2 + \sum_{l=1}^{\infty} V_{vl}^2}}$$

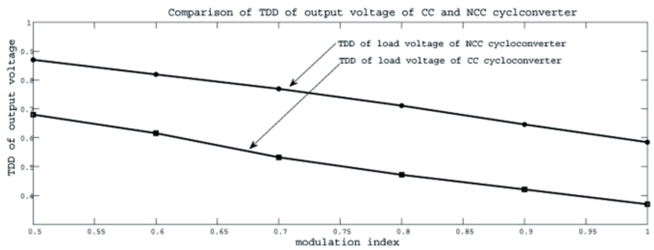
$$\text{ICDF}= \frac{I_1}{\sqrt{I_1^2 + \sum_{l=1}^{\infty} I_{El}^2}}$$

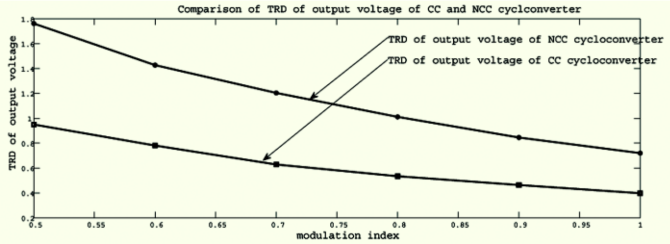
The performance of the frequency changer related to the output voltage waveform is characterised by the output voltage wave indices. It is generally an objective of the power frequency changer that to minimize total RMS distortion and TDD. Similarly the quality of the input current waveform is expressed by the input current wave indices. More is the ICDF better is the quality of input waveform.











From the DWT analysis of CC and NCC cycloconverter it can be concluded that CC harmonic behavior is better then NCC. From TRD, TDD, analysis of output voltage and output current as above it is seen that for modulation index of 1 and output frequency of 10 Hz, the TRD (in p.u) of load voltage for NCC and CC cycloconverter are 0.7205 and 0.3977 respectively, whereas TDD of load voltage(in p.u) for NCC and CC cycloconverter are 0.5846 and 0.3696.

Similarly TRD of output current for NCC and CC are 0.0911 and 0.05 respectively. Thus the total RMS distortion in output current of NCC is more than CC. Now considering the distortion in input current, the TRD of input current in (p.u) NCC is 0.4723 while in CC it is 0.44. The ICDF (in p.u) of input current are 0.9042 and 0.91 for NCC and CC respectively, whereas the maximum subharmonic in the input current in NCC cycloconverter is 4.2 percent of fundamental and in CC it is 2.077 percent of fundamental. So subharmonic in input current of CC cycloconverter is 50 percent less as compared to NCC cycloconverter.

The subharmonic amplitude in output voltage of NCC is 2 percent while for CC mode it is 1 percent of fundamental. Subharmonic in the output voltage has very harmful effect. The component of load voltage because of high frequency harmonic, results in load current of lower amplitude because of load inductance, whereas for subharmonic motor inductance is low, consequently it may cause high subharmonic current.

There is a limit in the maximum output frequency of cycloconverter in order to limit the subharmonic in the output voltage. As CC performance is better then NCC, so maximum achievable frequency in CC is more then NCC. In CC center tapped reactor is used in between positive and negative group of thyristor, this causes poor power factor and poor efficiency as compared to NCC. The NCC necessitates the use of quite sophisticated control scheme in order to achieve the desired performance.

In NCC the converter is allowed to conduct during its associated half cycle. During the idle half cycle, the converter is completely blocked, through suitable control of its firing pulses. Thus only one converter is in conduction at any one time, and no current circulates between the converter. Whereas in CC the firing pulses are applied continuously to both the converter, without regard to the direction of load current. This results in each converter producing exactly the same wanted alternating voltage component at its output terminals. The operation of the power circuit is such that a relatively large amount of current, in addition to the circulating ripple current, circulates between the two converters. Since the wanted voltage components generated at the output terminals of each converter are equal to one another, there can be no difference in voltage at the wanted output frequency developed across the circulating current reactor. Thus the amplitude of the wanted voltage component at the mid point of this reactor must be same as that of the either of the individual converter. However the general appearance of raw voltage waveform at this point is different to that of the voltage waveform of either of the constituent converters. This is because the waveform is the instantaneous average of the constituent waveforms and certain harmonic components contained in individual converter waveform cancel one another and therefore do not appear at the output terminal. Thus CC has better harmonic performance then NCC.

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